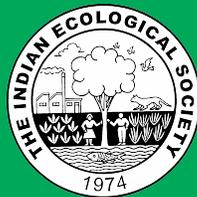


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Effect of Integrated Nutrient Management on Leaf and Fruit Characteristics of High Yielding Walnut Varieties of Kashmir Valley, India

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Abstract: This study reports the effect of conjoint application of inorganic fertilizers with organic manure on some leaf and fruit characteristics of four high yielding walnut varieties of Kashmir. The experiment consisted of four different nutrient supplementation: inorganic fertilizer, vermicompost, poultry manure and farmyard manure used in different combinations. All treatments were mixed well with soil and applied in the first week of December during 2016 and 2017. Leaf nutrient status of different varieties varied non-significantly however treatments had a significant effect on leaf nutrient status. SPAD index of SKAU/040 variety was significantly higher than rest of the varieties. SKAU/008 showed significantly higher protein and phenolic content with higher antioxidant activity than rest of the varieties. Pooled data recorded varieties treated with T4 showed highest value of SPAD index and leaf macro and micronutrients. Conjoint application of inorganic manure with vermicompost showed maximum fruit yield and fruit weight in selection SKAU/008. Overall integrated management improved the protein, fat, ash content, higher total phenolic content and enhanced antioxidant activity. Thus, conjoint application of inorganic fertilizers with vermicompost should be preferred over other organic manures for maximizing fruit yield, nutritional and nutraceutical content of walnut fruits with substantial improvement in leaf nutrient status irrespective of the walnut variety used.

Keywords: Integrated nutrient management, Walnut, Leaf nutrient status, Fruit yield, Fruit nutrition, Fruit antioxidant activity

Asia is one of the leading producers of walnut with china producing 1.75 million tons followed by Iran. The annual walnut production of India is 47000 tons of which 98 per cent are contributed by Jammu and Kashmir state. In Jammu and Kashmir state walnut is grown on an area of about 89788 ha with annual production of about 163745 metric tons (Anonymous) with the productivity of 1.823 metric tons per hectare. The demand of quality walnuts is increasing day by day in the national and international market due to its high nutritional and nutraceutical importance. Fertilization treatments have the potential for increasing growth and nut production of walnuts. The application of fertilizers to add N, P and K have influenced the growth of tree and production of fruits like chestnut, grapes, pears, figs and walnut trees. However, intervention of chemical fertilizers for increasing crop production has resulted in negative environmental impacts through nitrate leaching and nitrous oxide emissions. The increased use of fertilizers in non-judicious manner, has led to diminishing soil productivity and multiple nutrient deficiencies (Dhaliwal et al 2017). The gravity of environmental degradation caused by the faulty cultivation

practices has led to focus on ecologically sound, viable and sustainable farming systems. Hence, production of horticultural crops has undergone enormous changes in the recent years due to the development of innovative technologies including nutrient management practice. Minimizing use of chemical fertilizers in fruit growing is a goal of integrated fruit production. Industrialized countries, such as in the USA, EU, Canada etc., are convinced that organic agriculture may represent a more achievable and much-needed alternative, in order to reduce the use of agrochemicals, preserving soil, water and biodiversity. The organic manures, when applied to soil increases the fertility status of soil and favorably influence the crop yield for several years. It has been reported that farmyard manure, vermicompost and poultry manure have increased growth, yield and quality in different crops (Sahu et al 2017, Verma and Kaur 2016). Application of vermicompost along with mineral fertilizers has given encouraging results in terms of crop productivity and maintenance of soil health (Madarakhandi et al 2015). Singh and wallia (2015) also reported improved fruit yield and growth of baby corn. There

is ample data regarding the influence of type and quantity of fertilizer on yield and quality of food crops however, influence of integrated nutrient management on walnut leaf and fruit quality is not documented anywhere. Due to conflicting reports regarding the overall production and quality of foods affiliated to organic farming, benefits of agro-ecological farming practices need to be widely tested. Hence, this study was designed to explore the effect of different organic and inorganic regimes on leaf nutrient status, yield, nutritional and nutraceutical aspects of walnut fruit.

MATERIAL AND METHODS

The experimental orchard is located at Ambri Apple Research Station PahnShopian at 33.72°N latitude and 74.83° E longitudes, at an elevation of 2057 m above msl, representing high hill zone of the state. The climate of the area is typically temperate. Before application of manures and chemical fertilizers a composite soil sample of the experimental orchard was drawn and analysed for different chemical properties (Table 1).

The studies were conducted on 9 years old four bearing selections SKAU/002 (S1), SKAU/008 (S2), SKAU/024 (S3), SKAU/040 (S4), of walnut grafted on seedling rootstock. For the conduct of experiment, trees with uniform age and vigor, placed at 6m × 6m were selected. The treatments were laid out in a randomized block design (factorial), containing five replications of three tree each. The details of treatment are:

- T1 = NPK recommended as per package of practices through inorganic fertilizers),
 T2 = 100 % through manure (FYM 50% + vermicompost 25% + poultry manure 25%),
 T3 = 75% NPK through inorganic fertilizers + 25 % through manure (FYM),
 T4 = 75 % NPK through inorganic fertilizers + 25 % through manure (vermicompost),
 T5 = 75 % NPK through inorganic fertilizers + 25 % through manure (poultry manure),
 T6 = 75 % NPK through inorganic fertilizers + 25 % through manure (1/3 FYM+ 1/3 Vermicompost + 1/3poultry manure).

The recommended dose for first year was 200g N, 50g P and 200g K and for second year 250g N, 60g P and 250g K using urea, DAP and MOP as inorganic fertilizer source. There were 24 treatment combinations. Farmyard manure, vermicompost; poultry manure and inorganic fertilizer were applied to each replication as per the treatment details. All fertilizers and manures were applied in the first week of December beneath the tree canopy and mixed well with soil.

Sampling: Soil samples before implementation of the experiment and after harvest of crop were collected at a depth of 0-50cm for analysis of macro and micronutrients. Leaf samples from walnut trees were collected in the month of August (15Th). Leaf Sampling was carried out between 8 and 10 a.m. on bright days and middle leaflets were used for sampling.

Chlorophyll content (SPAD value): The chlorophyll content of fully expanded leaf was determined by SPAD (Soil Plant Analysis Development) [Minolta-SPAD 503 Osaka, Japan] meter which is a convenient and reliable tool for in situ chlorophyll measurement of plants and has been used for different crops including walnut. The SPAD value (expressed in SPAD index) was the mean of fifteen measurements on the leaflet.

Leaf macro and micro status: Plant samples were oven dried at 600°C for 48 hours and ground to pass through a 40-mesh screen. Total nitrogen content was determined by micro Kjeldahl's method, total phosphorus content was determined by Venedomolybdo phosphoric acid yellow colour method. Total potassium, calcium, magnesium and micronutrients viz. zinc, manganese, iron and copper content were estimated by Perkin Elmer Atomic Absorption Spectrophotometer and the results were expressed in percentage on dry weight basis.

Physico-chemical analysis: After harvesting, the nuts from each tree were dehulled, dried, weighed and expressed in Kg per tree. The weight of ten nuts randomly selected was recorded. Protein, fat and ash content of walnut kernels were determined according to AOAC (1998).

Table 1. Chemical properties of experimental orchard soil before start of experiment and organic fertilizer used in the experiment

	Macroelements (%)					Microelements (ppm)				
	C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Zn (ppm)	Cu(ppm)	Mn (ppm)
OS	1.15a±0.1	308c±0.05	17.5c±0.1	230d±0.5	1197.45c±1.05	160.23c±0.5	48.9a±0.2	0.98a±0.05	2.58a±0.03	64.2b±0.05
FYM	10.22b±0.5	0.68a±0.01	0.32a±0.05	0.73a±0.03	0.72a±0.05	0.18a±0.01	144.20b±0.5	15.30b±0.2	2.40a±0.05	62.24b±0.02
VC	17.85d±0.5	2.48b±0.01	0.89b±0.01	1.67c±0.02	0.82a±0.01	0.17a±0.03	162.15c±0.3	22.00d±0.1	3.72b±0.01	71.50c±0.05
PM	14.55c±0.5	2.97b±0.05	0.95b±0.03	1.19b±0.05	1.84b±0.05	0.41b±0.01	202.81d±0.5	18.00c±0.1	2.93a±0.05	52.50a±0.05

Values are mean ± standard deviations with different letters implying significant difference between values.

OS: orchard soil; FYM: farmyard manure; VC: Vermicompost; PM: Poultry manure

Antioxidant Assays

DPPH scavenging activity: The DPPH scavenging activity of different extracts was measured using the method proposed by Shafi et al (2017) with slight modifications. Shoot extracts (100 µl) at various concentrations (0.1, 0.15, 0.2, 0.25 and 0.3 µg/ml) were mixed with 1 ml of 0.005% DPPH and 2.4 ml of methanol. The mixture was thoroughly mixed using a Vortex (EU Labnet International Edison, NJ, USA) and kept in the dark for 30 min. The absorbance was measured at 517 nm using a spectrophotometer (Hitachi U-2900, Tokyo, Japan) against a methanol blank with DPPH, excluding extract. Results were expressed as percent of inhibition (% inhibition) of the DPPH. Percentage of inhibition of the DPPH was calculated according to the following equation:

$$\text{Inhibition(\%)} = [(Ac - As) / Ac] \times 100$$

Where, Ac is absorbance of control and As is absorbance of the sample. The DPPH scavenging activity of sample extracts was used for calculating IC₅₀ using straight-line equation $y = mx + c$.

Total phenolic content: Total phenolic content of the extracts was determined using a FC (Folin-Ciocalteu) assay, as described by Baba et al (2016). Each extract (100 µl) having concentration of 0.3 µg/ml was mixed with 250 µl of FC reagent. The mixture was left to react for 5 min at room temperature (20°C). Five ml of 20% sodium carbonate solution was added, the mixture was mixed using the Vortex and the total volume was made to 5 ml by adding distilled water. The solutions were mixed and incubated for 1 hr at 37°C. The absorbance was measured at 765 nm. A calibration curve was prepared using a standard solution of gallic acid. Results were expressed as mg GAE/g DW (dry weight).

Statistical analysis: Statistical analysis was done using a commercial statistical package SPSS.10.1 (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Cholorphyll content (SPAD index): Maximum SPAD index was observed in treatment T₄ (43.45) which differ significantly from T₁, T₂, T₃ and T₅ but are statistically at par with treatment T₅ (Figure 1).

Leaf macronutrients: Different selections do not show significant difference in leaf nutrient status treatments and had significant effect on leaf macro and micro-nutrient status (Table 2). A conjoint application of inorganic fertilizer with organic manures resulted in a significant increase in the leaf macronutrient status. Similar results were also reported in coconut seedling by Reddy et al (2001) and in papaya by Shivputra et al (2004). Maximum leaf nitrogen content was

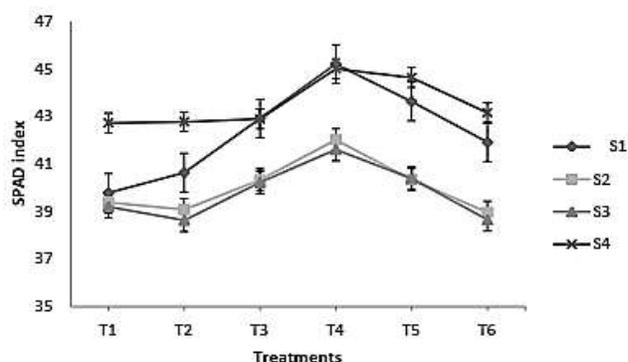


Fig. 1. Effect of integrated nutrient management on SPAD index of walnut leaves nitrogen and magnesium from combined application of inorganic fertilizer with vermicompost. These results agree with those obtained by Mishra et al (2011)

observed in treatment T₄ (2.79%) followed by T₅, T₁ and T₃, while lowest was recorded in treatment T₂ and T₆ (2.71%). Phosphorus content of leaves differed significantly with different treatments with highest P content in treatment T₄ (0.36 %). The highest K content was observed in treatment T₄ (1.72 %) followed by T₁ and T₅, while lowest was in treatment T₆. The highest leaf NPK content in treatment T₄ might be because application of vermicompost along with NPK must have enhanced mineralization of organic nitrogen thus making more nitrogen available to the plants. Higher nitrogen can also be due to the improvement in soil aeration, better soil moisture retention in root zone, increased microbial nitrogen fixation due to the conjoint application and improved its availability to the plants. The addition of vermicompost improves physical properties of soil, moisture retention in soil rhizosphere, improved root development by mycelial network of arbuscular mycorrhizal fungi, thus increased the water absorption and hence improved nutrient contents of leaf (Gupta et al 2005). Phosphorus applied to the soil in inorganic form get fixed but addition along with organic manure release P slowly due to microbial culture present in the soil, solubilized the fixed phosphorus and make it easily and readily available to plants. Different workers have reported increased leaf NPK content with combined application of inorganic fertilizer and vermicompost (Mitra et al 2010). Maximum leaf calcium was observed in treatment T₄ (2.58%) followed by T₅ and T₃, while as lowest was in T₁ (2.25 %). Highest magnesium content was recorded in T₄ (≈0.57 %) and minimum in T₁ (0.51 %). This increased calcium and magnesium content in leaves might be because vermicompost is a rich source of calcium and with the application of vermicompost, availability of Ca would have increased hence more leaf Ca. These results are in confirmation with the findings of Anitha and Prema (2003)

who reported more Ca in vermicompost. The results are in corroboration with Morselli et al (2004) reported that addition of organic manures enhanced the leaf content of P, K, Mg and Ca. Emmanuel et al(2010) also reported increased tissue concentration of N, P, K, Ca and Mg with application of organic manure in African cherry nut.

Leaf micronutrients: The highest leaf iron content was observed with T₅ (107.71 ppm) which was significantly different from rest treatments except T₄, whereas lowest iron

content was in T₁ (85.86 ppm). Maximum copper content was in T₄ (10.35 ppm) followed by T₅, T₃ and T₆ while minimum copper content was observed in T₁ (3.48ppm). The higher leaf iron status in T₅ might be due to higher iron content in poultry manure. Leaf zinc content was also highest in t T₄ (23.76 ppm), which is statistically at par with treatment T₅ but show marked differences with all other treatments. The higher concentration of leaf micronutrients in combined application of inorganic and vermicompost application might

Table 2. Effect of integrated nutrient management on leaf mineral content

		T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
N	S ₁	2.77aC	2.70bE	2.71cD	2.78dA	2.72eB	2.69fE
	S ₂	2.78aC	2.71bE	2.74cD	2.79dA	2.76eB	2.71fE
	S ₃	2.76aC	2.70bE	2.71cD	2.78dA	2.75eB	2.72fE
	S ₄	2.78aC	2.72bE	2.72cD	2.79dA	2.75eB	2.70fE
P	S ₁	0.23aD	0.30bB	0.21E	0.37dA	0.24eD	0.27fC
	S ₂	0.25aD	0.29bB	0.21cE	0.36dA	0.24eD	0.26fC
	S ₃	0.25aD	0.28bB	0.22cE	0.36dA	0.25eD	0.27fC
	S ₄	0.24aD	0.29bB	0.21cE	0.37dA	0.24eC	0.26fC
K	S ₁	1.63aB	1.55bD	1.57cC	1.73dA	1.59eC	1.51E
	S ₂	1.66aB	1.54bD	1.58cC	1.71dA	1.60eC	1.52E
	S ₃	1.67aB	1.55bD	1.59cC	1.72dA	1.61eC	1.52E
	S ₄	1.69aB	1.54bD	1.57cC	1.73dA	1.59eC	1.51E
Ca	S ₁	2.27aE	2.34bD	2.44cC	2.58dA	2.55eB	2.46fC
	S ₂	2.25aE	2.35bD	2.42cC	2.58dA	2.56eB	2.44fC
	S ₃	2.26aE	2.33bD	2.43cC	2.60dA	2.55eB	2.45fC
	S ₄	2.24aE	2.33bD	2.45cC	2.58dA	2.58eB	2.44fC
Mg	S ₁	0.51aD	0.53bC	0.54cB	0.57dA	0.54eB	0.53B
	S ₂	0.50aD	0.53bC	0.53cB	0.56dA	0.53eB	0.52A
	S ₃	0.51aD	0.52bC	0.54cB	0.57dA	0.53eB	0.52A
	S ₄	0.51aD	0.53bC	0.54cB	0.57dA	0.54eB	0.52B
Fe	S ₁	84.86aD	94.33bB	95.72cB	107.27dA	109.27eA	91.12fC
	S ₂	85.58aD	94.59bB	95.5cB	105.5dA	106.49eA	89.56fC
	S ₃	86.40aD	96.49bB	97.43cB	106.93dA	107.26eA	89.91fC
	S ₄	86.61aD	95.42bB	95.39cB	108.25dA	107.8eA	91.09fC
Cu	S ₁	2.85aF	7.11bE	8.86cC	9.58dA	9.33eB	7.72fD
	S ₂	2.99aF	6.56bE	8.34cC	10.4dA	9.47eB	8.31fC
	S ₃	4.18aF	6.45bE	9.18cC	10.94dA	10.09eB	8.03fD
	S ₄	3.92aF	6.21bE	8.85cC	10.48dA	10.13eB	7.73fD
Zn	S ₁	20.74aB	21.43bB	21.43cB	24.43dA	23.37eA	21.92B
	S ₂	20.25aB	22.05bB	22.17cB	23.33dA	23.81eA	21.56B
	S ₃	20.21aB	21.97bB	21.98cB	23.84dA	23.52eA	22.47B
	S ₄	20.25aB	21.47bB	22.56cB	23.45dA	22.96eA	20.80B

Values are mean \pm standard deviations (n=3) measurements with different letters in a column (small) and row(capital) in a specific assay vary significantly ($p \leq 0.05$) T₁=NPK (recommended as per package of practices) through inorganic fertilizers, T₂=FYM, vermicompost and poultry manure (2:1:1), T₃ = (NPK: FYM in the ratio of 3:1), T₄ = NPK: vermicompost (3:1), T₅ = NPK: poultry manure (3:1), T₆ = 75% NPK through inorganic fertilizers + 25% through manure (1/3 FYM + 1/3 vermicompost + 1/3 poultry manure). S₁ =SKAU/002, S₂=SKAU/008, S₃=SKAU/024, S₄ =SKAU/040

be due to the reason that vermicompost must have improved soil properties like microbial population, enzymatic activities especially dehydrogenase and hydrogenase that increased the availability of micronutrients in vermicompost treated soils.

Physico-chemical analysis: Fruit yield in four walnut varieties varied significantly in the order $S_2 > S_1 > S_3 > S_4$. Fruit yield obtained after application of inorganic fertilizer (T1) and organic manure (T2) varied non-significantly irrespective of the walnut varieties studied. No significant difference in fruit yields through organic and inorganic fertilization was previously reported in strawberry (Hargreaves et al 2008). However, a conjoint application significantly affected the fruit yield in walnut varieties. Highest fruit yield was found in walnut varieties with treatment T4 (5.87 kg tree⁻¹) that was significantly higher than treatment T5 (5.30 kg tree⁻¹) and treatment T6 (4.92 kg tree⁻¹) (Fig. 2a). Wójcik and Filipczak (2015) also reported a higher fruit yield in Tibetan blackcurrants using a combination of organic and inorganic fertilizer while lowest yield was reported for organic combinations only. Fruit weight in S_2 (12.56 g) was significantly higher than rest of the walnut varieties while the lowest value was observed in S_3 (11.87 g). Treatments significantly affected fruit weight of walnut varieties (Fig. 2b).

Application of organic manure (T2) resulted in a significant decrease in the fruit weight than inorganic fertilizer (T1). Integrated nutrient management significantly affected the fruit yield in all the walnut varieties under study. Among different treatments, maximum fruit weight (13.16 g) was in T4 while minimum fruit weight (11.68g) in T6. Sileshi et al (2011) also observed similar trend in six paprika cultivars. Addition of vermicompost along with inorganic fertilizer showed highest results for fruit yield. Similar results have been reported in groundnut (Sahana 2019) and apple (Raina et al 2011). This increase in fruit parameter with combined application of vermicompost and inorganic fertilizers might be because vermicompost through the supply of important micro-nutrients and enzyme activation may have improved the fruit parameters. Fruits from different varieties were studied for protein, lipid and ash content (Table 3). The S2 variety showed significantly higher protein fat and ash content. Treatments did not show any remarkable differences in the nutritional content except for protein. Dangour et al (2009) also reported no significant difference in nutritional quality of organically and inorganically produced foods. T1 resulted in significantly higher protein content of fruits than organic treatment (T2). Lower protein content in organically produced food stuffs is very well documented

Table 3. Effect of integrated nutrient management on nut characteristics

Spacing		T1	T2	T3	T4	T5	T6
Protein	S1	16.1aB	15.25aC	16.33aB	16.93aA	16.67aB	16.37aB
	S2	18.37bB	17.52bC	18.6bB	19.2bA	18.94bB	18.64bB
	S3	17.11aB	16.36aC	17.44aB	18.04aA	17.78aB	17.48aB
	S4	16.65aB	15.8aC	16.88aB	17.48aA	17.22aB	16.92aB
Fat	S1	58.25aB	57.4aC	58.48aB	59.08aA	58.82aB	58.52aB
	S2	58.63aB	57.78aC	58.86aB	59.46aA	58.74aB	58.9aB
	S3	58.24aB	57.39aC	58.47aB	59.07aA	58.81aB	58.51aB
	S4	58.38aB	57.53aC	58.61aB	59.21aA	58.85aB	58.65aB
Ash	S1	1.52aC	0.67aD	1.75aB	2.35aA	2.09aB	1.79aB
	S2	1.94bC	1.09bD	2.17bB	2.77bA	2.51bB	2.21bB
	S3	1.64aC	0.79aD	1.87aB	2.47aA±0.02	2.21aB	1.91aB
	S4	1.48aC	0.63aD	1.71aB	2.31aA±0.02	2.05aB	1.75aB
TPC (mg GAE/g dw)	S1	60.84aE	63.69aD	64.92aC	67.02aA±0.02	65.26aB	64.96aC
	S2	61.74bE	64.59bD	65.82bC	67.92bA±0.05	66.16bB	65.86bC
	S3	61.62bE	64.47bD	65.7bC	67.86bA±0.03	66.04bB	65.74bC
	S4	60.60aE	63.45aD	64.68aC	66.78aA±0.05	65.02aB	64.72aC
DPPH (EC ₅₀)	S1	0.21aE	0.19aD	0.21aC	0.26aA±0.01	0.24aB	0.22aC
	S2	0.25bE	0.23bD	0.25bC	0.30bA±0.02	0.28bB	0.26bC
	S3	0.23bE	0.21bD	0.23bC	0.28bA±0.01	0.26bB	0.24bC
	S4	0.19aE	0.17aD	0.19aC	0.24aA	0.22aB	0.21aC

See Table 1 for details

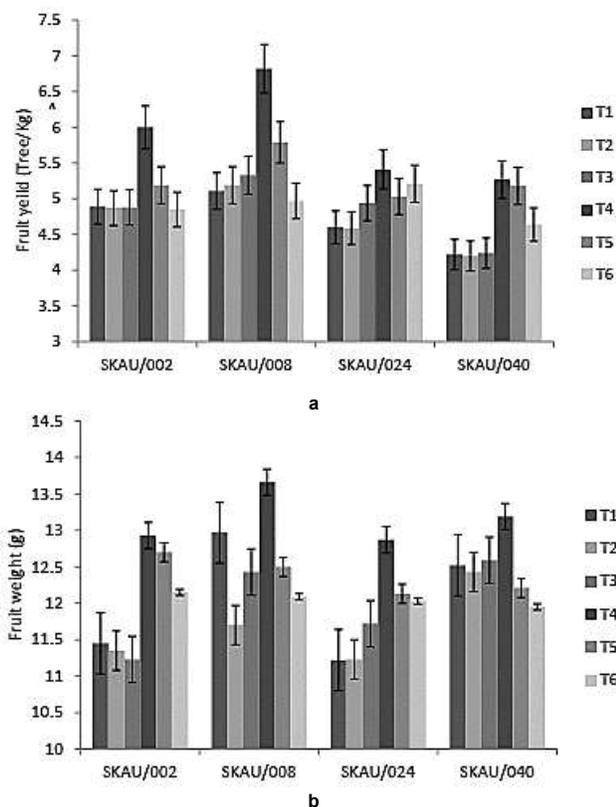


Fig. 2. Effect of integrated nutrient management on a) Fruit yield and b) Fruit weight

(Worthington 2001). However, a conjoint application of organic and inorganic fertilizer significantly improved the nutritional profiling viz; protein, fat and ash content in all walnut varieties with highest values recorded for T4. Higher results for T4 can be due to better establishment of microbes through vermicompost that would have helped the soil to become ready to serve zone for essential nutrients to plant root system.

Total phenolic content (TPC): Among different varieties, S₂ showed significantly higher value for TPC while lowest value was in S₄. Different treatments significantly affected the total phenolic content of varieties in the order T4>T5>T6≈T3>T2 (Table 3). Application of organic manures significantly increased the total phenolic content in comparison to application of inorganic manure in all varieties. TPC of walnuts obtained by addition of organic manure walnut was ≈5% higher than TPC of fruits obtained through inorganic fertilization. Higher TPC thorough organic manuring than inorganic fertilization was previously reported in beans (Yahya et al 2017) and tomatoes (Toor et al 2006). A higher TPC content due to organic manures can be because inorganic fertilizers supply more bioavailable nitrogen that may accelerate the plant growth but not the secondary metabolites. Among organic manures highest TPC was

found with the application of T4>T5>T6≈T3>T2. TPC of walnuts treated with T4 was 10% higher than the TPC of T1. Higher results for vermicompost were previous also reported by Omar et al (2012). Higher values due to vermicompost can be due to fundamental differences between different sources of supplements. In addition, enzymatic activity of worms in vermicompost as well as the presence of beneficial microorganism may positively affect the plant growth.

DPPH radicle scavenging activity: Antioxidant activity of walnut varieties varied significantly with the type of nutrient management employed (Table 3). Antioxidant activity of walnut fruits showed a similar trend to that of TPC. Inorganic fertilizers resulted in lower DPPH radicle scavenging activity than organic fertilizers. Similar results were reported in cabbage (Bimova and Pokluda 2009). Antioxidant activity in walnut fruits due to application of organic fertilizers showed the trend as T4>T5>T6≈T3>T2. Antioxidant activity of fruits is strongly correlated to their total phenolic content (Muzzaffar et al 2016) that explains the antioxidant activity trend of walnut fruits in this study.

CONCLUSION

Chemical fertilizers can be used in combination with economic and eco-friendly organic manures to achieve substantial productivity. The integrated nutrient management of walnut is one of the important factors to boost the yield and improve the quality of nuts. A combination of inorganic and organic nutrient sources improved fruit yield with enhanced fruit nutritional and nutraceutical quality of walnut. Conjoint application of inorganic fertilizers with vermicompost exerted a significant role in improving leaf nutrient status and fruit quality of walnut rather than independently using organic or inorganic nutrient sources. Among different organic nutrient sources, vermicomposting should be preferred over other organic manures for integrated nutrient management in walnuts.

REFERENCES

- Amin F, Masoodi FA, Baba WN, Khan AA and Ganie A 2017. Effect of different ripening stages on walnut kernel quality: Antioxidant activities, lipid characterization and antibacterial properties. *Journal of food science and technology* **54**: 3791-3801.
- Anitha S and Prema A 2003. Vermicompost boost crop production. *Indian Farming News* **53**: 15-18.
- Baba WN, Din S, Punoo, HA, Wani TA, Ahmad M and Masoodi F A 2016. Comparison of cheese and paneer whey for production of a functional pineapple beverage: Nutraceutical properties and Shelf life. *Journal of Food Science and Technology* **53**: 2558-2568.
- Bímová, P and Pokluda R 2009. Impact of organic fertilizers on total antioxidant capacity in head cabbage. *Horticulture Science* **36**: 21–25.
- Dangour AD, Dодhia SK, Hayter A, Allen E, Lock K and Uauy R 2009. Nutritional quality of organic foods: A systematic review.

- American Journal of Clinical Nutrition* **90**: 680-685.
- Dhaliwal SS, Dhaliwal MK, Shukla AK and Manchanda JS 2017. Long term effect of integrated nutrient management on distribution of total Zn, Cu, Fe and Mn under rice-wheat system. *Indian Journal of Ecology* **44**(3): 543-547.
- Emmanuel IMJ and Francis OA 2010. Comparative evaluation of different organic fertilizers on soil improvement, leaf mineral composition and growth performance of African cherry nut (*Chrysophyllum albidum* L.) seedlings. *Journal of American Science* **6**: 217-223.
- Gupta RK, Sharma KN, Singh B, Singh Y and Arora BR 2005. Effect of urea and manure addition on changes in mineral N-content in soil profile at various growth stages of wheat. *Journal of Indian Society of Soil Science* **53**: 74-80.
- Hargreaves JC, Adl MS, Warman PR and Rupasinghe HPV 2008. The effects of organic and conventional nutrient amendments on strawberry cultivation: Fruit yield and quality. *Journal of the science of the food and agriculture* **88**: 2669-2675.
- Lee KE 1985. *Earthworms: Their ecology and relationships with soils and land use*. Academic Press Inc.
- Verma G and Kaur S 2016. Residual effect of integrated nutrient management practices on soil nutrient status and yield attributes. *Indian Journal of Ecology* **43**(2): 605-607.
- Madarakhandi S, Patil DR, Madawal SI and Kumar BR 2015. Integrated nutrient management in kinnow mandarin (*Citrus deliciosa* Tenore). *Indian Journal of Ecology* **42**(1): 113-117.
- Mishra S, Choudhary MR, Yadav BL and Singh SP 2011. Studies on response of integrated nutrient management on growth yield of ber. *Indian Journal of Horticulture* **68**: 318-321.
- Mitra SK, Gurling MR and Pathak PK 2010. Integrated nutrient management in high density guava orchards. Proc. 11nd IS on guava and other myrtacral. (Eds. W. Rohde and G. Fermin). *Acta Horticulturae* 849.
- Morselli TBGA, Sallis MG, Terra S and Fernandes HS 2004. Response of lettuce to application of vermicompost. *Revista Científica Rural* **9**: 1-7.
- Muzzaffar S, Baba WN, Nazir N, Masoodi FA, Bhat MM and Bazaz R 2016. Effect of storage on physicochemical, microbial and antioxidant properties of pumpkin (*Cucurbita moschata*) candy. *Cogent Food and Agriculture* **2**: e1163650.
- Omar NF, Hassan SA, Yusoff UK, Abdullah NA, Wahab PE and Sinniah U 2012. Phenolics, flavonoids, antioxidant activity and cyanogenic glycosides of organic and mineral-base fertilized cassava tubers. *Molecules* **17**: 2378-2387.
- Raina JN, Kumar A and Suman S 2011. Effect of conjoint application of organic manure and chemical fertilizer on soil nutrient status and productivity of apple (*Malus domestica* Borkh.). *Progressive Horticulture* **43**: 259-263.
- Reddy DS, Kumar SN and Prabhu SR 2001. Evaluation of alternative media to potting mixture for raising coconut seedlings in polybags. *Journal of Plantation Crops* **29**: 62-65.
- Regueiro J, Sañchez-González C, Vallverdu-Queralt A, Simal-Gandara J, Lamuela-Raventós R and Izquierdo-Pulido M 2013. Comprehensive identification of walnut polyphenols by liquid chromatography coupled to linear ion trap-Orbitrap mass spectrometry. *Food Chemistry* **152**: 340-348.
- Ruijun W, Shi W, Yijun X, Mengwuliji T, Lijuan Z and Yumin W 2015. Antitumor effects and immune regulation activities of a purified polysaccharide extracted from *Juglans regia*. *International Journal of Biological Macromolecules* **72**: 771-775.
- Sahu YK, Chaubey AK, Prahalad K, Kulhary LK and Chowdhury T 2017. Effect of integrated nutrient management on soil biological properties and yield of rice in Inceptisol. *Indian Journal of Ecology* **44**(4): 804-807.
- Shafi M, Baba WN, Masoodi FA and Bazaz R 2017. Wheat-water chestnut flour blends: Effect of baking on antioxidant properties of cookies. *Journal of food science and technology* **53**: 4278-4288.
- Shi A, Liu K, Wang H and Liu Y 2001. Effect of house hold waste and animal manure compost on growth of Chinese chestnut and soil. *Journal of Beijing Agricultural College* **16**: 46-51.
- Shivputra SS, Patil CP, Swamy GSK and Patil PB 2004. Cumulative effect of VAM fungi and vermicompost on nitrogen, phosphorus, potassium and chlorophyll content of papaya leaf. *Mycorrhiza News* **16**: 15-16.
- Sileshi W, Akinnifesi FK, Ondwe FM, Ajayi OC, Mng'omba S and Mwafongo K 2011. Effect of organic fertilizer on the growth and fruit yield of six paprika (*Capsicum annum* L.) cultivars in Malawi. *Agroforestry Systems* **83**: 361-372.
- Singh G and Walia SS 2015. Influence of Integrated Nutrient Management on Growth and Yield of Babycorn (*Zea mays* L.). *Indian Journal of Ecology* **42**(2): 346-348.
- Toor RK, Savage GP and Heeb A 2006. Influence of different types of fertilisers on the major antioxidant components of tomatoes. *Journal of Food Composition and Analysis* **19**: 20-27.
- Venkitaswamy R and Khan HH 2002. Integrated nutrient management in coconut, pp 410-413. In: Proceedings of the 15th Plantation Crops Symposium, held in December 2002 at Mysore, India.
- Wójcik P and Filipczak J 2015. Growth and early fruit production of 'Tiben' blackcurrants fertilised with pre- and post-planting applications of mineral fertilisers and swine manure. *Scientia Horticulturae* **185**: 90-97.
- Worthington V 2001. Nutritional quality of organic versus conventional fruits, vegetables and grains. *Journal of Alternative and Complementary Medicine* **7**: 161-173.
- Yahya HM, Haron H and Dang TN 2017. Total phenolic content and antioxidant capacity of beans: Organic vs inorganic. *International Food Research Journal* **24**: 510-517.
- Zhang H, Pan T and Zhangm F 2004. Effect of base fertilizer applied in different periods on growth and yield of grape. *Tianjin Agricultural Science* **10**: 43-44.
- Zhuhua Z, Rongting X, Yi G, Hongxia W and Huating Y 2004. Studies on the indexes of tree structure and its regulating in young precocious walnut. *Journal of Hebei Agricultural University* **27**(6): 30-33.
- Sahana CS and Premaradhya N 2019. Influence of mulching, hydrogel and nutrient management on seed quality parameters of summer groundnut (*Arachis hypogaea* L.). *Journal of Pharmacognosy and Phytochemistry* **8**(4): 1023-1026.



Evaluation of Ground Water Quality and Suitability for Irrigation in Nathusari Chopta Block of Sirsa District (Haryana, India) using Geo-informatics

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Abstract: The study area was fall under semiarid climatic condition where groundwater serves as the most consistent source of water for their domestic and agricultural activities. Seventy eight groundwater samples were collected and analyzed for pH, electrical conductivity (EC), anions (HCO_3^- , CO_3^{2-}) and cations (Ca^{2+} , Mg^{2+} and Na^+). From the results of the analyses and measurements, the suitability of the groundwater for irrigation were evaluated based on the EC, sodium adsorption ratio (SAR), permeability index (PI), residual sodium carbonate (RSC), Kelly's ratio (KR) and US salinity laboratory diagram. The interpolation technique of geospatial technology was also used to evaluate and mapping of spatial changeability of EC, pH, SAR, RSC and groundwater quality, which provide first-hand information about the quality of groundwater. The analysis of above cites phenomena showed that the EC of groundwater ranged from 450 to 16300 $\mu\text{s}/\text{cm}$ and 61.04% of the samples fall under unsuitable and 25.97% under doubtful category respectively. These unsuitable and doubtful categories were more prominent in central, North-east and West as rising trends in the area and occupied 72.91% and 26.31% area of study area, respectively. The central and western part of area is most affected by this groundwater quality and most of the area suffers from waterlogging and soil salinity. As per US salinity diagram the groundwater of the area falls within the high salinity-low sodium hazard and medium salinity-low sodium hazard classes. Regarding the indices viz. RSC, SAR, PI and KR, the results showed that more than 90% of the samples were found to be within the safe limit and likely suitable for agricultural irrigation purposes. The major aim of the study was to find out pre-treatment and monitoring of the studied samples if they were to be utilized for irrigation. One option is to beat this issue to grow salt tolerant crops.

Keywords: Groundwater quality, Geospatial technology, Anions, Cations, SAR, KR, RSC

Groundwater is the main source of water that meets the agricultural, industrial and household requirements. During the past few decades, the contest for economic development allied with the population growth and urbanization has led to the major changes in land use, thus resulting in more demand of water for these activities (Nag and Das 2014). Water quality is decreasing due to the rapid growth of a large number of industries as well as other infrastructures. These human activities have a significant effect on the water quality of the particular region and therefore, the need for community recognition and enforcement of the Land-use Legislation, better drainage, treatment plant construction and catchment management in these areas has been recommended (Chauhan and Bhardwaj 2017). The surface freshwater bodies are rapidly declining day by day today's need to conserve these freshwater ecosystems (Abhishek et al 2020). The usable water resource is not sufficient in India for irrigation. Due to this, efforts are required to enhance the source of water for irrigation in agriculture (Ahamed et al 2013). As per Agricultural Statistics of Haryana 2016-17, the irrigation facilities in the state mainly cover by canals (38.8%) and tube-well (61.2%). The groundwater is largely used in irrigation so the quality and suitability of groundwater is major

requirement for sustainable crop production.

The groundwater quality for irrigation depends upon the mineral constituents present in the water and is essential to maintain the soil crop productivity at a higher level. Assessment of groundwater quality for irrigation was prerequisite for sustainable agricultural development and crop production, so care should be taken before water gets contamination (Vinothkanna et al 2020). The excessive ground water draft from randomly distributed tube-wells for irrigation purposes has changed the ground water level, quantity and quality scenario. The basic feature controlling ground water quality is dissolved substances, which are generally called as the salts. The salts should contain small amounts of dissolved solids originating from dissolution or weathering of the rocks.

The interactions of water, soil, rock and source of various pollutants are responsible for the inequality of groundwater quality. Sequentially to excess withdrawal of groundwater can also change the natural quality of groundwater. Groundwater quality was also decreasing day by day due to anthropogenic activities like excess amount of fertilizers and pesticides used for crop yield (Kumar et al 2019). Keeping in view the aforementioned facts, the present study was

undertaken to evaluation and suitability of groundwater quality for irrigation purposes in Nathusari Chopta block of district Sirsa, Haryana.

MATERIAL AND METHODS

Location of the study area: The 'Nathusari Chopta block' of Sirsa district is situated on the border of Haryana and Rajasthan. It is located between 29°13'21" to 29°31'28" North latitude and 74°54'13" to 75°18'40 East longitude.

Methodology: The 78 groundwater samples were collected during 2019 from private tube-well, hand-pump and wells in pre cleaned sterilized polyethylene plastic bottles (Fig. 1). The ground water samples were analyzed for hydro-chemical parameters of calcium (Ca), magnesium (Mg) and sodium (Na⁺). The physical parameters like electrical conductivity (EC) were also measured by conductivity meter and pH by pH meter. All chemical parameters are expressed in milli equivalent per liter except pH and EC. To find irrigation water quality based on EC, SAR and RSC, water samples were classified into different categories as per the classification of All India Coordinated Research Project (AICRP) on Management of Salt Affected Soils and Use of Saline Water in Agriculture (AICRP-1989, Table 1). In order to find the suitability of groundwater in agricultural irrigation, several indices such as sodium absorption ratio (SAR),

permeability index (PI), residual sodium carbonate (RSC), Kelly's ratio (KR) electrical conductivity (EC) and US salinity laboratory diagram have been used. The concentrations of the ions were interpreted and calculated from standard equations as (Table 2).

RESULTS AND DISCUSSION

Electrical conductivity (EC): The EC indicated that 61.04 % (47 samples) fall within the unsuitable category; while 20 (25.97%) and 8 samples (10.39 %) fall within the doubtful and permissible categories, respectively. Only 2 samples (2.60%) fall within the good categories (Table 3, Fig. 2).

Residual sodium carbonate (RSC): All samples of study area are within the safe quality categories for irrigation this indicates that water is suitable for irrigation. The RSC values varied from -91.3 to 0.78 meq l⁻¹. Most samples (95%) showed negative values which indicated that dissolved calcium and magnesium contents were higher than carbonate and bicarbonate contents. It indicates that 100% of the samples have a good water quality where RSC values are less than 1.25 meq l⁻¹ (Table 4).

Sodium adsorption ratio (SAR): The SAR values in the study area range from -3.43 to 9.04 meq l⁻¹, which is less than 10 and all the samples of the study area have been in excellent quality of groundwater to suitability for irrigation. There is no threat of sodium consideration in soil as per SAR. The higher the SAR values in the water, the greater the risk of sodium. A plot of groundwater data on the US salinity diagram (Richards 1968), in which the EC is taken as salinity hazard and SAR as alkalinity hazard (Fig. 3), shows 19.48 % of the samples fall within the medium salinity-low sodium type of water (C2-S1) and 40.26 % fall under medium salinity-low sodium class (C3-S1). More over 45% of the samples fall within the high-salinity hazard-medium sodium hazard class (C3-S2) (Table 5). Groundwater that fall within the C1-S1 and C2-S1 can be used for irrigation on all types of soil with little danger of the development of harmful levels of exchangeable sodium. However, C3- S2 and C3-S4 types of water could only be used to irrigate certain semi-tolerant crops.

Table 1. Irrigation water quality classification

Water quality	Class	Quality parameter		
		EC (dS m ⁻¹)	SAR	RSC (meq L ⁻¹)
Good	A	< 2	<10	<2.5
Saline	B			
Marginally saline	B ₁	2-4	<10	<2.5
Saline	B ₂	>4	<10	<2.5
High SAR saline	B ₃	>4	>10	<2.5
Alkali water	C			
Marginally alkali	C ₁	< 2	<10	2.5-4
Alkali	C ₂	< 2	<10	>4
Highly alkali	C ₃	Variable	>10	>4

Table 2. Equations used to calculate the irrigation induces

Index	Equation	Reference
Sodium adsorption ratio	$SAR = \frac{Na^+}{[(Ca^{2+} + Mg^{2+}) / 2]^{1/2}}$	Ragunath (1987)
Kelly's ratio	$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$	Kelly (1963)
Permeability Index	$PI = \frac{(Na + \sqrt{HCO_3}) \times 100}{Ca + Mg + Na}$	Doneen (1964)
Residual sodium carbonate	$RSC = (CO_3 + HC_3 - (Ca + Mg))$	Eaton (1950)

pH: The pH of groundwater samples ranged from 6.7 to 8.4 with a mean value of 7.31 indicating that the water is neutral to alkaline in nature (Fig. 4). The lowest pH was observed in Jogiwala and highest in Mochiwali. The variations in pH are relatively small and the results also show that the alkaline pH is particularly due to bicarbonate and not due to carbonate alkalinity (Ahmad et al 2013). The higher pH of most of the groundwater samples may be due to considerable sodium, calcium, magnesium, carbonate and bicarbonate concentration (Al-Tabbal and Al-Zboon 2012) as carbonates and bicarbonates are hydroxyl generating ions (Bhat et al 2018).

Permeability index (PI): Permeability index of the soils can be affected by the long term use of the irrigation water when it contains high concentrations of salts. It is a crucial parameter for assessing the suitability of irrigation water. In accordance with PI, water can be classified as Class I, II and III and class I stand for PI% values more than 75, Class-II PI% varied between 25-75 and Class-III covers the PI% less than 25. The present area the groundwater samples varied from- 557.89 to 89.64 with an average of 32.57%, while as 68.83 % (53 samples) of groundwater fall within II class and 27.27% (21 Samples) with in III class categories, respectively.

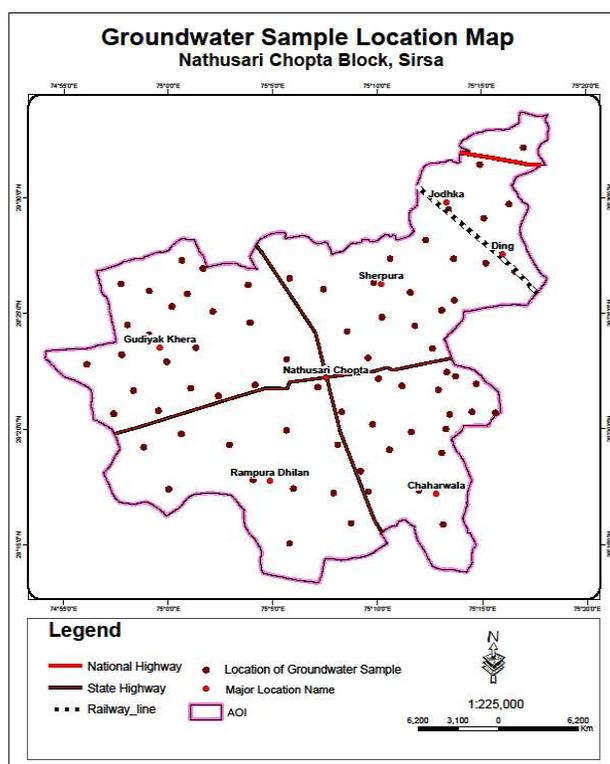


Fig. 1. Groundwater sample location map

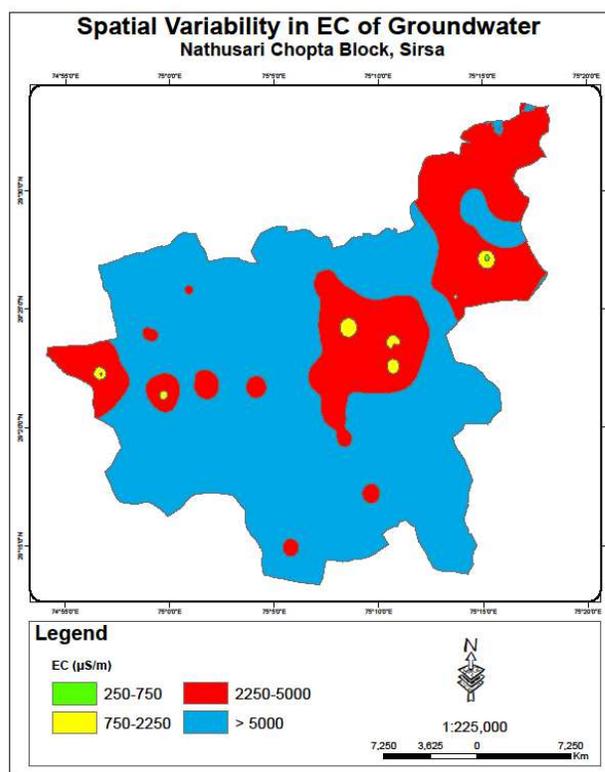


Fig. 2. Spatial variability in EC of groundwater

Table 3. Groundwater quality based on EC

Criteria	Parameter	Category	Range	No. of sample	Percent of samples
USSL classification after Richards (1954)	E.C. (µS/m)	Excellent	< 250	Nil	Nil
		Good	250-750	2	2.60
		Permissible	750-2250	8	10.39
		Doubtful	2250-5000	20	25.97
		Unsuitable	>5000	47	61.04

Table 4. Suitability of irrigation water based on RSC

Criteria	Parameter	Value range	Suitability for Irrigation	Area in Sq. km	Percent of study area
EEC classification in Lloyd and Heathcote (1985)	RSC(meq/l)	< 1.25	Suitable	756.44	100
		1.25–2.5	Marginal	0	0
		> 2.5	Unsuitable	0	0

Kelly's Ratio (KR): Waters with a KR value <1 are regarded suitable for irrigation, while those with higher values are considered unsuitable. In the present study area, the KR values of groundwater varied from -0.86 to 2.26 while as the majority (80.52%) of the collected samples fall within the permissible limit of <1 and thus are considered suitable for the agricultural irrigation. Only 19.48% (15 Samples) of collected groundwater fall within unsuitable class as per KR

Table 5. Groundwater suitability class

Water quality	Class	Number of sample	Per cent of sample
Very good	C1- S1	2	2.60
	C2-S1	15	19.48
Medium	C2-S2		
	C2-S3	31	40.26
	C3-S1		
Bad	C2 - S4	17	22.08
	C3-S2		
Very bad	C3 - S3	12	15.58
	C3 - S4		

Table 6. Groundwater quality classification of Nathusari Chopta block

Water quality	Class	Number of sample	Per cent of sample
Good	A	10	12.99
Saline	B	Nil	Nil
Marginally saline	B ₁	11	14.29
Saline	B ₂	56	72.73

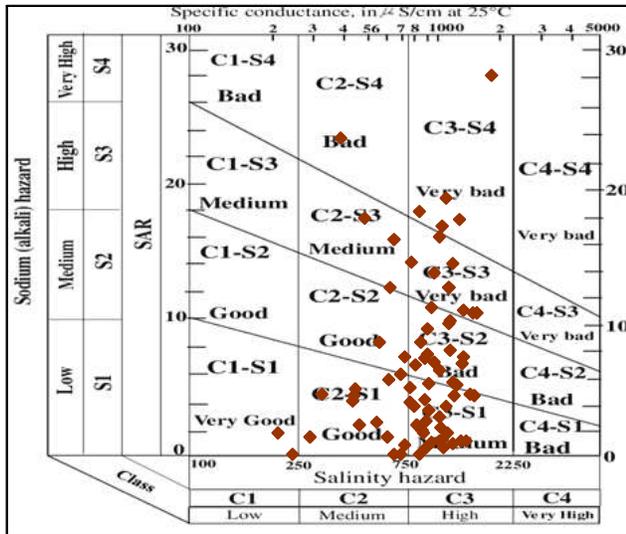


Fig. 3. Specific conductance

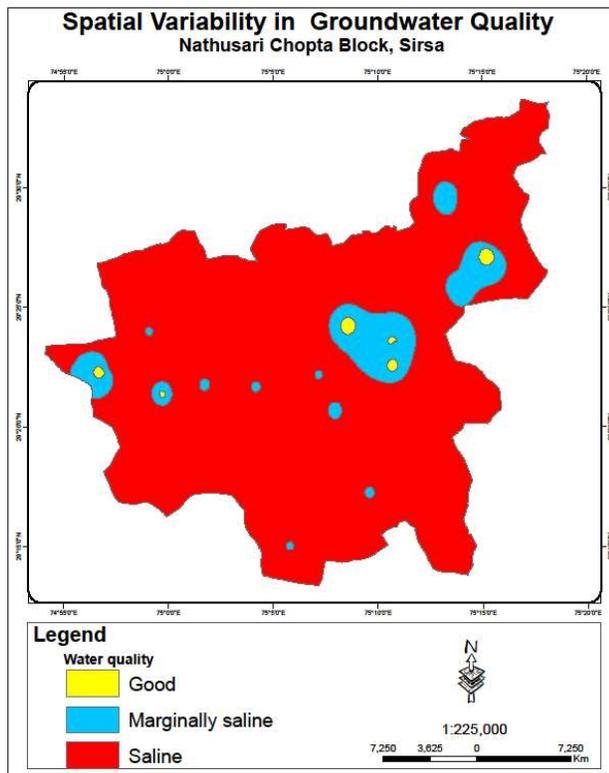


Fig. 4. Spatial variability in groundwater quality

index.

Groundwater quality as per AICRP Criteria: According to AICRP (1989) on Management of Salt Affected Soils and Use of Saline Water in Agriculture classification, in the present study area out of 77 groundwater samples 72.73% (56 samples) fall within saline category; while as 10 samples (12.99%) and 11 samples (14.29%) fall within the good and marginally saline categories, respectively (Table 6, Fig. 4).

CONCLUSION

The overall groundwater qualities vary from marginally saline to saline category. Based on EC, 87% of the samples of groundwater were under unsuitable and doubtful category for irrigation purpose. The high salinity in groundwater mostly central and south-west part of area was affected by this groundwater quality. These areas were also face the problem of waterlogging and soil salinity. In this situation saline groundwater quality is more dangerous for the area. Thus, more attention should be paid on groundwater salinity variations in future management for sustainable utilization. Other indices (RSC, SAR, and PI and KR) of groundwater quality for irrigation suitability, the result showed of PI that 72.73% groundwater samples falls under Class I and II, making the groundwater suitable for irrigation. The US salinity diagram also reveals that majority of the groundwater fall within the high salinity-low sodium (C3-S1) hazard and high salinity-medium sodium (C3-S2) hazard class. The remaining indices showed that more than 90% of the samples were found to be within the safe limit and likely

suitable for agricultural irrigation purposes. The subtle use of geospatial technology in spatial distribution of groundwater quality for sustainable development management of resources and aware to use of groundwater for irrigation first know suitability has been demonstrated in the present study.

REFERENCES

- Al-Tabbal JA and Al-Zboon KK 2011. Source evaluation of physicochemically contaminated groundwater of Dera Ismail Khan area, Pakistan. *Environmental Monitoring and Assessment* **175**: 9-121.
- Abhishek Nandal, Naveen Kaushik, Yadav SS, Rao AS, Neetu Singh and Gulia SS 2020. Water quality assessment of pond water of Kalanaur Block, Rohtak, Haryana. *Indian Journal of Ecology* **47**(1): 1-6.
- Agricultural Statics of Haryana 2016-2017. <http://esaharyana.gov.in/en-us/State-Statistical-Abstract-of-Haryana>.
- Ahamd AJ AS 2013. Assessment of groundwater quality for irrigation use in Alathur Block, Perambalur District, Tamilnadu, South India. *Applied Water Science* **3**: 763-771.
- AICRP 1989 1998-91. *All India Coordinated Research Project on Management of Salt Affected Soils and Use of Saline Water in Agriculture*. Karnal: Central Soil Salinity Research Institute.
- Bhat MA, Grewal, M S, Wani SA, Singh S, Dinesh, Grewal KS and Arya VS 2018. Application of geoinformatics for groundwater characterization. *Journal of the Indian Society of Soil Science* **66**(6): 237-248.
- Chauhan Shalini and Bhardwaj SK 2017. Effect of different land use on quality of water in Solan Block of Himachal Pradesh. *Indian Journal of Ecology* **44**(4): 808-812.
- Doneen LD 1964. *Notes on Water Quality in Agriculture*. Department of Water Science and Engineering, University of California, Water Science and Engineering, p. 400.
- Etteieb S, Cherif S and Tarhouni J 2017. Hydrochemical assessment of water quality for irrigation: A case study of the Medjerda River in Tunisia. *Applied Water Science* **7**: 469-480.
- Eaton FM 1950. Significance of Carbonate in Irrigation Water. *Soil Science* **67**: 112-133.
- Kelly WP 1963. Use of saline irrigation water. *Soil Science* **95**(4): 355-391.
- Kumar PS and Balamurugan P 2019. Suitability of ground water for irrigation purpose in Omalur Taluk, Salem, Tamil Nadu, India. *Indian Journal of Ecology* **46**(1): 1-6.
- Lloyd and Heathcote 1985. Study and interpretation of the chemical characteristics of natural water. *US Geological Survey Water-Supply Paper* **2254**, 263.
- Nag SK and Das S. 2014. Quality assessment of groundwater with special emphasis on irrigation and domestic suitability in Suri I & II Blocks, Birbhum District, West Bengal, India. *American Journal of Water Resources* **2**(4): 81-98.
- NS R 2018. Groundwater quality from a part of Prakasam District, Andhra Pradesh, India. *Applied Water Science* **8**(1): 8-30.
- Raghnath HM 1987. *Groundwater*, 2nd Ed. Wiley Eastern Ltd. New Delhi, India, pp. 344-369.
- Richards LA 1954-68. *Diagnosis and improvement of saline and alkali soils*. USDA Hand Book, No. 60.
- Sharma BK (2005) *Water Pollution*, 4th edn. Goel Publishing House, Meerut.
- Vinothkanna S, Rajee R and Senthilraja K 2020. Assessing ground water quality for the suitability of irrigation in Dindigul District, Tamil Nadu, India. *Indian Journal of Ecology* **47**(1): 23-29.
- USSL (US Salinity Laboratory) 1954. *Diagnosis and improvement of saline and alkaline soils*. Agriculture Handbook No. 60 USDA, p. 160.
- Wilcox LV 1955. *Classification and Use of irrigation water*, Washington: US Department of Agriculture, Circular No. 969, p. 19.



Post Emergent Non Chemical Formulations for Weed Management in Maize

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Abstract: The objectives of the study were to find out the best post emergent non chemical formulations for weed management in maize. Among the weeds, itchgrass (*Rottboellia cochinchinensis*) was dominant. Lower total dry weight of weeds were at 20 days after sowing (DAS) in plots treated with vinegar 20%, followed by traditional formulation @ 10 l ha⁻¹ (cow urine + lemon fruit + *Terminalia chebula*). At 45 DAS, lower dry weight of weeds was observed in hand weeding twice on 20 and 45 DAS. At 20 DAS, more than 88% weed control efficiency was observed in post emergence application of vinegar 20 % and post emergence application of vinegar 20 + hand weeding on 45 DAS. Among different post emergent non-chemical formulations, higher grain yield (7214 kg ha⁻¹), lower weed index (1.38%) and higher returns on invest (93.29) were obtained in post emergence application of vinegar 20% + hand weeding on 45 DAS followed by early post emergence application of traditional formulation @ 10 l ha⁻¹ (cow urine + lemon fruit + *T. chebula*) + hand weeding on 45 DAS.

Keywords: Maize, Non chemical formulation, Vinegar, Weed flora, Weed management

Maize (*Zea mays* L.) is the most adaptable food crop of universal importance. It is the third most important food grain crop after rice and wheat in India providing food, feed, fodder and as a source of basic raw material for manufacturing number of industrial products. Due its cultivation in rainy season and widely spaced planting, maize gets infested with variety of weeds and subjected to heavy weed competition during the first 4-6 weeks after emergence (Saini et al 2013). Very low to high range of actual yield losses (8.6-51%) and economic losses of USD 750 million (estimated) were observed due to weeds in maize in India (Gharde et al 2018). Increasing herbicide usage is a prime concern today. Indiscriminate uses of herbicides are having serious environmental and ecological effect. The overuse of herbicides has also lead to the fast evolution of herbicide-resistant weeds (Beckie 2006, Egan et al 2011, Powles and Yu 2010). Use of same group of herbicides will lead to weed shift also. Ever increasing populations of herbicide resistant weeds, weed shift and consistent public pressure to reduce overall pesticide use, herbicide alternatives are now required without delay. Proper assessment and use of directed application of post emergent non chemical formulations are possible substitution for herbicidal weed management. Information on non-chemical formulations in weed control should be collected and assessed properly in research fields to meet the present and upcoming situation. Cost effectiveness of formulations also needs much attention in this regard. Less information is available on the changes in weed flora, due to use of post emergent non chemical

formulations for weed management in maize. This experiment aimed to study the changes in weed flora, yield and cost effective point of view for finding the best non chemical formulation for weed control in maize

MATERIAL AND METHODS

Location and soil: A field experiment was conducted during *Kharif* (first crop season) 2017 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. The farm is located in Western Agro climatic zone of Tamil Nadu (11°N latitude and 77°E longitude) and 426.7 m above mean sea level. The experiment was laid in randomized block design with ten treatments and three replications. The soil texture of the experimental site was sandy loam with slightly alkaline pH (8.4), low in available N (219 kg ha⁻¹), and medium in available P (15 kg ha⁻¹) and high in available K (449.8 kg ha⁻¹).

Agronomic practices: Maize hybrid COH (M) 6 released by TNAU was used as the test crop. Seeds were sown at a spacing of 60 cm x 25 cm in plots of size 4.8 m x 5 m. Recommended dose of nutrients at 250: 75: 75 kg NPK ha⁻¹ were applied. Entire dose of P and K and 25% of N were applied basally. Half the dose of N was top dressed at 25 DAS and the remaining 25% of N was top dressed at 45 DAS.

Non chemical formulations and its application: Spraying (early post emergence and post emergence) of non-chemical formulations as well as spraying followed by hand weeding was included in the treatments. Common salt (NaCl) was bought from the market and made into 30% concentration and vinegar at a concentration of 20% was used in respective

treatments. Traditional formulation was prepared by mixing 3 kg finely grounded powder of dried fruits of *Terminalia chebula*, juice of ten numbers of lemon fruit in 10 litre of one month old cow urine. This was kept for 15 days under shade after covering with gunny bag. Regular stirring was also done. Before spraying, the formulation was sieved using a muslin cloth. Early post emergence (EPOE) applications were done at two to six leaf stage of weeds (15th day of sowing) and post emergence (POE) at 20th day of sowing using knapsack sprayer fitted with deflector type nozzle and hood to avoid direct contact of the spray fluid with crop plants (protected spray). Hand weeding twice at 20 and 45 DAS and weedy check were also maintained for comparison. The details of treatment are in Table 2.

Weed flora: Observations on weeds in maize crop were recorded on 20 and 45 DAS. Weed species in unweeded control plot were observed, identified and grouped as grasses, sedges and broad leaved weeds and presented as weed flora of the experimental field. Weed density of grasses, sedges, broad-leaved weeds was recorded by using quadrat (0.5 m x 0.5 m) in four places at random and expressed as number m² to get absolute density (AD). Relative density of individual weed species and group wise weeds were worked out as detailed below and expressed as per cent.

$$\text{Relative density (RD \%)} = \frac{\text{Absolute density of a given species (No. m}^{-2}\text{)}}{\text{Total absolute density of all species (No. m}^{-2}\text{)}} \times 100$$

Weed dry weight: Data on weed dry weight was estimated by using quadrat of size 0.5 m x 0.5 m in four places at random. The weed species were pulled out and the samples were air dried and then oven dried at 80°C to attain a constant dry weight. Total dry matter of weeds was expressed as g m⁻² to find out the weed control efficiency.

Weed control efficiency: Weed control efficiency was calculated on the basis of weed dry weight recorded on each treatment at 20 and 45 DAS, using the formula of Mani et al (1973) and expressed in per cent.

$$\text{WCE (\%)} = \frac{\text{WDW}_c - \text{WDW}_t}{\text{WDW}_c} \times 100$$

Where, WCE is the weed control efficiency in per cent, WDW_c is weed dry weight in unweeded control plot (g m⁻²) and WDW_t is the weed dry weight in treated plot (g m⁻²).

Grain yield: The cobs harvested from net plot area of each treatment were sun dried, threshed, cleaned and grain yield (kg ha⁻¹) was recorded at a moisture level of 14 per cent.

Weed index: Weed index was calculated by following formula suggested by Gill and Vijaya Kumar (1966).

$$\text{WI} = \frac{X - Y}{X} \times 100$$

Where, X is the yield obtained in the weed free plot (kg ha⁻¹) and Y is the yield obtained in the respective treatment plot (kg ha⁻¹).

Economic evaluation: Cost effectiveness was calculated on the basis of returns on investment (ROI) as suggested by Zivenge et al (2013), were as follows,

$$\text{ROI} = (\text{Net returns/Production costs}) \times 100$$

Where, the expenditure incurred from sowing to harvest was worked out for finding the production cost and expressed in Rs ha⁻¹. Gross income obtained from grain and stover yields were calculated for individual treatments. Net return was calculated by deducting the cost of cultivation from gross return.

Statistical analysis: The observed data on weeds and crops were statistically analysed based on the procedure given by Gomez and Gomez (1984) to find out the treatment differences. The data on weed count and weed dry weight having higher variation were subjected to square root transformation ($\sqrt{X + 0.5}$) and analysed statistically.

RESULTS AND DISCUSSION

Weed flora: The weed flora of the experimental field during the cropping period primarily composed of grasses, sedge and broad leaved weeds. *Rottboellia cochinchinensis*, *Dactyloctenium aegyptium*, *Dinebra retroflexa* under grasses and *Digera arvensis*, *Corchorus olitorius*, *Trianthema portulacastrum* and *Acalypha lanceolata* under broad leaved weeds were observed (Table 1). *Cyperus rotundus* was the only sedge observed in the experimental field. Among the group of weeds, grass weeds registered higher absolute density (94 and 117 No. m⁻²) at 20 and 45 DAS and was followed by broad leaved weeds (52 and 65 No. m⁻²) and sedges were comparatively lower (3 No. m⁻² each) at 20 and 45 DAS respectively. Relative density of individual weed species of the experimental field showed that among weeds species *Rottboellia cochinchinensis* recorded higher relative density of 28.19 and 30.27% at 20 and 45 DAS. The grasses, broad leaved weeds and sedges constituted about 63.24, 35.14 and 1.62% of total weed flora at 45 DAS (Table 1). The similar spectrums of weeds were also reported by several workers (Mynavathi et al 2008, Swetha et al 2015). Among the weeds, grass weeds were dominant and itchgrass/corn grass (*R. cochinchinensis*) in the grass weed (Table 1). Both the corn grass and corn belongs to C₄ species and direct line of descent from *Rottboellia* through *Tripsacum* to *Zea* mainly contributed not only to the persistence but also to the noxiousness of *R. cochinchinensis* in maize and has become a major weed in tropical and sub-tropical regions.

Weed dry weight: Significant variations in weed dry weight were observed at 20 and 45 DAS due to the imposition of

non-chemical formulations (Table 2). At 20 DAS, considerable reduction in total weed dry weight recorded in POE vinegar 20% + hand weeding on 45 DAS which was comparable with POE vinegar 20% and the reason was rapid drying of the weeds as result of the contact action of vinegar. At sub-lethal levels, vinegar could be used to cause leaf damage in weeds outside of crop rows, which could reduce seed production and mitigate herbicide resistance development, as reported by Heap (2005). Vinegar might have caused widespread damage throughout the leaf tissue with lysis of cellular contents including the upper and lower epidermal cells (Evans et al 2009).

At 45 DAS, hand weeding twice on 20 and 45 DAS recorded significantly lower dry weight. This might be due to the prevention of emergence of second flush of weeds as a result of hand weeding, which resulted in vigorous growth of maize during all stages. This was followed by POE vinegar 20% + hand weeding on 45 DAS and POE vinegar 20% because of burning of weed foliage and reduction in vigour as reported by Evans et al (2009). At later stages, weed control was less in vinegar treated plots due to regrowth and new weed emergence. This might be due the fact that the underground roots might have unaffected by the application. These results are confirming the results of Evans and Bellinder (2009).

Weed control efficiency: POE vinegar 20% + hand weeding on 45 DAS and POE vinegar 20% recorded higher weed control efficiencies at 20 DAS of more than 88 per cent (Table 2). POE vinegar resulted in killing of weeds due to direct contact application and hence reduced the number of weeds

and ultimately with weed dry weight. There are earlier reports of 80 to 100% weed control using acetic acid (10 to 20%) concentration (Moran 2007).

Hand weeding twice on 20 and 45 DAS registered higher WCE at 45 DAS and was followed by POE vinegar 20% + hand weeding on 45 DAS and POE vinegar 20%. This might be due to reduction in weed survival, since the weeds get covered by soil, while using hand hoe and desiccation of soil surface might have inhibited the weed regeneration. Similar results of higher weed control efficiency due to hand weeding twice were also reported by Sanodiya et al (2013) and Das et al (2016). Reduction in WCE of vinegar treated plots was because of regrowth and new weed emergence. This was followed by EPOE traditional formulation @ 10 l ha⁻¹ (Cow urine + Lemon fruit + *T. chebula*) and EPOE traditional formulation @ 10 l ha⁻¹ (Cow urine + Lemon fruit + *T. chebula*) + hand weeding on 45 DAS, due to inhibitory effect of allelochemicals like syringic acid present in *T. chebula* or Indian walnut which reduced the hypocotyl length during seed germination which finally led to reduced dry weight of weeds. This was in accordance with the findings of Manikandan and Rejula (2008). Manikandan and Rejula (2008) also reported the inhibitory effect *T. chebula* containing hydroquinone, syringic acid, trans-cinnamic acid, gentisic acid, vanillic acid, and transferulic acid (phenolic acids) or else known as allelochemicals on seeding growth of *Cassia occidentals* and *Crotalaria retusa* from their bioassay studies. In addition to the Indian almond, the limonene is present in lemon fruit (Viuda-Martos et al 2009) even at a low concentrations of 0.1 and 0.5 µL limonene

Table 1. Weed flora of the experimental field

Weed	Common name	Family	20 DAS		45 DAS	
			AD (No. m ⁻²)	RD (%)	AD (No. m ⁻²)	RD (%)
Grasses						
<i>Rottboellia cochinchinensis</i>	Itch grass	Poaceae	42.00	28.19	56.00	30.27
<i>Dactyloctenium aegyptium</i>	Crowfoot grass	Poaceae	18.67	12.53	20.33	10.99
<i>Dinebra retroflexa</i>	Viper grass	Poaceae	33.33	22.37	40.67	21.98
Total			94.00	64.09	117.00	63.24
Sedge						
<i>Cyperus rotundus</i>	Purple nutsedge	Cyperaceae	3.00	2.01	3.00	1.62
Broad leaved weeds						
<i>Digera arvensis</i>	False amaranth	Amaranthaceae	40.00	26.85	47.33	25.58
<i>Corchorus olitorius</i>	Jew's mallow	Tiliacea	9.33	6.26	13.00	7.03
<i>Trianthema portulacastrum</i>	Horse purslane	Aizoaceae	1.00	0.67	2.00	1.08
<i>Acalypha lanceolata</i>	Indian copper leaf	Euphorbiacea	1.67	1.12	2.67	1.44
Total			52.00	34.90	65.00	35.14
Total weeds			149.00	100.00	185.00	100.00

inhibited the germination of the weed (*Amaranthus viridis* L.). It is concluded that limonene can be exploited in future era of weed management either directly or as a lead molecule due to its weed suppressing potential (Vaid et al 2011).

Grain yield: Post emergent non chemical formulations significantly influenced the grain yield in maize (Table 2). Higher and comparable grain yield were obtained in the plots hand weeded twice on 20 and 45 DAS (7315 kg ha⁻¹) and with post emergence application of vinegar 20% + hand weeding on 45 DAS (7214 kg ha⁻¹). Timely removal of weeds in hand weeding and killing of weeds due to directed application of vinegar has created a lesser weed infestation as well as weed competition. This is in accordance with the finding of Evans and Bellinder (2009). Favourable growing condition occasioned better nutrient uptake and finally resulted in an increased yield. These traditional weed management options created a yield difference of 3900 and 3799 kg ha⁻¹, respectively compared to weedy check. Early post emergence application of traditional formulation @ 10 l ha⁻¹ (Cow urine + Lemon fruit + *T. chebula*) + hand weeding on 45 DAS recorded next best in grain yield (6546 kg ha⁻¹). Inhibition of germination of weed seeds and seedling growth due to the presence of allelochemicals in *T. chebula* in the early stages and manual

removal of weeds by hand weeding on 45 DAS have created favourable condition and lesser weed competition between crop and weeds through reduced weed density and weed dry weight. Inhibitory effect of *T. chebula* due to the presence of allelochemicals on weed seeds was earlier reported by Manikandan and Rejula (2008). Lower grain yield was noticed in weedy check (3415 kg ha⁻¹) due to uncontrolled weed growth which recorded a decline of 53.32% in yield compared to the treatment hand weeding twice on 20 and 45 DAS.

Weed index: POE vinegar 20% + hand weeding on 45 DAS recorded lower weed index (1.38) compare to all other treatments (Table 2). This was followed by EPOE traditional formulation @ 10 l ha⁻¹ (Cow urine + Lemon fruit + *T. chebula*) + hand weeding on 45 DAS. Decrease in weed index was mainly due to improved growth of crop plants as a consequence of effective weed control by the vinegar and reduction of crop-weed competition. This enabled crop to take up more nutrients such as nitrogen, phosphorus and potassium which in turns accumulated more biomass and finally lead to more yield (Gaurav et al 2018). Weedy check resulted in higher weed index. This may be due to the uncontrolled weed growth during the crop period. These findings endorsed with Rao et al (2016).

Table 2. Effect of post emergent non chemical formulations on total weed dry weight and weed control efficiency at 20 and 45 DAS, yield, weed index, production cost, net return and returns on investment in maize

Treatment	Total weed dry weight (g m ⁻²)		WCE (%)*		Yield (kg ha ⁻¹)	WI (%)*	Production cost (Rs ha ⁻¹)*	Net return (Rs ha ⁻¹)*	ROI*
	20 DAS	45 DAS	20 DAS	45 DAS					
EPOE 30% common salt	5.49 (29.65)	18.53 (343.29)	30.7	22.3	4202	42.55	51823	14590	28.15
EPOE 30% common salt + HW on 45 DAS	5.45 (29.17)	18.58 (344.80)	31.8	22.0	4940	32.47	58623	19309	32.94
POE vinegar 20%	2.33 (4.94)	13.93 (193.70)	88.4	56.2	5712	21.91	53573	36416	67.97
POE vinegar 20% + HW on 45 DAS	2.30 (4.80)	13.81 (190.43)	88.8	56.9	7214	1.38	58673	54738	93.29
EPOE traditional formulation @ 10 l ha ⁻¹ (cow urine + lemon + <i>T. chebula</i>)	4.46 (19.56)	16.21 (262.39)	54.3	40.6	4224	42.26	49793	16945	34.03
EPOE traditional formulation @ 10 l ha ⁻¹ (cow urine + lemon fruit + <i>T. chebula</i>) + HW on 45 DAS	4.49 (19.74)	16.24 (264.69)	53.8	40.1	6546	10.51	54893	48057	87.55
EPOE traditional formulation @ 7.5 l ha ⁻¹ (cow urine + lemon fruit + <i>T. chebula</i>)	5.43 (29.02)	18.30 (335.76)	32.1	24.0	4167	43.03	49738	16133	32.44
EPOE traditional formulation @ 7.5 l ha ⁻¹ (cow urine + lemon fruit + <i>T. chebula</i>) + HW on 45 DAS	5.44 (29.10)	18.38 (337.57)	32.0	23.6	4986	31.84	56538	22108	39.11
HW twice on 20 and 45 DAS	6.52 (42.09)	5.18 (26.33)	1.6	94.0	7315	0.00	68953	46119	66.88
Weedy check	6.58 (42.76)	21.03 (442.07)	-	-	3415	53.32	48553	5594	11.52
LSD (0.05)	0.41	1.17			635				
C.V.	4.97	4.25			7.02				

Figures in parenthesis are mean of original values; Data subjected to square root transformation

*Data statistically not analysed

EPOE: Early post emergence application

POE: Post emergence application DAS: Days after sowing

HW: Hand weeding

Returns on investment: Post emergence application of vinegar 20% + hand weeding on 45 DAS resulted in higher returns on investment (ROI) (93.29%) because of its higher yield, due to better weed control which resulted in favourable growing environment with less weed competition and higher net return (Table 2). This was followed by early post emergence application of traditional formulation (Cow urine + Lemon fruit + *T. chebula*) @ 10 l ha⁻¹ + hand weeding on 45 DAS with a ROI of 87.55%. This might be due to good yield as well as cost effectiveness of the treatment adopted. ROI value of 66.88 % was obtained hand weeding twice on 20 and 45 DAS which recorded higher and comparable yield to that of POE vinegar 20% + hand weeding on 45 DAS. Higher grain yield recorded in hand weeding twice was not enough to project it as a cost effective management option due to its higher production cost (Rs 68953 ha⁻¹) involved in hand weeding operation. Lower net return obtained in weedy check due to competition for nutrients and space and low yield obtained has pull down the ROI to a magnitude of 11.52%. Similar results were also reported by Kaiira et al (2014).

CONCLUSION

Application of various post emergent non chemical formulations significantly affected the weed flora in maize. Post emergence application of vinegar 20% greatly influenced the weed flora in maize. Of the various post emergent non chemical formulations tested, post emergence application of vinegar 20% followed by hand weeding on 45 days after sowing resulted in higher grain yield, lower weed index and higher returns on investment and it can be used as a non-chemical weed control tool in maize. Combination of vinegar with other plant based products having allelopathic effects on weeds may be evaluated for managing weeds and research may also focus on the development of newer molecules analogues to the allelochemicals.

REFERENCES

- Beckie HJ 2006. Herbicide-resistant weeds: Management tactics and practices. *Weed Technology* **20**(3): 793-814.
- Das A, Kumar M, Ramkrushna G, Patel D, Layek J, Panwar A and Ngachan S 2016. Weed management in maize under rainfed organic farming system. *Indian Journal of Weed Science* **48**(2): 168-172.
- Egan JF, Maxwell BD, Mortensen DA, Ryan MR and Smith RG 2011. 2, 4-Dichlorophenoxyacetic acid (2, 4-D)-resistant crops and the potential for evolution of 2, 4-d-resistant weeds. *Proceedings of National Academy of Sciences* **108**(11): pp. 37
- Evans G and Bellinder R 2009. The potential use of vinegar and a clove oil herbicide for weed control in sweet corn, potato, and onion. *Weed Technology* **23**(1): 120-128.
- Evans GJ, Bellinder RR and Goffinet MC 2009. Herbicidal effects of vinegar and a clove oil product on redroot pigweed (*Amaranthus retroflexus*) and velvetleaf (*Abutilon theophrasti*). *Weed Technology* **23**(2): 292-299.
- Gaurav S, Meena R, Maurya A and Kumar S 2018. Nutrients uptake and available nutrients status in soil as influenced by sowing methods and herbicides in *kharif* maize (*Zea mays* L.). *International Journal of Agriculture Environment and Biotechnology* **11**(1): 17-24.
- Gharde Y, Singh P, Dubey R and Gupta P 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection* **107**: 12-18.
- Gill GS and Vijaya Kumar K 1966. Weed index: A new method of reporting weed control trials. *Indian Journal of Agronomy* **14**: 96-98.
- Gomez KA and Gomez AA 1984. *Statistical Procedures for Agricultural Research*, John Wiley & Sons, Hoboken, NJ, USA, p 690.
- Heap I 2005. The international survey of herbicide resistant weeds. <https://hracglobal.com/files/criteria-for-confirmation-of-herbicide-resistant-weeds.pdf>. Accessed: January 10, 2018.
- Kaiira M, Kagoda F and Gidoi R 2014. Exploring cost-effective maize integrated weed management approaches under intensive farming systems. *Uganda Journal of Agricultural Science* **15**(2): 191-198.
- Mani V, Malla M and Gautam K 1973. Weed-killing chemicals in potato cultivation. *Indian Farming* **23**(1): 17-18.
- Manikandan M and Rejula M 2008. Identification of allelochemicals from *Terminalia chebula*. *African Research Review* **2**(3): 306-314.
- Moran PJ 2007. Use of fungal bioherbicides and vinegar to control pigweeds in south Texas. In: Proceedings of the *Weed Science Society of America*. Champaign, IL. P. 199.
- Mynavathi V, Prabhakaran N and Chinnusamy C 2008. Evaluation of mechanical weeders in irrigated maize. *Indian Journal of Weed Science* **40**(3 & 4): 210-213.
- Powles SB and Yu Q 2010. Evolution in action: Plants resistant to herbicides. *Annual Review of Plant Biology* **61**: 317-347.
- Rao CHR, Prasad PVN and Venkateswarlu B 2016. Assessment of different herbicides on yield and economics of *kharif* maize (*Zea mays* L.). *International Journal of Agricultural Science Research* **6**(6): 409-414.
- Saini J, Rameshwar P, Chadha S, Sharma S, Bhardwaj N and Rana N 2013. Non-chemical methods of weed management in maize under organic production system. *Indian Journal of Weed Science* **45**(3): 198-200.
- Sanodiya P, Jha A and Shrivastava A 2013. Effect of integrated weed management on seed yield of fodder maize. *Indian Journal of Weed Science* **45**(3): 214-216.
- Swetha K, Madhavi M, Pratibha G and Ramprakash T 2015. Weed management with new generation herbicides in maize. *Indian Journal of Weed Science* **47**(4): 432-433.
- Vaid S, Batish DR, Singh H and Kohli R 2011. Phytotoxicity of limonene against *Amaranthus viridis* L. *The Bioscan* **6**(1): 163-165.
- Viuda-Martos M, Ruiz-Navajas Y, Fernández-López J and Pérez-Álvarez JA 2009. Chemical composition of mandarin (*C. reticulata* L.), grapefruit (*C. paradisi* L.), lemon (*C. limon* L.) and orange (*C. sinensis* L.) essential oils. *Journal of Essential Oil Bearing Plants* **12**(2): 236-243.
- Zivenge E, Shiferaw-Mitiku T, Thomas J and Ushadevi KN 2013. Economic performance of community garden in Zimbabwe. *Russian Journal of Agricultural and Socio-Economic Sciences* **9**(21): 18-22.



Synthesis and Characterization of Nano Hybrid Gentamycin with Zinc Oxide Layered Hydroxides

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Abstract: Zinc oxide (ZnO) nanostructure was prepared by using a sol-gel reaction between ZnO and gentamycin. Characterization was done using various techniques such as UV-VIS spectroscopy, Fourier transform infrared spectroscopy (FT-IR) and x-ray diffraction (XRD). The other techniques also used included scanning electron microscopy (SEM) and atomic force microscope (AFM). The results show the intercalation of gentamycin within ZnO is possible and they are of great importance to the field of chemical admixtures in bioinorganic composites. This study demonstrated the use of gentamycin as the normal way of intercalating ZnO layered hydroxides with the use of hydrothermal synthesis at a temperature of 40°C in the formation of stable complex gentamycin-ZnO nanoparticles. It released and characterized the end-composite structure of gentamycin power.

Keywords: ZnO, Nano materials, Gentamycin, Intercalations

Zinc oxide layered hydroxides (ZLHs) has two dimensional material and an ion exchange property. ZnO was intercalated with folic acid and a mixture containing two anions (2, 4- dichlorophenoxy Oacetate and 4- chlorophenoxy acetate) in its solution which acted as a host (Bashi et al 2013). This caused the substitution of smaller anions such as carbonate, nitrate and H₂O. The intercalations of ZnO are similar to those of the layered double hydroxide ZnO nanoparticles (Bashi et al 2012, Zhang et al 2006), when loaded are purposely packaged against pathogens which are foodborne (Li et al 2005, Xie et al 2006, Gleit et al 2006, Chen et al 2008, Shaheed et al 2014). Various morphologies of ZnO nanostructures are produced after synthesis such as nanowire, tetra pods, Nano rods, Nano flowers and also Nano belts. These methods can be obtained through wet chemistry (Li et al 2005, Xie et al 2006). Numerous endeavors are focused on the synthesis of ZnO materials (Bashi et al 2014). These methods of synthesizing ZnO particles are based on physical and chemical technologies. The growth of the crystals is controlled by organic complexation additives (Xu et al 2007, Lu et al 2007, Baltés et al 2008) which offer stability to the nanoparticle implying the importance of using effective measures to help induce conversion of the Zn complex into Zn organic nanoparticles. Zinc fibers were obtained through the decomposition procedure of bis (acetyl acetate) using ZnO at temperatures of high heat 110°C (Zhang et al 2007, Ghimbeu et al 2007). The main objective of this work was to explore the potential use of ZnO as a starting material for the intercalation of Gentamycin for the formation of a new

gentamycin –Zinc oxide Nano hybrid. Then, the resulting Nano hybrid could be used as a controlled release formulation of drug activity of Gentamycin in further application studies.

MATERIAL AND METHODS

ZnO and gentamycin were used without further purification. The 50 ml solution of (0.05, 0.1, 0.2 M) of gentamycin was prepared, mixed with a solution of 1gr of ZnO in 50 ml de-ionized water. The gel suspension was kept at 40°C for 18 hours, cooled, centrifuged and washed four times with de-ionized water, dried in the oven at 50°C, grinded and stored.

Powder (PXRD) was obtained with a Shimadzu XRD-6000 powder diffractometer using ($\lambda=1.540562 \text{ \AA}$) at 40 kV and 30 mA with a scan rate of 1 min. /degrees. Fourier Transform Infrared (FTIR) spectra were recorded by using a spectrophotometer (Bruker) in the range of 4000-400 cm⁻¹. The surface morphology and bulk structure of the sample were observed by scanning electron microscope (SEM) model vga-easy and AFM microscope, AFM model AA3000 and Advanced Angstrom Inc- USA.

RESULTS AND DISCUSSION

X-Ray diffraction technique: The evidence for the phase structure of the synthesized sample was obtained by XRD pattern, (Fig. 1) and the diffraction peaks can be indexed to those of hexagonal ZnO. After refinement, the lattice constants, $a=3.251 \text{ \AA}$, $c=5.210 \text{ \AA}$ were obtained, which is

very close to the reported value for ZnO ($a=3.253 \text{ \AA}$, $c=5.209$, JCPDS card, No.80-0075). The average particle size was estimated as 169 nm based on the Scherer equation, $D = \frac{K\lambda}{\beta \cos\theta}$, K is the shaping factor of average crystallite, λ is wavelength for the $K\alpha_1$ (1.54056 \AA), β is full width at half-maximum of the diffraction line and θ is Bragg's angle (Fig. 2). The first basic reflection corresponding to the highest d -value gives information about the interlayer distance. The intercalation of gentamycin shows well-ordered Nano hybrid. The observation of the other harmonics with the inter layer distance of phase (a), the interlayer distances of the plan d_{003} , d_{006} and d_{015} for the phase are 5.72, 10.54 and 22.3 \AA , respectively. The diffractions d_{003} , d_{006} and d_{009} are situated at 3.48, 2.23 and 0.264nm, respectively. This phase may be resulted from the orientation of one gentamycin molecule which attached perpendicular to the ZnO layer. This was confirmed by SEM image as a hexagonal-structure (Fig. 4). This indicated that gentamycin

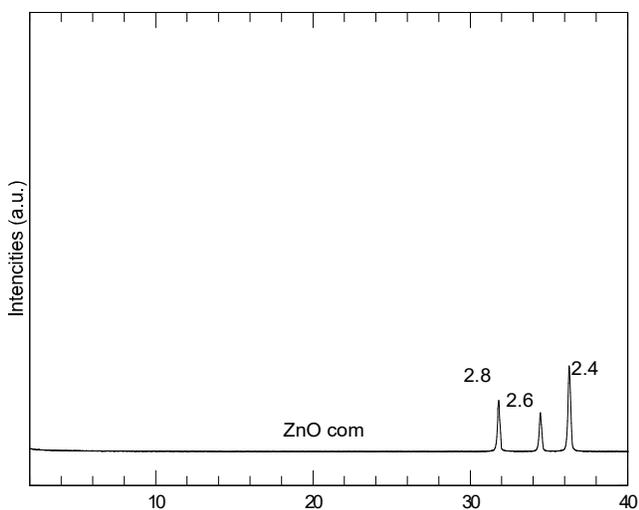


Fig. 1. PXRD of ZnO shows the three harmony characteristics of Zinc oxide

found its own way and assembled itself in the formation of the monophasic Nano hybrids. This made the intercalation of gentamycin more homogenized and crystalline. At the same time the peaks belong to ZnO ($2\theta=33.50$, 36.72 and 46.88) were reduced in intensity compared with the more intense pattern of gentamycin at (2.54) intercalated with ZnO. The test done by using SEM shows no change in the original hexagonal structure of ZnO. Intercalation was observed between the ZnO layers (Shen et al 2005).

Surface morphology studies (AFM and SEM): The ZnO sheet with a mean size of 70nm Figure. 3. The AFM observation is in good agreement with the data obtained by the XRD technique. The SEM image of ZnO (Fig. 4b) shows small particles clearly indicating the hexagonal lattice, but in the case of gentamycin-ZnO, the SEM (Fig. 4a) shows a different morphology of the resulted sample from the intercalation of gentamycin with ZnO. This was a good indication of the completion of intercalation

Atomic force microscope (AFM): The image of AFM (Fig. 3) shows the roughness of the surface is approximately 3.24nm. The root mean square indicate a high crystallinity of the resulted synthesis and sample shows a high regularity. The hybrid parameters show the distant peak to peak is approximately 14.6nm and the mean distance of ten peaks is 8.47nm which is a good indication that the intercalation successfully occurred. The surface mean ratio is 2.5nm with surface bearing index (6.69nm) and the particle height on z-axis is 14.29nm. AFM images of the ZnO layered and the Nano particles synthesized with the gentamycin-ZnO in two and three dimensions (Fig. 3).

Scanning electronic microscope (SEM): The SEM images show a good crystallinity of the hexagonal shape of the ZnO intercalated with gentamycin and was confirmed by the AFM and the XRD. The particle width of gentamycin-ZnO was nearly 169.2nm (Fig. 4). This is also a good indication of the conjugation of the gentamycin on the surface of ZnO.

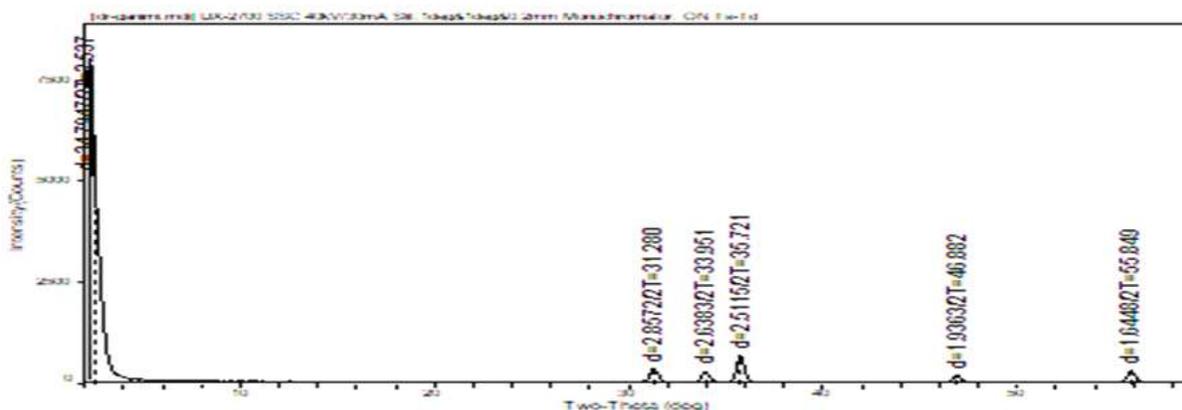


Fig. 2. PXRD pattern spectrum shows the gentamycin-Zinc oxide Nano hybrid

FTIR Technique: The different functional groups, the broad harmonic vibrations at 3400-3600 cm^{-1} corresponding to the stretching of hydroxyl from the water physically adsorbed (Fig. 5), and stretching of the OH groups 1648 cm^{-1} and the band from 1085-581 cm^{-1} which are attributed to the vibrations of the ZnO.

All the vibrations of ZnO were presented in the Nano hybrid of gentamycin-ZnO spectrum (Fig. 6). The FTIR spectrums provide further evidence for the intercalations in addition, some absorption bands are slightly shifted due to the interaction of both the anion and the host layer (Fig. 5, 6). The characteristic broad absorption bands of zinc layer hydroxide were superposing with the anion hydroxide observed, the water molecules at 3540-3370 cm^{-1} and the band due to the (C-O-H) stretching vibration of C-H stretching at 2932 cm^{-1} . The asymmetric and symmetric stretching of C=O appears at 1700 cm^{-1} . The bands at 1470 cm^{-1} attributed to C=C vibrations of the aromatic ring. The bands at approximately 1200 cm^{-1} are due to C-H twist vibrations. The gentamycin-ZnO Nano composites show a combination spectrum of both the host ZnO and the guest anions (Fig. 6). The bands located at 1467 cm^{-1} were due to the stretching vibration of C=C in the aromatic ring and the band 1409 cm^{-1} were due to CH_3 bending. The presence of carboxylate group, COO can be deduced by the observation of bands at 1712 and are due to C=O stretching. The band at 1583 are due to C-O-H bending, 783 and 893 cm^{-1} are due to symmetric and anti-symmetric vibrations of the COO- group

in the gentamycin intercalated in the inter layers of ZnO. Bands at 2400–2365 cm^{-1} are corresponded to C-H stretching mode. These are attributed to asymmetric and

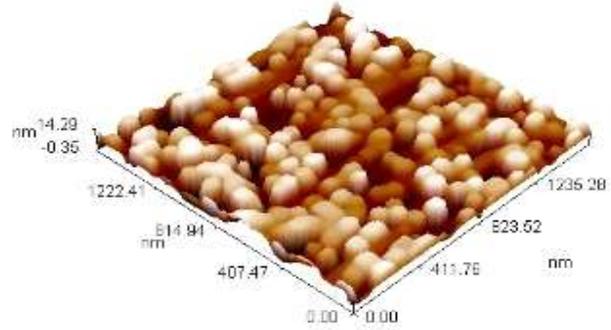


Fig. 3b. Atomic Forcing Microscope of the Nano hybrid of gentamycin-ZnO in 2D

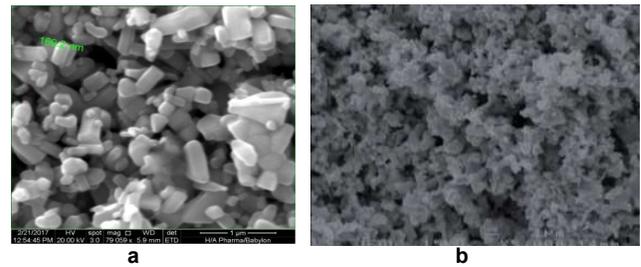


Fig. 4a. SEM image of gentamycin-Zinc oxide Nano hybrid shows the hexagonal crystals structure, SEM image; (b) Shows hexagonal crystals of ZnO

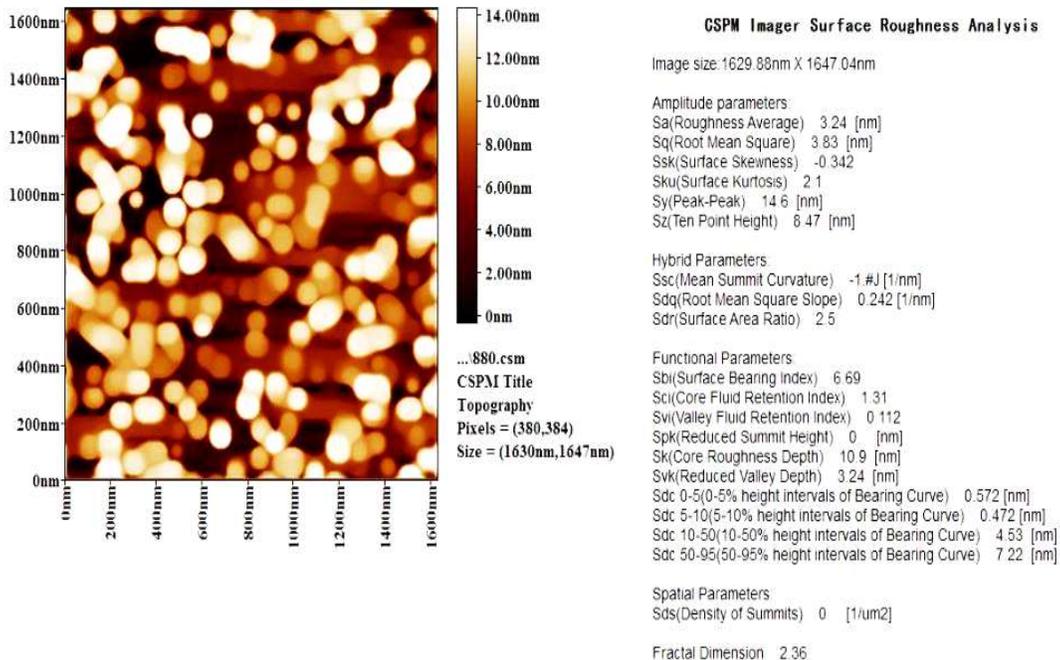


Fig. 3a. Atomic forcing microscope of the nano hybrid of gentamycin-ZnO in 3D

symmetric vibration, respectively (Tong et al 2006) whereas a band at around 1037, 1352 cm^{-1} is corresponded to ($-\text{C}-\text{O}-$) stretching vibration.

Controlled release of gentamycin into aqueous

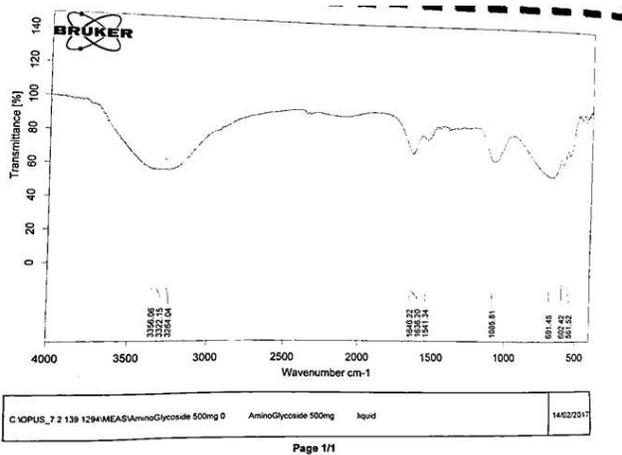


Fig. 5. Spectrum showing the vibrations of ZnO

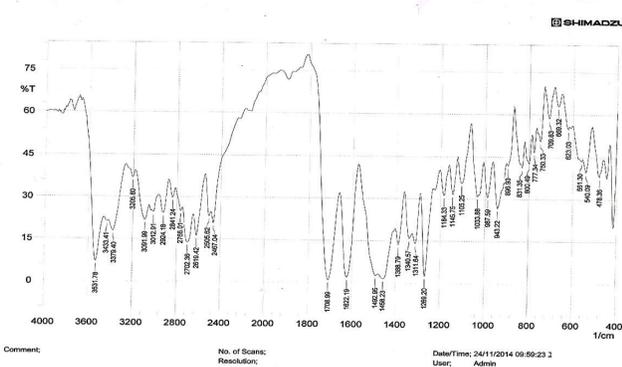


Fig. 6. FTIR spectrum of gentamycin-ZnO Nano hybrid

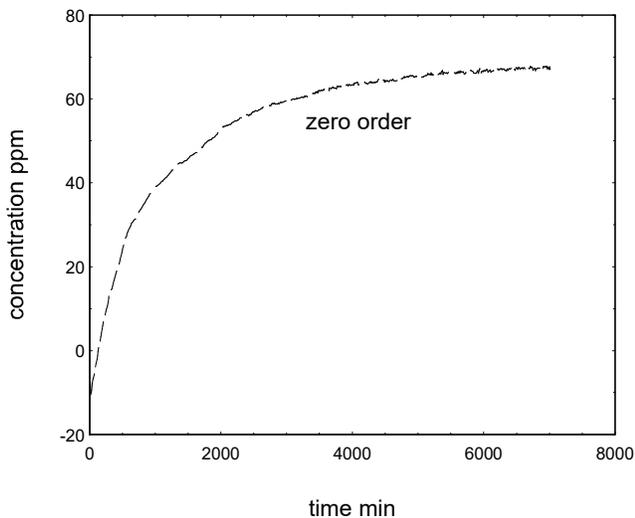


Fig. 7. Percent release of Gentamycin from the layer of ZnO

solutions: De-ionized water and carbonate aqueous solution; (0.005M) and (0.05M) were used to study the effect of the release media on the percentage release of gentamycin from gentamycin-ZnO Nano particles (Fig. 7). The collected gentamycin released into de-ionized water enlarged with contact time. The release was practically complete, with the first 33 hours. The accumulations reached 80% in the acidic pH=2. At the same time the release in alkaline media pH=13 is an 85% solution equilibrium that was achieved at around 33 hours. The amount of accumulated gentamycin released as well as the release rate increased with increasing initial concentrations of the carbonate ion in the aqueous solution. The CO_3^{2-} ions are ion-exchanged with the anions on to the nanocomposite surface and at the same time and gentamycin then released into the solution. The process slowed down as the time proceeded, due to the

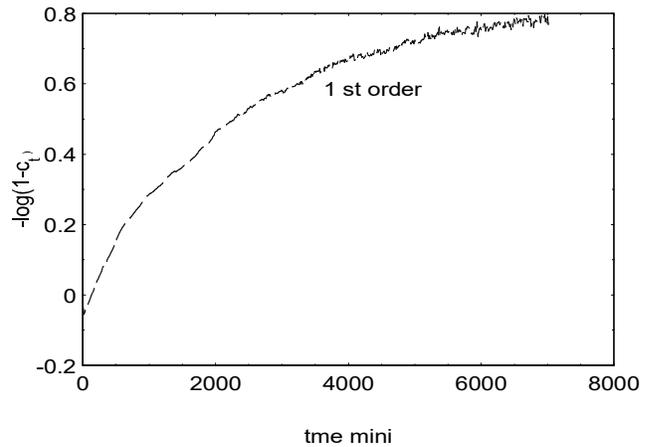


Fig. 8. 1st order of the release

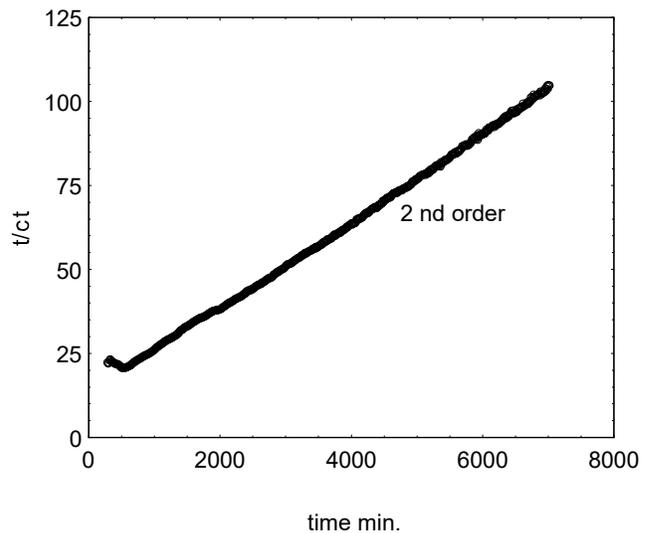


Fig. 9. 2nd order kinetic model of the release of gentamycin to the carbonate media ($t/C_t = 1/k_2 C_T^2 + t/C_T$)

equilibrium of CO_3^{2-} ion concentration in between the layers of ZnO and that in the solutions with carbonate as the counter anion. We applied the zero order (Fig. 7), 1st order (Fig. 8) and 2nd order (Fig. 9). We found that the release obeyed the pseudo second order kinetic model. ($t / C_t = 1/k_2 C_T^2 + t / C_T$), with $r^2 = 1$ and $K_2 = 0.0371$.

CONCLUSION

The intercalation of gentamycin within ZnO is possible. XRD characterization revealed large interlayer distances caused by the gentamycin intercalation. A maximum gallery height of (2.5) nm was observed for the intercalate gentamycin-ZnO. This confirms that not only surface adsorption, but the intercalation of the gentamycin-ZnO has taken place. These results are of great importance to the field of chemical admixtures in bioinorganic composites. This type of antimicrobial molecules was intercalated into ZnO phases.

REFERENCES

- Baltes C, Vukojevic S and Schüth F 2008. Correlations between synthesis, precursor, and catalyst structure and activity of a large set of CuO/ZnO/Al₂O₃ catalysts for methanol synthesis. *Journal of Catalysis* **258**(2): 334-344.
- Bashi AM, Haddawi SM and Mezaal MA 2013. Layered double hydroxides nanohybrid intercalation with folic acid used as a delivery system and their controlled release properties. *Arabian Journal for Science and Engineering* **38**(7): 1663-1680.
- Bashi AM, Zobir Mohd, Zainal Z, Mawardi R and Tichit D 2012. Simultaneous intercalation and release of 2,4-Dichloro- and 4-chloro phenoxy acetate into Zn/Al Layered double hydroxide. *Arabian Journal of Chemistry* **9**(2): S1457-S1463.
- Bashi Abbas M, Alganimi Ali Abd and Hashim S 2014. Characterizations of synthesized nano hybrid octyl gallate with ZnO LHS and determined its anti-microbial activities. *Journal of Chemistry and Materials Research* **6**(9): 7-15.
- Chen JF, Hu Y and Zheng XS 2008. Surfactant-assisted self-assembly growth of single-crystalline ZnO microflowers at low temperature. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* **313-314**: 576-580.
- Ghimbeu CM, Schoonman J, Lumberras M and Siadat M 2007. Electrostatic spray deposited zinc oxide films for gas sensor applications. *Applied Surface Science* **253**(18): 7483-7489.
- Glei M, Kirmse A, Habermann N, Persin C and Pool-Zobel BL 2006. Bread enriched with green coffee extract has chemo protective and antigen toxic activities in human cells. *Journal of Nutrition and Cancer* **56**(2): 182-192.
- Hussien Mohd Z, Zainal Z and Tichit D 2013. Synthesis and controlled release properties of 2,4-Dichloro Phenoxy acetate-zinc layered hydroxide nanohybrid. *Journal of Solid state Chemistry* **203**: 19-24.
- Li P, Wei Y, Liu H and Wang XK 2005. Growth of well-defined ZnO microparticles with additives from aqueous solution. *Journal of Solid State Chemistry* **178**(3): 855-860.
- Lu JJ, Lu YM, Tasi SI, Hsiung TL, Wang HP and Jang LY 2007. Conductivity enhancement and semiconductor-metal transition in Ti-doped ZnO films. *Optical Materials* **29**(11): 1548-1552.
- Shaheed SH, Alghanimi AAbd and bashi Abbas M 2014. Preparation of nano hybrid compounds from food preservative octyl gallate and studying some of its biological activities. *Kerbala Journal of Pharmaceutical Sciences* **5**(7): 277-289.
- Shen G, Bando Y and Lee CJ 2005. Synthesis and evolution of novel hollow ZnO urchins by a simple thermal evaporation process. *Journal of Physical Chemistry B* **109**(21): 10578-10583.
- Tong Y, Liu Y, Dong L, Zhao D, Zhang J, Lu Y, Shen D and Fan XJ 2006. Growth of ZnO nanostructures with different morphologies by using hydrothermal technique. *Journal of Physical Chemistry B* **110**(41): 20263-20267.
- Xie RG, Li DS, Zhang H, Yang DR, Jiang MH, Sekiguchi T, Liu BD and Bando Y 2006. Low-temperature growth of uniform ZnO particles with controllable ellipsoidal morphologies and Characteristic Luminescence Patterns. *Journal of Physical Chemistry B* **110**(39): 19147-19153.
- Xu P, Wen X, Zheng Z, Cox G and Zhu H 2007. Two-photon optical characteristics of zinc oxide in bulk, low dimensional and nanoforms. *Journal of Luminescence* **126**(2): 641-643.
- Zhang YY and Mu J 2007. One-pot synthesis, photoluminescence, and photocatalysis of Ag/ZnO composites. *Journal of Colloid and Interface Science* **309**(2): 478-484.
- Zhang Z, Chen H, Xiong, J, Chen Y and Lu Y 2006. Nanotip-based QCM biosensors, in: *Proceedings of the IEEE international Frequency control symposium and Exposition*, 545-549916. Powders by controlled precipitation from aqueous solution. *Journal of Materials Chemistry* **4**: 1611-1617.



Landslide Hazard Zonation Mapping using Power Method based AHP for Saklespur, India

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Abstract: In the present study, an attempt was made to develop landslide hazard zonation map using various thematic maps such as precipitation, slope, geology, aspect, land cover, distance from road, lineament density, distance from river, elevation by using AHP and modified power method based AHP technique. Mapping performed using AHP and PM-AHP concluded that 32 and 15% of the total taluk area falls under highly risk zone in Saklespur. Results concluded that PM-AHP provided better results in mapping the highly risk zone covering an area of 85% of the landslide hit locations whereas using AHP technique only 57% of the landslide hit location falls under highly risk zone.

Keywords: Landslides, Analytical hierarchy process, Power Method, Disaster, Remote Sensing, GIS

Geological, hydrological and atmospheric vicissitudes lead to calamitous destruction of flora and fauna, artificial constructions and fatalities resulting in socio economic disruption. Disaster events triggered by nature are inexorable but the rate of fatalities can be abridged by creating awareness among the people. Frequent occurrence of disasters events are recorded lately due to the incongruous enhancement accomplishments implemented by human life without considering earth natural system (Suresh and Yarrakula 2020a). Over 1 billion of people's life are critically affected by natural disasters during the past 2 decades due to the deficiency of possessions, framework and preparedness systems (Watson et al 2007). Changes occurring in earth's atmosphere and modification of topography due to human activities result in various natural and manmade disasters (Suresh and Yarrakula 2018a, 2019). Landslides are one among the various disasters that results in fatalities and loss of infrastructure and economy (Mata-Lima et al 2013). Among various natural disasters experienced within the Indian extent, one of the foremost hydrogeological hazardous event that distress major portion of India is landslides (Kapur 2005). Landslides are one of the most epoch-making hazards that have an impact on numerous locations of the subcontinent mainly during monsoon season (Senthilkumar et al 2017). Landslides are a natural process of earth's life cycle that hits the mountainous regions frequently during monsoon period (Suresh and Yarrakula 2020b). Landslides are failure of land mass down the slope affecting landscapes intimidating human life, flora, fauna and non-natural structures under unpredictable climatic and lithological conditions (Shirani and Pasandi

2019). Being a natural disaster existing in mountainous provinces, landslides distresses communal and economic development, specifically in emerging provinces. Himalayan range in the northern and north-eastern of India and Western Ghats and Eastern Ghats in the southern part of India are highly prone to landslide events resulting in casualties and economical loss. Varying topography along Himalayas and Western Ghats in India hold an astonishing historical catastrophic landslide events over decades.

MATERIAL AND METHODS

Saklespur is a hill station located along the Western Ghats at a mean sea level of about 956m, which is a tourist attraction spot well known for coffee, cardamom, pepper and areca plantations. Frequent landslides recorded in Saklespur had led to the damage of crop fields and for the villagers to migrate to rehabilitation camps. Figure 1 represents the location of the study area considered in the present study situated in 12.9442° N, 75.7866° E. Geology is utilised as a major layer for landslide vulnerability analysis and for the present study the geology layer of 1:50000 scale is obtained from Geological Survey of India (Fig. 2). Rainfall is a primary catalyst for landslides as most of the landslide in India are triggered by rainfall during the monsoon season. INSAT 3D HEM Rainfall data is collected from MOSDAC website for the period of 1st June 2019 to 31st August 2019 and the average of the datasets are calculated and utilised in the present study (Fig. 3). Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) of the study area is obtained from USGS earth explorer at a spatial resolution of 30m (Fig. 4). SRTM DEM obtained is utilised in obtaining the slope angle of the

region as shown in Fig. 5. Slope angle is one of the primary factors to be considered in landslide hazard zonation mapping which is directly proportional to landslides. Slope angle integrated with the input parameters such as rainfall and geological parameters can aid in understanding and characterising the landslide events in updating the vulnerable zones. Aspect for the study area is developed using SRTM DEM and is also considered as an instability factor based on the slope face during rainfall, sunlight and blowing winds which directly influence the distribution of vegetation, evapotranspiration, thickness of soil and degree of saturation of water (Fig. 6). The land use categories directly influence the occurrence of landslides (Fig. 7). Modifications to the natural features based on human requirements influence the landslides and one of the major human activities along the hilly regions that trigger landslides are deforestation. Land use/ land cover map for the study area is prepared with the aid of Sentinel 2 data with Bhuvan land cover map as reference. Distance from roads plays a major role in triggering landslides and the buffer zone created from the roads are shown in Figure 8. The drainage are obtained using DEM and the drainage density map is developed by using inverse distance weighting method (Fig. 9). Lineament density is prepared based on the density of lineaments using IDW method (Fig. 10). The layers collected are analysed and mapped using QGIS 3.10 LTR version for the identification of Landslide hazard zonation (LHZ) regions. Layers collected from various sources are assigned weights based on the confusion matrix developed using AHP technique. The detailed methodology adopted in the present study is shown in Fig. 11.

Analytical hierarchy process: Input parameters are compared based on the confusion matrix and the weights of each layer are obtained based on the eigen vector concept. Weighted eigen vector is analysed for the normalised matrix to validate the consistent ratio (CR) of the judgement matrix. Consistency ratio is the ratio of consistency index and the random consistency index obtained from Satty's book of random index values and if the values of consistency ratio is found to be less than 0.1, the weighs derived are proven to be correct. If the consistency ratio value calculated is greater than 0.1, the procedure has to be repeated with new set of values. Consistency ratio is given by the formula in equation 1,

$$CR = \frac{CI}{RI} \quad (1)$$

Table 1. Random Index values obtained from Saaty's book

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty 1977

Where, CR = Consistency Ratio, CI = Consistency Index, RI = Random Consistency Index = 1.45 (for n = 9) obtained from Table 1.

Considering all the input parameters a pairwise comparison matrix was generated based on the weightage of each layer to a scale of 1 to 9. In the present study, geology, rainfall and slope parameters are given higher weightage based on their influence to the landslide occurrence. Pair wise comparison matrix developed for all the nine parameters are shown in Table 2. Based on the pair wise comparison matrix developed using AHP technique, the weights of each spatial layer are determined. Weight obtained are solved with the comparison matrix using power method to obtain the accurate weights.

Power method based AHP: The most commonly used numerical method is adopted with AHP to derive the accurate weights of each layers based on its relationship with other layers as shown in equation 2. PM-AHP (Power Method – AHP) is carried out based on the iterations as mentioned below in equation 3.

$$A * X_1 = X_2 \quad (2)$$

Where, A is the pairwise comparison matrix, X_1 is weights obtained by the average of the rows of each parameter in the pairwise comparison matrix, X_2 is the new weights obtained based on the pairwise matrix and the weights. The iteration is repeated till the values of the weights of each parameter are found to be equal. The iteration repeats as follows till the values of X_{n-1} is equal to the values of X_n . PM – AHP pairwise comparison matrix is used in obtaining weights for each layer based on iterations and the obtained weights are listed in Table 3.

$$A * X_2 = X_3 \\ A * X_{n-1} = X_n \quad (3)$$

Based on the comparison matrix obtained using PM – AHP method, the modified weights are found to be equal and even if the iterations are repeated the weights for each layers will never change. Weights obtained by using PM-AHP is found to be consistent after five iterations providing the accurate values of each layers. Obtained PM-AHP Eigen vectors and AHP Eigen vectors are checked for the consistency ratio by using the formula in equation 4 with λ_{max} is the maximum Eigen value,

$$CI = \frac{\lambda_{max} - N}{N - 1} \quad (4) \\ CI = \frac{9 - 9}{9 + 1} = 0$$

$$CR = \frac{0}{1.45} = 0 \quad (\text{PM - AHP})$$

$$CI = \frac{9.49 - 9}{9 - 1} = 0.06125$$

$$CR = \frac{0.06125}{1.45} = 0.04 \quad (\text{AHP})$$

RESULTS AND DISCUSSION

Weights obtained by using AHP and PM - AHP are at an acceptable limit based on the CR values (CR should be less than 0.1) and it is found that the AHP based CR value is 0.04 whereas Power Method based CR values is 0 which defines that the weights obtained using PM- AHP method is perfectly

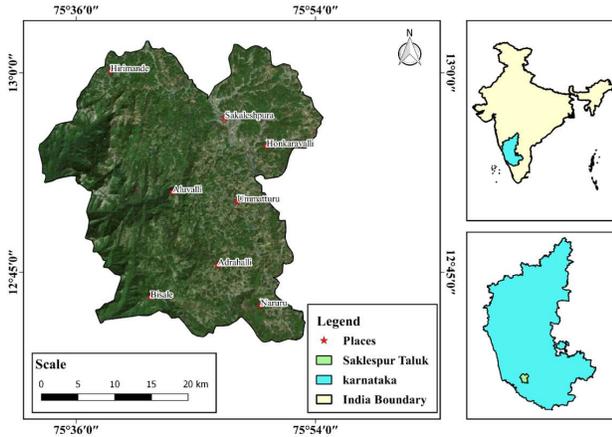


Fig. 1. Geographical location of the study area

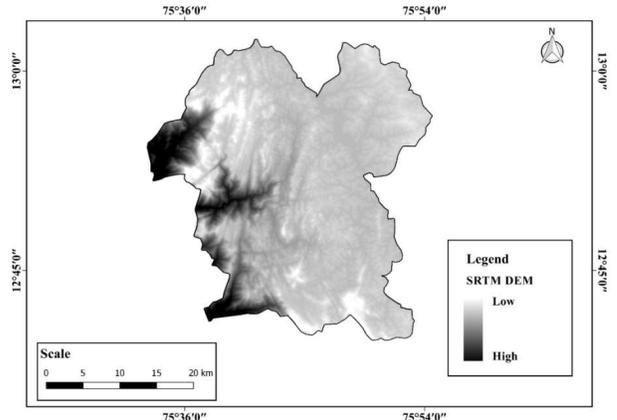


Fig. 4. SRTM DEM of Saklespur

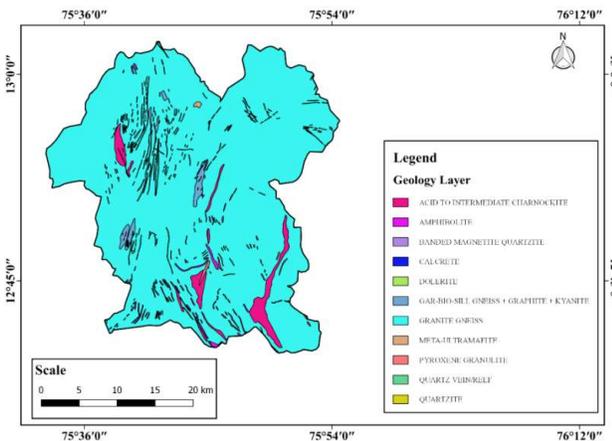


Fig. 2. Geology map of Saklespur

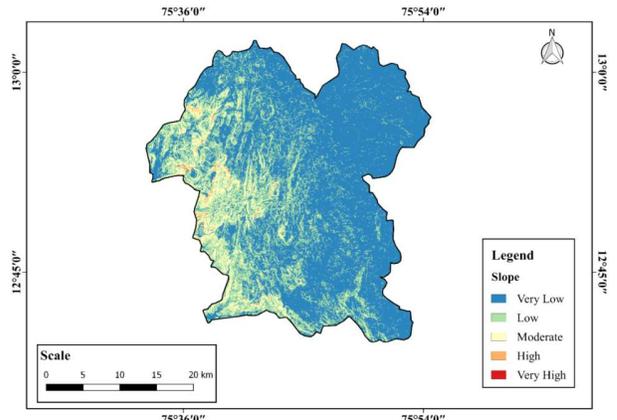


Fig. 5. Slope map of Saklespur

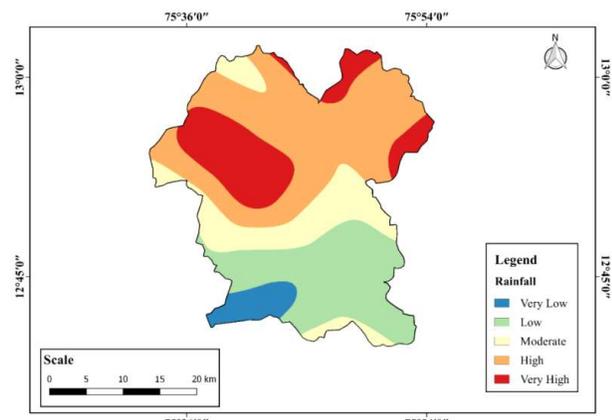


Fig. 3. Rainfall map of Saklespur

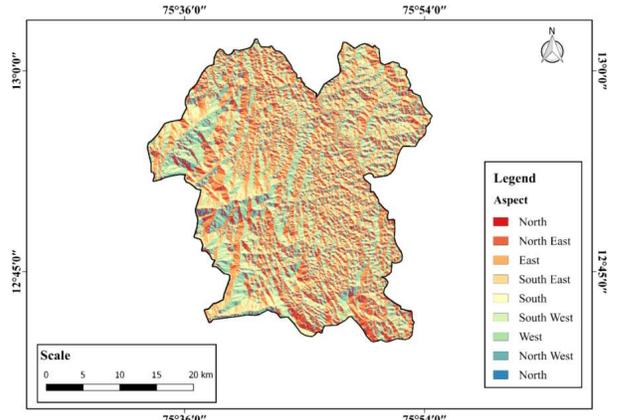


Fig. 6. Aspect map of Saklespur

consistent. Weights obtained are assigned for the corresponding layers and the overlay analysis is performed in QGIS platform for the identification of hazardous zones in Saklespur Taluk, Karnataka. Weights obtained using PM-AHP matrix are assigned for each layer and ranks for the classification of the layers (Table 4).

Based on the Power method based AHP it is found that around 32% of the area of Saklespur taluk falls under risk zone where only 2% of the district area falls under heavily risk regions. AHP results obtained concluded that around 15% of the area of Saklespur is prone to landslides and falls under heavy risk zone. Results display that only a part of the regions

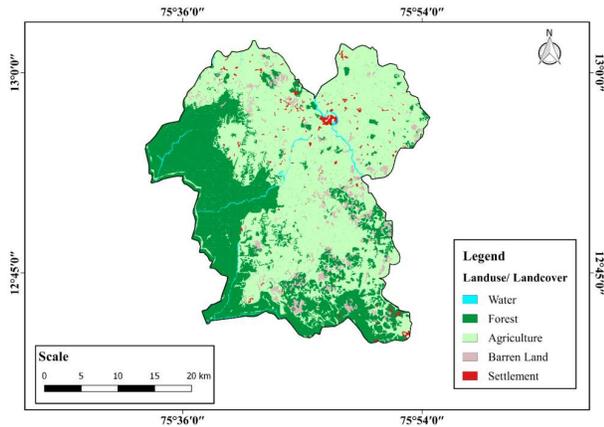


Fig. 7. Land use/ Land cover map of Saklespur

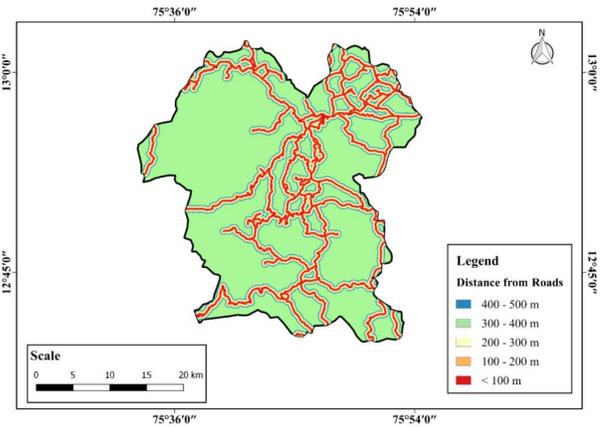


Fig. 8. Distance from roads

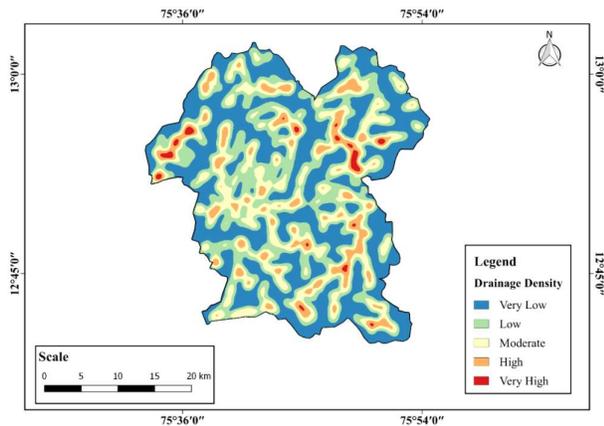


Fig. 9. Drainage density of Saklespur

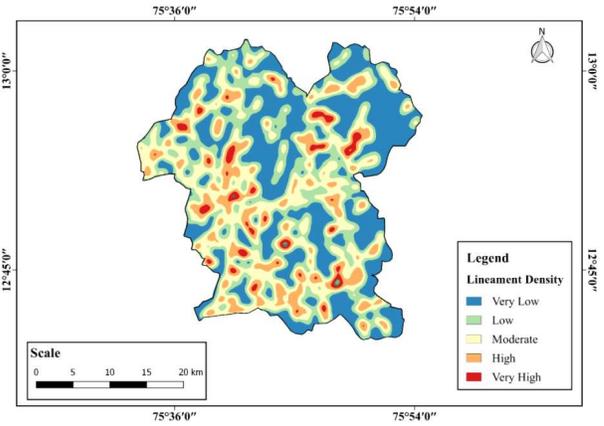


Fig. 10. Lineament density of Saklespur

Table 2. Pair-wise comparison matrix for AHP method

Weight-decision matrix	Precipitation	Slope	Geology	Aspect	Land cover	Distance from road	Lineament Density	Drainage Density	Elevation
Precipitation	1								
Slope	1/2	1							
Geology	1/2	1/3	1						
Aspect	1/3	1/3	1/3	1					
Land cover	1/4	1/3	1/2	1/2	1				
Distance from road	1/3	1/4	1/3	1/2	1/2	1			
Lineament density	1/3	1/3	1/4	1	1/2	1/2	1		
Drainage density	1/4	1/4	1/4	1/2	1/2	1	1/2	1	
Elevation	1/7	1/7	1/7	1/4	1/3	1/4	1/3	1/3	1
Sum	3.63	4.96	7.83	12.75	13.83	16.75	16.83	20.33	39

Table 4. Weightage obtained for various thematic layers with their classification

Layer	Classification	Values	Rank
Slope	Very Low	0 – 12.5	1
	Low	12.5 - 25	3
	Moderate	25 – 37.5	5
	High	37.5 - 50	7
	Very High	50 - 65	9
Weightage - PM-AHP-21.37, APH-21.9			
Aspect	North	0.00 - 22.50	9
	North-East	22.50 - 67.50	5
	East	67.50 - 112.50	1
	South-East	112.50 - 157.50	5
	South	157.50 - 202.50	7
	South-West	202.50 - 247.50	7
	West	247.50 - 292.50	5
	North-West	292.50 - 337.50	9
	North	337.50 – 360.00	9
Flat	-1.00	1	
Weightage - PM-AHP-8.21, APH-8.9			
Lineament Density	Very Low	0 - 36	1
	Low	36 - 72	3
	Moderate	72 - 108	5
	High	108 - 144	7
	Very High	144 - 181	9
Weightage - PM-AHP-6.61, APH-6.3			
Rainfall	Very Low	<4	1
	Low	4 - 7	3
	Moderate	7– 10	5
	High	10 - 13	7
	Very High	13 - 18	9
Weightage - PM-AHP-27.84, APH-24.4			
Distance from Roads		0 -100	9
		100 - 200	7
		200 - 300	5
		300 - 400	3
		400 - 500	1
Elevation	Very Low	1 - 358	1
	Low	358 - 583	3
	Moderate	583 - 808	5
	High	808 - 1033	7
	Very High	1033 - 1260	9
Weightage - PM-AHP-2.7, APH-2.3			
Drainage Density		0 -53	9
		53 - 106	7
		106 - 159	5
		159–213	3
		213 - 266	1

Cont...

Continues Table 4

Layer	Classification	Values	Rank
Weightage - PM-AHP-5.08, APH-4.9			
Landuse/Landcover			9
		Forest	3
		Agricultural	5
		Water	1
		Barren Land	7
Weightage - PM-AHP-7.38, APH-8.0			
Geology			5
		Pyroxene Granulite	7
		Calcrete	3
		Meta-Ultramafite	5
		Granite Gneiss	5
		Dolerite	5
		Quartz Vein/reef	1
		Banded Magnetite Quartzite	9
		Amphibolite	7
		Quartzite	9
	Acid to Intermediate Charnockite	7	
Weightage - PM-AHP-14.30, APH-16.7			

Table 5. Comparison of landslides hazard zones obtained using AHP and PM-AHP

	Area (sq. m)		Area (%)	
	PM-AHP	AHP	PM-AHP	AHP
Very low	9468624	15737462	0.93	1.55
Low	230280800	293742465	22.70	28.96
Moderate	451706786	548017493	44.53	54.03
High	301041428	153769643	29.68	15.16
Very high	21854238	3084813	2.15	0.30

in Saklespur is prone to landslides along the Western Ghats. Comparison of the historical landslides location in Saklespur Taluk, it is found that around 86% of the landslides fall under highly risk zone that is estimated using PM-AHP method and the comparison with that of AHP based LHZ map it is found that only 57% of the landslides are found to be recorded in highly risk zone and around 43% of the slides are recorded in the moderate zone, (Fig. 12, 13 and Table 5).

CONCLUSIONS

The study demonstrated the mapping of landslide hazard zones using AHP methods and based on the location of the historical landslides in Saklespur. PM-AHP method provided better result in mapping the hazardous zones by covering around 85% of the landslide hit region in heavily prone zones where as by using AHP method, only mapped 57% of the

landslides falls under heavily risk regions. Outcome of the study suggests that the modified AHP using Power Method can be used in mapping hazardous zones effectively compared to AHP method. Updation of the LHZ maps has to be done periodically with the changes in the land features and used by the local authorities in creating awareness among the general public and also take necessary measures to reduce the rate of fatalities. Located in the Western Ghats that is prone to landslides, occurrence of landslide events are very less when compared to places such as Munnar, Madikeri, Nilgiris, Western part of Pune district, etc., it failed to receive the attention of the researchers in studying the scenario of landslides in Saklespur. Even though few landslides are recorded necessary action has to be taken by the local authorities to keep them updated with the current scenario and educate the people on the effects of landslides and their damage to life and property.

REFERENCES

- Kapur A 2005. Insensitive India attitudes towards disaster prevention and management. *Economic and Political Weekly* **40**: 4551-4560.
- Kumar MK and Annadurai R 2013. Mapping of landslide susceptibility using geospatial technique: A case study in Kothagiri Region, Western Ghats, Tamil Nadu, India. *International Journal of Engineering Research & Technology* **2**: 2084-2091.
- Luu C, Von Meding J and Kanjanabootra S 2017. Analysing flood fatalities in Vietnam using national disaster database and tree-based methods. *Natural Hazards and Earth System Sciences Discussions* **2015**: 1-32.
- Mata-Lima H, Alvino-Borba A, Pinheiro A, Mata-Lima A and Almeida JA 2013. Impacts of natural disasters on environmental and socio-economic systems: What makes the difference? *Ambiente and Sociedade* **16**: 45-64.
- Saaty TL 1977. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology* **15**: 234-281.
- Senthilkumar V, Chandrasekaran SS and Maji VB 2017. Geotechnical characterization and analysis of rainfall induced 2009 landslide at Marappalam area of Nilgiris district, Tamil Nadu state, India. *Landslides* **14**: 1803-1814.
- Shirani K and Pasandi M 2019. Detecting and monitoring of landslides using persistent scattering synthetic aperture radar interferometry. *Environmental Earth Sciences* **78**: 1-24.
- Stephen A 2012. Natural disasters in India with special reference to Tamil Nadu. *Journal of Academia and Industrial Research* **1**: 59-67.
- Suresh D and Yarrakula K 2018a. Subsidence monitoring techniques in coal mining : Indian scenario. *Indian Journal of Geo-Marine Sciences* **47**: 1918-1933.
- Suresh D and Yarrakula K 2018b. GIS based multi-criteria decision making system for assessment of landslide hazard zones : Case study in the Nilgiris , India. *Indian Journal of Ecology* **45**: 286-291.
- Suresh D and Yarrakula K 2019. InSAR based deformation mapping of earthquake using Sentinel 1A imagery. *Geocarto International* **35**: 559-568.
- Suresh D and Yarrakula K 2020a. Assessment of topographical and atmospheric errors in Sentinel 1 derived DInSAR. *Geocarto International* **36**: 1-17.
- Suresh D and Yarrakula K 2020b. Evaluation of Sentinel 1 derived and open access Digital Elevation Model products in mountainous areas of Western Ghats, India. *Arabian Journal of Geosciences* **13**: 1-17.
- Vaishnavi B, Yarrakula K, Karthikeyan J and Thirumalai C 2017. An assessment framework for Precipitation decision making using AHP. In: *11th International Conference on Intelligent Systems and Control (ISCO)*. pp 418-421.
- Watson JT, Gayer M and Connolly MA 2007. Epidemics after natural disasters. *Emerging Infectious Diseases* **13**: 1-5.



Impact of different Fertilizers on Diazotrophic Community of Wheat Rhizosphere in The Semi-Arid Region, Jaipur, India

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Abstract: In terrestrial ecosystem, the nitrogen requirement is fulfilled by biological nitrogen fixation. The fixation of nitrogen on earth is done by diazotrophs. Agriculture practices like application of fertilizers influence the population of microbes in plant rhizosphere and in turn has impact on soil fertility. It is crucial to understand the effects of different fertilizers on diazotrophic diversity of the rhizosphere. Denaturing gradient gel electrophoresis (DGGE) was carried out to understand the bacterial community structure and real-time PCR was performed for *nifH* expression. Manure increased diazotrophic diversity and *nifH* expression in wheat rhizosphere, while urea fertilizer treatment decreased diazotrophic diversity and *nifH* expression. Compost manure in the rhizosphere could increase the availability of soil nutrients and might have positive impacts on soil fertility and crop productivity. The diversity of the *nifH* gene represents to be a suitable marker for predicting the capability of diazotrophs to fulfill the nitrogen demand of the ecosystem.

Keywords: Biological nitrogen fixation, Nitrogen-fixing bacteria, Rhizosphere, DGGE, *nifH*, Real-time PCR

Microbes have important role in maintaining soil health and functions of ecosystem. The rhizosphere is the zone in soil around the roots of plants which is rich in organic material and supplies nutrients like carbon, nitrogen, and energy needed for the growth of soil microbes. It is rich and diverse in composition of microbial population, resulting in uniqueness in soil nutrients and microbes present in the non-rhizosphere (Cordero et al 2020). A strong interaction between soil, plant roots, and microbes is present in rhizosphere (Kehinde et al 2019). These microbes are important for growth of plants and flow of energy in terrestrial ecosystem (Jacoby et al 2017). Nitrogen is an important nutrient after water and carbon that restricts the productivity of the plants (Rutting et al 2018). To increase crop production, nitrogen is applied in the form of chemical fertilizers which has negative impacts on the environment. This affects the quality of soil and water, contributes to the emission of greenhouse gases and employs consumption of non-renewable fossil fuels (Lin et al 2019). Therefore, Biological Nitrogen Fixation (BNF) remains a viable alternative for inorganic nitrogen fertilizers. The majority of BNF is accomplished by bacteria known as diazotrophs. Both symbiotic and free-living diazotrophs are the principle contributors of total nitrogen in an ecosystem (Pereira et al 2011). The chemical fertilizers have major impact on richness and diversity of soil microbes (Lin et al 2019). But, there is a lack of knowledge about the level of shifts in the diazotroph population with different types of fertilizers. For sustainable agriculture, it is important to understand the roles that wheat plants and fertilizers play in shaping diazotrophic communities

in wheat rhizosphere. This help us to advance soil fertility and crop productivity by using different fertilizer strategies.

MATERIAL AND METHODS

The soil samples were collected from Agriculture Research Institute, Jaipur (latitude: 24.5802 and longitude: 76.15135) from sandy-loam soil. The experimental design consisted of three sets, soil with no treatment (C), with compost manure (M), and 80 kg/h urea (U) contains 46% nitrogen according to the Indian Council of Agricultural Research (ICAR). The experiment was run in pots. Different sub pots were taken for each treatment. Each treatment was run in replicates. Internal surface area of each pot was 10, 10 and 8 cm in size. Experiment was started in November 2015 and ended in April 2016. Wheat variety Raj MR1 was used for cultivation and 20 seeds were sown in each pot. Pots were kept outside in the open natural environment and irrigated at regular interval (weekly basis). Soil samples were collected at stem elongation (after 60 days of seed sowing), grain filling stage (after 90 days of seed sowing), and harvesting stage (after 120 days of seed sowing) of the plant. During sampling, the whole plant with the roots took out from pots. For rhizosphere soil sample, the soil was removed from the surface of the roots. Sampling was done in replicates and stored at -20°C for molecular analysis and 4°C for physico-chemical parameters.

Soil physico-chemical properties: J. Forster's method was used for pH estimation Alef 1995. The soil moisture level was calculated by comparing the fresh and dry weight of soil

samples (105°C; 24h). Total organic carbon was estimated by using the Walkley-Black method (Schinner 1996). Kandeler and Gerber's method was used to estimate soil ammonium while Scharf and Wehrmann's method was utilized for nitrate content estimation (Schinner 1996).

DNA Isolation and *nifH* amplification: DNA of bacteria was isolated from soil using the MOBIO kit (Mo-Bio, USA). For the first reaction, universal gene primers were used to amplify a 370 bp fragment (Orr et al 2009). The second PCR was done with PolF and AQER primers produced 320 bp products (including GC clamp). Each 25 µl of PCR mixture contained 25 ng DNA, 1X Taq buffer, dNTP 200 µM each, primer 1 µM each, and Taq polymerase 1.5 U. PCR conditions as follows: 1 cycle at 94°C (5 min), 30 cycles at 94°C (1 min), 55°C (1 min), 72°C (2 min), 1 cycle at 72°C (7 min), and finally hold at 4°C in C1000TM Thermal Cycler (Bio-Rad). DGGE was done using the D-Code system (Bio-Rad, Germany) at 60 V for 16 hrs at 60°C (Baxter et al 2008). Bands were detected and relative intensities were calculated using Image Lab software (Bio-Rad). Unique bands were excised from the gel and reamplified using PolF and AQER without GC clamp and sequenced.

Quantification of *nifH* mRNA: *nifH* mRNA was quantified using SYBR Green chemistry by Real-time PCR. Reactions were set up using SYBER green (applied biosystem) with applied biosystem viia 7 system. Heating of the reaction mixtures was done at 95°C for 15 min to activate SYBER green, followed by 40 cycles of denaturation (95°C, 15 sec), annealing (60°C, 15 sec) and extension (72°C, 15 sec). *nifH* gene-specific PolF, and PolR primers were used. 16S rDNA was used as an internal control. For 16S rDNA primers used were 357F and 518R. Relative quantitation for *nifH* mRNA levels could be done by using the comparative $\Delta\Delta Ct$ method (Livak and Schmittgen 2001).

Calculations and statistical analyses: Pearson's correlation coefficient calculation was done with the help of program Sigmaplot version 12.5. Diversity index was estimated using number of bands present in samples, Principle component analysis (PCA) were calculated using MVSP (Multi-variate Statistical Program) software version 3.

RESULTS AND DISCUSSION

The pH of rhizosphere soil decreased significantly in compost manure and urea treated soil while in control sample no significant change was seen in pH (Table 1). For organic carbon content of rhizosphere soil samples, no significant change was observed in three treatments during all growth stages of plant. Exceptionally high organic carbon content (0.49 mg/g in %) was observed in compost manure treated soil during the harvesting stage. Manure treated samples showed a significant high level of ammonium (15.3µg/g dry weight of soil) content during the stem elongation stage. The nitrate content of the rhizosphere soil was minimum in the control sample and high in compost manure treatment. This may be related to more absorption of soil nitrate by roots of plants.

DGGE gel analysis revealed dissimilarity in *nifH* gene banding pattern profile of the soil samples (Fig. 1). Detection of each band was done based on relative front and large number of phylotypes was detected during all three plant growth stages. The diversity index values were calculated using the banding profile which varied in soil samples in all three treatments. The highest index value (3.1) was observed in rhizosphere soil at the grain filling stage in the compost manure treated sample and the lowest index value (2.5) was in urea treated soil sample at the stem elongation stage (Table 2). There was no significant difference in samples showed by Simpson, Chao1, and ACE indices. Additionally on comparing rhizosphere soil bacterial diversity was significantly different among soil samples. The species index values were showing a significant positive correlation with soil pH and ammonium concentration. But nitrate concentration showed a negative correlation. Soil pH showed a positive correlation with the Chao1 and ACE indices. The diversity index values help in calculating the richness and diversity of diazotrophic communities.

Diazotrophic community composition varied between the three treatments at the grain filling stage (Fig. 2). The relative abundance of unknown uncultured bacterium species decreased, whereas that of *Azospirillum lata*, *A. lipoferum*, *Sinorhizobium* sp. *Acinetobacter* and

Table 1. Physico-chemical properties of soil samples

Samples	pH			Organic carbon (mg/g in %)			Ammonium (µg/g dry weight of soil)			Nitrate (µg/g dry weight of soil)		
	Stem Elongation	Grain-filling	Harvesting	Stem Elongation	Grain-filling	Harvesting	Stem Elongation	Grain-filling	Harvesting	Stem Elongation	Grain-filling	Harvesting
Control	8.1±0.05	8.0±0.1	7.9±0.08*	0.43±0.03	0.37±0.02	0.42±0.02	2.45±0.02	0.39±0.01	0.11±0.03	0.96±0.02	0.53±0.06	0.05±0.04
Urea	7.7±0.03*	7.5±0.03	7.4±0.05	0.44±0.04	0.46±0.03	0.49±0.03	15.3±0.05*	4.8±0.01	3.6±0.03	6.13±0.01*	6.76±0.2*	3.73±0.01*
Manure	7.2±0.02	7.0±0.01	6.9±0.1	0.35±0.03	0.42±0.03	0.45±0.04	4.4±0.02	6.54±0.07*	5.13±0.03*	4.3±0.01	3.51±0.005	2.5±0.03

*Represents the significant difference between samples

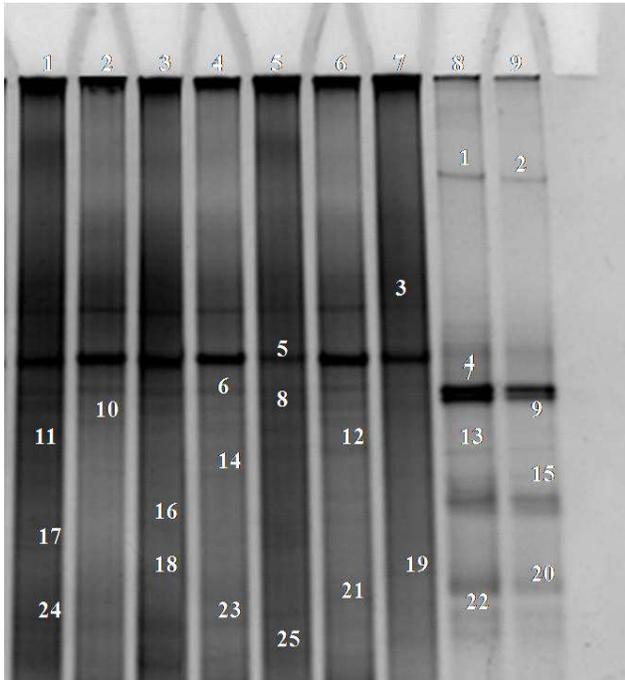


Fig. 1. 8% polyacrylamide gel showing DGGE profile of *nifH*. Numerical represents the number of bands excised from DGGE gel. Sample lanes are at top, Lane 1, 4, 7 are control sample, lane 2, 5, 8 are urea treated samples and lane 3, 6, 9 are manure treated samples

Azohydromonas australica (Fig. 2) increased with application of manure. The diazotrophic community compositions of control soil during three plant growth stages were more similar to each other. *Rubrivivax gelatinosus* phyla were commonly present in compost manure and urea treated samples (Fig. 2). Relative abundance of proteobacteria was observed in manure treatment, while that of unknown phylum of bacterial species was higher in the control and urea treated soil samples.

Principle component analysis (PCA) was used to identify the variation in species composition in soil samples. PCA demonstrated that plant growth phases and agricultural practices influenced the diazotrophic community structure (Fig. 3). PCA results showed that compost manure and plant root exudates were responsible for more diverse diazotrophic population in rhizosphere soil. Jaccard similarity index was calculated to make hierarchical clustering UPGMA (Fig. 4). The diazotrophic population in soil with different fertilizer treatments had significant correlation with soil parameters like pH, nitrate and ammonium. The results are presented in the form of a dendrogram showing the most similar cases or clusters linked most closely together. The vertical lines joining two cases or clusters indicate the level of similarity between them. Bray Curtis analysis also showed significant correlation between soil abiotic factors and

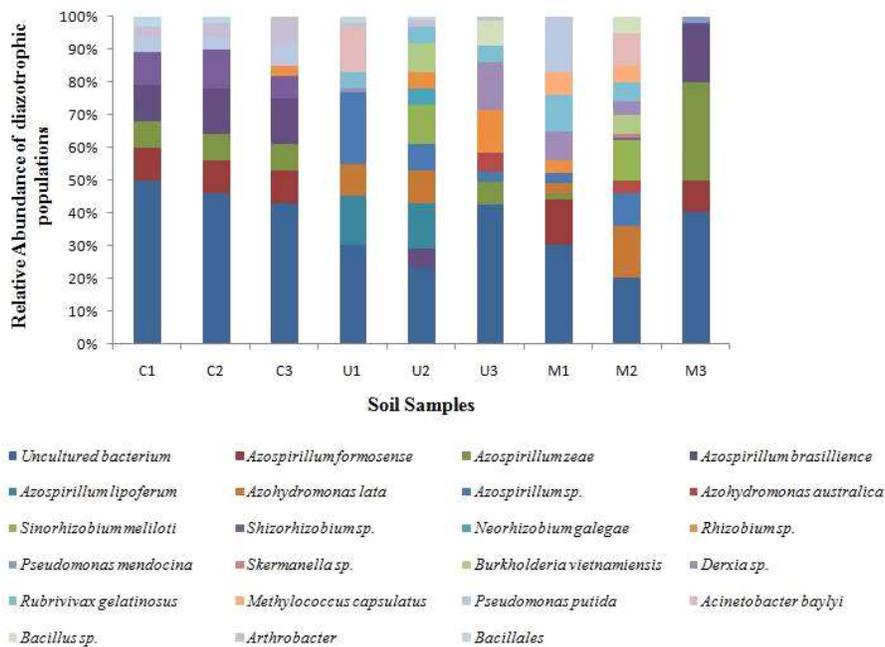


Fig. 2. Relative abundance of the diazotrophic populations from DGGE fingerprinting during fertilizer treatments

bacterial diversity.

In present studies, low pH value was observed in urea treated soil sample which may be due to application of fertilizers which lowers the soil pH by releasing H^+ into soil (Neina 2019). The high level of soil organic carbon content in compost treated sample during harvesting stage could be due to application of manure (Mekki et al 2017). The

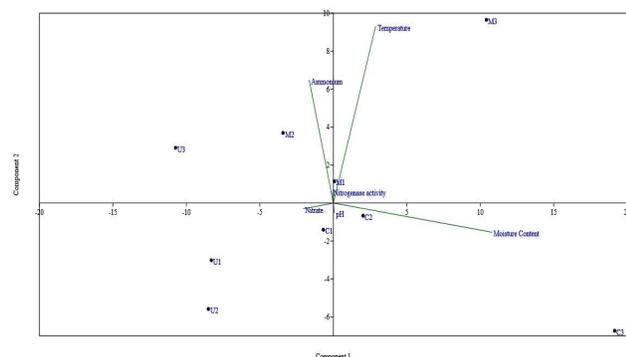


Fig. 3. Variations in the structure of the diazotrophic communities from DGGE fingerprinting during fertilizer treatments using principal correspondence analysis (PCA)

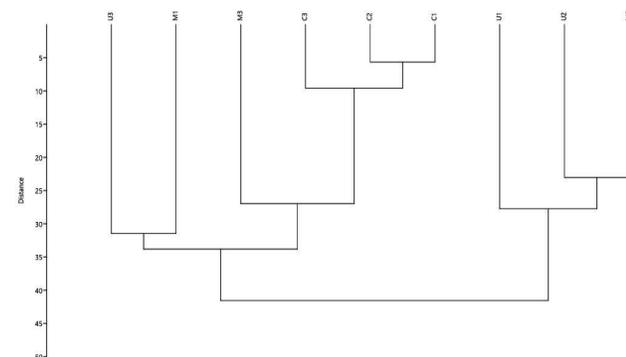


Fig. 4. Variations in the diazotroph communities as characterized by cluster analysis of the DGGE data for different fertilizer treatments. Soil samples without fertilizer (C), with urea (U) and with compost (M). 1, 2 and 3 show soil sample collection at stem elongation stage, grain filling stage and harvesting stages of plant growth respectively

concentration of soil ammonium and nitrate depends on the numerous factors like humus, fertilizers and abiotic (Gaitan et al 2019). It has been reported that chemical fertilizer application increases soil nitrate and ammonium content (Tripolskaja et al 2014). Plant species are also responsible for the varied concentration of mineral nitrogen. Crops accumulate more amounts of soil nitrate and ammonium in soil. Wheat crop is also responsible for a high concentration of soil ammonium and nitrate in soil (Yu et al 2014). Larger the value of diversity index shows the high richness and diversity of the population. Application of various types of fertilizers had different effects on bacterial richness and diversity (Lin et al 2018). Chemical fertilizers were reported for the decline of bacterial population in the soil, while organic fertilizers enhanced the bacterial richness and diversity (Bertherog et al 2014, Sapp et al 2015). In present study, diverse communities of nitrogen-fixing bacteria were present in rhizospheric soil samples of compost manure treatment. Manure is rich in organic matter which is absorbed and utilized by microbes for their functions (Liang et al 2020).

Soil microbiota participates in nutrient cycling and important for maintaining ecosystem stability. Studies have shown that ten bacterial groups are dominantly present in soil samples (Laurent et al 2010). Proteobacteria number was relatively high in the rhizosphere soil of wheat plant (Ai et al 2015). In present study phyla of bacteria and their relative abundances were significant different in all three treatments. *Azospirillum* species like *A. lata*, *A. lipoferum*, *Sinorhizobium* sp. *Acinetobacter* and *Azohydromonas australica* were richly present in the soil samples. They are broadly distributed ecologically and observed in enormous crop varieties of like rice, maize and wheat (Fukami et al 2018). Several bands in DGGE gel were representing unidentified bacterial species. These changes in the bacterial population may due to soil type or different climatic conditions (Cavicchioli et al 2019). This analysis helps us to show the capability of nitrogen fixing bacteria under different factors. Applications of fertilizers cause changes in the physico-chemical factors of soil, which results in changes the soil bacterial population (Ling et al 2016, Wang et al 2017). Previous studies have shown that

Table 2. Diversity index values for fertilizer treated soil samples

Diversity indexes	C1	C2	C3	U1	U2	U3	M1	M2	M3
Dominance_D	0.0625	0.0625	0.05	0.05882	0.04348	0.0625	0.05882	0.04762	0.05556
Simpson_1-D	0.9375	0.9375	0.95	0.9412	0.9565	0.9375	0.9412	0.9524	0.9444
Shannon_H	2.773	2.773	2.996	2.833	3.135	2.773	2.833	3.045	2.89
Evenness_e^H/S	1	1	1	1	1	1	1	1	1
Chao-1	136	136	210	153	276	136	153	231	171

*Represents the significant difference between samples. Soil samples without fertilizer (C), with urea (U) and with compost (M). 1, 2 and 3 show soil sample collection at stem elongation stage, grain filling stage and harvesting stages of plant growth respectively

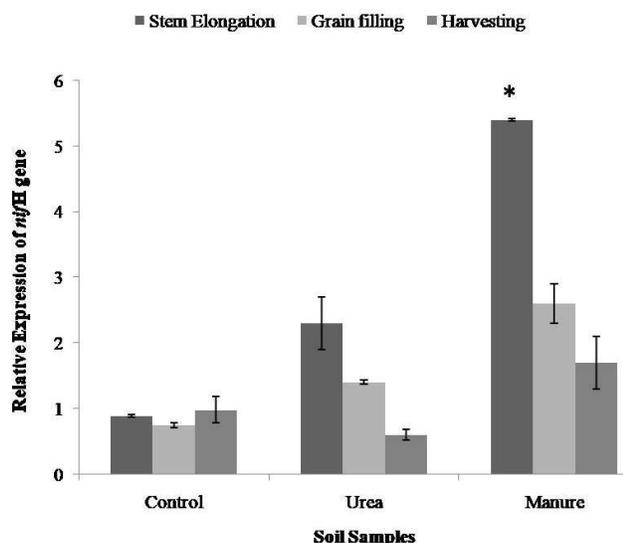


Fig. 5. mRNA expression profile of *nifH* gene in soil samples with fertilizer treatments

*Represents the significant difference between samples

soil parameters like pH, nitrate, and ammonium were crucial factors influencing the microbial population (Liu et al 2018, Zhalnina et al 2015). It also showed changes in diazotrophic community structure with different fertilizers. The soil nitrate, ammonium, and carbon make the availability of soil nutrient, which influences soil microbes. Composed manure improved the availability of nutrients in rhizosphere zone that resulted in growth of nitrogen-fixing bacteria but urea treatment decreased the availability nutrient. The diazotrophic population in with its nitrogenase activity in rhizosphere zone of soil. Diazotrophs play a crucial role in nitrogen cycle of the terrestrial ecosystem. Different fertilizer treatments caused changes in the functional diversity of diazotrophs and their structure which resulted in fertility of soil. The diversity of the *nifH* gene represents to be a suitable marker for predicting the capability of diazotrophs to fulfill the nitrogen demand of the ecosystem. This work may help us to show the working potential of diazotrophs. For biological nitrogen fixation is dependent on several environmental factors. Diverse nitrogen fixers need distinctive environmental parameters for atmospheric nitrogen fixation.

CONCLUSION

The variation in the nitrogen-fixing bacterial population in the sandy-loam soil of semi-arid region was observed. Compost manure increased the diazotrophic community population and nitrogenase activity but the urea treatment decreased diazotrophic diversity. Manure enhanced the population of *Azospirillum* sp. in the rhizosphere, while urea increased the population of unknown bacterial species. Soil

pH, organic carbon, ammonium, and nitrate were key parameters impacting the diazotrophic population and their functions in rhizosphere soil. This helps to understand the factors impacting diazotrophic bacteria and BNF will advance the nitrogen demand of earth.

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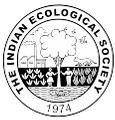
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REFERENCES

- Ai C, Liang G, Sun J, Wang X, Ping H, Wei Z and He X 2015. Reduced dependence of rhizosphere micro biome on plant-derived carbon in 32-year long-term inorganic and organic fertilized soils. *Soil Biology and Biochemistry* **80**: 70-78.
- Alef K and Nannipieri P 1995. *Methods in Applied Soil Microbiology and Biochemistry*. Academic Press, London, 55 and 59.
- Baxter J and Cummings SP 2008. The degradation of the herbicide bromoxynil and its impact on bacterial diversity in a top soil. *Journal of Applied Microbiology* **104**: 1605-1616.
- Berthrong ST, Buckley DH and Drinkwater LE 2013. Agricultural Management and Labile Carbon Additions Affect Soil Microbial Community Structure and Interact with Carbon and Nitrogen Cycling. *Microbial Ecology* **66**: 158-170.
- Cavicchioli R, Ripple WJ and Webster NS 2019. Scientists' warning to humanity: microorganisms and climate change. *Nature Reviews Microbiology* **17**: 569-586.
- Cordero J, Renato de Freitas JR and Germida JJ 2020. Bacterial microbiome associated with the rhizosphere and root interior of crops in Saskatchewan, Canada. *Canadian Journal of Microbiology* **66**(1): 71-85.
- Fukami J, Cerezini P and Hungria M 2018. *Azospirillum*: benefits that go far beyond biological nitrogen fixation. *AMB Express* **8**: 73.
- Gaitán JJ, Maestre FT, Bran DB, Buono GG, Dougill AJ, Martínez GG, Ferrante G, Guuroh RT, Linstädter A, Massara V, Thomas AD and Gabriel EO 2019. Biotic and Abiotic Drivers of Topsoil Organic Carbon Concentration in Dry lands have Similar Effects at Regional and Global Scales. *Ecosystems* **22**: 1445-1456.
- Ghaly AE and Ramakrishnan VV 2015. Nitrogen Sources and Cycling in the Ecosystem and its Role in Air, Water and Soil Pollution: A Critical. *Journal of Pollution Effects & Control* **3**:2.
- Jacoby R, Peukert M, Succurro A, Koprivova A and Kopriva S 2017. The role of soil microorganisms in plant mineral nutrition-current knowledge and future directions. *Frontiers in Plant Science* **8**: 16-17.
- Kehinde AO and Babalola OO 2019. Bacteria, fungi and archaea domains in rhizospheric soil and their effects in enhancing agricultural productivity. *International Journal of Environmental Research and Health* **16** (20): 3873.
- Laurent P, Andersson SGE, Battin TJ, Prosser JI, Schimel JP, Whitman WB and Sara H 2010. The ecological coherence of high bacterial taxonomic ranks. *Nature Reviews Microbiology* **8**: 523-529.
- Liang R, Hou RLI J, Lyu U Hang S Gong H and Ouyang Z 2020. Effects of different fertilizers on rhizosphere bacterial communities of winter wheat in the North China plain *Agronomy* **10**(1): 93-98.
- Lin W, Lin M, Hongyan Z H, Hongmiao W, Zhaowei L and Wenxiong L 2019. The effects of chemical and organic fertilizer usage on rhizosphere soil in tea orchards *Plos One* **14**(5): e0217018.
- Ling N, Zhu C, Xue C, Chen H, Duan Y, Peng C, Guo S and Shen Q 2016. Insight into how organic amendments can shape the soil microbiome in long-term field experiments as revealed by network analysis. *Soil Biology and Biochemistry* **99**: 137-149.

- Liu J, Peng D, Yang G, Zhu H, Zhu H, Fei Z and Zhong Z 2018. Effects of tree species and soil properties on the composition and diversity of the soil bacterial community following afforestation. *Forest Ecology and Management* **427**: 342-349.
- Mekki A, Aloui F and Sayadi S 2017. Influence of biowaste compost amendment on soil organic carbon storage under arid climate. *Journal of the Air and Waste Management Association* **69**(7): 867-877.
- Neina D 2019. The Role of Soil pH in Plant Nutrition and Soil Remediation. *Applied and Environmental Soil Science* 5794869:1-9
- Omar L Ahmed O and Majid NM 2015. Improving ammonium and nitrate release from urea using clinoptilolite zeolite and compost produced from agricultural wastes. *The Scientific World Journal* 57420: 1-12
- Orr CH, James A, Leifert C, Cooper JM and Cummings SP 2009. Diversity and activity of free-living nitrogen-fixing bacteria and total bacteria in organic and conventionally managed soils. *Applied Environmental Microbiology* **77**: 911-919.
- Rütting T, Aronsson H and Delin S 2018. Efficient use of nitrogen in agriculture *Nutrient Cycling in Agroecosystems* **110**: 1-5.
- Sapp M, Harrison M, Hany U, Charlton A and Thwaites R 2015. Comparing the effect of digestate and chemical fertiliser on soil bacteria. *Applied Soil Ecology* **86**: 1-9.
- Schinner F, Ohlinger R, Kandeler DE and Margesin RD 1996. *Methods in Soil Biology*. Springer Verlag, Berlin Heidelberg, New York **385**: 406-410.
- Tripolskaja L, Romanovskaja D, Slepeliene A, Razukas A and Sidlauskas G 2014. Effect of the chemical composition of green manure crops on humus formation in a soddy-podzolic soil. *Eurasian Soil Science* **47**(4): 310-318.
- Wang J, Xue C, Song Y, Wang L, Huang Q and Shen Q 2016. Wheat and rice growth stages and fertilization regimes alter soil bacterial community structure, but not diversity. *Frontiers of Microbiology* **7**: 1207.
- Yu Y, Xue L and Yang L 2014. Winter legumes in rice crop rotations reduces nitrogen loss, and improves rice yield and soil nitrogen supply. *Agronomy for Sustainable Development*. **34**: 633-640.
- Zhalnina K, Dias R, Quadros PDD, Davis-Richardson A, Camargo FAO, Clark IM, Mcgrath SP, Hirsch PR and Triplett EW 2015. Soil pH determines microbial diversity and composition in the park grass experiment. *Microbial Ecology* **69**: 395-406.

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Comparative Assessment on Physico-chemical Properties of Coal Mining Affected and Non-Affected Forest Soil at Changki, Nagaland

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Abstract: Coal mining activities along the forested hills and plains of various districts in Northeast India has caused substantial environmental damages altering the landscape and soil properties as well. The present study aims to evaluate the soil physico-chemical parameters of the coal mining affected forest (CMAF) and non-affected forest (NAF) at Changki, Nagaland, India. Soil samples were collected at varying depths from September, 2018 to August, 2019 covering the four seasons viz., winter, spring, summer and autumn. The soil parameters such as soil organic carbon, pH, porosity, soil moisture, particle density, exchangeable potassium, available nitrogen, available phosphorus and cation exchange capacity were higher in NAF soil in all the seasons. Comparative analysis between the results of the two sites indicates deteriorated soil quality and altered soil properties in the affected forest as the rejuvenating process is hampered while the soil nutrient availability and organic carbon composition in the NAF indicates fertile soil status.

Keywords: Changki, Coal mines, Disturbed forest, Soil quality, Seasonal values

Coal excavation is one of the major mining activities in North-East India and most of the production comes from opencast mines. However, unscientific mining of minerals poses serious consequences to the environment, resulting in soil erosion, reduction of forest cover at a greater scale and loss in biodiversity. Large scale denudation of forest cover, scarcity of water, pollution of air, water and soil, degradation of agricultural lands are some of the conspicuous environmental implications of coal mining (Gupta and Tiwari 2000). Mining gradually removes the fertile top layer of soil enriched with biomass of organic forest litters and hence has environmental repercussion. The overburden dumps deposited in un-mined forest build mine spoils and its impact can be felt over a vast area of land. Sarma (2002), Rai et al (2011) and Talukdar et al (2016) reported deteriorated soil quality in coal mining affected area with relatively low pH, low nutrients content and organic carbon. Nagaland, a state in northeast India is situated along the Indo-Burma biodiversity hotspot, lies between Latitude of 25° 06' N and 27° 04' N and Longitude of 93° 20' E and 95° 15' E. The state has a subtropical to warm temperate monsoonal climate with an annual average rainfall of 1,800-2,500 mm. Some of the mining sites reported by NPCB (2015) in Nagaland are at Mon, Longleng, Wokha and Mokokchung district. For decades, open cast coal mining has been taking place extensively in the forested hill slopes of Changki in Mokokchung district. The mining affected study site has coal

field covering an area of 52,000 m² and is surrounded by semi-deciduous forest. On average, overburden mine spoils of 250 tons are dumped annually at the borderline of adjacent forest which has greatly reduced the vegetation cover and drastically changed the forest landscape by altering the soil properties. Assessment of soil physico-chemical characteristics of coal mine is of utmost important because it not only paves the way of greater understanding the direction of improving soil fertility and bioremediation, but also is pre-requisite for assessing the process of spoil reclamation, leading to the vegetational development or succession with respect to time (Maharana et al 2013). Therefore, the present study aims to compare the soil physico-chemical characteristics between the coal mining affected and non-affected forest. This will impart knowledge and awareness on environmental issues occurring due to mining activities and initiate necessary steps to counter the repercussion effects.

MATERIAL AND METHODS

Experimental area and sampling site: The present study was conducted at two forest sites of Changki and designated as Coal Mining Affected Forest (CMAF) having a latitude - 26°26'18"N and longitude - 94°22'48"E with an altitude of 248 m above 'm a.s.l.' and Non-Affected Forest (NAF) which lies at latitude - 26°24'40"N and longitude - 94°23'31"E with an altitude of 598 m above 'm a.s.l.'. The CMAF is located adjacent to the coal fields along with residential area and

passing highway, it is more prone to anthropogenic activities like logging and plantation practices. However, the NAF being situated near the protected forest which is approximately 6 km away from the CMAF is not influenced by mining activities. Soil samples were collected from September, 2018 to August, 2019 covering the four seasons of winter, spring, summer and autumn. Random sampling position plot, one from each selected site was taken into consideration. Soils were sampled from three layers depth i.e 0-10 cm, 10-20 cm and 20-30 cm by using a sampling corer (area of 10 cm²). The landuse and landcover map of the study area is shown in Figure 1.

Soil and data analysis: Soil samples from each of the three layers were collected in airtight polythene bags and taken to the laboratory for analysing the parameters such as soil temperature (soil thermometer), pH (Jackson 1973), soil moisture content (gravimetric method), soil texture (pipette method given by Piper 1942), bulk density, particle density and soil porosity (core method), organic carbon (Walkley and Black's method 1934), available Nitrogen by Kjeldahl method using Kelplus Nitrogen estimation system, Phosphorus (Bray's no. 1 extract method, 1945) using spectrophotometer, Exchangeable Potassium using flame photometer (Photometric method) and Cation exchange capacity (Bower et al 1952). Pearson correlation matrix was calculated among the physico-chemical parameters of soil for the affected and non-affected forest in order to evaluate the significant relationship between the parameters by using statistical software SPSS version 21.

RESULTS AND DISCUSSION

Soil temperature: Soil temperature ranges from 21.7°C (NAF, Winter at 20-30cm) to 35°C (CMAF, Summer at 0-10cm). It varies seasonally and daily which may result from changes in radiant energy and energy variation taking place through the soil surface and also the rate of organic matter decomposition and mineralization of different organic materials (Onwuka 2016). The rich vegetation and soil moisture in NAF counters the rise of soil temperature upto some extent. Higher soil temperature in CMAF is due to less forest canopy cover and direct exposure of sunlight on the soil surface.

Soil texture: Soil texture represents the relative content of particle such as sand, silt and clay varying in sizes. Average value of sand (CMAF - 60.8%, NAF - 57.04%) was the major constituent of the soil samples in both the study sites, followed by silt (CMAF - 21.07%, NAF - 21.1%) and clay (CMAF - 18.05%, NAF - 21.2%). The greater percentage of sand content in CMAF increases aeration of soil which restricts the presence of moisture. Clay was comparatively

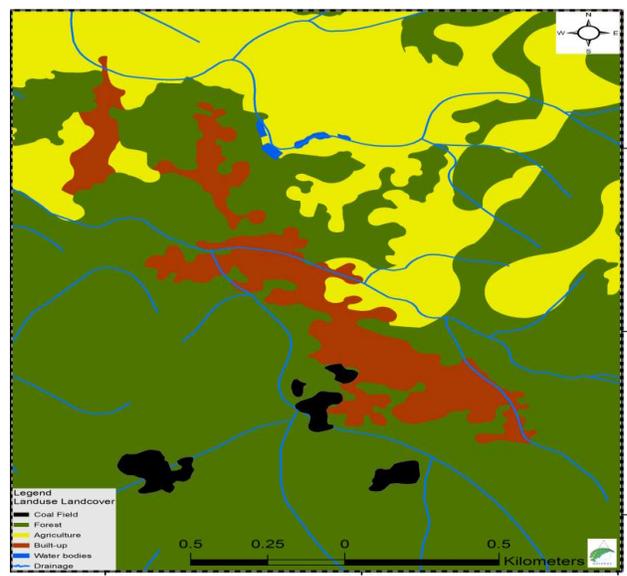


Fig. 1. Landuse and landcover map of the study area at Changki

higher in NAF and it serves as a medium for organic matter and water retainment capacity which increases soil fertility by influencing nutrient composition through sequestration and stabilization.

Soil porosity: The average soil porosity at the CMAF is 0.41% while NAF is 0.48%. The increasing organic matter contributes to the overall improvement in porosity in native soil (Gairola et al 2010) apparently the biomass from vegetation at NAF is higher than CMAF impacting the soil porosity as well.

Bulk density (BD): Bulk density is another important property for gaseous exchange, such as high bulk density would pose restriction to the growth of deeper rooted plants and may be one of the reasons of cessation of plant growth (Ghose et al 2004). CMAF has average bulk density of 1.44g cm⁻³ while NAF has 1.25g cm⁻³. Higher BD at CMAF can be due to low organic matter and moisture in the soil as these parameters stands in determining the BD.

Particle density (PD): The average soil particle density of NAF is 2.47g cm⁻³ and CMAF is 2.48g cm⁻³ as shown in Table 1. PD of soil plays a role in sustaining vegetation and impacting bulk density, soil moisture, water holding capacity and nutrient composition.

pH: pH is an important index of ecological condition of terrestrial environment (Rai et al 2011). The observed range of pH at NAF is 4.46 (Winter, 0-10 cm) -5.33 (Summer, 0-10 cm) and CMAF is 2.96 (Winter, 0-10 cm) -4.13 (Autumn, 20-30 cm). Considerably pH of all the sampling sites in NAF is slightly acidic and CMAF soil is acidic in nature. Coal spoils are rich in pyrites, sulphates and toxic metals which on

Table 1. Seasonal variation (Mean \pm S.D) in the soil physico-chemical properties of the coal mining affected and non-affected forest at Changki

Soil parameters	Soil depth (cm)	Season												Mean \pm S.D	
		Winter			Spring			Summer			Autumn			NAF	CMAF
		NAF	CMAF												
Soil temperature ($^{\circ}$ C)	0-10	22.7 \pm 2.04	24.7 \pm 2.09	23.7 \pm 2.4	25.7 \pm 3.34	32.4 \pm 3.43	35 \pm 2.05	32.3 \pm 4.35	34.6 \pm 3.36	27.3 \pm 0.45	29.4 \pm 0.58				
	10-20	22.4 \pm 1.98	23.7 \pm 2.75	23.5 \pm 2.31	25 \pm 3.12	31.8 \pm 3.12	34.7 \pm 2.1	32 \pm 4.38	34.2 \pm 3.23						
	20-30	21.7 \pm 2.13	23 \pm 2.95	22.9 \pm 1.94	24.6 \pm 3.19	31.3 \pm 3.41	34 \pm 1.91	31.6 \pm 4.2	33.7 \pm 3.45						
Sand (%)	0-10	58.4 \pm 1.05	59.63 \pm 5.4	56.5 \pm 5.42	59.26 \pm 2.7	54.9 \pm 3.1	60.96 \pm 0.85	51.83 \pm 4.64	59.16 \pm 1.61	57.04 \pm 1.53	60.8 \pm 1.004				
	10-20	60.1 \pm 0.91	61.36 \pm 5.2	57.86 \pm 5.29	59.96 \pm 4.33	58.03 \pm 3.78	62.33 \pm 1.46	53 \pm 4.97	59.96 \pm 1.64						
	20-30	62 \pm 1.15	62.26 \pm 5.2	59.26 \pm 4.21	61.16 \pm 3.5	59.03 \pm 4.2	62.9 \pm 1.04	53.6 \pm 4.55	60.7 \pm 1.37						
Silt (%)	0-10	19.86 \pm 2.82	20.9 \pm 0.36	20.3 \pm 2.55	21.13 \pm 0.97	22.6 \pm 0.96	21.96 \pm 0.6	20.53 \pm 2.17	19.96 \pm 0.89	21.1 \pm 0.5	21.07 \pm 0.34				
	10-20	21.2 \pm 1.74	20.43 \pm 1.36	18.6 \pm 2.7	20.16 \pm 0.5	21.13 \pm 1.36	21.73 \pm 0.64	22.26 \pm 3.32	20.8 \pm 0.26						
	20-30	20.56 \pm 1.88	20.8 \pm 0.79	21.23 \pm 3.15	21.66 \pm 2.05	21.63 \pm 2.15	21.9 \pm 0.87	23.33 \pm 2.66	21.46 \pm 0.72						
Clay (%)	0-10	21.7 \pm 1.96	19.46 \pm 1.65	23.2 \pm 3.25	19.6 \pm 3.3	22.5 \pm 3.29	17.06 \pm 1.34	27.63 \pm 3.23	20.86 \pm 1.02	21.2 \pm 2.4	18.05 \pm 1.23				
	10-20	18.7 \pm 0.87	18.2 \pm 1.53	20.2 \pm 2.45	19.2 \pm 3.19	20.83 \pm 2.48	15.93 \pm 0.85	24.73 \pm 3.4	19.23 \pm 1.62						
	20-30	17.43 \pm 0.75	16.93 \pm 1.13	19.16 \pm 1.97	17.16 \pm 1.56	19.33 \pm 2.05	15.23 \pm 0.25	19.9 \pm 3.6	17.83 \pm 1.95						
Soil porosity (%)	0-10	0.463 \pm 0.03	0.41 \pm 0.01	0.48 \pm 0.01	0.41 \pm 0.03	0.496 \pm 0.02	0.42 \pm 0.01	0.55 \pm 0.02	0.46 \pm 0.01	0.48 \pm 0.01	0.41 \pm 0.01				
	10-20	0.456 \pm 0.03	0.393 \pm 0.02	0.47 \pm 0.01	0.40 \pm 0.03	0.483 \pm 0.03	0.4 \pm 0.01	0.53 \pm 0.01	0.44 \pm 0.01						
	20-30	0.44 \pm 0.03	0.38 \pm 0.02	0.463 \pm 0.02	0.396 \pm 0.04	0.466 \pm 0.01	0.38 \pm 0.015	0.53 \pm 0.01	0.416 \pm 0.01						
Bulk density (g cm $^{-3}$)	0-10	1.36 \pm 0.09	1.45 \pm 0.06	1.24 \pm 0.06	1.44 \pm 0.1	1.18 \pm 0.01	1.39 \pm 0.03	1.09 \pm 0.06	1.32 \pm 0.02	1.25 \pm 0.04	1.44 \pm 0.04				
	10-20	1.39 \pm 0.09	1.49 \pm 0.03	1.3 \pm 0.07	1.49 \pm 0.09	1.21 \pm 0.03	1.43 \pm 0.01	1.12 \pm 0.05	1.36 \pm 0.03						
	20-30	1.43 \pm 0.07	1.57 \pm 0.04	1.35 \pm 0.08	1.54 \pm 0.09	1.25 \pm 0.02	1.49 \pm 0.02	1.1 \pm 0.07	1.38 \pm 0.04						
Particle density (g cm $^{-3}$)	0-10	2.55 \pm 0.07	2.47 \pm 0.05	2.43 \pm 0.08	2.49 \pm 0.12	2.38 \pm 0.1	2.44 \pm 0.07	2.43 \pm 0.15	2.49 \pm 0.1	2.47 \pm 0.02	2.48 \pm 0.01				
	10-20	2.59 \pm 0.05	2.483 \pm 0.07	2.5 \pm 0.1	2.55 \pm 0.13	2.37 \pm 0.09	2.4 \pm 0.07	2.44 \pm 0.12	2.45 \pm 0.08						
	20-30	2.61 \pm 0.07	2.56 \pm 0.05	2.54 \pm 0.09	2.58 \pm 0.14	2.37 \pm 0.02	2.44 \pm 0.06	2.46 \pm 0.08	2.39 \pm 0.09						
pH	0-10	4.46 \pm 0.15	2.96 \pm 0.2	4.6 \pm 0.1	3.2 \pm 0.26	5.33 \pm 0.15	3.86 \pm 0.3	5.06 \pm 0.15	3.9 \pm 0.34	4.95 \pm 0.09	3.57 \pm 0.09				
	10-20	4.6 \pm 0.1	3.13 \pm 0.25	4.63 \pm 0.15	3.3 \pm 0.2	5.46 \pm 0.11	3.96 \pm 0.28	5.16 \pm 0.23	3.96 \pm 0.32						
	20-30	4.73 \pm 0.2	3.13 \pm 0.23	4.73 \pm 0.11	3.3 \pm 0.2	5.53 \pm 0.15	4.1 \pm 0.34	5.2 \pm 0.26	4.13 \pm 0.2						
Moisture (%)	0-10	29.3 \pm 5.39	20.9 \pm 5.4	33.43 \pm 9.77	23.1 \pm 6.02	43.5 \pm 4.33	35.9 \pm 2.35	43.9 \pm 4.05	32.07 \pm 3.49	35.21 \pm 2.19	26.54 \pm 1.5				
	10-20	27.4 \pm 3.53	19.3 \pm 5.41	31.6 \pm 10.5	21.16 \pm 5.6	41.9 \pm 5.33	35.03 \pm 3.7	38.68 \pm 6.6	30.89 \pm 5.46						
	20-30	26.03 \pm 3.6	17.6 \pm 4.02	30.83 \pm 10.4	19.43 \pm 5.13	41.16 \pm 5.61	32.7 \pm 2.11	34.73 \pm 9	30.33 \pm 5.69						
Conductivity (μ S cm $^{-1}$)	0-10	221.1 \pm 6.83	272.8 \pm 5.94	245 \pm 5.11	328.1 \pm 16.6	237.6 \pm 8.77	334.7 \pm 6.7	234.4 \pm 4.7	295 \pm 12.9	230.1 \pm 4.78	302.4 \pm 5.01				
	10-20	219.3 \pm 2.75	268.13 \pm 2.4	240.8 \pm 6.28	318.6 \pm 15.2	228.5 \pm 11.6	330.6 \pm 8.11	234.6 \pm 5.08	290 \pm 12.02						
	20-30	214.5 \pm 3.02	265.36 \pm 3.3	236 \pm 4.25	313.2 \pm 16.2	220.8 \pm 10.8	328 \pm 5.67	228.8 \pm 7.42	283.9 \pm 6.27						

Table 1. Seasonal variation (Mean \pm S.D) in the soil physico-chemical properties of the coal mining affected and non-affected forest at Changki

Soil parameters	Soil depth (cm)	Season												Mean \pm S.D	
		Winter			Spring			Summer			Autumn			NAF	CMAF
		NAF	CMAF	NAF	CMAF	NAF	CMAF	NAF	CMAF	NAF	CMAF				
Cation Exchange Capacity (meq100g ⁻¹)	0-10	33.04 \pm 2.84	20.06 \pm 2.65	35.04 \pm 5.5	24.56 \pm 2.7	31.7 \pm 1.9	25.36 \pm 3.6	37.68 \pm 6.6	32.7 \pm 1.44	32.38 \pm 2.7	24.3 \pm 1.18				
	10-20	30.78 \pm 2.93	18.09 \pm 2.7	32.63 \pm 5.3	23.16 \pm 3.6	30.46 \pm 1.1	23.56 \pm 3.6	35.76 \pm 5.3	32.36 \pm 2.5	35.76 \pm 5.3	30.61 \pm 1.9				
	20-30	30.38 \pm 2.13	16.89 \pm 2.15	31.23 \pm 3.8	23.22 \pm 1.9	29.3 \pm 1.5	22.2 \pm 4.7	35.23 \pm 5.2	30.61 \pm 1.9	35.23 \pm 5.2	2.11 \pm 0.12				
Organic Carbon (%)	0-10	2.03 \pm 0.17	1.24 \pm 0.32	2.21 \pm 0.88	1.32 \pm 0.23	1.9 \pm 0.45	0.95 \pm 0.13	2.89 \pm 0.24	1.46 \pm 0.39	2.89 \pm 0.24	1.36 \pm 0.43				
	10-20	1.76 \pm 0.16	1.08 \pm 0.22	1.99 \pm 0.72	1.18 \pm 0.31	1.63 \pm 0.27	1.16 \pm 0.22	2.88 \pm 0.13	1.36 \pm 0.43	2.88 \pm 0.13	1.19 \pm 0.5				
	20-30	1.66 \pm 0.16	1.03 \pm 0.19	1.96 \pm 0.79	1.21 \pm 0.28	1.81 \pm 0.16	1.3 \pm 0.18	2.7 \pm 0.24	1.19 \pm 0.5	2.7 \pm 0.24	178.4 \pm 8.2				
Exchangeable Potassium (Kgha ⁻¹)	0-10	247.7 \pm 13.8	159.8 \pm 7.5	250 \pm 5.3	162.4 \pm 3.2	271.5 \pm 7.2	172.4 \pm 4.4	272.4 \pm 9.2	178.4 \pm 8.2	272.4 \pm 9.2	170.86 \pm 5.7				
	10-20	244.3 \pm 13.3	149.73 \pm 9.3	244.7 \pm 6.3	154.6 \pm 3.4	263.7 \pm 7.2	163.7 \pm 5.6	264.8 \pm 9.6	170.86 \pm 5.7	264.8 \pm 9.6	167.13 \pm 5.8				
	20-30	237.3 \pm 11.7	143.4 \pm 6.3	239.4 \pm 8.8	151.9 \pm 4.6	260.3 \pm 7.2	160.8 \pm 7.05	262 \pm 9.7	170.86 \pm 5.7	262 \pm 9.7	105.63 \pm 6.4				
Available nitrogen (Kg ha ⁻¹)	0-10	158.4 \pm 10.6	74.23 \pm 10.6	133.7 \pm 12.4	79.4 \pm 4.3	175.3 \pm 12.5	105.9 \pm 12.9	202.6 \pm 9.5	158.03 \pm 8.8	202.6 \pm 9.5	83.46 \pm 8.72				
	10-20	151.9 \pm 13.3	67.2 \pm 8.7	123.6 \pm 11.3	73.36 \pm 3.7	161.1 \pm 9.8	103.2 \pm 13	189.3 \pm 11.8	158.03 \pm 8.8	189.3 \pm 11.8	96.26 \pm 11				
	20-30	148.9 \pm 14.8	59.1 \pm 8.4	114.3 \pm 5.8	60.5 \pm 9.2	156.6 \pm 7.4	92.7 \pm 10.9	180.3 \pm 10.8	158.03 \pm 8.8	180.3 \pm 10.8	83.9 \pm 4.8				
Available phosphorus (Kg ha ⁻¹)	0-10	7.26 \pm 0.11	5.9 \pm 0.3	8.6 \pm 1.05	6.83 \pm 0.85	10.9 \pm 0.75	8.3 \pm 1.27	9.36 \pm 1.07	7.03 \pm 0.33	9.36 \pm 1.07	8.76 \pm 0.32				
	10-20	7.46 \pm 0.41	6 \pm 0.1	8.13 \pm 1.13	6.83 \pm 0.55	10.53 \pm 0.61	7.93 \pm 1.13	9.33 \pm 1.4	7.03 \pm 0.33	9.33 \pm 1.4	8.13 \pm 0.61				
	20-30	6.93 \pm 0.23	5.5 \pm 0.3	7.86 \pm 1.02	6.33 \pm 0.57	10.06 \pm 0.64	7.33 \pm 1.13	8.73 \pm 1.3	7.03 \pm 0.33	8.73 \pm 1.3	7.4 \pm 0.52				

oxidation can acidify soil pH of the CMAF. This in turn can retard the root system of plants while NAF has no intervention from mine dumps and the acidity level is therefore favourable for plant growth.

Soil moisture: Average means site soil moisture of CMAF (26.54%) is lower than NAF (35.21%). NAF in rainy-summer has the maximum moisture content with 43.5% at 0-10cm and minimum value of 17.6% was recorded at 20-30cm soil depth from CMAF in winter. It is evident that moisture content in soil is more in the rainy season as the soil capillaries (porosity) retain a lot of water from the run off (Mohapatra and Goswami 2012). Low moisture content in CMAF is due to higher content of sand, stone and lack of organic substances while higher organic matter and finer soil texture in NAF retains the soil moisture and increases its availability.

Electrical conductivity: The conductivity of CMAF and NAF was 302.4 μScm^{-1} and 230.1 μScm^{-1} respectively. The value of electrical conductivity at CMAF indicates higher concentration of salts of various chemicals, dissolved solids, trace metals, colloidal substances and ions which increases the soil conductivity.

Cation exchange capacity (CEC): The CEC at NAF (37.68 meq100g⁻¹) and CMAF (32.38 meq100g⁻¹) was highest in autumn at 0 - 10cm depth of soil. In the CMAF the soils are more or less sandy type where cation exchange capacity is lower than NAF soils. Results from the analysis also suggest that low cation exchange capacity has reduced soil organic carbon and nutrient properties of the soil (Bahrami et al 2010).

Organic carbon: The percentage of soil organic carbon in both the NAF (2.89%) and CMAF (1.46%) was recorded highest in autumn at 0-10cm depth of soil. The main sources of organic carbon in soil are plant debris, dead roots and the surface litter or dead leaves which are more abundantly available in NAF than in CMAF. Un-mined site has highest soil organic carbon content because of favourable conditions for microbial activity in the process of organic matter decomposition (Yadav et al 2015) which contributes to its formation.

Exchangeable potassium: The concentration of potassium in both the NAF (272.4 Kg ha⁻¹) and CMAF (178.4 Kg ha⁻¹) was highest in autumn at 0-10cm depth of soil while minimum in NAF (237.3 Kg ha⁻¹) and CMAF (143.4 Kg ha⁻¹) was recorded at 20-30cm depth of soil in winter season. Exchangeable K content is lowest in mining affected site which indicates low fertility status of the soil (Mukhopadhyay and Maiti 2010). Higher percentage of organic carbon and clay in autumn can elevate the content of potassium in soil, which was observed in NAF.

Available nitrogen: Highest available nitrogen was

Table 3. The correlation matrix between the various physico-chemical properties of coal mining affected forest at Changki

Soil parameters	Soil temperature	Sand	Silt	Clay	Soil porosity	Bulk density	Particle density	pH	Moisture	Conductivity	Cation exchange capacity	Organic carbon	Exchangeable potassium	Available nitrogen	Available phosphorus
Available phosphorus	.827**	-.155	.496	-.090	.217	-.588*	-.592*	.651*	.692*	.550	.591*	-.144	.641*	.854**	1
Available nitrogen	.924**	.159	.444	-.276	.425	-.641*	-.410	.783**	.837**	.606*	.599*	.001	.690*	1	
Exchangeable potassium	.841**	-.287	.242	.160	.638*	-.806**	-.389	.917**	.859**	.388	.810**	.187	1		
Organic carbon	-.113	.059	-.185	.207	.181	-.276	-.184	.196	-.105	-.119	.313	1			
Cation exchange capacity	.643*	-.304	-.116	.395	.708*	-.819**	-.328	.757**	.541	.101	1				
Conductivity	.610*	.146	.697*	-.409	.132	-.228	-.156	.535	.679*	1					
Moisture	.957**	-.065	.508	-.162	.540	-.687*	-.330	.872**	1						
pH	.846**	-.046	.308	-.036	.535	-.719**	-.395	1							
Particle density	-.395	.386	-.370	-.239	.167	.533	1								
Bulk density	-.742**	.496	-.189	-.455	-.745**	1									
Soil porosity	.555	-.263	-.076	.336	1										
Clay	-.158	-.860**	-.440	1											
Silt	.492	.005	1												
Sand	-.056	1													
Soil temperature	1														

findings of Adhikari and Bhattacharyya (2015) where they obtained correlations existing among soil organic carbon (C), nitrogen (N), phosphorous (P) and potassium (K).

Correlation analysis among the soil physico-chemical parameters of the coal mining affected forest: Soil temperature was positively significant with pH, moisture, potassium, available nitrogen and phosphorus while negatively significant with bulk density (Table 3). The rise of soil temperature increases P availability (Jiao et al 2016). Soil texture such as sand was negatively significant with clay as the proportion of sand increases the clay content decreases. The correlation of bulk density with soil temperature, soil porosity, pH and potassium was negatively significant. Pravin et al (2013) also observed correlation between bulk density and pH as negatively significant. pH has high positive significant correlation with available nitrogen, temperature, moisture, cation exchange capacity and potassium. Significant positive correlation was observed for moisture with available nitrogen, potassium and phosphorus. Positive significant correlation of cation exchange capacity was recorded with available nitrogen, phosphorus, temperature and soil porosity. Potassium was positively correlated with temperature, moisture and cation exchange capacity. Phosphorus is negatively significant with bulk density and particle density. Sandy soils have a limited capacity to stabilize organic compounds on mineral surfaces compared with clay, which affects the capacity, magnitude and rate of SOC storage (Feng et al 2013). CMAF has sandy type of soils, with low CEC which adsorb lesser quantities of cations and this implication is important when deciding on nutrient availability and its correlations.

CONCLUSION

The comparative analysis on soil physico-chemical characteristics conducted between the coal mining affected forest and non-affected forest at Changki shows the CMAF soil is adversely strained from its natural rejuvenating process due to the impacts of mine spoils from the overburden dumps. Nitrogen, phosphorus, potassium and soil organic matter were depleted in the CMAF. The impact of mining on the soil properties was felt even upto 30 cm in depth, suggesting that mine spoils can disrupt the root system and retards the growth of plants. NAF soil has rich organic matter from forest litter which serves as a soil restoring initiator that ensures the availability of nutrients for proper functioning of the forest ecosystem. If the trend of dumping overburden mine spoils and other anthropogenic activities continues at the CMAF site, detrimental environmental changes will affect the reclamation and restoration process of soil. Therefore, an urgent necessary strategy is required to dump the new

overburden in old landfills where coal has been excavated, separation of coal toxic spoils while dumping, the discharged of coal mining effluents should be treated, mine-dumping laws should be formulated and enforced by village councils or board members.

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REFERENCES

- Adhikari G and Bhattacharyya KG 2015. Correlation of soil organic carbon and nutrients (NPK) to soil mineralogy, texture, aggregation, and land use pattern. *Environmental Monitoring and Assessment* **187**(11): 735.
- Bray RH and Kurtz LT 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Sciences* **59**: 39-45.
- Bower CA, Reitemeier RF and Fireman M 1952. Exchangeable cation analysis of saline and alkali soils. *Soil Science* **73**: 251-261.
- Bahrami A, Emadodin I, Atashi MR and Bork HR 2010. Land-use change and soil degradation: A case study, North of Iran. *Agriculture and Biology Journal of North America* **1**(4): 600-605.
- Conant RT 2011. Temperature and soil organic matter decomposition rates-synthesis of current knowledge and a way forward. *Global Change Biology* **17**: 3392-3404.
- Chaudhari PR, Ahire DV, Ahire VD, Chkravarty M and Maity S 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications* **3**: 1-8.
- Feng WT, Plante AF and Six J 2013. Improving estimates of maximal organic carbon stabilization by fine soil particles. *Biogeochemistry* **112**: 81-93.
- Gupta D, Tiwari BK and Tripathi RS 2000. Coal mining in Jaintia hills, Meghalaya: An ecological perspective in Jaintia hills. A Meghalaya tribe: its environment, land and people. *Reliance and Publishing* **21**: 121-128.
- Ghose MK 2004. Effect of opencast mining on soil fertility. *Journal of Environment and Industrial Research* **63**: 1006-1009.
- Gairola SK and Soni P 2010. Role of soil physical properties in ecological succession of restored mine land: A Case Study. *International Journal of Environmental Science* **1**(4): 475-480.
- Jackson ML 1973. *Soil Chemical Analysis*. Prentice hall of India Pvt. Ltd., New Delhi, 498.
- Jiao F, Shi XR, Han FP and Yuan ZY 2016. Increasing aridity, temperature and soil pH induce soil C-N-P imbalance in grasslands. *Science Report* **6**: 19.
- Mukhopadhyay S and Maiti SK 2010. Natural mycorrhizal colonization in tree species growing on the reclaimed coalmine overburden dumps: Case Study from Jharia coalfields, India. *The Bioscan* **3**: 761-770.
- Mohapatra H and Goswami S 2012. Impact of coal mining on soil characteristics around Ib river coalfield, Orissa, India. *Journal of Environmental Biology* **33**: 751-756.
- Maharana JK and Patel AK 2013. Physico-chemical characterization and mine soil genesis in age series coal mine overburden spoil in chronosequence in a dry tropical environment. *Journal on Phylogenetics. Evolution Biology* **1**(1): 1-7.
- Nimmo JR 2004. Porosity and pore size distribution, pp. 295-303. In: Hillel D (ed). *Encyclopedia of Soils in the Environment*. Elsevier, London.
- Nagaland Pollution Control Board (NPCB) 2015. Government of Nagaland.
- Onwuka BM 2016. Effects of soil temperature on some soil properties and plant growth. *Journal of Agricultural Science* **6**(3): 89-93.
- Piper CS 1942. *Soil and plant analysis: Laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants*. University of Adelaide: Adelaide.
- Rai AK, Paul B and Singh G 2010. Assessment of top soil quality in the vicinity of subsided area in Jharia coalfield, Dhanbad, Jharkhand. *Report and Opinion* **2**(9): 1-6.
- Rai AK, Paul B and Singh G 2011. A study on the Bulk density and its effect on the growth of selected grasses in coal mine overburden dumps, Jharkhand, India. *International Journal of Environmental Sciences* **1**(6): 1350-1360.
- Sarma K 2002. *Coal mining and its impact on environment of "Nokrek biosphere reserve, Meghalaya*. Ph. D thesis submitted to Department of Geography, North Eastern Hill University, Shillong.
- Talukdar B, Kalita HK, Basumatary S and Sarma D 2016. Impact of coal mining on soil characteristics of Simsang River, Meghalaya, India. *Journal of Fundamental Renewable Energy* **6**(6): 45-86.
- Urik M and Nemcek KL 2012. Soil moisture and its effect on bulk density and porosity of intact aggregates of three Mollic soils. *Indian Journal of Agricultural Science* **82**(2): 172-176.
- Walkley AJ and Black IA 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Sciences* **37**: 29-38.
- Yadav RS, Pandya IY and Jangid MS 2015. Estimating status of soil organic carbon in tropical forests of Narmada. *International Research Journal of Environmental Sciences* **4**(1): 19-23.



Influence of different NPK Doses on Plant Growth and Soil Nutrient Contents of Apple (*Malus × domestica* Borkh.) Nursery

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Abstract: The present study was conducted to standardize NPK doses for nursery plants of apple. NPK doses were examined for their effects on growth of nursery plants of apple cv. Oregon Spur grafted on Merton 793 clonal rootstock and nutrient contents of nursery soil. The experiment comprised of 14 treatments where 12 treatments were combinations of NPK with 3 levels of N (N_1 , N_2 and N_3 @ 12, 15 and 18 g m⁻² nursery bed, respectively), two levels of P (P_1 and P_2 @ 3 and 6 gm⁻² nursery bed, respectively) and two levels of K (K_1 and K_2 @ 4.5 and 9 g m⁻² nursery bed, respectively), whereas two other treatments were Jeevamrut (10% drenching at fortnight intervals) and untreated control. The maximum linear growth, number of leaves per plant, leaf area, total root length, fresh and dry weight of roots, soil P and soil Mg were recorded in the plants treated with $N_3P_2K_1$. However, highest scion radial growth, internodal length, fresh and dry weight of shoots, total plant biomass, available soil N and soil K were registered by the plants subjected to $N_3P_2K_2$. The treatments $N_3P_2K_1$ and $N_3P_2K_2$ were statistically at par with one another with respect to majority of observations. Thus, the application of N:P:K @ 18:6:4.5 g m⁻² nursery bed, respectively was the most efficacious treatment and recommended for production of quality nursery plants of apple.

Keywords: Apple, Nursery, NPK, Plant growth, Soil nutrient contents

Apple is known as premiere fruit crop of the world and is an extremely important fruit crop in the north western Himalayan region of India. It is a crucial commercial fruit crop of Jammu and Kashmir, Himachal Pradesh and Uttarakhand, therefore serves a vital role in the economy of these hilly states. Good quality planting material is consequently the basic need of horticulture as production and productivity of an orcharding entrepreneur is highly dependent on quality of planting material. Shortage of quality planting material is the major bottleneck in the production of fruit crops. The planting material being raised by majority of nurseries in the country fails to meet the nursery standards and results in poor survival and orchard performance. In order to produce healthy and vigorous nursery plants, genuine nutrient management practices are needed to be followed. Nutrients, especially, NPK are needed to be provided to the nursery plants in balanced doses. Nitrogen is a key element essential for the formation of amino-acids, proteins and enlargement of new cells and tissues. It enhances the metabolic processes that are based on proteins leading to increase in vegetative growth (Wang et al 2008). It encourages the uptake and utilization of other nutrients including P and K and thus controls the overall growth of plants (Bloom 2015, Hemeryl 2016). The initial growth of plants in spring during cell division depends mainly on nitrogen (Bi et al 2004). Phosphorus is another very vital nutrient as it promotes early root formation

and helps the plants to survive under severe conditions. Potassium is equally important as it plays a significant role in uptake and transportation of water by the plant and is also required for manufacturing and translocation of sugars and starch. Good potassium nutrition also assists in the quick conversion of inorganic nitrogen into proteins, thus the efficiency of nitrogen fertilizer gets improved (Kumar et al 2006). Since the demand of quality planting material is on a high and uninterrupted supply of such planting material can be achieved by application of balanced doses of NPK. The objective of this study was to assess the effect of graded levels of NPK on plant growth and nutrient contents of nursery soil and find out their optimum doses for quality nursery production of apple.

MATERIAL AND METHODS

The experiment was carried at Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan during 2017-18 in a randomized block design with fourteen treatments viz., $T_1=N_1P_1K_1$ (12:3:4.5 g m⁻² nursery bed), $T_2=N_1P_1K_2$ (12:3:9 g m⁻² nursery bed), $T_3=N_1P_2K_1$ (12:6:4.5 g m⁻² nursery bed), $T_4=N_1P_2K_2$ (12:6:9 g m⁻² nursery bed), $T_5=N_2P_1K_1$ (15:3:4.5 g m⁻² nursery bed), $T_6=N_2P_1K_2$ (15:3:9 g m⁻² nursery bed), $T_7=N_2P_2K_1$ (15:6:4.5 g m⁻² nursery bed), $T_8=N_2P_2K_2$ (15:6:9 g m⁻² nursery bed), $T_9=N_3P_1K_1$ (18:3:4.5 g m⁻² nursery bed), $T_{10}=N_3P_1K_2$ (18:3:9 g m⁻² nursery bed), $T_{11}=N_3P_2K_1$ (18:6:4.5 g

m² nursery bed), T₁₂=N₃P₂K₂ (18:6:9 g m² nursery bed), T₁₃=Jeevamrut drenching (10%) at fortnight intervals and T₁₄= No chemical fertilizer/control. Each treatment was replicated thrice. FYM @ 8.0 kg m² nursery bed was applied at the time of bed preparation as per the treatments. Rootstocks of Merton 793, having uniform size and vigour were planted at a distance of 3×20 cm in nursery beds during January. After the rootstocks got established, tongue grafting was performed in the first week of March. Shoots of Oregon Spur were grafted at a height of 15 cm above the ground. N, P₂O₅ and K₂O were applied through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively. Full dose of single super phosphate (P₂O₅) and muriate of potash (K₂O) were applied after bed preparation before planting of rootstock in the month of January. Urea (N) was applied in split doses; first half was applied during transplanting of rootstock and another half during the onset of monsoon. Consistent and conventional cultural practices were adopted in the experiment including the application of FYM @ 8 kg m² bed. Jeevamrut was prepared by mixing cow dung (1 kg), cow urine (1 litre), gram flour (200 g), jaggery (200 g) and virgin soil (100 g) and making the final volume 20 litre with the tap water. After mixing the component and making the final volume, it was allowed to ferment for 7 days. During the process of fermentation, the solution was stirred clockwise regularly thrice a day. The properly fermented and well prepared jeevamrut was diluted ten times and applied at fortnightly interval in the form of soil drenching to each assigned bed right from the start of the experiment until the plants were uprooted. Fresh Jeevamrut was prepared for each application and applied @ 10 litre m² nursery bed area.

Linear and radial growth of the plant was measured at the end of season. To calculate the internodal length, height of the scion portion of the plant was divided by the number of nodes on the plant. The leaf area was measured with the help of an Automatic Leaf Area Meter (Licor Model-3100). To determine the fresh weight of shoots and roots, after uprooting the plants at the end of season, shoot and root portion was separated and cut into small pieces. The fresh weight of shoot and root segments was then recorded separately on electronic balance. To record the dry weight, the root and shoot segments were dried in an oven at 65 ± 5°C temperature until a constant weight was obtained. The length of the main roots was measured with the help of measuring tape. Total root length was measured with the help of root length scanner (Comair root length scanner). Total plant biomass was obtained by adding the dry weight of shoots and roots. To determine the soil nutrient contents, the soil samples from 0-45 cm depth were collected at the end of experiment from individual bed. The soil samples, thus

collected were dried in shade, grounded, sieved through 2 mm plastic sieve and stored in cloth bags. Samples were prepared for analysis in accordance with the procedure given by Piper (1966). Nitrogen was estimated by alkaline potassium permanganate method (Subbiah and Asija 1956). Phosphorus in soil was analyzed by stannous chloride reduced ammonium molybdate method using Olsen's extractant (Olsen et al 1954) and determined on Thermo-Scientific Spectronic 20 D+ at 660 nm wave length. Potassium was extracted with neutral ammonium acetate as per the procedure given by Merwin and Peech (1951). Potassium was estimated using Flame Photometer (MODEL TMF-45) and Calcium and magnesium were extracted with the neutral normal ammonium acetate and determined using Analyst 400 Atomic Absorption Spectrophotometer.

RESULTS AND DISCUSSION

The perusal of data reveals that the soil application of graded levels of NPK exerted a significant influence on the plant growth characteristics (Table 1). Plant growth parameters increased with increasing doses of NPK. The maximum linear growth (156.62 cm) and number of leaves per plant (53.00) were in plants in T₁₁ (N₃P₂K₁), followed by T₁₂ (N₃P₂K₂) and both these treatments were statistically at par with T₉ (N₃P₁K₁) and T₁₀ (N₃P₁K₂). Similarly, leaf area (24.35 cm²), total root length (14.90 m), fresh weight of roots (67.83 g) and dry weight of roots (38.17 g) were also observed with N₃P₂K₁ (T₁₁) which was followed by N₃P₂K₂ (T₁₂). However, increase in scion radial growth (5.23 mm), internodal length (3.38 cm) and total plant biomass (88.75 g) were significantly higher under N₃P₂K₂ (T₁₂), closely followed by N₃P₂K₁ (T₁₁) and both these treatments were statistically at par with T₉ (N₃P₁K₁) and T₁₀ (N₃P₁K₂). Similarly, the trees subjected to T₁₂ (N₃P₂K₂) exhibited significantly higher fresh and dry weight of shoots (95.51g and 51.0 g, respectively followed by T₁₁ (N₃P₂K₁) and both these treatments were statistically at par with T₁₀ (N₃P₁K₂) and T₁₃ (Jeevamrut drenching). The higher growth of nursery plants under increasing doses of NPK may be attributed to the fact that these nutrients are crucial determinants of plant growth and development. Fertilization with NPK improves plant growth by either increasing soil resources or by enhancing the ability of plants to garner resources by modifying soil pH (Lincoln et al 2003). Increasing dose of NPK fertilizers might have activated the physiological processes for rapid absorption and utilization of nutrients for the primary metabolic process. Nitrogen uptake and assimilation are essential growth-promoting processes in plants and has to be converted into amino acids after its uptake in plants. Thus, nitrogen supply enhanced the total and individual amino acid concentrations and indicates that

more N is channelled to the production of precursors of protein biosynthesis to provide basic compounds for rapid biomass production. Nitrogen plays an important role in synthesis of the plant constituents through the action of different enzyme activities and protein synthesis, thus improves the quantity of dry matter. P activates co-enzymes for amino acid production used in protein synthesis and K plays an important role in uptake and transportation of water and quick conversion of inorganic nitrogen into proteins. As a result, plants increase stem diameter, height, basal area and volume (King et al 2006). The results of present studies are in conformity with those of Cooke et al (2005), who

reported that high nutrient levels stimulate plant growth and biomass production. Similarly, Prado et al (2009) also reported significant increase in growth of shoot and root system in nursery plants of sweet orange with the application of N, P and K @ 918, 184, 876 mg dm⁻³ of substratum.

The different NPK doses on soil N, P, K, Ca and Mg contents of apple nursery soil indicate significant differences. The N, P, K, Ca and Mg contents in the nursery soil increased with the increasing doses of NPK. The maximum nitrogen (467.80 kg/ha) was in the nursery beds treated with N₃P₂K₂ (T₁₂) which was statistically at par with N₂P₂K₂ (T₈), N₃P₁K₁ (T₉), N₃P₁K₂ (T₁₀) and N₃P₂K₁ (T₁₁) but significantly higher than rest of

Table 1. Effect of graded levels of NPK on the growth of grafted nursery plants of apple cv. Oregon Spur

Treatment	Linear growth (cm)	Increase in radial growth of scion (mm)	Number of leaves	Internodal length (cm)	Leaf area (cm ²)	Total root length (m)	Fresh weight of shoots (g)	Dry weight of shoots (g)	Fresh weight of roots (g)	Dry weight of roots (g)	Total plant biomass (g dry weight basis)
T ₁ - N ₁ P ₁ K ₁	132.93	3.44	40.33	3.03	20.77	8.70	64.42	33.05	40.42	28.93	61.98
T ₂ - N ₁ P ₁ K ₂	134.00	3.56	41.00	3.06	21.71	8.50	65.85	36.67	41.06	29.29	65.96
T ₃ - N ₁ P ₂ K ₁	136.50	3.77	41.33	3.10	21.08	10.78	70.04	37.33	50.22	32.50	69.83
T ₄ - N ₁ P ₂ K ₂	139.68	3.27	41.67	3.12	21.22	10.85	72.33	38.08	52.65	32.42	70.50
T ₅ - N ₂ P ₁ K ₁	140.33	3.24	43.33	3.21	21.59	12.55	75.75	41.09	43.42	29.25	70.34
T ₆ - N ₂ P ₁ K ₂	142.40	4.01	44.33	3.24	21.32	12.51	76.09	41.53	43.44	28.94	70.47
T ₇ - N ₂ P ₂ K ₁	145.75	4.04	45.00	3.24	21.29	13.30	78.05	42.25	58.30	36.83	79.08
T ₈ - N ₂ P ₂ K ₂	151.58	4.92	47.33	3.27	21.74	13.60	81.68	42.42	57.33	34.93	77.34
T ₉ - N ₃ P ₁ K ₁	155.75	4.49	50.67	3.32	22.51	10.27	82.28	44.89	52.91	34.57	79.46
T ₁₀ - N ₃ P ₁ K ₂	155.25	4.46	50.33	3.34	23.27	10.31	86.47	45.61	54.58	33.83	79.44
T ₁₁ - N ₃ P ₂ K ₁	156.62	4.87	53.00	3.35	24.35	14.90	89.49	49.17	67.83	38.17	87.33
T ₁₂ - N ₃ P ₂ K ₂	156.00	5.23	50.00	3.38	23.97	14.50	95.51	51.00	62.67	37.75	88.75
T ₁₃ - Jeevamrut	144.53	4.11	48.67	3.20	22.82	9.33	88.14	42.92	45.10	29.98	72.90
T ₁₄ - Control	128.05	3.20	34.00	2.96	20.34	7.17	62.28	30.57	35.51	23.62	54.19
CD (p=0.05)	8.98	0.78	4.49	0.13	1.14	0.44	9.87	8.72	5.51	4.46	10.01

Table 2. Effect of graded levels of NPK on nutrient contents of apple nursery soil

Treatment	Nitrogen (kg ha ⁻¹)	Phosphorus (kg ha ⁻¹)	Potassium (kg ha ⁻¹)	Calcium (mg kg ⁻¹)	Magnesium (mg kg ⁻¹)
T ₁ - N ₁ P ₁ K ₁	383.67	58.83	315.76	1637.22	568.32
T ₂ - N ₁ P ₁ K ₂	387.71	60.45	333.03	1625.14	563.01
T ₃ - N ₁ P ₂ K ₁	391.33	69.94	319.99	1650.11	574.88
T ₄ - N ₁ P ₂ K ₂	407.00	72.52	328.57	1634.18	573.69
T ₅ - N ₂ P ₁ K ₁	418.00	62.65	325.29	1665.45	576.45
T ₆ - N ₂ P ₁ K ₂	435.67	63.95	350.68	1651.74	573.96
T ₇ - N ₂ P ₂ K ₁	447.00	75.90	330.90	1675.52	578.39
T ₈ - N ₂ P ₂ K ₂	448.00	74.78	354.02	1664.59	576.81
T ₉ - N ₃ P ₁ K ₁	456.19	65.40	341.63	1698.14	585.77
T ₁₀ - N ₃ P ₁ K ₂	462.10	67.58	367.62	1683.21	582.66
T ₁₁ - N ₃ P ₂ K ₁	465.34	78.87	349.89	1684.17	591.13
T ₁₂ - N ₃ P ₂ K ₂	467.80	76.91	370.67	1677.20	584.38
T ₁₃ - Jeevamrut	371.84	56.00	328.92	1682.41	573.21
T ₁₄ - Control	367.86	51.52	308.82	1618.60	561.95
CD (p=0.05)	20.17	8.71	18.50	42.71	12.33

the treatments. Similarly, the nursery beds subjected to $N_3P_2K_2$ (T_{12}) exhibited maximum potassium content ($370.67 \text{ kg ha}^{-1}$) and was significantly superior to all other treatments except $N_2P_2K_2$ (T_8) and $N_3P_1K_2$ (T_{10}). However, maximum soil phosphorus content (78.87 kg ha^{-1}) was observed in the soil of nursery beds fertilized with $N_3P_2K_1$ (T_{11}), which was statistically at par with those of $N_1P_2K_2$ (T_4), $N_2P_2K_1$ (T_7), $N_2P_2K_2$ (T_8) and $N_3P_2K_2$ (T_{12}). Similarly, maximum soil magnesium content ($591.13 \text{ mg kg}^{-1}$) was recorded in the soil of nursery beds subjected to $N_3P_2K_1$ (T_{11}) which was significantly higher than other treatments under study except $N_3P_1K_1$ (T_9), $N_3P_1K_2$ (T_{10}) and $N_3P_2K_2$ (T_{12}). The maximum soil calcium content ($1698.14 \text{ mg kg}^{-1}$) was registered by the nursery beds treated with $N_3P_1K_1$ (T_9) which was statistically at par with $N_2P_1K_1$ (T_5), $N_2P_2K_1$ (T_7), $N_2P_2K_2$ (T_8), $N_3P_1K_2$ (T_{10}), $N_3P_2K_1$ (T_{11}), $N_3P_2K_2$ (T_{12}) and Jeevamrut (T_{13}) treatments. The increase in the available N of soil with increasing N fertilizers doses may be anticipated due to increase in NH_4^+ ions and the conversion of these ions to NO_3^- ions by soil bacteria through nitrification. Phosphorus fertilizers in the soil increase the available P through production of carbonic acid in the presence of organic matter which increases solubility of phosphate compounds. The increase in potassium content with the increasing supply of NPK might be attributed to increase in K^+ ion concentration in the soil solution due to the increase in acidity resulting from N application which might have favoured sublimation of K and other cations. Potassium plays an important role in translocation of N, P, Ca, Mg and amino acids thus an ample supply of K is essential for efficient transport of these nutrients (Thomas and Thomas 2009). Ernani et al (2002), also recorded an increase in concentration of K in the soil with increasing level of KCl. Similar increase in available potassium content was also observed by Szweczek et al (2011) with increasing K level from 12 to 20 mg K 100 g^{-1} of soil. The increase in soil Ca content with the application of N, P and K might be due to addition of calcium in the form of single super phosphate to the soil.

CONCLUSION

The application of 18 g N, 6 g P and 4.5 g K m^{-2} nursery bed ($N_3P_2K_1$) to grafted nursery plants of apple cv. Oregon Spur registered significantly higher linear growth, number of leaves, leaf area, fresh and dry weight of roots, total biomass of plant, soil P and Mg content. However, radial growth of scion, internodal length, fresh and dry weight of shoots and soil N and K contents were found significantly higher under treatment comprising 18 g N, 6 g P and 9 g K m^{-2} nursery bed ($N_3P_2K_2$) Thus soil application of 18.0 g of N, 6.0 g of P and

4.5 g of K m^{-2} nursery bed was most effective and can be recommended for the production of quality nursery plants of apple on clonal rootstocks.

REFERENCES

- Bi G, Scagel CF, Cheng L and Fuchigami LH 2004. Effects of spring soil nitrogen application on nitrogen remobilization, uptake and partitioning for new growth in almond nursery plants. *Journal of Horticultural Science and Biotechnology* **79**: 431-436.
- Bloom AJ 2015. The increasing importance of distinguishing among plant nitrogen sources. *Current Opinion in Plant Biology* **25**: 10-16.
- Cooke JE, Martin TA and Davis JM 2005. Short-term physiological and developmental responses to nitrogen availability in hybrid poplar. *New Phytologist* **167**: 41-52.
- Ernani PR, Dias J and Flore JA 2002. Annual additions of potassium to the soil increased apple yield in Brazil. *Communications in Soil Science and Plant Analysis* **33**: 1291-1304.
- Hemerly A 2016. Genetic controls of biomass increase in sugarcane by association with beneficial nitrogen-fixing bacteria, In Plant and Animal Genome XXIV Conference. *Plant and Animal Genome*, during month of January.
- King N, Seiler J, Fox TR and Johnsen K 2006. The short-term effects of fertilization on loblolly pine photosynthesis and biomass. In: Conner KF, editor. *Proceedings of the 13th Biennial Southern Silvicultural Research Conference*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station, pp. 113-116.
- Kumar R, Kumar N and Kavino M 2006. Role of potassium in fruit crops: A Review. *Agriculture Review* **27**: 284-291.
- Lincoln MC, Will RE, Morris LA, Carter EA, Markewitz D and Britt JR 2003. Soil change and loblolly pine (*Pinus taeda*) seedling growth following site preparation tillage in the upper coastal plain of the south eastern United States. *Forest Ecology and Management* **180**: 335-344.
- Merwin and Peech M 1951. Exchange ability of soil potassium in the sand, silt and clay fractions as influenced by the nature and complementary exchangeable cations. *Soil Science Society of American Proceedings* **15**: 125-128.
- Olsen SR, Cole CV, Watanable FS and Dean LA 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. *USDA Circular* **939**: 1-19.
- Piper CS 1966. *Soil and Plant Analysis*. Hans Publications, Bombay, India, 368p.
- Prado RM, Rozane DE, Camarotti GS, Correia MAR, Natale W and Barbosa JC 2009. Effect of nitrogen, phosphorus and potassium levels on nutrition and production of seedlings of 'Valencia' sweet orange grafted on 'Carnation' lemon rootstock. *Science and Agrotechnology* **33**: 1560-1568.
- Subbiah BV and Asija GL 1956. A rapid procedure for the determination of available nitrogen in soils. *Current Science* **25**: 259-260.
- Szweczek A, Komosa A and Gudarowska E 2011. Effect of soil potassium levels and different potassium fertilizers on yield, macroelement and chloride nutrition status of apple trees in full fruiting period. *Acta Scientiarum Polonorum Hortorum Cultus* **10**: 83-94.
- Thomas TC and Thomas AC 2009. Vital role of potassium in the osmotic mechanism of stomata aperture modulation and its link with potassium deficiency. *Plant Signal Behaviour* **4**: 240-243.
- Wang ZH, Xie S and Malhi S 2008. Effects of fertilization and other agronomic measures on nutritional quality of crops. *Journal of the Science of Food and Agriculture* **88**: 7-23.



Assessment of Spatial and Seasonal Water Quality Variation of the Upstream and Downstream of Oum Er-rabia River in Morocco

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Abstract: The aim of this study was to assess changes in physicochemical parameters and nutrient concentrations with the season and to generate helpful data for water quality managers. The physicochemical properties of the river investigated were all within the recommended range of acceptable water quality (Temperature: 13.3 - 25.9; pH: 7.84 - 8.63; DO: 4.2- 9.2 mg l⁻¹) except for salinity which was higher than recommended threshold. However, the concentrations of heavy metals were negligible at the upstream, but the suspended matter was higher at the upstream (94 mg l⁻¹) than that of the downstream (0.026 mg l⁻¹). Water surface in the region of Oum Er-rabia has good water quality with high concentration of salinity and is suitable for drinking purposes after treatment.

Keywords: Physicochemical parameters, Nutrients, Water quality, Oum Er- rabia

Fresh water is vital to life and yet it is a finite resource and of all the water on earth, just 3% is fresh water. Although its composition is dependent on natural factors (geological, topographical, meteorological, hydrological and biological) and varies with seasonal differences in runoff volumes, weather conditions and water levels. Nevertheless, surface water quality is largely influenced by both natural processes and by anthropogenic inputs (Kazi et al 2009) such as discharge of untreated industrial effluent, agricultural and municipal run offs tend to change the physical and nutrient river water qualities (Gao 2014, Pan et al 2014). These activities pose serious threats to surface water quality and the ecosystem services of the river (Banunle et al 2018, Elayaraj et al 2011). Sustainable development is thus a difficult task to achieve without ensuring adequate quality and quantity of fresh water. In Morocco, awareness of environmental problems is rapidly increasing. In recent years, several studies, showing that the water quality of many rivers has been deteriorating with various anthropic activities (El Baghdadi et al 2015, Nadem et al 2015, Abbou and Fahde 2017). The vulnerability of water resources pollution in Moroccan rivers is due to industrial activity including oil mills, phosphate extraction, and sugar beet processing. The Oum Er Bia basin is the primary source of water for a variety of purposes (drinking, agriculture, industry, recreation) and also receives wastes from vast rural areas and several large cities along its banks. The protection of surface water in associated reservoirs is therefore crucial to providing suitable and safe drinking water for both rural and urbanized areas. This study compares

the upstream and downstream water qualities with the aim of assessing the level of purity of the Oum Er-rabia River and the anthropogenic impact on the quality of River Oum Er-rabia.

MATERIAL AND METHODS

Study area: The Oum Er-rabia River, which runs for approximately 35 000 km² from its source in *Middle Atlas* (at 1800 m) to the Atlantic Coast of *Azemmour* city, is among the national's longest, widest, and deepest rivers. It is located in the Center-Western of Morocco on the southern borders of the Mediterranean area of the northern hemisphere, straddling the 32nd parallel. It is based on the north-western slope of the limestone High Atlas and on an element of the Middle Atlas, and it slopes towards the northwest, towards the Atlantic Ocean: 31°19.33'-33°22.21"N lat and 5°8.55'-8°22.53'W Long (Loup 1962). Three sampling sites were target at Oum Er rbia (Fig. 1).

--S1 (31°19.33'N; 5°8.55'W): located on a Middle Atlas 30 km from Khénifra.

--S2 (32°22.21'N; 8°22.53'W): located 50 km from Settat city, just proximity to the city's urban waste.

--S3 (33°17'15.1"N; 8°20'22.0"W): located at the mouth

The selection of the sampling sites was based on different criteria related to the contamination vulnerability, and the exploitation of the area as drinking, agriculture, industry, recreation. The stations near to the river source were supposed to be less impaired by urban contamination and the stations downstream were supposed to be more impaired by this contamination type.

Field sampling and abiotic factors analysis: The water column is sampled seasonally at three points along the study area, during January-December, 2015. At each sampling location, the water temperature, pH, salinity, and dissolved oxygen (DO) were measured in situ. The other parameters were determined within 24 h in the laboratory according to the standard methods (Rodier et al 2009). The current study took place for a twelve month period (January-December 2015). The period between January-March and October-November 2015, was considered the wet season period while the period between April-September 2015 was considered the dry season. The sampling stations were selected on the basis of their contamination vulnerability, the stations near to the river source were supposed to be less impaired by urban contamination and the stations downstream were supposed to be more impaired by this contamination type.

Fourteen parameters hydrological criteria were measured along the Oum Er-rabia river typology were water temperature (T°), salinity (S), pH, dissolved oxygen (DO), suspended matter (DM), ammonium (NH_4^+), total phosphorus (ICP), zinc (Zn), copper (Cp), lead (Pb), chromium (Cr), cadmium (Cd), mercury (Mr), nickel (Ni). Temperature, salinity, pH, and dissolved oxygen were chosen to characterize this river (Table 1).

RESULTS AND DISCUSSION

Temperature followed a seasonal pattern, with a distinct thermocline in winter-spring and autumn at S1 and S2 (higher level in spring), contrariwise S3 indicated stable temperature. Generally, values recorded along the Oum Er-rabia river ranged between 13.3 and 25.9°C (Table 2). The temperature doesn't have any effect on salinity variations the whole year. The salinity of the downstream samples from the Oum Er-rabia river was higher than that of the upstream. The average salinity at the upstream was 2.02 PSU while that of the downstream sample was 29.425 PSU (Fig. 2). However, pH reported along Oum Er-rabia river was alkaline in all samples, it ranges from 8.4 to 8.63 at S1 and S2; whereas, at S3 ranges from 7.84 to 8.

The DO level at the downstream was slightly higher than that of the upstream (Fig. 2). The average DO recorded at the upstream was 6.425 mg l⁻¹ while that of the downstream was 6.78 mg/L. Suspended matter (DM) determined in the Oum Er-rabia river at both the upstream and downstream have shown the concentrations at the upstream (94 mg l⁻¹) were higher than that of the downstream (0.026 mg l⁻¹). The concentrations of heavy metals factors including arsenic, lead, copper, cadmium and mercury vary between 0 and 0.65 mg l⁻¹ in winter and between 0 and 0.26 mg l⁻¹ in summer. The statistically analysis of upstream and downstream were

significant (Table 2). There was no significant difference between the mean temperature and dissolved oxygen of the water samples. The results show significant difference in the salinity between the upstream and downstream. The pH at the upstream was significantly higher than that downstream. The NH_4^+ values vary between 0 and 0.65 mg l⁻¹ in winter and between 0 and 0.26 mg l⁻¹ in summer. NH_4^+ values remain below the normal rate set by the Moroccan standards except in S2 located downstream dam. In this station higher value was recorded, indicating moderate to highly polluted river water. The concentration DM in the Oum Er-rabia river at both the upstream and downstream show DM at the upstream (94

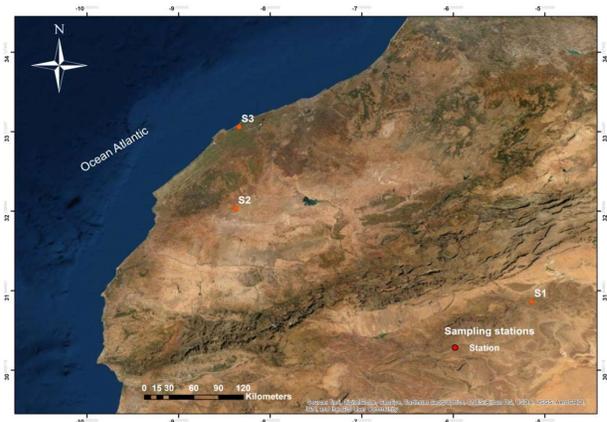


Fig. 1. A map showing the study area of the Oum Er-rabia river

Table 1. The water quality parameters and their analytical method in this study

Parameters	Analytical method	Unit
Temperature (T°)	Temperature probe	$^\circ C$
pH	Potentiometry/pH probe	
Salinity (S)	Hydrometer	PSU
Dissolved oxygen (DO)	Oximeter	mg O ₂ L ⁻¹
Ammonium (NH_4^+)	Spectrophotometry	mg L ⁻¹
Total phosphorus (ICP)	Spectrophotometry	mg L ⁻¹
Suspended matter (DM)	COD meter	mg O ₂ L ⁻¹
Zinc (Zn)	Flame atomic absorption spectrometry	mg L ⁻¹
Copper (Cp),	Flame atomic absorption spectrometry	mg L ⁻¹
Lead (Pb),	Flame atomic absorption spectrometry	mg L ⁻¹
Chromium (Cr),	Flame atomic absorption spectrometry	mg L ⁻¹
Cadmium (Cd),	Flame atomic absorption spectrometry	mg L ⁻¹
Mercury (Mr)	Flame atomic absorption spectrometry	mg L ⁻¹
Nickel (Ni)	Flame atomic absorption spectrometry	mg L ⁻¹

mg l⁻¹) were higher than that of the downstream (0.026 mg l⁻¹) but both were also lower (within acceptable threshold) than MG of 200 mg l⁻¹ and WHO threshold of 1000 mg l⁻¹.

Important factors in the quantitative balance of surface waters are precipitation and snowmelt. These factors have both quantitative and qualitative influences, mainly because of surface transport of sediment, pesticides, fertilizers etc. The rainfall in the Oum Er-rabia basin varies between 1100 mm on the Middle Atlas and 300 mm in the down river region with an average of 550 mm. Critical conditions may occur at the interactions of physical, chemical and biological characteristics of the receiving waters and pollutant loading sources. Such conditions can increase the adverse effects of a pollutant of concern (Syed et al 2006). DO concentrations along Oum Er-rabia basin at both the upstream and downstream were within the acceptable threshold of 5 mg l⁻¹ in comparison with the MG standard. Generally, summer is the critical period for low dissolved oxygen as increasing temperature reduces the dissolution of ambient DO in river water (Kumari et al 2013). Yang et al (2007) conjectured that the low DO values in summer were connected to the high activities of microorganisms requiring a lot of oxygen for metabolizing activities and for organic matters degradation. Water temperature increased as the water moves down stream and similar results were reported by El Morhit et al (2012) in downstream of Loukkos river (Maroc). In addition, Middle Atlas characterized by a humid cold climate, classified as Mediterranean mountain climate. Contrary to observations reported by Adiyiah et al (2013) along the River Tano in Ghana that water temperature on the other hand increased along the

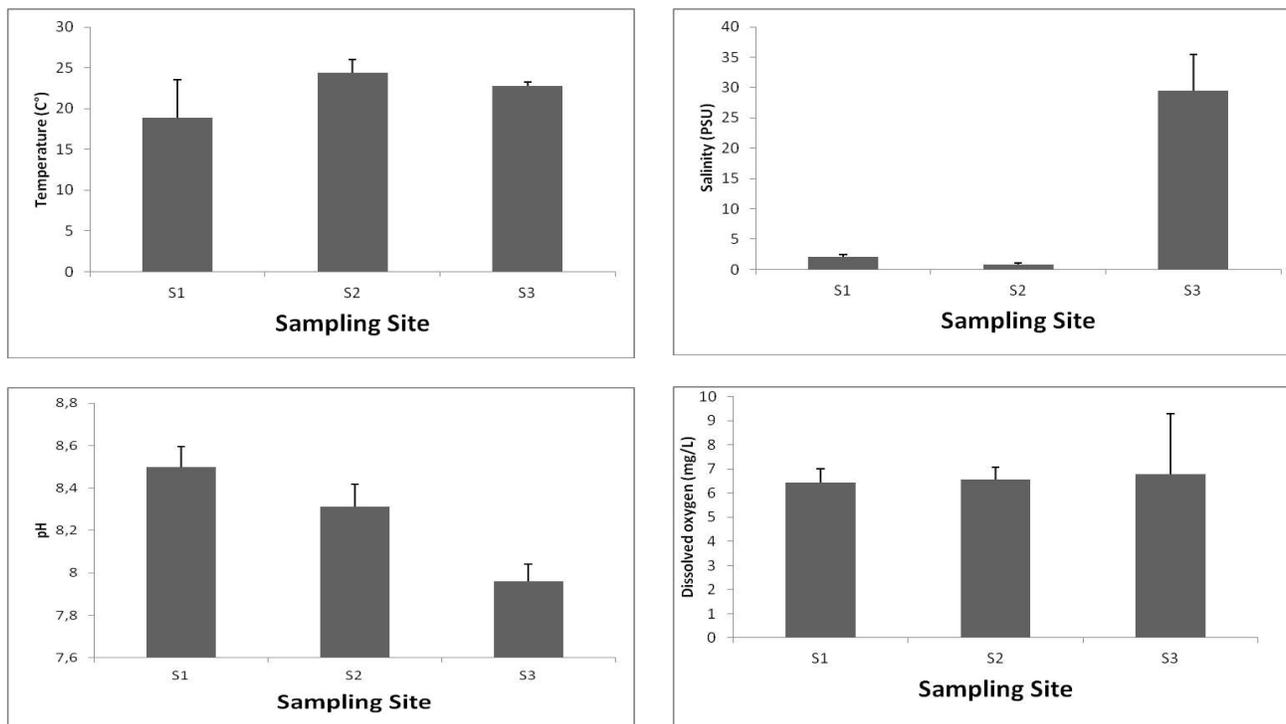
river course upstream throughout the sampling period and were observed to be higher upstream compared to the downstream. However, the temperature measured during the study period (at upstream and downstream) was statistically non-significant. The lower pH value at stations close to at the mouth point (S3) in summer was observed. The downstream samples recorded a minimum pH that is lower than that of the upstream. Generally, the recommended acceptable threshold for pH is 6.5 to 8.5 and 6.5 to 9.2, respectively for Moroccan surface water guidelines (2002) and the World Health Organization (WHO). The difference between the upstream pH and that of the downstream was relatively small. The higher pH values along Oum Er-rabia basin could be attributed to the release of alcalin forming substances such as sulphate, phosphate and nitrates into the water body. Phosphate might have entered the river through the detergents. Apart from these factors, the geology of the underlying rocks might have also contributed to the increased pH values observed. Both downstream and upstream salinity was outside the tolerable limits of the MG, the S2 has lower salinity than S1 which impacted by geological conditions. and S3 which influenced by ocean salinity. Moroccan surface water guidelines threshold limits for salinity at 0.055-0.408 and 0.408-0.724 PSU in upstream and downstream of many rivers (El Morhit et al 2012, Adiyiah et al 2013, Neissi et al 2019, Dunea et al 2020). NH₄⁺ values remain below the normal rate set by the Moroccan standards in both stations, except in S2 located downstream of the dam of Settat were higher than recorded. The possible explanation for higher value may due biodegradation of waste and inputs from

Table 2. Physico-chemical parameters analyzed at all stations

Parameters	22nd February 2015			15th May 2015			3rd August 2015			15th October 2015		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
T° (°C)	13.3	22.3	22	24.5	25,2	23	19,8	24,3	23	18	25,9	23
pH	8.48	8.25	8	8.63	8.38	8	8.49	8.2	7.84	8.4	8.42	8
S (PSU)	2.246	0.683	21	1.768	0.717	32.5	2.503	1.185	34.7	1.578	0.689	29.5
DO (mg L ⁻¹)	5.8	7.3	10	6.5	6.5	7.51	7.2	6.3	5.21	6.2	7.7	4.4
DM (mg L ⁻¹)	8	10	0.007	94	12	0.026	93	68	0.02	27	6	0.01
NH ₄ ⁺ (mg L ⁻¹)	<0.100	0.089	<0.100	0.154	0.65	<0.100	<0.100	0.246	<0.100	<0.100	<0.100	<0.100
ICP (mg L ⁻¹)	<0.15	<0.15	<0.15	0.32	0.25	<0.15	0.86	<0.15	<0.15	< 0.15	<0.15	<0.15
Zn (ml G ⁻¹)	0.06	<0.02	ND	<0.02	<0.02	ND	0.03	0.08	ND	<0.02	<0.02	ND
Cp (mg L ⁻¹)	<0.01	<0.01	ND	<0.01	<0.01	ND	<0.01	<0.01	ND	<0.01	<0.01	ND
Ld (mg L ⁻¹)	<0.0040	<0.0040	ND	<0.0040	<0.0040	ND	0.004	<0.0040	ND	<0.0040	<0.0040	ND
Cr (mg L ⁻¹)	<0.0040	<0.0040	ND	0.014	<0.0040	ND	0.02	<0.0040	ND	<0.0040	<0.0040	ND
Cd (mg L ⁻¹)	0.0011	<0.0010	ND	<0.0010	<0.0010	ND	0.001	<0.0010	ND	<0.0010	<0.0010	ND
Mr (mg L ⁻¹)	<0.0001	0.0002	ND	<0.0001	<0.0001	ND	<0.0001	<0.0001	ND	<0.0001	<0.0001	ND
Ni (mg L ⁻¹)	0.01	<0.00	ND	0.01	<0.00	ND	0.01	<0.00	ND	<0.00	<0.00	ND

Table 3. Results of an analysis of variance -one-way ANOVA

Sites	T	pH	S	DO	F	p	
S1/S2	0.05311	0.04759	0.8784	0.9894	T	3.991	0.05744
S1/S3	0.1887	0.0002231	0.0001838	0.9422	pH	34.14	6.281E-05
S2/S3	0.6919	0.001398	0.0001835	0.9803	S	86.47	1.332E-06
				DO	0.0549	0.9469	

**Fig. 2.** Averaged values for temperature, salinity, pH and dissolved oxygen measured for up and down streams of Oum Er rbia River

domestic, agricultural and industrial (Koukal et al 2004, Houti et al 2014). However, the values are in range of good quality water.

CONCLUSION

The estimation of the quality of surface water is complex due to spatial and temporal variations in water quality, could provide an overview of the temporal condition as well as seasonal and geographical evolution of the ecosystem. In the current case, the water surface in the region has good water quality. Nevertheless, several explanations can be suggested to account for the observed physicochemical improvement at all sites. such as dilution of contaminated Oum Er-rabia River water by uncontaminated water provide by the precipitation in winter season. More likely that most of the pollutants have been deposited in bottom sediments. It is expected that bottom sediments in this area would have elevated metal concentrations and some additional sampling. River bottom sediments in the area would be necessary to assess the extent

as well as the potential remobilization of this contamination.

REFERENCES

- Abbou F and Fahde A 2017. Bio-evaluation of water quality of the middle sebou by application of biotic indexes. *Larhyss Journal* **30**: 239-252.
- Badu M., Wemegah DD, Boadi NO and Brown FA 2013. Assessment of the nutrient load and selected heavy metals in the Owabi Reservoir and its Feeder waters. *American Journal of Scientific and Industrial Research* **4**(4): 337-343.
- Banunle A, Fei-Baffoe B and Otchere KG 2018. Determination of the physico-chemical properties and heavy metal status of the Tano river along the catchment of the Ahafo mine in the BrongAhafo Region of Ghana. *Journal Environ Anal Toxicol* **8**(3): 23-28.
- Dixon W and Chiswell B 1996. Review of aquatic monitoring program design. *Water Research* **30**: 1935-1948.
- Dunea D, Bretcan P, Tanislav D, Serban G, Teodorescu R, Iordache S, Petrescu N and Tuchi E 2020. Evaluation of water quality in Ialomita River basin in relationship with land cover patterns. *Water* **12**: 735.
- Elayaraj B and Selvaraju M 2015. Seasonal variations in physico-chemical parameters of Sri Kamatchiamman Temple Pond Chidambaram Taluk. Tamilnadu. *J Environ Treat Tech* **3**(2): 126-133.
- El Morhit M, Fekhaoui M, Serghini A, El Blidi S, El Abidi A, Yahyaoui A

- and Hachim M 2012. Étude de l'évolution spatio-temporelle des paramètres hydrologiques caractérisant la qualité des eaux de l'estuaire du Loukkos (Maroc). *Bulletin de l'Institut Scientifique. Rabat Section Sciences de la Vie* **34**(2): 151-162.
- El Baghdadi M, Oumeskou H, Barakat A, Nadem S and Rais J 2015. Effet de la Décharge publique de la ville de Béni-Mellal sur les Sédiments et les Sols au niveau d'Oued Sabeq. *Journal of Materials and Environmental Science* **6**(11): 3371-3381.
- Gao X, Zhou F and Chen CTA 2014. Pollution status of the Bohai Sea: An overview of the environmental quality assessment related trace metals. *Environnement International* **62**: 12-30.
- Hayzoun H, Garnier C, Durrieu G, Lenoble V, Le Poupon C, Angeletti B and Mounier S 2015. Organic carbon and major and trace element dynamic and fate in a large river subjected to poorly-regulated urban and industrial pressures (Sebou river, Morocco). *Science of the Total Environment* **502**: 296-308.
- Houti A, Benbrahim KF, El oualilalami A, Zbadi L and Rachiq S 2014. Qualité physicochimique et bactériologique de trois stations thermales dans les régions de Fès. Maroc. *Afrique Science* **10**(4): 158-168.
- Hulyal SB and Kaliwal BB 2011. Seasonal variations in physico-chemical characteristics of Almati Reservoir of Bijapur district Karnataka State. *International Journal of Environmental Protection* **1**(3): 58-67.
- Jackson A, Helena AL and Mike AA 2013. Comparative assessment of the upstream and downstream water qualities of river Tano in Ghana. *Journal of Environmental Science and Engineering A2*: 283-292.
- Kazi TG, Arain MB, Jamali MK, Jalbani N, Afridi HI, Sarfraz RA, Baiga JA and Shaha Abdul Q 2009. Assessment of water quality of polluted lake using multivariate statistical techniques. A case study. *Ecotox Environ Safe* **72**: 301-309.
- Koukala B, Dominika J, Vignatia D, Arpagausa P, Santiagoc S, Ouddaned B and Benaabidate L 2004. Assessment of water quality and toxicity of polluted Rivers Fez and Sebou in the region of Fez (Morocco). *Environmental Pollution* **131**: 163-172.
- Kumar M, Ramanathan A, Rao MS and Kumar B 2006. Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India. *Environmental Geology* **50**: 1025-1039.
- Martin J 1982. Le Moyen Atlas central: Etude géomorphologique. *Notes et Mémoires du Service géologique du Maroc. n°258 bis* **70**: 444.
- Mendiguchía C, Moreno C, Galindo-Riaño MD and García-Vargas M 2004. Using chemometric tools to assess anthropogenic effects in river water: A case study: Guadalquivir River (Spain). *Analytica Chimica Acta* **515**(1): 143-149.
- Moroccan Standards for surface water Quality 2002. *Official Bulletin No 5062*. http://www.sgg.gov.ma/BO/bulletin/Fr/2002/BO_5062_fr.PDF. Accessed 01.01.
- Mourhir A, Rachidi T and Karim M 2014. River water quality index for Morocco using a fuzzy inference system. *Environmental Systems Research* **3**(1): 1-12.
- Nadem S, El Baghdadi M, Rais J and Barakat A 2015. Evaluation de la contamination en métaux lourds des sédiments de l'estuaire de Bou Regreg (Côte atlantique, Maroc). *Journal of Materials and Environmental Science* **6**(11): 3338-3345.
- Neissi L, Tishehzan P and Albaji M 2019. Évaluation chimique de la qualité des eaux de surface en amont et en aval du barrage de Jare. Khuzestan. Iran. *Environmental Earth Science* **28**: 78-83.
- Pan J, Pan JF and Wang M 2014. Trace elements distribution and eco-logical risk assessment of seawater and sediments from Dingzi Bay, Shandong Peninsula, North China. *Marine Pollution Bulletin* **89**: 427-434.
- Reghunath R, Murthy TRS and Raghavan BR 2002. The utility of multivariate statistical techniques in hydrogeochemical studies: an example from Karnataka, India. *Water Research* **36**: 2437-2442.
- Syed AT and Jodoin RS 2019. Estimation of nonpoint-source loads of total nitrogen total phosphorous and total suspended solids in the Black Belle and Pine River basins, Michigan, by use of the PLOAD model. In U.S. *Geological Survey Scientific Investigations Report* **42**: 2006-5071.
- Simeonov V, Simeonova P and Tsitouridou R 2004. Chemometric quality assessment of surface waters: Two case studies. *Chem Eng Ecol* **11**: 449-469.
- Signh RP and Mathur P 2005. Investigation of variation in physicochemical characteristics of a freshwater reservoir of Ajmer city, Rajasthan. *International Journal of Environmental Science and Technology* **9**: 57-61.
- Tong S and Chen W 2002. Modelling the relationship between land use and surface water quality. *Journal of Environmental Management* **66**: 377-393.
- Wang YB, Liu CW, Liao PY and Lee JJ 2014. Spatial pattern assessment of river water quality: Implications of reducing the number of monitoring stations and chemical parameters. *Environmental Monitoring and Assessment* **186**(3): 1781-1792.
- Yang H, Shen Z, Zhang J and Wang W 2007. Water quality characteristics along the course of the Huangpu river, China. *Journal of Environmental Sciences* **19**(10): 1193-1198.



Groundwater Quality Analysis using WQI for Sahibabad (Uttar Pradesh)

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Abstract: In the study, an attempt has been made to find physicochemical properties of groundwater samples for Sahibabad Region of NCR, for Ghaziabad District of Uttar Pradesh. To find out the groundwater quality total 10 samples have been collected and tested. Total seven parameters, namely pH, conductivity, turbidity, residual chlorine, total dissolved solids, chloride and fluoridewere determined. Water quality index (WQI) has been determined by weighted arithmetic water quality index method. WQI shows that samples fall in the excellent water quality whereas 5 samples fall in good water quality. Only one sample falls in the poor quality of water category. The overall water quality for the region shows water is acceptable for drinking use.

Keywords: Groundwater, WQI, Weighted arithmetic mean method, Water quality

Groundwater is stored in and moves slowly through geological formations of soil, rocks and sand. Precipitation and surface water recharge is the main source of groundwater (Chakraborty et al 2016, Patil et al 2020). Industrial, commercial, municipal and agricultural activities all can affect groundwater quality. Contamination in groundwater is main cause for poor drinking water quality and loses of water supply. Due to increasing demand of groundwater, it is under threat in north-west India (Lapworth et al 2014, Chopra and Krishna 2014). Water quality index (WQI) used to expresses overall water-quality in a single number at any location and time which is based on different water quality parameters (Singh et al 2016, Solangi et al 2019).

Due to groundwater importance as a source of water supply, WQI have been extensively studied by different researchers and good treaties are available. Boateng et al (2015) used an approach and WQI for groundwater quality assessment for Ejisu-Juben Municipality of Ghana. Krishan et al (2016) used WQI for assessment of quality of groundwater for drinking purpose in Shamli and Muzaffernagar Districts of UP (India). Based on total five parameters (pH, total dissolved solids, hardness, chloride and sulphate), the result showed overall water quality class is good. Khan and Jhariya (2017) observed groundwater quality for drinking purpose using GIS and WQI in Raipur City of Chhattisgarh. Authors collected total 34 samples and 76% of samples were under excellent, very good and good quality whereas 24% of water samples were under poor & very poor quality. Abbasnia et al (2019) evaluated groundwater quality using WQI for drinking as well as for irrigation purpose for

Sistan and Baluchistan City of Iran. The result of the studied shows that for drinking purpose 1.2% sample fall in excellent quality, 52.1% as good, 39% as poor and 6% as very poor where as 1.7% samples were unsuitable for drinking. For irrigation purpose, 19.9% and 80.1% samples were in excellent and good classes respectively. As the Sahibabad is an industrial area of NCR, there is a need to study for evaluation of groundwater quality. This study was carried out with the aim to calculate different physicochemical properties of groundwater sample and based on these parameter obtained WQI for drinking purpose.

MATERIAL AND METHODS

The study was carried out at Sahibabad, NCR region of Ghaziabad District in Uttar Pradesh State, India. Sahibabad area located at 28°39' N and 77°50' E, 207 m above mean sea level. The average annual temperature of the area is 25°C and annual rainfall is 796 mm.

Methodology: The total 10 samples were collected from different location of Sahibabad (Table 1). All the collected samples of groundwater were analysed according to standard method of examinations for 7 physicochemical parameters. pH meter, conductivity meter, turbidity meter and TDS meter have been used to determine pH value, conductivity, turbidity and total dissolved solids in samples respectively. Fluoride and residual chlorine have been determined by color matching technique. Chloride has been determined by titration technique. Water quality parameters as per BIS: 105000-2012 used in the study (Table 3).

Water Quality Index: To determine the WQI value for different sample weighted arithmetic water quality index

classification, total 4 samples fell under excellent quality and 5 samples fell into good quality of water. One tested sample of groundwater was in poor water quality.

CONCLUSIONS

The total 9 of samples are fit for drinking purpose where as one sample is poor in quality. In Sahibabad region, continuous monitoring of groundwater is important in future due to established and growing industrialization in the area. The overall water quality of the region shows groundwater is suitable for drinking purpose. Continuous monitoring and awareness at industries are required to improve public health in this area.

REFERENCES

- Abbasnia A, Youssef N, Mahdi AH, Nabizadeh R, Radfard M, Yousefi M and Alimohammadi M 2019. Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: Case study of Sistan and Baluchistan province (Iran). *Human and Ecological Risk Assessment: An International Journal* **25**(4): 988-1005.
- Akter T, Jhohura FT, Akter F, Chowdhury TR, Mistry SK, Dey D and Rahman M 2016. Water Quality Index for measuring drinking water quality in rural Bangladesh: A cross-sectional study. *Journal of Health, Population and Nutrition* **35**(1): 1-12.
- BIS (Bureau of Indian Standards) 2012. *Specification for drinking water IS 10500:2012*, New Delhi, India.
- Boateng TK, Opoku F, Acquaaah SO and Akoto O 2016. Groundwater quality assessment using statistical approach and water quality index in Ejisu-Juaben Municipality, Ghana. *Environmental Earth Sciences* **75**(6): 489-502.
- Chakraborty S and Kumar RN 2016. Assessment of groundwater quality at a MSW landfill site using standard and AHP based water quality index: A case study from Ranchi, Jharkhand, India. *Environmental Monitoring and Assessment* **188**(6): 335-348.
- Chauhan A and Singh S 2010. Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. *Report and Opinion* **2**(9): 53-61.
- Chopra RPS and Krishan G 2014. Assessment of groundwater quality in Punjab. *Journal of Earth Science and Climate Change* **5**(10):1-3.
- Khan R and Jhariya DC 2017. Groundwater quality assessment for drinking purpose in Raipur City, Chhattisgarh using water quality index and geographic information system. *Journal of the Geological Society of India* **90**(1): 69-76.
- Krishan G, Singh S, Kumar C, Garg P, Suman G, Ghosh NC and Chaudhary A 2016. Assessment of groundwater quality for drinking purpose by using water quality index (WQI) in Muzaffarnagar and Shamli Districts, Uttar Pradesh, India. *Hydrology Current Research* **7**(227): 1-4.
- Lapworth DJ, MacDonald AM, Rao MS, Goddy DC and Darling WG 2015. Groundwater recharge and age-depth profiles of intensively exploited groundwater resources in northwest India. *Geophysical Research Letters* **42**: 7554-7562.
- Nas B and Berkta A 2010. Groundwater quality mapping in urban groundwater using GIS. *Environmental Monitoring and Assessment* **160**(1-4): 215-227.
- Patil VBB, Pinto SM, Govindaraju T, Hebbalu VS, Bhat V and Kannanur LN 2020. Multivariate statistics and water quality index (WQI) approach for geochemical assessment of groundwater quality: A case study of Kanavi Halla Sub-Basin, Belagavi, India. *Environmental Geochemistry and Health* **2020**: 1-18.
- Rodell M, Velicogna I and Famiglietti JS 2009. Satellite based estimates of groundwater depletion in India. *Nature* **460**(7258): 999-1002.
- Singh S and Hussian A 2016. Water quality index development for groundwater quality assessment of Greater Noida sub-basin, Uttar Pradesh, India. *Cogent Engineering* **3**(1): 117-125.
- Solangi GS, Siyal AA, Babar MM and Siyal P 2019. Groundwater quality evaluation using the water quality index (WQI), the synthetic pollution index (SPI), and geospatial tools: A case study of Sujawal district, Pakistan. *Human and Ecological Risk Assessment: An International Journal* **19**:1-21.
- Tyagi S, Sharma B, Singh P and Dobhal R 2013. Water quality assessment in terms of water quality index. *American Journal of Water Resources* **1**(3): 34-38.
- Yogendra K and Puttaiah ET 2008. Determination of water quality index and suitability of an urban water body in Shimoga Town, Karnataka. In *Proceedings of Taal2007: The 12th World Lake Conference* **342**: 346-354.



Estimate of Cd, Pb and Physico-Chemical Properties in Soils of Kani-qrzhalala Dumpsite in Erbil, Kurdistan Region of Iraq

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Abstract: The present study was designed for the estimation pollution status by two heavy metals cadmium, lead and the variation in physico-chemical characteristics of the soil samples taken from an open dumpsite in Kani-Qrzhalala - Erbil. (Latitude 36°13' N, longitude 43°58' E). Soil samples selected at different depths (0-10, 10-20 and 20-30 cm) were collected randomly at the dumpsite field with one sample as a control. The soil samples were analyzed for physico-chemical parameters and contaminated metals by cadmium and lead. The samples of dumpsite had higher silt and lower sand contents in comparison with the control site. The soil pH varied between 7.2 - 7.7 in the dump. The highest organic matter was (25 mg kg⁻¹ in dump soils. The levels of Pb, Cr, Cd and Ni ranged from 90.11-140.08, 1.05- 1.24, 0.95 -2.98 and 9.63 -11.8 mg kg⁻¹ in the dump and 12.08-28.83, 0.084-0.100, 0.10-0.73 and 7.61-8.00 mg kg⁻¹ in the control. All values of the heavy metals obtained in the study area were below the maximum allowable limit of soils used for farming purpose. Results of the simple geoaccumulation index (I_{geo}) for Pb, Cr, Cd and Ni indicated that the soil qualities were generally are under the class (1) uncontaminated status, but limited sampling sites fell in class 5, highly polluted index

Keywords: Heavy metals, Dumpsite soils, Physicochemical Properties, Igeo

The rapid increase in the recent years of the volume, type of solid waste and hazards waste generated in Kurdistan region especially in Erbil governorate mainly due to the economic growth and urbanization is observed. This flux is not treated or disposed in norms that can prevent pollution. In Erbil governorate, owing to the lack of awareness, all types of waste, especially solid waste including hazardous waste are often mixed with domestic wastes and disposal. The environment pollution by toxic metals characteristics of Cd, Cr, Ni, and Pb has become a worldwide disaster, affecting agriculture products and promoting to bioaccumulation and biomagnifications in the food chain. Certain toxic metals can abide in the environment for a long time and may induce course bioaccumulation of higher concentrations that may affect human health (Dipu et al 2011). Garbage dumps are commonly unhygienic and make up places in which malady-carrying infestation such as flies and rats grow rapidly (Bellebaum 2005). Different gases such as methane are released into the adjoining air as putrefy by microorganisms of the solid wastes and pollute the air by fires with pungent smoke and other scores of inconsistent. Liquids that flow and trickle in the course of the solid waste stack ultimately pollute the soil, surface water and ground water. Perilous resources like pesticides, trace elements, hydrocarbons that are disintegrating in this liquid frequently contaminate water and soil (Adelekan and Alawode 2011). Anikwe and Nwobodo (2002) recommended that incessant dumping of urban waste

on soil may augment in heavy metals in the surface water and soils that would be unfavorable to profound consuming plants. Heavy metals such as lead, chromium, cadmium, mercury, and nickel are of serious and foremost concern because of their harm plants, animals and soil organisms (Adelekan and Abegunde 2011, Brady et al 2014, Pan et al 2016, Weissmannova and Pavlovsky 2017, Ahmed and Khoshnaw 2019, Mwstefa and Ahmed 2019). The landfills management in Kurdistan region was poorly regulated and was not by the strategy of sustainable development. Moreover, there were almost limited studies and information about the environmental status of the landfill as a source of pollution. Therefore, this study aims to study the impacts of the refuses on some physicochemical properties of surrounding soils at three different depths from the landfill source and investigate the impacts of the mentioned landfill refuse on the levels of the metals in the same soil samples by applying the Geo-accumulation index (I_{geo}).

MATERIAL AND METHODS

Study area: Erbil, the capital city of Kurdistan region, the town is located in a arid to semi arid area with mean yearly rainfall of about 250 mm. Dump field investigated is located at the west of Erbil city lies between latitude 36°13' North and longitude 43°58' East, at the road of Erbil-Mosul governorate and is an open dump area for all of wastes (domestic, commercial, industry, and wastes from hospitals and clinics)

together without any segregation before dumping.

Soil sampling: After removing the overlying wastes of surface soil samples, were randomly collected from the deposit field at divergent depths of 0-10, 10-20 and 20-30 cm. The control sample collected at the same depths, from unfarmed land at 100 m away from the landfill. The soils were air dried ground and sieved through a 2 mm, and kept until use.

Determination of some physico-chemical properties of soil samples: Particle size distribution was determined by Hydrometer method (Rowels 1996). Soil pH was measured in soil extraction (1:5) using HANNA pH meter, model pH211 microprocessor pH meter (Jackson 1958). Organic matter was determined by the modified (Walkley and Black method) as described by Jackson (1958). Total Calcium Carbonate (CaCO_3) which involves the dissolution of carbonate in HCl (2M), followed by back titration with (0.1M) NaOH as described in Rowell (1996). The evaluation of soil contamination by heavy metals, Geoaccumulation index (I_{geo}), was calculated (Kowalska et al 2016)

Geo-accumulation index (I_{geo}) = $\log_2 C_i / (C_{ig} * 1.5)$ (1)

Where C_i is the measured concentration of the studied metal in the surface soil

C_{ig} is the geochemical background concentration or reference value of the metal, and

1.5 is constant that is used for litho logic variations of the heavy metal.

I_{geo} index can compare between the present and past pollution levels. Furthermore, I_{geo} index uses the multiplication factor of (1.5) to minimize the possible variation of lithogenic effects. However, I_{geo} index has also many weak points such as in case of using incorrect geological background (BG), unreliable results will be obtained, possible natural fluctuation within the geological background (BG) will also lead to mistaken results, and dismissing the possible capability of another present heavy metal for causing pollution Kowalska(et al 2016). Forstner et al (1993) have classified the geo-accumulation index into seven intensity classes and they are as follow: $I_{\text{geo}} \leq 0$ named as class 0 or uncontaminated; $0 < I_{\text{geo}} \leq 1$ called class 1 or uncontaminated to moderately contaminated; $1 < I_{\text{geo}} \leq 2$, termed class 2 or moderately contaminated; $2 < I_{\text{geo}} \leq 3$ named class 3 or moderately to strongly contaminated; $3 < I_{\text{geo}} \leq 4$ is termed as class 4 or strongly contaminated; $4 < I_{\text{geo}} \leq 5$ is considered as class 5 or strongly to very contaminated, and finally $I_{\text{geo}} > 5$ is regarded as class 6 or very strong contaminated.

Preparation of soil samples and heavy metals analyses: 0.5 gram of less than 0.5 mm size diameter air dry soil from

each samples was digested by mixed acid thoroughly using the nitric/ perchloric procedure, after appearance of white fumes, the digested samples were diluted and filtered and finally the volume were completed to 50 ml, a comprehensive description of this digestion method (Hseu et al 2002). The heavy metals concentrations such as Pb, Cr, Ni and Cd were determined using atomic absorption spectrophotometer (Alpha-4) after preparation of appropriate calibration standards. All samples were digested and analyzed in replicate.

RESULTS AND DISCUSSION

Physico-chemical characteristics of the studied Soil.

Soil Textural properties: The soil texture classes had higher silt and lower clay and sand contents in comparing with the control site which consists of fairly high clay parts, thus they display flexibility and hold up surface water flooding and contamination. This clay loamy to clayey texture of the control soils samples also favors leacheates and low permeability of water (Ahn 1993).

Hydrogen ion concentration (pH value): The pH in dumpsite varied from 7.2-7.7 against 7.6 in the control sample indicating a neutral reaction (Table 1).

Soil organic matter: Total organic matter presence in the soils ranged from low to moderate (Table 1). The content of organic matter in the dumping site soil varied from 13.81 to 25.85 g kg^{-1} against 15.99 in control. The soils of garbage dump clutch high quantity of organic matter at two locations and this may be due to the type of source of plant residues.

Total heavy metals concentrations (mg kg^{-1}) in soils regarding different soil depths:

The heavy metals Pb, Cd, Cr and Ni concentrations were much higher in the entire dumping site than control samples (100 m) away from the landfill area. The depths affected of heavy metal concentration which varied significantly with depth. The concentration of heavy metals in the soil of dump sites was limited to the top 15 cm.

Lead (Pb): The mean values of Pb in the landfill soil samples ranged 90.11-140.08 mg kg^{-1} against 12.87-28.83 mg kg^{-1} in control. The Pb was higher than observed by Koaser (2003), with the highest value of 14.2 mg kg^{-1} and the maximum allowable limits proposed for farmland soils 15 mg kg^{-1} of uncontaminated soils (Kabata-Pendias and Pendias 2011) and higher than the standard background rate of 10 mg kg^{-1} reported by Alloway (1995). This is in conformity with the results obtained from similar modification by Umoh and Etim (2013) for soils from dumpsites. Concentration of lead in the soils from both areas should be as a result of batteries dry cell, sewage waste water, atmospheric depositions of wastes and runoff. The sampling depth caused a significant

decrease on the total concentration of Pb in soil samples, the decrease of Pb under the effect of depth may be due to the heavy metals characteristics (Fig. 1). The characteristics localization of Pb near the soil surface in most soil samples is primarily related to surface accumulation of organic matter and an organic matter should be considered as an important sink of Pb polluted soils (Sheng Lu et al 2008). The highest value of lead ($140.08 \text{ mg kg}^{-1}$) was from (L_3D_1) and in depth (0-10 cm) and may be as a result of long term waste disposal because the waste disposed contained several sources of lead such as cans, fuels, pigments, wheels, and chemicals. Traunfeld and Clement (2001) identified that lead accumulated in the upper (20 cm) of the contaminated soil and is highly immobile. Ahmed (2012) observed that highest amount of Pb accumulated at surface soil. The lowest value of lead (90.11 mg kg^{-1}) was from the (L_1D_3) may be due to mobility which could not be easily leached to bottom layer and physical properties of the soil and soil pH value (Al-Khashman and Shawabkeh 2006). Al Farraj and Al Wabel (2007) also observed that the heavy metals concentration decrease with increasing soil depth. There results indicates that the maximum amount of Pb was concentrated on the soil

surface, Miclean et al (2009) reported that lead is especially accumulated in surface horizon of soil because its low water solubility within an environmentally relevant pH range results in very low mobility. Soil polluted at the surface with Pb deposits from aerial contamination show little indicators of metal leaching over many years. However, Al-Farraj and Al-Wabel (2007) indicated that the concentration of heavy metal decrease with increasing the depth.

Chromium (Cr): The average concentrations of Cr in the soil dumpsite various between $1.05 - 1.24 \text{ mg kg}^{-1}$, highest value of chromium was from (L_1D_3) while the lowest value of chrome was from the (L_3D_1). The values slightly higher than control sample ($0.084 - 0.10 \text{ mg kg}^{-1}$), but are at a standstill lower than the vital permissible level of 50 mg kg^{-1} for farmland soils recommended by MAFF (1992) and in agreement with the maximum allowable limit ($0.6 - 3.4 \text{ mg kg}^{-1}$) of Kabata - Pendias and Pendias (2011). Wastes consisting of lead-chromium batteries, colored polythene bags, discarded plastic materials and empty paint containers could be due to the sources of Cr in the soils.

Cadmium (Cd): The mean concentration of cadmium in the dumpsite soil samples were $0.95 - 2.09 \text{ mg kg}^{-1}$ (Fig. 3) and are

Table 1. Some physicochemical properties of the soils

Location No.	pH	O.C*	O.M*	T.CaCO ₃ *	Particle size distribution*			Soil Texture
					Sand	Silt	Clay	
1	7.7	14.86	25.85	268	197	533	270	Silty clay loam
2	7.6	13.41	23.33	271				
3	7.2	7.93	13.81	262				
4 (Control)	7.6	9.19	15.99	200	322	386	292	Clay loam

O.C- Organic carbon, O.M- Organic matter. * in g kg

Table 2. Concentration of heavy metals at different depths of soil (mg kg^{-1})

Locations and depths	Depths (cm)	Cd	Cr	Ni	Pb
L1D1	0-10	1.98	1.18	10.7	120.48
L1D2	10-20	2.07	1.23	11.7	94.27
L1D3	20-30	2.09	1.24	11.8	90.11
L2D1	0-10	0.95	1.11	10.0	133.81
L2D2	10-20	0.96	1.15	9.84	110.11
L2D3	20-30	1.31	1.17	9.63	108.91
L3D1	0-10	1.45	1.05	9.82	140.08
L3D2	10-20	1.52	1.13	10.5	133.2
L3D3	20-30	1.54	1.12	10.1	111.98
L4D1	0-10	0.73	1.00	8.00	28.83
L4D2	10-20	0.22	0.096	7.85	18.98
L4D3	20-30	0.10	0.084	7.61	12.78

L= Locations; D= Depths

with normal limits of 0.01-3.0 mg kg⁻¹ in soil MAFF (1992). The high level of cadmium (2.09 mg kg⁻¹) was from (L₁D₃) may be due to increase the mobility of cadmium by the effect of rain fall that cause leaching Cd from top layer or due to decreasing soil pH (Wuana and Okieimen 2011), while the lowest value of cadmium (0.95 mg kg⁻¹) was obtained from the (L₂D₁) and this may be due to geochemical properties of soil such as pH, organic matter, and inorganic legends. In addition Cd known as more mobile and highly soluble than other heavy metals. Cadmium in soil was not strongly affected by soil organic matter, but cadmium existed in solution as a free divalent cation (Cd²⁺) or with inorganic legends' Cl⁻, SO₄²⁻, or HCO₃⁻. The compound formation between metals and inorganic compounds Cl⁻ and SO₄²⁻ prevent the adsorption of Cd on soil and this may be due to the creation of cadmium complexes that were not strongly adsorbed by soil. Cadmium is precipitate as CdCO₃ or co-precipitate with CaCO₃ with resulting decrease in solubility/availability when soil pH > 7 (Saha et al 2017). Ahmed (2012) mentioned the highest value of Cd was accumulated at surface layer, while the lowest value recorded at bottom layer. The Cadmium values in the MSW soils at the locations study were in the allowable limits of Cd in the soils (EU 2006). **Nickel (Ni):** Nickel concentration in the landfill soils ranged from 9.63 to 11.80 mg kg⁻¹ slightly higher than the control soil samples (7.6-8.00 mg kg⁻¹) and results were located at the allowable limit (5-500 mg kg⁻¹ soil) of nickel according to Allen

et al (1974) and less than with the permissible range in United State (13-30 mg kg⁻¹ soil) (McBride, 1994). The highest value of nickel (11.8 mg kg⁻¹) was in L₁D₃. This may be due to soil contamination with different sources of nickel as a result of anthropogenic activities which leads to release higher level on nickel to the soil. Esakku et al (2003) observed that higher levels of heavy metals at the middle layer may be due to the downward migration of leacheates. The higher level of metals (Ni, Cd, Pb and Zn) occurred in MSW. The lowest value of nickel (9.63 mg kg⁻¹) was obtained from the (L₂D₃) and this low value may be due to high level of Fe and Mn oxides and a part of soil nickel occluded in Fe and Mn oxides also seems to be available to plant roots (Saha et al 2017). Ahmed (2012) was recorded lowest amount of Ni at bottom layer. The nickel concentration in MSW soils of the present study ranged from 96.3-11.80 mg kg⁻¹ and were in the range with the permissible limits of Ni in the soils (EU 2006). The highest values of Cd, Cr and Ni (2.09, 1.24 and 11.8 mg kg⁻¹) were from d₃, while the lowest 0.95, 1.05 and 9.63 mg kg⁻¹ from surface soils (d₁ and d₂) (Figure 4). These results agree with Das (2005) and Esakku et al (2003). The concentration of heavy metals both in natural and in converted soil at varying depth does not follow any specific trend. The concentration of some parameters increased with increasing depth and other parameters decreased with depths since the concentration does not follow any regular trend (Mamtaz and Chowdhury 2008). These results may be due to the single

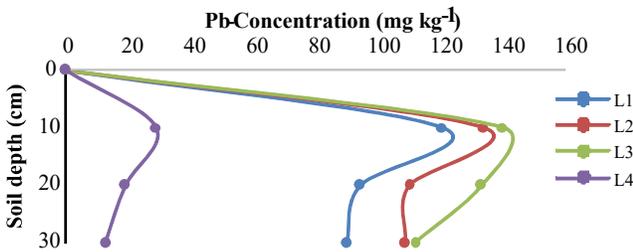


Fig. 1. Variation of Pb concentration in various plots and in different depths

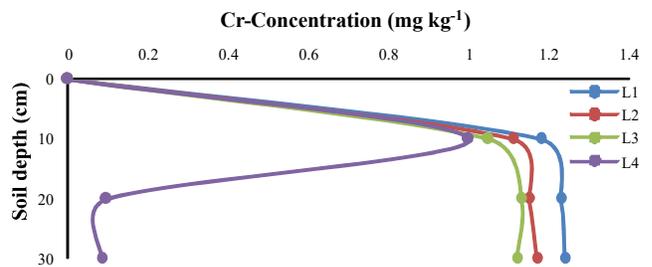


Fig. 2. The variation of Cr concentration in various plots and in different depths

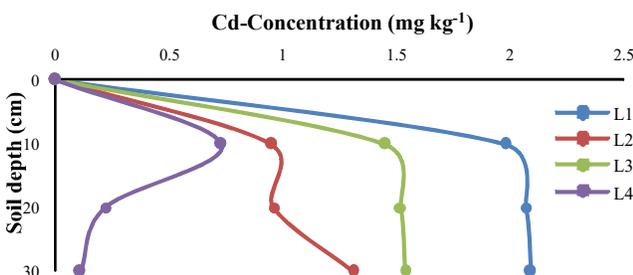


Fig. 3. Variation of Cd concentration at different depths

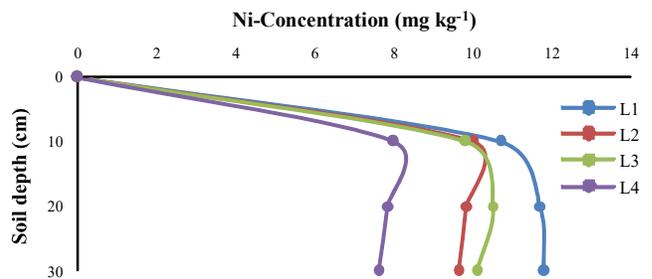


Fig. 4. Variation of Ni concentration at different depths

Table 3. Geoaccumulation index (I_{geo}) of metals in the soils

Locations no.	Cd	Cr	Ni	Pb
1	2.15	0.30	0.63	3.09
2	0.57	0.22	0.48	3.32
3	1.48	0.10	0.44	3.44
4	0.00	0.00	0.00	0.00

Table 4. Metal contamination in Kani - Qrzhalah soil based on I_{geo}

Station/ Items	Cd	Cr	Ni	Pb
1	4	1	1	5
2	1	1	1	5
3	3	1	1	5
4	0	0	0	0

Uncontaminated 1. Uncontaminated to moderate 2. Moderate 3. Moderate to strong, 4. Strong 5. Strong to very strong 6. Very strong

effect of the study factors since the combination between two factors or more may create different environmental condition. All values of heavy metals in the control samples observed the highest values of Pb, Ni, Cr and Cd (28.83, 8.0, 0.10 and 0.73 mg kg⁻¹) at the depth of 0-10cm of soil dumpsite and the lowest of 12.87, 7.61, 0.084 and 0.10 mg kg⁻¹ were at 20-30 cm

Indices assessment of soil heavy metals pollution: The Geoaccumulation Index (I_{geo}) for Pb, Cr, Ni, and Cd in landfill soil (I_{geo}) revealed that 11 values out of 16 (68% of the sampling sites) had values $0 < I_{geo} < 1$ indicating that those sampling sites are still unpolluted to moderately polluted (Simeon and Friday 2017) (Table 3). At sampling sites of location 3 of Cd estimated index of geo-accumulation was in class 3 ($1 < I_{geo} < 2$ (moderately polluted) and at location 1 of Cd of the estimated index of geo-accumulation fell in class 4 ($2 < I_{geo} < 3$ (moderately to high pollute). The index values of 16 (18.75% of the sampling sites) had values (3-4) indicating that those sampling sites are still high polluted soil. I_{geo} as a simple index cannot covers the effects of the whole studied metal in composed form, short working period and production of the dumpsites.

CONCLUSION

The Kani - qrzhalah refuges effects on soil properties such as increasing the heavy metals concentration at study area. The pollution level was placed under uncontaminated to highly contaminated classes depending on the value of Geoaccumulation index of the soil samples. The heavy metals concentrations in the affected area were higher in comparing with the control samples. The depth effects on the distribution of heavy metals and some of the heavy metals increased with depth and distance while others were

decreased. The metals such as Pb has very high polluted and Cd and Ni have moderate polluted while Cr has have unpolluted to moderate polluted status.

REFERENCES

- Adelekan BA and Abegunde KD 2011. Heavy metals contamination of soil and groundwater at automobile mechanic villages in Ibadan Nigeria. *International Journal of Physical Science* **6**(5): 1045-1058.
- Ahmed IT 2012. *Application of Chemical and Spectral Analysis Techniques for Assessing Soil Pollution by Some Heavy Metals in Selected Sites of Erbil City, Iraqi Kurdistan Region*. Ph.D. Dissertation, Salahaddin University.
- Ahmed IT and Khoshnaw MR 2019. Effect of different levels of phosphorus fertilizer on heavy metals concentration in corn (*Zea mays*) cultivated in oil polluted soil. *ZANCO Journal of Pure and Applied Sciences* **29**(5): 22-27.
- Ahn PM 1993. *Tropical Soils and Fertilizer Use*. Longman Scientific Technical, UK.
- Al-Khashman OA and Shawabkeh RA 2006. Metals distribution in soils around the cement factory in southern Jordan. *Environmental Pollution* **140**(3): 387-394.
- Allen SE, Grimshaw HM, Parkinson JA and Quarmby C 1974. *Chemical analysis of Ecological materials*. Blackwell. Sci. Osney. Mead, Oxford: p 565.
- Al-Farraj AS and Al-Wabel MI 2007. Evaluation of soil pollution around Mahd-Addahab mine. *Journal Saudi Society for Agriculture Science* **6**(2): 89-105.
- Alloway BJ 1995. *Trace Metals and Metalloids in Soils and their Bioavailability*. 3rd Ed. Black. Acad. Prof. Chapman. Hall. Glasgow., London: p 614.
- Anikwe MAN and Nwobodo KCA 2002. Long term effect of municipal waste disposal on soil properties and productivity of sites used for urban agriculture in Abakaliki, Nigeria. *Bioresource Technology* **83**(3): 241-250.
- Bellebaum J 2005. Between the herring Gull *Larus argentatus* and the Buldozer: Black-headed Gull *Larus ridibundus* feeding sites on a Refuse Dump. *Ornis Fennica* **82**: 166-171.
- Brady JP, Ayoko GA, Martens WN and Goonetilleke A 2014. Temporal trends and bioavailability assessment of heavy metals in the sediments of Deception Bay, Queensland, Australia. *Marine Pollution Bulletin* **89**(1): 464-472.
- Das D K 2005. *Introductory soil science*. Kalyani publishers, Delhi p. 53.
- Dipu S, Kumar AA and Thanga VSG 2011. Phytoremediation of dairy effluent by constructed wetland technology. *The Environmentalist* **31**(3): 263-278.
- Esakku S, Palanivelu K and Joseph K 2003. Assessment of heavy metals in a municipal solid waste dumpsite. *Centre for Environmental Studies, Anna University, Chennai-India*, pp. 139-145.
- European Union 2006. Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. *Journal of European Union* **364**: 324-365.
- Forstner U, Ahlf W and Calmano W 1993. Sediment quality objectives and criteria development in Germany. *Water Science Technology* **28**(8-9): 307-316.
- Hseu ZY, Chen ZS, Tsai CC, Tsui CC, Cheng SF, Liu CL and Lin HT 2002. Digestion methods for total heavy metals in sediments and soils. *Water, air, and soil pollution* **141**(1-4): 189-205.
- Jackson ML 1958. *Soil Chemical Analysis*. Prentice. Hall. INC. Publ., USA: p521.
- Kabata-Pendias A and Pendias H 2011. *Trace Elements in Soils and Plants*. 3rd Ed. CRC. Press. Boca.Raton., USA: p403.

- Kaoser S 2003. *Concept of copper mobility and compatibility with lead and cadmium in landfill liners*. Ph.D. thesis, Department of Bio Resource Engineering Macdonald Campus of McGill University Montreal, Quebec, Canada.
- Kowalska J, Mazurek R Ga, Siorek M, Setlak M, Zaleski T and Waroszewski J 2016. "Soil pollution indices conditioned by medieval metallurgical activity: A case study from Krakow (Poland)". *Environmental Pollution* (218): 1023-1036.
- MAFF (Ministry of Agriculture, Fisheries and Food) and Welch Office Agriculture Department 1992. *Code of Good Agriculture Practice for the Protection of Soil*. Draft Consultation Document, MAFF, London
- Mamtaz R and Chowdhury Md H 2008. Environmental pollution at a solid waste disposal site. *Pollution Research* 27(2): 207-212.
- Miclean M, Roman C, Levei E, Senila M, Abraham B and Cordos E 2009. *Heavy metals availability for plants in a mining area from North-Western Romania*. Research Institute for Analytical Instrumentation, Donath, Romania.
- Mwstefa SB and Ahmed IT 2019. Effect of phosphorus fertilization on phytoremediation efficacy of heavy metals by wheat and bean plants. *ZANCO Journal of Pure and Applied Sciences* 31(3): 18-27
- Pan L, Ma J, Wang X and Hou H 2016. Heavy metals in soils from a typical county in Shanxi Province, China: levels, sources and spatial distribution. *Chemosphere* 148 (Supplement C): 248-254.
- Rowell DL 1996. *Soil Science: Methods and application*. Harl. Longm. Publ., UK: p86.
- Saha JK, Selladurai R, Coumar MV, Dotaniya ML, Kundu S and Patra AK 2017. Soil Pollution-An Emerging Threat to Agriculture, *Springer* 10: 37-50.
- Shenglu Z, Fuqiang L, Shaohua W, Hong Fu Z and Kui R 2008. Heavy metals contents in soil profiles of typical agricultural lands in Yixing, Jiangsu Province, China. *Chinese Science Bulletin* 53(1): 177-187.
- Simeon E O and Friday K 2017. Index models assessment of heavy metal pollution in soils within selected abattoirs in Port Harcourt, Rivers State, Nigeria. *Singapore Journal of Scientific Research* (7): 9-15.
- Traunfeld JH and Clement DL 2001. *Lead in Garden Soils. Home and Garden*. Maryland cooperative Extension, University of Maryland.
- Umoh SD and Etim EE 2013. Determination of heavy metals content from dumpsites within Ikot Ekpene, Akwa Ibom State, Nigeria. *International Journal Engineering Science* 2(2): 123-129.
- Weissmannova HD and Pavlovsky J 2017. Indices of soil contamination by heavy metals methodology of calculation for pollution assessment (minireview). *Environ Monitoring Assess* 189(12): 616.
- Wuana RA and Okieimen FE 2011. Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *Isrn Ecology* 2: 25.



Contribution of Clay, Silt, Organic Matter, Free Iron Oxides and Active Calcium Carbonate in Cation Exchange Capacity in Wasit and Maysan Soils

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Abstract: This study was conducted to estimate the contribution of clay, silt, organic matter, iron oxides and active CaCO_3 in CEC of Wasit and Maysan soils with equation of Asadu and Chibuike (2015). There was highly significant positive correlation between the clay content and the CEC values ($r^2=0.74$). There was no significant correlation between the CEC and each of the silt content organic matter, iron oxides and active calcium carbonate. The relationship between CEC with the soil components (clay, free iron oxides, active calcium carbonate, silt, organic matter) were all positive and highly significant and with a higher correlation coefficient ($r^2=0.87$). The percentage of the contribution soil components for clay and free iron oxides was 69.04 and 18.29, respectively, while for active calcium carbonate, silt and organic matter was 6.671, 3.609 and 1.219% respectively.

Keywords: Clay, Silt, Organic matter, Free iron oxides, Active calcium carbonate

Cation exchange capacity (CEC) is one of the important chemical properties in soils, through which many of the soil components and their properties can be identified such as the content of clay, texture, porosity, permeability and the extent of the need to add fertilizers to the soil (Lorandi 2012, Dinesh et al 2020). Numerous studies have indicated that the physical and chemical properties of soils such as organic matter, the degree of soil interaction and the size of soil particles are factors affecting the CEC (Wang and Zhang 2009, Ljiljana et al 2015). The soil with a high content of clay has a high CEC with a linear correlation between them, The CEC have a linear relationship with organic matter compared to the distribution of soil particles volumes (clay and silt). Negative charges on the particles surfaces of the clay are obscured by the organic matter and results in a negative correlation between the particles of the clay particles and the CEC, depending on the difference in the quality of the clay minerals. The covering of the surfaces of the silt minerals with clay increase the contribution of the clay particles to the CEC compared to the silt particles. The aim of the observe the contribution of soil components (clay, free iron oxides, active calcium carbonate, silt and organic matter) on CEC.

MATERIAL AND METHODS

The study area located in the governorates of Wasit and Maysan, and this region represents the southern part of the Iraqi sedimentary plain at the latitudes $N0(33.06-)(32.08-)$ and longitude $E0(44.40-)(46.56-)$ (Al-Fatlawi 2016). The area was divided into three transects, within the area

between the left bank of the Tigris river and the mountainous at the Iraq-Iran border in the east. Pedons sites were chosen on the basis of the topographical location and were divided into two parts, sites flooded by torrents coming from the borderline, which include the sites of Pedons (Badra, Alshahabi, Chlatt, Tajaldyine, and Jassan), while the sites affected by sediment of Tigris river, included the Pedons at Alsawira, Aldabunie, and Ali algharbi). Statistical analysis was performed using SAS, 2012 for each of clay by applying Regression analysis using the model described by (Zar 1974).

$$y = a + b_1(x_1) + b_2(x_2) + b_3(x_3) + b_4(x_4) + b_5(x_5)$$

$y = \text{CEC}$, $x_1 = \text{clay percent}$, $x_2 = \text{silt percent}$, $x_3 = \text{OM percent}$, $x_4 = \text{free iron oxide percent}$, $x_5 = \text{percent of active CaCO}_3$

$b_1, b_2, b_3, b_4, b_5 = \text{Partial regression coefficients expressing the values of CEC For each independent variable } x_1, x_2, x_3, x_4, x_5, \text{ respectively.}$

The contribution of clay, silt, organic matter, free iron oxides, and percent CaCO_3 individually calculated from the regression equation were calculated using the mean of the variables, as shown by the following formula:-

$$X(\%) = 100bX^- / Y^- - a$$

When $X =$ The relative contribution of clay, silt, organic matter, free iron oxides, and active calcium carbonate

$X^- = \text{mean value of clay, silt, organic matter, free iron oxides, and active}$

$\text{calcium carbonate, } Y^- = \text{mean value of CEC, } a = \text{intercept/regression constant, } b = \text{partial regression}$

coefficient which is specific for each independent variable (clay, silt, organic matter, free iron oxides, and active calcium carbonate).

RESULTS AND DISCUSSION

Cation exchange capacity: The CEC of the soil pedons ranged from 12.85 (C1 horizon for soil Pedon of Chlatt site) to 32.00 Cmol.kg⁻¹ (Ab horizon at soil Pedon of Alsawira). The vertical distribution of the CEC did not show a specific pattern and was a random distribution in the soil of all study Pedons. The reason for the randomization distribution was that soils

are alluvial, consisted of deposits of various texture, depending on the speed and capacity of the conveyor water, causing random distribution of its components, in particular that of clay (Krull et al 2004, Ljiljan et al 2015, Yunan et al 2018). The horizontal distribution of the CEC affinity of all studied soils, except within the Pedon of Chlatt site recorded lowest CEC. This may be due to the lowest content of the clay particles and the high content of the sand particles in that pedon.

There was highly significant positive correlation between the clay content and the CEC ($r^2 = 0.74$), which

Table 1. Chemical and physical properties and CEC

N. pedone	Horizon	Depth cm	EC Ds.m ⁻¹	pH	CaCO ₃ total%	CaCO ₃ active %	silt %	Clay %	Fe _o %	OM %	CEC Cmol.kg ⁻¹
1 Badra	Ap	0-25	2.8	7.22	28.56	21.42	77.8	8.7	0.66	1.9	20.11
	C1	25-52	2.5	7.24	41.41	26.18	69.9	20.5	0.38	1.63	23.58
	C2	52-85	2.6	7.23	34.75	27.18	47.3	34.8	0.56	1.3	28.39
	C3	85	2.7	7.25	34.51	23.08	41.9	46.7	0.64	0.9	28.22
2 Tajaldyine	Ap	0-10	3.3	8.19	22.61	11.9	81.3	10.5	0.44	0.22	21.44
	C1	Oct-34	4.1	7.97	21.66	11.18	54.5	38.8	0.59	0.31	29.03
	C2	34-58	3.4	8.11	22.85	11.9	88	6.4	0.4	0.22	19.25
	Ab	58+	5.3	8.01	24.99	9.52	64.1	28.9	0.33	0.48	23.81
3 Alsawira	Ap	0-10	16	7.64	19.29	15.47	81.2	6.3	1.12	0.1	15.24
	Cz ₁	Oct-60	8.6	7.45	29.04	19.51	48	37.9	0.89	1.82	26.94
	Cz ₂	60-90	12.3	7.7	39.27	17.85	43.1	54.6	0.76	1.37	30.78
	Ab	90+	1.3	7.65	29.27	9.52	42	56.4	0.96	0.22	32
4 Al-Shihabi	Ap	0-10	3.9	7.78	37.5	21.18	44.5	30.1	0.85	0.44	23.95
	Cz ₁	Oct-38	5.9	7.73	36.8	22.13	20.4	46	0.64	0.22	24.59
	Cz ₂	38-72	7	7.53	45.1	23.08	43.9	40	0.81	0.66	30.39
	Ab	72+	2.7	7.45	49.7	27.37	36.2	39.8	1.28	1.55	18.18
5 Jassan	Ap	0-20	5.8	7.47	41.7	29.75	17.8	4.2	1.36	0.8	15.04
	C1	20-83	10.7	7.24	50.1	26.89	42.1	51.5	1.24	1.99	30.93
	C2	83-100	12.3	7.35	34.5	25.46	55.3	37.4	0.86	1.37	28.59
	Ab	100	11.1	7.2	52.7	27.37	54.2	19.6	0.81	1.55	18.28
6 Aldabunie	Ap	0-32	1.6	7.47	20.23	9.75	48.5	35.1	1.28	1.83	28.11
	C1	32-50	1	7.38	19.04	4.76	46.2	45.5	1.16	2	27
	C2	50-75	1	7.49	24.99	16.66	46.3	43.6	0.88	1.11	25.03
	C3	75	0.8	7.55	23.8	14.75	74	11.3	0.96	1.36	22.72
7 Chlatt	Ap	0-10	0.3	8.3	20.71	14.75	8.8	4.6	0.46	0.85	14.39
	C1	Oct-40	0.1	8.5	17.85	8.09	12.8	2.4	0.71	0.74	12.85
	C2	40-70	0.1	8.1	21.66	14.51	17.3	8.5	0.54	0.83	15.73
	Ab	70+	0.2	8.03	25.47	13.56	12.2	6.4	0.64	0.83	13.51
8 Alialgharbi	Ap	0-10	27	7.68	24.75	16.89	82.3	6.5	0.92	1.5	19.22
	Bz ₁	25-Oct	39.1	7.39	24.99	18.32	80.9	4.4	0.85	1.95	20.79
	Bz ₂	25-60	50	7.86	26.18	15.47	81.2	10.3	0.79	1.66	21
	Ab	60+	44.1	7.49	23.32	15.23	59.1	34.4	1.24	1.89	23.73

indicates the influence of the clay content on CEC in these soils. Statistical analysis did not show a high significant correlation between the CEC and the silt content ($r^2=0.02$), organic matter ($r^2=0.01$), free iron oxides ($r^2=0.004$) and active calcium carbonate ($r^2=0.005$). The relationship between the CEC with the summation of all components were positive and highly significant correlation coefficient ($r^2=0.87$) and higher than that recorded with the clay content. The clay particles have the effect and the greatest contribution to CEC compared to other soil components (Table 2). Correlation coefficient ($r^2=0.87$) increase between CEC with the combined components (clay, silt, organic matter, free iron oxides, active calcium carbonate) confirms the contribution of these components and their effect on CEC in these soils..

The percent of clay contribution in the CEC of these soils was 69.040%, while the content of iron oxides contributed by 18.29%. The percent active carbonate, silt, and organic matter contribution was 6.67, 3.60 and 1.21 respectively. The largest contribution of the clay particles to CEC of the soils is expected as clay fraction have a high surface area through the expanded mineral content, especially 2:1 minerals and interstratified minerals which provides many sites for

exchange on their surfaces and inter layers, which is reflected in increasing the CEC of these soils.

The iron oxides, which contributed 18.29% of the CEC indicate effect on CEC of soils, especially in soils with a pH=7.5-8. The availability of charges on their surfaces is of pH-dependent charges, especially if these oxides are present in the amorphous form. The high soil CEC was due to its high surface area (Rhoton et al 2000). Moreover these oxides may exist as coatings around different soil particle

Table 4. Relative contribution of soil components to clay, silt, organic matter, crystalline iron oxides and active calcium carbonate in the CEC

Component	SMA	Relative contribution %
CEC	22.900	
Clay	26.003	69.040
Silt	50.720	3.609
OM	1.087	1.219
Fe _d	0.841	18.295
CaCO ₃ active	17.833	6.671
	Total	98.834

Table 2. Simple and multiple linear regression relationship between the CEC and clay, silt, organic matter, crystalline iron oxides, and active calcium carbonate

Variables	Regression -b value	Straight Linear equation Y ^a =a+bx	R ²	Level of sig	
Clay	0.271	Y ^a =15.839+0.271Clay	0.74	**	
Silt	0.0034	Y ^a =21.157+0.0034 Silt	0.02	NS	
OM	0.982	Y ^a =21.832+0.982 OM	0.01	NS	
Fe _d	-1.678	Y ^a =24.500-1.678 Fe _d	0.004	NS	
CaCO ₃ active	0.061	Y ^a =21.809+0.061 CaCO ₃	0.005	NS	
Y ^a =a+b1(x1)+b2(x2)+b3(x3)+b4(x4)+b5(x5)					
Clay ,Silt, OM, Fe _d , and CaCO ₃ active			Y=11.94+0.291Clay+0.0078 Silt +0.123 OM+2.382Fe _d +0.041CaCO ₃ active	0.87	**
**(P<0.01)					

Table 3. Simple and multiple nonlinear regression relationship between the CEC and clay, silt, organic matter, crystalline iron oxides, and active calcium carbonate

Variables	Regression -b value	Straight Linear equation Y ^a =a+bx	r ²	Level of sig	
Clay	0.00472	Y ^a =18.255+0.0047Clay	0.67	**	
Silt	-0.00013	Y ^a =23.295-0.00013 Silt	0.01	NS	
OM	0.704	Y ^a =21.775+0.704OM	0.01	NS	
Fe _d	-0.589	Y ^a =23.477-0.589 Fe _d	0.003	NS	
CaCO ₃ active	0.0018	Y ^a =22.236+0.0018 CaCO ₃	0.006	NS	
Y ^a =a+b1(x1) ² +b2(x2) ² +b3(x3) ² +b4(x4) ² +b5(x5) ²					
Clay ,Silt, OM, Fe _d , and CaCO ₃ active			Y=14.72+0.00585Clay+0.00068 Silt +0.368 OM+1.257Fe _d +0.0041CaCO ₃ active	0.84	**
**(P<0.01)					

(clay particles and carbonate mineral surfaces) which are considered one of the important and predominant processes in calcareous soils (Uygun and Rimmer 2000).

The contribution of the active carbonate minerals was 6.67% to the CEC. This is possibly due to the high carbonate minerals content of these soils. This increases the capacity of specific and non-specific sorbing of many elements on their surfaces. The mechanism of adsorption of ions on the surfaces of carbonate minerals is carried out through the process of exchanging these ions with the calcium ion within the layers of those minerals which was called the Lattice –Ca layer.

The high content of carbonate minerals in all soils plays a significant role in influencing the nature of the physicochemical behavior of many ions and their interactions in those soils, and cause the great variation in the properties of these minerals and the nature of their presence in the soil material, which effect the overall chemical physical and

fertility soil properties. Besides the importance of the total content of carbonate minerals, the active part in these minerals is called active carbonate where active carbonates formed a large part of the total content of carbonate minerals in the study soils, which greatly affected the characteristics of these properties soils.

The contribution of silt fraction was 3.60% to the CEC. The contribution can be due to more than one reason. The first reason is the high content of silt and its superiority over other soil fractions in all soils. This can be due to the effect of the process of coating the clay fraction to the surfaces of the medium and coarse soil particles, which makes the latter to contribute to CEC in the soil (Morràs 1995, Turpault et al 1996). Thirdly, may be due to the effect of Clay-OM-Complexes, which leads to reduced interchange sites on the surfaces of clay and leads to an increase in the contribution of the very fine silt to the values of CEC (Asadu and Chibuike 2015).

There was decrease in the contribution of the organic matter to the values of the CEC in the study soils, which recorded a low rate of 1.219% as compared to the contribution of other components (Table 4). The contribution of the low organic matter to the CEC of the soils is expected, due to low vegetation, high temperatures, and a prolonged drought period, All of which led to a reduction in the content of organic matter in these soils. This affected its contribution to providing exchange sites on their surfaces that contribute to raising the values of cation exchange capacity (Snapp and Grandy 2011).

CONCLUSION

The vertical distribution of the CEC did not show a specific pattern and was a random distribution in the soil of all study Pedons. There was highly significant positive correlation between the clay content and the CEC. Statistical analysis did not show a high significant correlation between the CEC and each of the silt content, Organic matter, free iron oxides, and active calcium carbonate. The relationship between the CEC with the summation of all components were positive and highly significant correlation coefficient and higher than that recorded with the clay content. The clay particles have the effect and the greatest contribution to CEC compared to other soil components (free iron oxides, active calcium carbonate, silt, organic matter).

REFERENCES

- Al-Fatlawi LAI 2016. *The effect of the precipitation source on the mineral properties and heavy elements of some soils of Wasit and Maysan governorates*. Ph.D. Thesis, College of Agriculture, University of Baghdad.
- Asadu CLA and Chibuike GU 2015. Contributions of organic matter,

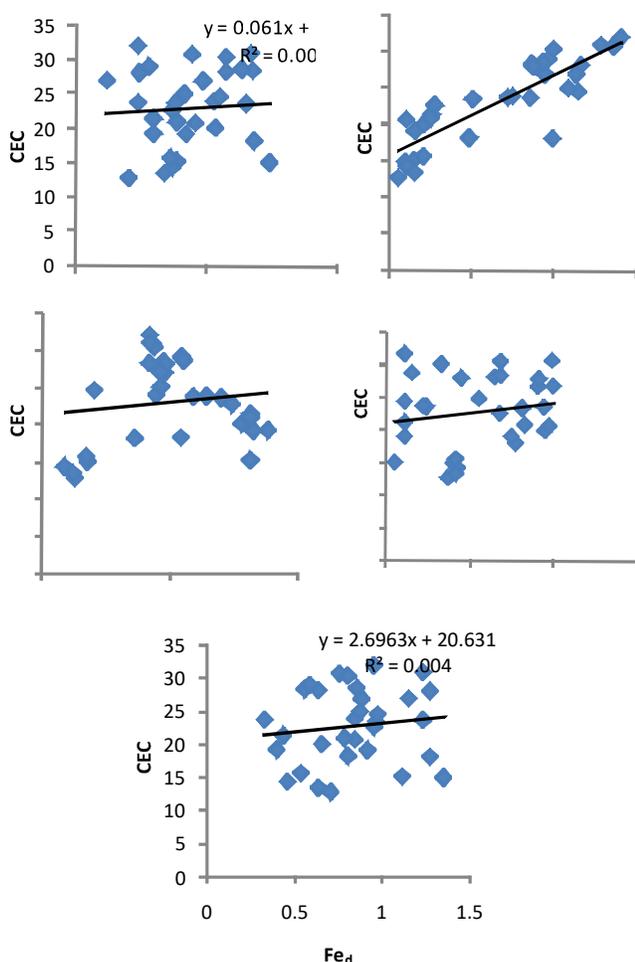


Fig. 1. Relationship between soil components (clay, silt, organic matter, active calcium carbonate, free iron oxides) and CEC

- clay and silt to the effective CEC of soils of different land use history. *Advances in Natural and Applied Sciences* **9**(8): 110-115.
- Dinesh Bhat MA, Sahoo J and Sharma MK 2020. Vertical distribution of nutrients vis-a-vis soil properties in different geomorphic units of north-eastern Haryana, India. *Indian Journal of Ecology* **47**(1): 58-67
- Krull ES, Skjemstad JO and Baldock JA 2004. *Functions of Soil organic matter and the effect on soil properties*. CSIRO Land and Water, PMB2, Glen Osmond SA 5064. GRDC Project No CSO 00029. Residue, Soil Organic Carbon and Crop Performance.
- Ljiljana N, Jovica V, Milivoj B, Vladimir Ć, Jovana G, Katarina M and Petar S 2015. The Colloid Fraction and Cation-Exchange Capacity in the Soils of Vojvodina, Serbia. *Ratarstvo Povrtarstvo* **52**(1): 18-23.
- Lorandi R 2012. Evaluation of Cation Exchange Capacity (CEC) in Tropical Soils Using Four Different Analytical Methods. *Journal of Agriculture Science* **4**(6): 278.
- Morrás HJM 1995. Mineralogy and Cation exchange capacity of the fine silt fraction in two soils from the Chao region (Argentina). *Geoderma* **64**: 281-295
- Rhoton FE, Bigham JM and Lindbo DL 2000. Properties of iron oxide in streams draining the loess upland of Mississippi. *Applied Geochemistry* **17**: 409-419.
- Rimmer DL and Greenland DJ 2006. Effects of calcium carbonate on the swelling behavior of a soil clay. *Journal of Soil Science* **27**(2): 129-139.
- SAS 2012. *Statistical Analysis System, Users Guide*. Statistical. Version 9.1st ed. SAS. Inst. Inc. Cary. N. C. USA.
- Snapp SS and Grandy AS 2011. *Advanced Soil Organic Matter Management*, Extension Bulletin E-3137, Michigan State University Extension, East Lansing.
- Turpault MP, Bonnaud P, Fichter J, Ranger J and Dambrine E 1996. Distribution of Cation exchange capacity between organic matter and mineral fractions in acid forest soils (Vosges mountains, France) *European Journal of Soil Science* **47**: 545-556.
- Uygur V and Rimmer D 2000. Reactions of zinc with iron coated calcite surfaces at alkaline pH. *European Journal of Soil Science* **51**(3): 511-516.
- Wang L and Zhang M 2009. Effects of soil properties on sorption of antibiotics. *Journal of Soil Science* **40**(02): 420-423. (In Chinese).
- Yunan D, Qiao X and Wang X 2018. Study on cation exchange capacity of agricultural soils. *IOP Conference Series: Materials Science and Engineering* **392**(4): p. 042039. IOP Publishing.
- Zar JH 1974. *Biostatistical Analysis*. Prentice Hall, Englewood Cliffs, New Jersey, USA.

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Modeling Infiltration and Water Distribution Process of Layered Soils Using HYDRUS-1D

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Abstract: Laboratory experiments were conducted to investigate the infiltration and wetting front under various thicknesses of the soil layers. Two layered of Northern Iraqi soils, including a sandy loam, silty loam and loamy sand of different depths, fine texture layer over coarse texture layer and coarse texture layer over fine texture layer were evaluated. The numerical model HYDRUS-1D based on the Richards equation was applied to simulate a series of infiltration processes accumulated infiltration and wetting front, with van Genuchten hydraulic parameters. R^2 (coefficient of determination) and RMSE (root mean square error) were used to show the degree of accurate prediction between the observed and simulated data. The accumulated infiltration and wetting front affected by the sequence and thickness of soil layers. An interface existing in the layered soils, whether a fine over coarse layer or a coarse over fine layer, had a common feature of limiting downward water movement. In general, the fine soil layer eventually controls the infiltration process in both cases of fine over coarse and coarse over fine providing the water front pass the interface between coarse and fine layer. The HYDRUS-1D provided accurate simulation results of accumulative infiltration and wetting front depths, since the R^2 values varies from 0.9 to 0.99, between simulated and observed values. RMSE values ranged between 1.3 to 1.6 for accumulative infiltration depths and between 0.6 and 0.9 for wetting front depths. The depression in R^2 and RMSE values was observed with the increasing of upper layer depths from 5 to 20 cm. This indicates that HYDRUS-1D model was capable of accurately simulating the various infiltration processes in multilayered soils.

Keywords: Infiltration, Wetting front, Layered soil, Modeling, HYDRUS-1D

Infiltration has a distinguished fundamental role in surface, subsurface agricultural irrigation and hydrology (Milla and Kish 2006). For evaluation of infiltration computation a huge number of mathematical models developed, which classified into empirical, semi-empirical models and physically based models, the semi-empirical and empirical models derived from experimental data such as Kostikov and Horton models (Aminul Islam et al 2019). The physically based models can easily describe the detailed infiltration process unlike the semi-empirical and empirical equations, which cannot give the detailed information of infiltration. The most famous physically based models are Richards's equation, which derived by using Darcy's law and the mass conservation. These equations have been solved numerically by using finite difference and finite element methods, which can be solved tediously by an iterative implicit technique. 1-D infiltration model based on layered soils have been developed, and this model was used to study infiltration in a three-layered system (seal-tillage-subsoil) (Damodhara Rao et al 2006). HYDRUS-1D software code was developed to solve the Richards's equation to simulate one and two dimensional water movement in variably saturated media (Simunek et al 2005). When water move from coarse to fine soils layer, wetting front reaches the finer soil due to the attraction for water of the underlying finer soil the infiltration rates slightly

increased and because of the fineness of the pores a markedly reduction happen owing to the resistance to flow. When water moves from fine texture layer into a coarser layer, water cannot enter the coarse soil layer until the water pressure sufficiently fill the larger pores and narrow flow channels occur through the entire coarse layer (Jury and Horton 2004).

The effective relationship between the observed and simulated data generated by using HYDRUS-1D simulation of infiltration rate and the accumulative infiltration was observed. However, modified Green-Ampt model could better describe the advancing of wetting front than HYDRUS-1D (Ying Maa et al 2010). Xiaofang et al (2018) used HYDRUS-1D to simulate infiltration, wetting front and water content during horizontal and vertical infiltration in wettable, slightly water-repellent, and strongly water-repellent soils and observed very good agreement, which confirmed the application of HYDRUS-1D in water-repellent soils. The aim of this study is to exam and evaluate HYDRUS-1D model in simulation the accumulated infiltration and advancing of wetting front with different soil textures, and with layered soils of different textures of different thickness at the top and the bottom of soil columns.

MATERIAL AND METHODS

Four different soils were used to study the infiltration and

wetting front process. Two from Ninawa governorate (Rashidiah and Mosul), longitude 43.20 and latitude 36.21, another from Erbil governorate (Challok and Shewarash) longitude 43.38 and latitude 36.17 (Jamel 1986). For five soil samples, initial water content, bulk density, soil texture, hydraulic conductivity and saturated water content were determined (Table 1). Water infiltration experiment under ponded condition were conducted using clear plastic tube of 14 cm inside diameter and 50 cm long with the same bulk density of the field. The flow was considered to be one-dimension with down ward vertical movement, the wetting front advances were measured with time during each experiment.

HYDRUS-1D package Ver. 4.0 were used for simulation. RMSE were used with the following equation.

$$RMSE = \sqrt{\frac{\sum (D_{field} - D_{hydrus_i})^2}{n}}$$

Table 1. Physical properties of the soils

Site	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Texture	Qi (%)	Qs (%)	Pb (kg/m3)
Mosul	586	300	112	Sandy loam	19.1	46	1.42
Rashidiah	328	540	132	Silty loam	19.9	51	1.4
Shewarash	792	112	96	Loamy sand	5.6	42.1	1.43
Challok	104	797	102	Silty loam	19	57	1.39

Table 2. Statistical parameters for measured and simulated accumulated infiltration and wetting front by HYDRUS-1D

Soil texture	Wetting front		Accumulated infiltration	
	RMSE	R ²	RMSE	R ²
Shewarash loamy sand	0.9405	0.9966	1.6351	0.9779
Challok silty loam	0.8587	0.9980	1.6739	0.9977
5 cm Shewarash loamy sand over 35 cm Challok silty loam	0.8018	0.9855	1.4012	0.9857
10 cm Shewarash loamy sand over 30 cm Challok silty loam	0.7728	0.9407	1.4551	0.9395
15 cm Shewarash loamy sand over 25 cm Challok silty loam	0.7439	0.9292	1.3783	0.9347
20 cm Shewarash loamy sand over 20 cm Challok silty loam	0.6528	0.9028	1.2209	0.9019
5 cm Challok silty loam over 35 cm Shewarash loamy sand	0.7957	0.9982	1.3626	0.9973
10 cm Challok silty loam over 30 cm Shewarash loamy sand	0.7008	0.9902	1.2148	0.9776
15 cm Challok silty loam over 25 cm Shewarash loamy sand	0.6512	0.9887	1.1608	0.9675
20 cm Challok silty loam over 20 cm Shewarash loamy sand	0.7362	0.9914	1.3975	0.9676
Mosul sandy loam	0.9087	0.9970	1.8154	0.9904
Rashidiah silty loam	0.8678	0.9979	1.5262	0.9895
5 cm Mosul sandy loam over 35 cm Rashidiah silty loam	0.8659	0.9797	1.6158	0.9912
10 cm Mosul sandy loam over 30 cm Rashidiah silty loam	0.7862	0.9609	1.5934	0.9798
15 cm Mosul sandy loam over 25 cm Rashidiah silty loam	0.8207	0.9323	1.6646	0.9753
20 cm Mosul sandy loam over 20 cm Rashidiah silty loam	0.8146	0.9287	1.6981	0.9750
5 cm Rashidiah silty loam over 35 cm Mosul sandy loam	0.7895	0.9978	1.5870	0.9959
10 cm Rashidiah silty loam over 30 cm Mosul sandy loam	0.7638	0.9857	1.4940	0.9945
15 cm Rashidiah silty loam over 25 cm Mosul sandy loam	0.7496	0.9816	1.4015	0.9971

RESULTUS AND DISCUTION

HUDRUS-1D have a very good ability to model the accumulated infiltration in one layer of different soil textures with little deviation from the observed data, over or under estimation (Table 3). This results supported by high values of R² which ranged from 0.979 to 0.990 between observed and simulated values of accumulated infiltration and low values of RMSE for all soils (Table 2). This agreement between observed and simulated data decrease as the soils became coarser and this agree with Mohammed et al (2010). HUDRUS-1D showed the same ability to model the wetting front in one layer of different soil textures with very small deviation between observed and simulated data of wetting front and approved statistically by high values of R² (0.996-0.998) and very small error of RMSE (0.85 – 0.94) for all soil textures. The silty loam soil textures have the best agreement with the simulated data of accumulated infiltration.

In soil column with two layers, loamy sand soil (shewarash) at the top followed by silty loam soil (challok) the prediction was accurate between predicted and observed accumulated infiltration and this matching was decreased as the thickness of the top layer increased as indicated by the decrease in of R² as the top layer became thicker (Table 2, 4). R² values were 0.9857, 0.9395, 0.9347, 0.9019 with the thickness of top layer 5, 10, 15, 20 cm, respectively. The overlap occurred at depths 15 and 20 cm between predicted

and observed accumulated infiltration curves, since when the top soil thickness are less than 15 cm the output of HYDRUS-1D model were more than observed accumulated infiltration values and the reverse happen when top soil thickness are equal or more than 15 cm. Huang et al (2011) also observe that HYDRUS-1D model give overestimated values of the infiltration volumes in the first 20 min, but then underestimated at later 20 min. The results showed that HYDRUS-1D model was capable of accurately simulating the various hydrological processes in multilayered soils. RMSE values for observed and predicted accumulated infiltration with all thickness values of top layer were very

small as can be noticed from (Table 2). For the same soil column of two layers loamy sand soil at top followed by silty loam soil, the predicting and observed wetting front values acts exactly the same as with accumulated infiltration except that the RMSE values were much smaller and reach half of their values and this indicate a very good estimate between measured and simulated wetting front values by HYDRUS-1D.

The same results were observed when soil column as a reverse of the first one were used, with two layers loamy silty loam soil (challok) at the top and loamy sand soil (shewarash) at the bottom (Table 5). The accurate prediction was observe

Table 3. Accumulated infiltration and Wetting front measured data and simulated by HYDRUS-1D for four soils Shewarash (loamy sand), Challok (silty loam), Mosul (sandy loam) and Rashidia (silty loam).

Time min	Shewarash (Loamy sand)		Challok (Silty loam)		Mosul (Sandy loam)		Rashidia (Silty loam)	
	Measured	HYDRUS	Measured	HYDRUS	Measured	HYDRUS	Measured	HYDRUS
2	21	12	15	15	18	8	18	3
5	46	19	18	23	40	13	22	14
10	55	28	21	33	51	18	27	20
15	64	35	25	43	63	23	32	25
20	72	41	28	48	72	27	37	29
25	79	47	32	54	78	30	41	32
30	86	53	34	59	83	34	45	35
40	97	63	36	69	96	40	50	41
50	107	74	39	78	109	45	56	47
60	117	83	42	86	119	50	61	51
70	127	92	44	93	127	55	66	56
90			53	106	143	65	75	64
120			61	124	155	71	88	75
150			68	140	18	8	99	85
Wetting front cm								
2	9	6	4	5	7	3	4	4.8
5	12	9	6	7	10	4.5	6	6.8
10	16	12	9	10	13	6	8	9.6
15	20	15	11	12	16	7.5	9	12
20	23	18	12	14	18	8.5	10	13.6
25	25	20	13	16	20	9.5	11	15.2
30	27	23	14	17	22	10.5	12	16.8
40	31	27	16	20	25	12	14	19.2
50	35	31	18	22	28	14	15	22.8
60	39	34	19	24	31	15.5	16	24.4
70	42	38	21	27	33	17	18	26
90			23	30	38	19.5	20	29.6
120			26	35	41	21.5	23	34.4
150			29	40			25	38.8

between predicted and observed accumulated infiltration and also wetting front values for all thickness of the top layer 5, 10, 15, 20 cm keeping the final depth of soil column at 40 cm (Table 2, 5). But no distinguished effect of the thickness of the top layer could be found, since the values of R^2 and RMSE did not vary with increasing of top layer thickness in great difference. The decreasing of R^2 with the increasing of soil top layer thickness for accumulated infiltration were 0.9973, 0.9776, 0.9675, 0.9676, respectively. However, RMSE have slightly differ results and there was small decrease with soil thickness increase, and this were the same results for wetting front. This indicate that when medium texture on the top followed by fine texture or the reverse (fine texture on the top

followed by medium texture), make no difference in the simulation of HYDRUS-1D of the accumulated infiltration and also wetting front and will benefit of using of HYDRUS-1D in soil water and irrigation applications. Ying Maa et al (2010) also observed similar findings.

Using soil columns with two layers coarse texture soil sandy loam (Mosul) followed by fine texture silty loam (Rashidiah) showed the same behavior for soil column with two layers loamy sand soil (shewarash) at the top followed by silty loam soil (challok), and this was true for both accumulated infiltration and wetting front (Fig. 1, Table 2). This show that HYDRUS-1D simulated data for both accumulated infiltration and wetting front were very similar to

Table 4. Accumulated infiltration and wetting front by HYDRUS-1D for two layered soils Shewarash (loamy sand) at the top followed by Challok (silty loam) for four depths of each soil

Time min	5cm (LS) / 35 cm (SL)		10cm (LS) / 30 cm (SL)		15cm (LS) / 25 cm (SL)		20cm (LS) / 20 cm (SL)	
	Measured	HYDRUS	Measured	HYDRUS	Measured	HYDRUS	Measured	HYDRUS
2	21	15	20	15	21	15	19	15
5	30	26	44	25	47	25	42	25
10	35	37	50	36	57	36	58	36
15	38	45	53	47	61	46	65	46
20	41	51	56	56	66	54	72	54
25	44	57	59	63	70	63	77	62
30	46	62	61	70	73	72	79	69
40	50	71	66	80	77	84	84	83
50	52	83	69	90	81	94	88	97
60	55	89	72	94	84	103	92	106
70	58	96	74	99	87	111	96	116
90	62	104	78	112	92	117	102	121
120	70	112	83	119	101	124	111	129
150	74	119	87	126	108	132	119	136
Wetting front (cm)								
2	7	3.6	8	5	9	5	9	5
5	9	6.4	12	7	12	7	12	7
10	12	9.6	15	9	16	9	17	9
15	13	12	16	12	19	11	20	11
20	15	14.4	18	14	21	13	23	13
25	16	16.4	19	16	22	15	25	15
30	18	18	20	18	24	17	26	16
40	20	21.2	21	21	25	21	28	20
50	22	25.2	23	24	27	24	30	23
60	23	27.4	24	27	28	27	31	26
70	24	29.6	25	30	30	29	32	29
90	26	32.8	27	35	32	34	34	34
120	29	38	30	38	35	37	38	39

Table 5. Accumulated infiltration and wetting front by HYDRUS-1D for two layered soils Challok (silty loam) at the top followed by Shewarash (loamy sand) for four depths of each soil

Time min	5cm (LS) / 35 cm (SL)		10cm (LS) / 30 cm (SL)		15cm (LS) / 25 cm (SL)		20cm (LS) / 20 cm (SL)	
	Measured	HYDRUS	Measured	HYDRUS	Measured	HYDRUS	Measured	HYDRUS
2	15	15	16	15	17	15	15	15
5	20	21	19	23	21	23	19	24
10	23	26	22	34	25	33	22	34
15	27	31	26	41	28	41	25	42
20	30	34	29	45	31	48	28	48
25	34	38	31	48	34	54	30	54
30	37	41	33	51	37	59	32	60
40	45	47	36	56	41	66	36	69
50	50	53	41	61	44	70	39	78
60	55	59	45	66	46	75	42	85
70	61	65	49	71	49	79	44	89
90	72	76	57	80	54	88	50	97
120	89	91	70	92	67	99	57	118
150	106	107	81	104	75	110	65	119
Wetting front (cm)								
2	4	4.4	4	4.4	5	4.4	4	4.4
5	6	5.6	6	6.8	7	7.2	6	7.2
10	8	7.2	8	9.6	9	10	9	10
15	10	8.4	9	11.2	11	12	11	12
20	11	9.6	10	12.4	12	14	12	14
25	12	10.8	11	13.2	13	15.2	13	15.6
30	14	11.6	12	14.4	14	15.6	14	17.2
40	16	13.6	14	16	16	17.6	16	20
50	18	15.2	16	17.2	18	18.8	18	20.8
60	21	16.8	18	18.8	19	20.2	19	22
70	23	18.4	20	20.4	21	21.6	20	23.6
90	27	21.6	23	23.2	24	24.4	23	26
120	33	25.6	28	26.4	28	28	26	29.2

the measured values, this enhanced by the high values of R^2 , which reaches 0.989 and 0.979 respectively, but this similarity decreased slightly with the increasing at the thickness of the top layer (Fig. 1).

The soil column of fine texture layer on top followed by coarse texture layer have the highest accuracy between measured and simulated data for both accumulated infiltration and wetting front, even at the increase of the thickness of the top fine layer (Fig. 2). These results can be proved from the increasing the values of R^2 (0.99) and decrease of RMSE values, even with the increase of the thickness of the top layer (Table 2). This indicate that HYDRUS-1D have a very good ability to simulate water

movement at the fine texture soils for both layered and non-layered soils.

CONCLUSIONS

The HYDRUS-1D can clearly and efficiently simulate infiltration and wetting front under various different textured soils as the measured and simulated data are very similar and have high values of R^2 . In spite of the complexity and difficulty of describing infiltration through layered soils, HYDRUS-1D kept its very good ability to simulate water movement even with the different soil textured layers (coarse textured layer on fine layer or fine textured layer on coarse layer), where the top thickness layer ranged from 5 to 20 cm.

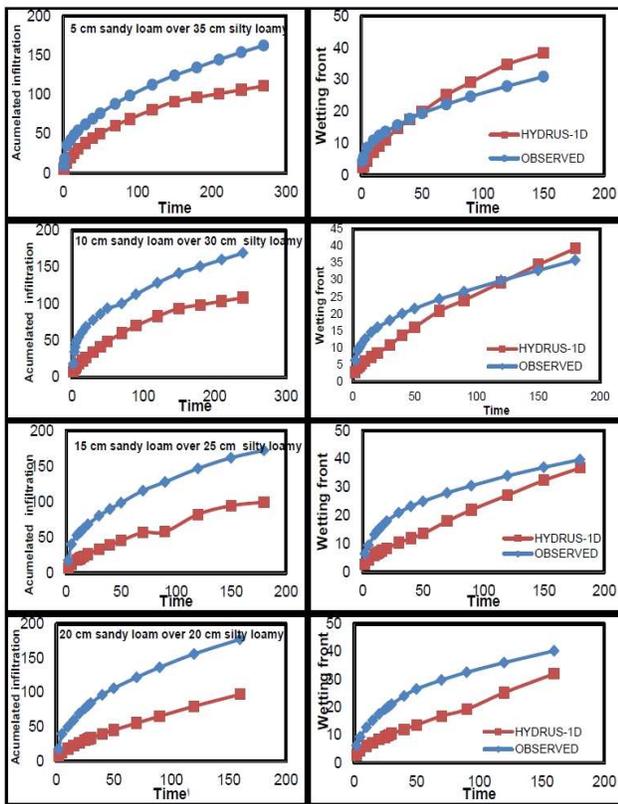


Fig. 1. Observed and simulated data by HYDRUS-1D of accumulated infiltration and wetting front for layered soil, (sandy loam) at the top followed by (silty loam) for four depths of each one

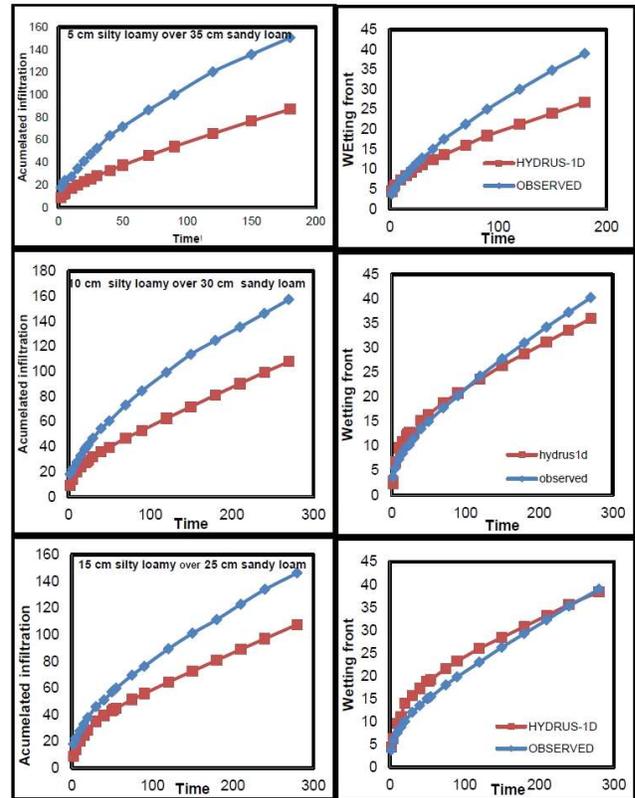


Fig. 2. Observed and simulated data by HYDRUS-1D of accumulated infiltration and wetting front for layered soil, (silty loam) at the top followed by (sandy loam) for three depths of each one

This indicate that HYDRUS-1D simulation data of water movement were similar to measured data for different soil texture but for fine texture were the best.

REFERENCES

Aminul Islam, Akhtar Uz Zaman and Dhruvjayoti Sen 2019. Spatial Variability Modeling of Field Infiltration Capacity. *Indian Journal of Ecology* **46**(3): 510-515.

Damodhara Rao M, Raghuvanshi NS and Singh R 2006. Development of a physically based 1D-infiltrator model for irrigated soils. *Agricultural Water Management* **85**: 165-174.

Huang M, Barbour SL, Elshorbagy A, Zettl JD and Si BC 2011. Infiltration and drainage processes in multilayered coarse soils. *Canadian Journal of Soil Science* **91**: 169-183.

Jamel Fard 1986. *Infiltration in two layered soil profiles under ponded conditions*. M.Sc. Thesis. College of engineering. University of Mosul. IRAQ.

Jury WA, Horton R 2004. *Soil Physics*. Sixth ed. Wiley, New York.

Milla K and Kish S 2006. A low-cost microprocessor and infrared

sensor system for automating water infiltration measurements. *Computers and Electronics in Agriculture* **53**: 122-129.

Mohammed EM, Alany EA and Muzahim MA 2010. Modeling of soil infiltration for different texture of northern soils of IRAQ using HYDRUS-1D. *Proceeding of the 7th Periodical Scientific Conference*, 24-25b Nov. 2010. DWRRC. Mosul University. IRAQ.

Simunek J, van Genuchten MTand Sejna M 2005. *The HYDRUS-1D Software Package for Simulating the One-Dimensional Movement of Water, Heat and Multiple Solutes in variably saturated Media, Version 3.0*. Department of Environmental Sciences, University of California Riverside, Riverside, California, USA.

Xiaofang Wang, Yi Li, Yichen Wang and Chuncheng Liu 2018. Performance of HYDRUS-1D for simulating water movement in water-repellent soils. *Canadian Journal of Soil Science* **98**(3): 407-420.

Ying Maa, Shaoyuan Fenga, Dongyuan Sua B, Guangyao Gaoa and Zailin Huoa 2010. Modeling water infiltration in a large layered soil column with a modified Green-Ampt model and HYDRUS-1D. *Computers and Electronics in Agriculture* **71**: 40-47.



Evaluation of Botanical Oils against Red Flour Beetle *Tribolium castaneum* (Herbst) Coleoptera: Tenebrionidae

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Abstract: Among botanical extracts used as insecticides, essential oils are promising alternatives to chemical insecticides. In this study, essential oils of *Eucalyptus sp.*, *Syzygium aromaticum*, *Cinnamomum verum*, *Sinapis alba* and *Lepidium sativum* were investigated for their insecticidal activity against one of the most destructive insect pest on stored material, the red flour beetle *Tribolium castaneum*. The fumigation with *Eucalyptus* and *C. verum* oils mixed methyl alcohol resulted in high mortality rates that of 60.67 and 63.33%, respectively, compared to significantly less mortality from the using the same oils alone. Findings also showed that *Eucalyptus* and *C. verum* showed more repellency than other oils with repellence rate of 46.66 and 33.33%, respectively 12h post treatment while all the oils resulted in 100% repellence after 36h of the treatment. In case of contact toxicity test, *Eucalyptus* and *C. verum* were also the most effective oils at 1h post treatment resulting in mortality rate of 20 and 10%, respectively, and 100% mortality 6h post treatment, while the other plant oils were effective even 24h post treatment.

Keywords: *Tribolium castaneum*, Red flour beetle, Botanical oils, Repellence, Wheat, Stored grains

The red flour beetle *Tribolium castaneum* is one of the most important insect pests of stored flour and wheat grains (Paranagama et al 2003) and causes direct losses in stored wheat due to feeding and high indirect losses by lowering the nutritional value of the flour because of the presence live insects, insect's skins and faces, as well as dead insects (Evaldo et al 2017, Naima et al 2018). Besides wheat, red rust beetle is also pest of stored cereals, cereal products, cocoa beans and dried fruits (Charles et al 2010). The insect's body may also carry many microorganisms on the outer and inner abrasion of the body, including *Beauneria bassiana*, *Verticillium lecanii* (Bosly and El-Banna 2015) and some pathogenic bacteria such as *Staphylococcus aureus* and *Escherichia coli*. Most chemical methods for control this pest are recently not favourable due to pesticide resistance developed by *T. castaneum* particularly to delramerthrin, commonly used for management of this pest after six generations (Shweta and Sant 2013). Using safe alternative methods from sources that are not harmful to human to control stored materials pests is of significance. These may include using plants materials and extracts and commercially produced botanical oils. The aim of this study, therefore, was to *in vitro* evaluate essential oils available in the local markets for their insecticidal activity against red flour beetle *T. castaneum*.

MATERIAL AND METHODS

The experiment was conducted at Department of Plant

Protection, University of Karbala. Five types of oils *Eucalyptus sp.*, *Syzygium aromaticum*, *Cinnamomum verum*, *Sinapis alba* and *Lepidium sativum* were obtained from the local markets and tested for their activities against the red flour beetle *Tribolium castaneum*. *T. castaneum* adult insects were collected from the main flour store in province of Karbala. The insects were divided into groups, placed containers with adequate amount of feed (flour) and maintained at temperature of 25±1 and relative humidity of 50-60 %. Newly hatched insects were used for experiments.

Fumigation: In this experiment pure oil vapour was used to test by fumigation. This experiment was done by placing ten insects in a small closed container 15x15x10 cm length, width and height sealed closed with cheese cloth. The container was exposed 1ml oil vaporized hot metal surface for 3 min. The containers then were totally sealed with their plastic covers and left in the room conditions. Each oil treatment included ten insects per container three replicates. The mortality rate was calculated 24 hours after the treatment. The oil was applied by diluting with ethanol alcohol at rate 1:3 (0.5 ml oil: 1.5 ml alcohol).

Repellence: In this experiment, petri dishes laterally perforated with 4 mm diameter four holes were used. Ten insects were placed in each plate with a small piece of cotton saturated with 0.5 ml of the oil in the centre of the dish. Each plate was placed in plastic container (30 cm long, 20 cm wide

and 15 cm high) container sealed with cheese cloth with three replicates for each type of oil. The number of insects that emerged from the dish through holes to the pot was recorded after 6, 12 and 24 hours after the treatment and the expulsion ratio was calculated (Wagan et al 2016).

Contact toxicity: Red flour insects were directly exposed to the vegetable oil use. The petri dish containing a filter paper saturated with 1mL of oil was used. Ten insects were placed on the treated filter paper in each dish and closed. The five oils were tested with three replicates for each type of oil. Insect mortality rates were recorded at 1, 2 and 3 days post exposure.

RESULT AND DISCUSSION

Fumigation: The exposing of the insects to different oil resulted in variable mortality rates as the oil used for fumigation differed in efficacy (Table 1). *Cinnamomum verum* and *Eucalyptus* sp. oils resulted in the mortality of 40 and 33.33%, respectively with significant difference and the lowest mortality rate (10.67%) was in *S. alba* oil. Insect mortality rates were much higher and significantly differed within a treatment where mixing plant oil was done with alcohol. The vapour of alcohol with *Cinnamomum verum* and *Eucalyptus* sp caused highest mortality of 63.33 and 60.67%, respectively compared to the pure oil of same plants. Mortality rate was increased from 20% in case of using *S. aromaticum* oil alone to 33.33% where the oil was combined with alcohol. Monteiro et al (2017) reported that the *C. verum* essential oil contains at least 36 different active compounds with a composition of 77.6% terpenes (aliphatic or aromatic monoterpenes or sesquiterpenes) and 8.3% phenylpropanoid aromatic esters. The main compounds found in *C. verum* oil were benzyl benzoate (65.4%) followed by linalool (5.4%), E-cinnamaldehyde (4.0%), -pinene (3.9%), -phellandrene (3.4%), eugenol (3.4%) and benzaldehyde (2.7%). Abbasipour et al (2012) also observed that fumigation with essential oil vapor of *Cinnamomum* resulted in mortality of 93.82% in red flour beetle *Tribolium castaneum*. Similarly, complete detergence (100%) in *Callosobruchus maculatus*, *Sitophilus oryzae* and *Tribolium castaneum* was due to eucalyptus oil fumigant 24h post application (Negahban et al 2007).

Repellence effect of botanical oils: *C. verum* oil showed maximum repellence among the other tested oils, and resulted in repellence of 46.66 and 90.00% at 12 and 24 hour post application, respectively. *L. sativum* oil showed the least repellent to the red flour beetle insects (20.00 and 43.33% after 12h and 24h post treatment, respectively). There was a significant difference between *L. sativum* oil and *C. verum* oil for 12 and 24 hours post treatment. However, all the oils did

not differ among each other for their repellence effect against *T. castaneum* and in complete repellence (100%) was 36 hr post application (Table 2). The repellent action of the tested botanical oils is mostly due to the interactions between the chemical components of the oil and the chemo-receptors on insect body wall (Yarmonlinsky et al 2009, Tyagi 2016)

Contact toxicity: *C. verum* and *Eucalyptus* sp oil were the most toxic to *T. castaneum* resulting in mortality of 20 and 10% 6h after exposing where the mortality rates increased to be 100% at 12 h post exposing to both botanical oils (Fig. 1). Brari and Thakur (2015) found that cinnamon oil had contact

Table 1. Effect of fumigation with different botanical oils on mortality rate of red flour beetle *T. castaneum*

Treatments (Botanical oils)	Mortality rate (%)	
	Pure oil	Oil/alcohol (1:3)
<i>Lepidium sativum</i>	20.00	40.00
<i>Sinapis alba</i>	10.67	36.67
<i>Syzygium aromaticum</i>	20.00	33.33
<i>Cinnamomum verum</i>	40.00	63.33
<i>Eucalyptus</i> sp	33.33	60.67
Control	0.00	0.00
CD (p=0.05)	23.72	49.43

Table 2. Repellence effect of different botanical oils on red flour beetle *T. castaneum*

Treatments (botanical oils)	Time after exposing (hours)		
	12	24	36
<i>Lepidium sativum</i>	20.00	43.33	100
<i>Sinapis alba</i>	30.00	60.00	100
<i>Syzygium aromaticum</i>	26.66	56.67	100
<i>Cinnamomum verum</i>	46.66	90.00	100
<i>Eucalyptus</i> sp	33.33	76.67	100
CD (p=0.05)	16.27	34.51	

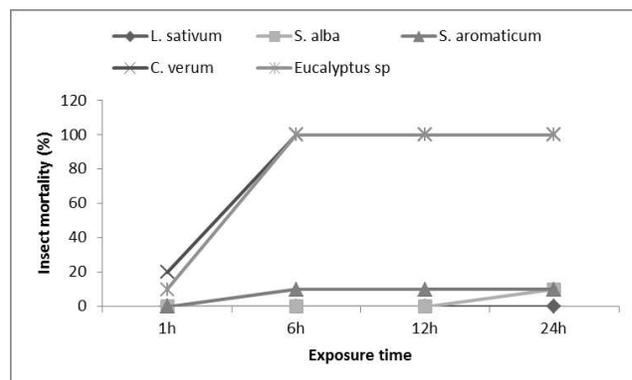


Fig. 1. Effect of contact toxicity of oils on *T. castaneum*

toxic activity causing 98 and 80% mortality in *C. maculatus* and *S. oryzae* adult insects, respectively, within 24h of treatment. It was also found that *T. castaneum* larva was more susceptible to contact toxicity action of *C. verum* oil (Mondal and Khalequzzaman 2006). In contact assay eucalyptus oil against *Sitophilus oryzae*, *Callosobruchus chinensis* and *Corcyra cephalonica* showed 90% of the insect population was killed after only 72h after exposing (Rani 2012).

CONCLUSION

The vegetable oils used differed in their effectiveness against the red flour beetle. The best results were obtained with *Cinnamomum verum* oil against red flour beetle, which led to the highest rate of mortality and repellence compared to other oils. There is possibility of relying on cinnamon products for controlling stored products insects with low risks on human health.

REFERENCES

- Abbasipour H, Mahmoudvand M, Rastegar F and Hosseinpour MH 2012. Chemical composition, fumigant toxicity and oviposition deterrence of *Cinnamomum zeylanicum* essential oil to three stored-product insects. *Archives Des Sciences* **65**(8): 533-542.
- Adarkwah C, Obeng-Ofori D, Bu'ttner C, Reichmuth C and Schöller M 2010. Bio-rational control of red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in stored wheat with Calneem oil derived from neem seeds. *Journal of Pest Science* **83**: 471-479.
- Bosly HA and El-Banna OM 2015. Isolation and identification of fungal growth on *Tribolium castaneum* in stored wheat flour. *Journal of Entomology and Nematology* **7**(2): 11-17.
- Bhari J and Thakur DR 2015. Insecticidal efficacy of essential oil from *Cinnamomum zeylanicum* Blume and its two major constituents against *Callosobruchus maculatus* (F.) and *Sitophilus oryzae* (L.). *Journal of Agricultural Technology* **11**(6): 1323-1336.
- Evaldo MP, Nogueira RM, Rita L, Faroni A, Soares MA and Oliveira MA 2019. Biological and reproductive parameters of *Tribolium castaneum* in Brazil nut. *Florida Entomologist* **102**(1): 76-78.
- Evaldo MP, Souza EQ, Nogueira R and Soares MA 2017. Damage Caused by *Tribolium castaneum* (Coleoptera: Tenebrionidae) in Stored Brazil nut. *Scientific Electronic Archives* **10**: 1.
- Khemira S, Ben Jemâa JM, Haouel S and Khoudj ML 2013. Repellent Activity of Essential Oil of *Eucalyptus astringens* against *Rhyzopertha dominica* and *Oryzaephilus surinamensis*. *Acta horticulturae* **997**: 207-213.
- Lobo AP, Gomes da Camara CA, Ramos de Melo JP and Martins de Moraes M 2018. Chemical composition and repellent activity of essential oils from the leaves of *Cinnamomum zeylanicum* and *Eugenia uniflora* against *Diaphania hyalinata* L. (Lepidoptera: Crambidae). *Journal of Plant Diseases and Protection* **126**: 79-87.
- Mondal M and Khalequzzaman M 2006. Toxicity of essential oils against red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *Journal of Biological Sciences* **14**: 43-48.
- Monteiro IN, Monteiro OS, Costa-Junior LM, Lima AS, Andrade EHA, Maia JGS and Mouchrek Filho VE 2017. Chemical composition and acaricide activity of an essential oil from a rare chemotype of *Cinnamomum verum* Presl on *Rhipicephalus microplus* (Acari: Ixodidae). *Veterinary Parasitology* **238**: 54-57.
- Naima D, Misbah A, Shahbaz H, Zafar I and Dilbar H 2018. Feeding preference and biology of *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) in different wheat varieties. *Journal of Entomology and Zoology Studies* **6**(3): 147-150.
- Negahban M, Moharrampour S and Sefidkon F 2007. Fumigant toxicity of essential oil from *Artemisia sieberi* Besser against three stored-product insects. *Journal of Stored Products Research* **43**: 123-128.
- Paranagama PA, Abeysekera KHT, Abeywickrama KP and Nugaliyadde L 2003. Fungicidal and anti-aflatoxigenic effects of the essential oil of *Cymbopogon citratus* (DC.) Stapf. (lemongrass) against *Aspergillus flavus* Link isolated from stored rice. *Letters in Applied Microbiology* **36**: 1-5.
- Prabha Kumari C, Sivadasan R and Jose A 2011. Microflora associated with the red flour beetle, *Tribolium castaneum* (Coleoptera: Tenebrionidae). *Journal of Agricultural Technology* **7**(6): 1625-1631.
- Rani PU 2012. Fumigant and contact toxic potential of essential oils from plant extract against stored Products Pests. *Journal Bio pesticides* **5**(2): 120-128.
- Singh S and Prakash S 2013. Development of resistance in *Tribolium castaneum*, Herbst (Coleoptera: Tenebrionidae) towards deltamethrin in laboratory. *International Journal of Scientific and Research Publications* **3**(8): 1-4.
- Haouel SH, Khouja ML, Boudabous A and Ben Jemâa JM 2012. Use of *Eucalyptus* essential oils as fumigant for the control of three stored food legume weevils. ARBER *Professional Congress Services*, Turkey 71-75.
- Tyagi V 2016. Repellent efficacy of some essential oils against *Aedes albopictus*. *Journal of Parasitic Diseases: Diagnosis and Therapy* **1**(1): 1-5.
- Wagan TA, Dingbang HU, Yueping HE and Muhammad N 2016. Repellency of three essential oils against red flour beetle *Tribolium castaneum* (Herbst, 1797) (Coleoptera: Tenebrionidae). *Turkish Journal of Entomology* **40**(4): 347-354.
- Yarmolinsky DA, Zuker CS and Ryba NJ 2009. Common sense about taste: from mammals to insects. *Cell* **139**: 234-244.



Documentation of Ethnomedicinal Plants used for Treating Rheumatoid Arthritis Disorder by Aboriginal Communities of Manar beat, Karamadai Range, Western Ghats, India

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Abstract: An ethnomedicinal survey was carried out in seven different villages of Manar beat (Melur slope RF and Nellithurai RF), Karamadai Range, Western Ghats, Tamil Nadu, India. The intend of the study was to document information regarding indigenous plant species used to treat anti-arthritis disorders. From the survey, a total of 76 plant species belonging to 69 genera and 36 families were reported with the help of standardized questionnaires among 46 tribal informants between the ages of 40-85 years. The study shows that plants belonging to the families Euphorbiaceae, Rutaceae, Capparidaceae and Asclepiadaceae are commonly used by traditional healers. The leaves form the major part of a plant for herbal preparation. In addition, 28 plants were becoming endangered, vulnerable, least concern and near threatened status. From the surveyed list 76 plants were used for rheumatism and the same species were used for other diseases. Decoction ranks first in the mode of administration. This study shows a high degree of ethnobotanical novelty in traditional folk medicine among the aboriginal people (Irular). Further pharmacological studies of these plants may provide some important drugs for the treating common rheumatoid arthritis disorders.

Keywords: Medicinal plants, Manar beat, Irulas, Folk medicine practitioners, Rheumatism

The plants are very functional source of various bioactive compounds which have direct or indirect use in the treatment of various human ailments. Due to rich diversity of biotic resources, India is ranked one of the 12 mega biodiversity countries in the tropics. The World Health Organization surveyed that about 80 per cent of the world's population, particularly tribal and rural areas are depended upon the herbal medicines for their primary health care needs. India is wealthy in ethnic diversity and has a well experienced knowledge of herbal medicines. Historically, Western Ghats are covered with dense forests that provide wild food and natural habitats to Aboriginal peoples and is a UNESCO World Heritage Site and is one of the eight "hottest hot-spots" of biological diversity in the world. Today, the use of medicinal plants for the treatment of many diseases is associated to folk medicine from different parts of the world.

In prehistory, India uses plant-based medicines with authority in alternative health systems such as Ayurveda, Unani, Siddha, homeopathy and naturopathy for the treatment of rheumatism in India (Kiran et al 2011). Rheumatoid arthritis (RA) is one of the most responsible illnesses in the world and also the largest problem today. It is an autoimmune disease which means that the immune system wrongly attacks healthy tissues. In normal human joints, the lining is very fragile and it causes very few blood

vessels but in the rheumatoid arthritis joints, the lining is very dense and crowded with the white blood cells. The occurrence of white blood cells produces pain, causing the joints swollen and stiff (Mahajan et al 2010). Today's lifestyle of the human beings like improper diet, lack of regular exercise, wrong posture, long working hours and use of laptops resulting to ultimately develop arthritis and rheumatoid arthritis. According to World Health Organization, 1.5% of the world population is affected by rheumatoid arthritis especially females facing the problem in huge amount than male between the ages of 40 and 50. Once the disease is diagnosed, treatment is prescribed to slow or end the progress of the disease. However, the available vaccines against rheumatism have yielded good results, even if the cost and side effects are noticeable. Hence the documentation of ethnic knowledge of RA is attracting the attention of several botanists and plant scientists who directing vigorous researches towards the discovery or rediscovery of several medicinal plants. However, the reports of ethnic knowledge on rheumatoid arthritis disease in India level are largely a small account. Eventually these ethnic people have higher traditional knowledge. Local people were keen to provide information and transfer indigenous knowledge about herbs from one generation to the next (Negi et al 2020). With this background, the study was undertaken to document the ethnobotanical

usage of various plants for the treatment of Rheumatoid arthritis (RA) disorder by Irula tribal communities in seven tribal villages of Western Ghats, Tamil Nadu, India.

MATERIAL AND METHODS

Study area: The Karamadai range has 22 tribal villages and 432 households with approximately 1546 people. Out of these 22 tribal villages, 10 villages are situated along with Bhavani and Kundah river and the remaining villages are dispersed inside the forest. The present study area Manar beat is confined to a major range in the Western Ghats of Nilgiris Biosphere Reserve, Coimbatore District which is one of the biodiversity hotspots in India. The ethnomedicinal field survey was conducted in 7 villages of Manar beat viz., Gethaikkadu, Manar, Korappathi, Veerakkal, Sundappatti, Veppamarathur and Baraliminnilayam (Fig. 1 and Table 1). More than 195 families and nearly 699 members of Irulas are living in the study area. One or two villages still doesn't have electricity facilities and the floristic diversity of this region is very high due to less anthropogenic activities. The area of investigation approximately lies 11°18' latitude and 76°53' longitude and has seven villages with a total area of about 2279 hec. Each village is found in different elevations from 442-493 MSL. The temperature of the study area is scarcely fluctuating year to year. Maximum mean daily temperature is 37°C during summer and minimum mean daily temperature is 15°C during winter. The annual average rainfall is 651 mm.

Inhabited tribal people (Irulas): Irulas are significant ethnic group of India and are one among the 550 tribal communities of India, living in different topographic habitats (plains, mountains, valleys, etc.) in Tamil Nadu. Mid twentieth century anthropological literature classified the Irulas under the Negrito ethnic group. The ancestors of these people are supposed to have from Africa to India.

Collection of ethnobotanical information: The ethnomedicinal documentation study was conducted from May 2018 to May 2019 with proper permission from the Principal Chief Conservator of Forests, Chennai and the District Forest Officer, Coimbatore under Section 28 of Wildlife Protection Act, 1972, in December. The villages selected were purposive. The data was gathered through conducting interviews, conversation and field perception with home grown healers and educated senior individuals of the study area using semi-organized poll. The interview consisted of two parts. The first parts dealt with the demographic profile of the informants and second part dealt with their medicinal plant knowledge. The questionnaire was translated in the local dialect to elucidate aspects like plant parts used, diseases treated, mode of preparation etc. Age of the interviewed informants ranged between 40 and 85.

Preservation of plant specimens: Standard method was followed to collect the plant material with floral characters (twig must be in flowering/ fruiting conditions). Plants with their correct nomenclature were arranged alphabetically by family name, vernacular name etc. as indicated by Bentham and Hooker (1862-1883) system of classification. The listed plants were identified with the help of standard floras such as Flora of Presidency of Madras (Gamble 1984) and the Flora of Tamil Nadu Carnatic (Matthew 1983). Later they were verified in the Botanical Survey of India, Southern Circle, TNAU Campus, Coimbatore, India. All the preserved specimens were deposited for future reference at the Department of Botany, Vellalar College for Women (Autonomous), Erode, Tamil Nadu, India with their accession numbers (VCW/BH/Acc. No.).

RESULTS AND DISCUSSION

The 76 plant species (Table 2) belonging to 69 genera and 36 families were reported by the forty-six informants (female 29 and male 17). The surveyed plants were used in treating various diseases mostly used for the treatment of Rheumatoid Arthritis. The most represented family was Euphorbiaceae and Rutaceae by high number of species with each seven species followed by Cappariaceae and Asclepiadaceae with four species each (Table 3 and Fig. 2). In terms of habit, there are 24 species of trees (32%), 18 species of shrubs (24%) followed by 14 species of climbers (18%), 11 species of herbs (14%), 2 species of epiphytes (3%) and 1 species of semi parasite (Fig. 3). Silambarasan and Ayyanar (2015) stated that Leguminosae and Asteraceae are dominant families used by the tribal communities in Palamalai region. Shyam Sundar Manna and



Fig. 1. Satellite view of Manar beat

Satyendra Prasad Mishra (2018) in another study in Jharagram district recorded 20 species of trees (38%), 17 species of herbs (33%), 11 species of shrubs (21%) and 4 species of climbers (8%).

Plant parts used for making herbal preparations were leaves, roots, whole plant, bark, seeds, fruit, latex, stem, flowers, wood, rhizome and fruit pulp. Leaves were the most often used part (43%) followed by roots (18 %) (Fig. 4). Sharmila et al (2015) in ethnopharmacobotanical documentations of some herbaceous medicinal plants used by Toda tribes of Thiashola, Manjoor, Nilgiris, Western Ghats, Tamil Nadu, India made similar observations. Das et al (2012) recorded from Paschim Medinipur district that among 21 medicinal plant species, 6 plant species becoming endangered and rest of the plants considered as vulnerable, less common and near threatened status. In the present study, among the 76 medicinal plant species, 28 plants were becoming endangered, vulnerable, least concern and near

threatened status (Fig. 5). The 76 plants were used for rheumatism disorder, 14 plants as antidote for snake bite and scorpion sting, 12 for fever, 11 for asthma, 7 for toothache, 6

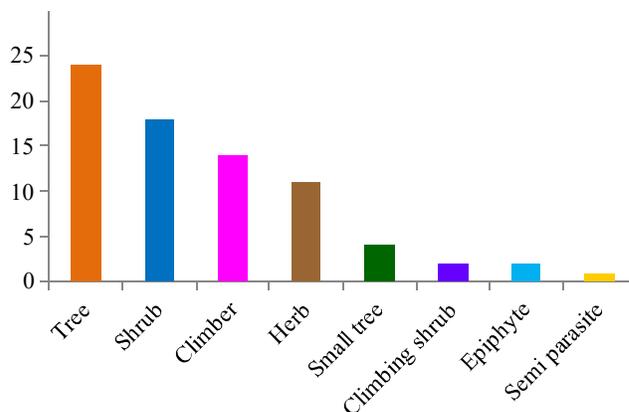


Fig. 3. Habit wise usage of medicinal plants for rheumatism

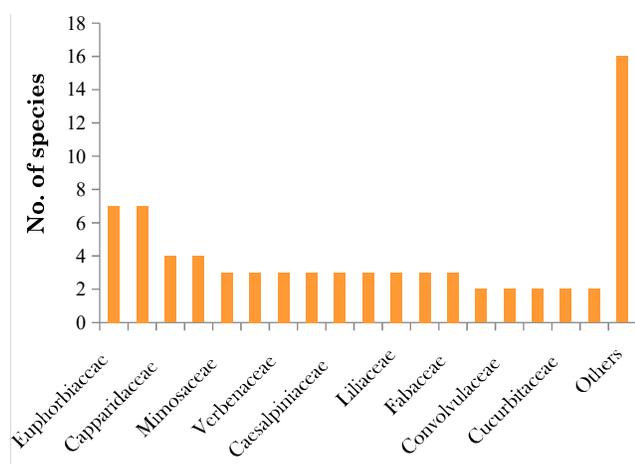


Fig. 2. Family wise distribution used for ethnomedicinal purposes

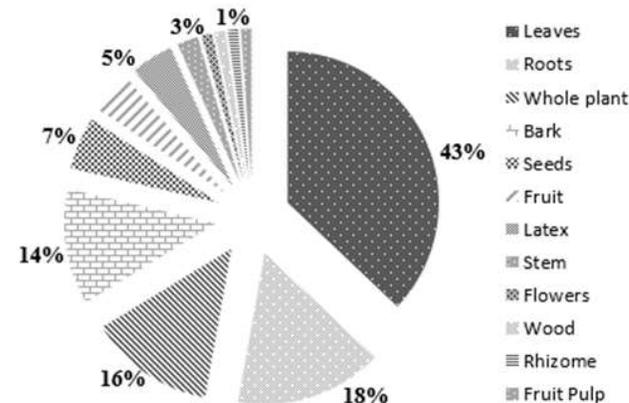


Fig. 4. Pie 3-D chart representing the different parts of medicinal plants used for the treatment of rheumatism

Table 1. Details of surveyed villages - Manar beat

Name of the village	Area (in ha)	Geographical position	Elevation	Temperature	No. of family	No. of population		Electricity	Irrigation/ non-irrigation	Reported plants
						Male	Female			
Gethaikkadu	17.20	11°13. 156' N 76°44. 250' E	479 MSL	Maximum 36.2° C Minimum 15.5° C	24	51	53	Electricity	Rain fed	14
Manar	38.00	11°13. 231' N 76°44. 408' E	485 MSL	Maximum 36.5° C Minimum 15.3° C	53	86	108	Hut Connection	Irrigation by Canal	26
Korappathi	30.00	11°13. 605' N 76°44. 672' E	493 MSL	Maximum 36.4° C Minimum 15.3° C	30	65	57	Electricity	Rain fed	12
Veerakkal	16.80	11°13. 849' N 76°45. 052' E	476 MSL	Maximum 36.2° C Minimum 15.4° C	14	21	21	Electricity	Rain fed	7
Sundappatti	18.80	11°14. 728' N 76°47. 230' E	442 MSL	Maximum 36.1° C Minimum 15.7° C	15	30	27	Electricity	Rain fed	8
Veppamarathur	12.80	11°14. 469' N 76°47. 477' E	472 MSL	Maximum 36.6° C Minimum 16.1° C	9	10	20	Electricity	Rain fed	4
Baraliminnilayam	30.00	11°14. 105' N 76°46. 413' E	451 MSL	Maximum 36.4° C Minimum 15.8° C	50	80	70	Electricity	Rain fed	5

Table 2. Ethnomedicinal plants used for the treatment of rheumatism in Manar beat, Karamadai range, Western Ghats, India

Botanical name	Family name	Local name	Habit	Parts used	Ecological status	Therapeutic uses	Mode of preparation
<i>Abrus precatorius</i> L. BHVCW 01	Fabaceae	Gundumani	C	Leaves	NE	Leaves – Leukoderma, swellings and rheumatism	Paste and powder
<i>Acanthus ilicifolius</i> L.	Acanthaceae	Kollimulli	S	Leaves	LC	Leaves – Snake bites, wounds, rheumatic joints	Decoction
<i>Achyranthes aspera</i> L. BHVCW 05	Amaranthaceae	Naayuruvi	H	Root	NE	Root – Relieve the pain of scorpion stings, rheumatism, stomach problems and skin diseases	Decoction, juice and paste
<i>Achyranthes bidentata</i> Blume.	Amaranthaceae	Karunaayuruvi	H	Root	NE	Root – Rheumatism, toothache and asthma	Decoction and juice
<i>Adenantha pavonine</i> L.	Mimosaceae	Anai-gundumani	T	Leaves	NE	Leaves – Used in the treatment of rheumatism and gout	Decoction
<i>Aerva tomentosa</i> Forsk.	Amaranthaceae	Perumpoolai	H	Roots and flowers	NE	Roots and flowers – Rheumatism, toothache and kidney disorders	Decoction and Paste
<i>Ailanthus excelsa</i> Roxb.	Simaroubaceae	Perru	T	Leaves	NE	Leaves – Rheumatism and postnatal care	Decoction and Tonic
<i>Alangium salvifolium</i> (Linn. f.) Wang.	Alangiaceae	Azinjil	T	Leaves	NE	Leaves – Asthma and reduce rheumatic pains	Juice
<i>Annona squamosa</i> L. BHVCW 14	Annonaceae	Sitapalam	T	Leaves and fruits	NE	Leaves and fruits – Aid digestion and treat rheumatism	Infusion
<i>Argyrea cuneata</i> Ker-Gawl. BHVCW 17	Convolvulaceae	Kanvalipoo	CS	Roots	R	Roots – Rheumatic joints, scorpion stings and to reduce obesity etc.	Decoction
<i>Asparagus racemosus</i> Willd. BHVCW 22	Liliaceae	Sataavari Kizhangu	C	Whole plant	VU	Whole plant – Diarrhoea, rheumatism, diabetes and brain complaints	Tonic
<i>Atalantia monophylla</i> (L.) Correa. BHVCW 23	Rutaceae	Kattu Elumichai	S	Fruit	NE	Fruit – Rheumatism and joint pains disorders	Decoction
<i>Azadirachta indica</i> A. Juss. BHVCW 24	Meliaceae	Vembu	T	Whole plant	LC	Whole plant – Used to treat eye diseases, leprosy, rheumatism, ringworm and ulcers	Decoction and juice
<i>Barleria prionitis</i> L. BHVCW 26	Acanthaceae	Chemulli	S	Leaves	NE	Leaves – Diuretic, fever, rheumatism, liver diseases, indigestion, constipation, jaundice and toothache	Juice, tonic and infusion
<i>Blachia umbellata</i> Baill.	Euphorbiaceae	Aatthumanthai	S	Leaves	R	Leaves – Rheumatism	Paste and Tonic
<i>Cadaba fruticosa</i> (L.) Druce. BHVCW 30	Capparidaceae	Vizhuthi	S	Roots	E	Roots – Coughs and rheumatism	Juice
<i>Capparis diversifolia</i> W. & A.	Capparidaceae	-	S	Whole plant	VU	Whole plant – Asthma, rheumatism, diabetes, paralysis, toothache and antidote for snakebite	Extraction
<i>Capparis grandiflora</i> Hook.f. & Thomson. BHVCW 33	Capparidaceae	Mudkondai/Thora ttimul	S	Leaves	NE	Leaves – Stomachic, diuretic, rheumatism, shortness of breath and anti-tumour	Decoction and juice
<i>Cardiospermum halicacabum</i> L. BHVCW 35	Sapindaceae	Mudakkattan	C	Whole plant	NE	Whole plant – Diuretic, rheumatism, stomach-ache, nervous diseases and snakebite	Juice
<i>Cassia auriculata</i> L. BHVCW 38	Caesalpinaceae	Aavaram	S	Roots and bark	NE	Roots and bark – Cure skin diseases and rheumatism	Decoction

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Table 2. Ethnomedicinal plants used for the treatment of rheumatism in Manar beat, Karamadai range, Western Ghats, India

Botanical name	Family name	Local name	Habit	Parts used	Ecological status	Therapeutic uses	Mode of preparation
<i>Cassia occidentalis</i> L.	Caesalpiniaceae	Peyaverai	S	Whole plant	NE	Whole plant – Hypertension, fevers, diabetes, eczema, biliousness, rheumatism and ringworm	Infusion
<i>Chloroxylon swietenia</i> DC.	Rutaceae	Purush	T	Leaves	VU	Leaves – Wounds, snakebites and rheumatism	Decoction
<i>Cinnamomum malabathrum</i> Miq.	Lauraceae	Talishapattiri	T	Leaves	NE	Leaves – Colic and rheumatism	Decoction
<i>Cissampelos pareira</i> L. BHVCW 42	Menispermaceae	Malai Thangivaer	C	Rhizome	NE	Rhizome – Cough, rheumatism, jaundice, snake bites and skin infections	Decoction, infusion and juice
<i>Cissus quadrangularis</i> L. BHVCW 43	Vitaceae	Pirandai	CS	Leaves	LC	Leaves – Cure rheumatic joints, wounds and burns	Infusion, paste and powder
<i>Citrullus colocynthis</i> (L.) Schrad. BHVCW 44	Cucurbitaceae	Varikuramathai	H	Roots	VU	Roots – Jaundice, rheumatism and urinary diseases	Powder and Pickles
<i>Clausena dentata</i> (Willd.) M. Roem.	Rutaceae	Kattu karveppilai	ST	Leaves and roots	LC	Leaves and roots – Colds and rheumatism	Decoction and tonic
<i>Clerodendron serratum</i> Spr.	Verbenaceae	Angaravalli	S	Leaves	NE	Leaves – Fever, chronic headache, skin infections, rheumatism and painful joints	Decoction
<i>Coccinia grandis</i> (L.) Voigt. BHVCW 47	Cucurbitaceae	Kovakai	C	Leaves	NE	Leaves – Skin eruptions, headache and rheumatism	Juice, decoction and infusion
<i>Crataeva religiosa</i> Forst.	Capparidaceae	Mavilankai	ST	Bark and leaves	NE	Bark and leaves – Rheumatism	Decoction and juice
<i>Daemia extensa</i> R.Br.	Asclepiadaceae	Kodalma	C	Latex	NE	Latex – Rheumatism, asthma and snakebites	Juice and decoction
<i>Dendrophthoe falcate</i> (L.f.) Ettingsh.	Loranthaceae	Pulluri	SP	Bark	NE	Bark – Rheumatism and induce deep sleep	Decoction and extraction
<i>Dodonaea viscosa</i> (L.) Jacq. BHVCW 60	Sapindaceae	Virali	S	Stems	E	Stems – Rheumatism	Decoction and infusion
<i>Drypetes roxburghii</i> (Wall.) Hurus.	Euphorbiaceae	Irukoli	T	Leaves and fruit	NE	Leaves and fruit – Liver complaints, colds, fevers and rheumatism	Decoction
<i>Dysoxylum malabaricum</i> Bedd.	Meliaceae	Vellaiyagil	T	Wood	E	Wood – Leprosy, inflammation and rheumatism	Decoction and Paste
<i>Endostemon viscosus</i> (Roth.) M. R. Ashby.	Lamiaceae	Senthulasi	S	Leaves	NE	Leaves – Rheumatism, fever, cold, cough and leprosy	Infusion
<i>Euphorbia antiquorum</i> L.	Euphorbiaceae	ChaturaKalli	T	Latex	EW	Latex – Rheumatism, toothache, earache and asthma	Tonic
<i>Euphorbia tirucalli</i> L.	Euphorbiaceae	Thirukalli	S	Latex	LC	Latex – Skin complaints, insect bites, rheumatism, toothache, earache and wound healing	Decoction and juice
<i>Ficus bengalensis</i> L.	Moraceae	Aalamaram	T	Latex	R	Latex – Fever, rheumatism, pains and toothache	Decoction, infusion and tonic
<i>Ficus benamina</i> L.	Moraceae	Pimpri	T	Leaves and bark	NE	Leaves and bark – Rheumatism and headaches	Juice
<i>Givotia moluccana</i> (L.) Sreem. BHVCW 66	Euphorbiaceae	Vellai-poothali	T	Seed and bark	NE	Seed and bark – Rheumatism, psoriasis and dandruff	Decoction and paste
<i>Gloriosa superba</i> L. BHVCW 67	Liliaceae	Kanthal malar	C	Leaves	LC	Leaves – Asthma, rheumatism, coughs, wounds and pimples	Decoction, paste, tonic and juice

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Table 2. Ethnomedicinal plants used for the treatment of rheumatism in Manar beat, Karamadai range, Western Ghats, India

Botanical name	Family name	Local name	Habit	Parts used	Ecological status	Therapeutic uses	Mode of preparation
<i>Glycosmis pentaphylla</i> Corr.	Rutaceae	Kuttivila	S	Whole plant	LC	Whole plant – Diarrhoea, coughs, rheumatism, anaemia and jaundice	Decoction, infusion, paste and juice
<i>Gymnema sylvestre</i> R.Br. BHVCW 68	Asclepiadaceae	-	C	Whole plant	NE	Whole plant – Rheumatism, inflammation and snake bites	Decoction, paste, juice and powder
<i>Harpullia arborea</i> (Blanco) Radlk.	Sapindaceae	NeiKottei	T	Seeds	LC	Seeds – Rheumatism	Infusion
<i>Hemidesmus indicus</i> R.Br. BHVCW 70	Asclepiadaceae	Nannari	C	Root	R	Root – Blood purifier, demulcent, diuretic, dyspepsia, fever, skin diseases, chronic coughs, swellings and rheumatic joints	Paste and tonic
<i>Holoptelea integrifolia</i> Planch.	Ulmaceae	Bachi	T	Bark	NE	Bark – Rheumatism, ringworm, scabies, ulcers and scorpion stings	Juice, paste and powder
<i>Ipomaea bracteata</i> L. BHVCW 74	Convolvulaceae	-	C	Whole plant	NE	Whole plant – Ulcer, fever and rheumatism	Decoction
<i>Jatropha curcas</i> L. BHVCW 81	Euphorbiaceae	Kattamanakku	S	Leaves	NE	Leaves – Jaundice, fevers and rheumatic pains	Infusion, paste and juice
<i>Justicia procumbens</i> L.	Acanthaceae	Kodakasalai	H	Leaves	NE	Leaves – Asthma, coughs, rheumatism, backache, laxative and diuretic	Decoction, infusion and juice
<i>Leucas aspera</i> Spr. BHVCW 84	Lamiaceae	Thumbai	H	Leaves	NE	Leaves – Rheumatism, skin diseases and snake bites	Decoction and juice
<i>Leucas lanata</i> Benth.	Lamiaceae	-	H	Leaves	NE	Leaves – Skin diseases, mild fevers, colds, rheumatism and snake bites	Decoction
<i>Lonicera japonica</i> Thunb.	Caprifoliaceae	-	C	Stems	NE	Stems – Rheumatoid arthritis	Infusion
<i>Ludwigia octovalvis</i> Roxb.	Onagraceae	Karamigida	H	Whole plant	LC	Whole plant – Carminative, diarrhoea, dysentery, nervous diseases and rheumatic pains	Decoction
<i>Naringi crenulata</i> (Roxb.) D.H. Nicolson.	Rutaceae	Magavilvam	T	Roots	NE	Roots – Rheumatism	Decoction, powder, tonic and Paste
<i>Odina wodier</i> Roxb.	Anacardiaceae	Odiyan	T	Bark	NE	Bark – Rheumatism, elephantiasis, ulcer, skin infection, wound healing and used as toothpowder	Decoction
<i>Pisonia aculeata</i> L.	Nyctaginaceae	Marukalli	S	Leaves and bark	NE	Bark and leaves – Used to relieve rheumatism	Decoction
<i>Pleiospermium alatum</i> (Wight & Arn.) Sw.	Rutaceae	Kurnthumullthalai	ST	Leaves and bark	NE	Leaves and bark – Used to cure Rheumatic pains	Decoction
<i>Plumbago zeylanica</i> L.	Plumbaginaceae	Venkodiveli	H	Leaves	NE	Leaves – Rheumatism and headache	Decoction, tonic, juice, powder and Paste
<i>Pongamia glabra</i> Vent. BHVCW 102	Fabaceae	Pungamaram	T	Seed and leaves	LC	Seed – Bronchitis, whooping cough, sores and rheumatic joints Leaves – Rheumatism, cough and skin diseases	Decoction, infusion, juice, tonic and powder
<i>Premna latifolia</i> Roxb. BHVCW 104	Verbenaceae	Erumai	ST	Leaves	NE	Leaves – Rheumatic arthritis, coughs, headaches, backaches and fevers	Decoction

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Table 2. Ethnomedicinal plants used for the treatment of rheumatism in Manar beat, Karamadai range, Western Ghats, India

Botanical name	Family name	Local name	Habit	Parts used	Ecological status	Therapeutic uses	Mode of preparation
<i>Glycosmis pentaphylla</i> Corr.	Rutaceae	Kuttivila	S	Whole plant	LC	Whole plant – Diarrhoea, coughs, rheumatism, anaemia and jaundice	Decoction, infusion, paste and juice
<i>Gymnema sylvestre</i> R.Br. BHVCW 68	Asclepiadaceae	-	C	Whole plant	NE	Whole plant – Rheumatism, inflammation and snake bites	Decoction, paste, juice and powder
<i>Harpullia arborea</i> (Blanco) Radlk.	Sapindaceae	NeiKottei	T	Seeds	LC	Seeds – Rheumatism	Infusion
<i>Hemidesmus indicus</i> R.Br. BHVCW 70	Asclepiadaceae	Nannari	C	Root	R	Root – Blood purifier, demulcent, diuretic, dyspepsia, fever, skin diseases, chronic coughs, swellings and rheumatic joints	Paste and tonic
<i>Holoptelea integrifolia</i> Planch.	Ulmaceae	Bachi	T	Bark	NE	Bark – Rheumatism, ringworm, scabies, ulcers and scorpion stings	Juice, paste and powder
<i>Ipomaea bracteata</i> L. BHVCW 74	Convolvulaceae	-	C	Whole plant	NE	Whole plant – Ulcer, fever and rheumatism	Decoction
<i>Jatropha curcas</i> L. BHVCW 81	Euphorbiaceae	Kattamanakku	S	Leaves	NE	Leaves – Jaundice, fevers and rheumatic pains	Infusion, paste and juice
<i>Justicia procumbens</i> L.	Acanthaceae	Kodakasalai	H	Leaves	NE	Leaves – Asthma, coughs, rheumatism, backache, laxative and diuretic	Decoction, infusion and juice
<i>Leucas aspera</i> Spr. BHVCW 84	Lamiaceae	Thumbai	H	Leaves	NE	Leaves – Rheumatism, skin diseases and snake bites	Decoction and juice
<i>Leucas lanata</i> Benth.	Lamiaceae	-	H	Leaves	NE	Leaves – Skin diseases, mild fevers, colds, rheumatism and snake bites	Decoction
<i>Lonicera japonica</i> Thunb.	Caprifoliaceae	-	C	Stems	NE	Stems – Rheumatoid arthritis	Infusion
<i>Ludwigia octovalvis</i> Roxb.	Onagraceae	Karamigida	H	Whole plant	LC	Whole plant – Carminative, diarrhoea, dysentery, nervous diseases and rheumatic pains	Decoction
<i>Naringi crenulata</i> (Roxb.) D.H. Nicolson.	Rutaceae	Magavilvam	T	Roots	NE	Roots – Rheumatism	Decoction, powder, tonic and Paste
<i>Odina wodier</i> Roxb.	Anacardiaceae	Odiyan	T	Bark	NE	Bark – Rheumatism, elephantiasis, ulcer, skin infection, wound healing and used as toothpowder	Decoction
<i>Pisonia aculeata</i> L.	Nyctaginaceae	Marukalli	S	Leaves and bark	NE	Bark and leaves – Used to relieve rheumatism	Decoction
<i>Pleiospermium alatum</i> (Wight & Arn.) Sw.	Rutaceae	Kurnthumullthalai	ST	Leaves and bark	NE	Leaves and bark – Used to cure Rheumatic pains	Decoction
<i>Plumbago zeylanica</i> L.	Plumbaginaceae	Venkodiveli	H	Leaves	NE	Leaves – Rheumatism and headache	Decoction, tonic, juice, powder and Paste
<i>Pongamia glabra</i> Vent. BHVCW 102	Fabaceae	Pungamaram	T	Seed and leaves	LC	Seed – Bronchitis, whooping cough, sores and rheumatic joints Leaves – Rheumatism, cough and skin diseases	Decoction, infusion, juice, tonic and powder
<i>Premna latifolia</i> Roxb. BHVCW 104	Verbenaceae	Erumai	ST	Leaves	NE	Leaves – Rheumatic arthritis, coughs, headaches, backaches and fevers	Decoction

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Table 2. Ethnomedicinal plants used for the treatment of rheumatism in Manar beat, Karamadai range, Western Ghats, India

Botanical name	Family name	Local name	Habit	Parts used	Ecological status	Therapeutic uses	Mode of preparation
<i>Prosopis cineria</i> (L.) Druce.	Mimosaceae	Vannimaram	T	Bark	NE	Bark – Asthma, bronchitis, piles, dysentery, leprosy, rheumatism and scorpion stings	Decoction
<i>Pseudarthria viscida</i> W. & A.	Fabaceae	Nirmalli	S	Roots	NE	Roots – Headache, diuretic, asthma, cough, bronchitis, worms, fevers, vomiting, diarrhoea, diabetes and rheumatism	Juice and tonic
<i>Salvadora persica</i> L.	Salvadoraceae	Uka	S	Seeds	LC	Seeds – Rheumatism	Tonic, powder and decoction
<i>Sansevieria roxburghiana</i> Schult.f.	Liliaceae	-	H	Whole plant	NE	Whole plant – Febrifuge, purgative and rheumatism	Tonic
<i>Sida cordifolia</i> L. BHVCW 113	Malvaceae	Mayir-manikham	H	Whole plant	NE	Whole plant – Rheumatism, relieve itching and irritation of chickenpox	Tonic and juice
<i>Solanum trilobatum</i> L. BHVCW 114	Solanaceae	Thoodhuvalai	C	Whole plant	NE	Whole plant – Asthma, blood vomiting, rheumatism and leprosy	Juice and decoction
<i>Tamarindus indica</i> L. BHVCW 118	Caesalpiniaceae	Puli	T	Fruit pulp and leaves	LC	Fruit pulp – Cure fevers and rheumatism Leaves – Rheumatism, throat infection, cough, fever, intestinal worms and wounds	Decoction
<i>Toddalia asiatica</i> Lam. BHVCW 122	Rutaceae	Kattu-milagu	C	Leaves	NE	Leaves – Rheumatism, lung diseases and asthma	Infusion and tonic
<i>Trewia nudiflora</i> L.	Euphorbiaceae	Aattharasu	T	Root	NE	Root – To relieve rheumatic affliction	Decoction
<i>Wattakaka volubilis</i> (L.fil.) Stapf. BHVCW 126	Asclepiadaceae	Kurincha	C	Leaves	NE	Leaves – Dyspepsia, rheumatic pain, cough, fever, cold and eye infections	Paste
<i>Vanda tessellate</i> Hk. BHVCW 125	Orchidaceae	Kantanakuli	E	Roots	LC	Roots – Dyspepsia, bronchitis, inflammations, piles, rheumatism and scorpion stings	Decoction
<i>Vanda Testacea</i> (Lindl.) Rchb.	Orchidaceae	-	E	Leaves and roots	NE	Roots and leaves – Bronchitis, piles, rheumatism, dysentery, cold, scorpion sting, boils and fever	Juice
<i>Vitex altissima</i> L.f.	Verbenaceae	Mayilainochi	T	Bark	NE	Bark – Rheumatic swellings	Paste and decoction
<i>Xylia xylocarpa</i> Taub.	Mimosaceae	Iruvel	T	Seeds	NE	Seeds – Rheumatism, piles and leprosy	Decoction
<i>Zizyphus glabrata</i> W.	Rhamnaceae	Karakodamaram	T	Fruits	NE	Fruits – Fever, cough and rheumatism	Decoction

for diuretic, 5 for jaundice and wound (Fig. 6). Considering the mode of preparation, the commonly prepared herbal medicines in the form of decoction (66%) followed by juice (36%), paste and tonic (22% each). Ayyanar and Ignacimuthu (2004) have reported 14 plants are used for the treatment of skin diseases and 15 plants are used for the treatment of poisonous bites.

The ethnomedicinally documented data was compared

with the available literature and found that many of the usages listed are not recorded earlier (Rathna et al 2009, Rout et al 2009, Nagariya et al 2010). The plant species reported in the current investigation were cross checked with other accessible writing and it was discovered that a portion of the plant species mentioned in the current study were recorded before by various specialists. Previously similar ethnobotanical studies have been reported in different

villages to document the traditional knowledge that has been vanishing (Dhivya and Kalaichelvi 2016, Ayyanar and Ignacimuthu 2011). Based on this database, can concluded that the medicinal values claimed by the Irula tribe of Karamadai reserve forest area are high significance towards curing of different ailments in a traditional manner with their novel nature of choice and planning of herbal medicines from therapeutic plants.

The knowledge on the folklore uses of the medicinal

Table 3. Percentage of plant families used for the treatment of rheumatism disorder

Name of the family	Number of species	Percentage of the species
Euphorbiaceae	7	9.21 %
Rutaceae	7	9.21 %
Capparidaceae	4	5.26 %
Asclepiadaceae	4	5.26 %
Mimosaceae	3	3.94 %
Acanthaceae	3	3.94 %
Verbenaceae	3	3.94 %
Amaranthaceae	3	3.94 %
Caesalpinaceae	3	3.94 %
Sapindaceae	3	3.94 %
Liliaceae	3	3.94 %
Lamiaceae	3	3.94 %
Fabaceae	3	3.94 %
Orchidaceae	2	2.63 %
Convolvulaceae	2	2.63 %
Meliaceae	2	2.63 %
Cucurbitaceae	2	2.63 %
Moraceae	2	2.63 %
Others	16	31.57 %

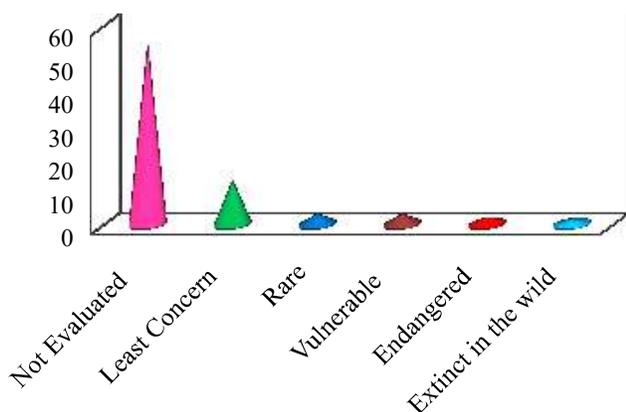


Fig. 5. The conservation status for surveyed medicinal plants

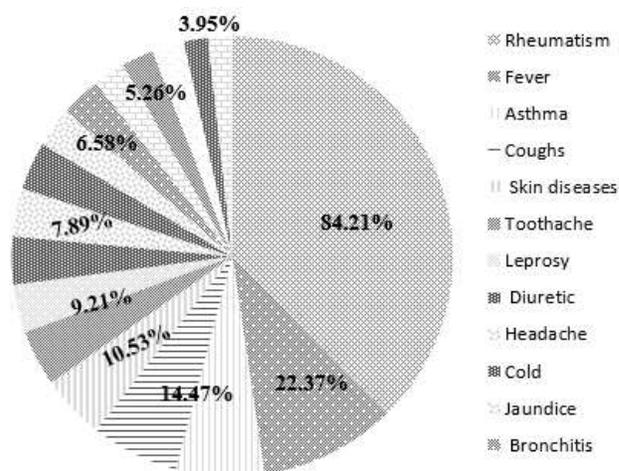


Fig. 6. Statistic of therapeutic effects from the study area

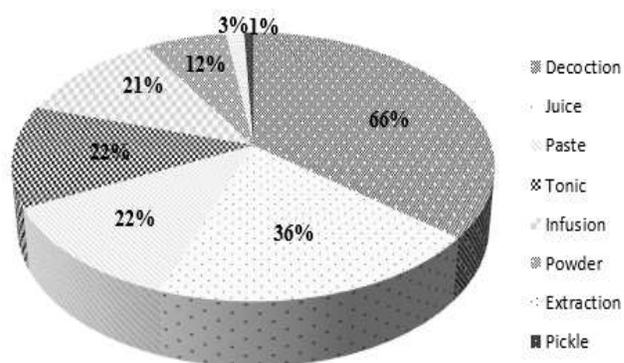


Fig. 7. Pie chart representing different form of medicinal plant species taken for the treatment of rheumatism

plants leads to open up ways for effective utilization of herbal medicines in future. The findings of the present investigation mainly focused on the role of medicinal plants which are helpful in curing many diseases. The study results are more useful to discover new drugs to cure RA. This inventory showing plants with high medicinal values, represents the immense potential role for economic growth through sustainable gathering and trade.

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REFERENCES

- Ayyanar M and Ignacimuthu S 2011. Ethnobotanical survey of medicinal plants commonly used by the Kanitribals in Tirunelveli hills of Western Ghats, India. *Journal of Ethnopharmacology* **134**(3): 851-864.
- Ayyanar M and Ignacimuthu S 2004. Medicinal plants used by the tribal of Tirunelveli hills, Tamil Nadu to treat poisonous bites and skin diseases. *Indian Journal of Traditional Knowledge* **4**(3): 229-236.
- Bentham G and Hooker JD 1862-1883. *Genera Plantarum*, Weldon and Wesley Ltd., Germany. Vols. I. II & III.
- Das PK and Mondal AK 2012. A Report to the rare and endangered medicinal plants resources in the dry deciduous forest areas of Paschim Medinipur district, West Bengal, India. *International Journal of Drug Discovery and Herbal Research* **2**(2): 418-429.
- Dhivya SM and Kalaichelvi K 2016. A study on traditional medicinal plants of Pillur beat (Pillur slope RF and Nellithurai RF), Karamadai range, Coimbatore district, Tamil Nadu. *Journal of Pharmaceutical and Biological Research* **4**(2): 39-51.
- Gamble JS 1984. Flora of the Presidency of Madras, Bishen Singh, Mahendra Pal Singh, Dehradun Vol. **1-3**.
- Kiran D, Rohilla A, Rohilla S and Khan MU 2011. *Phyllanthus amarus*: An ample therapeutic potential herb. *International Journal of Research in Ayurveda and Pharmacy* **2**: 1096-1099.
- Mahajan N, Kaur J, Rawal S, Sharma A, Sen K and Baboo S 2010. Adult rheumatoid arthritis: A review. *International Journal of Pharmaceutical Research and Development* **2**(2): 1-9.
- Matthew KM 1983. *The Flora of the Tamil Nadu Carnatic*. The Rapinet Herbarium, St. Joseph's College, Tiruchirapalli **3**: 278-279.
- Nagariya AK, Meena AK, Jain D, Gupta BP, Yadav AK and Gupta MR 2010. Medicinal plants used in the healing of skin diseases in different regions of India: A review. *International Journal of Chemical and Analytical Science* **1**(5): 110-113.
- Negi K, Amol Vasishth, Reena Joshi and Vinod Kumar 2020. Ethnobotanical uses of medicinal plants in part of Pauri Garhwal. *Indian Journal of Ecology* **47**(4): 1091-1098.
- Rathna P, Prashaanth G and Kumar DA 2009. Ethno-medico botany of medicinal plants for the treatment of diabetic activity in Krishna district, Andhra Pradesh. *International Journal of Pharmaceutical Research and Development* **8**: 1-9.
- Rout SD, Panda T and Mishra N 2009. Ethno-medicinal plants used to cure different diseases by tribals of Mayurbhanj district of North Orissa. *Ethno-Medicine* **3**(1): 27-22.
- Sharmila S, Kalaichelvi K and Abirami P 2015. Ethnopharmacobotanical informations of some herbaceous medicinal plants used by Toda tribes of Thiashola, Manjoor, Nilgiris, Western Ghats, Tamilnadu, India. *International Journal of Pharmaceutical Sciences and Research* **6**(1): 315-320.
- Shyam Sundar Manna and Satyendra Prasad Mishra 2018. Ethnomedicinal survey of plants used by tribal in Lalgarh forest range, West Bengal, India. *The Journal of Phytopharmacology* **7**(2): 199-202.
- Silambarasan R and Ayyanar M 2015. An ethnobotanical study of medicinal plants in Palamalai region of Eastern Ghats, India. *Journal of Ethnopharmacology* **172**: 162-178.

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Sustainable Nutritional Supplementation for Green Economy through Hydroponics System

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Abstract: Hydroponics is a cultivation of plants without soil with formulated nutrient medium growing in a fabricated set of unit. The present study focused on the nine different medicinal and ornamental plants. They were grown in the hydroponics unit supplied with macro and micro nutrients of three different treatments ranges from 200ppm to 450ppm. Experiment was laid to study the length of plants, number of shoot lets and number of days of experimentation with replicates. *Dieffenbachia bowmannii* showed highest length of 38 to 50 cm at 4th & 5th week compared to the remaining plants grown in hydroponics unit. Number of multiple shoots was increased in *Mentha arvensis* grown to the length of 19-45cm with 15-37 numbers of shoots and Table top plant with 25-38 shoots after five weeks of nutritional treatment. Mostly in the process of hydroponics the growth rate and shoots number increased followed by Table top, *Mentha arvensis*, *Capsicum annum*. This study gives the comparative values of growth rate in selected plants through hydroponics system.

Keywords: Green economy, Hydroponics system, Medicinal plants, Nutritional supplements

Hydroponics is an emerging young science in agriculture, farming. It has been formulating as a commercial technique since 40 years. However, outdoor and indoor field greenhouse cultivation was adapted in short period for the growth of fresh vegetables. It balances the source of fresh water and balances the nutrition automatically and promotes the suitable growing media with best hydraulic, physical, and chemical properties, like Rockwool and coir, and helps the plant nutrition and irrigation via modern fertigation equipment and automation technologies (Savvas and Gruda 2018). Hydroponics promotes the growth of plants in absence of soil with requirement of elements, nutrients, minerals similar to that of soil, as the soil holds and supports the roots and plants. In case of hydroponics in absence of soil also it eliminates soil born diseases/weeds and attains the need of plant nutrition and can sustain to stress resistant, mature faster, yields best quality products and finally reaches the customers and consumer needs. Hydroponics growing systems have been developed to get higher yield and quality, to preserve water and land, to save labour and to protect the environment. Yields with hydroponics have averaged around 20 to 25% higher than in conventional cultivation (Parera et al 2009). Growing populations and economies, changing diets, as well as climate change, are leading to increasing water use plus the associated demands on the environment Thus, costly and time-consuming tasks of soil sterilization, soil amelioration can be avoided with hydroponics cultivation (Anonymous 2008,

National Gardening Association 2008, El 2009). Plants in hydroponics grow upto two times faster with higher yields than with conventional soil farming methods due to high oxygen levels to the root system, optimum pH levels for increased nutrient and water uptake and optimum balanced and high grade nutrient solutions (Infoplease 2007, Shamanshop 2007, Fresh from the Garden 2007). Compared to traditional systems, carrots growing hydroponically assure high nutritional content. Since it can be easier to define whether the required amount of nutritional content is present in the carrot or not through regular hydroponic growing system. (Asaduzzaman et al 2013), Encountering the water stresses within the country, the hydroponic agriculture does not seem to be the wave of the future. Green sustainability is gaining a very important place in many countries which are thriving at making their population aware of the environment threats which are being caused by improper disposal of wastes and wastage of resources in terms of high energy usage around the world. Besides, the greenhouse hydroponic can yield the fresh crops throughout the year, irrespective of seasons and make easily available in the local markets with better prices because of its appearance, quality and chemical free. With respect to the regulation of natural sources and ecosystem changing the large growing rate of the population and this brings to the question how to feed the world population. (Delaide et al 2017). There occurs the overtaken of planetary boundaries of biosphere integrity (Ragnarsdóttir et al 2011, Sverdrup and

Ragnarsdottir 2011). By viewing this more resourceful and sustainable agricultural system must be urbanized. (Tyson et al 2011). Besides the commercial soilless culture steps forward slowly while it is anticipated to develop rapidly through coming years along with demands for the food security, changes in climate, shortage of water all these forcefully makes to pay more consideration on soilless culture. Soilless culture totally depends on chemical nutrient solution despite of system like hydroponic, aeroponic and substrate. Here in this study we used the coco peat as a medium in hydroponic system, while environmental and ecological concerns in the recent years suggested mitigating the use of peat because it may destroy endangered wetland ecosystems worldwide (Abul-Soud et al 2016). At the same time, they are the need of local substrate for plant growth and substitute's peat along with compost with variety of compositions without any negative effect. As soilless culture is in demand in recent years helps this study to focus on the different flowering and ornamental plants to study their growth in hydroponic system along with standard medium with the different treatments for about five weeks so that this study helps in giving standard outcome for the improvement of selected plants can be grown in larger units of hydroponic system.

MATERIAL AND METHODS

The investigations were carried out by the collection of plant samples at Vignan's medicinal plant garden (Seed Grant, F. No: VFSTR/Reg/A4/14/2016-17/590) under the

department of biotechnology, Vignan's university, Vadlamudi, Guntur Dist. Andhra Pradesh, India.

Experimental design: The study laid out in recovery drip system, size of 100 (sq. Ft) with an anti-insect mesh, 15m wide, 15.0 m length and 4.70m height. The pressurized irrigation system (on each shelf) was controlled with gate valves. The conductive and distribution pipes of the nutritive solution were made of black PVC, 1cm diameter with one nebulizer each 25 cm of distance, with a consumption of 3L hr⁻¹ each device. Seedlings of each plantlet was placed in each slot running with the nutritive solution containing Ca (300 ppm), Mg (400 ppm), NPK (260 ppm), boric acid (300 ppm), Zn (400 ppm) and S (300 ppm) was applied from the 5th to 12th day after sowing pH 6.5 and E.C 1.10 ds m⁻¹ in a 500 L water tank circulated through PVC tube. This is supplied with the temperature range of 22°C and a relative humidity of 70%. Experiment was laid to study the length of plantlets in cm (LP), no. of shootlets produced (S), no. of days to grow (D) was determined. The study was conducted on *Mentha sachalinensis* (Mint), *Capsicum annum* (Green chili), *Epipremnum aureum* (Money plant), *Dieffenbachia* (Croton), *Plectranthus scutellarioides* (Coleus), Table top rose, *Colocasia esculenta* (Elephant ear plant), *Lilium longiflorum* (Lily) and *Epipremnum aureum* (Golden) collected from Vignan Herbal Medicinal Garden, Vadlamudi, Guntur, India.

RESULTS AND DISCUSSION

The maximum plant height from 2 to 12 WAT (Table 2)

Table 1. Three different treatments with different conc. of nutrients on selected hydroponic plants

Treatments	Ca (PPM)	Mg (PPM)	Cu (PPM)	Zn (PPM)	B (PPM)	NPK (gm)
T1	1800	1170	1000	1250	2000	50gm
T2	2000	4000	2000	2000	2000	25gm
T3	4000	3000	3000	4000	3000	25gm

Table 2. Effects of different concentrations of nutrients on the length (cm) of hydroponic plants (upto 5 weeks)

Name of the plant	Length (cm)														
	1 st week			2 nd week			3 rd week			4 th week			5 th week		
	T1	T2	T3												
<i>Capsicum annum</i>	5	7	7	5	9	10	12	15	17	18	19	19	20	20	21
<i>Dieffenbachia bowmannii</i> ,	10	12	14	15	20	20	22	24	26	30	31	38	43	47	50
Table top	6	12	15	15	19	20	22	24	25	28	29	30	32	35	38
<i>Epipremnum aureum</i>	2	4	9	11	13	16	17	23	25	26	27	27	28	29	30
<i>Mentha arvensis</i>	4	5	8	10	15	17	22	25	28	31	32	36	39	41	45
<i>Lilium longiflorum</i>	5	10	15	15	16	16	18	19	21	23	24	27	30	31	33
<i>Colocasia esculenta</i>	6	6	7	9	13	14	16	18	19	20	20	21	21	22	23
<i>Plectranthus scutellarioides</i>	3	3	5	6	6	7	9	12	15	19	20	20	20	20	20
<i>Epipremnum aureum</i> (Golden)	2	4	8	6	7	10	10	12	15	17	20	22	23	24	25

was measured. Three different treatments with different concentrations of nutrients on selected hydroponic plants after every 15 days (Table 1). The same plants were used throughout the duration of experiments. The data collected included: plant height and number of shoots/plant (Table 3). These parameters were determined after every two weeks between 2 and 12 WAT. Flower harvesting was performed when all the buds were opened, i.e., 13 WAT. Quality of the plant was determined by the length of the stem and number branches/flower. Concentration ranges of essential mineral elements according to various authors (Cooper 1988).

The length of hydroponics plants of *Capsicum annum* (Fig. 5) was varied from 17-21cm after the -5 weeks of transfer with 13-15 multiple shoots. Table top (Fig. 9) showed its length of 14-38cm after 3-5 weeks with 25-38 multiple shootlets. *Epipremnum aureum* (Money plant) (Fig. 8) showed its length of 10-30cm after 4-5 weeks with 15 multiple shootlets. *Mentha arvensis* (Fig.6) showed its length of 19-45 cm after 3-5 weeks with 15 -40 multiple shootlets. *Lilium longiflorum* (Fig. 1) showing its length of 15-33cm after 4-5 weeks with 13-15 multiple shootlets. *Colocasia esculenta* (Fig.2) showed its length of 14-23cm after 4-5 weeks with 4 multiple shootlets. *Plectranthus scutellarioides* (Fig.4) with its length of 10-20cm after 3-4 weeks with 11 multiple shootlets. *Epipremnum aureum* (Golden) (Fig. 7) ranging its length from 25-28 cm after 4-5 weeks with 3 -11 multiple shootlets.

High water holding capacity induced higher vegetative growth in hydroponics culture of ornamental plants like Oriental hybrid lily (*Lilium asiatic*) (Ryota 2002). Similar report made by Galukucocopeat (2011). Growing media containing organic matter like coco peat can stimulate root growth and provide high water holding capacity, which provide a buffer in high temperatures and crop load demand without compromising air supply, coco peat or coir peat

stimulated the roots of the present hydroponic plants with expanded length. The maximum plant length was in *Dieffenbachia bowmannii* followed by *Mentha arvensis*, Table top, *Lilium longiflorum*, grown under coir peat medium compared to the vegetative method. There was significant increase in the number of shoots in selected hydroponic plants observed in Table top, *Mentha arvensis*, *Dieffenbachia bowmannii*, *Lilium longiflorum*, etc.,

Schnitzler et al (2004) observed better plant growth, fruit yield and quality in bell pepper (*Capsicum annum* L.) grown in wood fiber substrate. The present work also states the



Fig. 1. Growth index of *Lilium longiflorum* plant

Table 3. Effects of different concentrations of nutrients on the number of shoots in hydroponic plant for up to 5 weeks

Name of the plant	1 st week			2 nd week			3 rd week			4 th week			5 th week		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
<i>Capsicum annum</i>	2	2	2	5	6	8	9	10	10	11	11	12	12	12	13-15
<i>Dieffenbachia bowmannii</i> , Table top	3	4	4	3	4	4	4	4	5	4	4	5	5	5	6
<i>Epipremnum aureum</i>	8	9-10	12	12	15	16	17	19	22	24	27	30	33	36	38
<i>Epipremnum aureum</i>	2	2	4	5	5	7	8	9	10	10	11	11	12	13	15
<i>Mentha arvensis</i>	10	12	15	17	17	20	23	26	27	29	30	32	34	35	37
<i>Lilium longiflorum</i>	2	3	5	5	6	6	8	8	10	10	10	12	12	14	15
<i>Colocasia esculenta</i>	2	2	2	3	3	3	3	4	4	4	4	4	4	5	6
<i>Plectranthus scutellarioides</i>	2	3	3	3	4	4	4	4	5	5	6	7	8	10	11
<i>Epipremnum aureum</i> (Golden)	3	3	3	3	3	3	4	4	5	6	6	6	7	8	10

growth of *Capsicum annuum* in the presence of coir peat with highest concentration of Mg (4000ppm) in different treatments started showing from 4th week follows to 5th week indicated the better results than other plants. Zoran Bročić et

al (2019) studied the two different cultivation systems, aeroponics and hydroponics in greenhouse beds, were compared for the production of potato minitubers. Simon et al (2013) optimized the hydroponic growth systems for nutritional and physiological analysis of *Arabidopsis thaliana* and other plants and produces plants with similar growth kinetics to soil-grown plants. Highest number of shootlets and growth index of different selected hydroponic plants grown in presence of coir peat could probably by highest



A: Colocasia at 2nd week showing 14cm with 2 shootlets
 B: Colocasia at 3rd week showing 19cm with 2 shootlets
 C: Colocasia at 4th week showing 21cm with 3shootlets
 D: Colocasia at 5th week showing 23cm with 4 shootlets

Fig. 2. Growth index of *Colocasia esculenta* plant



A- Dieffenbachia bowmannii showing its length 14cm with 3shoots at 1st week.
 B-Dieffenbachia bowmannii showing its length 20cm with 4shoots at 2nd week.
 C-Dieffenbachia bowmannii showing its length 26cm with 3-4-shoots at 3rd week.
 D-Dieffenbachia bowmannii showing its length 38cm with 5 shoots at 4th week.
 E,F-Dieffenbachia bowmannii showing its length 50cm with 5-6 shoots at 5th week.

Fig. 3. Growing index of *Dieffenbachia bowmannii*



A- *Plectranthus scutellarioides* showing the length of 22cm at 4th week with 7 shootlets.
 B- *Plectranthus scutellarioides* showing the length of 22cm at 5th week with 11 shootlets.

Fig. 4. Growth index of *Plectranthus scutellarioides* (Coleus)



A- *Capsicum annuum* showing its length 7cm with 1-2shootlets at 1st week.
 B-*Capsicum annuum* showing its length 10cm with 5-8shootlets at 2nd week.
 C-*Capsicum annuum* showing its length 17cm with 10 shootlets at 3rd week.
 D-*Capsicum annuum* showing its length 19cm with 12 shootlets at 4th week.
 E-F:*Capsicum annuum* showing its length 21cm with 13-15 shootlets at 5th week.

Fig. 5. Growing index of *Capsicum annuum*



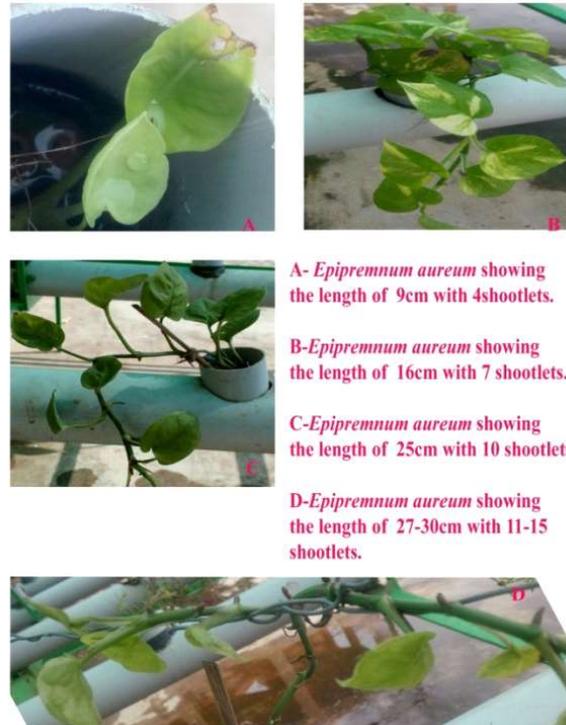
Fig. 6. Growth index of *Mentha arvensis*

Growth index of Golden Money Plant



Fig. 7. A: *Epipremnum aureum* at 1st week showing 10cm with 3 shootlets, B: *Epipremnum aureum* (Golden) at 3rd week showing 15cm with 5 shootlets, C: *G. money* plant at 4th week showing 22cm with 6-7 shootlets, D: *G. Money* plant at 5th week showing 25-28cm with 10 shootlets

water holding and nutrient hold capacities of the medium. Hsu et al (2008) observed a higher flower stem length and number of flowers per stem in *Oncidium orchids* (*Oncidium altissimum*) grown using Rockwool when compared to peat moss, crushed stone, bark and charcoal. Marinou et al (2013) reported that use of saw dust, coco soil & pumice can increase the growth abundantly for the cultivation of straw berry. Many variations in growth responses were influenced by different nutrient contents of potting mixes. Almost the



A- *Epipremnum aureum* showing the length of 9cm with 4shootlets.

B-*Epipremnum aureum* showing the length of 16cm with 7 shootlets.

C-*Epipremnum aureum* showing the length of 25cm with 10 shootlets.

D-*Epipremnum aureum* showing the length of 27-30cm with 11-15 shootlets.



Fig. 9. Top/10 'o' clock plan

results output to the availability of nutrients is an vital factor influencing plant growth (Lazcano et al 2009). But differences in physical and biological properties of the substrate may also be responsible for studied changes (Tringovska and Dintcheva 2012).

CONCLUSIONS

In this research work hydroponics, plant's roots alone take up the amount of water they need at any one time and leave the rest in the reservoir for later. In the current study water that provide at one time will be taken up by the plants for longer time thus gives the forward step for the water conservation for longer period. The treatments given for the 9 plants and with standard medium helps the plants to grow at maximum height where Table top showed its better growth and gives multiple shootlets followed with *Mentha arvensis*, *Capsicum annum*, *Epipremnum aureum*, *Lilium longiflorum*, etc. We can see the better the yield if approached as it needs. It is recommended that this technique can be adapted as a step to produce the food crops and medicinal plants to meet the global demand, and thereby benefits domestic needs and commercial indoor.

REFERENCES

- Anonymous 2008. A primer on hydroponics cut <http://www.gpnmag.com/A-Primer-pn-Hydroponic-Cut-Tulips-articles>, 3267, 10/07/08.
- Asaduzzamana Md, Yutaro Kobayashi, Fuad Mondal Md, Takuya Band, Hitoshi Matsubara, Fumihiko Adachi and Toshiki Asaoa 2013. Growing carrots hydroponically using perlite substrates. *Scientia Horticulturae* **159**: 113-121
- Cooper A 1988. Chemicals needed to prepare 1000 litres of nutrients solution. In: *Hydroponics (soilless culture). Soilless culture book* (English) 18 p. An html. Document. Hydroponics website.
- Delaide B, Delhaye G, Dermience M, Gott J, Soyeurt H and Jijakli MH 2017. Plant and fish production performance, nutrient mass balances, energy and water use of the paff box, a small-scale aquaponic system. *Aquacultural Engineering* **78**: 130-139.
- El-Naggar AH 2009. Response of *Dianthus caryophyllus* L. plants to foliar nutrition. *World Journal of Agriculture Science* **5**: 622-630
- Fresh from the Garden, 2007. Introduction to hydroponics. http://www.diynetwork.com/diy/gr_vegetables/articles/0_2029_DIY_13846_4050774_00.html, 14.08.2007.
- Galukucocopeat 2011. Galuku coco peat growing bags fact sheet. <http://www.cocopeat.com.au/technical/hydroponics/reports/growingbags.asp>, 13/07/11.
- Hsu JH, Lin YH and Lin RS 2008. Effect of Cultural Medium and Hydroponics Culture on Growth and Flower Quality of *Oncidium Gower Ramsey*. http://www.actahort.org/members/showpdf?booknrnrnr=761_68.
- Lazcano C, Arnold J, Tato A, Zaller JG and Domínguez J 2009. Compost and vermin compost as nursery pot components: effects on tomato plant growth and morphology. *Spanish Journal of Agricultural Research* **7**(4): 994-951.
- Marinou E, Chrysargyris A and Tzortzakis N 2013. Use of sawdust, coco soil and pumice in hydroponically grown strawberry. *Plant Soil Environment* **59**(10): 452-459.
- Abul-Soud MA, Emam AMH, Hawash M, Mohammed H and Maharik ZY 2016. The utilization of vermicomposting outputs in ecology soilless culture of lettuce. *Journal of Agriculture and Ecology Research International* **5**(1): 1-15.
- Infoplease 2007. Hydroponics <http://www.infoplease.com/ce6/sci/A0824732.html>, 14/08/07.
- National Gardening Association 2008. Gladiolus planting guide. <http://nga-gardenshop.stores.yahoo.net/gladiolus.html>, 26/5/08.
- Parera R 2009. Hydroponics in commercial food production. <http://ezinearticles.com/?Hydroponics-in-Commercial-Food-Production.74>, 10/07/09.
- Ryota T, Kazunori M, Musao T and Kazuyoshi S 2002. Studies on the hydroponics of oriental hybrid lily. *Journal of Niigata Agriculture Research Institute* **5**: 65-74.
- Savvas D and Gruda N 2018. Application of soilless culture technologies in the modern greenhouse industry: A review. *European Journal of Horticultural Science* **83**(5): 280-293.
- Schnitzler WH, Sharma AK, Grud NS, and Heuberger HT 2004. A low-tech hydroponics system for bell pepper (*Capsicum annuum* L.). *Acta Horticulturae* **644**(3): 47-52.
- Shamanshop 2007. *Hydroponics*. <http://www.shamanshop.net/hydro2.htm>, 14/08/07.
- Simon J Conn, Bradleigh Hocking, Maclin Dayod, Bo Xu, Asmini Athman, Sam Henderson, Lucy Aukett, Vanessa Conn, Monique K Shearer, Sigfredo Fuentes, Stephen Tyerman D and Matthew Gilliam 2013. Protocol: Optimizing hydroponic growth systems for nutritional and physiological analysis of *Arabidopsis thaliana* and other plants. *Plant Methods* **9**(4): 1-11.
- Ragnarsdóttir KV, Sverdrup H and Koca D 2011. Challenging the planetary boundaries 1: Basic principles of an integrated model for phosphorous supply dynamics and global population size. *Applied Geochemistry* **26**: 303-306.
- Sverdrup HU and Ragnarsdóttir KV 2011. Challenging the planetary boundaries 2: Assessing the sustainable global population and phosphate supply, using a systems dynamics assessment model. *Applied Geochemistry* **26**: 307-310.
- Tringovska I and Dintcheva T 2012. Vermicompost as substrate amendment for tomato transplant production. *Sustainable Agriculture Research* **1**(2): 115-122.
- Tyson RV, Treadwell DD and Simonne EH 2011. Opportunities and challenges to sustainability in aquaponic systems. *HortTechnology* **21**(1): 6-13.
- Zoran Broć, Mirko Milinkovi, Ivana Momčilovi, Jasmina Oljača, Biljana Veljković, Drago Milošević and Dobrovoj Pošćić 2019. Comparison of aeroponics and conventional production system of virus-free potato mini tubers in Serbia. *Agro-knowledge Journal* **20**(2): 95-105.



Studies on Nesting Colonies of Heronry Birds in Bhavnagar City, Gujarat, India

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Abstract: Heronry birds mostly prefer the wetland ecosystem for their breeding activities. However, many of those utilize urban ecosystems for their nesting activities as they found suitable breeding habitats viz. dense tree colonies within city areas. To deliver inputs into the habitat management and conservation of these birds, number of nests of heronry birds in the urban environment of the Bhavnagar city, Gujarat, were examined. The identification of potential nesting grounds and counting of nests of five heronry bird species (Painted stork, Black-headed Ibis, Red-naped ibis, Eurasian spoonbill, Little cormorant) was done in eight potential habitats of the Bhavnagar city area. This surveying activity carried out from June 2017 to May 2018. The peak breeding season of selected water birds was observed from late summer (April-May) to winter (January-February). A total of 506 nests were counted from the study areas which shows proximity to water bodies and among these 33% were observed from Krishnakumarsinhji Town Hall followed by 30% from Manila bag. Principle trees such as *Azadirachta indica*, *Peltophorum pterocarpum*, *Polyalthia longifolia* and *Syzygium cumini* observed to prefer by water birds. Relationship between tree height and number of nests, co-occurrence of nesting of water birds and their behavior to build nests near water bodies were studied.

Keywords: Nesting ecology, Heronry birds, Nesting tree, Bhavnagar city

Multi-species heronry survey in city areas of Bhavnagar was studied for some breeding and ecological aspects. Four Ciconiiform birds, Painted stork (*Mycteria leucocephala*), Eurasian Spoonbill (*Platalea leucorodia*), Black-headed Ibis (*Threskiornis melanocephalus*), Red-naped Ibis (*Pseudibis papillosa*) and one Pelecaniform member Little Cormorant (*Phalacrocorax niger*) considered into this account. All selected water birds were common resident and seen around water bodies like lakes, marshes, rivers, lagoons, salt pans, shallow coastal areas and even in fields of Saurashtra, Kachchh and Gujarat (Ganpule 2016). Heronry also termed as rookery which means an assembly of nests high in a mass of trees which comprises water bird crowds like herons, egrets, storks, ibises, pelicans, spoonbills, darter, and cormorants (Urfi et al 2005, Roshnath and Sinu 2017).

Water birds were strong colonial and choose areas for breeding only after careful evaluation of the prevailing safety measures. Breeding success in water birds principally depends on interspecies and intraspecies interactions in heronries (Roshnath et al 2019). They choose the site which protects nests from the predators, adverse climatic conditions and offers constant resources for nesting, breeding, foraging, and feeding (Hilaluddin et al 2003, Evans et al 2015, Minias and Kaczmarek 2013). The accessibility of nesting trees and nesting materials are also the most

important factors which attract the water birds and besides these, features including the size, height, canopy, number of branches also have a key role for selecting the nesting area. (Erwin et al 1998, Baxter and Fairweather 1998, Ajitha and Jose 2013). Permanent populations can be established upon the colonizing abilities that may help to adopt more in the urban climates (Moller 2008), but formation and elimination of heronries is a continuous process (Frederick and Mayer 2008).

Water birds usually breed in wetlands, mangrove and marshy areas and parks, parks and gardens in urban areas. Similarly, in Bhavnagar city and nearby places they are found nesting within human-inhabited areas such as residential area and non-residential, roads sides (Sashikumar and Jayarajan 2007). According to Chakraborty & Majmudar (2018) 26 species of water bird reported to nest colonially in India among these, 22 water bird species breed in Gujarat (Pandey et al 2010) which includes herons, storks, ibis, pelicans, egrets, and cormorants etc. Bhavnagar city situated close to the Arabian ocean and several wetlands, as well as inlets of several rivers, open into Gulf of Khambhat. It comprises many large trees and green spaces beside streets, highways, and other public gardens. Various researchers and NGOs have documented the population of water birds in this area (B.I.R.D surveys 2005 2007 and 2010,

Pandey et al 2010, Parasharya and Gadhvi 2019). The main objectives of the present work were to study water bird heronries in the Bhavnagar city and identify the nesting tree species of heronry birds.

MATERIAL AND METHODS

Bhavnagar is, located near the Gulf of Khambhat in Saurashtra peninsula of the western part of Gujarat state, placed between 21° 00' and 22° 30' N Latitudes and 71°15' and 72°30' E Longitudes and has a hot semi-arid climate. Initially, more than 20 places were visited in and around Bhavnagar city. Among these prominent sites where nesting activities of heronry birds observed, eight sites were selected namely, Pill Garden (PG), Mahila Bag (MB), Krishnakumarsinhji Town Hall (TH), Railway Colony (RC), Railway Hospital (RH), INARCO Company (IC), Anandnagar (AN) and University Campus (UC) because nesting activities observed in these sites only (Fig. 1, Table 1). The dominant terrestrial vegetation in these areas consists of trees of *Syzygium cumini*, *Cocos nucifera*, *Polyalthia longifolia*, *Butea monosperma*, *Peltophorum pterocarpum*, *Ficus benghalensis*, *Mangifera indica*, *Prosopis cineraria*, *Azadirachta indica*, *Millettia pinnata*, *Adansonia digitate*, *Ficus religiosa*, *Acacia nilotica*, *Ficus amplissima*, *Holoptelea integrifolia*, *Delonix regia* etc. Other stations were utilized by heronry birds for other purposes like feeding and roosting.

From these different sites, heronry nesting data was collected from July 2018 to March 2019. Direct observation and Ground count method were selected for the study (Fasola et al 2011). A pair of Nikon (7x35) binocular and camera (Canon 200D) was used to minimize the disturbance. Bird species were identified in the field by using Grimmett et al (1999). A sample nest was monitored on a

regular basis, nest height, tree preference, and the average height of the tree were recorded. Bird species were recorded as nesting only if the active nest was observed. Active nests were identified with the occurrence of incubating adults, or nestlings/ eggs. Geographic features of selected sites were obtained by using Google Earth. Standard software was used for quantitative and qualitative analysis of the data.

RESULTS AND DISCUSSION

Number of nests: The study was conducted in Bhavnagar city area of Gujarat state and explores eight potential breeding sites which are public gardens and residential areas of the town. A total of 506 nests were observed on various trees from selected sites. Among these highest 271 nests were of Painted storks followed by 101, 68, 58 and 8 nests of Little cormorants, Black-headed ibis, Eurasian spoonbill, and Red-naped ibis (Fig. 2). All the nests of Painted stork recorded from three sites only viz., Pill garden (42%), Mahila bag (32%) and Town hall (26%) whereas, Black-headed ibis nests were observed in Mahila bag (90%) and Railway hospital (10%). Eurasian spoonbill builds their nests in isolated colonies within three distinct areas which are Railway hospital (53%), Inarco company (26%), and Railway colony (21%). Little cormorant observed to utilize two closely placed habitats, Mahila bag (95%) and Town hall (5%), and lastly fewer nests of Red-naped ibis recorded in Anandnagar and university campus area (Fig. 3).

Bray-Curtis similarity graph indicates there were three groups based on number of nests. The first group comprises pill garden, mahila bag and town hall as these sites were noticed with great mass of nests whereas second and third groups of other sites which shows more closer to each other in terms of numbers of nests (Fig. 4). Among recorded

Table 1. Description of selected stations

Station	location type	Coordinates	Area (km ²)	Traffic load	Nesting materials	Foraging options	Distance from water body (s) (km)
PG	Public garden	21°46' 19.99" N 72°08' 28.97" E	0.058	Very high	Adequate	High	0.43
MB	Public garden	21°46' 28.48" N 72°08' 45.65" E	0.012	high	Adequate	High	0.17
TH	Public garden	21°46' 25.72" N 72°08' 05.79" E	0.015	high	Adequate	High	0.11
RC	Residential Area	21°46' 09.88" N 72°07' 09.62" E	0.100	Low	Adequate	High	0.74
RH	Residential Area	21°45' 39.57" N 72°06' 56.65" E	0.010	Very high	Adequate	High	0.89
IC	Industrial Area	21°45' 57.47" N 72°09' 10.24" E	0.012	Low	Adequate	High	1.30
AN	Residential Area	21°46' 49.42" N 72°10' 07.63" E	0.022	Low	Adequate	High	0.62
UC	Non-residential area	21°45' 19.55" N 72°08' 29.68" E	0.025	Low	Adequate	High	1.36

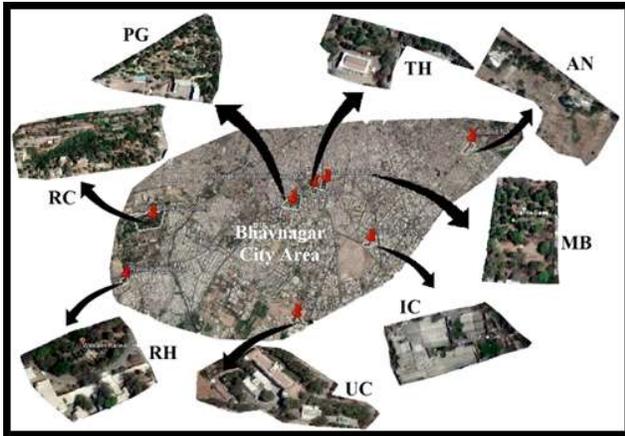


Fig. 1. Location map of study area

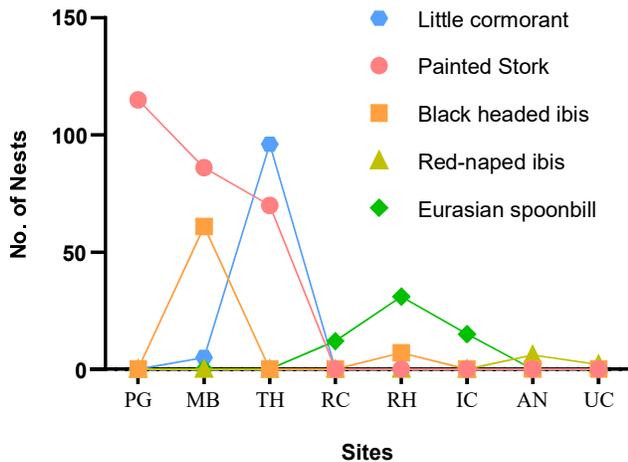


Fig. 2. No. nest of selected heronry birds in study area

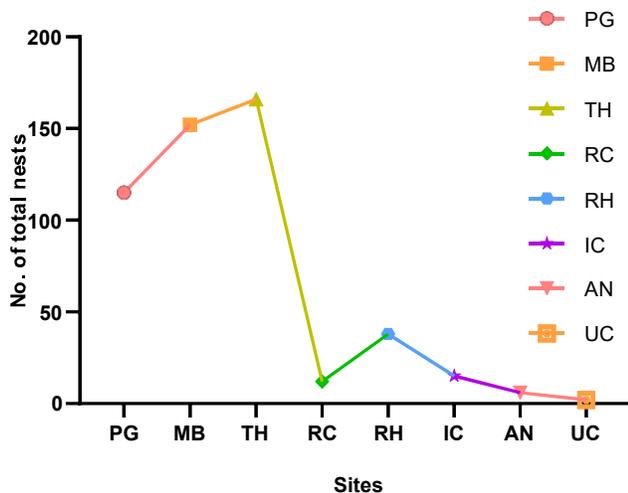


Fig. 3. No. nest in study area

heronries in Bhavnagar city area, fewer are established heronries in this semi-arid region with less than 600 mm rainfall and temperature range of 13°C to 42°C. The suitable climate of Bhavnagar city supports about 12 to 15 species of water birds. Including heronry birds like Little egret (*Egretta garzetta*), Intermediate egret (*Ardea intermedia*), Cattle egret (*Bubulcus ibis*), Black-crowned night heron (*Nycticorax nycticorax*), Western reef heron (*Egretta gularis*).

Areas that rich in the context of suitable large trees, feeding ground nearby and low predation pressure, probably set the city a preferred breeding ground for the waterbirds (Roshnath and Sinu, 2017). Along with nesting locations, year-round nutrition resources, less predatory pressure and stable climatic conditions offered by an urban ecosystem (Fischer et al 2012, Seedikkoya and Azeez 2012, Ajitha and Jose 2013, Griffin et al 2017, Roshnath et al 2019). Many authors have suggested that a low predatory pressure favours water bird nesting activities in urban areas so, the nest site selection, nesting preference, and architecture of nests directly correlate with the predation rate (Garg 2016).

Nesting activity: Nesting activities like courtship, nest building, incubation, fledging and nestling feeding observed superficially for studying about their breeding season. Painted storks were observed to perform these activities during September-October and which lasts up to winter, while Eurasian spoonbill performed activities bit early during August-September. In the case of Black-headed ibises and little cormorants, the courtship and nest building were observed during July whereas they incubate their eggs and nourish their nestlings during August-September. Red-naped

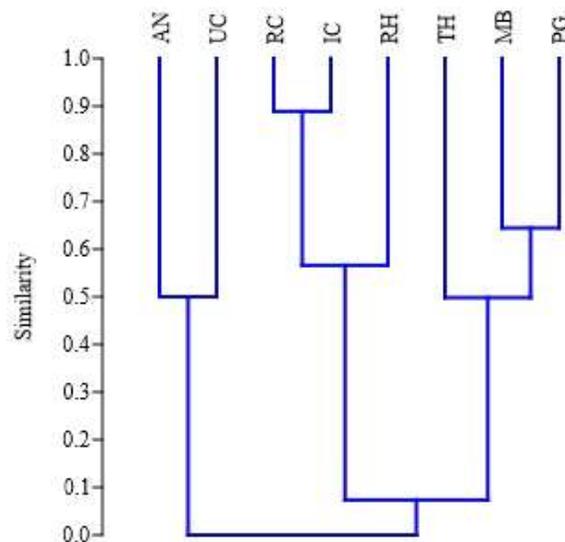


Fig. 4. Bray-Curtis similarity index of observed heronries in selected nesting sites

ibises observed busy in these activities in post-monsoon or pre-winter during February-March. The nest of heronry birds was severely damage due to heavy rainfall and sometimes nestlings fallen from the nest. It was also observed that the heronry birds reuse whole nest or some time they use materials from old nest for construction of new nest (Fig. 5).

Trees used for nesting: Selected five heronry bird species found to build their nests on 16 different tree species namely, *Syzygium cumini*, *Cocos nucifera*, *Polyalthia longifolia*, *Butea monosperma*, *Peltophorum pterocarpum*, *Ficus benghalensis*, *Mangifera indica*, *Prosopis cineraria*, *Azadirachta indica*, *Millettia pinnata*, *Adansonia digitate*, *Ficus religiosa*, *Acacia nilotica*, *Ficus amplissima*, *Holoptelea integrifolia* and *Delonix regia*. Total 225 trees were utilized for nesting activity by heronry birds in the study area. Major nest trees were *Peltophorum pterocarpum* (29%) followed by *Polyalthia longifolia* (20%), *Syzygium cumini* (12%), *Azadirachta indica* (11%), and *Ficus benghalensis* (8%) Whereas, other nest trees contributed approximately up to 1-5 % only which may differ according to sites (Fig. 6).

Selected all sites comprises numerous large trees, which forms green uneven carpet 9-12 meters up from the ground. Waterbirds use trees to construct nests set up on the upper canopies of large trees (Roshnath et al 2019). Waterbirds used different trees for building nests however, some water birds showed preferences towards nesting trees species (Ali & Ripley 1978). According to Naher (2015) selection for Nesting was not dependent on the tree species but dependent on some closely placed trees.

Tree composition in the heronry: Pill garden consists of two principle nesting trees *Azadirachta indica* (38.70%) and *Peltophorum pterocarpum* (26.80%) whereas, another station comprises about maximum numbers of *Polyalthia longifolia* (35%) and *Azadirachta indica* (31%) within the total mass of nesting trees. *Syzygium cumini* (12%) and *Ficus religiosa* (8%) also showed considerable numbers in selected stations. Bray-Curtis similarity graph indicates Pill garden and Town hall comprises similar micro-habitats in context of plant diversity and measurements. Mahila Bag, University campus and Railway colony areas showed similarity as comprises same plant species but in numbers. Where the small areas principally contain *Azadirachta indica* (Fig. 6 and Fig. 7). All selected plants are tall, leafy and placed at considerable distances from water. Bird-like Red-naped Ibis (Black Ibis) also found to nest on the tall electric pole (Sangha 2013).

Relationship between tree height and no. of nests: Height of nesting trees was observed between 9 to 12 meters. Selected species were observed to build their nests on a specific range of heights of trees. Painted storks and Red-

naped ibis were used to construct their nests and showed affinities with upper and upper-middle canopy, average 10 meters while Eurasian spoonbill and Black-headed ibis observed to build their nests on an upper-middle canopy of up to 10.36 meters. Little cormorant prefers top canopies and observed to construct their nests on the height of about 11 meters with a greater number of heights among selected heronry birds (Fig. 8). Most nests were observed in the upper and middle canopy areas of tall trees (Chaudhury and Koli 2018), same result was also observed in the present study. Dense canopy prevents the nestlings falling right on the



Fig. 5. Photo collage of heronry bird at study areas (a) Painted storks building nests on *Mangifera indica*, (b) Black-headed ibis nests on *Polyalthia longifolia* (c) Eurasian Spoonbill incubating eggs, (d) Black-headed ibis nests on *Cocos nucifera* (e) *Coutship* little coremorants (f) Painted storks collecting nest material, (g) Inactive nest, (h) Nestling fallen to the ground, (i) Courtship of Black-headed ibis

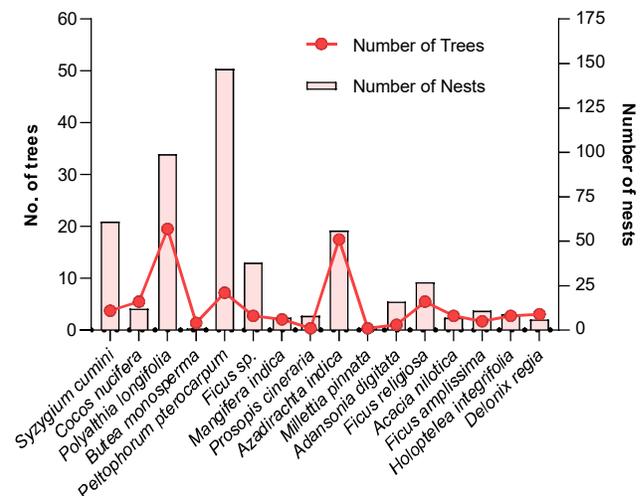


Fig. 6. No. of nests recorded on tree species

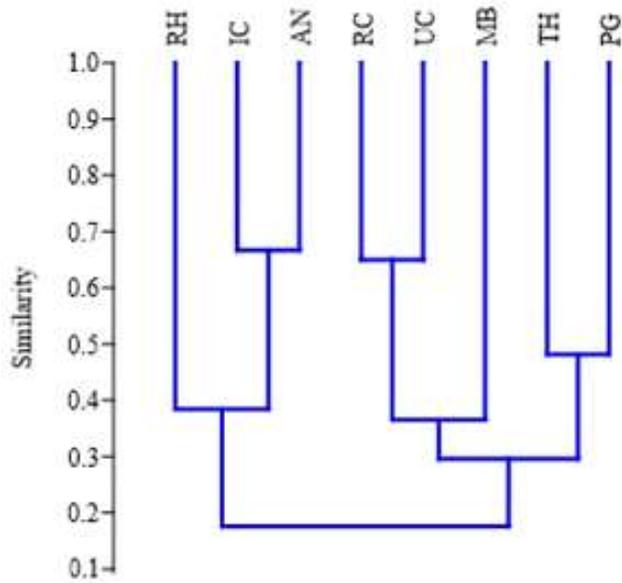


Fig. 7. Bray-Curtis similarity index of observed tree species in study area

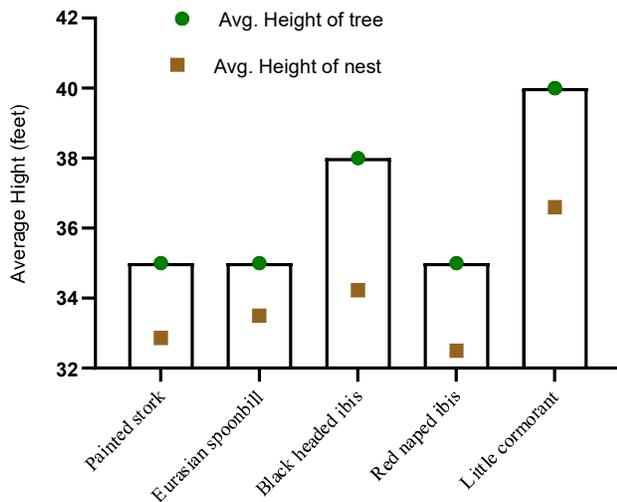


Fig. 8. Average tree height and heronry bird nest height

ground and decreases thermal stress to new-borns (Dayananda and Hosetti 2009, Senma and Acharya 2010) and building nesting on the upper canopy or heightened could be advantageous in getting elevation infrequent flights.

Spatial association/co-occurrence of nesting species in the heronry: Painted storks were observed to share nesting ground with Black-headed ibises and Little cormorants in large heronries areas occupying dense trees, however, their sub-colonies not reported frequently in selected areas. Eurasian spoonbills showed considerable dissociation with other bird species, their nesting activities noticed in the quite

isolated and sparsely grown tree areas. Red-naped ibises showed lesser evidence of nesting together with other heronry birds and showed a similar trend to Eurasian Spoonbills to build nests on fewer disturbance areas.

Species preference of nesting trees: Painted storks were reported to preferring wide range of plant species namely *Syzygium cumini*, *Polyalthia longifolia*, *Peltophorum pterocarpum*, *Ficus benghalensis*, *Mangifera indica*, *Azadirachta indica*, *Adansonia digitate*, *Ficus religiosa*, *Acacia nilotica*, *Ficus amplissima*, and *Delonix regia*. Eurasian spoonbills found to construct nests on *Azadirachta indica*, *Delonix regia* and *Holoptelea integrifolia*. Black-headed ibis nests principally noticed on *Syzygium cumini* and *Polyalthia longifolia* but also found to utilize *Cocos nucifera*, while Red-naped ibises recorded to build their nests on *Azadirachta indica* and *Cocos nucifera*. Little cormorants were observed quite choosy about building of nests, their colonies observed only on a plant species *Peltophorum pterocarpum*.

Water body distance from the nesting sites: All five selected heronries bird species which tend to construct nests in colonies near to the water bodies. All the colonies found here were found around freshwater sources. Three sites, Pill Garden, Mahila Bag and Town hall, where the largest heronries observed were the closest (< 0.5 km) to the water body Gangajaliya Lake in the center of the city. As these sites surround the lake area birds can access the water body for food. Railway Colony and Railway Hospital areas were placed at the accessible distance from Gaurishankar Lake (< 1 km). University Campus and Anandnagar were the sites which are distantly placed from water bodies but quite reachable. Very few nests were observed distance from the water bodies (Table 1). As regards the conservation status nearly all the species colonizing in the present heronries are belongs to least concern Eurasian spoonbill, Red-naped ibis and Little cormorant except two, Painted stork and Black-headed Ibis which have near threatened status (IUCN\ 2012). Public Gardens, as well as residential areas within and around Bhavnagar city, are relative safe (Parasharya and Naik 1990) and desirable for nesting of water birds and these novel conditions offer possibilities for bird species that approve surviving with the challenges of fluctuating environments. Urbanization theatrically alters the historical habitats within species have evolved (Alberti et al 2017), considering high human density (Kight and Swaddle 2007), increase in artificial light (Dominoni et al 2013, Gaston et al 2010), increase of chemical pollution (Hui 2002), raised levels of noise (Laiolo 2010). The man-made stresses like close building towers, cell-phone towers, noisy motorways, light pollution and high lighting towers, vehicular discharges, waste discharge and

direct human access to the nests make heronries vulnerable (Chakraborty & Maunder 2018). According to previous reports, in 1979 there were only about 40 nests of Painted stork were recorded from Pill garden and Gogh area of Bhavnagar city and during 2003 number of recorded nests was 482 and during 2004 it was 328 (Parasharya and Naik, 1990) and now 271. These overall figures suggest heronry size of painted storks decreased by the time. However, nesting data about other heronry birds was may be recorded but not published. Nevertheless, waterbirds are well protected in Bhavnagar city areas because of the cultural environment of a dominant religious group of residents in the city which protects against harassment and killing of birds (Parasharya and Naik, 1990). Not only for birds but also conscious about preserving trees in the surroundings. It was observed that fledglings of painted stork were most affected by firecrackers during Diwali festival and strings of the flying kites during kite-flying festival, due to awareness in public and emergency help by the forest department and NGO's mortality of birds are decreasing. Due to increase urban developments and alteration in feeding ground, there is a need for conservation for heronries in the city area.

CONCLUSION

Bhavnagar city area comprises eight potential sites that serve the best ecological conditions, protection and suitable climatic conditions for breeding activities for multi species heronries. Five heronry bird species namely Painted stork (*Mycteria leucocephala*) Little Cormorant (*Microcarbo niger*) Black-Headed Ibis (*Threskiornis melanocephalus*) Eurasian Spoonbill (*Platalea leucorodia*) and Red-naped Ibis (*Pseudibis papillosa*) were reported nesting in eight areas of Bhavnagar city. Despite being public areas, Mahila Baag, Town hall and Pill Garden are the sites which are quite rich with different and tall tree species which provide all essential facility for building nests. However, these sites were much closer to a small water body, Gangajaliya Lake which may also play a key role in serving as a feeding ground. These birds take long flights for food in wetlands, saltpans and coastal areas surrounding Bhavnagar city. Plantation of tress like *Ficus benghalensis*, *F. religiosa*, *Azadirachta indica*, *Syzygium cumini*, *Cocos nucifera*, *Polyalthia longifolia*, *Peltophorum pterocarpum*, *Mangifera indica*, and *Delonix regia* supports great number of nesting pairs. A constant, scientific, and long-term monitoring and intensive care is required for conservation of these precious heronries of Bhavnagar city.

REFERENCES

- Ajitha KV and Boby Jose 2015. Kallettumkara Heronry, An Ideal Breeding Site for Waterbirds in Kerala, South India. *International Journal of Science and Research (IJSR)* 4(3): 923-927

- Alberti M, Correa C, Marzluff JM, Hendry AP, Palkovacs EP, Gotanda KM, Hunt VM, Apgar TM and Zhou Y 2017. Global urban signatures of phenotypic change in animal and plant populations 2017. *Proceedings of the National Academy of Sciences of the United States of America* 114: 8951-8956.
- Ali S and Ripley SD 1978. *Handbook of the birds of India and Pakistan*, Oxford University Press, New Delhi, Volume 1 (2ed.) pp. 39-41.
- Baxter GS and Fairweather PG 1998. Does available foraging area, location or colony character control the size of multispecies egret colonies? *Wildlife Research* 25(1): 23-32
- Chakraborty DC and Majumder S 2018. Urban Heronries of Kolkata Metropolitan: An Insight to Nest Stratification, Resource Based Guilds and Conservation Priorities. *Asian Journal of Conservation Biology* 7(2): 106-112.
- Chaudhury S and Koli VK 2018. Population status, habitat preference, and nesting characteristics of black-headed ibis *Threskiornis melanocephalus* Latham, 1790 in southern Rajasthan, India. *Journal of Asia-Pacific Biodiversity* 11(2): 223-228.
- Dayananda GY and Hosetti BB 2008. Nesting and nidification activities of the Black headed Ibis (*Threskiornis melanocephalus*) in mid-western Ghat region of Karnataka, South India. *Current Biotica* 2: 439-452.
- Dominoni D, Quetting M and Partecke J 2013. Artificial light at night advances avian reproductive physiology. *Proceedings of the Royal Society B-biological Sciences* 280: 20123017
- Erwin RM, Nichols JD, Eyster TB, Stotts DB and Truitt BR 1998. Modelling colony-site dynamics: A case study of gull-billed terns *Sterna nilotica* in coastal Virginia. *The Auk* 115(4): 970-978.
- Evans BS, Ryder TB and Reitsma R 2015. Characterizing avian survival along a rural-to-urban land use gradient. *Ecology* 96: 1631-1640.
- Fasola M and Alieri R 1992. Conservation of heronry Ardeidae sites in North Italian agricultural landscapes. *Biological Conservation* 62: 219-228.
- Fischer JD, Cleeton SH and Lyons TP 2012. Urbanization and the predation paradox: The role of trophic dynamics in structuring vertebrate communities. *BioScience* 62: 809-818.
- Frederick PC and Meyer KD 2008. Longevity and size of Wood stork (*Mycteria americana*) colonies in Florida as guides for an effective monitoring strategy in Southeastern United States. *Waterbirds* 31: 12-18.
- Ganpule P 2016. The Birds of Gujarat: Status and Distribution. *Flamingo* Vol. VIII 3 - XII 4.
- Garg A 2016. Nest-plant correlation and predator preclusion in Asian Open-bill storks (*Anastomus oscitans*): A case study from Nawabgunj bird sanctuary, India. *Indian Forester* 142: 179-186.
- Gaston KJ, Davies ZG and Edmondson JL 2010. *Urban environments and ecosystem functions*. Urban Ecology, Springer Dordrecht Heidelberg London New York. 35-52.
- Griffin AS, Tebbich S and Bugnyar T 2017. Animal cognition in a human-dominated world. *Animal Cognition* 20: 1-6
- Grimmett R, Inskipp C and Inskipp T 1999. *Pocket guide to the birds of the Indian Subcontinent*. New Delhi, Oxford University Press, pp 1-384
- Hilaluddin, Shah JN and Shawl TA 2003. Nest site selection and breeding success by Cattle Egret *Bubulcus ibis* and Little Egret *Egretta garzetta* in Amroha, Uttar Pradesh, India. *Waterbirds* 26: 444-448.
- Hui CA 2002. Concentrations of chromium, manganese, and lead in air and in avian eggs. *Environmental Pollution* 120: 201-206.
- Seedikkoya K, and Azeez PA 2012. Breeding biology of Little Egret *Egretta Garzetta* in Kerala Southern India. *Journal of the Bombay Natural History Society* 109(1 & 2): 96-100.
- Kight CR and Swaddle JP 2007. Associations of anthropogenic

- activity and disturbance with fitness metrics of eastern bluebirds (*Sialia sialis*). *Biological Conservation* **138**: 189-197.
- Laiolo P 2010. The emerging significance of bioacoustics in animal species conservation. *Biological Conservation* **143**: 1635-1645.
- Minias P and Kaczmarek K 2013. Is it always beneficial to breed in the centre? Trade-offs in nest site selection within the colony of a tree-nesting waterbird. *Journal of Ornithology* **154**: 945-953.
- Moller AP 2008. Flight distance of urban birds, predation, and selection for urban life. *Behavioral Ecology and Sociobiology* **63**: 63-75.
- Naher H 2015. Nesting colonies of little cormorant (*Phalacrocorax niger*) in different study areas of Bangladesh. *Bangladesh Journal of Zoology* **42**(1): 35-44.
- Pandey CN, Tatu KS and SB Munjpara 2010. *Survey of Colonial Breeding Waterbirds of Gujarat State*. Gujarat Ecological Education and Research (GEER) Foundation, Gandhinagar, p 111.
- Parasharya BM and Gadhvi IR 2019. First report of successful breeding of Greater Flamingo in the Gulf of Khambhat, India, outside its traditional nesting range. *Indian BIRDS* **15**(5): 136-139.
- Parasharya BM and Naik RM 1990. *Ciconiiform birds breeding in Bhavnagar City, Gujarat: A study of their nesting and plea for conservation*. Conservation in Developing Countries. Proc. Centenary Seminar, Bombay Natural History Society, p 429-445.
- Roshnath R and Sinu PA 2017. Are the heronry birds adapting to urbanization? *Zoo's Print* **32**(12): 27-33.
- Roshnath R and Sinu PA 2017. Nesting tree characteristics of heronry birds of urban ecosystems in peninsular India: Implications for habitat management. *Current Zoology* **63**(6): 599-605.
- Roshnath R, Athira K, and Sinu PA 2019. Does predation pressure drive heronry birds to nest in the urban landscape? *Journal of Asia-Pacific Biodiversity* **12**(2): 311-315.
- Sangha HS 2013. Nesting of black Ibis *Pseudibis papillosa* on electricity pylons near Bikaner, Rajasthan, India. *Indian BIRDS* **8**(1): 10-11.
- Sashikumar C and Jayarajan O 2007. Census of the heronries of north Kerala. *Malabar Trogon* **5**(1): 2-8.
- Senma RC and Acharya CA 2010. Nest and nest contents of near threatened black Headed Ibis (*Threskiornis melanocephalus*). *Asian Journal of Animal Science* **4**: 146-147.
- Urfi AJ, Sen M, Kalam A and Meganathan T 2003. Counting birds in India: Methodologies and trends. *Current Science* **89**(12): 1997-2003.

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Study of Seed Dispersal by the Indian Sloth Bear (*Melursus ursinus*) in Nawada Forest Division, Bihar (India)

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Abstract: Sloth bears (*Melursus ursinus*) are mainly myrmecophagous, but in the present study, fruit seeds were found in 40 scats and 25 scats of sloth bear collected during summer and monsoon respectively in Nawada Forest Division, Bihar, India. Seeds of three of four plant species collected from scats germinated faster than seeds not passing through bears. Seeds of fleshy fruit species were found intact in the scats of sloth bear. In the summer season, scats were dominated by seeds of *Syzygium cumini* (family Myrtaceae), *Cassia fistula* (family Fabaceae) and *Mangifera indica* (family Anacardiaceae). In the monsoon season, fruits were less frequent in scats but those of *S. cumini*, *Buchanania lanzan* (family Anacardiaceae) predominated. Maximum seed germination was observed in *S. cumini* (84%), followed by *B. lanzan* (70%), *C. fistula* (58%) and *Mangifera indica* (48%). However, the seed germination time was significantly different in both unpassed and passed seeds of those plant species except *Cassia fistula* species. These results suggest that the sloth bear may play an important role in the population dynamics of fleshy-fruited species of the region.

Keywords: *Melursus ursinus*, Sloth bear, Seed dispersal, Scat analysis, Nawada Forest Division, Bihar

The importance of forests cannot be underestimated. Forests cover nearly a third of all land on the earth, providing vital organic infrastructure for some of the planet's densest, most diverse collection of life. Forest is important for biodiversity, environment and ecological benefits, food security, soil conservation potential and mitigation of the climate change and job opportunity in tropics (Kumar et al 2018). The biodiversity of forests is depleting at an alarming rate due to anthropogenic activities and climate change (Reddy et al 2011, Devi et al 2019). Moreover, habitat quality depends on both functional and structural pattern of landscape. Nature of forest habitat shape complexity becomes a new subject matter in biodiversity management (Mandal and Chattarjee 2020). Seed dispersal is a key success in plant communities and frugivory is very important in vertebrate communities (Corlett 2017). The role of bears in seed dispersal is inevitable (Fredriksson et al 2006, Ngoprasert et al 2011, Steinmetz et al 2013). Indian sloth bear, *Melursus ursinus* is one such bear species among housekeeping species of Indian forest. They play an important role in seed dispersal and termite control as both are considered vital for long term sustenance of forest ecosystems. The role of sloth bears as seed dispersal is helpful in the population dynamics of fleshy -fruit species in South India. The bears have a great influence on the species composition of plants in their ecosystem (Harrer and Levis 2018). The sloth bear being adapted to myrmecophagous, makes them unique among all bear species, endemic to

Indian Subcontinent and widely spread from the foothills of Himalayas to the southern end of Western Ghats. They are mostly prevalent in India, Nepal, Bhutan and Sri Lanka. Sloth bears exhibit several adaptations to their subtropical and tropical habitat and to their diet and travel large distances in dispersing seasonal food. They have large tongues and mobile snouts and an adaptation to its mode of feeding on ants and termites. Huge feet and enormous claws of sloth bears are suitable for digging up termites' colony. However, earlier studies indicate that diets of sloth bears may vary seasonally and geo-graphically depending on availability of fruit and hardness of mounds that harbour colonies of termites. Yoganand et al (2005) suggested that sloth bears seem to have a behavioural adaptation to avoid hot weather conditions in their habitat by reducing daytime activity. They are efficiently adapted to tropical environment. Studies of Mewada and Dharaiya (2010) on seasonal dietary composition of sloth bear in North Gujarat suggest variations in their diet depending on the availability and abundance of insects and food resources. Mewada et al (2019) also suggested the fruits as the major food resource for sloth bear, and the factors affecting their availability will directly affect the foraging activities of sloth bears. The diet composition of sloth bear with respect to insects-fruits ratio, varies with the seasonal and geographical location (Mewada and Dharaiya 2010, Sukhadiya et al 2013). During fruiting season of trees, 70-90% of bear diet may comprise of fruits, while for the rest of the seasonal year, more than 80% of the diet may comprise

of termites and other insects respectively (Seidensticker et al 2011, Yoganand et al 2013). Palei et al (2020) reported that the major diet of sloth bear comprises of *Ziziphus mauritiana* during summer and winter season. However, little information is known about the role of sloth bear as seed dispersal agents in Indian forests particularly in Bihar. The objective of this study was to determine seasonal diet composition of sloth bear in Nawada Forest Division, Bihar using macroscopic and microscopic analysis of scats remain and germination period of fruit seeds.

MATERIAL AND METHODS

For evaluation of role of the sloth bear in seed dispersal in Bihar (India), the sloth bear scats were monitored for the occurrence of fleshy fruits and seeds in scats. Germination potential of seeds were also assessed. The study was carried out at Nawada Forest Division (24° 52' 47.99" N latitude and 85°31' 47.99" E longitude), consisting 518 km² protected area, located in Nawada District of Bihar. The vegetation of this sanctuary is tropical dry deciduous with a dominance of *Ziziphus* (Mill.) sp. (family Rhamnaceae), *Syzygium cumini* (L.) (family Myrtaceae), *Madhuca indica* (Gmel) (family Sapotaceae), *Buchanania lanzan* (Spreng) (Family Anacardiaceae), *Ficus* (L.) sp (family Moraceae) and *Lantana camara* (L.) of family Verbenaceae (invasive species). The scats were collected from Rajauli Forest Range (RFR), Kauwakol Forest Range (KFR), and Nawada Forest Range (NFR) of Nawada Forest Division, Bihar (Fig. 1). The study was carried out in the forest areas as well as along the walking and traileed roads from August 2016 to October 2019. Scat collection and analysis was done following the methods used by Bargali et al (2004) and Ramesh et al (2009). The seeds found in scats were germinated in adequate soil moisture and identified, Identification of plant species were verified by the presence

of claw marks of the sloth bear in the tree trunk located near the scat sites. The claw marks of sloth bear indicated that the bear had climbed the tree to seek the fruits. The food items found in scats were separated into plant and animal parts (Maxwell-Lefroy 1909). Comparison of germination period of seeds passed in the gut of sloth bear and unpassed seed was analysed following Sreekumar and Balakrishnan (2002). To assess the seeds passage through the gut of sloth bears affected germination, seeds retrieved from scats were spread in plots of 5m². Overall seeds of each species were planted 10 cm apart and replicated three times (30 seeds for each species). Unpassed seeds collected from intact fruits of each species were germinated in an identical fashion.

RESULTS AND DISCUSSION

A total of 65 scats of *Melursus ursinus* was collected during the study period. Based on frequency of occurrence in scats, plants species contributed highest followed by the insects (28.9%) and mammalian hairs (10.3%) (Table 1). Among the plant species, *Ziziphus* sp. (14.8%) ranked highest among the plants followed by *Aegle marmelos* (L.) of Rutaceae family (13.3%) (Table 2). During winter, insects were mostly utilized by the sloth bears (Khanal and Thapa 2014). Plants showed lesser contribution in diet during winter season in comparison to summer and monsoon season. The relative importance of the plant materials in bear diets during summer and monsoon season may be due to seasonal flowering and fruiting. Overall, 20 plant species were found in scats of sloth bear. The seed collected from plant species included *Buchanania lanzan*, *Mangifera indica*, *Cassia fistula* and *Syzygium cumini*. In summer, *Zyzyphus* sp. (36%) was most frequently utilized food by the sloth bear followed by *Aegle marmelos* (28%) and *Syzygium cumini* (24%). *Zizipus* species appearing to be important food item for the bear in the study area is supported by the findings of Sukhadiya et al

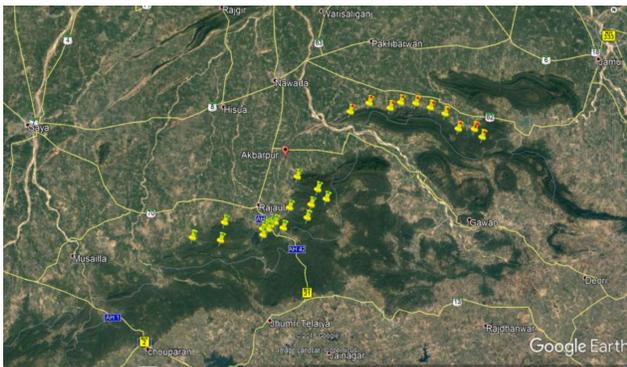


Fig. 1. Map showing scat collection in different forest ranges in Nawada Forest Division, Nawada district, Bihar (Image from Google earth)

Table 1. Frequency of occurrence of animal food items in the scats of sloth bears by seasons

Group	Food items	Summer (n=40) FO (%)	Monsoon (n=25) FO (%)
Mammalian food	Bone	0.0	1.0
	Hair	4.2	2.0
Unidentified material		0.0	4.8
Insect food	Honey bees	8.5	0.0
	Larvae of beetles	3.0	5.2
	Black ants	2.3	3.2
	Red ants	0.7	2.8
	Termites	6.0	11.0

(2013) and Palei et al (2014). With the onset of the monsoon, fruits comprised the major diet of sloth bear are *S. cumini* (42%), followed by *P. acaulis* (24%) along with the materials of animal origin. Ants and termites constituted most of the animal food, irrespective of the season. Seeds from fleshy fruit species were found intact in the scats of sloth bear. In the summer season, scats were dominated by seeds of *S. cumini*, *C. fistula* and *M. indica*. In the monsoon season, fruits were less frequent in scats but those of, *S. cumini*, *B. lanzan* predominated (Table 2).

Maximum seed germination was observed in *S. cumini* (84%), followed by *B. Lanzan*, *C. fistula* and *M. indica*. However, the seed germination time was found significantly different in both unpassed and passed seeds of those plant species except *C. fistula* species. Of the seeds, three of the species namely, *S. cumini*, *B. lanzan* and *M. indica* showed significant decreased germination time following seed passage (Table 3).

Seed passage through the digestive gut of sloth bear appeared to increase the germination rate of few species without showing any detrimental effect on the germination behaviours of any of the species in the present study.

Table 3. Germination time of seed species collected from sloth bear scats (passed seed) and fruits collected below tree canopies (unpassed)

Plant species	Germination period (days) (Mean± SD)		t-value
	Unpassed seeds	Passed seeds	
<i>Buchanania lanzan</i>	16.7 ± 2.98 (N=28)	14 ± 4.75 (N=28)	0.01
<i>Syzygium cumini</i>	8.4 ± 1.46 (N=27)	7.6 ± 1.17 (N=27)	0.02
<i>Mangifera indica</i>	21.1 ± 3.85 (N=28)	23.1 ± 3.35 (N=28)	0.04
<i>Cassia fistula</i>	14.4 ± 2.76 (N=26)	8.6 ± 1.68 (N=26)	4.08

Although, variation in the time of germination of seed passage observed may be attributed by several factors such as fruit morphology, fruit size, seed coat thickness, fruit retention time and chemical constituents of the fruit pulp etc. The diet and macronutrient, gut microbiomes and canal of ursids and other mammals has also been reported by several workers (Fredriksson et al 2006, Delsuc et al 2014, Costello et al 2016) supporting the myrmecophagous nature of sloth bears.

Table 2. Frequency of occurrence of fruits in scats of the sloth bear in summer and monsoon season

Plant species (Common name)	Months	Parts consumed	Summer (N=40) FO (%)	Monsoon (N=25) FO (%)
<i>Ziziphus jujuba</i> (Ber)	October-February	FL/UF	36	0.0
<i>Ficus benghalensis</i> (Bar)	March-June	UF/RF	1.0	0.0
<i>Dendrocalamus strictus</i> (Bans)	March, July-August, February	TS	1.0	2.2
<i>Aegle marmelos</i> (Bel)	March-August, February	FL, L, UF, RF	28	12
<i>Mangifera indica</i> (Am)	April-August	FL, UP, RF,	1.6	0.6
<i>Cassia fistula</i> (Amaltas)	January-December except-April-May	SP	12.1	0.0
<i>Cucurbita</i> sp. (Seetaphal)	February-July	UF, RF, FL	0.0	1.5
<i>Syzygium cumini</i> (Jamun)	July-August	RF	24	42
<i>Ziziphus oenoplia</i> (Dithor)	October-January	UF, RF	6.5	2.4
<i>Ficus glomerata</i> (Dumar)	February-June	UF, RF	0.8	6.6
<i>Anogeissus latifolia</i> (Dhatuira)	June-March	RF, FL, UF	1.6	1.2
<i>Semecarpus anacardium</i> (Bhelwa)	June-December	FL, UF, RF	6.8	9.8
<i>Pithecellobium dulce</i> (Jalebi)	February-May	UF, RF	0.0	4.3
<i>Phoenix acaulis</i> (Khajur)	July-October	RF	0.0	24
<i>Madhuca indica</i> (Mahua)	March-June	FL, UF, RF	4.5	0.0
<i>Buchanania lanzan</i> (Piar, Chirongji)	January-March	RF, UF	0.0	13.5
<i>Bridelia retusa</i> (Kajh)	May-September	FL, RF	3.3	0.0
<i>Diospyros melanoxylon</i> (Kend)	May-July	UF, RF	2.6	0.0
<i>Ficus religiosa</i> (Pipal)	March-July	UF, RF	1.6	2.8
<i>Canthium parviflorum</i> (Khadbar)	July-October	FL, RF	0.0	22.2

L=Leaves; FL=Flower buds and flowers; UF=Unripe fruits; RF=Ripe fruits; SP=Seeds/Pods; BS=Bark/Stem; T=Tuber; TS=Tender Shoot

CONCLUSION

The analysis of data on foods found in scats of sloth bears in Nawada Forest Division, Bihar suggests that they are omnivorous with adaptation of myrmecophagy. Their feeding habits of fleshy fruit plants favour the dispersal of fruit seeds. The role of seed dispersal by the sloth bears is relevant to the forest restoration efforts in Indian region and particularly in Bihar where the total forest area is only about 7.27% of the geographical area of the state. The study also provided important background for conservation management of the species *Melursus ursinus*.

REFERENCES

- Bargali HS, Akhtar N and Chauhan NPS 2004. Feeding ecology of sloth bears in a disturbed area in Central India. *Ursus* **15**(2): 212-217.
- Corlett RT 2017. Frugivory and seed dispersal by vertebrates in tropical and subtropical Asia: An update. *Global Ecology and Conservation* **11**: 1-22.
- Costello CM, Cain S, Pils S, Frattaroli L, Haroldson MA and van Manen FT 2016. *PLoS ONE*. **11**(5): e0153702. <https://doi.org/10.1371/journal.pone.0153702>.
- Delsuc F, Metcalf JL, Parfrey LW, Song SJ, Gonzalez A and Knight R 2014. Convergence of gut microbiomes in myrmecophagous mammals. *Molecular Ecology* **23**: 1301-1317.
- Devi K, Samant SS, Puri S and Lal M 2019. Diversity, structure and regeneration pattern of tree communities in Kanawar Wildlife Sanctuary of Himachal Pradesh, North East Himalaya, India. *Indian Journal of Ecology* **46** (1): 94-103.
- Fredriksson GM, Wich Sa and Trisno 2006. Frugivory in sunbears (*Helarctos malayanus*) is linked to El Nino related fluctuations in fruiting phenology, East Kalimantan, Indonesia 2006. *Biological Journal of the Linnean Society* **89**(3): 489-508.
- Harrer LGF and Levi T 2018. The primacy of bears as seed bearers in salmon-bearing ecosystems. *Ecosphere* **9**(1): e02076.
- Khanal S and Thapa T B 2014. Feeding ecology of sloth bears in Chitwan National Park, Nepal. *Journal of Institute of Science and Technology* **19**(2):118-122.
- Kumar V, Tiwari A and Desai BS 2018. Pattern of floristics and biodiversity of angiosperms of Purna Wildlife Sanctuary, Mahal, Gujrat. *Indian Journal of Ecology* **45**(2): 260-265.
- Mandal M and Chattarjee NS 2020. Geo-statistical analysis to understand nature of forest patch shape complexity in Panchet Forest Division under Bankura district, West Bengal. *Indian Journal of Ecology* **47**(1): 96-101.
- Maxwell-Lefroy H 1909. *Indian insect life: A manual of the insects of the plains (tropical India)*. Pusa Agricultural Institute. Published by Calcutta and Simla: Thacker, Spink & Co. pp 786.
- Mewada T and Dharaiya N 2010. Seasonal dietary composition of sloth bear (*Melursus ursinus*) in the reserve forest of Vijayanagar, North Gujarat, India. *Tiger Paper* **37**(2): 8-13.
- Mewada TP, Tiwari UL and Kotia A 2019. Fruiting species influence the seasonal use of habitat by sloth bear in and around Balaram Ambaji Wildlife Sanctuary, Gujarat, India. *Notulae Scientiae Biologicae* **11**(2): 183-190.
- Ngoprasert D, Steinmetz R, reed DH, Savini T and Gale GA, McCorquodale 2011. Role of fruit on habitat selection of Asian bears in a tropical forest. *Journal of Wildlife Management* **75**(3): 585-595.
- Palei HS, Pratyush P and Sahu HK 2014. Dry season diet of the sloth bear (*Melursus ursinus*) in Hardagarh Wildlife Sanctuary Eastern India. *Proceedings of Zoological Society* **67**(1): 4-7.
- Palei HS, Debata S and Sahu HK 2020. Diet of sloth bear in an agroforest landscape in Eastern India. *Agroforestry Systems* **94**(1): 269-279.
- Ramesh T, Sankar K and Qureshi 2009. Additional notes on the diet of sloth bear *Melursus ursinus* in Mudumalai Tiger Reserve as shown by scat analysis. *Journal of Bombay Natural History Society* **106**(2): 204-206.
- Reddy CS, Babur S, Amarnath G and Pattanaik 2011. Structure and floristic composition of tree stand in tropical forests in the Eastern Ghats of Northern Andhra Pradesh, India. *Journal of Forestry Research* **22**(4): 491-500.
- Seidensticker J, Yoganand K and Johnsingh AJT 2011. Sloth Bears living in seasonally dry tropical and moist broadleaf forests and their conservation. *The Unique Ecology and Conservation of Tropical Dry Forests in Asia, Smithsonian Institution Scholarly Press*, pp. 217-236.
- Sreekumar PG and Balakrishnan M 2002. Seed dispersal by the sloth bear (*Melursus ursinus*) in South India. *Biotropica* **34**(3): 474-477.
- Steinmetz R, Garshelis DL, Chutipong W and Seuaturien N 2013. Foraging ecology and coexistence of Asiatic black bears and sunbears in a seasonal tropical forest in Southeast Asia. *Journal of Mammalogy* **94**(1): 1-18.
- Sukhadiya D, Joshi JV and Dharaiya N 2013. Feeding ecology and habitat use of sloth bear in Jassore Wildlife Sanctuary, Gujarat, India. *Indian Journal of Ecology* **40**(1): 14-18
- Yoganand K, Johnsingh AJT and Rice CG 2005. *Evaluating Panna National Park with special reference to the ecology of sloth bear*. Wildlife Institute of India, Dehradun, India. Final Project Report. 172p.
- Yoganand K, Rice CG and Johnsingh AJT 2013. *Sloth bear Melursus ursinus*. In *Mammals of South Asia University Press, Hyderabad, India*, pp. 438-456.



Population Control of *Docioctaurus maroccanus* by *Pistacia lentiscus* and *P. vera*

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Abstract: The invasion of insect pests is causing significant losses on crops and agricultural land, for this reason locust control remains one of the major concerns in the strategy of protecting crops in arid and semi-arid regions. The present study was conducted for evaluation of bio-insecticidal of the essential oils of *Pistacia lentiscus* and *Pistacia vera* of the Anacardiaceae family in the region of Tlemcen by molecular modeling methods. The work consists of studying the inhibition of the α -amylase enzyme of the species *Docioctaurus maroccanus* which is a digestive enzyme by molecular docking. The molecular dynamics simulation study showed good result for the myrcène a functional inhibitor for the activity of α -amylase enzyme. The result obtained confirms the bio-insecticide effect of the genus *Pistacia* family of Anacardiaceae.

Keywords: Essential oil, *Pistacia lentiscus*, *Pistacia vera*, *Docioctaurus maroccanus*

The Mediterranean Basin hotspot is one of the most remarkable regions on earth for its' great biological (plant and animal) and landscape diversity, marked by a unique climate with cool, wet winters and hot, dry summers, which favours the establishment of various kind of vegetation. Vegetation consists chiefly of deciduous trees and perennial plants. The Anacardiaceae family is part of this vegetation, particularly in northern Algeria, which include trees, shrubs containing oleoresinous secretory channels. In fact, they exude oils, milky sap, resin or wax with various applications. Currently, aromatic plants have a considerable advantage due to the gradual discovery of the applications of their essential oils in health care and other areas of economic interest. The essential oils of aromatic plants have medicinal properties and act as anti-inflammatory, antiseptic, antiviral, antifungal, bactericidal, antitoxic, insecticidal, tonic, stimulating, and calming (Ouhererre et al 2018). These essential also provide effective control of insect pests.

Docioctaurus maroccanus is one of the main locust pests of the order Orthoptera. Due to the favourable ecological conditions, these pests can be dangerous when they proliferate and cause damage to crops through their gregariousness (El Ghadraoui et al 2003). The economic and ecological impact of locusts on crops and pastures has long been recognized. For such needs, the focus is rather on the biological control of these species. For this purpose, with the development of computer tools, molecular modeling and specifically molecular docking (molecular assembly or docking) has quickly taken over biological research field. Molecular docking's main objective is to predict the most

favourable conformation (position and relative orientation) of the ligand within its receptor (Bekkal Brikci 2019). The present work is related to comparing the bio-insecticide power of two aromatic plants which are *Pistacia lentiscus* and *Pistacia vera* to control the locust pests, *Docioctaurus maroccanus* Thunberg, 1815.

The *Pistacia lentiscus* is a shrub belonging to the branched (ramified) anacardiaceae family, three meters high, with a strongly pungent resin smell. It is widespread in the Mediterranean basin, growing in the wild in scrub (maquis) and garrigues in all types of soils, although it prefers siliceous grounds. In Algeria, mastic tree is found along the telland forest areas. (More and White 2005). It prefers nutrient-poor soils, low water and also in long exposure to high temperatures and solar radiation. The "*Pistaciavera*" is a dioecious tree (male and female flowers growing on different shrubs) (Oukbli 2005), with an average height of 6 to 8 m, and plays crucial role in the balance of the semi-desert ecosystem through its developed root-system and is cultivated in the arid and semi-arid areas of Asia (Middle East) and Africa (Maghreb), but also in Australia, in some American countries (United States and Mexico), and Mediterranean Europe areas (Benmahiou 2009).

MATERIAL AND METHODS

Enzyme and inhibitors preparation: The ligands used were chosen based on the most important efficiency in each part of the plant (leaf and fruit) (Table 1) The chemical structure of these ligands was obtained from the database "Pubchem" (Table 2), and drew up the ligands from the

software "Chemdraw" version 12.0.2.1076, then saved them in « .Mol » format, the reafter optimized the ligands with "Hyperchem" software version 8.0.10 and saved them in « .Mol » format for molecular docking with the Molecular Operating Environment « MOE » software.

Molecular docking protocol: Molecular docking calculations were performed using the default standard MOE software parameters (Molecular operating environment, 2013). A docking simulation essentially consists of two stages: the docking itself and the scoring.

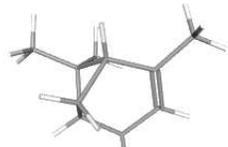
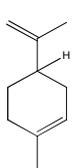
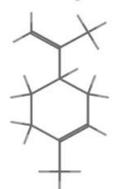
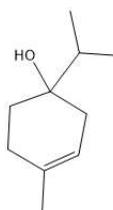
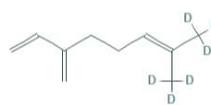
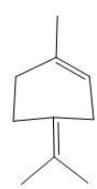
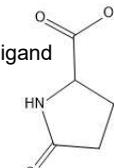
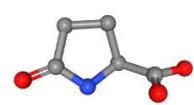
- Docking is the selection stage, which consists of placing the ligand in the active site of the protein and sampling the possible conformations, positions and orientations (poses), retaining only those that represent the most favorable modes of interactions.
- Scoring is the ranking stage, which consists in evaluating the affinity between the ligand and the protein and giving a score to the poses obtained during the docking phase. This score will enable the best pose among all those proposed to be selected (Boucherit 2012).

Molecular dynamics simulation: The molecular dynamics simulation study was carried out for the ligand that was declared as the best among the selected molecules. From the analysis of the results, it was concluded that was the best ligand among the selected ligands and molecules. The molecular dynamics simulations study of myrcene and 1CLV docked complex was performed by iMODS. It is a fast, user-friendly and effective molecular dynamics simulation tool that can be used efficiently to investigate the structural dynamics of the protein complexes. It provides the values of deformability, B-factor (mobility profiles), eigenvalues, variance, co-variance map and elastic network. For a complex or protein, the deformability depends on the ability to deform at each of its amino acid residues. The eigenvalue has relation with the energy that is required to deform the given structure and the lower the eigenvalue, the easier the deformability of the complex. Moreover, the eigenvalue also represents the motion stiffness of the protein complex. iMODS is a fast and easy server for determining and

Table 1. Molecules present in the essential oils of the plants

Plant species	Essential oil (%)	
	Leaf	Fruits
<i>Pistacia lentiscus</i>	- α -pinène 11 - limonène 10.3 - Myrcène 39.2 - Terpinèn.4.ol 29.9 - α -terpinéol 15	- α -pinène 22 - β -myrcène 54
<i>Pistacia vera</i>	- α -pinène 30 - Terpinolène 17.6 - Bornyl acétate 11.3	- α -pinène 54.6 - Terpinolène 31.2

Table 2. 2 D&3D representations of the all ligands used in the experiment

Compound name	2D structure	3D structure
α pinène		
limonène		
Myrcène		
Terpinèn-4-ol		
α -terpinéol		
β -myrcène		
Terpinolène		
Co-cristallized ligand		

Ligands structures were taken from PubChem server (www.pubchem.ncbi.nlm.nih.gov)

measuring the protein flexibility (Lopez-Blanco et al 2011, 2014, Prabhakar et al 2016, Awan et al 2017).

RESULTS AND DISCUSSION

Molecular docking simulation: In order to find the residues that form the largest active site of amino-acids on the enzyme to get an interaction with ligands, "Finder site" module on the "MOE" software was used. The enzyme 1CLV contains 20 enzymatic cavities whose largest active site is made up of 21 amino acids that are: LEU 49- TRP 56- TRP 57- TYR 60- GLN 61-HIS 99-GLY 102- MET 103- LEU 150- VAL 151-LEU 153- ARG 183-ASP 185- ALA186-GLU 222-ILE 224-HIS 286-ASP 287-ARG 290ASN 331-ASP332.

After the enzyme and ligands preparation, the next stage is the positioning of these inhibitors in the active site of the 1CLV enzyme. This requires the docking module using the "MOE" software. Once the ligand-receptor complex is formed (Fig. 4), it will adapt the most stable conformation, namely with the lowest energy level. In order to compare the stability of the ligands reviewed in the active site of the 1CLV enzyme, molecular docking between the enzyme and the ligands was conducted (Table 5).

The molecules that had the lowest binding energy of docking score were considered the best molecule and inhibiting the target receptor as the lower binding energy



Fig. 1. *Pistacia lentiscus*

Table 3. Propriétés de testées molécules

Ligands	Weight (g/mol)	TPSA (Å ²)
α -pinène	136,23	0(0: don, 0: acc)
limonène	136,23	0(0: don, 0: acc)
Myrcène	136,23	0(0: don, 0: acc)
Terpinèn.4.ol	154,25	20,2(1: don, 1: acc)
α -terpinéol	154,25	20,2(1: don, 1: acc)
β- myrcène	136,23	0 (0: don, 0: acc)
Terpinolène	136,23	0 (0: don, 0: acc)
Bornyl acétate	196,29	26,3(0: don, 2: acc)

Table 4. Properties of the α-amylase enzyme

Protein	Classification	Method	Resolution	Number of chains	Chain length
1CLV	HYDROLASE	X-Ray diffraction	2 Å°	two chains	503



Fig. 2. *Pistacia vera*

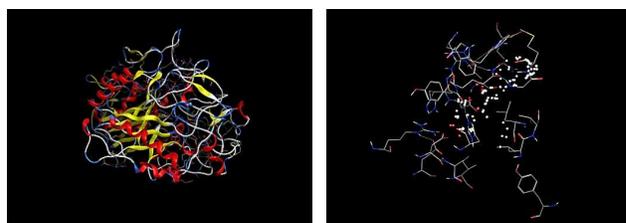


Fig. 3. α-amylase enzyme 3D structure. The structure was taken from Protein Data Bank online server (<https://www.rcsb.org/>) and Molecular Operating Environment (MOE)

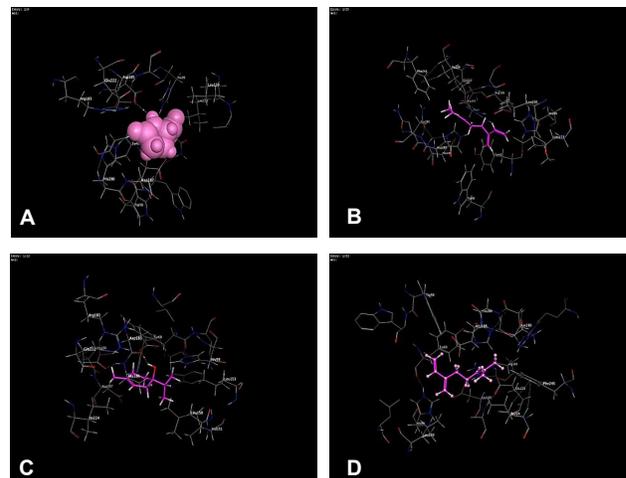


Fig. 4. 3 D representations of the best pose interactions between the ligands and their receptor. A. interaction between co-cristallization ligand and 1CLV, B. interaction between myrcène and 1CLV, C. interaction between terpinèn-4-ol and 1CLV, D. interaction between bornyl acétate and 1CLV. The 3 D representations of the best pose interactions between the ligands and their respective receptors were visualized using Molecular Operating Environment (MOE)

Table 5. Docking results (binding energy) of all ligands and the control along their respective number of hydrogen bonds as well as interacting amino acids

Name of ligands	Docking score (binding energy) Kcal/mol	Interacting residues of the target	Types of bonds	Distance(A°)	Energies (kcal-mol)
Myrcène	-4.7707	/	/	/	/
β -Myrcène	-4.6807	/	/	/	/
Terpinen-4-ol	-4.6694	OD1-ASP185	H-donor	3.26	-1.0
Bornyl acétate	-4.6049	/	/	/	/
α -Terpineol	-4.5059	OD1-ASP185	H-donor	2.99	-1.9
Terpinolene	-4.4409	/	/	/	/
Limonène	-4.42	/	/	/	/
α - pinène	-4.1707	/	/	/	/
(Co-cristallisation ligand)	-3.55	OD1-ASP185	H-donor	3.41	-0.7
		NE2-HIS286	H-acceptor	3.04	-4.4
		ND1-HIS99	Ionic	3.87	-0.8
		NE2-HIS99	Ionic	3.23	-3.1
		NE2-HIS99	ionic	3.83	-0.9

corresponds to higher binding affinity (Simon et al 2017). The highest score obtained after docking is that of myrcène with a score of -4.7707 kcal/mol, followed by β -Myrcène with a score of -4.6807 kcal/mol, Terpinen-4-ol with a score of 4.6694 kcal/mol and one hydrogen interaction with ASP-185 of OD1 target active site, the score of the co-cristalized ligand is -3,5513 kcal/mol, 5 interactions ASP185, HIS286, HIS99, HIS99, HIS99. The complex formed by myrcène-1CLV has the lowest values energy and giving the best docking score compared to co-cristalized ligand. According to these docking results can classify, myrcène as the good inhibitor of the enzyme 1CLV compared to the all ligands studied.

Enzyme-ligand interaction: Interactions between 2.5 and 3.1 are considered strong and interactions between 3.1 and 3.55 are assumed to be average. Interactions above 3.55 are weak or absent (Marianna et al 2006). We have shown the interactions between the ligands and the enzyme (Fig. 5). The distances measured between the ligands and the amino-acids of the active site varied between 2.99° and 3.26°. The average interactions between terpinen-4-ol and the active site of the enzyme -amylase with a distance of 3.26 A°, this interaction is considered average because it lies between 3.1Å and 3.55Å, this interaction is between OD1 and the aminoacid ASP185 present in the enzymatic cavity of our enzyme with an energy of -1.0kcal / mol.

The normal mode analysis (NMA) of Myrcene-1CLV complex is illustrated in Figure 6a. The deformability graph illustrates that the peak in the graphs correspond to the regions in the protein with deformability (Fig. 6b) The Bfactor graph of the complex gives easy visualization and understanding of the comparison between the NMA and the PDB field of the complex (Fig. 6c). The eigenvalue of the

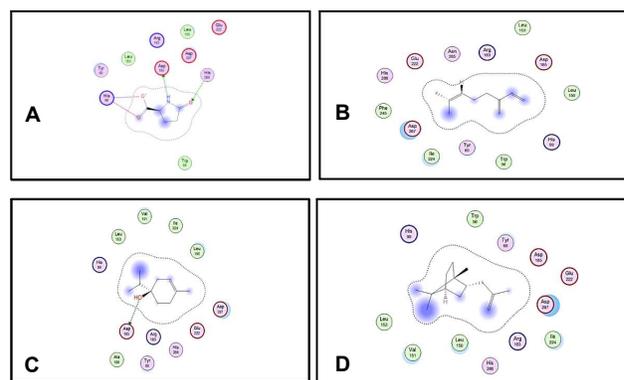


Fig. 5. 2 D representations of the best pose interactions between the ligands and their receptor. A. interaction between co-cristallized ligand and 1CLV, B. interaction between myrcène and 1CLV, C. interaction between terpinen-4-ol and 1CLV, D. interaction between bornyl acétate and 1CLV. The 2 D representations of the best pose interactions between the ligands and their respective receptors were visualized using Molecular Operating Environment (MOE)

complex is illustrated in Figure 6d. The docked complex generated eigenvalue of 3.500969e-04. The variance graph indicates the individual variance by red colored bars and cumulative variance by green colored bars (Fig 6). Figure 6f illustrates the co-variance map of the complexes where the correlated motion between a pair of residues is indicated by red color, uncorrelated motion is indicated by white color and anti-correlated motion is indicated by blue color. The elastic map of the complex shows the connection between the atoms and darker gray regions indicate stiffer regions (Fig. 6g). From the molecular dynamics study of myrcene- 1CLV docked complex, it is clear that the complex had a very good

amount of deformability as well as it had low eigenvalue of $3.500969e-04$, for this reason, this lower eigenvalue, represent the easier the deformability of the complex (Fig. 6b, 6d) and also represents the motion stiffness of the protein complex. However, the variance map showed high degree of cumulative variances than individual variances (Fig. 6e). The covariance and elastic network map also produced satisfactory results (Fig. 6f and 6g).

The use of chemical pesticides has a harmful impact on

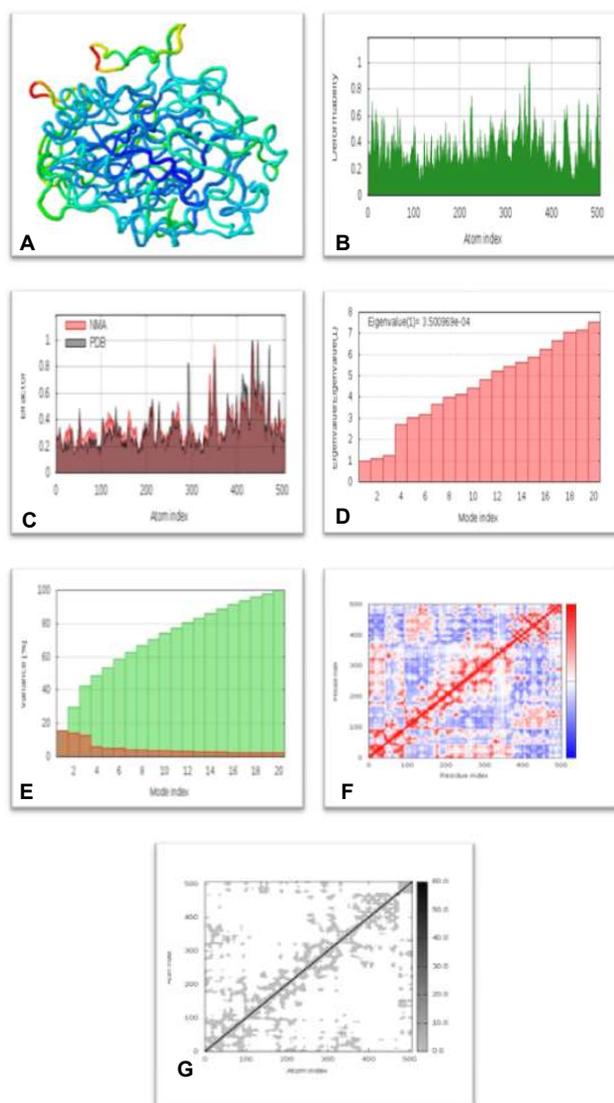


Fig. 6. Results of molecular dynamics simulation of myrcene-1CLV. (a) NMA mobility, (b) deformability, (c) B-factor, (d) eigenvalues, (e) variance (red color indicates individual variances and green color indicates cumulative variances), (f) co-variance map (correlated (red), uncorrelated (white) or anti-correlated (blue) motions) and (g) elastic network (darker gray regions indicate more stiffer regions) of the complex

human health and environment; therefore, the healthiest method is the use of plants for their biocidal activity (toxic, repellent, anti-appetant) against a wide range of bio-aggressors (pests). The use of plant extracts as insecticides has long been recognized. Indeed, pyrethrum, nicotine, rotenone have already been used as agents for insect control. Bouchareb (2016) mentioned that, *Pistacia lentiscus* has significant insecticidal potential against the *Toxoptera aurantii* aphid. Regarding the review and according to the results obtained; the *myrcene* obtained from the extraction of leaves and the β -*Myrcene* extracted from the fruit of *Pistacia lentiscus* are the best inhibitors of the α -amylase enzyme when compared with the components of *Pistacia vera*.

CONCLUSION

The aim of our study is to investigate the potent of new natural's compounds such as myrcène, terpinèn-4-ol, bornyl acétate, extracted from *Pistacia lentiscus* and *Pistacia vera* to inhibit the enzyme α -amylase présent in the digestive system of *Dociostaurus marrocanus* in order to control this pest species. Theoretically tested the use of molecular modeling more precisely the molecular docking of the "MOE" software and Molecular Dynamics simulation; the inhibitory potency of ligands resulting from the extraction of essential oils from the "leaves and fruit" part of the following plants: *Pistacia lentiscus* and *Pistacia vera* that belong to the anacardiaceae family. It can be concluded that myrcène of the species *Pistacia netiscus* has an inhibitory potency of the α -amylase enzyme to control *Dosciostaurus marrocanus*.

REFERENCES

- Anastasia Tsokou, Katerina Georgopoulou, Eleni Melliou, Prokopios Magiatis and Eugenia Tsitsa 2007. Composition and enantiomeric analysis of the essential oil of the fruits and the leaves of from Greece. *Molecules* **12**: 1233-1239.
- Awan F, Obaid A, Ikram A and Janjua H 2017. Mutation-structurefunction relationship based integrated strategy reveals the potential impact of deleterious missense mutations in autophagy related proteins on hepatocellular carcinoma (HCC): A comprehensive informatics approach. *International Journal of Molecular Sciences* **18**(1): 139. doi: 10.3390/ijms18010139
- Bahareh Rafiei, Mohammad Ghadamyari, Sohrab Imani, Vahid Hosseinaveh and Ali Ahadiyat 2016. Purification and characterization of amylase in Moroccan locust, α *Dociostaurus marrocanus* Thunberg (Orthoptera: Acrididae) and its inhibition by inhibitors from *L. Phaseolus vulgaris*. *Toxin Reviews* **3-4**: 90-97.
- Bekkal Brikci Sohayb 2019. *Contrôle biologique du nématode des Citrus (Cobb 1913) (Tylenchylidae) Tylenchulus semipenetrans par des substances naturelles*. Mémoire master en écologie. Université de Tlemcen.
- Benmahioul B 2009. *Amélioration de la micropropagation in vitro du pistachier (Pistacia vera L.) en vue de l'extension des vergers en Algérie*. Thèse de Doctorat Es Sciences, Université des Sciences et de la Technologie - Oran. 129P.
- Boucherit H 2012. *Etude théorique des interactions intervenant dans l'inhibition de la méthionine aminopeptidase de mycobacterium tuberculosis par diverse molecules*. Thèse de magister en

- biochimie. Constantine: Université Mentouri Constantine. Algérie 71p.
- Crosby DG 1966. Natural pest control agents. *Advanced Chem. Ser.* **53**: 1-16.
- Hassan Amhamdi, Fatima Aouinti, Jean Paul Wathelet and Ali Elbachiri 2009. Chemical composition of the essential oil of *Pistacia lentiscus*. Rec. Nat. L. from Eastern Morocco. *Production* **2**: 90-95.
- Lahsen EL Ghadraoui, Daniel Petitand Jamal EL Yamani 2018. Le site Al-Azaghar (Moyen-Atlas, Maroc) : un foyer grégarigène du criquet marocain *Dociostaurus maroccanus* (Thunb., 1815). Université Sidi Mohammed Ben Abdellah, Faculté des Sciences et Techniques, Département de Biologie, *Bulletin de l'Institut Scientifique*, Rabat, section *Sciences de la Vie*, 2003, n°25, 81-86
- Lopez-Blanco JR, Aliaga JI, Quintana-Ort_ ES and Chac_on P. 2014. iMODS: Internal coordinates normal mode analysis server. *Nucleic Acids Research* **42**(W1): 271-276.
- Lopez-Blanco JR, Garz_on JI and Chac_on P2011. Mod: Multipurpose normal mode analysis in internal coordinates. *Bioinformatics* **27**(20): 2843-2850.
- Marianna Usai, Giorgio Pintore, Bruno Tirillini and Mario Chessa 2006. Essential oil composition of different aerial parts of *Pistacia terebinthus* L. growing wild in Sardinia. *Journal of Essential Oil Research* **18**(July/August): 383-385.
- More D and White J 2005. Encyclopédie des Arbres: Plus de 1800 Espèces et Variétés du Monde, (Ed.). *Flammarion* **22**: 18-24.
- Ouhererre Asmaa and Abidat Rabiaa 2018. Caractérisation et l'effet de l'accolte sur la composition des huiles essentielles de *Schinus molle* L. mémoire de master in microbiology applied. Université Djillali Bounnama Khmiss meliana.
- Oukabli A 2005. Le pistachier Un arbre fruitier et forestier. Transfert de technologie en agriculture N° 125, Pp : 1-4.
- Ould el hadj M, Tankari Dan-Badjo Abderahmen, Halouane F and Doumandji S 2003. Etude comparative de la toxicité des extraits de trois plantes acridifuges sur les larves du cinquième stade et sur les adultes de Forskal, 1775 *Schistocerca gregaria* 81- Orthoptera-Cyrtacanthacridinae Courrier du Savoir 386.
- Prabhakar PK, Srivastava A, Rao KK and Balaji PV 2016. Monomerization alters the dynamics of the lid region in view publication stats view publication stats *Campylobacter jejuni* CstII: An MD simulation study. *Journal of Biomolecular Structure and Dynamics* **34**(4): 778-791. doi:10.1080/07391102.2015.1054430
- Regnault-Roger Catherine and Hamraoui Abdelaziz 1997. Control of Phytophagous Insects by Aromatic Plants And Their Allelochemical. *Molecules* **28**: 401-412.
- Simon L, Imane A, Srinivasan KK, Pathak L and Daoud I 2017. In silico drug-designing studies on flavanoids as anticancer agents: Pharmacophore mapping, molecular docking, and Monte Carlo method-based QSAR Modeling. *Interdisciplinary Sciences: Computational Life Sciences* **9**(3): 445-458.



Effect of Vehicular Traffic on Wild Animals in Anaikatty Hills, Southern Western Ghats, India

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Abstract: An increase in road networks causing a significant impact on tropical biodiversity, especially the ones passing through forest protected zones have a negative impact on wild animals. The mortality rates of wild animals were investigated by using a fortnight sampling method in the selected stretch of state highway 164, of Anaikatty Hills, Tamil Nadu. The sampling was performed in two different seasons namely dry and wet from June 2015 to December 2019. A total of 96 species and 419 individuals of road kill observed. Birds are the most affected taxa (30.21 %), followed by reptiles (28.13 %), butterflies (20.83 %), mammals (11.45%), amphibians (5.21 %) and odonates (4.17 %) were least affected by vehicular traffic. Conservation and management implications are essential to prevent the local extinction of wildlife from Anaikatty reserve forest.

Keywords: Biodiversity, Conservation, Roadkill, Vehicular traffic

Roads are widely reflected to be a major source of disturbance to wildlife (Plante et al 2019) and are now being gradually drawn-out into remote regions of wildlife where they can force perpetual barriers to faunal movements (Dean et al 2019). In general, the effects range from habitat fragmentation, changes in animal distribution patterns, movements, the aberration in the population, biological changes, and direct mortalities (Row et al 2007, Shepard et al 2008). Similarly, the rate of road kills often exceeds the natural death rate and has the potential to affect all individuals in a population equally, unlike predation (Periquit et al 2018). The impact of roads on wildlife has been extensively studied outside India (Forman et al 2003), especially the effects of vehicular traffic on biodiversity. In India, infinitesimal attention has been drawn to road ecological studies (Sunder 2004). According to the National Highways Authority of India (NHAI), India has the second largest road system in the world (Rajvanshi et al 2007). The impact of the road networks and the mortality accounts extend across taxa - from soil invertebrates, butterflies, reptiles, amphibians, birds, and mammals (Boominathan et al 2008). The present study investigates the road impact on wildlife fauna in the state highway which runs parallel to Anaikatty reserve forest in Coimbatore, Tamil Nadu.

MATERIAL AND METHODS

The present road kill survey was conducted in the stretch of 10 km (Fig. 1) of State Highway (SH 164; 11° 6' 58.35" N, 76° 44' 52.19" E and 11° 4' 36.88" N, 76° 49' 25.71" E) between June 2015 and December 2019. The road stretch is

surrounded by tropical thorn forests and tropical mixed dry deciduous (Balasubramanian et al 2015). Besides, the road connects two Indian states namely Kerala and Tamil Nadu, and further heads-up to Silent Valley National Park (SNP), which attracts a large number of tourists annually, and hence there is heavy vehicular traffic in the proposed surveyed study stretch SH 164. The road stretch was surveyed during the fortnight hours on foot once in a day (during early morning 0600-0800 hrs) based on fortnight survey method (Baskaran and Boominathan 2010). The dead animals were identified to species level and in most cases the carcass has removed from the road to avoid the repeat counts (Bhupathy et al 2011). The road stretch was searched thoroughly for any presence of kills' and we did not collect any dead specimens for any future correspondence. Besides, the study was restricted to selective orders viz. butterflies, amphibians, reptiles, birds, odonates, and mammals. Species identification was done by using standard field guides and consulting subject experts.

RESULTS AND DISCUSSION

A total of ~2100 km walk surveys were conducted along the 10 km stretch of the SH 164 road from June 2015 to December 2019. Of, a total of 419 individual kills were observed in five years and a total of 96 species belonging to five orders viz., 5 amphibians, 29 birds, 20 butterflies, 4 odonates, 11 mammals, and 27 of reptiles (Fig. 2). Among these 96 species, 55 species are Least Concern, and two species are listed as vulnerable (*Prionailurus rubiginosus*) and (*Panthera pardus*). Further, the result has been

classified into seasonal patterns (viz. dry and wet season) to look at their mortality rate across taxa levels. But, due to our inadequate sampling, all orders were pooled together to reduce the sampling errors. Consequently, the mortality rate of all taxa during the fortnight day survey was significantly different as compared with seasonal patterns ($Z= 6.5$, (Dry) $n1 = 230$, (Wet) $n2 = 230$, $P<0.0001$). The wet season has a more mortality rate of $n=300$ as compare with dry season $n= 119$ (Fig. 3). A similar study performed by Bhupathy et al (2011) has shown the high mortality in the monsoon season (reptiles & amphibians). During the monsoon season, there was a large migration of butterflies and odonatans in

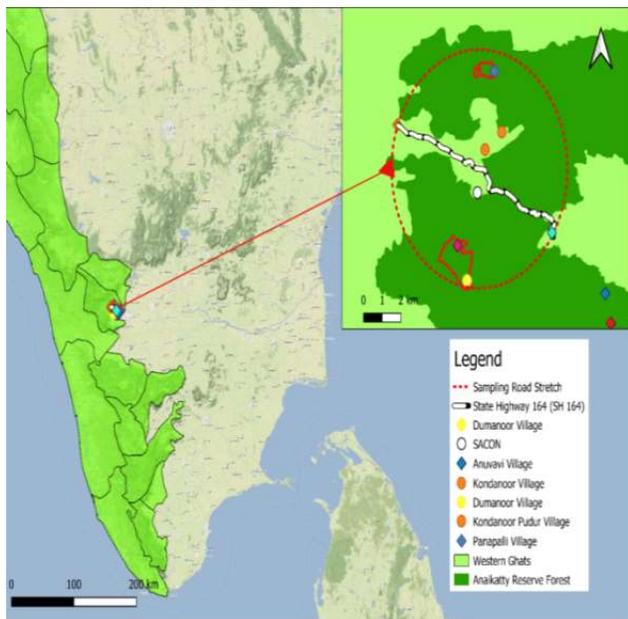


Fig. 1. Sampling road stretch in Anaiakatty hills, Southern Western Ghats, India

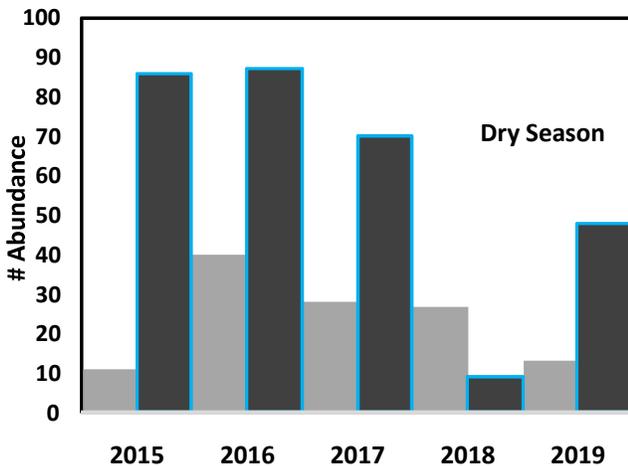


Fig. 2. Road kills observed from June 2015 to December 2019 concerning seasonal patterns

Table 1. Species observed during road kill survey in Anaiakatty hills, southern Western Ghats, India

Species	IUCN Status	
	LC	NA
Amphibian		
<i>Duttaphrynus melanostictus</i>	†	-
<i>Euphlyctis cyanophlyctis</i>	†	-
<i>Fejervarya limnocharis</i>	†	-
<i>Microhyla rubra</i>	†	-
<i>Microhyla Sp.</i>	-	-
<i>Accipiter badius</i>	†	-
<i>Acridotheres fuscus</i>	†	-
Birds		
<i>Acridotheres tristis</i>	†	-
<i>Aegithina tiphia</i>	†	-
<i>Ardeola grayii</i>	†	-
<i>Bubulcus ibis</i>	†	-
<i>Caprimulgus asiaticus</i>	†	-
<i>Centropus sinensis</i>	†	-
<i>Chrysomma sinense</i>	†	-
<i>Copsychus saularis</i>	†	-
<i>Corvus macrorhynchos</i>	†	-
<i>Cuculus canorus</i>	†	-
<i>Eudynamis scolopacea</i>	†	-
<i>Francolinus pondicerianus</i>	†	-
<i>Gallus sonneratii</i>	†	-
<i>Hierococcyx varius</i>	†	-
<i>Merops orientalis</i>	†	-
<i>Orthotomus sutorius</i>	†	-
<i>Pavo cristatus</i>	†	-
<i>Phaenicophaeus viridirostris</i>	†	-
<i>Pitta brachyura</i>	†	-
<i>Pycnonotus cafer</i>	†	-
<i>P.jocosus</i>	†	-
<i>P. luteolus</i>	†	-
<i>Saxicoloides fulicata</i>	†	-
<i>Streptopelia chinensis</i>	†	-
<i>S. decaocto</i>	†	-
<i>Treron phoenicoptera</i>	†	-
<i>Turdoides striatus</i>	†	-
Butterflies		
<i>Catopsilia pomona</i>	-	†
<i>Cepora nerissa</i>	-	†
<i>Danaus chrysippus</i>	†	-
<i>Euploea core</i>	†	-
<i>E. sylvester</i>	-	†
<i>Eurema hecabe</i>	-	†
<i>Graphium doson</i>	-	†
<i>Hypolimnas bolina</i>	-	†
<i>Ixias marianne</i>	-	†
<i>I. pyrene</i>	-	†
<i>Junonia almana</i>	†	-
<i>J. hierta</i>	†	-

<i>J. iphita</i>	-	†
<i>J. lemonias</i>	-	†
<i>P. crino</i>	-	†
<i>P. demoleus</i>	-	†
<i>P. polytes</i>	-	†
<i>Phalanta phalantha</i>	-	†
<i>Tirumala septentrionis</i>	-	†
<i>Troides minos</i>	†	-
Mammals		
<i>Axis axis</i>	†	-
<i>Fanambulus palmarum</i>	†	-
<i>Lepus nigricollis</i>	†	-
<i>Mus sp.</i>	-	†
<i>Panthera pardus</i>	-	-
<i>Pipistrellus mimus</i>	†	-
<i>Prionailurus rubiginosus</i>	-	-
<i>Suncus murinus</i>	-	†
<i>Suncus Sp.</i>	-	-
<i>Sus scrofa</i>	†	-
<i>Tragulus meminna</i>	†	-
Odonates		
<i>Anax guttatus</i>	†	-
<i>Brachythemis contaminata</i>	†	-
<i>Diplacodes trivialis</i>	†	-
<i>Pantela flavescens</i>	-	†
Reptiles		
<i>Ahaetulla nasuta</i>	-	†
<i>A. pulverulenta</i>	†	-
<i>Bungarus caeruleus</i>	-	†
<i>Calotes calotes</i>	-	†
<i>C. versicolor</i>	-	†
<i>Chamaeleo zeylanicus</i>	†	-
<i>Chrysopelea ornata</i>	†	†
<i>Daboia russelii</i>	†	-
<i>Dendrelapsis tristis</i>	-	†
<i>Eryx johnii</i>	-	†
<i>Eutropis carinata</i>	†	-
<i>Fowlea piscator</i>	-	†
<i>Hypnale hypnale</i>	-	†
<i>Indotyphlops braminus</i>	-	†
<i>Liopeltis calamaria</i>	-	†
<i>Lissemys punctata</i>	†	-
<i>Lycodon anamallensis</i>	-	-
<i>L. aulicus</i>	†	-
<i>Macropisthodon plumbicolor</i>	-	†
<i>Melanochelys trijuga</i>	-	†
<i>Naja naja</i>	-	†
<i>Oligodon arnensis</i>	-	†
<i>O. taeniolatus</i>	†	-
<i>Ptyas mucosa</i>	-	†
<i>Python molurus molurus</i>	-	†
<i>Sibynophis subpunctatus</i>	-	†
<i>Uropeltis bhupathyi</i>	-	†

IUCN- International Union for Conservation of Nature

* LC- Least Concern, NA- NotAssessed, † - denotes "LC", - denotes "NA"

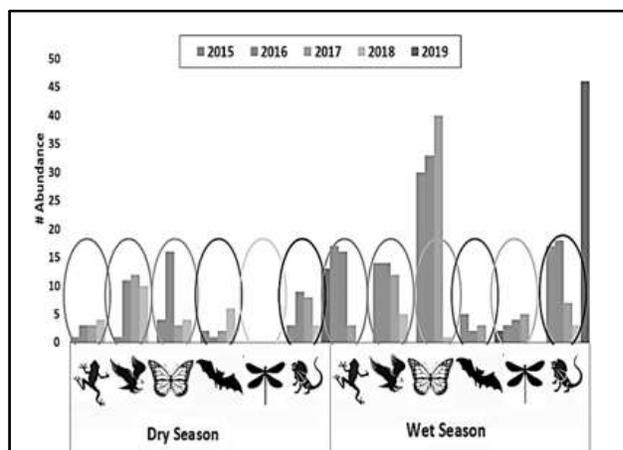


Fig. 3. Road kills and mortality of various orders

Anaikatty hills (Sony and Arun 2015). Also, during night hours these cold blood animals move towards tar road for thermoregulation. Therefore, most of the individuals were killed during the wet season as compared with the dry season. During monsoon days we observed a great number of mortality in the Anaikatty reserve forest in the following orders amphibians, reptiles, butterflies & odonates (Fig. 1). Secondly, road SH 164 is running parallel to Anaikatty reserve forest - which is considered a factor that is affecting the regular movement of wild animals. The major reason behind the collisions is that, the species migrate for resources and get caught in vehicular traffic. The road kill notably on largely herbivores (*Elephas maximus*, *Rusa unicolor* & *Axis axis*) and following reptilian, amphibians, odonates & butterflies showing significant effects in the wet season. During week holidays there is a large number of vehicle movements in the SH 164 (proposed stretch) because the roads head up to Silent Valley National Park (Sony and Arun 2015). We consider this can attribute another reason for high road kills in the proposed site. In India, there are numerous road lanes are running through protected zones (Baskaran and Boominathan 2010), which cause a significant effect on wildlife fauna. Therefore, these road lanes should be monitored prudently along with strict guidelines to protect wild animals (Karthik et al 2018). The results indicate that sampling stretch needs a strict guidelines on vehicle movements (every 1km stretch, there should be a one-speed hump and animal signboards). This will form awareness among people and possibly reduce road kills in the studied sites in the future.

REFERENCES

- Baskaran N and Boominathan D 2010. Roadkill of animals by highway traffic in the tropical forests of Mudumalai Tiger Reserve, southern India. *Journal of Threatened Taxa* 2(3): 753-759.

- Balasubramanian P, Manikandan P, Prakash L and Anbarasu C 2015. *Flowering plants of SACON Campus in the Anaikatty Hills, Western Ghats*. Sálim Ali Centre for Ornithology and Natural History, Coimbatore, p. 220. January, 2016.
- Bhupathy S, Srinivas G, Kumar NS, Karthik T and Madhivanan A 2011. Herpetofaunal mortality due to vehicular traffic in the Western Ghats, India: A case study. *Herpetotropicos* **5**(2): 119-126.
- Boominathan D, Asokan S, Desai AA and Baskaran N 2008. Impact of highway traffic on vertebrate fauna of Mudumalai Tiger Reserve, southern India. *Convergence Journal* **10**(1-4): 52-63.
- Dean WRJ, Seymour CL, Joseph GS and Foord SH 2019. A review of the impacts of roads on wildlife in semi-arid regions. *Diversity* **11**(5): 81.
- Forman RTT, Sperling D, Bissonette JA, Clevenger AP, Cutshall CD, Dale VH, Fahrig L, France RL, Heanue K, Goldman CR and Jones J 2003. *Road ecology: Science and solutions*. Island Press. <https://doi.org/10.5860/choice.40-6438>,
- Karthik P, Kalaimani A and Nagarajan R 2018. An inventory on herpetofauna with emphasis on conservation from Gingee Hills, Eastern-Ghats, Southern India. *Asian Journal of Conservation Biology* **7**(1): 2-16.
- Plante J, Jaeger JA and Desrochers A 2019. How do landscape context and fences influence roadkill locations of small and medium-sized mammals? *Journal of Environmental Management* **235**: 511-520.
- Périquet S, Roxburgh L, le Roux A and Collinson WJ 2018. Testing the value of citizen science for roadkill studies: A case study from South Africa. *Frontiers in Ecology and Evolution* **6**: 15.
- Rajvanshi A, Mathur VB and Usman LA 2007. Best Practice Guidance for Biodiversity-Inclusive Impact Assessment: A Manual for Practitioners and Reviewers in South Asia. CBBIA-IAIA guidance Series, Capacity Building in Biodiversity and Impact Assessment (CBBIA) PROJECT, International Association for Impact Assessment (IAIA), North Dakota, U.S.A. 215 pp.
- Row JR, Blouin-Demers G and Weatherhead PJ 2007. Demographic effects of road mortality in black rat snakes (*Elaphe obsoleta*). *Biological Conservation* **137**(1): 117-124.
- Shepard DB, Dreslik MJ, Jellen BC and Phillips CA 2008. Reptile road mortality around an oasis in the Illinois corn desert with emphasis on endangered Eastern Massasauga. *Copeia* **2**: 350-359.
- Sony RK and Arun PR 2015. A case study of butterfly road kills from Anaikatty Hills, Western Ghats, Tamil Nadu, India. *Journal of Threatened Taxa* **7**(14): 8154-8158.
- Sunder GKS 2004. Mortality of herpetofauna, birds and mammals due to vehicular traffic in Etawah District, Uttar Pradesh, India. *Journal Bombay Natural History Society* **101**(3): 392-398.

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Feeding Potential of *Axinoscymnus puttarudriahi* Kapur and Munshi on Invasive Whitefly, *Aleurothrixus trachoides* (Back) Infesting *Capsicum annum* L.

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Abstract: Investigation has been carried out to evaluate the feeding potential of *Axinoscymnus puttarudriahi* Kapur and Munshi, a less explored predatory coccinellid on an invasive whitefly species, *Aleurothrixus trachoides* (Back) infesting chilli plants. Larval stage of the beetle consumed 1458.33 whitefly eggs which is around 12.85 per cent of the total feeding potential (11351 eggs) of the beetle during its life cycle, while the adult stage of *A. puttarudriahi* was more potent in regulating whitefly population with 87.15 per cent (9892.67) consumption of whitefly eggs. The 1st, 2nd, 3rd and 4th larval instars and adult of *A. puttarudriahi* showed average per day intake of 21.82, 61.12, 184.69, 377.04 and 261.22 whitefly eggs, respectively. Findings of this study emphasize the importance of conserving *A. puttarudriahi* in the natural ecosystem and exploiting them in ecologically based integrated pest management programmes of whitefly pests.

Keywords: *Axinoscymnus puttarudriahi*, *Aleurothrixus trachoides*, Chilli, Feeding potential, Developmental duration

Insects are one among the most successful animal groups in the world owing to their highly diverse nature. The world food production has been adversely affected by the increasing crop loss risk caused by various insect pests. Among these, invasive alien pests are a serious threat to ecosystem. An invasive pest species is an exotic one which is introduced from one geographic region to other either intentionally or accidentally and after establishing locally dominant, replaces native biodiversity. They also cause huge economic crop loss due to their rapid spread and establishment (Sharma et al 2018). *Aleurothrixus trachoides* (Back) is an economically important invasive whitefly species commonly known as Solanum whitefly due to its preference for solanaceous host plants viz., chilli, brinjal, tomato etc. The whitefly is a native of Neotropical region, recently invaded and established in North America, Pacific, West Africa, Central America, Carribean, South America and South East Asia. In India it was first reported from Karnataka infesting *Duranta erecta* L. and later, its infestation was reported in 24 host plants of 11 families from Karnataka, Kerala, Maharashtra and Tamil Nadu. In chilli, *A. trachoides* is known to cause heavy economic loss due to sucking of plant sap and production of honey dew which further cause sooty mould growth and reduction in photosynthetic leaf area (Sundararaj et al 2018). The extensive use of chemical pesticides to manage insect pests resulted negative impacts on the ecosystem. Hence in the past two decades, the concept of Integrated Pest Management (IPM) is gaining momentum, of

which biological control of crop pests are more recognized for their eco-friendly and economically sound pest management strategies (Dhaliwal et al 2015). Various efforts were made to develop a long term sustainable management for whiteflies by exploring its naturally occurring biocontrol agents (Abd-Elkareim et al 2019).

The role of predatory coccinellids (Coccinellidae; Coleoptera) in pest management has a long history and are proved as potential biocontrol agents in managing soft bodied insect pests. Despite of various investigations on predatory coccinellids, many of them are remaining less explored regarding their diversity and feeding potential. *Axinoscymnus puttarudriahi* Kapur and Munshi, a tiny beetle predated upon whiteflies, is one such less investigated member. In India, only one species has been recorded under the genus *Axinoscymnus* (Poorani 2002). These beetles are known to feed upon various whiteflies infesting crops in India (Mani and Krishnamoorthy 1999, Mani and Krishnamoorthy 2006, Mohan 2017 and Vidya and Bhaskar 2017). Both adults and grubs are predatory in nature and known to feed all life stages of whiteflies (Boopathi 2013). Ramanujam et al (2014) reported predation of *A. puttarudriahi* on *A. trachoides* infesting chilli plants. The present study was an attempt to highlight the significance of *A. puttarudriahi* as a biocontrol agent and to evaluate its feeding potential on *A. trachoides* infesting *C. annum*.

MATERIAL AND METHODS

Maintenance of prey culture: Chilli seedlings of one month old were planted in plastic pots of 15 x 12 cm dimension placed in an insect cage (45 x 45 x 45 cm). After two weeks, nucleus culture of *A. trachoides* collected from the chilli fields of the Instructional Farm, College of Agriculture, Vellayani was inoculated and maintained in the seedlings kept in the enclosed cage.

Rearing of predator: Nucleus culture of *A. puttarudriahi* was collected from *A. trachoides* infested chilli fields of the Instructional Farm, College of Agriculture, Vellayani. Different life stages of the predator were documented. The culture was reared in plastic containers of 100 ml size provided with fresh chilli leaves infested with whitefly. Adult beetles emerged were transferred to cages (45 x 45 x 45 cm) where whitefly infested fresh chilli twigs were kept as a bouquet and the tip of the twigs were covered with absorbent cotton and immersed in a conical flask containing water. Eggs laid on chilli leaves were collected daily and kept separately in petridishes (9 x 1 cm) equipped with moist tissue paper to avoid drying of leaves. The larvae emerged from these eggs were used for the experiments.

Experimental protocol: The investigation was carried out at Department of Agricultural Entomology, College of Agriculture, Vellayani under standard conditions of temperature ($28 \pm 2^\circ\text{C}$) and relative humidity ($70 \pm 5\%$). Fresh chilli leaves containing five hundred eggs of *A. trachoides* were placed in a petri dish (9 cm diameter) having moist tissue paper to avoid drying of leaves. One newly emerged first instar grub of *A. puttarudriahi* was released to each petriplate with the help of camel hair brush. Observations were taken at an interval of 12 hours and fresh chilli leaves with five hundred whitefly eggs were provided each time. The number of whitefly eggs consumed within 12 hours and duration of each instar were recorded. The experiment was continued till the grub entered into pre pupal stage and pre pupa was kept for adult emergence. To determine feeding potential of adult, newly emerged adults were transferred individually in petri plates and fresh chilli leaves containing thousand eggs of whitefly were supplied every day for each adult. Observations were recorded at 24 hours interval till the death of the beetle. A total of 15 replications were maintained.

The feeding potential of both grub and adult was determined by calculating the number of eggs consumed by each stage of the predator. Surviving preys were counted and deducted from the total number provided to estimate the predation rate. Number of prey consumed by each predatory grub (instar-wise) during the total larval feeding period was worked out. Observations were taken on developmental time viz., egg period, duration of each instar, pre pupal period,

pupal period and adult longevity of *A. puttarudriahi*. Per day predatory potential was also calculated by dividing total feeding in each stage of predator by respective feeding duration in days.

Statistical analysis: Data on number of whitefly eggs consumed by each stage of predator and number of days during the development of the predator from egg to adult were analysed using one-way analysis of variance in completely randomized design.

RESULTS AND DISCUSSION

The adults are small oblong oval beetles of 1.4 to 1.6 mm long with head and pronotum yellowish, elytra light brown to dark brown with two large median oval pale yellow spots on each elytra. They laid eggs singly and randomly within the whitefly colonies. The eggs are elongate oval, pale white in colour. After egg hatching, the first instar larvae remained inactive for a while and fed on the life stages of whitefly very near to it. Grubs covered with white waxy filaments. The entire grub period comprised of four instars and later instars were more active than early instars. The mature later instar grubs after voracious feeding moved onto the whitefly infested older chilli leaves and aggregated on underside of leaves. Tip of their abdomen remained attached to the substratum by means of secretions and they entered into a non-feeding state known as pre pupa and after one or two days prepupa transformed into pupal stage. Aggregation of pupal stage is a common feature in the family coccinellidae (Richards 1980). A few days later adults emerged and started feeding on prey. These beetles after mating laid eggs in prey colony and the life cycle continued (Plates A-F).

The preliminary studies on feeding of *A. puttarudriahi* on different life stages of *A. trachoides* showed that the egg stage of whitefly is more preferred by both grubs and adults of *A. puttarudriahi*. Wijesekera and Kudagama (1990) observed *A. puttarudriahi* feeding on whitefly eggs in Sri Lanka. Studies conducted by Boopathi (2013) also confirmed that the egg stage of *Aleurodicus dispersus* Russell as the most preferred stage by *A. puttarudriahi* compared to other life stages of the whitefly. Hence the experiment was carried out on the egg stage of *A. trachoides* (Table 1).

Developmental duration of *A. puttarudriahi* on *A. trachoides*: The developmental duration of the beetle from egg stage to adult ranged from 53 to 62.5 days with a mean developmental period of 56.27 ± 2.66 days. The mean incubation period of egg was 3.57 ± 0.32 days. The first instar grub remained in this stadium for a mean period of 1.5 ± 0.0 days. Second instar stage of grub took a mean period of 1.6 ± 0.21 days. Mean duration of third and fourth instars was 2.1 ± 0.21 and 2.5 ± 0.19 days, respectively. Total grub period

ranged from 7 to 8 days with mean duration of 7.7 ± 0.32 days. After the voracious feeding in fourth instar stage, grub stopped feeding and entered in pre pupal stage for a mean period of 1.47 ± 0.23 days and then transformed into pupa. The mean pupal period was 5.53 ± 0.40 days. The longevity of adult beetle ranged from 35 to 44 days with mean duration of 38 ± 2.75 days. This finding is in agreement with Boopathi (2013) who conducted studies on biology of *A. puttarudriahi* on cassava whitefly, *A. dispersus* and reported the egg period, first, second, third and fourth instar grubs, pre-pupal period, pupal period and adult longevity of *A. puttarudriahi* were 3.5, 1.7, 1.9, 2.5, 2.8, 1.9, 5.9 and 38.3 days.

Feeding potential of *A. puttarudriahi* on *A. trachoides*:

Results of experiment on feeding potential of *A. puttarudriahi* on *A. trachoides* eggs revealed that a single beetle is capable of consuming 11351 whitefly eggs during its entire life cycle. Minimum consumption was in first instar grubs (32.73) and an increase in feeding potential was observed as the grub passes from early to late instars. Second and third instars recorded a mean consumption of 96.4 and 388.6 eggs, respectively. Fourth instars showed voracious feeding habit with mean consumption of 940.6 eggs which is more than the total consumption of first three instars. The beetle consumed a mean of 1458.33 eggs during its entire grub period which is 12.85 per cent of the total consumption of the beetle (11351) during its life cycle. Adult beetle was potential predator with 87.15 per cent (9892.67 eggs) of the total consumption. The per day predatory potential of 1st, 2nd, 3rd and 4th instars of *A. puttarudriahi* were 21.82, 61.12, 184.69 and 377.04 whitefly eggs, respectively, while a single adult beetle was capable of consuming 261.22 whitefly eggs per day (Fig. 1). Lalitha et al (2018) observed the feeding potential of the predatory coccinellid, *Scymnus latifolius* Poorani, which

Table 1. Developmental duration and feeding potential of *Axinoscymnus puttarudriahi* on egg stage of *Aleurothrixus trachoides* under in vitro condition

Life stages of <i>A. puttarudriahi</i>	Developmental duration in days (Mean \pm SE)	Total number of <i>A. trachoides</i> eggs consumed (Mean \pm SE)
Egg	3.57 ± 0.32^a	-
Grub		
1 st instar	1.5 ± 0.0^h	32.73 ± 4.86^g
2 nd instar	1.6 ± 0.21^h	96.40 ± 5.73^f
3 rd instar	2.1 ± 0.21^g	388.60 ± 50.13^e
4 th instar	2.5 ± 0.19^f	940.60 ± 52.62^d
Total	7.7 ± 0.32^c	1458.33 ± 72.35^c
Pre pupa	1.47 ± 0.23^h	-
Pupa	5.53 ± 0.40^d	-
Adult	38 ± 2.75^b	9892.67 ± 460.16^b
Total	56.27 ± 2.66^a	11351 ± 462.81^a

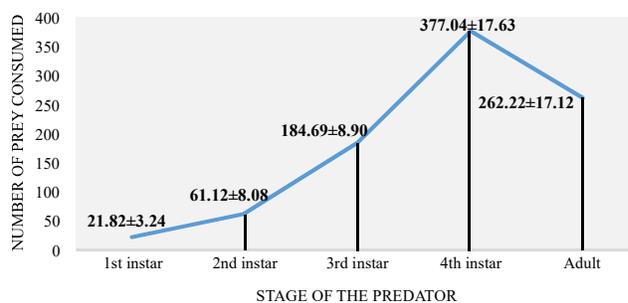


Fig. 1. Per day predatory potential of *A. puttarudriahi* on *A. trachoides* eggs

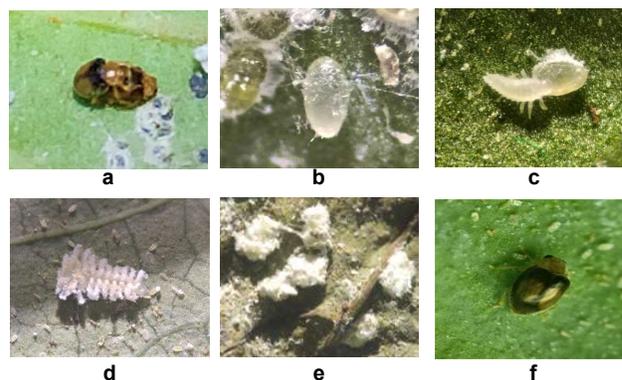


Plate 1. A- Mating of adult beetles; B- Egg of *A. puttarudriahi*; C- Newly emerged first instar grub of *A. puttarudriahi* feeding on whitefly nymph; D- Grub of *A. puttarudriahi*; E- Aggregation of pupae of *A. puttarudriahi*; F- Adult feeding on whitefly

belongs to the same tribe (Tribe Scymnini) of *A. puttarudriahi*, on the egg stage of the mealybug *Paracoccus marginatus* Williams & Granara de Willink. They reported that feeding potential of the beetle increased significantly with development in instars. Consumption of mealy bug eggs was more in adult of *S. latifolius* compared to grubs.

CONCLUSION

The developmental duration of *A. puttarudriahi* comprised 3.57 days of egg period, 7.7 days of grub period, pre pupal and pupal duration of 1.47 and 5.53 days and 38 days of adult longevity. The grub consumed 1458.33 whitefly eggs while the adult stage of *A. puttarudriahi* was potent predator and average per day intake of 261.22 whitefly eggs. The findings of the present investigation clearly showed the potential of *A. puttarudriahi* as a biocontrol agent against *A. trachoides*. The conservation of this predator in the natural ecosystem will help to regulate the whitefly population to a great extent. Future scope of this work lies in utilizing the biocontrol potential of this beetle in ecologically based

integrated pest management programs against whitefly pests.

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REFERENCES

- Abd-Elkareim AI, Jabbar AS and Marouf AE 2019. Effects of feeding floral resource on potential of *Bemisia tabaci* Parasitoids. *Indian Journal of Ecology* **46**(3): 636-639.
- Boopathi T 2013. *Biological Control and Molecular Characterization of Spiralling Whitefly, Aleurodicus Dispersus Russell on Cassava and Brinjal*. Ph.D. Dissertation, Tamil Nadu Agricultural University, Coimbatore, India.
- Dhaliwal GS, Jindal V and Mohindru B 2015. Crop losses due to insect pests: Global and Indian scenario. *Indian Journal of Entomology* **77**(2): 165-168.
- Lalitha N, Chatterjee H, Santhakumar MV and Kumar SN 2018. Predatory potential of new species of *Scymnus* Kugelann, *Scymnus latifolius* Poorani sp. nov. (Coleoptera, Coccinellidae) on papaya mealybug *Paracoccus marginatus* infesting mulberry. *Journal of Entomology and Zoology Studies* **6**(4): 1803-1807.
- Mani M and Krishnamoorthy A 1999. Natural enemies and host plants of spiralling whitefly, *Aleurodicus dispersus* Russel (Aleyrodidae, Homoptera) and its natural enemies on guava in India. *Entomon* **24**(1): 75-80.
- Mani M and Krishnamoorthy A 2006. Colonization of introduced parasitoid, *Encarsia guadeloupae* Viggiani, on the exotic spiralling whitefly, *Aleurodicus dispersus* Russell, Infesting Ornamentals. *Journal of Horticultural Sciences* **1**(2): 148-151.
- Mohan M 2017. *Management of American Serpentine Leaf Miner Liriomyza trifolii (Burgess) Dietars in Tomato*. M.Sc. Dissertation, Kerala Agricultural University, Thiruvananthapuram, India.
- Poorani J 2002. An annotated checklist of the coccinellidae (Coleoptera) (Excluding Epilachninae) of the Indian Subregion. *Orient Insects* **36**: 307-383.
- Ramanujam B, Shylesha AN, Joshi S, Murthy KS, Rangeshwaran R, Mohan M, Subhaharan K and Verghese A 2014. *All India Coordinated Research Project on Biological Control of Crop Pests Annual Progress Report*, ICAR National Bureau of Agricultural Insect Resources, Bangalore, India.
- Richards AM 1980. Defensive adaptations and behaviour in *Scymnodes lividigaster* (Coleoptera: Coccinellidae). *Journal of Zoology* **192**: 157-168.
- Sharma KR, Jaiswal DK, Babul SR and Saraoj AK 2018. Impact of invasive insect pests species on agro ecosystem in India. *Indian Journal of Agriculture and Allied Sciences* **4**(1): 19-26.
- Sundararaj R, Amuthavalli T and Vimala D 2018. Invasion and establishment of the solanum whitefly *Aleurothrixus trachoides* (Back) (Hemiptera: Aleyrodidae) in South India. *Current Science* **115**(1): 29-31.
- Vidya CV and Bhaskar H 2017. Scymnini (Coleoptera: Coccinellidae) associated with major sucking pests of Kerala. *Journal of Biological Control* **31**(4): 212-216.
- Wijesekera GAW and Kudagamage C 1990. Life history and control of 'spiralling' whitefly *Aleurodicus dispersus* (Homoptera: Aleyrodidae): fast spreading pest in Sri Lanka. *Quarterly Newsletter, Asia and Pacific Plant Protection Commission* **33**(2): 22-24.

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Studies on Batch Adsorption of Gemifloxacin using Hybrid Beads from Biomass

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Abstract: Adsorbents are constantly being explored for better removal of waste from aquatic system to make it cost effective and environmental friendly. Batch adsorption studies were carried out for elimination of gemifloxacin from synthetic aqueous solution by using low cost efficient beads. Beads made from plant materials were characterized using SEM, EDX and FTIR. The parameters like contact time (30-180 min), initial concentration (30–50 mg/L), pH (3–11) and adsorbent dose (0.1–1.0 gm/50 mL) were systematically investigated. Inverse relation found between adsorption percentage and antibiotic concentration in water, whereas direct relation observed between adsorption percentage and adsorbent dosage. Maximum adsorption was found at different pH with different combination bead, pH 5.0 for AWC beads (50% almond shell: 25% walnut shell: 25% chitosan) and pH 7.0 for CAW (50% chitosan: 25% almond shell: 25% walnut shell) and WAC beads (50% walnut shell: 25% almond shell: 25% chitosan). Langmuir adsorption isotherm is well befitting in case of CAW beads whereas Freundlich adsorption for the case of AWC and WAC beads. The adsorption rate follows Lagergren pseudo second order kinetics. On the whole, the results of the study indicate that beads in all the combinations taken in the study are very efficient material for the removal of antibiotics from effluents.

Keywords: Antibiotic, Adsorption, Isotherms, Kinetics, Synthesized beads

Antibiotic accumulation has become the cause of concern to the scientists and environmentalists (Azhar et al 2016), as their potential impact on non-target species is also high. Effects have been reported on body growth, weight, survival of microorganisms (Azhar et al 2016) and also allergic reactions and the development of antibiotic resistance (Bao et al 2014). Thus, the highest concern is to eradicate these harmful chemicals from aquatic environment. There are reports of attempts on removal of antimicrobials from wastewater treatment systems. Some methods are being incorporated for removal of antibiotics like reverse osmosis (Zularisam et al 2006), membrane filtration (Malaeb et al 2011, Becker et al 2016), ozonation (Amouzgar and Salamatinia 2015). However, most of these techniques are costlier, results in by-product formation or not effective enough. Therefore, adsorption technology has become a choice of practice, which demonstrates efficient route to remove pollutants, due to comparable low-cost application and their ease of operation (Zhang et al 2014). Some low-cost adsorbents used paper towel (Xie et al 2016), corn bracts (Yu et al 2017), walnut shell (Yu et al 2016) and rice husk (Chen et al 2016). Chitosan have been extensively studied as sorbents for the removal of wide ranging waterborne contaminants including organic and inorganic pollutants viz. dyes (Chiou et al 2004), antibiotics (Adriano et al 2005), metals (Igherase et al 2014). Walnut and almond

shells are organic residues with good stability, large specific surface area, high mechanical strength, good chemical stability and easy regeneration which have been effectively implemented in the removal of pollutants by adsorption (Flores-Cano et al 2016, Maaloul et al 2017). These are known as a low-cost adsorbent (Kamar and Nechifor 2015), and are widely applied in various environmental pollution control technologies (Yu et al 2016). The objectives of current studies were preparation and characterization of different combination beads (chitosan + walnut shell and/or almond shell) and adsorption kinetics of antibiotics from water by using these prepared combination beads.

MATERIAL AND METHODS

Synthesis of chitosan, walnut and almond shell beads:

Chitosan was used without further purification. Walnut and almond shells were collected from local market and washed twice with distilled water to remove the dust, dried at 105°C for 24 hrs, then grinded, sieved separately and packed in zipper packs for further use. Chitosan, walnut and almond shell powder used in combination (AWC 2:1:1, CAW 2:1:1, WAC 2:1:1) were dissolved in glacial acetic acid (2.0%). The solutions were agitated by a magnetic stirrer (8–10 h) at room temperature (23 ± 2 °C). Then with the help of syringes the solution was released drop wise into a NaOH (0.5M) to form spherical beads, and was kept for minimum 16 h in NaOH

(0.5M) for imbibitions. For activation purpose the beads (1.5 gm) were treated with 15 ml glutaraldehyde solution (2.5%) at pH 5.0. The beads were stirred (150 rpm) for 3 h at room temperature. It was followed with washing of the activated beads to remove unreacted glutaraldehyde until a neutral pH is obtained. Finally, the beads were dehydrated in hot air oven at 50 °C for 24 hrs and stored in air tight bottles for further use.

Surface characterization: The beads were characterized using FT-IR spectrophotometer (Shimadzu-8400) in range 4000-450⁻¹ cm. Scanning Electron Microscope (SEM-JEOL 6100) was used for bead characterization. The elemental composition of surfaces was analyzed by Energy Dispersive X-ray Spectroscopy (EDX).

Batch adsorption: The removal efficiency of the beads was studied by batch adsorption. In a conical flask (250 ML), 0.1g beads were agitated along with gemifloxacin (10-50 mg/50ml) at 150 rpm 30±2 °C temperature. After attaining the equilibrium the adsorbent was separated and aqueous phase containing antibiotic were examined by employing UV-spectrophotometer. The effect of different adsorption parameters such pH (3-11), initial concentration (10-50 mg/l), reaction time (30-180 min) and adsorbent dosage (0.1-1 gm) were evaluated. The removal efficiency of gemifloxacin by prepared beads was calculated according to the equations as follows (Kumar et al 2018):

$$\% \text{ removal} = \frac{C_0 - C_e}{C_e} \times 100$$

Where, C₀ (mg/L) and C_e (mg/L) denote the initial and equilibrium concentration of the target contaminant, respectively. All experiments were conducted in triplicates.

RESULTS AND DISCUSSION

Surface characterization: The spectrograms for the beads were taken within the range of 450-4000 cm⁻¹, which was performed to identify the groups there on the exterior of the adsorbent that can potentially favor the adsorption of antibiotics. N-H, OH and CO groups are found in the prepared beads, which are considered as a good choice for adsorption process (Kumar et al 2018). The first bands between 3700-3800 cm⁻¹ attributes to the stretching vibration of C-H bond suggesting either presence of alkenes or aromatic compounds. The peaks at 3273 cm⁻¹, 3255 cm⁻¹ and 3288 cm⁻¹ in ACW, CAW and WAC beads indicate Hydrogen bonding O-H stretch suggesting the presence of phenols and alcohols. The sharp peaks at 2359 cm⁻¹, 2362 cm⁻¹ and 2355 cm⁻¹ confirm a presence of N-H group for amines (Mala and Dutta 2019). When aldehyde groups of glutaraldehyde reacts with amino groups of beads, the amine groups may be formed (Migneault et al 2004). The transformation is

supported by the presence of peaks at 1643 cm⁻¹, 1647 cm⁻¹ and 1649 cm⁻¹, highlights a C=O stretch suggestive of alkenes. After adsorption the peaks have become restrained in case of AWC beads. The peaks close to 1000 cm⁻¹ have become less reflective and intense in terms of height. The peaks between 1550-1350 cm⁻¹ show more sub-peaks at the top and a drastic reduction in size or intensity. The other major peak between 3750-3000 cm⁻¹ has considerably become more flat, lesser in size and intensity. The peaks became intensified after adsorption in case of CAW beads. There was not much considerable difference between the before and after adsorption peaks on WAC beads (Mala and Dutta 2019).

Scanning electron micrographs presents the surface morphology of synthesized beads before and after adsorption. The AWC beads (Fig. 1a) before adsorption SEM image show topographical features of being irregular to wavy in appearance. The surface shows different gradients of density along with presence of sparsely scattered fissures and occasional pores. The images of beads after adsorption (Fig. 1b) still appears to be multiple layered but individually aggregates present more of an even surface topography and resembling clouds of an overcast sky. In case of CAW (Fig.

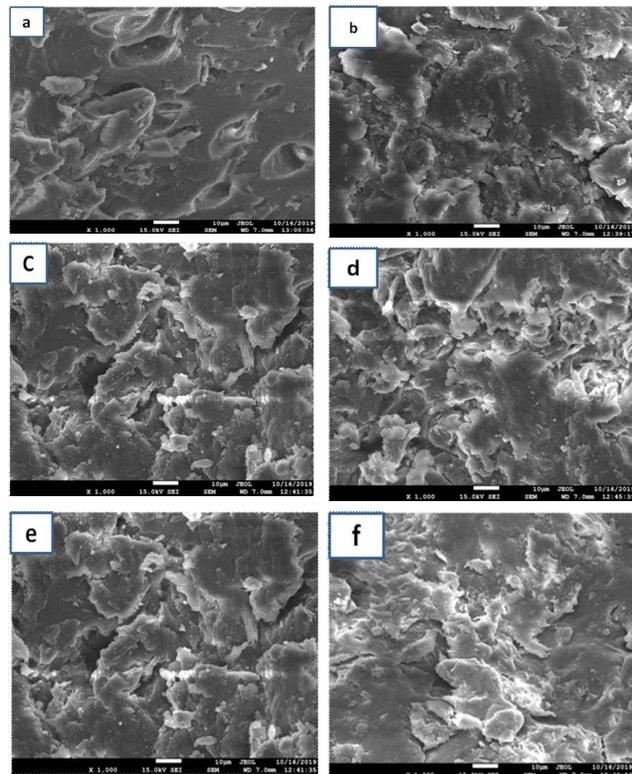


Fig. 1. SEM micrograph images of AWC (a- before adsorption, b- after adsorption), CAW (c- before adsorption, d- after adsorption), WAC beads (e- before adsorption, f- after adsorption)

1c) beads SEM image shows surface topography to be multiple layered and uneven along with formation of chunks of varying sizes fissures and conspicuous pores can be also seen selectively. The post processed image (Fig. 1d) shows that the agglomerates previously formed have mellowed down in terms of size and adhesion pattern thereby clearly indicating an activity. The WAC bead (Fig. 1e) surface seems rough, multiple layered, scattered in patterns of being sparse, discrete to be assorted somewhere thus giving an uneven outlook. The post processed SEM image (Fig. 1f) after adsorption shows, agglomerates have become more condensed, tightly packed thereby look more coerced, though the surface seems to be still rough, multiple layered but overall seems to be more fortified. Energy dispersive spectra (EDX) define the elemental peaks. The EDX spectra of ACW, CAW and WAC beads show the elemental composition of beads is mentioned on graphs and the beads contain maximum percentage of carbon followed by oxygen.

Effect of contact time on percentage adsorption: The percentage removal of antibiotic by beads with contact time (0-180) is shown in Figure 2. It is found that the adsorption efficiency of synthesized beads increased rapidly as the contact time increased upto 120 min, and afterward reduced gradually. In the beginning the removal of gemifloxacin was rapid and dropped gradually till it reached equilibrium with time. It is basically due to saturation of the beads with drug (Azarpira 2016). The contact times for further studies were selected as 180 mins as equilibrium was attained at 120mins. The graph depicts that adsorption percentage reached 86 %, 90 % and 85 % in case of AWC, CAW and WAC beads respectively in 180 min.

Effect of initial concentration on percentage adsorption: The investigation was done by utilizing various concentrations of the gemifloxacin (10 to 50 mg/L) while keeping all other conditions constant in order to check the effect of the initial concentration of the antibiotic on adsorption (Fig. 3). Removal of the gemifloxacin, decreased

from 95% to 65 % (AWC beads), 93 % to 68 % (CAW beads) and 94% to 68% (WAC beads) respectively, when concentration increased from 10 to 50 mg/l. In the beginning, the percentage removal of gemifloxacin was rapid due to the larger surface area of adsorbent available, but it dropped gradually till it reached equilibrium with time. It is mainly due to saturation of the active site which does not permit further adsorption (Balarak et al 2016).

Effect of adsorbent dosage on percentage adsorption: In order to understand the effect of adsorbent dosage on adsorption, dosage varied from 0.1-1 g/50ml of solution. The adsorption of gemifloxacin was a function of adsorbent dosage at given conditions (Fig. 4). The gemifloxacin adsorption increased from 83 to 92% on WAC beads, when the adsorbent dosage increased from 0.1 to 1 g/ 50 ml. The adsorption was also observed to increase from 81% to 90 % and 81% to 89 % in case of AWC and CAW beads respectively at same conditions. The results obtained can be put forward by the fact that by raising the dosage of adsorbents, the active sites of the adsorbent surface increases and more antibiotic molecules can be adsorbed on the beads (Kakavandi et al 2014; Ahsan et al 2018). A direct

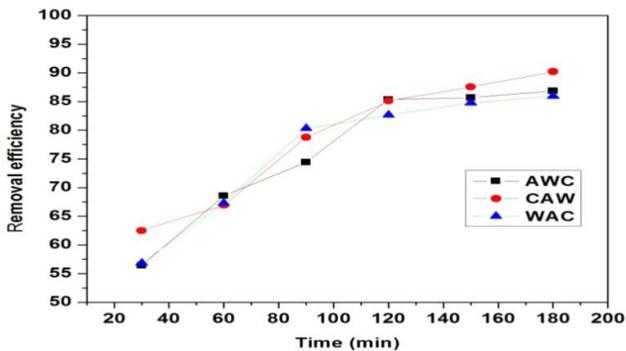


Fig. 2. Adsorption efficiencies on AWC, CAW and WAC beads of gemifloxacin at different time periods

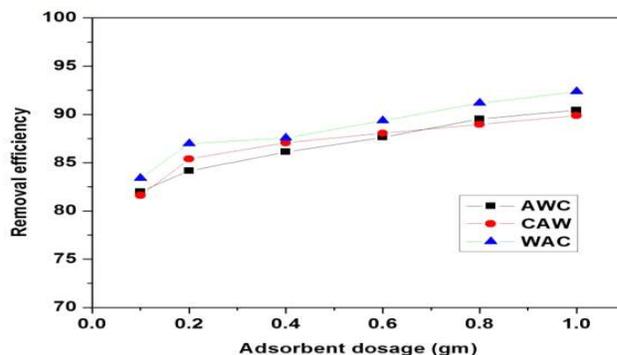


Fig. 3. Adsorption efficiencies on AWC, CAW and WAC beads of gemifloxacin at different initial concentrations

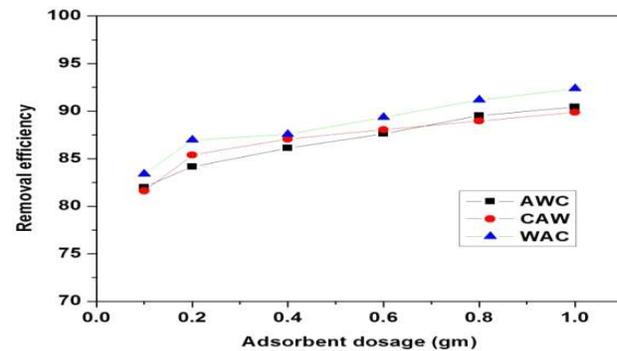


Fig. 4. Adsorption efficiencies on ACW, CAW and WAC beads of gemifloxacin at different adsorbent dosage

relation could be established by stating the influence of available surface area and charge on the beads to interact with antibiotics (Chen et al 2014). When the dosage increased from 0.1 to 1 g/L, the gemifloxacin adsorption percentage also increased slightly (83-92 on WAC, 81-90 on AWC, 81-89 on WAC beads). Therefore, for all subsequent studies, 0.1 g/L adsorbent dosage was adequate as only small increase would have been accomplished using larger amount of adsorbent.

Effect of pH on biosorption of antibiotic: The pH of solution is effective for adsorption process, when adsorbent and adsorbates are dependent on acid-base characteristics (Ahsan et al 2018, Yadav et al 2018). The adsorption efficiencies of beads were studied at different pH (3-11) values with fixed initial concentration of antibiotic (30 mg/l) and time period of 180 min. At lower pH, fluoroquinolone antibiotics carry positive charges due to protonation of amine groups and at higher pH, they behave as anion due to deprotonation of carboxylic groups, however; at neutral pH Zwitter ion exists (Yadav et al 2018). Thus, the study was spread over with range from pH 3-11. The maximum gemifloxacin removal was observed at pH 5.0 with AWC beads (82 %), which is also found in a research where in amoxicillin adsorption increases from pH 2-5 as the carboxyl functional groups (-COOH) on the amoxicillin readily dissociate to carboxylate (-COO⁻) which increases electrostatic attraction between amoxicillin and the adsorbent (Putra et al., 2009; Moussavi et al 2013). Maximum adsorption of gemifloxacin was found at pH 7.0 on CAW (84%) and WAC (80%) beads, because of its Zwitter ionic form which may be due to protonated amine groups that still able to help in adsorption (Yadav et al 2018). The reduction in adsorption was endorsed due to deprotonation of C=O groups on antibiotic and beads, which significantly cause repulsion between negative charges found on beads and antibiotics (Jiang et al 2013). It was analyzed from the Figure 5 that WAC beads follow lower level of adsorption onto its surface as compared to other two compositions. From the FTIR analysis it was found that all the three different beads contain OH, and CO groups which give negative charges due to oxygen containing groups (Yadav et al 2018). The pH of the solution manipulate surface charges of the adsorbent and the structure of antibiotic molecules (Yadav et al 2018) there by affects the adsorption process and further removal from synthetic water.

Adsorption isotherm: Adsorption isotherms details the association between the amounts of adsorbates adsorbed by the adsorbent (Q_e) and the adsorbate residual concentration after the system has reached equilibrium state (C_e) at constant temperature (Kumar et al 2018). The mechanism of

adsorption is explained by using a number of isotherm models. The equilibrium information was analyzed utilizing Langmuir and Freundlich isotherm models (Pal et al 2017).

The linear form of Freundlich isotherm is as

$$\frac{1}{Q_e} = \frac{1}{Q} + \frac{1}{bQC_e}$$

The equation for Freundlich is represented as:

$$\log Q_e = \log K_f + \frac{1}{n} \log C_e$$

where Q - Langmuir adsorption capacity (mg/g), b - Langmuir constant; K_f -Freundlich constant

The Langmuir isotherm can be described by separation (RL) factor.

$$RL = \frac{1}{L} + bC_0$$

C_0 - maximum concentration of adsorbate. The amount of RL factor specify Langmuir isotherm (unfavorable ($RL > 1$), linear ($RL = 1$), favorable ($0 < RL < 1$) or irreversible ($RL = 0$)) (Kumar et al 2018). Langmuir model assumes monolayer adsorption on homogeneous surface of adsorbent. Freundlich isotherm accepts heterogeneous surface energies. (Kumar et al 2018). Figure 6 (A-B) shows the graphs of Langmuir and Freundlich isotherms respectively. Table 1 gives the values of constants for the isotherms. The comparison values of R^2 (non-linear regression coefficient) for the isotherms concludes that the Langmuir model is better followed in case of CAW beads and Freundlich adsorption better in case of AWC and WAC beads.

Adsorption kinetics:

In order to evaluate the kinetics of the adsorption experiment, data obtained from adsorption studies are fitted to Lagergren Pseudo first order and second order models. The kinetics of adsorption helps in finding out the nature of adsorption (Kumar et al 2018).

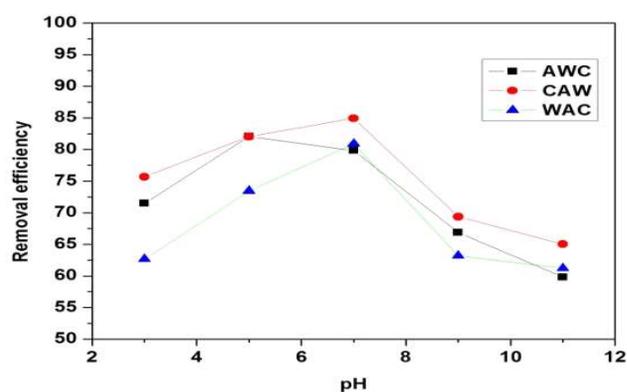


Fig. 5. Adsorption efficiencies on, AWC, CAW and WAC beads of gemifloxacin at different pH conditions

Lagergren pseudo-first order equation:

$$\text{Log}(Q_e - Q_t) = \text{log } Q_e - \frac{K_1}{2.303} t$$

Lagergren pseudo-second order equation:

$$\frac{t}{Q_t} = \frac{1}{h} + \frac{t}{Q_2e}$$

Q_e and Q_t are the antibiotic amount adsorbed (mg/g) by adsorbent at equilibrium and at time t (min.). k^1 (min^{-1}) represents rate constant for Lagergren pseudo first order, $h =$

$k_2 Q_{2e}^2$ and k_2 (in mg/g/min) denotes the rate constant for Lagergren pseudo second order (Kumar et al 2018). The straight line plots of $\text{log}(Q_e - Q_t)$ against time (t) for pseudo 1st order reaction and t/Q_t against time (t) for the pseudo 2nd order kinetics (Fig. 7 (A-B)). Table 2 represents the rate parameter k_1 , k_2 , Q_e and R_2 of gemifloxacin. It is apparent on the basis of R_2 values adsorption Lagergren pseudo second order kinetic model.

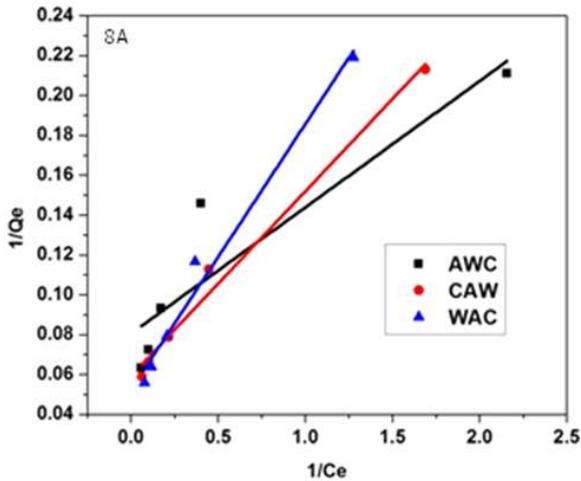


Fig. 6a. Langmuir Isotherm for synthesized beads

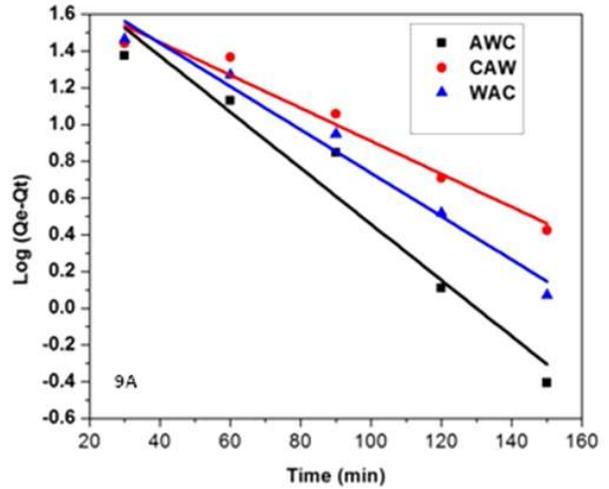


Fig. 7a. Lagergren pseudo first order

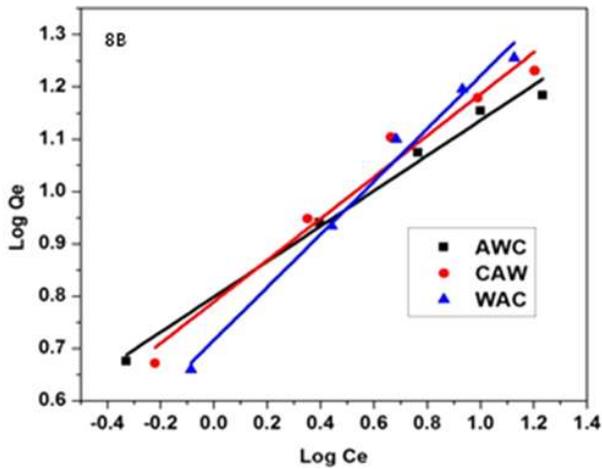


Fig. 6b. Freundlich Isotherm for synthesized beads

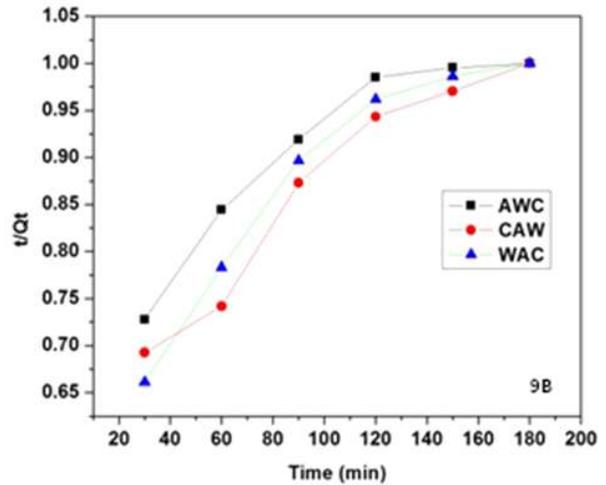


Fig. 7b. Lagergren pseudo second order

Table 1. Adsorption isotherm constants

Langmuir	Constants			Freundlich	Constants		
	AWC	CAW	WAC		AWC	CAW	WAC
Q	12.47	16.887	19.877	Kf	6.290	6.147	5.194
B	1.270	0.640	0.392	1/n	0.337	0.397	0.505
R ²	0.639	0.967	0.955	R ²	0.972	0.934	0.970
SD	0.015	0.004	0.006	SD	0.017	0.029	0.023

Table 2. Comparison of various kinetics models (Lagergren Pseudo)

	First order			Second order			
	AWC	CAW	WAC	AWC	CAW	WAC	
Q	96.640	64.387	84.489	Qe	96.153	102.04	98.030
K ₁	0.035	0.020	0.027	h	5.878	4.108	4.130
R ²	0.888	0.916	0.942	k ₂	0.000	0.000	0.000
SD	0.187	0.094	0.102	R ²	0.998	0.986	0.997
				SD	0.018	0.042	0.022

CONCLUSIONS

The low-cost hybrid beads as adsorbent was prepared by using chitosan, almond and walnut shell for the removal of gemifloxacin. The prepared beads are having advantages because of their biodegradability, low cost and easy to synthesize. The characterization was done by SEM, EDX and FTIR. SEM data suggests that the beads are irregular to wavy in appearance with pores. The presence N-H, O-H and CO groups (as per FTIR) and elemental carbon with oxygen (EDX) shows that the hybrid beads are good choice for adsorption process. Parameters like effect of pH, initial concentration, dosage and time on the adsorption was systematically investigated. The optimal contact time for equilibrium studies was found to be 120 min for synthesized beads, but the reaction time was continued till 180 minutes. The highest adsorption was attained at pH 5.0 in case of AWC beads and at pH 7.0 on CAW and WAC beads. The adsorption isotherms data in case of CAW beads fitted well with Langmuir model and follow Freundlich model in case of AWC and WAC beads. Adsorption followed the pseudo second order mechanism in case of all beads types.

REFERENCES

- Adriano WS, Veredas V, Santana CC and Gonçalves LB 2005. Adsorption of amoxicillin on chitosan beads: Kinetics equilibrium and validation of finite bath models. *Biochemical Engineering Journal* **27**(2): 132-137.
- Amouzgar P and Salamatinia B 2015. A short review on presence of pharmaceuticals in water bodies and the potential of chitosan and chitosan derivatives for elimination of pharmaceuticals. *Journal of Molecular and Genetic Medicine* **4**: 001.
- Azarpira H and Balarak D 2016. Rice husk as a biosorbent for antibiotic metronidazole removal: Isotherm studies and model validation *International Journal of Chemical Technology Research* **9**(7): 566-573.
- Azhar MR, Abid HR, Sun H, Periasamy V, Tadé MO and Wang S 2016. Excellent performance of copper based metal organic framework in adsorptive removal of toxic sulfonamide antibiotics from wastewater. *Journal of Colloid and Interface Science* **478**: 344-352.
- Ahsan MA, Islam MT, Hernandez C, Castro E, Katla SK, Kim H, Lin Y, Curry ML, Gardea-Torresdey J and Noveron JC 2018. Biomass conversion of saw dust to a functionalized carbonaceous materials for the removal of tetracycline sulfamethoxazole and bisphenol A from water. *Journal of Environmental Chemical Engineering* **6**(4): 4329-4338.
- Bao X, Qiang Z, Chang JH, Ben W and Qu J 2014. Synthesis of carbon-coated magnetic nanocomposite (Fe₃O₄@ C) and its application for sulfonamide antibiotics removal from water. *Journal of Environmental Science* **26**(5): 962-969.
- Becker D, Della Giustina SV, Rodriguez-Mozaz S, Schoevaart R, Barceló D, de Cazes M, Belleville MP, Sanchez-Marcano J, de Gunzburg J, Couillerot O and Völker J 2016. Removal of antibiotics in wastewater by enzymatic treatment with fungal laccase-degradation of compounds does not always eliminate toxicity. *Bioresource Technology* **219**: 500-509.
- Balarak D and Mostafapour FK 2016. Canola residual as a biosorbent for antibiotic metronidazole removal. *The Pharmaceutical and Chemical Journal* **3**(2):12-17.
- Chiou MS, Ho PY and Li HY 2004. Adsorption of anionic dyes in acid solutions using chemically cross-linked chitosan beads. *Dyes and Pigments* **60**(1): 69-84.
- Chen Y, Wang F, Duan L, Yang H and Gao J 2016. Tetracycline adsorption onto rice husk ash an agricultural waste: its kinetic and thermodynamic studies. *Journal of Molecular Liquids* **222**: 487-494.
- Flores-Cano JV, Sánchez-Polo M, Messoud J, Velo-Gala I, Ocampo-Pérez R and Rivera-Utrilla J 2016. Overall adsorption rate of metronidazole dimetridazole and diatrizoate on activated carbons prepared from coffee residues and almond shells. *Journal of Environmental Management* **169**: 116-125.
- Igberase E, Osifo P and Ofomaja A 2014. The adsorption of copper (II) ions by polyaniline graft chitosan beads from aqueous solution: equilibrium kinetic and desorption studies. *Journal of Environmental Chemical Engineering* **2**(1): 362-369.
- Kakavandi B, Esrafilii A, Mohseni-Bandpi A, Jonidi Jafari A and Rezaei Kalantary R 2014. Magnetic Fe₃O₄@ C nanoparticles as adsorbents for removal of amoxicillin from aqueous solution. *Water Science and Technology* **69**(1): 147-155.
- Kamar FH and Nechifor AC 2015. Removal of copper ions from industrial wastewater using walnut shells as a natural adsorbent material. *UPB Scientific Bulletin Series B* **77**(3): 142-150.
- Kumar M, Dosanjh HS and Singh H 2018. Magnetic zinc ferrite-alginate biopolymer composite: as an alternative adsorbent for the removal of dyes in single and ternary dye system. *Journal of Inorganic and Organometallic Polymers and Materials* **28**(5): 1688-1705.
- Malaeb L and Ayoub GM 2011. Reverse osmosis technology for water treatment: state of the art review. *Desalination* **267**(1): 1-8.
- Moussavi G, Alahabadi A, Yaghmaeian K and Eskandari M 2013. Preparation characterization and adsorption potential of the NH₄Cl-induced activated carbon for the removal of amoxicillin antibiotic from water. *Chemical Engineering Journal* **217**: 119-128.
- Maaloul N, Oulego P, Rendueles M, Ghorbal A and Díaz M 2017. Novel biosorbents from almond shells: Characterization and adsorption properties modeling for Cu (II) ions from aqueous solutions. *Journal of Environmental Chemical Engineering* **5**(3): 2944-2954.

- Mala AA and Dutta J 2019. Acute and chronic toxicity of fluoroquinolone antibiotics through fresh water cladoceran *Daphnia magna*. *Indian Journal of Ecology* **46**(4): 874-879.
- Putra EK, Pranowo R, Sunarso J, Indraswati N and Ismadji S 2009. Performance of activated carbon and bentonite for adsorption of amoxicillin from wastewater: mechanisms isotherms and kinetics. *Water Research* **43**(9): 2419-2430.
- Pal P and Pal A 2017. Surfactant-modified chitosan beads for cadmium ion adsorption. *International Journal of Biological Macromolecules* **104**: 1548-1555.
- Xie A, Dai J, Chen X, He J, Chang Z, Yan Y and Li C 2016. Hierarchical porous carbon materials derived from a waste paper towel with ultrafast and ultrahigh performance for adsorption of tetracycline. *RSC Advances* **6**(77): 72985-72998.
- Yu F, Li Y, Han S and Ma J 2016. Adsorptive removal of antibiotics from aqueous solution using carbon materials. *Chemosphere* **153**: 365-385.
- Yu Y, Zhou Y, Wang Z, Torres OL, Guo R and Chen J 2017. Investigation of the removal mechanism of antibiotic ceftazidime by green algae and subsequent microbial impact assessment. *Scientific Reports* **7**(1): 1-11.
- Yadav S, Goel N, Kumar V, Tikoo K and Singhal S 2018. Removal of fluoroquinolone from aqueous solution using graphene oxide: experimental and computational elucidation. *Environmental Science and Pollution Research* **25**(3): 2942-2957.
- Zularisam AW, Ismail AF and Salim R 2006. Behaviours of natural organic matter in membrane filtration for surface water treatment - a review. *Desalination* **194**(1-3): 211-231.
- Zhang Y, Shen Z, Dai C and Zhou X 2014. Removal of selected pharmaceuticals from aqueous solution using magnetic chitosan: Sorption behavior and mechanism. *Environmental Science and Pollution Research* **21**(22): 12780-12789.

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Comparative Analysis and Characterization of Lipase Producing Alkaliphilic Bacteria Isolated from Lonar Soda Lake, India

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Abstract: Microbial culture dependent phenotypic and genomic characteristic were observed for lipase producing bacteria. Out of twenty nine isolates; thirteen bacterial strains were obtained lipase producing bacterial strains. These strains were subjected to physiological and standard biochemical characterization along with 16S rDNA sequencing for their identification. The phylogenetic position indicated the bacterial strains were related to phylum Firmicutes and belongs to *Bacillus cereus* OCW31, *Bacillus pumilus* DW21, *Bacillus pseudofirmus* DW41 and *Bacillus flexus* AW32. These four strain selected for production and, partial characterizations of lipase due to maximum lipolytic activity. The lipase was highly stable over a broad temperature from 40 to 90°C and optimum enzyme activity was found to be 70°C for *B. cereus* ICW31. The effect of organic solvents on the lipase activity was determined. The data elucidate that the lipase from *B. flexus* AW32 and *B. pseudofirmus* DW41 was highly active than *B. cereus* OCW31 and *B. pumilus* DW21 in all organic solvents tested. The lipase was enhanced the activity in presence of CaCl_2 , MnSO_4 , for *B. pseudofirmus* DW41 and *B. pumilus* DW21 while NiCl_2 enhanced the lipase activity produce by *B. pseudofirmus* DW41 and *B. cereus* OCW31. The information for enzyme production and optimization of lipase has a bright future towards the improvement and production of novel enzymes for biotechnological potential.

Keywords: Lonar lake, Lipase, Alkaliphilic bacteria, Bacillus

The extremophilic environment found all over the world and harbors wealth of diverse microorganisms which belong to the Archaeal and bacterial domain of life (Rothschild and Mancinelli 2001). These environments include location of extreme temperature, alkaline, pressure and salinity. The alkaliphilic bacterial strains that required more than 8 pH for growth have useful application in industrial process and biotechnological potentials novel application are being investigated. They produce novel extracellular metabolites, polysaccharides, lipase, amylase, protease and xylanase, exopolysaccharide and poly-hydroxyalkanoate. The enzyme were used in industrial sector, which have been extracted and purified from bacteria and fungi (Egorova and Antranikian 2005). They are supposed to be unique and specific tool in industrial biotransformation protocol that run at extreme conditions. Generally *Bacillus* are able to produce of such enzymes are significant because not only their enzymes are alkaline tolerant but may also thermostable. Microbial lipases are the most important group of enzymes with applications in various industries. Lipase also work as biocatalysts in organic media, for transesterification process, synthesis of chiral compounds etc. Several strategies include discovery of new extremophilic species with novel biocatalytic features and search for unique and novel gene sequences from the total environmental genome pool (Singh et al 2009). This genome of extremophiles can be used for various applications like phylogenetic analysis etc. The

phylogenetic analysis is helpful in novel horizons for this type of study and shows their effort by giving answers of their origin, adaptation and other characteristics that forms the base for bioprospecting. The extremophilic environment of many microorganisms has stimulated extreme efforts to understand the physiological adaptations for survival in extreme environments and to probe the potential biotechnological applications of their stable cellular components. In this study, screening method for determination of extracellular lipolytic activity, which is produced by four *Bacillus* isolated from Lonar Soda lake. The optimum temperature and salt concentration of the extracellular lipase activities and kinetic parameters were also determined for further characterization.

MATERIAL AND METHODS

Collection of Lonar lake water and sediment sample: Water and sediment samples collected in sterilized plastic bottles and the total four medium were used for enrichment and isolation. Screening for lipolytic activity and followed by their identification were performed (Tambekar and Dhundale 2012).

Identification of the bacterial culture: Bacterial cultures were examined for their cultural, morphological character, and standard biochemical test were performed according to Bergey's Manual of systematic bacteriology.

Screening of bacterial alkaliphiles for lipolytic activity:

Isolates were screened for lipolytic activities on nutrient agar containing lipid (Egg yolk 10mL, Peptone 5.0, Yeast Extract 1.5, Agar 20.0, pH 10). The inoculated plates were incubated at 37°C for 48 h and lipolytic activity were observe.

Phylogenetic analysis: The amplified 16S rRNA gene PCR products from four isolates were directly sequenced after purification by precipitation with polyethylene glycol and NaCl procedure and directly sequenced on the Applied Biosystems Model 3730 DNA sequence (Foster, California USA). The 16S rRNA sequence were analysed using BLAST program Multiple Sequence Alignment of approximately 900 bp sequences were performed using CLUSTAL W, version 1.8. A phylogenetic tree was constructed from evolutionary distances using the neighbor-joining method of MEGA 4 program package.

Preparation of crude enzyme extracts: The 100 mL broth (peptone 5.0g, Nacl 5.0g, and Yeast Extract 3.0g, Clove oil 10mL, pH 10) were prepared. The sterile broth was inoculated and incubated for 48h at 37°C. The centrifugation of the broth culture at 10,000 rpm for 15 min was carried out. The supernatant served as crude enzyme source.

Characterizations of Crude Lipase Enzyme

Estimation of lipase activity: Estimation of lipase was carried out with 5 mL of olive oil emulsion in a flask, 5 ml of TrissHcl buffer, 1 mL of enzyme source was added and incubated for 10 min at 37°C. After incubation 10mL of acetone: methanol solutions were added to stop the reaction. Then add 2 to 4 drops of phenolphthalein indicator and then titrate with 0.025N NaOH solution One enzyme unit (unit/ml) is defined as the amount of enzyme which releases 1 μ mole of fatty acid. Characterization of lipase was carried out. The Effect of temperature and salt concentration on alkaline lipase activity and other kinetic parameter were performed (Tambekar et al 2013).

RESULTS AND DISCUSSION

Screening of bacterial isolates: Total twenty nine different bacterial strains were isolated from water and sediment sample of Lonar Lake, out of these thirteen isolates were lipase producer. The isolates were screened on the basis of biochemical characteristics as described earlier and further confirmed by 16S rDNA sequencing and four bacterial strains were selected for the further production and characterizations on the basis of maximum lipolytic activity. The phylogenetic position indicated the bacterial strains were related to phylum Firmicutes and belongs to *Bacillus cereus* OCW31, *B. pumilus* DW21, *B. pseudofirmus* DW41 and *B. flexus* AW32 (Fig 1). Some lipase producing bacterial strains have also been studied earlier from the same moderately halophile environment (Hashemite al 2011).

Effect of incubation time: The incubation time is an important factor for extra-cellular lipase activity. The amount of lipase activity was observed during specific time. The maximum lipase activity was observed on 10min for *B. pumilus* DW21, 30 min for *B. pseudofirmus* DW41, while 60 mins required for *B. cereus* OCW31 and *B. flexus* AW32 (Fig. 2).

Effect of different Carbon Sources on lipase production: The maltose was the best carbon source for production of lipase for *B. flexus* but xylose was best carbon source for *B. pumilus* DW21 and *B. cereus* OCW31 (Fig. 3). The production of lipase was intensely decreased with galactose for all four tested bacteria. *G. stearothermophilus* were found optimum lipase production in presence of glucose and galactose.

Effects of Different Nitrogen Sources on lipase production: When different nitrogen source were used to check the activity of lipase, Lipase from *B. cereus* OCW31 and *B. flexus* AW32 were show high activity presence of ammonium as a nitrogen source and *B. pumilus* DW21 was show less activity as compare to other lipases (Fig. 4). *Corynebacterium paurometabolum* showed optimum production in medium containing potassium nitrate and sodium nitrate (Joshi et al 2006).

Effect of different NaCl concentration on lipase activity: The effects of different NaCl concentrations ranging from 0.5-4 M was carried out under standard assay conditions. The

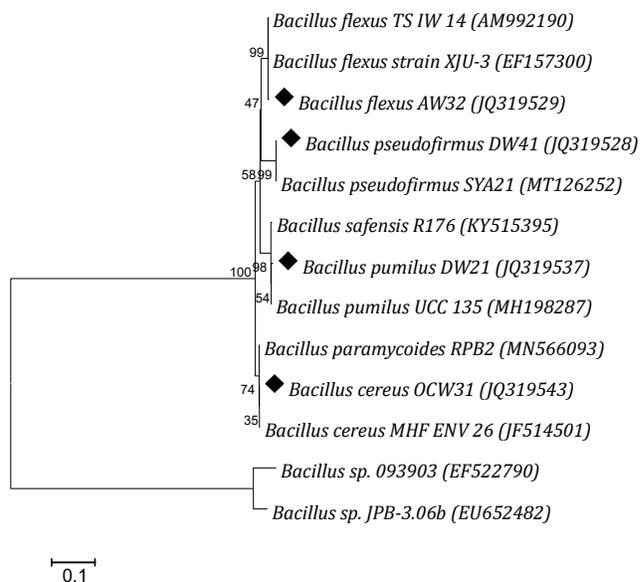


Fig. 1. Phylogenetic tree based on a comparison of the 16S ribosomal DNA sequences of Lonar lake isolates and some of their closest phylogenetic relatives. The numbers on the tree indicates the percentages of bootstrap sampling derived from 1,000 replications

enzyme shows maximum enzymatic activity (1.1 Units/mL, 100%) at 1.5M and at 2 M NaCl concentration for *B. flexus*, *B. cereus* while the *B. pseudofirmus* and *B. pumilus* were sensitive to NaCl (Fig. 5).

Effect of substrate on production of lipase: In the present studies, ground nut oil, soya oil, mustard oil, kardai oil, coconut oil and sunflower oil were used for production of lipase. The coconut oil was best substrate for lipase production to *B. cereus* OCW31 and *B. pumilus* DW21. Sunflower oil and mustard oil were best substrate for *B. pseudofirmus* DW41 while *B. cereus* OCW31 and *B. flexus* AW32 were unable to produce lipase in presence of mustard oil. *B. cereus* OCW31 cannot produce the lipase in presence of soyabean oil whereas soyabean oil was the best substrate for *Corynebacterium paurometabolum* (Joshi et al 2006) (Fig. 6).

Effect of temperature on activity of lipase: Effect of temperature on lipase activity was observed by incubating the enzyme at different temperature ranging from 40-90°C with standard assay condition. The temperature profile of lipase activity produced from *Bacillus cereus* OCW31 showed maximal enzymatic activity at 70°C, which indicated that the enzyme was stable at high temperature. Subsequently, the enzyme activity progressively decreased at 80° and 25% lipase activity decreased at temperature were 50°C. The lipase activity from *B. flexus* AW32, *B. pumilus* DW 21 and *B. pseudofirmus* DW41 exhibit optimum activity found at 50°C (Fig. 7). The lipase from *Acinetobacter lwoffii* CR9

showed optimum activity at 40°C and pH optimum at 8.0 while *Crynebacterium paurometabolum* exhibit maximum activity of lipase at 25°C (Joshi et al 2006).

Effect of substrate concentration on activity of lipase: The different concentrations of substrate were assayed

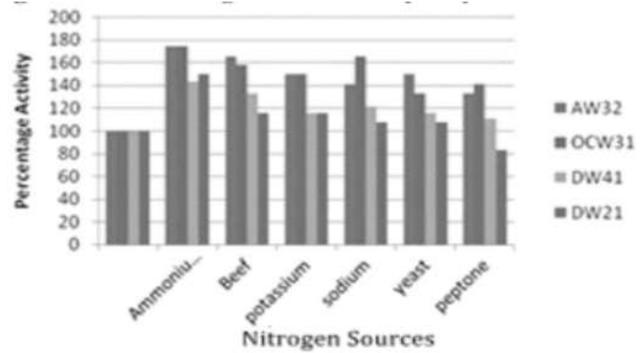


Fig. 4. Effect of nitrogen source on lipase production

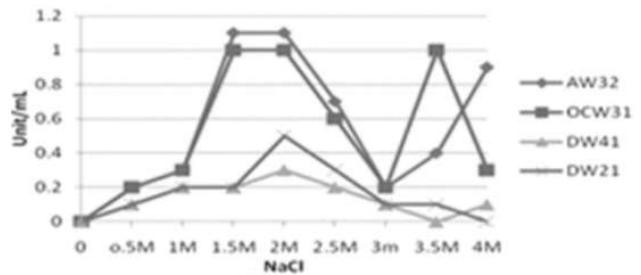


Fig. 5. Effect of NaCl on activity of lipase

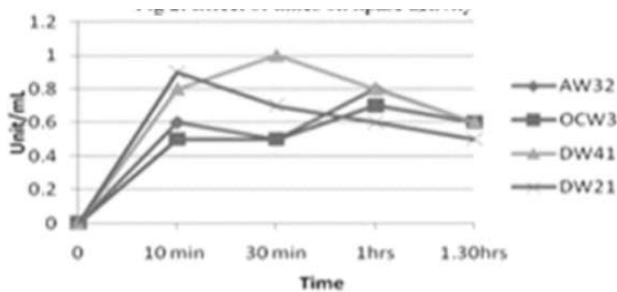


Fig. 2. Effect of times on lipase activity

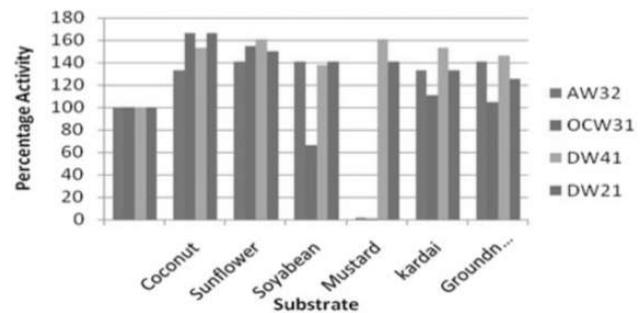


Fig. 6. Effect of substrate on production of lipase

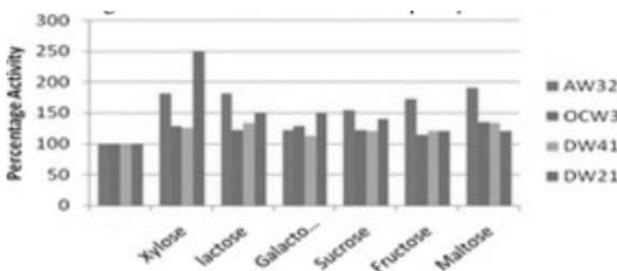


Fig. 3. Effect of carbon source on lipase production

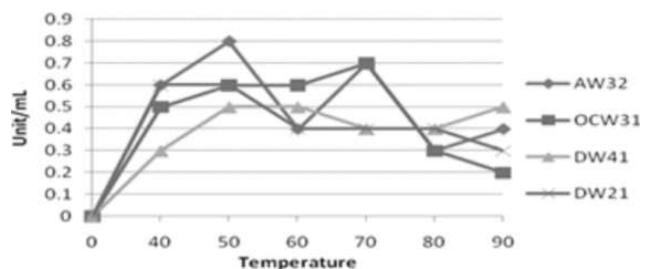


Fig. 7. Effect of temperature on activity of lipase

ranging from 1-3 mL under constant assay conditions. Substrate utilization revealed that during the period of 10 minutes incubation at 37°C, the 2.5mL substrates were required for optimum activity for *B. cereus* OCW31 and *B. flexus* AW32 while 1 ml and 2mL substrate were required for *B. pumilus* DW21 and *B. pseudofirmus* DW41 respectively (Fig. 8).

Influence of various organic solvents on lipase activity:

The lipase from *B. flexus* AW32 and *B. pseudofirmus* DW41 was highly active than *B. cereus* OCW31 and *B. pumilus* DW21 in all organic solvents. Lipase enzyme produced from *Bacillus flexus* AW32 and *B. pseudofirmus* DW41 were observed in presence of methanol and acetone. All the solvents have an enhancing effect of the activity of lipase produced by *Bacillus flexus* AW32 and *B. pseudofirmus* DW41 (Fig. 9).

Influence of different metal ions on activity of enzyme lipase:

Metal ions have different effects on activity of lipase.

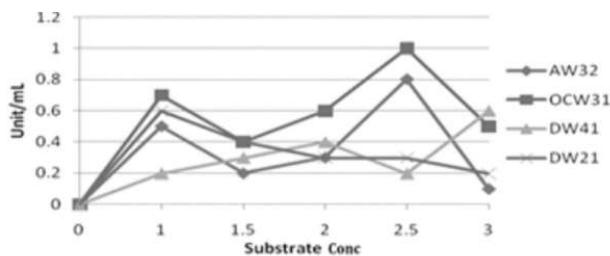


Fig. 8. Effect of substrate on activity of Lipase

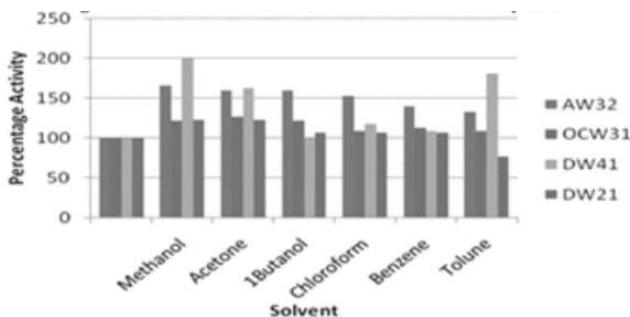


Fig. 9. Effect of solvent on production of Lipase

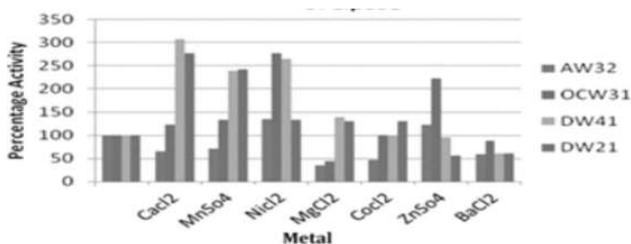


Fig. 10. Effect of metal on concentration on production of Lipase

The lipase was enhanced the activity in presence of CaCl₂, MnSO₄, for *B. pseudofirmus* DW41 and *B. pumilus* DW21 while NiCl₂ enhanced the lipase activity produce by *B. pseudofirmus* DW41 and *B. cereus* OCW31. However, the lipase activity was inhibited by BaCl₂, MgCl₂, CoCl₂ (Fig. 10). Finding of this study provides a window for lipase producing *Bacilli* from Lonar Lake. These alkaline enzymes have industrial and biotechnological application due to their tolerance to harsh industrial process (Horikoshi 1999). This study indicated the haloalkaliphilic indigenous *bacilli* as rich sources of lipase enzyme but it is needed to explore the enzyme production and purification.

CONCLUSION

Optimum enzyme activity was at 70°C for *B. cereus*. The lipase from *B. flexus* AW32 and *B. pseudofirmus* DW41 was highly active than *B. cereus* OCW31 and *B. pumilus* DW21 in all organic solvents tested. The lipase was enhanced the activity in presence of CaCl₂, MnSO₄, for *B. pseudofirmus* DW41 and *B. pumilus* DW21, while NiCl₂ enhanced the lipase activity produce by *B. pseudofirmus* DW41 and *B. cereus* OCW31. The diverse extracellular enzymes detected in the current study might also provide a resource for novel biocatalysts discovery and application, especially for high-temperature and alkaline conditions. Recently the increasing demand of lipase has bright future towards the developing and production of novel enzymes for entirely new areas of biotechnological applications involving molecular enzymology.

REFERENCES

- Chaga G, Porath J and Illeni T 1993. Isolation and purification amyloglucosidase from *Halobacterium sodomense*. *Biomedical Chromatography* **7**: 256-261.
- Chang RC, Chou SJ and Shaw JF 1994. Multiple forms and functions of *Candida rugosa* lipase. *Biotechnology and Applied Biochemistry* **19**: 93-97.
- Egorova K and Antranikian G 2005. Industry relevance of thermophilic archaea. *Current Opinion in Microbiology* **8**: 649-655.
- Ghasemi Y, RasoulAmini S, Kazemi A, Zarrini G, Morowvat MH and Kargar M 2011. Isolation and characterization of some moderately halophilic bacteria with lipase activity. *Microbiology* **80**(4): 483-487.
- Horikoshi K 1999. Alkaliphiles: Some applications of their products for biotechnology. *Microbiology Molecular Biology Review* **63**: 735-750.
- Hough DW and Danson DJ 1999. Extremozymes. *Current Opinion Chemistry and Biology* **3**: 39-46.
- Jaeger KE and Reetz MT 1998. Microbial lipases form versatile tools for biotechnology. *Trends in Biotechnology* **16**: 396-403.
- Joshi GK, Sumar K, Tripathi BN and Sharma V 2006. Production of alkaline lipase by *Corynebacterium paurometabolum*, MTCC 6841 isolated from lake Naukuchiatal, Uttaranchal State, India. *Current Microbiology* **52**: 354-358.
- Rodriguez-Valera F 1992. Biotechnol potential of halobacteria.

- Biochemical Society Symposium* **58**: 135-141.
- Rothschild LJ and Mancinelli RL 2001. Life in extreme environments. *Nature* **409**: 1092-1101.
- Schumacher K, Heine E and Hocker H 2001. Extremozymes for improving wool properties. *Journal of Biotechnology* **89**: 281-288.
- Singh R, Kaushik S, Wang Y, Xiang Y, Novak I, Komatsu M, Tanaka K, Cuervo A M and Czaja M J 2009. Autophagy regulates lipid metabolism. *Nature* **458**: 1131-1135.
- Tambekar DH, Mundekar SP and Bombode VB 2013. Partial characterization and optimization of lipase production from bacillus cereus Isolated from Haloalkaliphilic Lonar lake. *International Journal of Life Sciences Biotechnology and Pharma Research* **2**(3): 249-256.
- Tambekar DH and Dhundale VR 2012a. Phylogenetic analysis of lipase producing bacteria using physiological and molecular techniques from the Lonar crater region. *International Journal of Applied Microbiology Science* **1**(2): 24-31.
- Tambekar DH and Dhundale VR 2012b. Studies on the physiological and cultural diversity of *Bacilli* characterized from Lonar Lake. *Bioscience Discovery* **3**(1): 34-39.
- Valero F, Del Rio JL, Poch M and Sola` C 1991. Fermentation behavior of lipase production by *Candida rugosa* growing on different mixtures of glucose and olive oil. *Journal of Fermentation and Bioengineering* **72**: 399-401.
- Ventosa A and Nieto JJ 1995. Biotechnological applications and potentialities of halophilic microorganisms. *World Journal of Microbiology and Biotechnology* **11**: 85-94.

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Patterns of Forest Bird Assemblages and Feeding Guild Structure in Lesser Garhwal Himalayas, Uttarakhand, India

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Abstract: This study examined avifaunal assemblage patterns and feeding guild structure in the forest habitat of a part of Garhwal Himalayas foothills. Field studies were conducted from January 2015 to December 2016. Birds were surveyed by standardized Verner's line transects method. A total of 201 species belonging to 44 families were recorded in the area. The family Muscicapidae (14.92%) was dominant followed by Corvidae (13.43%). The estimated Bird Species Richness (BSR) and diversity (BSD) were greater in a low elevation forest sites in comparison to mid and high elevation sites. Analysis of trophic guild structure showed high insectivory (55.22%) in the area. The foraging behavior study showed a high arboreal pattern (42.78%) than other foraging strategies viz., understory, and terrestrial. This study area harbors five threatened species and hence requires the attention of the conservation biologist for protection of the habitat. Regular monitoring of avian community structure in the Himalayas is also required with preference to lower foothills which are more prone to human disturbances.

Keywords: Avian diversity, Guild structure, Foraging behavior, Tropical forest, Garhwal Himalayas

Quantifying species diversity not only provides information on patterns of avian species assemblages in habitat but also provide information on susceptibility to invasions (the proportion of native and exotic species) and trophic structure necessary for ecosystem resilience (Nichols and Nichols 2003). There are some studies on avifaunal diversity and community structure in the Himalayan hills (Bhatt and Joshi 2011, Naithani and Bhatt 2012, Bhattacharyya et al 2019). Despite these studies, the diversity, status, and feeding guilds of birds in some forest ranges of lesser Himalayas are poorly studied or not recorded systematically yet (Kukreti and Bhatt 2014). For temperate regions of worlds like Europe, Australia and North American bird species foraging guild have been well documented (Adamik and Kornan 2004, Kornan et al 2013) but there are few studies from the tropical region of Asia and Africa (Powell et al 2015). Thus, there is a gap of knowledge about avifaunal ecological studies especially in tropical forest types of lower Himalayan ranges. In this study, an attempt has been made to find out avian assemblages and feeding guild structure of bird community in different forest sites of Kotdwar and Laldhang forest ranges of the Lansdowne forest division of Uttarakhand, India.

MATERIAL AND METHODS

Lansdowne forest division is situated in the southwest portion of district Pauri Garhwal between 29° 37' to 30° 2' N and 78° 19' 13" to 78° 43' 0" E. The Rajaji National Park is in the western side of the study area and Corbett Tiger Reserve

towards in the east . The altitude of the forest division varies from 200 m to 2000 m. The slope and relief of the forest division is somewhere less than 200 m/km and in some places between 200-400 m/km. The three study sites are: low elevation site A (Kanvashram: 200-600 m asl; 29° 47' 49. 98" N-78° 27' 39.09" E), mid-elevation site B (Nadikatal: 600-900 m asl; 29° 54' 40.38" N-78° 26' 13.96" E) and high-elevation site C (Mungaon: 900-1200 m asl; 29° 54' 25.43"N-78 °25' 49.70" E). The climate of the area generally tropical varies from high temperature in summers to severely cold, depending upon the seasons and the altitude of the specific location. Climatically the area is divided into three distinct seasons viz., rainy season (July to September), winter (October to February), and summer (March to June). The forest of the area varies from moist to dry deciduous tropical forest, the major floral species found in the study area are occupied by *Shorea robusta* and associated species such as *Dalbergia sissoo*, *Acacia catechu*, *Cassia fistula*, *Syzygium cumini*, *Mallotus philippensis*, *Aegle marmelos*, *Ziziphus mauritiana*, *Ougeinia oojeinensis*, *Bombax ceiba*, *Albizia odoratissima*, *Anogeissus latifolia*, *Holarrhena pubescens*, *Ficus benghalensis*, *Holoptelea integrifolia* and *Haldina cordifolia*. Major Shrubs of the study sites are *Parthenium hysterophorus*, *Murraya koenigii*, *Lantana camara*, *Ardisia solanacea*, *Clerodendrum infortunatum*, *Desmodium triflorum* and *Asparagus adscendens*.

Field procedure: The biodiversity assessment was carried out using the line transect method (Verner 1985). In 24 transects, 288 visits were made consecutively between

years from January 2015 to December 2016, covering all the seasons. All transects were of equal length (1km) and about 30 m in width. Birds were not recorded if seen outside the 30 m width to each side of the transect. Observations were carried out once in a month in predefined transects/routes. The aim was to walk along straight transects, but due to the hilly terrain of the area and deep steep, this was not always possible. At least 5 minutes were spent at some vantage point/place in the predefined transect, if necessary, during which all birds identified by sight or by call were recorded to minimize the number of birds missed. The number of individuals of each bird species was recorded in each transects. In summer, bird counts were undertaken between 5:00 to 8:00 am and 4:00 to 6:00 pm, in winters, transects were covered between 6:30 to 9:30 am and 3:00 to 6:00 pm on fine days. This protocol was maintained in subsequent years. For identification of birds, a field guide by Grimmett et al (2001) and Ali (2002) was used. Foraging layers were identified and classified as: arboreal >10 m; terrestrial, understory 0- 10 m. The foraging and feeding guilds of aerial, nocturnal feeders and raptors were assigned according to their ecological data present to date.

Bird species diversity (BSD) and bird species richness (BSR) were measured using Shannon's index and Margalef's richness index respectively using PAST 3.21 statistical software (Hammer et al 2001). Statistical software Estimate S version 9.1.0 (Colwell 2018) was used to obtain the estimated value of species richness, to assess the true species richness for each site, non-parametric estimators (Chao1, Chao2, Jackknife1, Jackknife2, and Bootstrap) were assessed, as these non-parametric estimators are considered more accurate and less sensitive to problems related to sample coverage and variation in species sampling probability. The data for two consecutive years were generated for each site by pooling the mean of each transect per month. Kruskal-Wallis one way ANOVA computed in PAST 3.21 statistical software (Hammer et al 2001), was used to test the difference in richness and diversity of birds between the study sites.

RESULTS AND DISCUSSION

A total of 201 species belonging to 44 families were recorded in the area, the details of their abundance, residential status, and threatened category according to IUCN World Conservation Union (IUCN 2018) (Table 1). Threatened bird species according to the IUCN Red List category were 2.48% (5 species), Alexandrine Parakeet *Psittacula eupatria*, River Lapwing *Vanellus duvaucelii*, Egyptian Vulture *Neophron percnopterus*, White-rumped Vulture *Gyps bengalensis* and Himalayan Griffon *Gyps*

himalayensis. The 107 species (53%) were resident to the study area. The rest of the species were either winter migrants (48; 24%) or summer migrants (12; 6%) or altitudinal migrants (34; 17%). Out of 201 bird species, the maximum number of species (77.11%) were found in Kanvashram (low-elevation site A), 62.68% in Nadikatal (mid-elevation site B) and minimum 48.25% in Mungaon (high-elevation site C) (Table 2). Among the 44 families, Muscicapidae had the highest number of species (30), followed by Corvidae and Sylviidae. The analysis of the relative abundance of bird species (Table 3) revealed that Red-vented Bulbul *Pycnonotus cafer*, Alexandrine Parakeet *Psittacula eupatria*, Oriental White-eye *Zosterops palpebrosus*, Plum-headed Parakeet *Psittacula cyanocephala*, and Indian Peafowl *Pavo cristatus* were dominant species of forest habitat. The non-parametric estimators (Chao1, Chao2, Jackknife1, Jackknife2, and Bootstrap) showed a high estimated species richness than the observed species richness at all sites (Table 2). The avian diversity (BSD) and richness (BSR) values varied significantly between elevations. The highest value was found at low elevation (BSD: $H = 14.08$, $p = 0.00001$; BSR: $H = 16.8$, $p = 0.00003$) as compared to mid or high elevation.

Feeding guild structure and foraging layer: The insectivores account for more than half of the dietary guild (55.22%) and rest combinations of dietary guild, which includes maximum carnivores (12.44%), frugivore insectivores (8.46%), frugivores (5.47%), omnivores (4.48%), followed by carnivore insectivores, granivores, granivore insectivores, nectivore insectivores and frugivore carnivores (Fig. 1). The highest percentage was of arboreal feeders (42.8%), followed by terrestrial (30.3%) and understory (26.9%). There were 18 types of dietary guilds according to foraging layers of birds (Fig. 2). Arboreal foraging diet guild was highest than other dietary combinations viz., terrestrial, and understory. In the present study, a total of 201 species belonging to 44 families were recorded. This species richness in the area maybe because of high habitat heterogeneity as seen in other parts of the world (Weisberg et al 2014, Cooper et al 2020), as the forest varies from moist to dry, from mixed to nearly pure Sal forest, depending on the aspect and slope. The mean species diversity and richness in each study site were of similar magnitude. The high resource supply may also be responsible for high diversity or abundance. It is also a well-known fact that a state of considerable high equilibrium was found in avian communities as increased temperature provides more energy to growth and reproduction by decreasing thermoregulatory loads (Lennon et al 2000). The non-parametric estimators used had performed well, as their

Table 1. List of the avian species observed in the study area

Family/Scientific name	Common name	Residential status	Abundance	IUCN status*
Phasianidae				
<i>Pavo cristatus</i>	Indian Peafowl	R	c	Least Concern
<i>Gallus gallus</i>	Red Junglefowl	R	f	Least Concern
<i>Lophura leucomelanos</i>	Kalij Pheasant	R	f	Least Concern
<i>Francolinus francolinus</i>	Black Francolin	R	r	Least Concern
<i>F. pondicerianus</i>	Grey Francolin	R	u	Least Concern
<i>Perdica asiatica</i>	Jungle Bush Quail	R	u	Least Concern
Picidae				
<i>Celeus brachyurus</i>	Rufous Woodpecker	R	r	Least Concern
<i>Dendrocopos macei</i>	Fulvous-breasted Woodpecker	R	f	Least Concern
<i>D. canicapillus</i>	Grey-capped Pygmy Woodpecker	R	c	Least Concern
<i>D. hyperythrus</i>	Rufous-bellied Woodpecker	R	f	Least Concern
<i>Picus chlorolophus</i>	Lesser Yellownape	R	r	Least Concern
<i>P. canus</i>	Grey-headed Woodpecker	R	f	Least Concern
<i>P. flavinucha</i>	Greater Yellownape	R	r	Least Concern
<i>P. xanthopygaeus</i>	Streak-throated Woodpecker	R	r	Least Concern
<i>Dinopium benghalense</i>	Black-rumped Flameback	R	c	Least Concern
<i>D. shorii</i>	Himalayan Flameback	R	r	Least Concern
<i>Chrysocolaptes lucidus</i>	Greater Flameback	R	u	Least Concern
Megalaimidae				
<i>Megalaima zeylanica</i>	Brown-headed Barbet	R	c	Least Concern
<i>M. virens</i>	Great Barbet	R	r	Least Concern
<i>M. asiatica</i>	Blue-throated Barbet	R	f	Least Concern
<i>M. haemacephala</i>	Coppersmith Barbet	R	r	Least Concern
<i>M. lineata</i>	Lineated Barbet	R	r	Least Concern
Bucerotidae				
<i>Ocyrceros birostris</i>	Indian Grey Hornbill	R	c	Least Concern
Upupidae				
<i>Upupa epops</i>	Common Hoopoe	R	c	Least Concern
Coraciidae				
<i>Coracias benghalensis</i>	Indian Roller	R	f	Least Concern
<i>Eurystomus orientalis</i>	Dollarbird	R	r	Least Concern
Alcedinidae				
<i>Alcedo atthis</i>	Common Kingfisher	R	f	Least Concern
Halcyonidae				
<i>Halcyon capensis</i>	Stork-billed Kingfisher	R	r	Least Concern
<i>H. smyrnensis</i>	White-throated Kingfisher	R	c	Least Concern
Cerylidae				
<i>Ceryle rudis</i>	Pied Kingfisher	R	f	Least Concern
<i>Megaceryle lugubris</i>	Crested Kingfisher	WM	r	Least Concern
Meropidae				
<i>Merops orientalis</i>	Green Bee-Eater	R	c	Least Concern
<i>M. leschenaulti</i>	Chestnut-headed Bee-Eater	R	f	Least Concern
<i>Nyctyornis athertoni</i>	Blue-bearded Bee-Eater	R	r	Least Concern
Cuculidae				
<i>Hierococcyx varius</i>	Common Hawk Cuckoo	RAM	f	Least Concern
<i>Phaenicophaeus leschenaultii</i>	Sirkeer Malkoha	SM	r	Least Concern
<i>Eudynamys scolopacea</i>	Asian Koel	R	c	Least Concern

Cont...

Continues Table 1

Family/Scientific name	Common name	Residential status	Abundance	IUCN status*
Centropodidae				
<i>Centropus sinensis</i>	Greater Coucal	R	u	Least Concern
Psittacidae				
<i>Psittacula eupatria</i>	Alexandrine Parakeet	R	f	Near Threatened
<i>P. krameri</i>	Rose-ringed Parakeet	R	c	Least Concern
<i>P. himalayana</i>	Slaty-headed Parakeet	RAM	u	Least Concern
<i>P. cyanocephala</i>	Plum-headed Parakeet	R	c	Least Concern
Strigidae				
<i>Glaucidium cuculoides</i>	Asian Barred Owlet	R	r	Least Concern
<i>G. radiatum</i>	Jungle Owlet	R	u	Least Concern
<i>Otus sunia</i>	Oriental Scops Owl	R		
Caprimulgidae				
<i>Caprimulgus macrurus</i>	Large-tailed Nightjar	R	r	Least Concern
Columbidae				
<i>Streptopelia orientalis</i>	Oriental Turtle Dove	RAM	f	Least Concern
<i>S. tranquebarica</i>	Red Collared Dove	SM	r	Least Concern
<i>Chalcophaps indica</i>	Emerald Dove	R	r	Least Concern
<i>Treron sphenura</i>	Wedge-tailed Green Pigeon	RAM	r	Least Concern
<i>T. phoenicoptera</i>	Yellow-footed Green Pigeon	RAM	r	Least Concern
<i>T. apicauda</i>	Pin-tailed Green Pigeon	R	u	Least Concern
Rallidae				
<i>Amaurornis phoenicurus</i>	White-breasted Waterhen	R	r	Least Concern
Scolopacidae				
<i>Actitis hypoleucos</i>	Common Sandpiper	WM	r	Least Concern
<i>Tringa ochropus</i>	Green Sandpiper	WM	r	Least Concern
Charadriidae				
Charadriinae				
<i>Vanellus duvaucelii</i>	River Lapwing	R	f	Near Threatened
<i>V. indicus</i>	Red-wattled Lapwing	R	c	Least Concern
Accipitridae				
Accipitrinae				
<i>Pernis ptilorhynchus</i>	Oriental Honey-buzzard	R	u	Least Concern
<i>Elanus caeruleus</i>	Black-shouldered Kite	R	f	Least Concern
<i>Milvus migrans</i>	Black Kite	RAM	c	Least Concern
<i>Neophron percnopterus</i>	Egyptian Vulture	R	u	Endangered
<i>Gyps bengalensis</i>	White-rumped Vulture	R	r	Critically Endangered
<i>G. himalayensis</i>	Himalayan Griffon	WM	r	Near Threatened
<i>Spilornis cheela</i>	Crested Serpent Eagle	WM	u	Least Concern
<i>Accipiter badius</i>	Shikra	R	f	Least Concern
<i>A. nisus</i>	Eurasian Sparrowhawk	WM	u	Least Concern
<i>A. gentilis</i>	Northern Goshawk	WM	r	Least Concern
<i>Butastur teesa</i>	White-eyed Buzzard	R	u	Least Concern
<i>Spizaetus cirrhatu</i>	Changeable Hawk Eagle	SM	u	Least Concern
Falconidae				
<i>Falco tinnunculus</i>	Common Kestrel	WM	r	Least Concern
Phalacrocoracidae				
<i>Phalacrocorax niger</i>	Little Cormorant	R	u	Least Concern
Ardeidae				
<i>Egretta garzetta</i>	Little Egret	WM	f	Least Concern
<i>Mesophoyx intermedia</i>	Intermediate Egret	WM	r	Least Concern

Cont...

Continues Table 1

Family/Scientific name	Common name	Residential status	Abundance	IUCN status*
<i>Bubulcus ibis</i>	Cattle Egret	R	c	Least Concern
<i>Ardeola grayii</i>	Indian Pond Heron	R	r	Least Concern
Pittidae				
<i>Pitta brachyura</i>	Indian Pitta	SM	r	Least Concern
Eurylaimidae				
<i>Psarisomus dalhousiae</i>	Long-tailed Broadbill	SM	r	Least Concern
Irenidae				
<i>Chloropsis hardwickii</i>	Orange-bellied Leafbird	WM	r	Least Concern
<i>C. aurifrons</i>	Golden-fronted Leafbird	R	u	Least Concern
Laniidae				
<i>Lanius cristatus</i>	Brown Shrike	WM	u	Least Concern
<i>L. schach</i>	Long-tailed Shrike	R	c	Least Concern
<i>L. tephronotus</i>	Grey-backed Shrike	WM	r	Least Concern
Corvidae				
Corvinae				
<i>Urocissa erythrorhyncha</i>	Red-billed Blue Magpie	RAM	u	Least Concern
<i>Cissa chinensis</i>	Common Green Magpie	R	r	Least Concern
<i>Dendrocitta vagabunda</i>	Rufous Treepie	R	c	Least Concern
<i>D. formosae</i>	Grey Treepie	RAM	f	Least Concern
<i>Corvus splendens</i>	House Crow	R	c	Least Concern
<i>C. macrorhynchos</i>	Large-billed Crow	R	c	Least Concern
Oriolini				
<i>Oriolus oriolus</i>	Eurasian Golden Oriole	SM	r	Least Concern
<i>O. xanthornus</i>	Black-hooded Oriole	R	f	Least Concern
<i>O. traillii</i>	Maroon Oriole	RAM	r	Least Concern
<i>Coracina macei</i>	Large Cuckooshrike	R	u	Least Concern
<i>C. melaschistos</i>	Black-winged Cuckooshrike	RAM	r	Least Concern
<i>C. melanoptera</i>	Black-headed Cuckooshrike	R	f	Least Concern
<i>Pericrocotus roseus</i>	Rosy Minivet	SM	r	Least Concern
<i>P. cinnamomeus</i>	Small Minivet	R	f	Least Concern
<i>P. ethologus</i>	Long-tailed Minivet	RAM	f	Least Concern
<i>P. flammeus</i>	Scarlet Minivet	RAM	r	Least Concern
<i>Hemipus picatus</i>	Bar-winged Flycatcher-shrike	R	f	Least Concern
Dicrurinae				
Rhipidurini				
<i>Rhipidura hypoxantha</i>	Yellow-bellied Fantail	RAM	f	Least Concern
<i>R. albicollis</i> Dicrurini	White-throated Fantail	R	c	Least Concern
<i>Dicrurus macrocercus</i>	Black Drongo	R	c	Least Concern
<i>D. leucophaeus</i>	Ashy Drongo	WM	r	Least Concern
<i>D. caerulescens</i>	White-bellied Drongo	R	r	Least Concern
<i>D. aeneus</i>	Bronzed Drongo	RAM	r	Least Concern
<i>D. hottentottus</i>	Spangled Drongo	RAM	f	Least Concern
Monarchini				
<i>Hypothymis azurea</i>	Black-naped Monarch	R	r	Least Concern
<i>Terpsiphone paradisi</i>	Asian Paradise-flycatcher	RAM	f	Least Concern
Aegithinae				
<i>Aegithina tiphia</i>	Common Iora	R	r	Least Concern
Malaconotinae				
<i>Tephrodornis pondicerianus</i>	Common Woodshrike	R	f	Least Concern
Cinclidae				
<i>Cinclus pallasii</i>	Brown Dipper	R	r	Least Concern

Cont...

Continues Table 1

Family/Scientific name	Common name	Residential status	Abundance	IUCN status*
Musciapidae				
Turdinae				
<i>Monticola cinclorhynchus</i>	Blue-capped Rock Thrush	SM	r	Least Concern
<i>M. solitarius</i>	Blue Rock Thrush	WM	r	Least Concern
<i>Myophonus caeruleus</i>	Blue Whistling Thrush	RAM	c	Least Concern
<i>Zoothera citrina</i>	Orange-headed Thrush	SM	r	Least Concern
<i>Turdus boulboul</i>	Grey-winged Blackbird	RAM	u	Least Concern
Muscicapinae				
Muscicapini				
<i>Muscicapa sibirica</i>	Dark-sided Flycatcher	WM	f	Least Concern
<i>M. dauurica</i>	Asian Brown Flycatcher	SM	r	Least Concern
<i>Ficedula strophciata</i>	Rufous-gorgeted Flycatcher	WM	r	Least Concern
<i>F. parva</i>	Red-throated Flycatcher	WM	r	Least Concern
<i>F. westermanni</i>	Little Pied Flycatcher	R	f	Least Concern
<i>F. tricolor</i>	Slaty-blue Flycatcher	WM	r	Least Concern
<i>Eumyias thalassina</i>	Verditer Flycatcher	RAM	f	Least Concern
<i>Niltava sundara</i>	Rufous-bellied Niltava	RAM	u	Least Concern
<i>Cyornis unicolor</i>	Pale Blue Flycatcher	WM	r	Least Concern
<i>C. rubeculoides</i>	Blue-throated Flycatcher	SM	f	Least Concern
<i>Culicicapa ceylonensis</i>	Grey-headed Canary-Flycatcher	RAM	c	Least Concern
Saxicolini				
<i>Luscinia pectoralis</i>	White-tailed Rubythroat	WM	r	Least Concern
<i>L. svecica</i>	Bluethroat	WM	f	Least Concern
<i>Copsychus saularis</i>	Oriental Magpie Robin	R	c	Least Concern
<i>C. malabaricus</i>	White-rumped Shama	R	r	Least Concern
<i>Saxicoloides fulicata</i>	Indian Robin	R	c	Least Concern
<i>Phoenicurus coeruleocephalus</i>	Blue-capped Redstart	WM	r	Least Concern
<i>P. ochruros</i>	Black Redstart	WM	f	Least Concern
<i>Chaimarrornis leucocephalus</i>	White-capped Water Redstart	WM	f	Least Concern
<i>Rhyacornis fuliginosus</i>	Plumbeous Water Redstart	WM	f	Least Concern
<i>Enicurus maculatus</i>	Spotted Forktail	R	r	Least Concern
<i>Saxicola torquata</i>	Common Stonechat	WM	f	Least Concern
<i>S. caprata</i>	Pied Bushchat	R	f	Least Concern
<i>S. ferrea</i>	Grey Bushchat	RAM	u	Least Concern
<i>Cercomela fusca</i>	Brown Rock Chat	R	c	Least Concern
Sturnidae				
<i>Sturnus malabaricus</i>	Chestnut-tailed Starling	RAM	f	Least Concern
<i>Acridotheres fuscus</i>	Jungle Myna	R	c	Least Concern
Sittidae				
Sittinae				
<i>Sitta castanea</i>	Chestnut-bellied Nuthatch	R	u	Least Concern
<i>S. frontalis</i>	Velvet-fronted Nuthatch	R	u	Least Concern
Tichodrominae				
<i>Tichodroma muraria</i>	Wallcreeper	WM	u	Least Concern
Certhiidae				
Certhiinae				
Certhiini				
<i>Certhia himalayana</i>	Bar-tailed Treecreeper	WM	r	Least Concern
Paridae				
Parinae				
<i>Parus major</i>	Great Tit	R	c	Least Concern
<i>P. monticolus</i>	Green-backed Tit	RAM	u	Least Concern

Cont...

Continues Table 1

Family/Scientific name	Common name	Residential status	Abundance	IUCN status*
<i>P. xanthogenys</i>	Black-lored Tit	R	r	Least Concern
Aegithalidae				
<i>Aegithalos concinnus</i>	Black-throated Tit	R	r	Least Concern
Hirundinidae				
Hirundininae				
<i>Riparia paludicola</i>	Plain Martin	R	u	Least Concern
Pycnonotidae				
<i>Pycnonotus melanicterus</i>	Black-crested Bulbul	RAM	r	Least Concern
<i>P. jocosus</i>	Red-whiskered Bulbul	R	u	Least Concern
<i>P. leucogenys</i>	Himalayan Bulbul	R	c	Least Concern
<i>P. cafer</i>	Red-vented Bulbul	R	c	Least Concern
<i>Hypsipetes leucocephalus</i>	Black Bulbul	RAM	f	Least Concern
Cisticolidae				
<i>Prinia criniger</i>	Striated Prinia	WM	u	Least Concern
<i>P. flaviventris</i>	Yellow-bellied Prinia	WM	r	Least Concern
<i>P. hodgsonii</i>	Grey-breasted Prinia	R	c	Least Concern
<i>P. socialis</i>	Ashy Prinia	R	f	Least Concern
<i>P. inornata</i>	Plain Prinia	R	f	Least Concern
Zosteropidae				
<i>Zosterops palpebrosus</i>	Oriental White-eye	R	c	Least Concern
Sylviidae				
Acrocephalinae				
<i>Cettia pallidipes</i>	Pale-footed Bush Warbler	WM	u	Least Concern
<i>Orthotomus sutorius</i>	Common Tailorbird	R	c	Least Concern
<i>Phylloscopus collybita</i>	Common Chiffchaff	WM	f	Least Concern
<i>P. inornatus</i>	Yellow-browed Warbler	WM	r	Least Concern
<i>P. humei</i>	Hume's Warbler	WM	u	Least Concern
<i>P. trochiloides</i>	Greenish Warbler	RAM	u	Least Concern
<i>P. reguloides</i>	Blyth's Leaf Warbler	WM	r	Least Concern
<i>Seicercus burkii</i>	Golden-spectacled Warbler	WM	u	Least Concern
<i>S. xanthoschistos</i>	Grey-hooded Warbler	RAM	f	Least Concern
Garrulacinae				
<i>Garrulax albogularis</i>	White-throated Laughingthrush	R	u	Least Concern
<i>G. leucolophus</i>	White-crested Laughingthrush	RAM	u	Least Concern
<i>G. lineatus</i>	Streaked Laughingthrush	R	u	Least Concern
Sylviinae				
Timaliini				
<i>Pellorneum ruficeps</i>	Puff-throated Babbler	RAM	u	Least Concern
<i>Pomatorhinus erythrogeus</i>	Rusty-cheeked Scimitar Babbler	RAM	u	Least Concern
<i>P. schisticeps</i>	White-browed Scimitar Babbler	RAM	u	Least Concern
<i>Stachyris pyrrhops</i>	Black-chinned Babbler	R	f	Least Concern
<i>Turdoides striatus</i>	Jungle Babbler	R	c	Least Concern
<i>Macronous gularis</i>	Striped Tit-Babbler	SM	u	Least Concern
<i>Leiothrix lutea</i>	Red-billed Leiothrix	RAM	f	Least Concern
<i>Minla cyanouoptera</i>	Blue-winged Minla	R	r	Least Concern
Sylviini				
<i>Sylvia curruca</i>	Lesser Whitethroat	WM	u	Least Concern
Alaudidae				
<i>Alauda gulgula</i>	Oriental Skylark	WM	r	Least Concern
Nectariniidae				
Nectariniinae				
Dicaeini				

Cont...

Continues Table 1

Family/Scientific name	Common name	Residential status	Abundance	IUCN status*
<i>Dicaeum erythrorhynchos</i>	Pale-billed Flowerpecker	R	f	Least Concern
<i>D. ignipectus</i> Nectariniini	Fire-breasted Flowerpecker	WM	r	Least Concern
<i>Nectarinia asiatica</i>	Purple Sunbird	R	c	Least Concern
<i>Aethopyga siparaja</i>	Crimson Sunbird	R	f	Least Concern
<i>A. ignicauda</i>	Fire-tailed Sunbird	WM	u	Least Concern
Passeridae				
Passerinae				
<i>Passer rutilans</i>	Russet Sparrow	R	r	Least Concern
<i>Petronia xanthocollis</i>	Chestnut-shouldered Petronia	R	f	Least Concern
Motacillinae				
<i>Motacilla alba</i>	White Wagtail	WM	f	Least Concern
<i>M. maderaspatensis</i>	White-browed Wagtail	R	f	Least Concern
<i>M. citreola</i>	Citrine Wagtail	WM	r	Least Concern
<i>M. flava</i>	Yellow Wagtail	WM	u	Least Concern
<i>M. cinerea</i>	Grey Wagtail	RAM	u	Least Concern
Ploceinae				
<i>Ploceus philippinus</i>	Baya Weaver	R	f	Least Concern
Estrildinae				
<i>Lonchura striata</i>	White-rumped Munia	WM	r	Least Concern
<i>L. punctulata</i>	Scaly-breasted Munia	R	f	Least Concern
Fringillidae				
Fringillinae				
<i>Serinus pusillus</i>	Fire-fronted Serin	WM	r	Least Concern
<i>Carpodacus erythrinus</i>	Common Rosefinch	WM	f	Least Concern

Abbreviations: R, Resident; SM, Summer Migrant; WM, Winter Migrant; RAM, Resident Altitudinal Migrant; c, Common; u, Uncommon; f, Fair; r, Rare.
 *IUCN: IUCN Red List data for observed species according to IUCN version 2018-2.

values show less affected by the spatial scale of the sampling, also these estimators showed higher values of BSR in low elevation site A, which may be due to the presence of mixed vegetation as well as the presence of vegetation cover which provides resources, and microhabitat for the perching, roosting and nesting site. In our study, low elevation site A (Kanvashram) has a larger area than steeper terrain of mid and high elevation sites of forest habitat. It has been assumed that for birds, with an increase in elevation the availability of resources diminishes due to variations in vegetation composition, forest stand structure, and availability of land area (Waterhouse et al 2003). In the present study, the five most dominant species with high relative abundance in the forest habitat are: *Pycnonotus cafer*, *Psittacula eupatria*, *Zosterops palpebrosus*, *Psittacula cyanocephala*, and *Pavo cistatus*, indicating that the floristic structure of the study area is suitable for breeding and feeding of these species. Of these species, *Zosterops palpebrosus* was dominant in all forest sites, while *Psittacula eupatria* was dominant in site A and site B; *Pycnonotus cafer*, and *Psittacula cyanocephala* were dominant in site B and site C, presence of same species in different habitats/elevations with high relative abundance reflect their habitat and feeding

Table 2. Showing mean values of BSD, BSR, estimated species richness (S_{est}) and species richness estimators (Chao 1, Chao 2, Jackknife 1, Jackknife 2 and Bootstrap) for forest sites

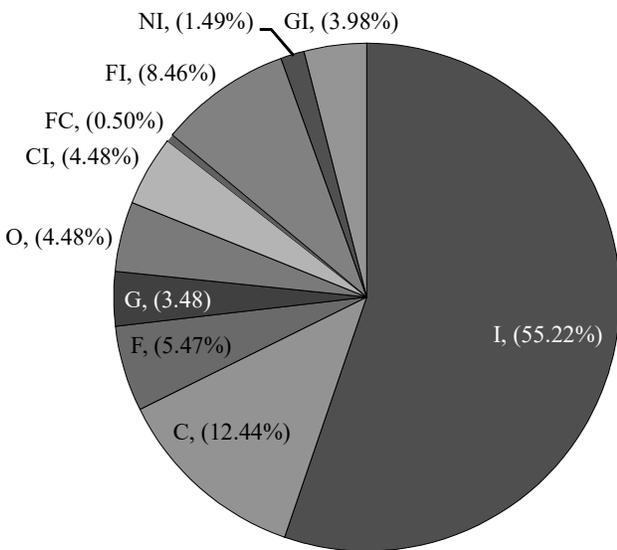
	Site A	Site B	Site C
BSD	4.31±0.15	4.17±0.13	3.84±0.49
BSR	14.70±1.97	12.67±1.28	9.75±0.79
Total Species Recorded	155	126	97
Estimators:			
S_{est}	138.681±2.684	114.452±2.144	87.207±4.407
Individuals	116467	90285	65422.5
Chao 1	148.302±7.029	121.919±12.54	100.466±11.515
Chao 2	159.685±6.747	123.204±4.859	96.133±4.923
Jackknife 1	155.554±9.416	126.170±5.618	97.272±4.218
Jackknife 2	151.736±14.943	121.880±8.166	94.532±7.181
Bootstrap	147.161±9.41	120.425±5.424	92.340±4.022

guild preferences in the study area. *Psittacula eupatria* which is a near-threatened species perhaps due to anthropogenic habitat loss, was one of the dominant in low-elevation site A and mid-elevation B, because of the presence of adjoining agricultural fields with variety of autumn and spring crops (*Oryza sativa*, *Zea mays*, *Glycine max*, *Sorghum vulgare*,

Triticum aestivum, *Hordeum vulgare*, *Brassica compestris*, and *Brassica juncea* etc.), and presence of fruiting trees like *Ficus palmata*, *Ficus auriculata*, *Ziziphus jujuba*, *Aegel marmelos*, *Syzygium cumini* etc.

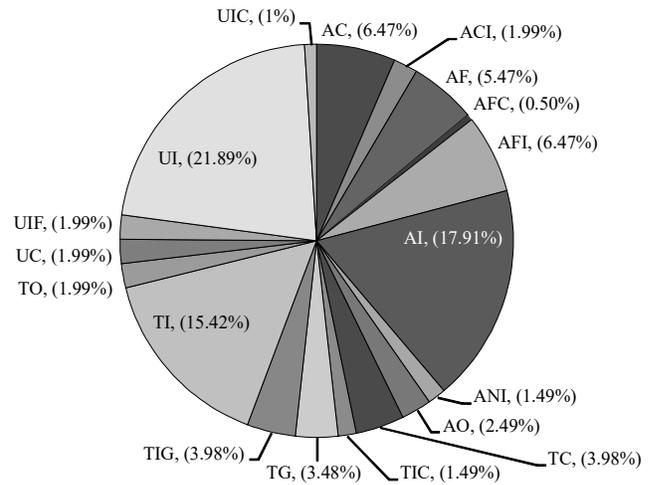
Bird's ecological niche and its dietary adaptations are defined by their diet requirement. In the present study insectivorous dietary guild found to be dominant over carnivores, omnivores, frugivores, and granivores. The other dietary combinations followed by these major dietary guilds were frugivore insectivores, granivorous insectivores, and carnivorous insectivores. The dietary combinations found in the least number in the study area were nectivore insectivores and frugivore carnivores. The structure of dietary guilds appears to be similar to other studies conducted in the Indian subcontinent (Johnsingh and Joshua 1994) and Thailand (Siri et al 2019) where insectivory found to be the dominant guild. Arboreal foraging strategy found to

be a common dietary preference than terrestrial and understory, also the pooled data for each foraging layer showed a high preference for arboreal insectivores than understory insectivores and terrestrial insectivores. Robinson et al (2000) observed that in tropical sites, arboreal guild structure is the most specious guild where arboreal insectivores and arboreal omnivores are highest in numbers. Similarly, a global study on dietary guild richness pattern showed an increase in species richness towards the equator for arboreal/terrestrial guild and intermediate for frugivores, granivores and carnivores while shallower for all other guilds types across a latitudinal gradient (Kissling et al 2012). A long term study from temperate forests of Poland also showed significant increasing trends in abundance of crown foraging insectivores and nesters (Wesolowski et al 2002). In the present study, good numbers (26.9%) of understory insectivory were observed. This may be due to the mixed



Abbreviations: C, carnivore; FI, frugivore insectivore; F, frugivore; O, omnivore; G, granivore; CI, carnivore insectivore; NI, nectivore insectivore, FC, frugivore carnivore; I, insectivore; GI, granivore insectivore

Fig. 1. Relative percentage of avian community's dietary guild structure



Abbreviations: UI, understory insectivores; AI, arboreal insectivores; TI, terrestrial insectivores; AC, arboreal carnivores; AFI, arboreal frugivore insectivores; AF, arboreal frugivores; TG, terrestrial granivores; TGI, terrestrial granivore insectivores; TC, terrestrial carnivores; AO, Arboreal omnivores; ACI, arboreal carnivore insectivores; UIF, understory insectivore frugivores; UC, understory carnivores; TO, terrestrial omnivores, TIC, terrestrial insectivore carnivores; ANI, arboreal nectivore insectivores; UIC, understory insectivore carnivores; AFC, arboreal frugivore carnivores

Fig. 2. Relative percentage of feeding guild with reference to foraging layer

Table 3. Showing relative abundance (RA) of top 5 dominant species of forest sites

Site A		Site B		Site C	
Species	RA (%)	Species	RA (%)	Species	RA (%)
<i>Psittacula eupatria</i>	2.37	<i>Pycnonotus cafer</i>	2.60	<i>Pycnonotus cafer</i>	4.04
<i>Pavo cristatus</i>	2.31	<i>Psittacula cyanocephala</i>	2.52	<i>Zosterops palpebrosus</i>	3.57
<i>Zosterops palpebrosus</i>	1.99	<i>Zosterops palpebrosus</i>	2.51	<i>Psittacula cyanocephala</i>	3.43
<i>Leiothrix lutea</i>	1.89	<i>Psittacula eupatria</i>	2.50	<i>Prinia socialis</i>	3.42
<i>Turdoides striatus</i>	1.88	<i>Pycnonotus leucogenys</i>	2.27	<i>Nectarinia asiatica</i>	3.15

vegetation structure (mixed forest with patches of riverine habitats) which appears to be responsible for the year-long presence of insects and arthropods in the study area. The understory insectivores are threatened in tropics because of frequent fires and fragmentation of forests with other immediate threats such as deforestation, agricultural expansion, urbanization, and logging. The decline in the population of birds in its turn may result in outbursts of insect pests in tropical forests and adjoining agricultural areas (Powell et al 2015).

CONCLUSIONS

The low elevation forest habitats support a higher number of species as compared to mid and high elevation. The study area also harbors five threatened species and hence requires the attention of the conservation biologists for protection of the habitat. The presence of insectivores in a relatively high percentage in the area would be helpful to the stability of ecosystems with their services such as control of insect pests. From the biodiversity conservation perspective, regular monitoring on avian community structure in the Himalayas is also required with preference to lower foothills which are more prone to human disturbances.

REFERENCES

- Ali S 2002. *The book of Indian birds*. Thirteenth edition. Bombay Natural History Society, India, 321 pp.
- Adamik P and Korňan M 2004. Foraging ecology of two bark foraging passerine birds in an old-growth temperate forest. *Ornis Fennica* **81**(1): 13-22.
- Bhatt D and Joshi KK 2011. Bird assemblages in natural and urbanized habitats along elevational gradient in Nainital district (western Himalaya) of Uttarakhand state, India. *Current Zoology* **57**(3): 318-329.
- Bhattacharyya S, Rawat GS and Adhikari BS 2019. Faunal abundance along timberline ecotone in western Himalaya with reference to anthropogenic pressure and season: A case study. *Tropical Ecology* **60**(2): 288-298.
- Cooper WJ, McShea WJ, Forrester T and Luther DA 2020. The value of local habitat heterogeneity and productivity when estimating avian species richness and species of concern. *Ecosphere* **11**(5): 1-17.
- Colwell RK 2018. *Estimate S: Statistical estimation of species richness and shared species from samples*, Version 9.1.0.
- Grimmett R, Inskipp C and Inskipp T 2001. *Pocket guide to the birds of Indian Subcontinent*. Oxford University Press, New Delhi, India, 374p.
- Hammer O, Harper DAT and Ryan PD 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica* **4**(1): 1-9.
- International Union for Conservation of Nature. 2018. *The IUCN Red List of Threatened Species*. Version 2018-2. IUCN, Gland, Switzerland.
- Johnsingh AJT and Joshua J 1994. Avifauna in three vegetation types on Mundanthurai Plateau, South India. *Journal of Tropical Ecology* **10**(3): 323-335.
- Kissling WD, Sekercioglu CH and Walter J 2012. Bird dietary guild richness across latitudes, environments and biogeographic regions. *Global Ecology and Biogeography* **21**(3): 328-340.
- Kornan M, Holmes R, Recher H, Adamik P and Kropil R 2013. Convergence in foraging guild structure of forest breeding bird assemblages across three continents is related to habitat structure and foraging opportunities. *Community Ecology* **14**(1): 9-100.
- Kukreti M and Bhatt D 2014. Birds of Lansdowne forest division and adjacent suburban landscapes, Garhwal Himalayas, Uttarakhand, India: Community structure and seasonal distribution. *Biodiversitas* **15**(1): 80-88.
- Lennon JJ, Greenwood JJD and Turner JRG 2000. Bird diversity and environmental gradients in Britain: A test of the species-energy hypothesis. *Journal of Animal Ecology* **69**(4): 581-598.
- Naithani A and Bhatt D 2012. Bird community structure in natural and urbanized habitats along an altitudinal gradient in Pauri district (Garhwal Himalaya) of Uttarakhand state, India. *Biologia* **67**(4): 800-808.
- Nichols OG and Nichols FM 2003. Long-term trends in faunal recolonization after Bauxite mining in the Jarrah forest of southwestern Australia. *Restoration Ecology* **11**(3): 261-272.
- Powell LL, Cordeiro NJ and Stratford JA 2015. Ecology and conservation of avian insectivores of the rainforest understory: A pantropical perspective. *Biological Conservation* **188**: 1-10.
- Robinson WD, Brawn JD and Robinson SK 2000. Forest bird community structure in central Panama: influence of spatial scale and biogeography. *Ecological Monographs* **70**(2): 209-235.
- Siri S, Ponpituk Y, Safoowong M, Marod D and Duengkae P 2019. The natural forest gaps maintenance diversity of understory birds in Mae Sa-Kog Ma Biosphere Reserve, northern Thailand. *Biodiversitas* **20**(1): 181-189.
- Verner J 1985. *Assessment of Counting Techniques*, pp. 247-302. In: Johnston RF (eds.). *Current Ornithology* MA, Boston.
- Weisberg PJ, Dilts TE, Becker ME, Young JS, Wong-Kone DC, Newton WE and Ammon EM 2014. Guild-specific responses of avian species richness to lidar-derived habitat heterogeneity. *Acta Oecologica* **59**: 72-83.
- Wesołowski T, Tomiałojć L, Mitrus C and Rowiński P 2002. The breeding bird community of a primaeval temperate forest (Białowieża National Park, Poland) at the end of the 20th century. *Acta Ornithologica* **37**(1): 27-45.
- Waterhouse FL, Mather MH and Seip D 2003. Distribution and



Avifaunal Diversity from Shahpur Campus of the Central University, Himachal Pradesh India

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Abstract: The present study covers the avifaunal diversity documented in the year 2015 to 2018 from the temporary academic block (TAB), Shahpur campus, Central University of Himachal Pradesh, India. Direct observation was made to document avifaunal diversity to prepare first checklist of avifaunal diversity. A total of 114 bird species belonging to 12 orders and 42 families were recorded from the campus and the surrounding area. The diversity pattern and the species abundance represent the effect of regional microclimate and vegetation association. The few encounters of the large frugivorous species near build environment indicate extinction from habitat degradation in the surrounding area. The presence of some specialized species in the particular habitat can be correlated with floral assemblage and the microhabitat of the area.

Keywords: Avifauna, Checklist, Conservation, Diversity, Kangra

The regular monitoring and assessment of any taxa is a prerequisite for proper management and conservation. The terrestrial eco regions in the Indian Himalayan Region (IHR) have distinct biogeographic characteristics and identified as a mega hotspot for biological diversity (Myer 2000, Kumar et al 2018). The geobotanical landscapes and habitat diversity provides unique floral assemblage for various species to flourish. The birds are one of the unique omnipresent fauna which occupies or uses both terrestrial and wetland habitats for roosting, foraging and breeding activities. The bird occupies the status of primary consumer, i.e. herbivorous (Amo et al 2013), frugivorous (Mueller et al 2014), granivorous (Connolly et al 2014), i.e., insectivorous (Powell et al 2015, Rajashekara and Venkatesha 2017) and nectarivorous (Bennett et al 2014). Birds are considered as specialized creatures well known for various ecological services contributing to maintain a healthy and sustainable ecosystem from their omnivorous nature (Burin et al 2016). Birds contribute in maintaining a sustainable ecosystem by seed dispersal, pollination and controlling pest insect infestation. A number of studies established the relation of climate change and its associated phenomenon with the diversity, distribution, changes in the level of competition, predation and migratory phenology (Crick 2004, Gregory et al 2009). Bird diversity can be used as an environmental indicator that reflects the health of the ecosystem, so the area specific studies are required.

The IHR is known to have 80 % of the bird diversity of the Indian subcontinent with a total of 940 bird species with largest number of threatening species in Asia (Mandal et al

2018). There are 1,567 studies focusing on the bird diversity of the Himalayan region and from Himachal Pradesh, there are 193 publications from 1833 to 2016 (Chandra et al 2018). There are many areas in the hilly mountainous region, which are facing the impact of urbanization and climate change. The composition of bird species in the developing urban environment, particularly the university premise under the influence of large human intervention provides an important subject for the study. The aim of the present study was to prepare the first checklist of the avifaunal diversity for the Central University Himachal Pradesh (CUHP), India.

MATERIAL AND METHODS

Study area: The present study was conducted in Shahpur campus of Central University of Himachal Pradesh (CUHP), District Kangra, Himachal Pradesh, India (76.156629°N and 32.224464°E). The Kangra Valley is characterized by snow-capped Dhauladhar Ranges in the north and area with moderate topography toward south. The study site is located in the area under moderate topography characterized by southward flowing small temporary stream mainly filled with rainfed water and one permanent stream in the extreme end toward the western side. The centre of the study area is characterized by agglomeration of three academic institutions, so to prepare the checklist different habitats in vicinity was also included, covering the diverse microclimate and vegetation assemblage from agriculture, aquatic, grassland, forest and urban habitat. The dominant tree species in the area are *Mangifera* sp., *Bauhinia variegata*, *Morus alba*, *Syzygium cumini*, *Pistacia integerrima*, *Phoenix*

humilis and *Pinus* sp., while shrub species include *Carissa opaca* and *Berberis* spp. The northeast part occupies small patches of *Pinus* sp. forest and few buildings, mainly scattered along the national highway.

Methodology: The present survey was carried out in the year 2015-2018, with some well-planned surveys by moving along a particular habitat in a linear transects (200-500 m) or by some occasional spotting in different seasons of the year. These surveys were carried out in the morning 7:00 am to 9:00 am and evening 5:00 pm to 6:30 pm. The direct observation was recorded in the field with naked eye, binocular (Hanumex 30x60) or camera (Nikon p900 and Nikon 3300 with 70-300 mm zoom lens). The abundance of the bird species was assigned on the basis of their sightings

as very common (VC), common (C) and rare (R) for the species which were sighted in whole year, a specific season and once or twice in the study period, respectively.

RESULTS AND DISCUSSION

This study document a total of 114 bird species belonging to 12 orders and 42 families. The small area of ~1-2 km a varied habitat and a huge avifaunal diversity. The family Muscicapidae (chats and flycatchers) was dominant with the contribution of 14 species of birds (Table 1). The bird species are also presented in different plates from image 1 to 114 photographed in the study area. The species marked in the rare category are mainly migratory species. Some of the birds species are mainly encountered in some specific month

Table 1. Checklist of the bird diversity from the Shahpur campus, Central University Himachal Pradesh, India

Sr. no./ Image no.	English name	Scientific name	Alternative name(s)	Abundance
Galliformes-Phasianidae (partridges, pheasants and grouse)				
1	Common Quail	<i>Coturnix coturnix</i> (Linnaeus 1758)	Grey Quail	R
2	Black Francolin	<i>Francolinus francolinus</i> (Linnaeus, 1766)	Black Partridge	R
3	Red Junglefowl	<i>Gallus gallus</i> (Linnaeus 1758)		R
Columbiformes-Columbidae (pigeons)				
4	Rock Pigeon	<i>Columba livia</i> (Gmelin JF 1789)	Rock Dove, Blue Rock Pigeon	VC
5	Oriental Turtle Dove	<i>Streptopelia orientalis</i> (Latham 1790)	Rufous Turtle Dove	C
6	Eurasian Collared Dove	<i>Streptopelia decaocto</i> (Frisvaldszky 1838)	Indian Ring Dove	R
7	Spotted Dove	<i>Streptopelia chinensis</i> (Scopoli 1786)	Western Spotted Dove, Eastern Spot- ted Dove	VC
Cuculiformes-Cuculidae (cuckoos)				
8	Greater Coucal	<i>Centropus sinensis</i> (Stephens 1815)	Crow-pheasant	C
9	Asian Koel	<i>Eudynamys scolopaceus</i> (Linnaeus 1758)	Common Koel	R
10	Common Cuckoo	<i>Cuculus canorus</i> (Linnaeus 1758)	Eurasian Cuckoo	R
11	Brown Crake	<i>Zapornia akool</i> (Syke 1832)		C
12	White-breasted Waterhen	<i>Amaurornis phoenicurus</i> (Pennant 1769)		R
Pelecaniformes- Ardeidae (herons)				
13	Indian Pond Heron	<i>Ardeola grayii</i> (Sykes 1832)	Paddybird	R
14	Cattle Egret	<i>Bubulcus ibis</i> (Linnaeus 1758)		C
Phalacrocoracidae (cormorants)				
15	Little Cormorant	<i>Microcarbo niger</i> (Vieillot 1817)		R
Charadriidae (plovers and lapwings)				
16	Red-wattled Lapwing	<i>Vanellus indicus</i> (Boddaert 1783)		C
Scolopacidae (sandpipers)				
17	Green Sandpiper	<i>Tringa ochropus</i> Linnaeus 1758		R
Accipitriformes-Accipitridae (kites, hawks and eagles)				
18	Egyptian Vulture	<i>Neophron percnopterus</i> (Linnaeus 1758)	Scavenger Vulture	R
19	White-rumped Vulture	<i>Gyps bengalensis</i> (J.F. Gmelin 1788)	White-backed Vulture	R
20	Shikra	<i>Accipiter badius</i> (J.F. Gmelin 1788)		R

Cont...

Continues Table 1

Sr. no./ Image no.	English name	Scientific name	Alternative name(s)	Abundance
21	Eurasian Sparrowhawk	<i>Accipiter nisus</i> (Linnaeus 1758)		R
22	Black Kite	<i>Milvus migrans</i> (Boddaert 1783)	Pariah Kite, Black-eared Kite	C
Strigiformes- Strigidae (owls)				
23	Asian Barred Owlet	<i>Glaucidium cuculoides</i> (Vigors 1831)	Barred Owlet	C
Bucerotiformes- Bucerotidae (hornbills)				
24	Indian Grey Hornbill	<i>Ocyrceros birostris</i> (Scopoli 1786)	Common Grey Hornbill	C
Upupidae (hoopoes)				
25	Common Hoopoe	<i>Upupa epops</i> (Linnaeus 1758)	Eurasian Hoopoe	R
Piciformes- Picidae (woodpeckers)				
26	Speckled Piculet	<i>Picumnus innominatus</i> (E. Burton 1836)		R
27	Lesser Golden-backed Woodpecker	<i>Dinopium benghalense</i> (Linnaeus 1758)	Black-rumped Flameback	R
28	Lesser Yellow-naped Woodpecker	<i>Picus chlorolophus</i> (Vieillot 1818)	Lesser Yellownape	R
29	Grey-headed Woodpecker	<i>Picus canus</i> (J.F. Gmelin 1788)	Grey-faced Woodpecker	R
30	Grey-capped Pygmy Woodpecker	<i>Dendrocopos canicapillus</i> (Blyth 1845)	Grey-crowned Pygmy Woodpecker	C
31	Fulvous-breasted Pied Woodpecker	<i>Dendrocopos macei</i> (Vieillot 1818)	Fulvous-breasted Woodpecker	R
32	Brown-fronted Pied Woodpecker	<i>Dendrocopos auriceps</i> (Vigors 1831)	Brown-fronted Woodpecker	C
Ramphastidae (toucans and barbets)				
33	Great Barbet	<i>Psilopogon virens</i> (Boddaert 1783)	Great Hill Barbet, Hill Barbet	C
34	Brown-headed Barbet	<i>Psilopogon zeylanicus</i> (J.F. Gmelin 1788)	Large Green Barbet	R
35	Blue-throated Barbet	<i>Psilopogon asiaticus</i> (Latham 1790)		C
Coraciiformes- Coraciidae (rollers)				
36	Indian Roller	<i>Coracias benghalensis</i> (Linnaeus 1758)	Indochinese Roller	C
Alcedinidae (kingfishers)				
37	White-throated Kingfisher	<i>Halcyon smymensis</i> (Linnaeus 1758)	White-breasted Kingfisher	R
Falconiformes- Falconidae (falcons and caracaras)				
38	Common Kestrel	<i>Falco tinnunculus</i> (Linnaeus 1758)	Eurasian Kestrel	R
Psittaciformes- Psittaculidae (Old World parrots)				
39	Slaty-headed Parakeet	<i>Psittacula himalayana</i> (Lesson 1832)	Himalayan Parakeet, Himalayan	R
40	Plum-headed Parakeet	<i>Psittacula cyanocephala</i> (Linnaeus 1766)	Blossom-headed Parakeet	R
41	Alexandrine Parakeet	<i>Psittacula eupatria</i> (Linnaeus 1766)	Large Indian Parakeet	C
42	Rose-ringed Parakeet	<i>Psittacula krameri</i> (Scopoli 1769)		R
Campephagidae (minivets and cuckooshrikes)				
43	Scarlet Minivet	<i>Pericrocotus flammeus</i> (Forster JR 1781)	Orange Minivet	R
Passeriformes- Dicruridae (drongos)				
44	Black Drongo	<i>Dicrurus macrocercus</i> (Vieillot 1817)		C
45	Ashy Drongo	<i>Dicrurus leucophaeus</i> (Vieillot 1817)	Grey Drongo	C
46	Hair-crested Drongo	<i>Dicrurus hottentottus</i> (Linnaeus 1766)	Spangled Drongo	R
Rhipiduridae (fantails)				
47	White-throated Fantail	<i>Rhipidura albicollis</i> (Vieillot 1818)	White-throated Fantail-flycatcher;	R
Laniidae (shrikes)				
48	Long-tailed Shrike	<i>Lanius schach</i> (Linnaeus 1758)	Rufous-backed Shrike	R

Cont...

Continues Table 1

Sr. no./ Image no.	English name	Scientific name	Alternative name(s)	Abundance
Corvidae (crows and jays)				
49	Rufous Treepie	<i>Dendrocitta vagabunda</i> (Latham 1790)	Indian Treepie	C
50	Grey Treepie	<i>Dendrocitta formosae</i> (Swinhoe 1863)	Himalayan Treepie	R
51	Yellow-billed Blue Magpie	<i>Urocissa flavirostris</i> (Blyth 1846)	Gold-billed Magpie	C
52	Red-billed Blue Magpie	<i>Urocissa erythroryncha</i> (Boddaert 1783)	Blue Magpie	R
53	Large-billed Crow	<i>Corvus macrorhynchos</i> (Wagler 1827)	Jungle Crow, Indian Jungle Crow	C
Monarchidae (monarchs and paradise-flycatchers)				
54	Indian Paradise-flycatcher	<i>Terpsiphone paradisi</i> (Linnaeus 1758)	Asian Paradise-flycatcher	R
Nectariniidae (sunbirds)				
55	Purple Sunbird	<i>Cinnyris asiaticus</i> (Latham 1790)		R
56	Crimson Sunbird	<i>Aethopyga siparaja</i> (Raffles 1822)	Yellow-backed Sunbird	R
Estrildidae (waxbills)				
57	Scaly-breasted Munia	<i>Lonchura punctulata</i> (Linnaeus 1758)	Spotted Munia	C
Passeridae (sparrows, snowfinches and allies)				
58	House Sparrow	<i>Passer domesticus</i> (Linnaeus 1758)		VC
59	Russet Sparrow	<i>Passer cinnamomeus</i> (Gould 1836)	Cinnamon Tree Sparrow, Cinnamon Sparrow	VC
Motacillidae (wagtails and pipits)				
60	Paddyfield Pipit	<i>Anthus rufulus</i> (Vieillot 1818)		C
61	Grey Wagtail	<i>Motacilla cinerea</i> (Tunstall 1771)		R
62	White-browed Wagtail	<i>Motacilla maderaspatensis</i> (J.F. Gmelin 1789)	Large Pied Wagtail	C
63	White Wagtail	<i>Motacilla alba</i> (Linnaeus 1758)	Pied Wagtail	C
Fringillidae (finches, euphonias and Hawaiian honeycreepers)				
64	Common Rosefinch	<i>Erythrura erythrura</i> (Pallas 1770)		R
65	Yellow-breasted Greenfinch	<i>Chloris spinoides</i> (Vigors 1831)	Himalayan Greenfinch	R
Emberizidae (Old World buntings)				
66	White-capped Bunting	<i>Emberiza stewarti</i> (Blyth 1854)	Chestnut-breasted Bunting	R
Stenostiridae (fairy-flycatcher and crested-flycatchers)				
67	Yellow-bellied Fairy-fantail	<i>Chelidorhynch hypoxanthus</i> (Blyth 1843)	Yellow-bellied Fantail, Yellow-bellied Fantail-flycatcher	C
68	Grey-headed Canary-flycatcher	<i>Culicicapa ceylonensis</i> (Swainson 1820)	Grey-headed Flycatcher	R
Paridae (tits, chickadees)				
69	Coal Tit	<i>Periparus ater</i> (Linnaeus 1758)	Spot-winged Tit/Crested Black Tit	R
70	Cinereous Tit	<i>Parus cinereus</i> (Vieillot 1818)	Grey Tit/Great Tit (with <i>P. major</i>)	VC
71	Black-lored Tit	<i>Machlolophus xanthogenys</i> (Vigors 1831)	Yellow-cheeked Tit	R
Cisticolidae (cisticolas)				
72	Zitting Cisticola	<i>Cisticola juncidis</i> (Rafinesque 1810)	Streaked Fantail Warbler	R
73	Grey-breasted Prinia	<i>Prinia hodgsonii</i> (Blyth 1844)	Franklin's Wren Warbler	C
74	Jungle Prinia	<i>Prinia sylvatica</i> (Jerdon 1840)	Jungle Wren Warbler	R
75	Ashy Prinia	<i>Prinia socialis</i> (Sykes 1832)	Ashy Wren Warbler	R
76	Common Tailorbird	<i>Orthotomus sutorius</i> (Pennant 1769)		C
Hirundinidae (swallows)				
77	Red-rumped Swallow	<i>Cecropis daurica</i> (Laxmann 1769)	Striated Swallow	VC

Cont...

Continues Table 1

Sr. no./ Image no.	English name	Scientific name	Alternative name(s)	Abundance
78	Barn Swallow	<i>Hirundo rustica</i> (Linnaeus 1758)	Common Swallow	R
Pycnonotidae (bulbuls)				
79	Black Bulbul	<i>Hypsipetes leucocephalus</i> (J.F. Gmelin 1789)	Square-tailed Bulbul, Himalayan Black Bulbul	C
80	Himalayan Bulbul	<i>Pycnonotus leucogenis</i> (J.E. Gray 1835)	White-cheeked Bulbul	VC
81	Red-vented Bulbul	<i>Pycnonotus cafer</i> (Linnaeus 1766)		VC
Phylloscopidae (Old World leaf warblers)				
82	Lemon-rumped Warbler	<i>Abrornis chloronotus</i> (J.E. & G.R. Gray 1847)	Pale-rumped Warbler, Pallas's Leaf Warbler	C
83	Grey-hooded Leaf Warbler	<i>Seicercus xanthoschistos</i> (J.E. & G.R. Gray 1847)	Grey-headed Flycatcher Warbler	C
Aegithalidae (long-tailed tits)				
84	Black-throated Tit	<i>Aegithalos concinnus</i> (Gould 1855)	Black-throated Bushtit	R
Zosteropidae (white-eyes and yuhinas)				
85	Oriental White-eye	<i>Zosterops palpebrosus</i> (Temminck 1824)		C
Timaliidae (scimitar babblers and allies)				
86	White-browed Scimitar Babbler	<i>Pomatorhinus schisticeps</i> (Hodgson 1836)	Slaty-headed Scimitar Babbler	R
87	Rusty-cheeked Scimitar Babbler	<i>Erythrogonys erythrogonys</i> (Vigors 1831)		C
88	Black-chinned Babbler	<i>Cyanoderma pyrrhops</i> (Blyth 1844)	Red-billed Babbler	R
89	Puff-throated Babbler	<i>Pellorneum ruficeps</i> (Swainson 1832)	Spotted Babbler	R
Leiothrichidae (babblers, laughingthrushes and allies)				
90	Jungle Babbler	<i>Turdoides striata</i> (Dumont 1823)		VC
91	Streaked Laughingthrush	<i>Trochalopteron lineatum</i> (Vigors 1831)	Bhutan Laughingthrush	R
92	Rufous Sibia	<i>Heterophasia capistrata</i> (Vigors 1831)	Black-capped Sibia	R
Certhiidae (treecreepers)				
93	Bar-tailed Treecreeper	<i>Certhia himalayana</i> (Vigors 1832)	Himalayan Treecreeper	C
Sturnidae (starlings)				
94	Common Starling	<i>Sturnus vulgaris</i> (Linnaeus 1758)	European Starling	R
95	Brahminy Starling	<i>Sturnia pagodarum</i> (J.F. Gmelin 1789)	Black-headed Myna, Brahminy Myna	R
96	Chestnut-tailed Starling	<i>Sturnia malabarica</i> (J.F. Gmelin 1789)	Grey-headed Myna	R
97	Common Myna	<i>Acridotheres tristis</i> (Linnaeus 1766)	Indian Myna	VC
98	Jungle Myna	<i>Acridotheres fuscus</i> (Wagler 1827)		R
Muscicapidae (chats and flycatchers)				
99	Indian Robin	<i>Saxicoloides fulicatus</i> (Linnaeus 1766)	Indian Black Robin	C
100	Oriental Magpie Robin	<i>Copsychus saularis</i> (Linnaeus 1758)		VC
101	Rufous-bellied Niltava	<i>Niltava sundara</i> (Hodgson 1837)		R
102	Verditer Flycatcher	<i>Eumyias thalassinus</i> (Swainson 1838)		VC
103	Spotted Forktail	<i>Enicurus maculatus</i> (Vigors 1831)		R
104	Blue Whistling Thrush	<i>Myophonus caeruleus</i> (Scopoli 1786)		VC
105	White-tailed Rubythroat	<i>Calliope pectoralis</i> (Gould 1837)	Himalayan Rubythroat	C
106	Slaty-blue Flycatcher	<i>Ficedula tricolor</i> (Hodgson 1845)		R
107	Blue-fronted Redstart	<i>Adelura frontalis</i> (Vigors 1831)		C
108	Plumbeous Water Redstart	<i>Rhyacornis fuliginosa</i> (Vigors 1831)	Plumbeous Redstart	VC
109	White-capped Water Redstart	<i>Chaimarrornis leucocephalus</i> (Vigors 1831)	River Chat, White-capped Redstart	VC
110	Chestnut-bellied Rock Thrush	<i>Monticola rufiventris</i> (Jardine & Selby 1833)		R
111	Common Stonechat	<i>Saxicola torquatus</i> (Pallas 1773)	Collared Bushchat	R
112	Pied Bushchat	<i>Saxicola caprata</i> (Linnaeus 1766)		R
113	Grey Bushchat	<i>Saxicola ferreus</i> (J.E. & G.R. Gray 1847)	Dark-grey Bushchat	VC
Turdidae (thrushes)				
114	Grey-winged Blackbird	<i>Turdus boulboul</i> (Latham 1790)		R





Image 61. Grey Wagtail
(*Motacilla cinerea*)



Image 62. White-browed Wagtail
(*Motacilla maderaspatensis*)



Image 63. White Wagtail
(*Motacilla alba*)



Image 64. Common Rosefinch
(*Carpodacus erythrinus*)



Image 65. Himalayan
Greenfinch (*Chloris spinoides*)



Image 66. White-capped
Bunting (*Emberiza stewarti*)



Image 67. Grey-hooded
Warbler
(*Phylloscopus xanthoschistos*)



Image 68. Grey-headed
Canary-flycatcher
(*Culicicapa ceylonensis*)



Image 69. Coal Tit
(*Periparus ater*)



Image 70. Cinereous Tit
(*Parus cinereus*)



Image 71. Black-lored Tit
(*Machlolophus xanthogenys*)



Image 72. Zitting cisticola
(*Cisticola juncidis*)



Image 73. Grey-breasted Prinia
(*Prinia hodgsonii*)



Image 74. Jungle Prinia
(*Prinia sylvatica*)



Image 75. Ashy Prinia
(*Prinia socialis*)



Image 76. Common Tailorbird
(*Orthotomus sutorius*)



Image 77. Red-rumped Swallow
(*Hirundo daurica*)



Image 78. Barn Swallow
(*Hirundo rustica*)



Image 79. Himalayan Black
Bulbul
(*Hypsipetes leucocephalus*)



Image 80. Himalayan Bulbul
(*Pycnonotus leucogenys*)



Image 81. Red-vented
Bulbul (*Pycnonotus cafer*)



Image 82. Pale-rumped Warbler
(*Phylloscopus chloronotus*)



Image 83. Grey-hooded Leaf
Warbler
(*Seicercus xanthoschistos*)



Image 84. Black-throated Tit
(*Aegithalos concinnus*)



Image 85. Oriental White-eye
(*Zosterops palpebrosus*)



Image 86. White-browed Scimitar
Babbler
(*Pomatorhinus schisticeps*)



Image 87. Rusty-cheeked
Scimitar-babbler
(*Erythrogenys erythrogenys*)



Image 88. Black-chinned
babbler
(*Cyanoderma pyrrhops*)



Image 89. Puff-throated
Babbler
(*Pellorneum ruficeps*)



Image 90. Jungle Babbler
(*Turdoides striata*)



Image 91. Streaked
Laughingthrush
(*Trochalopteron lineatum*)



Image 92. Rufous Sibia
(*Heterophasia capistrata*)



Image 93. Bar-tailed
treecreeper
(*Certhia himalayana*)



Image 94. Common Starling
(*Sturnus vulgaris*)



Image 95. Brahminy Starling
(*Sturnia pagodarum*)



Image 96. Chestnut-tailed
Starling
(*Sturnia malabarica*)



Image 97. Common Myna
(*Acridotheres tristis*)



Image 98. Jungle Myna
(*Acridotheres fuscus*)



Image 99. Indian Robin
(*Saxicola fulvicatus*)



Image 100. Oriental Magpie Robin
(*Copsychus saularis*)



Image 101. Rufous-bellied
Niltava (*Niltava sundara*)



Image 102. Verditer
Flycatcher
(*Eumyias thalassinus*)



Image 103. Spotted Forktail
(*Enicurus maculatus*)



Image 104. Blue Whistling
Thrush (*Myophonus caeruleus*)



Image 105. Himalayan
Rubythroat (*Calliope pectoralis*)



Image 106. Slaty-blue
Flycatcher (*Ficedula tricolor*)



Image 107. Blue Fronted
Redstart
(*Phoenicurus frontalis*)



Image 108. Plumbeous
Redstart
(*Phoenicurus fuliginosus*)



Image 109. White-capped
Water Redstart
(*Chaimarrornis leucocephalus*)



Image 110. Chestnut-bellied
rock thrush
(*Monticola ruiventris*)



Image 111. Common
Stonechat with catch
(*Saxicola torquatus*)



Image 112. Pied Bushchat
(*Saxicola caprata*)



Image 113. Grey Bushchat
(*Saxicola ferreus*)



Image 114. Grey-winged
Blackbird
(*Turdus boulboul*)

of the year which includes Common Quail, Asian Koel, Egyptian Vulture, White-rumped Vulture, Eurasian Sparrowhawk, Common Hoopoe, Lesser Yellow-naped Woodpecker, Scarlet Minivet, Spangled Drongo, Rufous Treepie, Grey Treepie, Asian Paradise flycatcher, purple Sunbird, White-browed Wagtail, White Wagtail, Common Rosefinch, Himalayan Greenfinch, White-capped Bunting, Grey-headed Canary-flycatcher, Coal Tit, Black-lored Tit, Zitting Cisticola, Black-throated Tit, White-browed Scimitar Babbler, Rusty-cheeked Scimitar-babbler, Black-chinned Babbler, Streaked Laughing thrush, Rufous Sibia, Common Starling, Brahminy Starling, Chestnut-tailed Starling, Jungle Myna, Rufous-bellied Niltava, Spotted Forktail, Himalayan Rubythroat, Slaty-blue Flycatcher, Blue Fronted Redstart, Chestnut-bellied rock Thrush, Pied Bushchat and Grey-winged Blackbird. During the survey this has also been noticed that some of the species were recorded mainly in a particular habitat and the major contribution was from forest and grassland habitat. The Common Quail, Black Francolin, Red Junglefowl and Zitting Cisticola were mainly sited either in forest or agricultural habitat. The Brown Crake, White-breasted Water hen, Indian Pond Heron, Green Sandpiper and Plumbeous Water Redstart were mainly restricted near water bodies and the drainage area. Cattle Egret, Common Stonechat and Paddy field Pipit are mainly recorded in the agricultural field. Most of the other species were omnipresent with few exceptions. A number of checklists are available for different university and institutional premises to understand the influence of human intervention, assemblage with vegetation cover and variation with habitat diversity (Subramanean and Davidar 2004, Jain et al 2005, Upadhye et al 2008, Ali et al 2013, Aggarwal et al 2016, Chakdar et al 2016, Rajashekara and Venkatesha 2017). Some of these studies have demonstrated the role of university campuses in conserving avifaunal diversity (Gupta et al 2009, Manohar et al 2017, Kabir et al 2017, Rajashekara and Venkatesha 2017, 2019). The study area represents the huge number of bird diversity despite the fact the number of rare species particularly the shy birds were encountered very less indicating the effect of current development and the increase of human population from the other educational institutions in the surrounding area.

CONCLUSION

The role of academic institutions is well known in conserving biological diversity. The present study provides the first checklist of avifaunal diversity from the temporary academic block at the Shahpur Campus of the Central University of Himachal Pradesh, India representing a total of 114 bird species in the study period. The few encounters of

some of the selected bird species in the study region indicating the effect of population exposure and habitat degradation. The present checklist of avifaunal diversity in the study will provide an understanding of human intervention and habitat degradation at different stages of development in academic institution.

REFERENCES

- Aggarwal A, Tiwari G and Harsh S 2016. Avian diversity and density estimation of birds of the Indian Institute of Forest Management Campus, Bhopal, India. *Journal of Threatened Taxa* **7**: 6891-6902.
- Ali AMS, Shanthakumar SB, Kumar SR, Chandran R, Marimuthu SS and Arun PR 2013. Birds of the Salim Ali Centre for Ornithology and Natural History Campus, Anaikatty Hills, Southern India. *Journal of Threatened Taxa* **5**: 5288-5298.
- Amo L, Jansen JJ, Van Dam NM, Dicke M and Visser ME 2013. Birds exploit herbivore-induced plant volatiles to locate herbivorous prey. *Ecology Letters* **16**: 1348-1355.
- Bennett JM, Clarke RH, Thomson JR and Nally RM 2014. Variation in abundance of nectarivorous birds: Does a competitive despot interfere with flower tracking? *Journal of Animal Ecology* **83**: 1531-1541.
- Burin G, Kissling WD, Guimaraes PR, Sekercioglu CH and Quental TB 2016. Omnivory in birds is a macro evolutionary sink. *Nature Communications* **7**: 11250.
- Chakdar B, Choudhury P and Singha H 2016. Avifaunal diversity in Assam University Campus, Silchar, India. *Journal of Threatened Taxa* **8**: 8369-8378.
- Chandra K, Gupta D, KC Gopi, B Tripathy and Kumar V 2018. Faunal diversity of Indian Himalaya: 1-872. (Published by the Director, *Zoological Survey of India*, Kolkata).
- Connolly BM, Pearson DE and Mack RN 2014. Granivory of invasive, naturalized, and native plants in communities differentially susceptible to invasion. *Ecology* **95**: 1759-1769.
- Crick HQP 2004. The impact of climate change on birds. *Ibis* **146**: 48-56.
- Gregory RD, Willis SG, Jiguet F, Vorisek P, Klvanova A, Strien A, Huntley B, Collingham YC, Couvet D and Green RE 2009. An indicator of the impact of climatic change on European bird populations. *PLoS ONE* **4**: e4678.
- Gupta SK, Kumar P and Malik MK 2009. Avifaunal diversity in the university campus of Kurukshehra, Haryana. *Journal of Threatened Taxa* **1**: 629-632.
- Jain NK, Patel SN and Patel MV 2005. Birds of Gujarat university campus, Ahmedabad. *Zoo's Print Journal* **20**: 2111-2113.
- Kabir MT, Ahsan MF, Rahman MM and Islam MM 2017. A checklist of the avian fauna of Chittagong university campus, Bangladesh. *Journal of Threatened Taxa* **9**: 10325-10333.
- Kumar P, Singh V and Singh A 2018. Seabuckthorn (*Hippophae* spp.) Conserve plant diversity in the fragile mountain ecosystem of cold desert Himalaya. *Journal of Biodiversity* **9**: 53-68.
- Mandal K, Bhattacharya K, Chatterjee P, Dey PK, Maheswaran G and Alam I 2018. *Aves. In, faunal diversity of Indian Himalaya: 831-854* (Published by the Director, Zoological Survey of India, Kolkata). <https://nmhs.org.in/pdf/BOOKS/03.Faunal%20Diversity%20of%20Indian%20Himalaya.pdf>. Downloaded on 31 March 2020.
- Manohar KA, Ramachandran A, Syamili MS, Sreekumar ER, Mohan N, Anjali J, Reddy A and Nameer PO 2017. Birds of the Kerala Agricultural university campus, Thrissur District, Kerala, India - an update. *Journal of Threatened Taxa* **9**: 10585-10612.
- Mueller T, Lenz J, Caprano T, Fiedler W and Bohning-Gaese K 2014. Large frugivorous birds facilitate functional connectivity of fragmented landscapes. *Journal of Applied Ecology* **51**: 684-692.

- Myers N, Mittermeier RA, Mittermeier CG, Fonseca GAB and Kent J 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.
- Powell LL, Cordeiro NJ and Stratford JA 2015. Ecology and conservation of avian insectivores of the rainforest understory: A pantropical perspective. *Biological Conservation* **188**: 1-10.
- Rajashekara S and Venkatesha MG 2017. Seasonal incidence and diversity pattern of avian communities in the Bangalore university campus, India. *Proceedings of the Zoological Society* **70**: 178-193.
- Rajashekara S and Venkatesha MG 2019. Additions to the birds of Bangalore university campus (BUC), India. *Proceedings of the Zoological Society* **72**: 197-201.
- Subramanean J and Davidar P 2004. Changes in avifauna over a sixteen-year period in the Pondicherry university campus. *Newsletter for Ornithologists* **1**: 50-52.
- Upadhye MV, Jadhav U, Utekar AY and Patil RC 2008. Avifauna of Mumbai university campus. *Ecology and Environment Conservation* **14**: 461-464.

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Plant Community Analysis of Bhubaneswar Smart City, Odisha, India

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Abstract: Analysis of the plant community in four sites of each of Central and Transition zones of Bhubaneswar city showed that in the transition zone, *Mangifera indica* L., *Neolamarckia cadamba* (Roxb.) Bosser were the dominant trees. From the calculated values of relative frequency, relative density, relative dominance and importance value index, *Delonix regia* was quite dominant. In the Transition zone *M. indica* L. followed by *N. cadamba* (Roxb.) Bosser. were present in high population. Raunkiaer's frequency class, indicated that half of the sites in the central zone and three out of four sites in the transition zone were disturbed in terms plant community. Family Importance Value index, that Poaceae was the most dominant family followed by Cyperaceae and Fabaceae. The distribution pattern showed that in the central Zone, out of 276 species, 146 species showed contagious distribution, 90 species had random distribution and 40 species had regular distribution. In the transition zone, with 286 species recorded, 155, 84 and 47 species showed, contagious, random and regular distribution respectively. Because of more anthropogenic activities in the core areas, species richness was more in the transition zone than the central zone. The various above parameters showed marked differences among the study sites because of variations in soil conditions, local climate and biotic interferences.

Keywords: Community, Diversity index, relative dominance, Importance value Index, Family Index value

Cities provide ample opportunities to their citizens for economic development, better living standards, jobs and educational opportunities leading to migration of people from villages to cities. This continuous and unabated migration over the years has made cities densely populated and unsustainable. It has been predicted by UNO (Stanley 2008) that the number of people in Indian towns and cities will reach at 814 million by 2050. Under the smart city mission, announced by the Government of India, Bhubaneswar the capital of Odisha has been declared as one of the cities for comprehensive development of its physical, institutional, social and economic infrastructure. As such it attracts the attention of policy makers, and planners, and the government has been putting lots of stress to make it a model city for others. At the time of construction of new capital in 1948, Bhubaneswar and its surrounding areas supported a thick vegetation cover, mostly of deciduous type and the biodiversity was remarkably rich (Rout and Dash 1998). However with expansion of capital city, the rich flora of Bhubaneswar has largely been replaced by shrubs with stunted growth. Though some study has been conducted by botanists on the flora of Bhubaneswar, there is no comprehensive study that could throw light for the future planning and development of Bhubaneswar modern city from vegetational perspective. Under this background, the present study was conceptualized to make quantitative study

of vegetational patches and look for plant community analysis.

MATERIAL AND METHODS

Bhubaneswar is located in the Khurda district of Odisha, India between 20°12' N to 20 25' N latitude and 85 44' E to 85 55' E longitude on the Western fringe of the coastal plain across the main axis of the Eastern Ghats. The present study is confined to the Bhubaneswar city coming under Bhubaneswar Municipality Corporation (BMC) having an area of 146 Sq.km. with 67 wards. The present study was based on primary data collected through the survey from holistic and eco-systematic perceptiveness. The plants collected repeated field trips were identified in the Botany section of Regional Institute of Education, Bhubaneswar and documented following the "The Botany of Bihar and Orissa" (Haines 1925) and "Flora of Orissa" (Saxena and Brahman 1996). For plant community (vegetation) analysis, the central part of the Bhubaneswar city was taken as the Central zone (CZ). Samples were collected from randomly selected four wards such as WN-28, WN-17, WN-37 and WN-36. The area 10 km radius surrounding the Central Zone was considered as the Transition Zone (TZ). Sampling wards in this zone included WN-23, WN-02, WN-32 and WN-67.

Plant community was quantitatively analyzed following Quadrature method. From each (Central and Transition) zone,

four sampling sites were randomly selected and from each site, 10 quadrates were taken and the size of each quadrate was decided looking into the nature of vegetation of the locality. Vegetation data were analyzed by their synthetic characters like abundance (A), frequency (F), density (D), relative density (RD), relative frequency (RF), relative dominance (RDO), basal area (BA), importance value index (IVI) following the standard formulae (Kormondy 1969). Family importance value (FIV) was calculated (Ganesh et al 1996) representing the sum of relative density, relative diversity and relative dominance of the family. Abundance / Frequency (A/F) ratio was calculated to describe the distribution pattern of species (Curtis and Cotton 1956).

Abundance: It represents the number of individuals of any species per unit area of occurrence. It was calculated as follows:

$$\text{Abundance} = \frac{\text{Total no. of individual of the species in all quadrats}}{\text{No. of quadrats in which species occurred}}$$

Frequency: Frequency is the number of sampling units in which a particular species occurs and this was calculated as follows:

$$\text{Frequency} = \frac{\text{No. of quadrats in which species occurred}}{\text{Total no. of sampling unit studied}}$$

Density: The number of individuals of the species in an unit area is its density. It was calculated as follows

$$\text{Density (\%)} = \frac{\text{No. of individuals of the species}}{\text{Total area studied}}$$

Dominance: Dominance is the stem area occupied by stem of a species in any given area. It is calculated by measuring the diameter of the individual stems and adding the stem areas of the species in a given area.

Basal area of the species = Sum of the basal areas of all individuals present.

Relative density: This is calculated by the following formula

$$\text{Relative density} = \frac{\text{Density of the species}}{\text{Total density of all the species}} \times 100$$

Relative frequency: Relative frequency of the species is calculated by using the following formula:

$$\text{Relative frequency} = \frac{\text{Frequency of the species}}{\text{Total frequency of all species}} \times 100$$

Relative dominance: This is calculated by the following formula

$$\text{Relative dominance} = \frac{\text{Dominance (cover) of the species}}{\text{Total dominance of all species}}$$

Importance Value Index (IVI): This is a value that reflects the relative importance of the individual species in the study area. It is calculated by adding relative density, relative dominance and relative frequency values for each species (Curtis and Cotton 1956, Philip 1959).

IVI = Relative Dominance + Relative Density + Relative Frequency.

Family Importance Value (FIV): It represents the sum of relative density, relative diversity and relative dominance of the family.

FIV = Relative Density + Relative Diversity + Relative Dominance (for single family)

Abundance / Frequency ratio (A/F): This is the ratio of the abundance and frequency of the given species (Curtis and Cotton 1956). It is used to describe the distribution pattern of the species in the area. The distribution of plants is said to be regular, random and clumped or contagious when the value of A/F ratio is <0.025, 0.025-0.05 and >0.05 respectively.

Diversity indices: Diversity indices are values propounded by various ecologists which incorporate several parameters into single values. Diversity indices such as Shannon – Wiener Index, Concentration of Dominance (CD), Species Richness (SR) and Species Evenness (SE) were calculated for herb, shrub and tree species both for Central as well as Transition Zones (Simpson 1949, Whittaker 1977)

Shannon - Wiener Index: It is a measure of general diversity (Shannon and Wiener 1963) determined with the information function.

$$H' = - \sum_{i=1}^s p_i \ln p_i$$

Where H' = Shannon index of general diversity

Pⁱ = proportion of its species in that community i.e. n_i / N

ln = natural log

s = Total number of species present in the area

p_i = n_i / N

Where n_i = No. of Individuals in a species

N = Total number .of individuals in all species present.

The Shannon index is a measure for diversity (Shannon 1949). Values smaller than 2 indicate low diversity, while values greater than 2 point to a high diverse stand.

Concentration of dominance (CD): It is the inverse of diversity is measured by Simpson's index (Simpson 1949)

$$H' = - \sum_{i=1}^s (p_i)^2$$

Where Pⁱ = proportion of its species in that community

Species richness (SR): Species richness is a measure of the number of species found in a sample. It is calculated by the number of species present in the sample is divided by the square root of the number of individuals in the sample. This particular measure of species richness is known as D (Menhinick's index). (Whittaker 1977)

D = s / √N

Where s = The number of different species present in the sample, and

N = Total number of individuals one species.

Species evenness (SE): The distribution of individuals over species is called species evenness. It is measure of the

relative abundance of different species making up the richness of an area. This evenness is an important component of diversity indices (Leinster and Cobbold 2012). Several equations have been proposed to calculate evenness from diversity measure. The most important and accepted one is Pielou index (J). It is calculated as

$$J = \frac{H'}{\ln(s)}$$

Where J= Pielou's Equitability index

H' = Shannon Wiener diversity index

S = Total no. of species present in the area

ln = logarithm to the base.

The Pielou's index is a measure of how evenly distributed abundance is among the species that exists in a community. The Pielou index is defined between 0 and 1, where 1 represents a community with perfect evenness and decreases to zero as the relative abundances of the species diverge from evenness.

RESULTS AND DISCUSSION

In the Central Zone, 592 plant species were recorded in all the three seasons from which 314 plants were common. As such 278 different plant species were recorded in the four selected sites. Similarly in the Transition Zones, 294 different plant species were recorded. In the Central Zone, *Delonix regia* had the highest population size followed by *Anacardium occidentale* L., *Mangifera indica* L., etc. In the Transition Zone, *Managifera indica* L. had the highest population size followed by *Neolamarckia cadamba* (Rox b.) Bosser. As reflected from the calculated values, in the Central Zone, *Delonix regia* had high values in terms of relative frequency (6.410), relative density (24.861) and relative dominance (15.911) (Table 1). *Strychros nuxvomica* L. had the lowest values reflecting its thin population. In the Transition Zone, RF, RD and RDo values for *Mangifera indica* were 9.677, 23.595 and 28.334 respectively reflecting dominance nature. The second dominant species was

Table 1. Calculated values of relative frequency, relative density, relative dominance and importance value index for selected plants species in the Central Zones of Bhubaneswar city

Name of the plant species	Relative frequency (RF)	Relative density (RD)	Relative dominance (RDo)	Important value index (IVI)
<i>Delonix regia</i> (Boj ex Hook) Raf.	6.41	24.86	15.91	47.18
<i>Anacardium occidentale</i> L.	5.76	11.04	10.88	27.69
<i>Mangifera indica</i> L.	4.48	4.14	10.25	18.88
<i>Artocarpus heterophyllus</i> Lam	3.84	6.90	5.94	16.69
<i>Acacia nitotica</i> (L.) Delle ssp. Indica (Benth) Brejan.	5.76	6.07	0.50	12.35
<i>Azadirachta indica</i> A. Juss.	2.56	2.76	6.38	11.71
<i>Eucalyptus citriodora</i> Hook.	3.84	2.76	4.08	10.69
<i>Neolamarckia cadamba</i> (Roxb.) Bosser.	4.48	3.31	1.71	9.52
<i>Bombax ceiba</i> L.	3.20	1.93	4.217	9.35
<i>Albizia lebbeck</i> (L.) Benth.	1.92	0.82	6.12	8.88
<i>Aegle marmelos</i> (L.) Corr.	1.28	4.14	2.65	8.07
<i>Buchanania lanzan</i> Spreng.	3.20	2.76	1.76	7.73
<i>Semecarpus anacardium</i> L.f.	2.56	1.65	3.07	7.29
<i>Tamarindus indica</i> L.	1.92	1.10	3.12	6.15
<i>Ficus religiosa</i> L.	2.56	1.38	1.73	5.67
<i>Chloroxylon swietiana</i> DC.	2.56	2.48	0.57	5.62
<i>Cassia fistula</i> L.	1.92	1.10	2.55	5.58
<i>Dalbergia sissoo</i> Roxb.	2.56	1.38	0.88	4.82
<i>Lannea coromandelica</i>	1.92	0.82	2.05	4.80
<i>Tectona grandis</i> L.f	1.92	1.10	1.46	4.49
<i>Diospyrus malabarica</i> (Desr.) Kostel	2.56	1.10	0.45	4.12
<i>Dalbergia lanceolaria</i> L.f.	1.92	1.10	0.95	3.97
<i>Phoenix sylvestris</i> (L.) Roxb.	1.92	0.82	1.22	3.97
<i>Holarrhena pubesceus</i> (Buch. Ham.)	1.28	0.82	1.71	3.82
<i>Syzgium cumini</i> (L.) Skeels	1.92	1.10	0.70	3.73

Neolamarckia cadamba (Roxb.) (Table 2). From frequency class distribution of plant species in both Central and Transition Zones, it was observed that Central Zone site-1 and site-4 showed disturbed vegetation whereas in the Transition Zone, except site-2, other three sites (Site – 1, Site – 3, and Site – 4) showed disturbed vegetation (Table 3).

The importance value index (IVI) values ranged between 1.171 to 47.183 in Central Zones (Table 1) and 3.887 to 61.607 in Transition Zones (Table 2). The dominant species in terms of IVI values were *D. regia*, *A. occidentale* in central zones and *M. indica*, *Neolamarckia cadamba* in transition zones (Fig. 1, 2). Importance value (FIV) data showed that the most dominant family was Poaceae (57.73) followed by Cyperaceae (37.11) and Fabaceae (26.80) (Fig. 3). In terms of species richness, family Poaceae (33 genera 56 species) had the highest species richness followed by Cyperaceae (6 genera, 36 species). In central zone, out of

276 species, 146 species show contagious distribution, 90 species had random distribution and 40 species had regular distribution. *Petrospermum acerifolium*, *Acacia nilotica*, *Butea Monosperma* etc. were contagiously distributed, *Ficus racemosa* the, *Bombax ceiba*, *Artocarpus heterophyllus*, etc. were randomly distributed. In the Transition Zone, out of 286 species, 155 species showed contagious distribution, 84 species had random distribution and 47 had regular distribution (Table 4). Different diversity indices like species diversity (SD), concentration of dominance (CD), species richness (SR) and species evenness (SE) for tree, shrub and herb species for both Central and Transition Zones (Table 5).

The flora of Bhubaneswar and its surroundings are broadly classified as north tropical moist deciduous (mixed) type. The entire area before construction of the capital city was under different reserve forests covering 1553.6886 Sq.Km (27%) of the total area of 5664 sq.km dominated by

Table 2. Calculated values of relative frequency, relative density, relative dominance and importance value index for selected plants (Trees) species Transitional (TZ) Zones of Bhubaneswar city

Name of the plant species	Relative frequency (RF)	Relative density (RD)	Relative dominance (RDo)	Important value index (IVI)
<i>Mangifera indica</i> L.	9.67	23.59	28.33	61.60
<i>Neolamarckia cadamba</i> (Roxb.) Bosser.	9.67	18.53	10.81	39.02
<i>Butea monosperma</i> (Lam.) Taub.	7.52	10.67	5.44	23.64
<i>Ficus benghalensis</i> L. var. <i>bengalensis</i>	3.22	1.68	14.64	19.56
<i>Aegle marmelos</i> (L.) Corr.	5.37	4.49	3.33	13.20
<i>Ficus religiosa</i> L.	3.22	1.68	8.09	13.00
<i>Artocarpus heterophyllus</i> Lam.	4.30	2.80	3.84	10.95
<i>Azadirachta indica</i> A. Juss.	4.30	2.80	3.44	10.55
<i>Bauhinia variegata</i> L.	5.37	2.27	0.42	10.29
<i>Tamarindus indica</i> L.	3.22	2.27	3.76	9.24
<i>Limonia acidissima</i> L.	3.22	2.80	2.72	8.76
<i>Simarouba glance</i> DC	3.22	2.80	2.39	8.43
<i>Annova squamosa</i> L.	5.37	2.27	0.21	7.83
<i>Plumeria rubra</i> L.	4.30	2.24	0.68	7.23
<i>Bombax ceiba</i> L.	3.22	1.68	2.17	7.08
<i>Phoenix sylvestris</i> (L.) Roxb.	3.22	1.68	1.47	6.38
<i>Terminalia bellirica</i> (Gaertn.) Roxb.	3.22	2.24	0.85	6.32
<i>Dalbergia lanceolaria</i> L.f.	3.22	2.24	0.54	6.01
<i>Cassia fistula</i> L.	2.15	1.68	1.32	5.16
<i>Syzygium cumini</i> (L.) Skeels.	2.15	1.12	1.37	4.65
<i>Albizia lebbecu</i> (L.) Benth.	2.15	1.12	1.23	4.50
<i>Ziziphus mauritiana</i> Lam.	2.15	1.68	0.63	4.97
<i>Dillenia indica</i> L.	2.15	1.12	0.95	4.23
<i>Madhuca indica</i> Gmel.	2.15	1.12	0.61	3.88
<i>Diospyros melanoxyton</i> Roxb.	2.15	1.12	0.61	3.88

Sal and Bamboos. The biotic factors have changed the original characters of the vegetation and presently the North-western part of the city, the Bharatpur Reserve Forest spreads over 847.53 Sq.Km.(OFDC 2017). The distribution of plant species in different sites of the central zone, it was observed that the site-1(CZ-1) and site-2 (CZ-2) had more number of species as compared to other sites. It could be due to institutional campus territory which is well protected and conserved without disturbance. Plants in site-3 (CZ-3) and site-4 (CZ-4) were less in number because of developmental works such as construction of buildings and high rise apartments, roads, etc. The transition zone that stands in continuation with forest areas beyond its limit had more number of plant species in rainy season. In two of its sites (TZ-3 and TZ-4) plants were less in number, probably due to construction activities round the year. Structure, composition and function are the three important attributes of plant communities. The analytical features such as RF, RD, RDO, IVI and species diversity (SD) showed marked differences among the study sites. This possibly could be due to variations in soil conditions, local climate and biotic (positive/negative) interferences (Timilsina et al 2017). The vegetation of any place is the outcome interaction of many

factors such as the elevation, soil, species composition and biotic interferences.

In the present study, 52.89 (Central Zone) and 54.19 (Transitional Zone) percent of the total species showed contagious pattern of distribution which is the characteristic feature of natural vegetation. Among the sites, an overview distribution pattern (A/F ratio) for herb, shrub and tree layers showed contagious growth pattern followed by random. The nature of distribution shows a ray of natural impact over anthropogenic disturbance, of course not in any case as it happens in a forest community. The diversity index ranged from 1.746 to 3.185 for trees, 1.764 to 2.571 for shrubs and 1.904 to 2.746 for herbs. The diversity index is generally higher in tropical forests (5.06) whereas for Indian forest, it ranged between 0.83 to 4.90.(Kumar et al 2006). The diversity index though cannot be compared with the forest community mentioned above, may certainly be considered not very poor as usual in case of modern cities. The species dominance for shrubs and herbs was higher in transitional zone than the central zone. However in transitional zone, TZ-1 and TZ-2 showed more species richness than the CZ-1 and CZ-2 of central zone. This could be because of less degree of interference in the Transitional Zone. However, low species

Table 3. Frequency class distribution of plant species in both central & transition Zones of Bhubaneswar city

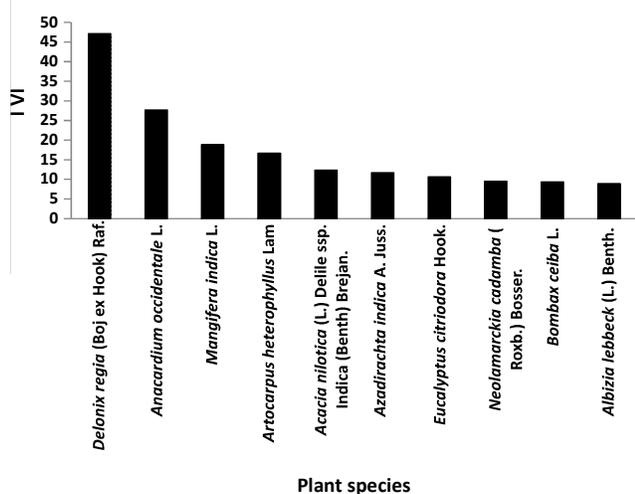
Frequency	Site-1 (CZ-1)		Site-2 (CZ-2)		Site-3 (CZ-3)		Site-4 (CZ-4)	
	No. of species	Per cent of total no. of spp.	No. of species	Per cent of total no. of spp.	No. of species	Per cent of total no. of spp.	No. of species	Per cent of total no. of spp.
Central Zones (TZ)								
1-20	43	51.80	49	56.32	29	63.04	27	66
21-40	18	21.68	12	13.79	7	15.21	6	13.33
41-60	4	4.81	3	3.44	2	4.34	1	2.22
61-80	16	7.22	9	10.34	4	8.09	3	6.66
81-100	12	14.45	14	16.09	6	13.04	8	17.77
Transition Zones (TZ)								
	Site-1 (TZ-1)		Site-2 (TZ-2)		Site-3 (TZ-3)		Site-4 (TZ-4)	
1-20	35	28.45	28	31.46	14	35	10	29.41
21-40	36	29.26	22	24.71	8	20	11	32.35
41-60	10	8.13	5	5.61	2	5	1	2.94
61-80	22	17.88	15	16.85	5	12.5	6	17.64
81-100	20	16.26	19	21.34	12	30	5	14.70

Table 4. Distribution pattern of plant species in central and transition Zones

Distribution	Central Zone		Transition Zone	
	No. of species	Per cent of species	No. of species	Per cent of species
Regular (< 0.025)	40	14.49	47	16.43
Random (0.025 – 0.05)	90	32.60	84	29.37
Contagious (>0.05)	146	52.89	155	54.19

Table 5. Species diversity, concentration of dominance, species richness and species evenness of the Central and Transition Zones of Bhubaneswar city

Site	Parameter	Tree	Shrub	Herb
CZ-1 (TZ-1)	SD	2.416 (2.821)	2.114 (2.571)	2.413 (2.746)
	CD	0.125 (0.193)	0.156 (0.089)	0.1149 (0.092)
	SR	4.174 (5.817)	3.372 (4.232)	2.463 (2.637)
	SE	0.615 (0.841)	0.849 (0.843)	0.942 (1.302)
CZ-2 (TZ-2)	SD	2.98 (3.185)	2.142 (2.521)	2.150 (2.634)
	CD	0.062 (0.090)	0.144 (0.135)	0.142 (0.145)
	SR	6.123 (6.476)	2.761 (2.350)	2.181 (1.197)
	SE	0.768 (0.970)	0.828 (0.974)	0.965 (1.015)
CZ-3 (TZ-3)	SD	1.746 (3.015)	1.854 (2.015)	2.043 (2.183)
	CD	0.327 (0.089)	0.148 (0.139)	0.138 (0.173)
	SR	3.524 (5.432)	2.372 (2.431)	2.182 (1.835)
	SE	0.617 (0.915)	0.842 (1.942)	0.745 (0.726)
CZ-4 (TZ-4)	SD	2.047 (1.990)	1.764 (1.842)	1.904 (1.940)
	CD	0.119 (0.317)	0.147 (0.167)	0.185 (0.134)
	SR	4.242 (4.215)	2.242 (2.435)	1.464 (2.248)
	SE	0.645 (0.794)	0.843 (0.817)	0.945 (0.846)
Average (CZ/TZ)	SD	2.290 (2.750)	1.968 (2.246)	2.127 (2.365)
	CD	0.158 (0.172)	0.148 (0.132)	0.144 (0.136)
	SR	4.515 (5.485)	2.68 (2.862)	2.072 (1.753)
	SE	0.661 (0.868)	3.362 (0.894)	0.899 (0.972)



richness in the central zone, could be due to anthropogenic activities, such as road expansion, construction of residential areas, etc. Further because of invasion of large number of alien species, species richness level increased by lowering the dominance of few other species.

The concentration of dominance (CD) ranged from 0.132 to 0.158. This value reported for plant community stands always at the bottom line with an indication of diversity than dominance. The evenness of plant species in Transition Zone shows more values than the Central Zone as the number of individuals of most abundant species is extremely greater than the least abundant species. The species dominance for shrubs and herbs was higher in transitional Zone than the

Fig. 1. IVI of some dominant species in Central Zone of Bhubaneswar city

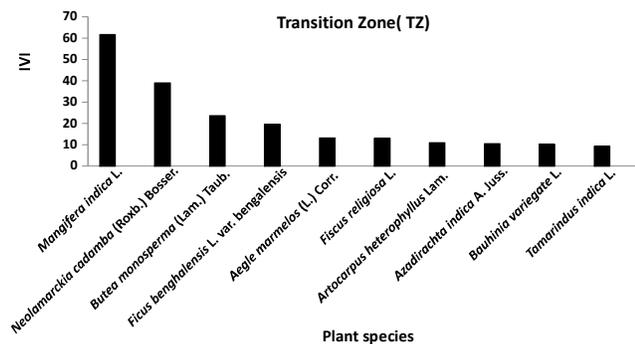


Fig. 2. IVI of some dominant species in Transition Zone of Bhubaneswar city

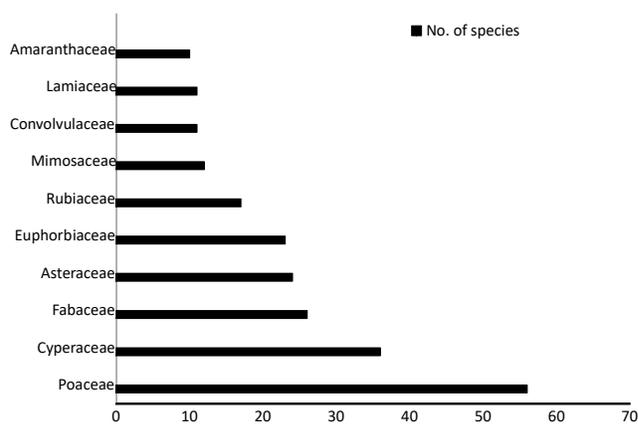


Fig. 3. Family-level dominance based on species richness and family importance value (FIV)

central zone. However in the transitional zone, TZ-1 and TZ-2 showed more species richness than the CZ-1 and CZ-2 of central zone. This could be because of less degree of interference in the Transitional Zone. However, due to anthropogenic activities, such as road expansion, modernization of the city, construction of residential areas, etc. in the central zone, low species richness was recorded. Further due to invasion of large number of alien species, species richness of shrubs and herbs level increases by lowering the dominance of few other species. This situation is suitable to release resources available to early successional species and increasing environmental heterogeneity that provides a basis for specialization and resource partitioning. From Raunkier's frequency class analysis, Central Zone, sites such as CZ-1 and CZ-2 were undisturbed (uniform) whereas CZ-3 and CZ-4 exhibited disturbed vegetation. Similarly in the transitional zone, except TZ-2, other three sites (TZ-1, TZ-3 and TZ-4) showed disturbed vegetation. This indicated that the vegetation is under severe anthropogenic, biotic and abiotic stress. With the increase of aesthetic sense among people specially students, and women, many gardens and a forestation programmes in the undisturbed site (uniform) have been initiated in and around the city, which became the major sites for introduction of new species.

CONCLUSION

Phyto-sociological attributes reveals that there is a gap between the values of different parameters (frequency, density, abundance). There are many trees having lower IVI needs to be more attention. Bhubaneswar being a fast expanding city, there is an urgent need for proper planning with emphasis on minimising anthropogenic interference(s) at least in undisturbed sites in the core and peripheral zones of the city in order to keep the age old vegetation especially

trees intact besides their sustainable use.

REFERENCES

- Curtis JT, Cotton G 1956. *Plant Ecology Workbook Laboratory Field Reference Manual*. Burgess Publishing Co. Minnesota.
- Ganesh T, Ganesan R, Soubadradevy M Davidar P and Bawa KS 1996. Assessment of plant biodiversity at a mid-elevation evergreen forest of Kalakad-Mudanthurai tiger reserve, Western Ghat, India. *Current Science* **71**: 379-92.
- Haines HH 1921-25. *The Botany of Bihar and Orissa*. 6 Parts. Adlard and Sons & West Newman Ltd., London.
- Kormondaj EJ 1969. *Concepts of Ecology*. Prentice Hall. Inc., Englewood Cliffs, New Jersey.
- Kumar A, Saxena A and Marcot BG 2006. Tree species diversity and distribution patterns in tropical forests of Garo hills. *Current Science* **91**(10): 1370-1381.
- Kulshrestha SK 2016. Smart cities: A new competitive approach to urban transformations. Institute of Town planner. *Indian Journal* **13**(1): 1-19.
- Leinster T and Cobbold CA 2012. Measuring diversity: The importance of species similarity. *Ecology* **93**(3): 477-489.
- OFDC Report 2017. *Annual Report of Forest Department*. Orissa Forest Development Corporation, Government of Orissa, Bhubaneswar.
- Philips EA 1959. *Methods of Vegetation Study*. A Holt Dryden book-Henry Holt and Company, Incorporation.
- Raunkiaer C 1934. *The Life Form of Plants and Statistical Plant Geography*. Oxford University Press, UK.
- Rout DK, Dash MC 1998. *Environment status of Bhubaneswar*. Orissa Pollution Control Board, Bhubaneswar.
- Saxena HO and Brahmam M 1994-96. *Flora of Orissa*. Vol.1-4. Orissa Forest Development Corporation, Bhubaneswar.
- Shannon CE 1949. *The mathematical theory of communication*. University Illinois press, Urbana.
- Shannon CE, Wiener W 1963. *The mathematical theory of communication*. University Illinois press, Urbana.
- Simpson EH 1949. *Measurement of Diversity*. Nature.
- Stanley 2008. Monitoring land-cover changes: A comparison of change detection techniques. *International Journal of Remote sensing* **20**: 139-339.
- Timilsina N, Ross MS and Heinen JT 2017. A community analysis of Sal (*Shorea robusta*) forests in the Western Terai of Nepal. *Forest Ecological Management* **41**: 223-234.
- Whittaker RH 1977. Dominance and diversity in land plant communities. *Science* **147**: 250-260.



Description of Embryonic Development of Prawn *Macrobrachium dayanum* Henderson, 1893 (Decapoda, Palaemonidae) based on the Staging Method

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Abstract: The present communication is an attempt to record the developmental changes during the embryonic development of freshwater prawn, *Macrobrachium dayanum*. The incubation period ranged from 20 to 35 days. The freshly oviposited eggs were olive green in colour with the mean length and breadth being 0.32 and 0.24mm, respectively. Various embryonic stages i.e., pre-cleavage stage, cleavage stage, gastrula stage, germinal disc stage, embryo stage, caudal papilla stage, c-shape stage, eye-spot stage, pigmented eye stage, segmented abdomen stage, pre-hatching stage and hatching stages respectively were differentiated and recorded based upon the various morphological events. The description of these morphological events can be used as a tool for authenticating the taxonomic status of a species and differentiating it from other related species, exhibiting overlapping adult characters which is a commonly encountered problem among decapod crustaceans in general and freshwater prawns in particular.

Keywords: *Macrobrachium dayanum*, Freshwater prawn, Embryonic stages

The general biology of this diverse genus, *Macrobrachium* is relatively well studied while other aspects for instance, the embryology of certain species like *M. dayanum* is yet poorly recorded. In Palaemonid prawns, the centrolecithal eggs are incubated in the specially protected pouch which is present ventrally between the pleopods of females, generally known as brood chamber until hatching, for ensuring the high survival rate of the embryos (Charniaux et al 1992). Palaemonid prawns offer a unique and valuable tool for understanding developmental processes due to its peculiarity of carrying eggs externally in the pouch which allows a systematic tracking of embryonic development. A ripe ovigerous *Macrobrachium dayanum* female can be identified easily due to the presence of broader pleura to form a brood chamber in order to carry the eggs during the breeding season. *M. dayanum* is an important freshwater prawn in the region extending from North India to the North-Eastern states of the Indian subcontinent. An attempt to establish embryological study in sometime past was done by Muller (2003) in *M. olfersi*, Habashy et al (2012) in *M. rosenbergii* and Sudhakar et al (2014) in *M. idea*. In the want of any detailed report on embryonic development stages particularly with regard to *M. dayanum*, the present investigations have been undertaken to establish the complete tracking on embryonic development of this prawn based on the morphological differentiation in living as well as the fixed embryos. The studied embryological phases in the form of stages could be

used as a reference tool for studying the embryonic process in this species and can also be extended as a guide to judge the developmental stages of other related species in experimental as well as natural conditions.

MATERIAL AND METHODS

The adult live specimens of the freshwater prawn, *Macrobrachium dayanum* were obtained from the Chadwal area 32° 77'N latitude and 74° 89' E longitude of the Kathua district in the Jammu region of J&K. The animals were taken to the laboratory and were placed in the departmental poly-house ponds under constant aeration and 12:12 light: dark cycle. Ten ovigerous females were regularly monitored by removing several eggs in a day at 12 hour interval from the periphery of the brood pouch during first two days and 24 hour interval during the remaining developmental period, until the hatching occurred. The average total length of the female was 52.7mm with mean fecundity of 160 eggs. The percentage scale of development time in total was established as 0% (freshly laid eggs) to 100% (hatching). Live embryos were observed with a video monitoring device attached to stereomicroscope (Leica). Various physicochemical parameters were recorded by using standard methods (APHA 2000).

RESULTS AND DISCUSSION

The length of the fertilised eggs was in the range 0.32 to

0.37mm and width 0.24 to 0.28mm. The freshly oviposited eggs were olive green in colour (Fig. 1). The average incubation period was 20 to 35 days. As the development progressed, the colour of the eggs changed through olive green to pale yellow, then brownish yellow and finally to dull whitish indicating the complete exhaustion of egg yolk for meeting the nutritional requirements of developing eggs. By this time, fully developed embryos become clearly visible in the brood chamber of mother. The whole egg mass becomes glued together with a jelly like substance so as to form a protective layer against any microbial attack or chemical change in the specially formed brood chamber during the breeding season. The brood chamber acts as a protective storage house for the egg mass as well as it offers adherence to jelly coat with the surrounding pleopod setae. Based upon the developmental processes viz. morulation, blastulation, gastrulation, segmentation, formation of optic vesicle, eye development, 11 morphologically distinct stages could be identified.

Pre-cleavage stage: 0-5% of the development takes place in this stage. The egg yolk was olive green in colour and was tightly enveloped by the outer transparent chorion layer forming an oval shape in the eggs. The yolk was uniformly distributed throughout the egg having characteristic granular yolk mass. As such, negligible development was evident during this phase (Fig. 2A).

Cleavage stage: 4-9% of the development takes place in this stage. This stage was characterised by the presence of several similar sized blastomeres. Due to repeated cell division, the developing embryo appeared like a ball of cells. Size of the embryo appears to have reduced (Fig. 2B).

Gastrula stage: 9-14% of the development takes place in this stage. The blastoporal area was formed by the gradual migration of blastomeres towards the egg pole. A pale yellow depression was formed surrounded by the embryonic cells continuously migrating towards the inner part of the egg (Fig. 2C).

Germinal disc stage: This stage presents about 14-22% of development. With the progressive cell stage, the continuous

immigration of embryonic cells led to the formation of superficial cell layers to establish a V-shaped disc like structure known as germinal disc. The high-density areas were formed around the blastopore and germinal disc. (Fig. 2D).

Embryo stage: 22-29% of the development takes place in this stage. A typical embryonic structure could be observed in one hemisphere of the egg. The outlines of antennules, antennae and mandible buds could be differentiated in the pale white embryo separated from the yolk on one hemisphere of the egg mass while most of the egg volume was being occupied by 95% of olive-green yolk. The stomodaeum could clearly be demarcated in the centre region of the embryo (Fig. 2E).

Caudal papilla stage: 29-34% of the development takes place in this stage. This embryonic stage was characterised by the development of the well-marked caudal papilla and optic lobes in the denser area of the upper and lower extreme ends of the germinal disc. The rudiments of the three pairs of appendages as buds made their appearance (Fig. 2F).

C-shaped stage: 34-50% of the development takes place in this stage. The size of the embryo increased mainly on the antero-posterior axis. Developing embryo acquired a

Table 2. Physicochemical parameters

Physicochemical parameter	Mean value
Air temperature (°C)	27.3±1.21
Water temperature (°C)	21.6±0.12
Depth (cm)	30.2±0.32
pH	7.82±0.43
FCO ₂ (mg l ⁻¹)	1.89±1.24
DO (mg l ⁻¹)	9.45±0.65
CO ₃ ²⁻ (mg l ⁻¹)	Absent
HCO ₃ ⁻ (mg l ⁻¹)	510.6±0.23
Ca ⁺⁺ (mg l ⁻¹)	31.6±0.73
Mg ⁺⁺ (mg l ⁻¹)	15.45±0.25
Cl ⁻ (mg l ⁻¹)	32.5±0.42

Table 1. Intensities of embryonic movements in different developmental stages

Embryonic stages	Per cent stage development	Movements		
		Heartbeat	Spasms	Appendage movement
C-shape stage	34-50	-	-	-
Eye-spot stage	50-65	Irregular	Frequent and Sudden	-
Pigmented eye stage	65-74	Irregular	Frequent	Random
Segmented abdomen stage	74-90	Rhythmic with slight pauses	Frequent	Random
Pre-hatching stage	90-100	Rhythmic	Frequent	Controlled (Pleopods and Mouth parts)

characteristic C shaped structure. Due to the growth of caudal papilla, it was observed to be folded ventrally thus demarking its median lines. The rudiments of five pairs of appendage buds could be seen along the caudal papilla. The bifurcation of the antennules became visible (Fig. 2G).

Eye-spot stage: 50-65% of the development takes place in this stage. This stage was characterised by the appearance of the eye-buds as thin fine line at the posterior part of the optic lobe. The optic lobe was seen bended antero-laterally thus covering the major part of the yolk. First glimpse of the different types of chromatophores in the anterior region was seen during this stage, thus providing a colourful appearance to the developing embryo. The presence of eye buds and chromatophores clearly demarked the anterior region from the rest of the body of embryo. Irregular faded heartbeat could be observed along with random spasms as first body movements (Fig. 2H).

Pigmented eye stage: 65-74% of the development takes place in this stage. The stage had been so named because rudimentary eyes made their appearance and stage also characterized a gradual increase in the pigmented area of the optic lobe. Simultaneously, the caudal papilla kept on folding which resulted in considerable overlapping of the optic lobes. The round shape at the extremity of the caudal papilla now began to appear as a rudiment of the telson. The appendages continued to gain length and overlapping. The cephalothorax was clearly seen as organised structure. The movements of the embryo as irregular heart beat and sudden spasms were clearly visible and were recorded (Fig. 2I).

Segmented abdomen stage: 74-90% of the development takes place in this stage. The egg attained elongated shape due to a gradual increase in the size of the embryo. The thoracic and abdominal appendages eventually became parallel to each other due to folding of the thoracic appendages towards the abdomen. The telson overlaps the optic lobes. The embryo occupied about 75% of the egg volume by progressive exhaustion of the yolk. The drastic increase in the eye index was the most peculiar feature of this stage. Segmentation in the abdomen was clearly individualized from the rest of the embryo (Fig. 2J).

Pre-hatching stage: 90-100% of the development takes place in this stage. The embryo was seen occupying almost all the space of the egg thus reducing the yolk to a meagre of 5-10% of the volume restricted at the region behind the optic lobe. Eye-pigmentation became pronounced covering one-third of the optic lobes, forming pigmented oval eye. Various segments of the body could be easily recognized. The dorsal body of the embryo was seen protected by a thick cuticle covering as carapace. Different types of chromophores were visible throughout the egg surface. The appendages

(antennules, antennae, 3 pairs of pleopods, 2 pairs of periopod) were observed to be folded towards the abdomen due to the limited egg space. All the appendages could be observed to be positioned in organised and overlapping manner. The telson was considerably posterior beyond the optic lobe (Fig. 2K).

Hatching stage: 100% of the development takes place in this stage. The hatching process was very slow, gradual and hatching took place in batches for 2-3 days. Hatching was accompanied by stretching of the body and continuous pecking of the anterior region thus forcing the egg shell to elongate and puncture gradually. The puncture caused yolk to ooze out at first followed by head and finally the abdomen. The active hatching was aided by jerky movements that were sufficiently forceful to be seen with the naked eyes. The larvae were yellowish-brown in colour and mean length was found to be 6.0mm. Regarding their structural details; the larvae were almost similar to the post-larvae except some structures like telson and maxillae. Telson was broad having round posterior margin with faint median notch while it was narrow with convex posterior margin in adults. Maxillae were not prominent, distinctly bilobed palp with endites being less setose unlike post larvae. (Fig. 2L).

In the present study, the newly laid eggs were olive green which changed to pale yellow, brownish yellow followed by dull white at the time of hatching while it were been reported as green in *Macrobrachium rosenbergii* (Ling 1969), orange in *Macrobrachium heterochius* (Guest 1979), greenish yellow in *Macrobrachium lamarrei* (Uno and Sao, 1969), thus revealing the colour of embryo to be a species specific character. The present observations were in line with Sudhakar et al (2014) that the newly laid eggs were enveloped with a jelly coat which protected them from physical and chemical stresses and helped to maintain the internal environment. Muller et al (2007) differentiated the various embryonic development events in *Macrobrachium americanum* and *M. olfersii* as major and minor events. The major development events included the appearance of germinal disc, chromatophores, optic lobe pigmentation and onset of heartbeat whereas the minor development events included lack of segmentation in mouth appendages. Present observations are however, in agreement with several previous recordings particularly stating that the chromatophores and eye buds appeared first during the developmental period.

Major factors influencing the development were observed on the basis of percentile staging while Garcia-Guerrero et al (2003) considered that even in the congeneric species the duration of the development might vary since it was governed by various external factors, the most important and



Fig. 1. *Macrobrachium dayanum* - ovigerous female

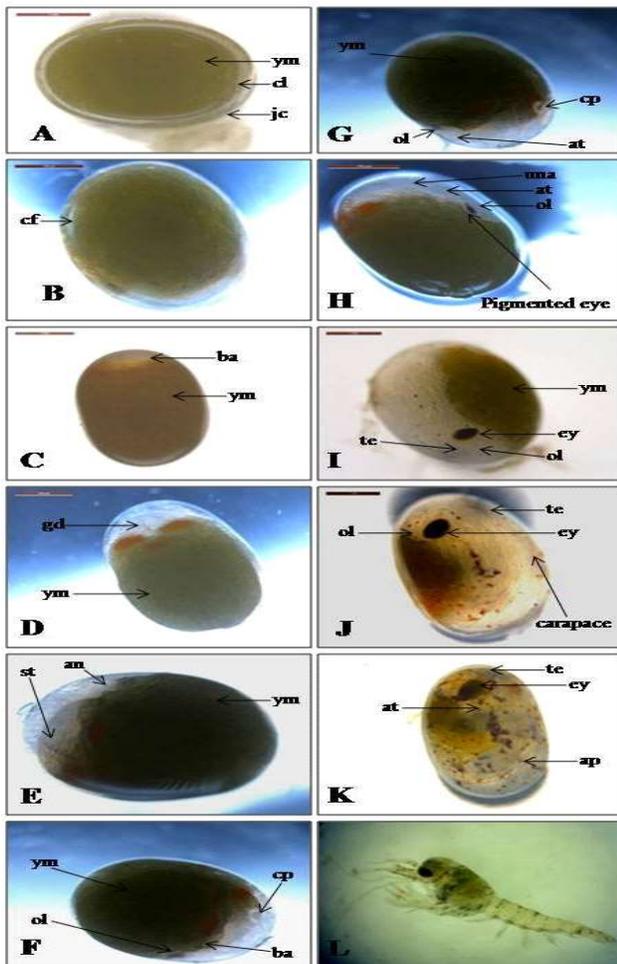


Fig. 2. Embryonic stages of the development of *Macrobrachium dayanum*. A. Pre cleavage, B. Cleavage, C. Gastrula, D. Germinal disk, E. Embryo stage, F. Caudal papilla stage, G. C-shaped embryo, H. Eye bud stage, I. Pigmented eye stage, J. Segmented, K. Pre-hatching, L. Hatched larva. an=antennulae, at=antennae, ba=blastoporal area, cf=cleavage furrows, cp=caudal papilla, ey=eye, gd=germinal disk, ol=optic lobe, ap=appendages, te=telson, una=undifferentiated appendages, ym=yolk mass

determinant being the prevailing temperature conditions of environment at any particular point of time. He also concluded that it was difficult to record the slight differences in the developmental stages while studying basic taxonomy. Garcia-Guerrero and Henderickx (2009) conducted the study on *Macrobrachium americanum* and recorded that the species had an incubation period of 18 days at 24°C and described them in 10 stages, which was recorded as 14 days in *Macrobrachium olfersii* (Muller et al 2003), 21 days in *M. potiuna* (Muller et al 2004) and 18-20 days in *Macrobrachium rosenbergii* (Habashy et al 2012). Presently however, a comparatively extended embryonic period of 20 to 35 days has been recorded in *M. dayanum*. The hatching process was very slow and gradual and it continued for 2-3 days, young ones emerged out in batches and these observations were perfectly in line with those recorded by Seitz et al (2005) who postulated that the developing eggs showed considerable difference in hatching even within the same clutch. Yao et al (2006) found that the egg increased its water content in order to maintain higher water pressure for embryo to rupture the egg membrane which in turn aided in efficient hatching. Present species is an economically important species as has been established by its nutritional status and therefore, warrants extensive investigations of its biological parameters, which is a basic requirement for establishing successful culture endeavours of any species. Further, the description of embryology represents one basic step required in this direction as it can definitely be used as a tool for future studies which deals with the ontogeny and taxonomy of a species. This would enable the aquaculturists to get rid of unwanted species at juvenile stages itself as the availability of pure seed has always been a major bottleneck in rearing of any aquaculture species particularly when seed is collected from nature.

CONCLUSION

The freshly oviposited eggs in this species were olive green in colour with length and width in the range 0.32 and 0.28mm, respectively. The whole egg mass was glued together in specially formed brood chamber. The development of embryo undergoes various stages until hatching. Hatching took place in batches. The newly hatched larvae were yellowish brown in colour.

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REFERENCES

APHA 2000. Standard methods for the examination of water and wastewater: 20th edition. *Choice reviews Online* 37: 2737-2792.

- Charniaux CH, Payen GG and Ginsburger VT 1992. Arthropoda-Crustacea, Sexual differentiation. Reproductive Biology of Invertebrates in KG Adiyodi and RG Adiyodi (eds). *John Wiley and Sons, New York* **5**: 281-323.
- Garcia-Guerrero MU and Hendrickx ME 2009. External description of the embryonic development of the prawn, *Macrobrachium americanum* Bate, 1868. (Decapoda, Palaemonidae) based on the staging method. *Crustaceana* **82**(11): 1413-1422.
- Garcia-Guerrero MU, Hendrickx ME and Villarreal H 2003. Description of the embryonic development of *Cherax quadricarinatus* Von Martens. 1868 (Decapoda) Based on the staging method. *Crustaceana* **76** (3): 280-296.
- Guest WC 1979. Laboratory life history of the palaemonid shrimp *Macrobrachium amazonicum* (Heller) (Decapoda, Palaemonidae). *Crustaceana* **37**:141-151.
- Habashy MM, Sharshar KM and Hassan M 2012. Morphological and histological studies on the embryonic development of the freshwater prawn, *Macrobrachium rosenbergii* (Crustacea, Decapoda). *Journal of Basic and Applied Zoology* **65**: 157-165.
- Jalihah DR, Sankolli KN and Shenoy S 1993. Evolution of larval developmental patterns and the process of fresh waterization in the prawn genus *Macrobrachium* Bate, 1868 (Decapoda, Palaemonidae). *Crustaceana* **65**: 365-376.
- Ling SW 1969. The general biology and development of *Macrobrachium rosenbergii* (de Man). *FAO Fish Reporter* **57**: 589-606.
- Muller Y, Ammar D and Nazari E 2004. Embryonic development of four species of palaemonid prawns (Crustacea, Decapoda), pre-naupliar, naupliar and post- naupliar periods. *Revista Brasileira De Zoologia* **21**: 27-32.
- Muller Y, Nazari E and Simoes-Costa M 2003. Embryonic stages of the freshwater prawn *Macrobrachium olfersii* (Decapoda, Palaemonidae). *Journal of Crustacean Biology* **32**: 869-875.
- Muller YM, Pacheco C, Simoes CMS, Ammar D and Nazari EM 2007. Morphology and chronology of embryonic development in *Macrobrachium acanthurus* (Crustacea, Decapoda). *Invertebrate Reproduction and Development* **50**(20): 67-74.
- Seitz R, Vilpoux K, Hopp U, Harzsch S and Maier G 2005. Ontogeny of the *Marmorkrebs* (marbled crayfish): A parthenogenetic crayfish with unknown origin and phylogenetic position. *Journal Experimental Zoology* **303**: 393-405.
- Shailender M, Suresh Babu CH, Sarmal KP and Kishor B 2012. Effects of temperature and salinity on growth, hatching rate and survival of the giant freshwater prawn, *Macrobrachium rosenbergii* (de Man) under captive conditions. *International Journal of Bioassays* **1**(11): 150-155.
- Sudhakar S, Soundarapandian P, Varadharajan D and Dinakaran GK 2014. Embryonic Development of *Macrobrachium idea*. *Coastal Development* **17**(1):1-6.
- Yao J, Zhao YL, Wang Q, Zhou ZL, Hu XC, Duan XW and Anchuan G 2006. Biochemical compositions and digestive enzyme activities during the embryonic development of prawn, *M. rosenbergii*. *Aquaculture* **253**: 573-582.
- Yonge CM 1937. The nature and significance of the membranes surrounding the developing eggs of *Homarus vulgaris* and other Decapoda. *Proceedings of the Zoological Society of London* **107**: 499-517.



Mapping of Total Suspended Matter based on Sentinel-2 data on the Hooghly River, India

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Abstract: This study aims to develop a regional algorithm for monitoring and retrieval of total suspended matter concentration (C_{TSM}) using in-situ C_{TSM} data, in-situ remote sensing reflectance (R_{rs}) data and Sentinel 2 MSI data on Hooghly River. The field measurements were carried for 20 stations using Satlantic Hyperspectral Ocean Colour Radiometer (HyperOCR) and water samples were also collected at a depth of 0.5m from April to May 2018. The concentration of total suspended matter varies from 132 to 540 mg L⁻¹. The calibration was done for 70% of the data between in-situ C_{TSM} and in-situ remote sensing reflectance and the remaining 30% of the data is used for in-situ validation. The in-situ validation result shows the band combination of B7/B2 has higher fitting. For satellite validation, Sentinel 2 Multispectral Instrument (MSI) satellite data applies to the in-situ validation models to the retrieval of C_{TSM} , which also confirms the band ratio of B7/B2 gives a good correlation with $R^2=0.75$. The study shows, the applicability of Sentinel 2 MSI data for retrieval of C_{TSM} in Hooghly River, Kolkata. The Sentinel 2 MSI B7/B2 is highly recommended for mapping a higher concentration of suspended matter in the study area, respectively.

Keywords: Total suspended matter, Hyperspectral radiometer, Regional algorithm, Sentinel 2 MSI data, Hooghly river

In optical remote sensing, the water is classified into the case I and case II water. The case I water is dominant of phytoplankton, which is specifically for the open ocean. The case II water is significantly dominated by the chlorophyll-a concentration (Chl-a), total suspended matter concentration (C_{TSM}) and coloured dissolved organic matter (CDOM). Mostly inland water bodies, estuary and its coastal areas come under case II water. The importance of understanding the optical properties of Case II water is necessary for monitoring and protecting the aquatic environment (Avinash et al 2012). Among all optically active substance, the concentration of total suspended matter plays a major role because of its impact in the light transmission, transportation of minerals and nutrients, contamination and deposition of sediments in water bodies.

In specific at case II water, anthropogenic and man-made activities may dominate the C_{TSM} distribution pattern. The C_{TSM} values are spatially heterogeneous and temporally dynamic in all water bodies. Therefore, obtaining the result of C_{TSM} at high spatiotemporal level helps to understand the driving force of the water bodies and further for maintaining the aquatic ecosystem. Even through field and lab-based measurements can provide more accurate results however, it is costly and may not possible for more temporal and spatial analysis. In opposite to that, the satellite remote sensing is used to provide an economic approach for monitoring the water constituents (Merina 2017). Bhaskaran et al (2014) encountered a high sedimentation issue that requires

intermittent support by the method of dredging. Ramakrishnan et al (2013) results show the increase of sediment concentration will increase the water-leaving radiance in the Gulf of Cambay. In a satellite-based ocean colour remote sensing, Sentinel-2 MSI data is used in optical studies of water because of its least spatial resolution. Sentinel-2 MSI satellite around the sun-synchronous polar orbit can provide a better spatial resolution of 10, 20 and 60m and a temporal resolution of 2 to 5 days. Sentinel-2 MSI satellite data set is employed to retrieve the total suspended matter concentration value in a turbid estuary (Liu et al 2017).

Dornhofer et al (2016) have processed the Sentinel-2 MSI satellite data for the analysis of optically active substances over the inland water shows the acceptable result. Gernez et al (2015) retrieved the C_{TSM} from Sentinel -2 MSI data in the turbid estuary region. Manzo et al (2015) results show the accuracy of Sentinel 2 MSI satellite data for obtaining the optically active substances in the Italian Lakes by using the bio-optical model. Kutser et al (2016) used the Sentinel-2 MSI data to retrieve C_{TSM} and it is observed to be more beneficial than Landsat 8 OLI for black lakes. The universal algorithm for the retrieval of the C_{TSM} will not be applicable for all study areas (Pradhan et al 2005). So the regional based algorithm is required for a more accurate model. To develop the regional algorithm for retrieval of C_{TSM} , the empirical algorithm was created between band ratio of in-situ Remote sensing reflectance (R_{rs}) and in-situ C_{TSM} .

The objective of this present study in the Hooghly River,

Kolkata includes prediction the spectral signature and measures the concentration of C_{TSM} in the in-situ water samples as well as comparison and validation of in-situ C_{TSM} data with in-situ R_{rs} and satellite R_{rs} data.

MATERIAL AND METHODS

Study area: The Hooghly river is situated roughly between the latitudes 22.02°–21.90° N and longitudes 88.07°–88.01° E in the state of West Bengal, India which is passing through 2 major cities called Kolkata and Howrah then finally joined in the Bay of Bengal. The widening of the river increases gradually to downstream from Haldia port which creates “Hooghly Estuary”. In the mainstream of the Hooghly river, two important ports were located. One is Kolkata port constructed in 1870, which is a major port in India on the riverine of about 150 km of length from Coastal region. Another one is Haldia Port which is constructed during 1977 at Haldia to reduce the ship traffic in Kolkata port. Haldia port is now facing the problem of dredging and siltation for a long time. The sediment deposition occurs majorly in downstream of the Hooghly estuary because of a decrease in flow velocity of the water. To operate the Haldia port, continuous monitoring of C_{TSM} is important which will also helpful in timely the maintenance of dredging and siltation for a long time (Prasad and Singh 2010).

In-situ measurement: The field survey was carried out from April to May 2018 (pre-monsoon period). Twenty samplings were fixed along the estuarine region of the Hooghly River. Each sampling location reached by using a global positioning system (Garmin Ltd., USA). To minimise the error in the in-situ data collection, the boat was switched off to avoid the turbulence in sampling point and then measurements were done in the shallow free area of the boat. The surface water samples were collected in 0.5m depth using the Niskin water sampler. To measure the spectral signature of water, Satlantic HyperOCR sensors are used. The sensor in the instrument used to measure the water-leaving radiance (L_w) and downwelling irradiance (E_d) which gives the optical properties of the water. The Satlantic HyperOCR radiometer has a spectral range of 350 nm to 800 nm with the spectral data collection interval of 3.3 nm. All the collected data stored in the computer with dot raw extension (RAW). SatCon is a software developed by the Sea-Bird Scientific Company (<http://www.seabird.com>) for processing radiometer data (RAW). The final product of the processed data will provide the water-leaving radiance (L_w) and downwelling radiance (E_d). The in-situ remote sensing reflectance (R_{rs}) data is calculated by the ratio of water-leaving radiance (L_w) and downwelling radiance (E_d) (Minu et al 2016).

$$R_{rs}(\lambda) = \frac{L_w(\lambda)}{E_d(\lambda)} \dots\dots\dots (1)$$

Laboratory analysis: To measure the concentration of total suspended matter (C_{TSM}), all the collected water samples were filtered through pre-dried and weighted Whatman GF/F glass fiber filter paper of 0.45 μ m pore size and 47 mm diameter (Strickland et al 1972). The filter papers were kept at 60°C for 6 hours in the hot-air oven and reweighted again at room temperature. The concentration of total suspended matter is obtained by dividing the difference value between the final weight (g) and initial weight (g) by the volume of sample (ml).

$$CTSM (mg l^{-1}) = \frac{\text{Final weight (g)} - \text{Initial weight (g)}}{\text{Volume of sample (ml)}} \quad (2)$$

Satellite data acquisition and processing: The Sentinel 2 MSI have a wide view of 290 km and it contains a total number of 13 spectral bands which has the range from visible to shortwave infrared (SWIR) region, and it has a spatial resolution of 60m (3 bands), 20m (6 bands), 10m (4 bands). Sentinel 2 MSI L1C images captured on 15 May 2018 were downloaded from the European Space Agency website (<https://scihub.copernicus.eu/dhus/>). Sentinel Application Platform (SNAP) is open-source software which helps to process the Sentinel products such as opening and exploring Sentinel data, masking, band visualization, atmospheric correction etc. All satellite data processing was done by using SNAP software. The image correction for atmospheric effect (iCOR) is a tool in the SNAP software which is helping for atmospheric correction in the Sentinel 2 MSI data over the land and water (Keukelaere et al 2018). After the atmospheric correction, satellite remote sensing reflectance (R_{rs}) data can be easily retrieved from the satellite imagery by marking the sampling location (View-Tool-Windows-Pin manager) in the SNAP software (Malenovský et al 2012). In satellite validation, retrieved remote sensing reflectance data will be applied to the newly developed model for spatial and temporal mapping of C_{TSM} .

Model development: To develop the model, 70% of the in-situ data were used for calibration and 30% of the data is used for validation. For satellite validation of the model, Sentinel 2 MSI data were applied to the developed model. The total dataset is sorted from low to high based on C_{TSM} values. The systematic sampling is the statistical method that allows the researcher to select 70% of the data for calibration and 30% of the data for validation in equal distribution manner. The spectral signature of *in-situ* R_{rs} is plotted and analyzed. Among the different regression analysis, the polynomial regression analysis gives a good correlation between in-situ C_{TSM} and in-situ R_{rs} (other regression results are not shown). There are different band ratio model was developed between in-situ C_{TSM} and in-situ R_{rs} . Out of that, the

top 5 well-correlated models were selected for further analysis of in-situ and satellite data validation.

In-situ and Satellite validation: The in-situ validation datasets are applied to calibrated models for estimation of C_{TSM} . The retrieved C_{TSM} is compared with measured in-situ C_{TSM} data. The statistical analysis such as root mean square error (RMSE), mean absolute percentage error (MAPE) and the coefficient of determination (R^2) values were calculated between the measured and estimated values to select the best fitting and validation accuracy. The Sentinel 2 R_{rs} is applied to the newly developed models to retrieve C_{TSM} values. The retrieved C_{TSM} values used to provide the spatial distribution of total suspended matter concentration in the study area (Sraavanthi et al 2013).

RESULTS AND DISCUSSION

In-situ & satellite data: The in-situ remote sensing reflectance spectra show that the study area is dominant of TSM concentration. The peak near 780nm indicates the dominance of C_{TSM} in the spectral signature of water sample (Fig. 2). The increase of C_{TSM} will increase the remote sensing reflectance and vice versa. There are two C_{TSM} dominant peaks near 705 nm and 780nm. All the dataset are

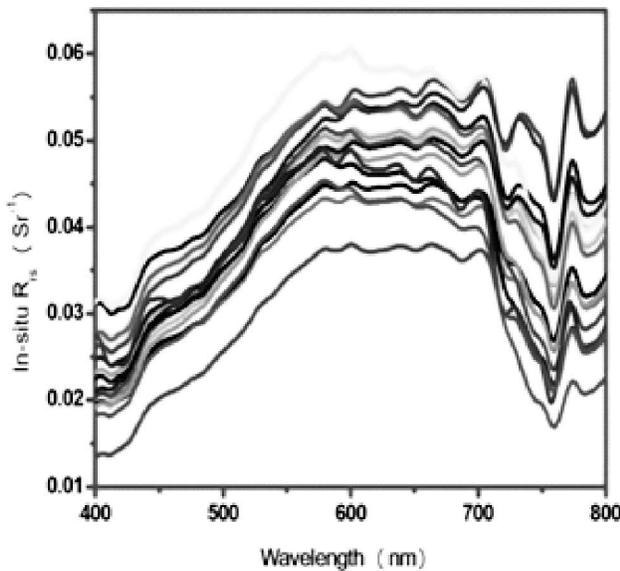


Fig. 1. Spectral signature of in-situ water sample from Satlantic HyperOCR Radiometer

statistically derived (Table 1).

Model development: The C_{TSM} retrieval models were developed by the polynomial regression analysis between in-situ C_{TSM} and in-situ R_{rs} (Fig. 3). The band combination of B3/B7 shows a high correlation with the coefficient of determination ($R^2= 0.74$) and followed by B7/B3 have a R^2 value of 0.73. In the best 5 models, the least correlation occurred in the ratio of B7/B4 with $R^2=0.69$ (Fig.3e).

In-situ data validation: For *in-situ* validation, the remaining 30% of the *in-situ* R_{rs} data is applied to the newly developed model (Fig. 4). Validation dataset shows the band combination of B7/B2 has the highest correlation of 79% and next to that B7/B3 show $R^2= 0.74$. The band ratio of B2/B7 model gives the poor correlation in the validation graph with $R^2=0.06$. Among all models, band combination of B7/B2 were acceptable for retrieval of C_{TSM} values in the Hooghly River (Fig. 4b). To evaluate the accuracy of the developed model, statistical analysis such as coefficient of determination (R^2), root mean square error (RMSE), mean absolute percentage error (MAPE) were calculated (Siswanto et al 2011).

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^n (forecast - actual)^2 \right]^{1/2} \quad (3)$$

$$MAPE = (1/N) * \sum (|actual-forecast|/|actual|) * 100 \dots (4)$$

Satellite data validation: For the satellite validation, scatter plot between C_{TSM} values derived from the Sentinel 2 band ratio (a) B3/B7 (b) B7/B2 (c) B2/B7 (d) B7/B3 (e) B7/B4 against measured C_{TSM} (Fig. 5). The band ratio of B7/B2 retrieved model is well correlated with measured TSM concentration with 75% of accuracy. Among the five models, the band ratio of (a) B3/B7 (b) B7/B2 (d) B7/B3 can be suitable for monitoring TSM concentration in the Hooghly

Table 2. Sentinel 2 MSI bands along with central wavelength and resolution

Band	Wave length (nm)	Resolution (m)
B1-Coastal aerosol	443	60
B2-Blue	490	10
B3-Green	560	10
B4-Red	665	10
b5-red edge	705	20
B6-Red edge	740	20
B7-Red edge	783	20

Table 1. Statistical analysis of calibration and in-situ & satellite validation data sets of TSM concentration

Datasets	No. of total data	Min. C_{TSM} (mg L ⁻¹)	Max. C_{TSM} (mg L ⁻¹)	Average C_{TSM} (mg L ⁻¹)	S.D C_{TSM} (mg L ⁻¹)	C.V (%)
Calibration	14	183	461	313	95	30.4
in-situ validation	6	137	540	314	193	61.5
Satellite validation	18	222	343	269	42	15.5

S.D – Standard deviation, C.V – Coefficient of Variation

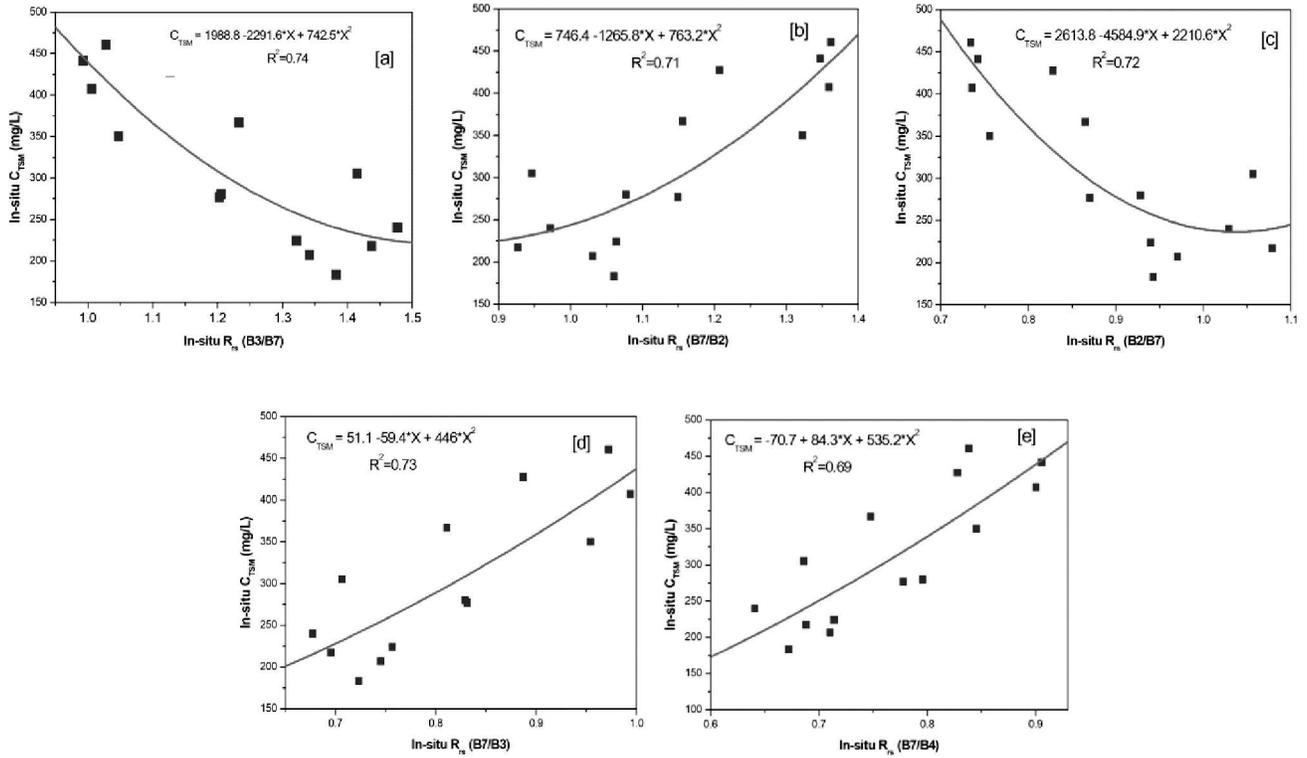


Fig. 3. Development of band ratio algorithm between in-situ remote sensing reflectance and in-situ C_{TSM} (a) B3/B7 (b) B7/B2 (c) B2/B7 (d) B7/B3 (e) B7/B4

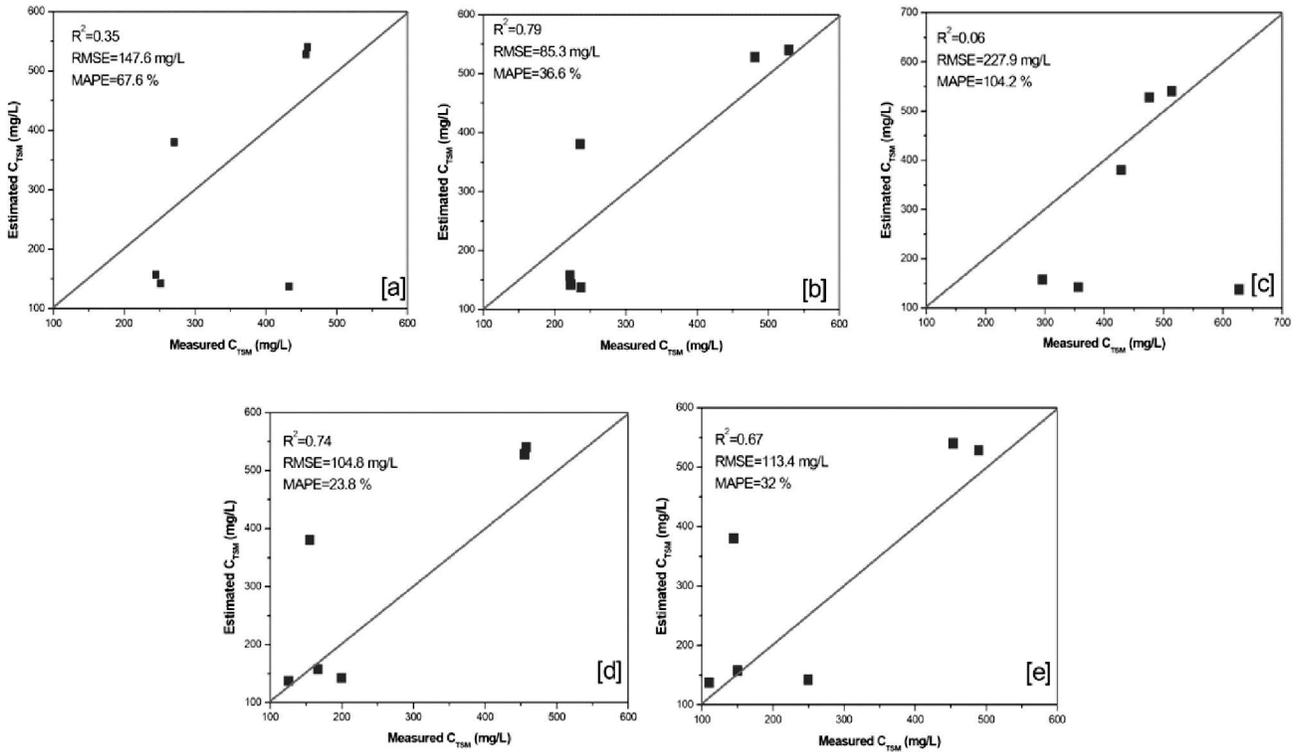


Fig. 4. Scatter plot between estimated and measured C_{TSM} for in-situ validation datasets (a) B3/B7 (b) B7/B2 (c) B2/B7 (d) B7/B3 (e) B7/B4

River. Similar to *in-situ* validation, band ratio of B7/B2 based model gives better results in the estimation of C_{TSM} from satellite data. The band ratio of B2/B7 model has performed very low. The C_{TSM} is higher in the northern region and its concentration decrease gradually when it comes to the south part of the Hooghly river (Fig. 6). After the satellite validation, retrieved TSM concentration shows the clear spatiotemporal distribution of TSM concentration throughout the Hooghly River.

The study area belonging to the high suspended sediment concentration which is recorded in the previous study by Pitchaikani et al (2019). In the present study the concentration of total suspended matter in the downstream of estuarine were 221 to 256 mg l⁻¹, whereas, near to upstream or port region, a higher concentration is observed in the range of 280 to 343 mg l⁻¹. The higher concentration of suspended matter is due to the geographical structure of the area and gradually decreased in terms of depth and width of the estuarine region from mouth to upstream. In the study area, the width of the upstream was 3 km and gradually increased to 13 km in the mouth region. The study area is located in the international ship route and it is India's longest river line port. Due to the turbulence of ship movement, waves and tide action, sediments are re-suspended in the surface water which leads to water appear to be in brown colour and the region became higher sediment concentration. Models

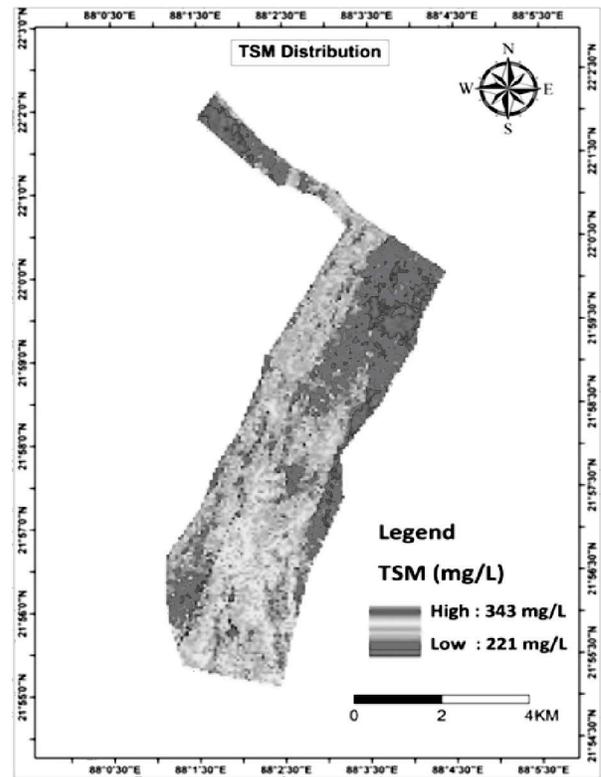


Fig. 6. Concentration of total suspended matter (C_{TSM}) retrieved from Sentinel-2 MSI satellite for the band combination of B7/B2

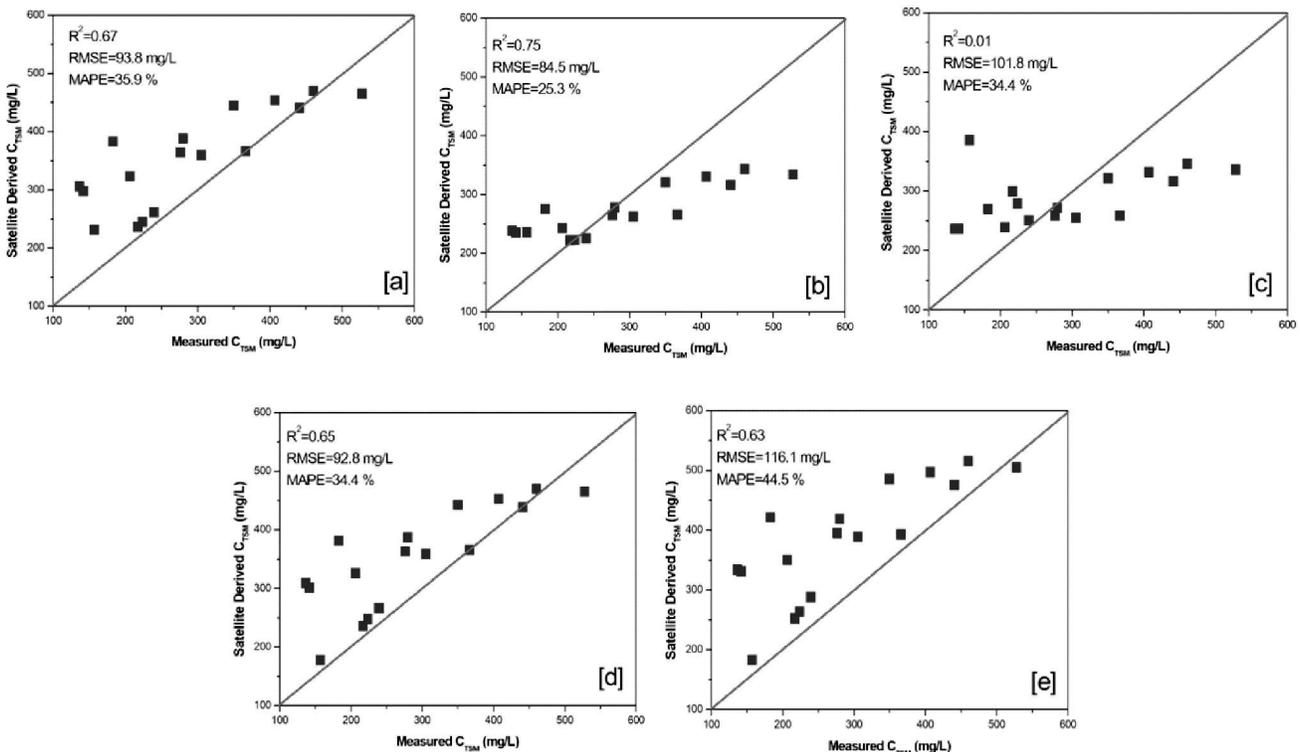


Fig. 5. Scatter plot of satellite derived C_{TSM} against measured C_{TSM} (a) B3/B7 (b) B7/B2 (c) B2/B7 (d) B7/B3 (e) B7/B4

based on Sentinel band B1-B5 gives poor correlation. As compare to higher wavelength in Sentinel-2 band, the lower wavelength is affected by strong backscattering and absorption properties of water.

Therefore shorter wavelength bands are not suitable for retrieval of higher C_{TSM} . The calibration results show that band combination of B2/B7 has poor fitting accuracy. This explains the band ratio of shorter wavelength may be contributed by phytoplankton absorption at 665 nm, Colour Dissolved Organic matter observation at 440 nm. However, the lower concentration of suspended matter can be well correlated with Sentinel-2 bands (B1-B5) in case 2 water. The higher band ratio is not possible due to limitation in *in-situ* spectral values. The band combination of B7/B2 is recommended for retrieval of higher TSM concentration. To achieve the better result, the time difference between the sample collection and Sentinel 2 satellite pass should be within 3 hours and also applying the best and adequate atmospheric correction model of Sentinel 2 data (iCOR) need to be concentrated. Finally, the Sentinel 2 MSI data shows the high load of TSM concentration (C_{TSM}) in the northern part of the study and it's gradually decreased when it reaches the near to the Bay of Bengal.

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CONCLUSIONS

The present study monitors the total suspended matter concentration in the Hooghly River, Kolkata using *in-situ* C_{TSM} , *in-situ* R_{rs} data and satellite R_{rs} data. This study helps to identify the spectral signature of TSM concentration with the help Satlantic HyperOCR radiometer data. The remote sensing reflectance data is derived from Satlantic hyperspectral radiometer gives the spectral signature of TSM concentration. The band combination of B7/B2 in the *in-situ* validation data shows the higher validation accuracy and also the same for satellite validation result shows higher accuracy. The newly developed regional algorithm for retrieval of TSM concentration was working well. The validation result also proved that B7/B2 region belongs to the higher concentration of total suspended matter. The developed regional algorithm will help monitor TSM concentration in the study area.

REFERENCES

- Avinash K, Jena B, Vinaya M, Jayappa K, Narayana and Bhat HG 2012. Regionally tuned algorithm to study the seasonal variation of suspended sediment concentration using IRS-P4 Ocean Colour Monitor data. *The Egyptian Journal of Remote Sensing and Space Science* **15**(1): 67-81.
- Bhaskaran PK, Mangalagiri S and Bonthu S 2014. Dredging Maintenance Plan for the Kolkata Port, India. *Current Science* **107**: 1125-1136.
- Dörnhöfer K, Göritz A, Gege P, Pflug B and Oppelt N 2016. Water constituents and water depth retrieval from Sentinel-2A-A first evaluation in an oligotrophic lake. *Remote Sensing* **8**(11): 941.
- Gernez P, Lafon V, Lerouxel A, Curti C, Lubac B, Cerisie S and Barillé L 2015. Toward Sentinel-2 high resolution remote sensing of suspended particulate matter in very turbid waters: SPOT4 (Take5) Experiment in the Loire and Gironde Estuaries. *Remote Sensing* **7**(8): 9507-9528.
- Keukelaere LD, Sterckx S, Adriaensen S, Knaeps E, Reusen I, Giardino C and Vaiciute D 2018. Atmospheric correction of Landsat-8/OLI and Sentinel-2/MSI data using iCOR algorithm: validation for coastal and inland waters. *European Journal of Remote Sensing* **51**(1): 525-542.
- Kutser T, Paavel B, Verpoorter C, Ligi M, Soomets T, Toming K and Casal G 2016. Remote sensing of black lakes and using 810 nm reflectance peak for retrieving water quality parameters of optically complex waters. *Remote Sensing* **8**(6): 497.
- Liu H, Li Q, Shi T, Hu S, Wu G, Zhou Q 2017. Application of Sentinel 2 MSI Images to Retrieve Suspended Particulate Matter Concentrations in Poyang Lake. *Remote Sensing* **9**: 761.
- Malenovsky Z, Rott H, Cihlar J, Schaepman M E, García Santos G, Fernandes R and Berger M 2012. Sentinels for science: Potential of Sentinel-1, -2, and -3 missions for scientific observations of ocean, cryosphere, and land. *Remote Sensing of Environment* **120**: 91-101.
- Manzo C, Bresciani M, Giardino C, Braga F and Bassani C 2015. Sensitivity analysis of a bio-optical model for Italian lakes focused on Landsat-8, Sentinel-2 and Sentinel-3. *European Journal of Remote Sensing* **48**(1): 17-32.
- Merina RN 2017. Evaluation of sediment using GIS approach in southern Tamilnadu, India. *Indian Journal of Ecology* **44**: 179-184.
- Minu P, Lotliker AA, Shaju S, Ashraf PM, Kumar TS and Meenakumari B 2016. Performance of operational satellite bio-optical algorithms in different water types in the southeastern Arabian Sea. *Oceanologia* **58**(4): 317-326.
- Pitchaikani JS, Ramakrishna R, Bhaskaran PK, Ilangovan D and Rajawat AS 2019. Development of regional algorithm to estimate suspended sediment concentration (SSC) based on the remotely sensed reflectance and field observations for the hooghly estuary and West Bengal coastal waters. *Journal of the Indian Society of Remote Sensing* **47**(1): 177-183.
- Pradhan Y, Thomaskutty AV, Rajawat AS and Nayak S 2005. Improved regional algorithm to retrieve total suspended particulate matter using IRS-P4 ocean colour monitor data. *Journal of Optics A: Pure and Applied Optics* **7**(7): 343-349
- Prasad AK and Singh RP 2010. Chlorophyll, calcite and suspended sediment concentrations in the Bay of Bengal and the Arabian Sea at the river mouths. *Advances in Space Research* **45**(1): 61-69.
- Ramakrishnan D, Bharti R and Das M 2013. A technique for estimation of suspended sediment concentration in very high turbid coastal waters: An investigation from Gulf of Cambay, India. *Marine Geology* **346**: 256-261.
- Saraswathy R and Pandian PK 2018. Estimation and mapping chlorophyll-a concentration in Pulicat Lagoon, South India Using Sentinel 2AR. *Indian Journal of Ecology* **45**(3): 533-537.

Siswanto E, Tang J, Yamaguchi H, Ahn YH, Ishizaka J, Yoo S and Kawamura H 2011. Empirical ocean-color algorithms to retrieve chlorophyll-a, total suspended matter, and colored dissolved organic matter absorption coefficient in the Yellow and East China Seas. *Journal of Oceanography* **67**(5): 627-650.

Sravanthi N, Ramana I, Yunus Ali P, Ashraf M, Ali M and Narayana A 2013. An algorithm for estimating suspended sediment

concentrations in the coastal waters of india using remotely sensed reflectance and its application to coastal environments. *International Journal of Environmental Research* **7**(4): 841-850.

Strickland JDH, Parsons TR and Strickland JDH 1972. *A Practical Handbook of Seawater Analysis*. Ottawa: Fisheries Research Board of Canada.

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Biological Degradation of Complex Crude Oil Refinery Waste Sludge by Consortia of Bacteria during Tailored Composting

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Abstract: This study aimed at biologically degrading complex crude oil refinery waste sludge by using a consortium of bacteria in a tailored composting process. All experimental process was incubated for 10 months at room temperature. The results revealed that microbial growth and activities were enhanced as indicated by an increase in temperature, moisture level, pH value, and respiration rate in all the compost pile. Polymerase chain reaction with specific universal primers was used for identification, and other molecular techniques were employed for the characterization of bacteria that utilized PAHs. The sequenced amplicons were identified as *Bacillus*, *Microbacterium hominis*, *Rhodococcus*, *Brevibacterium frigoritolerans*, *Enterococcus mundtii*, *Sanguibacter soli*, *Gordonia*, *Burkholderia*, *Pseudomonas*, *Clostridium sordellii*, *Cellulosimicrobium funkei*, *Sphingomonas*, *Micrococcus aloeverae*, *Ochrobactrum*, *Sporosarcina*, *Dietzia*, *Streptomyces*, *Bhargavaea*, *Arthrobacter* and *Staphylococcus* species. Automated Soxhlet extractor with Dichloromethane and gas chromatography/mass spectrometry was used to quantitatively determine the PAH reduction. Results showed a reduction between 36.52 and 99.98%. Tailored co-composting with animal manures was positive in degrading PAHs present in complex crude oil waste sludge.

Keywords: Animal manures, Bacteria spp., Bioremediation, Co-composting, Crude oil refinery sludge, PAHs

Crude oil is an essential natural mineral resource and when refined; its products are highly depended on for everyday life and activities. As the demand for crude oil and its refined products increases, the waste product increases. This waste is a thick, viscous mixture of sediments, water, oil, and high hydrocarbon concentration known as crude oil waste sludge. It is a contaminant encountered during crude oil refining, cleaning of oil storage vessels, and waste treatment (Liu et al 2010, Islam 2015, Jiao et al 2017). This contaminant enters the environment because of human activities, and it causes lethal and sub-lethal toxic effects to the environment (Hassanshahian et al 2012, Ibut and Bajhaiya 2013, Liu et al 2014, Winqvist et al 2014, Ohanmu et al 2019). Crude oil sludge and its components are cytotoxic, mutagenic, and potentially carcinogenic, this calls for human concern (IARC 2007, Bayoumi 2009, Kumar et al 2011, Ibut and Bajhaiya 2013, Ferradji et al 2014, Zaki et al 2014). Besides, it is highly recalcitrant under normal conditions. Such characteristics are attributed to their strong molecular bonds, high molecular weights, hydrophobicity, and relatively low solubility in water (Ibut and Bajhaiya 2013).

Different techniques in many studies have been used to remediate crude oil sludge and other hydrophobic organic compounds contaminated soil and groundwater (Srinivasarao-Naik et al 2011, Udotong et al 2011, Ferradji et al 2014). However, these attempts have not been conclusive; as each technique has its challenges such as expensive

equipment and high-energy requirements, generation of toxic by-products that may need further treatment, and lack of available land space for landfill disposal (Liu et al 2010, Das and Chandran 2011). Among all the methods used previously, biological techniques, which is the use of microorganisms for the degradation of contaminants, stands out as the most environmentally friendly option (Das and Chandran 2011, Chemlal et al 2012, Ibut and Bajhaiya 2013). This is because indigenous microbes involved in biological degradation adapt and subsequently synthesize enzymes that degrade these contaminants into simpler, lower molecular chains and less toxic compounds (fatty acids, CO₂, and H₂O) (Das and Chandran 2011, Hassanshahian et al 2012, Ferradji et al 2014, Liu et al 2014, Winqvist et al 2014). Hence, biological techniques such as composting have greater advantages over others as a scientifically intense procedure tailored to specific site conditions. It is a technique that relies on activities of diverse and adapted successive microbial populations combining the action of both mesophilic and thermophilic organisms, carefully controlled parameters, a mixture of nutrients and rich organic materials to improve bioremediation of contaminants (De-qing et al 2007, Jain et al 2011, Dadrasnia et al 2013, Garcia et al 2013). In composting, the microbial activities generate high temperatures, which increase the solubility of contaminants and induces microbial co-metabolic activity (Sheetal 2012). Furthermore, as the

compost matures, the pollutants are degraded, digested, metabolized, and transformed into humus as well as inert products by the active microorganisms within the compost mixture (Wang et al 2011, Garcia et al 2013, Singh and Chandra 2014, Vanishree et al 2014). These features and more have made composting interesting and to stand out as an advantage among other biological methods in treating contaminants. Besides, composting could be an *ex-situ* or *in situ* process and if compared to other methods, the use of composted material and co-composting as a bioremediation technique may promote soil sustainability and re-use. This study was designed to biologically degrade complex crude oil refinery waste sludge by a consortium of bacteria in a tailored composting process.

MATERIAL AND METHODS

Co-composting experimental procedures: Garden soil was homogenized, air-dried, and analyzed to determine the soil type, organic carbon content, total nitrogen content, total phosphorus content (C: N: P), soil pH, and water holding capacity (WHC). Crude oil waste sludge was collected from an oil refinery company in Durban, KwaZulu-Natal, South Africa, and its composition was characterized using an automated Soxhlet extractor with Dichloromethane and gas chromatography/mass spectrometry (GC/MS) (Haleyur et al 2016). The typical PAH composition of the crude oil waste sludge used in this study included: 98.2 mg kg⁻¹ naphthalene; 6.0 mg kg⁻¹ acenaphthylene; 9.2 mg kg⁻¹ acenaphthene; 27.5 mg kg⁻¹ fluorene; 14.9 mg kg⁻¹ phenanthrene; 41.6 mg kg⁻¹ anthracene; 2.4 mg kg⁻¹ fluoranthene; 14.1 mg kg⁻¹ pyrene; 4.1 mg kg⁻¹ benzo[a]anthracene; 54.8 mg kg⁻¹ chrysene; 23.7 mg kg⁻¹ benzo[b]fluoranthene; 2.6 mg kg⁻¹ benzo[k]fluoranthene; 10.0 mg kg⁻¹ benzo[a]pyrene; 5.1 mg kg⁻¹ perylene; 10.1 mg kg⁻¹ indeno(1,2,3-cd)pyrene; 11.6 mg kg⁻¹ dibenzo[a,h]anthracene; 9.4 mg kg⁻¹ benzo[ghi]perylene; and 3.9 mg kg⁻¹ benzo[e]acephenathrylene. Cow, horse, pig, and poultry manures were collected from the University of Pretoria farm, Onderstepoort, Pretoria, South Africa. These manures were characterized for total organic carbon, nitrogen, phosphorus content (C: N: P). Metals in crude oil waste sludge and soil samples were quantified using PerkinElmer Optima 5300 DV inductively coupled plasma optical emission spectroscopy, ICP-OES (PerkinElmer Inc., Massachusetts, USA) after aqua regia (1/3 HNO₃-HCl, v/v) digestion as described by Sibanda et al (2019). The composition of the manure and soil used in these experiments are summarized in Tables 1 and 2 below. The bulking agent used to enhance aeration was wood-chips of 8-10cm x 0.3-0.5cm. Tetrachloromethane (CCl₄, 99.55%, molar mass 153.8236 g mol⁻¹, density 1.594 g ml⁻¹ at 20°C) was

purchased from Merck South Africa and used to dissolve the oil sludge before mixing with soil.

Then, in each composting pile, 300 g of crude oil sludge was dissolved in 400 ml of (CCl₄). Each mixture was added to 1 kg of soil, homogenized, and air-dried at room temperature to evaporate excess CCl₄. Wood chips were mixed with each amended soil in a ratio of 1:2 (w:v) soil: wood chips. The mixture of about 2.34 kg each was separately mixed with about 1.17 kg of either pig, cow, horse, or poultry manures in a ratio of 2:1(w:w). Then a portion was used as the control with no manure added. All treatments including the control were incubated in triangular PVC troughs measuring 22cm (length) x 9.2cm (Depth) x 20cm (width) with perforated holes on the lids for aeration at room temperature for 10 months. All treatments were replicated three times. Parameters such as temperature changes, moisture content, pH level, carbon dioxide evolution were measured which was used to monitor microbial growth and activities. The ash content of the compost mixture was determined at the initial stage and the end of the composting experiment. Then, bacteria capable of degrading complex crude oil waste sludge present in compost piles were isolated and characterized using molecular methods.

Culture Dependent Microbiological Analyses

Isolation of crude oil sludge degrading bacteria:

Enrichment cultures were prepared in mineral salts medium (MSM) containing in mg l⁻¹; 500 mg KH₂PO₄, 500 mg MgSO₄·7H₂O, 500 mg NaH₂PO₄·H₂O, 500 mg NH₄Cl, 4000 mg NaCl, 500 mg NaHCO₃ and 500 mg Na₂CO₃ were prepared and dispensed into 250 ml Erlenmeyer flasks. Trace elements solutions contained in mg l⁻¹ distilled water 1500 mg FeCl₂·H₂O, 9000 mg NaCl, 197 mg MnCl₂·4H₂O, 900 mg CaCl₂, 238 mg CoCl₂·H₂O, 17 mg CuCl₂·H₂O, 287 mg ZnSO₄, 50 mg AlCl₃, 62 mg H₃BO₃, 24 mg NiCl₂·6H₂O, 10 ml 10.18 M HCl (32%) were prepared and filter-sterilised through 0.2 µm Millipore filter membrane and 1 ml each was added to the MSM in the flasks. All solutions were dispensed under aseptic conditions. Fifteen grams (15g) of a composite mixture of each compost samples were added in 250 ml Erlenmeyer flasks containing 100 ml sterile MSM spiked with 10 ml oil sludge as source carbon and energy. Control experiments like the one described above, but without oil sludge were set up. The flasks were stoppered with aluminum foil wrapped cotton wool bungs and incubated in the dark at 28°C on a rotary shaker at 150 rpm for 21 days. All experiments were set up in triplicates. One milliliter (1ml) of the culture was aseptically sub-cultured into another 250 ml flasks containing 100 ml sterile MSM spiked with 10 ml of oil sludge and incubated for another 21 days at 28°C in a rotary shaker in the dark. At the end of each incubation period,

samples were taken from each flask to determine the concentrations of selected PAHs using gas chromatography/mass spectrometry (GC/MS). Oil-degrading bacteria were isolated from the enrichment cultures by serial dilution (10^{-6}). A 0.1 ml aliquot of each diluent from the 10^{-6} to 10^{-8} dilutions were inoculated on the mineral salts agar (MSA) plates. The plates were incubated for 21-28 days at 28°C and checked daily for bacteria growth before they become overcrowded. Distinct colonies were purified on nutrient agar plates by streaking to obtain single colonies and the single colonies were inoculated into 10 ml nutrient broth mixture and incubated for three days at 28°C. These methods were adapted from Mashreghi and Marialigeti (2005) and amended to suit the present study.

Molecular characterization of isolates: DNA extraction was conducted using the cetyltrimethylammonium bromide method (CTAB). The pure cultures from the nutrient broth were vortexed and about 1.5 ml was transferred into 2 ml Eppendorf tubes and centrifuged with a microcentrifuge (Eppendorf Mini spin plus, 12 x 1.5/2.0 ml) at 14000 rpm for 5 min. The pellets were recovered which were then resuspended in a solution containing 567 µl of tris ethylene diamine tetraacetic acid buffer (Tris EDTA or TE buffer), 30 µl of 10% sodium dodecyl sulfate (SDS), 3 µl of proteinase K (20 mg ml^{-1}) and incubated at 65°C for 1h. Then 180µl of 5 M NaCl and 80 µl of 10% CTAB solutions were added to the mixture and incubated for 10 min at 65°C. Equal volumes (400 µl) of phenol and chloroform were added to each tube and centrifuged at 14000 rpm for 15 min and then the DNA was precipitated by adding 0.6 ml cold isopropanol to 300 µl of the supernatant in each tube. The precipitate was centrifuged at 14000 rpm for 15 min and DNA pellets were washed with 200 µl of 70% ethanol by spinning at 14000 rpm for 10 min. The supernatant was discarded, and the DNA pellets were air-dried. About 100µl of TE buffer was added to the dried DNA pellets, followed by 1 µl of RNAase and was incubated at 37°C for 60 mins, respectively.

Polymerase chain reaction (PCR) and sequencing: One Taq Quick-load 2X master mix with standard buffer aliquot for the PCR was dispensed into individual PCR tubes and different template DNA samples were added to each tube. The negative control was used to check for contamination in the master mix. The PCR reagents in each tube amounted to 25 µl containing: The convenient quick-load master mix formulation, which contains dNTPs, MgCl₂, buffer components, and stabilizers as well as two commonly used tracking dyes for DNA gels. On a 1% agarose gel in 1X TBE or 1X TAE, Xylene Cyanol FF migrates at ~4 kb and Tartrazine migrates at ~10 bp. Both dyes are present in concentrations that do not mask comigrating DNA bands. To each tube, one

Taq Quick-load 2X master mix with standard buffer was added (12.5 µl), 16S universal primers (primer1 0.5 µl forward 27F (5'–3': AGA GTT TGA TCC TGG CTC AG), and primer2 0.5 µl reverse 1492R (5'–3': ACG GCT ACC TTG TTA CGA CTT), sterile sabax water (9.5µl) and DNA samples (2 µl). The PCR reactions were performed using MJ Mini thermal cycler (Bio-Rad, Hercules, CA, USA) as follows: 1 cycle at 95°C for 10 s, followed by 34 cycles at 95°C for one second, 53°C for 1 min and 72°C for 15 s. A final extension step at 72°C for 1 min was performed for 1 cycle. The reaction was held at 4 °C until the amplicons were removed from the thermal cycler. The PCR products (20 µl each) were later cleaned up using 160 µl of 13% polyethylene glycol (PEG) 8000, 20 µl of 5 M NaCl solution, and 200 µl of 70% ethanol. The amplicons were then assessed by running 1% agarose gel electrophoresis and viewed in the Gel Doc imager (Bio-Rad). Cleaned PCR products were sent to Inqaba Biotechnological Industries and were sequenced using 16S universal primers (907R (5'–3': CCGTCAATTC MTTTRAGTTT). The sequences of the 16S rRNA region obtained were edited using BioEdit software. Edited sequences were copied in a FASTA format for blasting on National Centre for Biotechnology Information (NCBI) website. Phylogenetic analyses of bacterial sequences from each treatment, control, cow, horse, pig, and poultry were aligned differently using the online version of MAFFT software. The phylogenetic analyses were done using Mega 4 software and the evolutionary distance of the isolates was computed using neighbor-joining (NJ) methods as reported in earlier publications (Ubani et al 2016). The bootstrap consensus tree was inferred from 1000 replicates and all positions containing gaps as well as missing nucleotide data were eliminated from the dataset. *Vibrio cholerae* was used as the out-group.

Screening of bacterial isolates for crude oil sludge degradability: The screening of bacterial capability to grow and utilize crude oil sludge was done by inoculating isolates on mineral salts agar plates overlaid with 1.5% crude oil sludge; incubated at 30°C for 3-7 days (Liu et al 2014). Distinct colonies were purified by streaking and were stored in tubes containing nutrient broth at 4°C for further screening and characterization.

Screening with 2,6-dichlorophenol indophenol: Stored bacteria cultures were screened further by inoculating isolates into test tubes containing Luria-Bertani broth and incubated for 24hr at 37°C at 180 rpm. After 24 h, a mixture of 0.5% (w/v) 2,6-dichlorophenol indophenol (2,6-DCPIP), 0.1% Tween 80 and 3% (v/v) crude oil sludge was introduced into the tubes. The treatment was incubated for 7 days at 28°C under rotatory conditions and monitored daily for a

colour change from blue (oxidized) to colourless (reduced) indicating that crude oil sludge present was utilized by bacteria making them good bioremediation agents. The control treatment was prepared without inoculum (Ahirwar and Dehariya 2013, Obi et al 2016). After the colour change at the end of 7days, then the liquid medium was filtered separating the biomass. The filtrate was centrifuged at 8 000 x g for 15 min and the supernatant was collected and analyzed using 600nm ultraviolet-visible (UV-VIS) spectrophotometer (Thermo Scientific, GENESYS 10S U-VIS Spectrophotometer). Percentage utilization of PAHs present in crude oil sludge by bacteria isolates was calculated by:

$$\text{Percentage degradation} = 1 - \frac{\text{Absorbance of treated sample}}{\text{Absorbance of control}} \times 100$$

Residual PAH Analysis: The extraction of PAHs from compost samples was performed using an automated Soxhlet extractor an EPA method 3541 (Haleyur et al 2016). The stock standard was restek cat No 8270-1, which contains a semivolatile mix, purchased from Sigma Aldrich, South Africa. The concentration of the stock standard was 1000ppm (mg l^{-1}), used to prepare the calibration standards of 10, 30, and 50ppm. The working standard solution was prepared from the surrogate standard using dichloromethane. Calculation of the required concentrations was based on the chemical formula: Equation: $1 = C_1V_1 = C_2V_2$
Where C_1 = Concentration of stock solution, C_2 = Concentration to be made, V_1 = Volume to be determined, V_2 = Volume required.

The analysis of the semivolatile compounds (PAHs) present in the sample extracts was quantified by GC/MS using US EPA 8270 (Weavers et al 2006, Smith and Lynam 2009, Bobak 2010). The GC/MS was Agilent 7860GC system and 5975C MSD, equipped with a 7683B autosampler. The sampler syringe was 5.0 μl and the splitless injection was 1.0 μl . The carrier gas used was helium 30 cm s^{-1} and at a constant flow rate of 1 ml min^{-1} . The inlet, split less, 260°C, purge flow was 50 ml min^{-1} at 0.5 min and the gas saver was at 80 ml min^{-1} at 3 min. The inlet liner was the deactivated dual taper direct connection. The column was Agilent HP-5 ms ultra-inert 30 m x 0.25 mm x 0.25 μm film thickness. The oven program was started at 40°C for 1minute to 100°C (15°C/min), 10°C/min to 210°C (1 min), 5°C/min to 310°C, and it was held for 8 min. The detection was MSD source at 300°C, quadrupole at 180°C, transfer line at 290°C, scan range 45 to 450 amu. PAHs were identified by retention times matching to standards concentration. The value of the chromatogram was quantified using peak area integration. All reagents used were analytical grade and were used without further purifications.

RESULTS AND DISCUSSION

The characteristics of the garden soil used and the C: N: P ratios of the animal manures used in this study (Table 1 and 2). The soil sample was sandy loam and contains some trace elements as shown by its characteristics, nutrients necessary to support plant growth, and a good microbial population (Mann 2008). The animal manures were rich in C: N: P and their ratios were in substantial amounts, which were necessary to stimulate microbial growth, and activities in the compost pile (Table 2).

Residual PAH Analysis after composting: The characteristics of the crude oil sludge before composting showed 18 PAHs of both low and high molecular weight hydrocarbons were present in substantial quantities with a few metals such as Zn (8.33 mg kg^{-1}), Fe (46.35 mg kg^{-1}), and Mg (22.37 mg kg^{-1}). However, many components of crude oil sludge were not detected because they were below the detection limits ($<0.01 \text{ mg kg}^{-1}$) by the GC/MS used. All initial concentrations of PAH were calculated considering the dilution factors. The hazardous PAHs components are a family of compounds that have the potential to cause cancer (Bayoumi 2009, Kumar et al 2011, Shaoping and Laishi 2011, Ibuot and Bajhaiya 2013, Ferradji et al 2014, Zaki et al 2014). These PAHs do not act directly as carcinogens but react in

Table 1. Characteristics of garden soil used for the experiment

Soil parameter	Characteristics [Conc]
Sand [% wt]	61.3
Silt [% wt]	21.3
Clay [% wt]	9.3
Texture	sandy loam
pH (H_2O)	5.56
Total organic carbon in % [mg kg^{-1}]	13.01
Total organic N % [mg kg^{-1}]	3.94
Total P [mg kg^{-1}]	4.4
Cr [mg kg^{-1}]	121.7
Pb [mg kg^{-1}]	31.91
Ni [mg kg^{-1}]	10.13
Cu [mg kg^{-1}]	38.08
Zn [mg kg^{-1}]	9.65
Mn [mg kg^{-1}]	92.38
Fe [mg kg^{-1}]	67.04
Co [mg kg^{-1}]	2.45
Mg [mg kg^{-1}]	22.37
Dry matter content [% DM]	90.48
Moisture content [% MC]	9.52
Water holding capacity [% WHC]	32.62

the body together to form PAH epoxides that are active carcinogenic agents (CONCAWE 2005, IARC 2007, Bayoumi 2009).

After the composting period, the results obtained from

Table 2. Characteristics of animal manures used for the experiment

Animal manures	Total organic C % [mg kg ⁻¹]	Total organic N % [mg kg ⁻¹]	Total organic P % [mg kg ⁻¹]
Poultry	277±63	49.2±14.2	254±14
Cow	109±8	54.9±5.9	46±8
Horse	81±3	52.7±2.7	50±2
Pig	904±84	50.6±5.9	252±29

the GC/MS analysis showed that the reduction in the selected PAHs ranged between 36.52 and 99.98% for ten months incubation (Table 3). It was not easy to establish whether the LMW compounds were reduced faster or slower because of the large variation in the initial concentrations as some HMW compounds were depleted faster than the LMW. However, the HMW compounds were degrading more slowly compared to the LMW ones, like when the Naphthalene is compared to compounds like Dibenzo (a, h) anthracene and Benzo (ghi) perylene mostly in cow and poultry amended co-compost. The current results indicate of the effects of the type of composting approach used in this experiment. The crude oil sludge can be treated with tailored composting to

Table 3. Average final reduction of selected PAHs in poultry (PM), horse (HM), cow (CM), pig (SM), and Control (CT) compost piles after 300 days (Mean ± standard error)

Selected PAHs [§]	Initial Conc. (mg kg ⁻¹)	Residual concentration (mg kg ⁻¹) [†]				
		PM	HM	CM	SM	CT
Naphthalene (2)	98±6.2	0.07±0.02 (99.9)	0.04±0.01 (99.9)	0.03±0.00 (99.9)	0.06±0.01 (99.9)	2.91±0.10 (97.0)
Acenaphthylene (3)	6.0±0.8	0.37±0.06 (93.8)	0.24±0.06 (96.0)	0.49±0.07 (91.9)	0.23±0.09 (96.2)	0.96±0.08 (84.0)
Acenaphthene (3)	9.2±1.2	0.25±0.05 (97.3)	0.01±0.00 (99.9)	0.07±0.01 (99.2)	0.01±0.00 (99.9)	1.21±0.31 (86.8)
Fluorene (3)	27±3.1	0.91±0.07 (96.7)	0.01±0.00 (99.9)	0.11±0.04 (99.6)	0.01±0.00 (99.9)	4.39±0.91 (84.0)
Anthracene (3)	42±4.6	0.19±0.00 (99.5)	0.01±0.00 (99.9)	0.25±0.07 (99.4)	0.01±0.01 (99.9)	1.11±0.07 (97.3)
Phenanthrene (3)	15±2.1	3.55±0.42 (76.1)	0.09±0.03 (99.4)	0.17±0.03 (98.9)	0.06±0.02 (99.6)	4.44±1.21 (70.2)
Fluoranthene (4)	2.4±0.6	0.26±0.08 (89.1)	0.18±0.05 (92.4)	0.47±0.06 (80.3)	0.15±0.06 (93.7)	0.94±0.05 (60.5)
Pyrene (4)	14±1.1	0.96±0.00 (93.2)	0.77±0.09 (94.5)	2.97±0.43 (78.9)	0.29±0.03 (97.9)	3.23±0.81 (77.0)
Chrysene (4)	55±4.2	1.46±0.16 (97.3)	1.19±0.21 (97.8)	2.31±0.32 (95.8)	0.64±0.12 (98.8)	10.0±2.13 (81.7)
Benzo [a] anthracene (4)	4.1±1.2	1.15±0.03 (71.8)	1.05±0.01 (74.3)	2.59±0.61 (36.5)	0.82±0.10 (79.9)	2.64±0.57 (35.3)
Benzo [b] fluoranthene (5)	24±2.7	0.97±0.01 (95.9)	1.00±0.04 (95.8)	1.15±0.08 (95.1)	0.87±0.09 (96.3)	1.99±0.08 (91.6)
Benzo [k] fluoranthene (5)	2.6±0.3	1.07±0.08 (59.4)	0.98±0.03 (62.9)	0.81±0.03 (69.3)	1.27±0.31 (51.9)	1.27±0.21 (51.9)
Benzo[a]pyrene (5)	10.0±1.8	1.72±0.32 (82.7)	1.75±0.8 (82.4)	2.51±0.58 (74.8)	1.71±0.23 (82.8)	2.74±0.89 (72.5)
Perylene (5)	5.1±2.0	1.52±0.28 (69.9)	1.81±0.45 (64.2)	2.15±0.01 (57.4)	1.94±0.18 (61.6)	2.52±0.23 (50.1)
Indenol [1,2,3-cd] pyrene (6)	10±2.9	2.98±0.01 (70.6)	1.50±0.47 (85.2)	2.59±0.63 (74.4)	1.35±0.41 (86.7)	4.35±1.16 (57.1)
Dibenzo [a,h] anthracene (5)	12±1.9	6.97±0.45 (39.7)	2.92±0.33 (74.8)	5.22±0.92 (54.9)	2.12±0.18 (81.7)	6.97±1.56 (39.8)
Benzo [ghi] perylene (6)	9.4±1.1	5.63±0.79 (40.3)	2.58±0.00 (72.6)	5.11±0.73 (45.8)	2.10±0.78 (77.7)	5.63±1.07 (40.3)
Benzo [e] acephenanthrylene (5)	3.9±0.1	0.93±0.13 (75.9)	0.98±0.05 (74.6)	1.09±0.03 (71.8)	0.81±0.05 (79.0)	1.93±0.33 (50.0)

[§]The number of benzene rings in different PAHs is given in bracket

[†]Percent degradation of each PAH under different manure composting is provided in the bracket

achieve elevated levels of degradation of components of crude oil sludge.

Physicochemical parameters measured during composting:

There was an increase in temperatures in all the composts piles amended with manure except the control experiment, which contained no manure. Poultry manure amended compost pile showed a higher temperature than other manure-amended piles. This could be because of the high nitrogen content of the poultry manure, which may have stimulated microbial growth and activities. The initial decrease in temperature in cow manure maybe because the compost retained much water than other compost piles. During composting, the temperature of the compost fluctuated in all the experiments indicating enhanced microbial activities, with cow manure compost showing the lowest temperature (Fig. 1), the temperature in the control experiment remained low between 22 and 23°C during the treatment period due to relatively low microbial activity, possibly because of lower nutrient and low organic matter content compared to the ones with manure amendments. The increase in temperature was anticipated to positively affect the biodegradation of hydrocarbons within the compost mixtures, as high temperatures affect the solubility of the organic compounds and enhance their bioavailability and biodegradability. The moisture levels in these experiments were observed to be relatively stable at about 50% from the first month of incubation to the eighth month. This is because the experiments were covered with sparsely perforated plastic lids to retain moisture and moisture contents of between 50 and 80% enhance biodegradation of organic contaminants in soil. The moisture levels in the control experiments were stable at about 44% within the same period (Fig. 2). Microbial growth and activities are normally maintained at their optimum at these moisture levels and degradation of the target contaminants is enhanced. Therefore, moisture is necessary not only to meet the physiological requirements of microorganisms. It is also needed for the transportation of nutrients, metabolic by-products within and outside the microorganisms, and for their activities. This enhanced the reduction in the concentration of the hydrocarbon contaminants. The pH in poultry, cow, pig, horse, and control experiments increased, respectively. There was a sharp pH decrease after the fifth month in all treatment, then a slight increase was observed in the control, cow, and horse compost pile. The poultry compost pile had a sharp increase while the pig decreased in the seventh month. It eventually became stable with little fluctuation during the remaining composting period (Fig. 3).

Biodegradation of organic contaminants is faster at neutral or near-neutral pH level (6.9 or 7) and is more

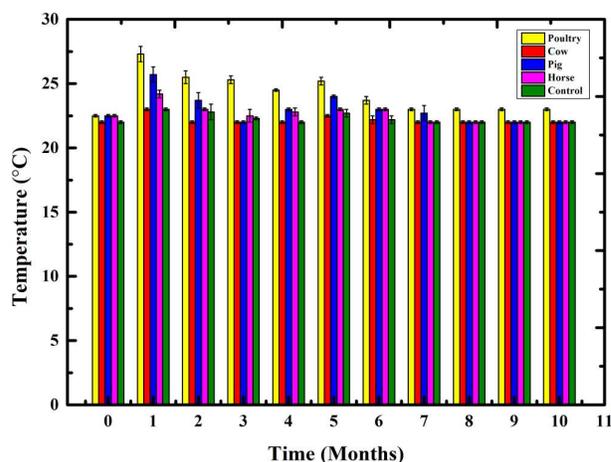


Fig. 1. Temperature of the composts during the incubation of the compost piles (Mean \pm standard error)

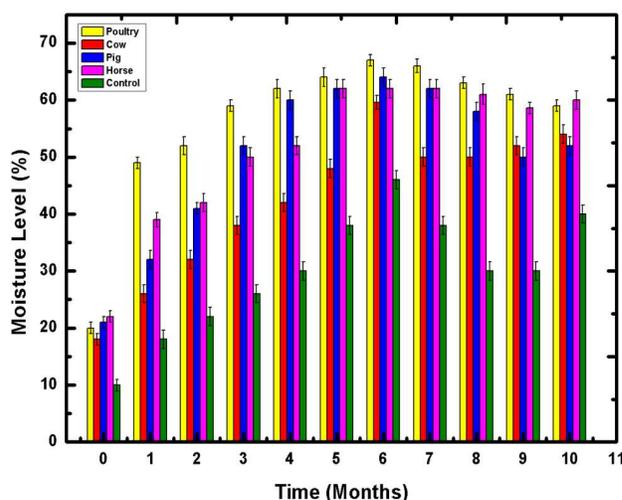


Fig. 2. Moisture level of the composts during the incubation of the co-composting of the contaminated soils (Mean \pm standard error)

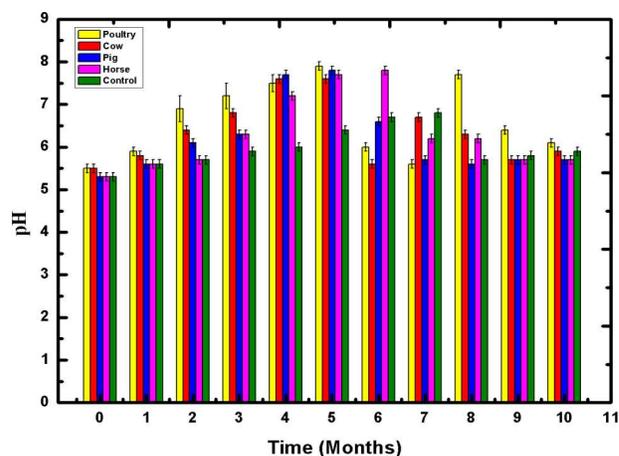


Fig. 3. pH of the composts during the period of incubation of the co-composting of the contaminated soil (Mean \pm standard error)

favorable to bacteria. The pH values in this study were within the recommended pH range for composting organic compounds. The increase in pH of the compost pile may be a result of the high content of ammonia from the manure. The decrease observed after the fifth month maybe because of the degradation of compost materials and petroleum hydrocarbon. Besides, the decrease maybe because of the release of intermediates and other products that have a low pH effect on the compost mixture according to Lee et al (2007). Ash content of the compost mixture showed that there was no significant difference from the initial soil-compost mixture and that at the end of the composting period (Table 4). Therefore, there were no significant changes in the mineral components of the soil at the end of the composting period. This further agrees that the composting process does not alter the soil components after treatment.

The respiration rate increased in the first six months of composting in all the experiments while the control experiments were stable from the fourth month. The increase observed in the respiration experiment showed an increase in microbial activities in the compost pile mixture (Fig. 4). This may be due to the utilization of substrates by microorganisms (nutrients and hydrocarbons) in the compost mixture. Carbon dioxide emission increased as the treatment proceeds and compost piles turned for aeration. This is the effect of oxygen consumption on the growth and activities of the degrading microorganisms. The respiration rate of the soil microorganism decreased slightly in the fourth month as the horse and control compost pile were stable during this period. This indicates the reduction in the microbial population by a succession of mesophilic to thermophilic and availability of the target contaminants in the compost piles system. This also indicates that co-metabolic activities of the microorganisms have contributed to enhancing the reduction of the concentration of hydrocarbon contents of crude oil sludge in the compost pile mixture. The control set up which had no manures showed an increase in the respiration experiment. This may also be due to bacteria growth and activities observed in the control compost pile because bacteria capable of degrading PAHs were present and isolated from the control compost pile. The decrease in the respiration rate observed towards the end of the treatment process may be due to the decrease in carbon from the crude oil-sludge components. Lack of carbon in the compost system may have reduced the population of the degrading microorganisms present in the compost pile mixture. This is possible because carbon is the source of energy. Respiration experiments have been used to study/monitor the aerobic biodegradation of contaminants in contaminated soils. In this study, soil respiration experiments were helpful to quantify

the effects of the nutrients and microorganisms from animal manures as well as those from the soil in the bioremediation of crude oil sludge. Nutrients encouraged microbial growth and enhanced the utilization of hydrocarbons in the compost pile. The results obtained from the characterized garden soil sample used in this experiment showed that trace elements were present in the soil sample. The trace elements included copper, zinc, iron, chromium, lead, nickel, manganese, cobalt, and magnesium. Many of these metallic elements play an essential role in the function of microorganisms. However, an excess of these essential trace metal elements and non-essential trace metal elements can be toxic to microorganisms. Besides, aeration by turning the compost piles at intervals enhanced microbial growth and activities. The increase in microbial activities was reflected as an increase in the respiration rate. The moisture level, pH, temperature, and carbon dioxide evolution results obtained in this study showed that microbial activities and breakdown of the organic hydrocarbons substrates present in the compost pile systems were enhanced.

Screening of bacterial isolates for oil sludge degradability: It was observed that between 21-28 days of

Table 4. Ash mass (g) initial stage and end-of-the composting period (10 months) (Mean \pm standard error)

Soil-compost mixture	Initial	End
Poultry	4.03 \pm 0.21	4.08 \pm 0.16
Cow	4.01 \pm 0.19	4.01 \pm 0.20
Pig	3.77 \pm 0.15	3.78 \pm 0.14
Horse	3.34 \pm 0.04	3.36 \pm 0.04
Control	4.04 \pm 0.33	4.07 \pm 0.32

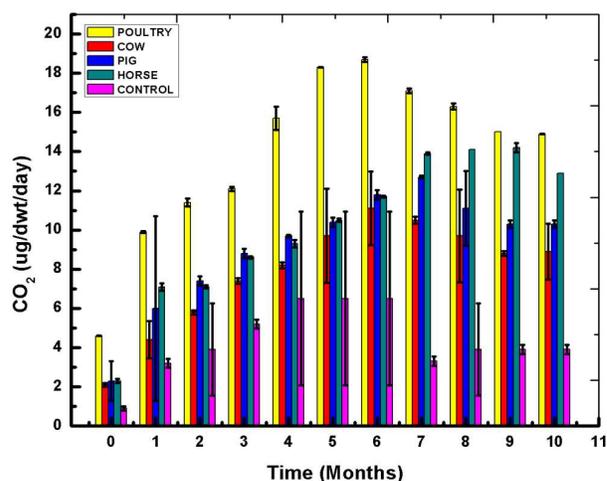


Fig. 4. Respiration rate of soil microorganisms in the composts during the incubation of the co-composting of the contaminated soils (Mean \pm standard error)

incubation all bacteria isolates were able to grow on mineral salt agar overlaid with crude oil sludge as the only source of carbon. For the 2,6-DCPIP screening, 23 of the 46 isolates showed a positive reaction to the redox indicator, identified as the best degrader because they were able to change the color of 2,6-DCPIP in the shortest possible time from blue (oxidized) to colourless (reduced) indicating that crude oil sludge present was utilized by bacteria making them good bioremediation agents. The bacteria isolates that showed positive results between 3-7 days with 2,6-dichlorophenol indophenol (2,6-DCPIP) screening test include *Bacillus thuringiensis* strain OS21, *Bacillus subtilis* strain CO41, *Rhodococcus equi* strain CO20, *Bacillus pumilus* strain CO102, *Staphylococcus succinus* subsp. strain Po45, *Paenibacillus* sp. strain CO15, *Clostridium sordelli* strain H3, *Bacillus atrophaeus* strain Pi1, *Pseudarthrobacter oxydans* strain Po341, *Sporosarcina* sp. strain Po35, *Sanguibacter* sp. strain Po47, *Streptomyces* sp. strain Po62, *Bhargavaea* sp. strain Po129, *Cellulosimicrobium funkei* strain H4a, *Sphingomonas* sp. strain H151, *Enterococcus mundtii* strain CT10, *Gordonia* sp. strain CT122, *Micrococcus aloeverae* strain MC10, *Lysinibacillus xylanilyticus* strain Po49a, *Arthrobacter* sp. strain Po1i, *Sanguibacter soli* strain CT121, *Burkholderia paludis*. strain CT22 and *Dietzia* sp. strain PO41. In this study culture medium (MSM) amended with

2,6-DCPIP and crude oil sludge was used to test the capability of isolated bacteria in utilizing crude oil sludge. The colour of the redox indicator 2,6-DCPIP changed from blue to colourless indicating that crude oil sludge present was utilized. The percentage utilization of crude oil sludge by these isolates ranged from 43.38 to 83.15%, indicating their potential to metabolize hydrocarbon present in the medium. *Sphingomonas* sp. strain H151 showed 83.15% which had the highest capability to utilize crude oil sludge, followed by *Bacillus thuringiensis* 81.19%, and the least was *Enterococcus Mundtii* strain CT10 43.38% (Fig. 5). The bacteria species identified and tested have been reported to have the potential to degrade petroleum wastes and other toxic organic solvents (Katsivela et al 2005, Zhang et al 2005, Veeranagouda et al 2006, Rajaei et al 2013, Santisi et al 2015).

These results obtained from the compost piles have shown that composting can be used to degrade PAHs present in crude oil sludge (Ouyang et al 2005, Jose et al 2006, Meintanis et al 2006). Parameters measured in all compost piles attributed to the degradation of PAHs. The ability of isolates from the compost to degrade the target PAH was established in enrichment culture (Table 5) and supported by the degradability-screening test (Fig. 5). Furthermore, the identified bacteria were phylogenetically

Table 5. Reduction in concentrations of selected PAHs in enrichment culture (Mean \pm standard error)

Selected PAHs §	Initial Conc. (mg kg ⁻¹)	Enrichment culture (Residual concentration) (mg kg ⁻¹)†	Final subculture (Residual concentration) (mg kg ⁻¹)†
Naphthalene (2)	98 \pm 6.2	19.06 \pm 0.1 (80.59)	31.77 \pm 2.14(66.67)
Acenaphthylene (3)	6.0 \pm 0.8	41.16 \pm 1.2 (83.20)	51.38 \pm 1.92(75.04)
Acenaphthene (3)	9.2 \pm 1.2	39.14 \pm 0.99(82.62)	48.93 \pm 3.96(74.99)
Fluorene (3)	27 \pm 3.1	1.01 \pm 0.09 (83.20)	1.68 \pm 0.76 (66.73)
Anthracene (3)	42 \pm 4.6	1.59 \pm 0.64 (78.12)	2.65 \pm 1.67 (66.63)
Phenanthrene (3)	15 \pm 2.1	4.62 \pm .69 (84.61)	5.78 \pm 1.81 (74.99)
Fluoranthene (4)	2.4 \pm 0.6	9.09 \pm 0.18 (84.87)	13.48 \pm 2.53(66.67)
Pyrene (4)	14 \pm 1.1	0.29 \pm 0.14 (80.73)	0.48 \pm 0.16 (66.67)
Chrysene (4)	55 \pm 4.2	0.36 \pm 0.13 (83.67)	0.38 \pm 0.21 (73.61)
Benzo [a] anthracene (4)	4.1 \pm 1.2	2.71 \pm 1.06 (76.47)	3.61 \pm 1.4 (66.67)
Benzo [b] fluoranthene (5)	24 \pm 2.7	8.95 \pm 1.7 (81.69)	11.19 \pm 2.26(75.01)
Benzo [k] fluoranthene (5)	2.6 \pm 0.3	0.26 \pm 0.13 (83.71)	0.55 \pm 0.21 (61.81)
Benzo[a]pyrene (5)	10.0 \pm 1.8	4.33 \pm 1.28 (85.54)	7.20 \pm 1.94 (66.67)
Perylene (5)	5.1 \pm 2.0	0.43 \pm 0.14 (72.48)	0.72 \pm 0.29 (66.82)
Indenol [1,2,3-cd] pyrene (6)	10 \pm 2.9	1.44 \pm 0.46 (88.55)	1.81 \pm 0.9 (74.93)
Dibenzo [a,h] anthracene (5)	12 \pm 1.9	1.16 \pm 0.23 (76.92)	1.45 \pm 0.58 (74.91)
Benzo [ghi] perylene (6)	9.4 \pm 1.1	2.38 \pm 0.18 (74.76)	48.93 \pm 3.96(74.99)
Benzo[e]acephenanthrylene (5)	3.9 \pm 0.1	1.16 \pm 0.23 (73.83)	1.01 \pm 0.14 (73.83)

§The number of benzene rings in different PAHs is given in bracket.

† Percent degradation of each PAH under different manure composting is provided in the bracket

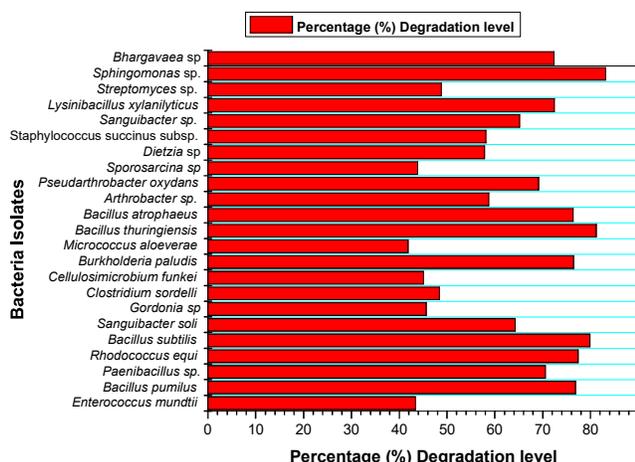


Fig. 5. Percentage degradation level revealed by testing the ability of bacteria isolates to change the colour of 2,6-DCPIP in the shortest possible time as they utilize PAHs present in crude oil sludge as the sole source of carbon

grouped into 3 phyla *Firmicutes*, *Proteobacteria*, and *Actinobacteria*. In compost piles amended with pig manure, the bacteria identified included the following genera, *Bacillus* spp., *Bacillus atrophaeus* strain BL2, *Bacillus* sp. IHB B 3571, *Bacillus* sp. strain IU32(12), *Bacillus fusiformis* strain LL 58, *Arthrobacter* spp., *Burkholderia paludis* strain MSh1, *Ochrobactrum* sp. LJJS1-2, *Lysinibacillus fusiformis* strain PP68, *Rhodococcus equi* strain Ushuaia, *Rhodococcus* sp. CHNTR32, *Rhodococcus* sp. *Microbacterium* sp. strain MPR-AND1B, and *Brevibacterium frigoritolerans*.

In compost pile amended with cow manure the bacteria identified include *Variovorax* spp., *Arthrobacter* spp., *Bacillus subtilis* strain ATF-4016S rRNA gene, *Bacillus Licheniformis* strain F1 16S rRNA gene, *Bacillus pumilus* EI-24-8, *Bacillus* sp. strain 39endo, *Bacillus safensis* strain S-I10, *Bacillus zhangzhouensis* strain APBSIITMB23, *Bacillus subtilis*, *Bacillus pumilus* strain c10, *Staphylococcus Succinus* strain SSY00116S RNA gene, *Staphylococcus* spp. and *Staphylococcus saprophyticus*, *Microbacterium hominis* strain DSM 12509, *Paenibacillus* sp. K619, *Rhodococcus equi* strain Ushuaia, *Brevibacterium frigoritolerans* strain. In compost pile amended with poultry manure, the bacteria, identified include *Paenibacillus* spp. *Bacillus* spp., *Bacillus Licheniformis* Isolate, *Bacillus* sp. YAS1, *Bacillus zhangzhouensis* strain LA023, *Bacillus pumilus* strain TCD56.5, *Bacillus fusiformis* strain LL 58, *Bacillus megaterium* strain CDK25, *Bacillus velezensis* strain, *Lysinibacillus fusiformis* strain Lr11/1, *Staphylococcus* sp. strain Firmi-16, *Staphylococcus succinus* subsp. *Succinus*, *Rhodococcus* sp. strain Actino-53, *Rhodococcus corynebacterioides* strain DSM 20151, *Burkholderia paludis*

strain MSh1, *Clostridium sordelli* strain MJJ0609-3-1, *Arthrobacter* sp. Cr2, *Pseudarthrobacter oxydans* strain LCX2, *Sporosarcina* sp. BYMS04, *Dietzia* sp. strain PRIM-49, *Sanguibacter* sp. M2T8B10, *Microbacterium* sp. JJD-1, *Streptomyces* sp. FZ42Bhargavaea sp. and *Brevibacterium frigoritolerans*. In compost pile amended with horse manure, the bacteria identified include *Bacillus circular* strain 3399BRRJ 16S rRNA gene, *Bacillus pumilus*, *Bacillus safensis* strain S-I10, *Rhodococcus equi* strain Ushuaia, *Pseudomonas* sp. SMB12, *Pseudomonas* sp. K2DN344, *Rhodococcus hoagii* strain DSSKP-R-001, *Pseudomonas stutzeri* strain WWvii23, *Clostridium sordelli* strain MJJ0609-3-1, *Cellulosimicrobium funkei* strain NPZ-121T, *Rhodococcus* sp. SH05-06, *Rhodococcus* sp. strain A23, *Rhodococcus* sp. Q5, *Microbacterium hominis* strain DSM 12509, *Bacillus pumilus* strain MK1, *Burkholderia cepacia* strain FC2980, *Burkholderia paludis* strain MSh1, *Sphingomonas* sp. VITPTHJ and *Arthrobacter globiformis*. In control experiment, the bacteria isolated include *Bacillus aryabhatai* strain 7L5 16S rRNA gene, *Bacillus thuringiensis*, *Staphylococcus* spp., *Paenibacillus lautus* strain 3566BRRJ16S rRNA gene, *Ralstonia* spp. *Enterococcus mundtii* strain Tni-9, *Sanguibacter soli* strain DCY22, *Gordonia* sp. strain N-6-2, *Rhodococcus* sp. strain A23, *Bacillus safensis* strain S-I10, *Microbacterium hominis* strain DSM 12509, *Burkholderia lata* strain 383, *Burkholderia cenocepacia* strain ESS9, *Gordonia amicalis* strain 6-1, *Sanguibacter soli* strain DCY22. and *Geobacillus* spp. These isolates have been allocated the accession numbers (JQ808080 – JQ808120 and MK854826 CO111- MK854993 CT92), which shows their close related genera from the GenBank. The distinct grouping of these organisms strongly supported the phylogenetic relationship between the organisms with high bootstrap. These isolates represent distinct groups that are closely related to form a coherent group in a synergistic relationship to degrade their target pollutants (Barnabas et al 2013). This implies that the animal manures were rich in nutrients necessary for basic microbial activities such as nitrogen, carbon, and phosphorus, which were in substantial amounts and are necessary to stimulate microbial growth and activities in the compost pile (Popenda and Włodarczyk-Makula 2015). There are other studies of hydrocarbon biodegradation experiments, mostly those of weathered contamination of crude oil, however, it should be noted that crude oil waste sludge is inhibitory to microbial growth and not amenable to biodegradation, particularly with the content of high molecular weight polycyclic aromatic hydrocarbons (HMW-PAHs). The current study is an indication of the effects of the type of composting approach used in this experiment, tailored co-composting piles of animal manure

and crude oil sludge. Thus, the study is unique and demonstrates that crude oil waste sludge can be treated with a tailored composting process to achieve elevated levels of degradation of components of crude oil waste sludge. Since it has been established that co-composting with animal manure enhanced crude oil waste sludge degradation and it is necessary to identify the diverse microbial composition in such tailored composting piles with such degrading capabilities.

CONCLUSION

The wide variety of bacteria identified are responsible for the degradation of the crude oil refinery sludge components in the compost piles. This was possible since these bacteria can adapt, grow, and survive in such compost systems, may potentially degrade the oil sludge components. The degradation of crude oil sludge components is done by bacteria consortia through the production of enzymes, biosurfactants, and using the hydrocarbons as a source of carbon and energy to survive. Furthermore, the biosurfactant produced by these bacteria is capable of enhancing the solubility of PAHs present in crude oil sludge co-compost media. As biosurfactants enhanced the solubility of PAHs, the biodegradation rate of petroleum hydrocarbons (PAHs) increased in the media. There was a 36.52 to 99.98% reduction of the PAHs. Biosurfactants can also increase the cell surface hydrophobicity of biosurfactant-producing strain which results in high uptake of PAHs. This also means that as the cell surface hydrophobicity increased, there was bioavailability of PAHs in the aqueous phase, which made it easier for microorganisms to degrade organic contaminants (PAHs). Thus 36.52 to 99.98% reduction of PAHs obtained in this study. Therefore, co-composting with animal manures may be suitable for practical field application for effective *in situ* and *ex-situ* bioremediation of complex crude oil refinery waste sludge. The co-composting process is an effective and controlled technology (with attributes such as nutrients, temperature, moisture, a large population of microbes) for the degradation of crude oil sludge. The composting process does not alter the soil components after treatment. At the end of the process, the residual products are not hazardous to the environment, which is one of the advantages of the composting process.

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REFERENCES

Ahirwar S and Dehariya K 2013. Isolation and characterization of

hydrocarbon-degrading microorganisms from petroleum oil contaminated soil sites. *Bulletin of Environmental and Scientific Research* **2**(4): 5-10.

Barnabas J, Saha S, Singh V and Das S 2013. Effect of enzymes extracts on bacterial degradation of garage petroleum oils. *Journal of Environmental Science, Computer Science and Engineering and Technology* **2**(2): 206-211.

Bautista LF, Sanz R, Molina MC, Gonzalez N and Sanchez D 2009. Effect of different-ionic surfactants on the biodegradation of PAHs by diverse aerobic bacteria. *International Biodeterioration and Biodegradation* **63**: 913-922.

Bayoumi RA 2009. Bacterial bioremediation of polycyclic aromatic hydrocarbon in heavy oil contaminated soil. *Journal of Applied Sciences Research* **5**(2):197-211.

Bobak DM 2010. *Polycyclic Aromatic Hydrocarbon Characterization in Otter Creek, Northwest Ohio*. Submitted as partial fulfillment of the requirements for the Master of Science Degree in Geology, College of Graduate Studies, University of Toledo.

Bojes HK and Pope PG 2007. Characterization of EPA's 16 priority pollutant polycyclic aromatic hydrocarbons (PAHs) in tank bottom solids and associated contaminated soils at oil exploration and production sites in Texas. *Regulatory Toxicology and Pharmacology* **47**(3): 288-295.

Chemlal R, Tassit A, Drouiche M, Lounici H, Drouiche N and Mameri N 2012. Microbiological aspects study of bioremediation of diesel-contaminated soils by biopile technique. *International Biodeterioration & Biodegradation* **75**: 201-206.

CONCAWE 2005. Conservation of Clean Air and Water in Europe. Report 6/05 Classification and labelling of Petroleum substance according to the EU dangerous substance directive (CONCAWE recommendations- July 2005).

Dadrasnia A, Shahsavari N and Emenike CU 2013. Remediation of contaminated sites. *Hydrocarbon Intech Open*, pp.66-82.

Das N and Chandran P 2011. Microbial degradation of petroleum hydrocarbon contaminants: An overview. *Biotechnology Research International* **10**:113 p.

De-qing S, Jain Z, Zhao-long G, Jian D, Tian-Li W, Murygina, V and Kalyuzhnyi S 2007. Bioremediation of oil sludge in the Shengli oilfield. *Water, Air, and Soil Pollution* **185**: 177-184.

Eneji A E, Honna T, Yamamoto S and Masuda T 2006. Influence of composting conditions on plant nutrient concentrations in manure compost. *Journal of Plant Nutrition* **26**(8): 1595-1604.

Ferradji F Z, Mnif S, Badis A, Rebbani S, Fodil D, Eddouaouda K and Sayadi S 2014. Naphthalene and crude oil degradation by biosurfactant producing *Streptomyces* spp. isolated from Mitidja plain soil (North of Algeria). *International Biodeterioration and Biodegradation* **86**: 300-308.

Garcia AE 2013. *Remediation of common superfund site pollutants by composting or the use of composting materials: A review*. Master of Science in civil engineering with a concentration in environmental engineering, San Diego State University.

Haleyur N, Shahsavari E, Mansur AA, Koshlaf E, Morrison PD, Osborn AM, and Ball AS 2016. Comparison of rapid solvent extraction systems for the GC-MS/MS characterization of polycyclic aromatic hydrocarbons in aged, contaminated soil. *MethodsX* **3**: 364-370.

Hassanshahian M, Emtiazi G and Cappello S 2012. Isolation and characterization of crude-oil-degrading bacteria from the Persian Gulf and the Caspian Sea. *Marine Pollution Bulletin* **64**: 7-12.

IARC 2007. International Agency for Research on Cancer. A guide to the hazardous waste regulations reference number, HWR08 version 3.1-June 2007.

Ibuot AA and Bajhaiya A 2013. Biodegradation of crude oil sludge using municipal solid waste as a bulking agent. *Asian Journal of Biological Sciences* **6**(4): 207-213.

Jain PK, Gupta VK, Gaur RK, Lowry M, Jaroli DP and Chauhan UK 2011. Bioremediation of petroleum oil contaminated soil and water. *Research Journal of Environmental Toxicology* **5**(1): 1-26.

Jose AM, Jose LM, Teresa H and Carlos G 2006. Bioremediation by composting of heavy oil refinery sludge in semiarid conditions.

- Biodegradation* **17**(3): 251-261.
- Katsivela E, Moore ER, Maroukli D, Strömpl C, Pieper D and Kalogerakis N 2005. Bacterial community dynamics during in situ bioremediation of petroleum waste sludge in landfarming sites. *Biodegradation* **16**(2):169-180.
- Kumar A, Munjal A and Sawhney R 2011. Crude oil PAH constitution, degradation pathway, and associated bioremediation microflora: An overview. *International Journal of Environmental Sciences* **1**(7): 1420-1439.
- Lee SH, Lee S, Kim DY and Kim JG 2007. Degradation characteristic of waste lubricants under different nutrients conditions. *Journal of Hazardous Materials* **143** (1-2): 65-72.
- Liu H, Yao J, Yuan Z, Shang Y, Chen H, Wang F, Masakorala K, Yu C, Cai M, Blake RE, and Choi MMF 2014. Isolation and characterization of crude-oil-degrading bacteria from the oil-water mixture in Dagang oilfield, China. *International Biodeterioration and Biodegradation* **87**: 52-59.
- Liu T, Hou J, Zuo Y, Bi S and Jing J 2011. Isolation and characterization of a biosurfactant producing bacterium from Daqing oil-contaminated site. *African Journal of Microbiology Research* **5**(21): 3509-3514.
- Liu W, Luo Y, Teng Y, Li Z and Ma LQ 2010. Bioremediation of oily sludge-contaminated soil by stimulating indigenous microbes. *Environmental Geochemistry and Health* **32**(1): 23-29.
- Machin-Ramirez CAI, Okoh DK, Morales M, Mayolo-Deloisa R and Quintero Trejo-Hernandez 2008. Slurry-phase biodegradation of weathered oily sludge waste. *Chemosphere* **70**: 737-744.
- Mann C 2008. Our good earth. *National Geographic magazine*: **214** (3): 80-107.
- Mashreghi M and Marialigeti 2005. Characterization of bacteria degradation petroleum derivatives isolated from contaminated soil and water. *Journal of Sciences* **16**(4): 317-320.
- Meintanis C, Chalkou KI, Kormas KA and Karagoumi AD 2006. Biodegradation of crude oil by thermophilic bacteria isolated from a volcano island. *Biodegradation* **17**(2): 3-9.
- Obi LU, Atagana HI and Adeleke RA 2016. Isolation and characterisation of crude oil sludge degrading bacteria. *SpringerPlus* **5**(1): 1946.
- Olivera NL, Nieves M L, Lozada M, del Prado G, Dionisi HM and Sineriz F 2009. Isolation and characterization of biosurfactant-producing *Alcanivorax* strain: Hydroxylase gene analysis. *Research in Microbiology* **160**(1):19-26.
- Ouyang W, Liu H, Murygina V, Yu Y, Xiu Z and Kalyuzhny S 2005. Comparison of bioaugmentation and composting for remediation of oil sludge. A field-scale study in China. *Process Biochemistry* **40**: 3763-3768.
- Paulauskiene T, Zabukas V and Vaitiekunas P 2009. Investigation of volatile organic compound (VOC) emission in oil terminal storage Tank Park. *Journal of Environmental Engineering and Landscape Management* **17**(2): 81-89.
- Pernilla T, Gashaw M, and Eva NK 2007. Potential and utilization of thermophiles and thermo stable enzymes in bio refining. *Microbial Cell Factories* **6**(1): 9.
- Popenda A and Włodarczyk-Makula M 2015. The application of biosurfactants into the removal of selected micro pollutants from soils and sediments. *Desalination and Water Treatment* **57**(3): 1255-1261.
- Rajaei S, Seyedi S M, Raiesi F, Shiran B and Raheb J 2013. Characterization and potentials of indigenous oil-degrading bacteria inhabiting the rhizosphere of wild oat (*Avena fatua* L.) in South West of Iran. *Iranian Journal of Biotechnology* **11**(1): 32-40.
- Santisi S, Cappello S M, Mancini G, Hassanshahian M, Genovese L, Giuliano L and Yakimov MM 2015. Biodegradation of crude oil by individual bacterial strains and a mixed bacterial consortium. *Brazilian Journal of Microbiology* **46**(2): 377-387.
- Shaoping K and Laishi Z 2011. Pollution characteristics and risk assessment of polycyclic aromatic hydrocarbons (PAHs) in soils in winter around Zhongyuan Oilfield, China, soil and sediment contamination. *Soil and Sediment Contamination* **20**(1): 75-86.
- Sharma SK and Mudhoo A 2010. Composting as a bioremediation technique for hazardous organic contaminants. *Green chemistry for environmental sustainability*. Taylor & Francis, Boca Raton, pp 215-247.
- Sheetal S 2012. Bioremediation: A boon to hydrocarbon degradation. *International Journal of Environmental Sciences* **2**(4): 2408-2424.
- Sherry A, Grant RJ, Aitken CM, Jones DM, Head IM and Gray ND 2014. Volatile hydrocarbons inhibit methanogenic crude oil degradation. *Frontiers in Microbiology* **5**: 131.
- Sibanda T, Selvarajan R, Msagati T, Venkatachalam S and Meddows-Taylor S 2019. Defunct gold mine tailings are natural reservoir for unique bacterial communities revealed by high-throughput sequencing analysis. *Science of the Total Environment* **650**: 2199-2209.
- Singh K and Chandra S 2014. Treatment of petroleum hydrocarbon polluted environment through bioremediation: A review. *Pakistan Journal of Biological Sciences* **17**(1):1-8.
- Smith D and Lynam K 2009. Semivolatile organics analysis using an Agilent J&W HP-5ms Ultra inert capillary GC column. *Agilent Technologies, Inc 5990-3416EN*.
- Srinivasarao-Naik B, Mishra IM and Bhattacharya SD 2011. Biodegradation of total petroleum hydrocarbons from oily sludge. *Bioremediation Journal* **15**(3):140-147.
- Ubani O, Atagana HI, Thantsha MS and Rasheed A 2016. Identification and characterization of oil sludge degrading bacteria isolated from compost. *Archives of Environmental Protection* **42**(2): 67-77.
- Udotong IR, Udotong IJ, Inam E and Kim K 2011. Bioconversion of crude oil production into soil conditioner using sawdust as an organic amendment. US EPA method 3541. *Geosystem Engineering* **14**(2): 51-58.
- Vanishree M, Thatheyus AJ and Ramya D 2014. Biodegradation of petrol using *Aspergillus* sp. *Annual Research & Review in Biology* **4**(6): 914-923.
- Veeranagouda Y, Emmanuel Paul PV, Gorla P, Siddavattam D and Karegoudar TB 2006. Complete mineralization of dimethylformamide by *Ochrobactrum* sp. DGVK1 isolated from the soil samples collected from the coalmine leftovers. *Applied Microbiology and Biotechnology* **71**(3): 369-375.
- Wang Q, Zhang S, Li Y and Klassen W 2011. Potential approaches to improving biodegradation of hydrocarbons for bioremediation of crude oil pollution. *Journal of Environmental Protection* **2**(01): 47-55.
- Weavers LK, Sun P, Taerakul P and Walker HW 2006. Characterization of polycyclic aromatic hydrocarbons (PAHs) on lime spray dryer (LSD) ash using different extraction methods. *Chemosphere* **62**: 265-274.
- Winqvist E, Bjorklof K, Schult E, Rasanen M, Salonen K, Anasonye F, Cajthaml T, Steffen KT and Jorgensen KS 2014. Bioremediation of PAH-contaminated soil with fungi from the laboratory to field scale. *International Biodeterioration and Biodegradation* **86**: 238-247.
- Zaki MS, Ata SN, Abdelzaher MF and Hammam AMM 2014. Effects of environmental oil spills on commercial fish and shellfish in Suez Canal and Suez gulf regions. A review. *Life Science Journal* **11**(2): 269-274.
- Zhang R, Cui Z, Jiang J, He J, Gu X and Li S 2005. Diversity of organophosphorus pesticide-degrading bacteria in a polluted soil and conservation of their organophosphorus hydrolase genes. *Canadian Journal of Microbiology* **51**(4): 337-343.
- Zhao B, Zhu L, Li W and Chen B 2005. Solubilisation and biodegradation of phenanthrene in mixed anionic-nonionic surfactant solutions. *Chemosphere* **58**: 33-40.



Segregating Direct and Indirect Dimensions in Ecosystem Services Valuation: The case of A Coastal Wetland Ecosystem of South India

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Abstract: This paper provides insights into the multiple (direct and indirect) benefits of Kuttanad coastal wetland ecosystem in Kerala. Total annual direct ecosystem services generated from the wetlands are INR 8.45 billion or USD 0.11 billion per annum at 2020 prices. The estimates of the case study indicate that the annual value of indirect ecosystem services is thrice of direct provisioning services (Rs 22.52 billion or USD 0.31 billion per annum at 2020 prices). The valuation study would improve the knowledge and awareness of economic importance of wetland ecosystems among the various stakeholders including the policy makers of the society and their sustainable management to benefit the society.

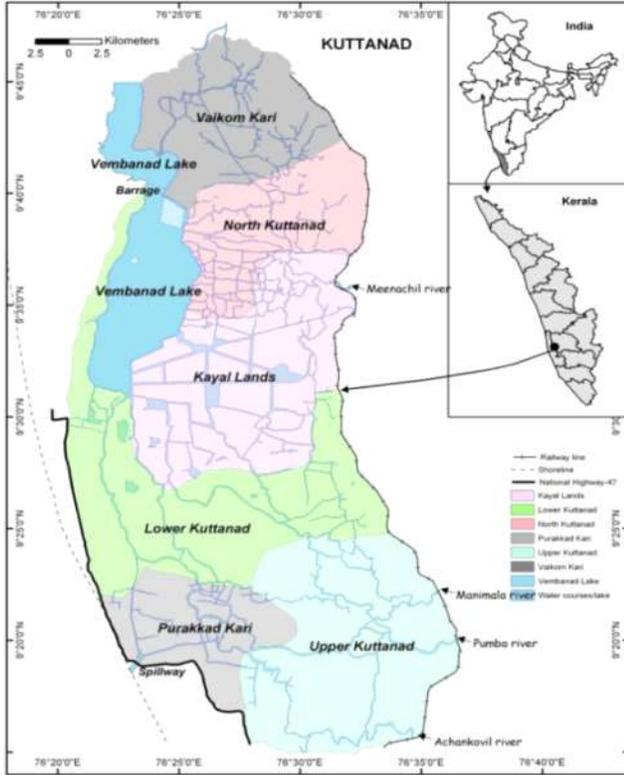
Keywords: Wetland, Ecosystem services, Direct-use value, Indirect-use value, Travel cost method

Wetlands are diverse and productive ecosystems in the world. They are valuable and ecologically sensitive ecosystems that provide useful services to mankind and hence are of vital importance to human well-being (Manh et al 2020, Millennium Ecosystem Assessment 2005, TEEB Foundations 2010, Costanza et al 2014). Examples include production of direct consumable goods (food, water, timber, fish), habitats for flora, fauna, environmental regulation and stabilization (carbon sequestration, nutrient cycles) and recreational or aesthetic components (Sarkar et al 2019). Despite their relevance, value of wetlands is often limited to the economics of market valued services available from resource exploitation. Consequently, the multiple and often joint services provided by these ecosystems are usually hidden in nature and hence they are under-presented in the national forefront. Consequently, wetlands are facing enormous anthropogenic pressures, leading to high environmental damage and degradation. The extensive benefits drawn by human beings from wetlands for day-to-day activities, livelihood and recreational purposes imply its utmost significance. Thereby, degradation of wetlands may worsen-off human welfare. These pertinent issues are addressed across the globe by various multi-disciplinary researchers. Kuttanad wetland is a Ramsar site which provides numerous ecological goods and services but is under tremendous stress due to rapid urbanization, industrialization and agricultural intensification. The unique ecology of Kuttanad wetland ecosystem has supported a multiplicity of enterprises based on inland fisheries, paddy,

coconut, and several other allied enterprises. Despite being a source of livelihood to the vulnerable groups like farmers and fishermen, the multiple-use potential is seriously undermined due to overall neglect as well as a narrow management regime focusing only on direct agricultural benefits. The multiple-use potential of the coastal wetland ecosystems is poorly understood and underrepresented in cost-benefit estimation of the wetland restoration programmes thus resulting in inadequate policy and financial supports to protect them. Even though the direct use values have been estimated in several studies, there is a dearth of studies which elaborate on mutualistic interactions and intangible services wetlands provide. The lack of adequate and comprehensive inventory of any ecosystem on a national level is evident. Ecosystem inventory and inclusion of economic value of ecosystem services are quintessential in policy making. With this background this study aims to provide deeper insights into the multiple (direct and indirect) benefits of Kuttanad wetland ecosystem. This paper focuses on quantifying both direct and indirect services and methodological approaches associated with them.

MATERIAL AND METHODS

The study was conducted in the Ramsar site Kuttanad wetlands which are spread across the districts of Alappuzha, Kottayam and Pathanamthitta. Nearly 57 per cent of the KWS is shared by Alappuzha district, 30 per cent by the Kottayam district and remaining 13 per cent by the Pathanamthitta district (Fig. 1). A representative area of the wetland



Source: Vijayan and Ray (2015)

Fig. 1. Study area of Kuttanad wetland ecosystem

ecosystem was selected from different agro-ecological and socio-economic environments in Kuttanad. Focus group discussions were held with stakeholders, ecologists and environmental scientists to delineate the ecosystem services provided by coastal wetlands. Based on these discussions and in-depth literature surveys, biophysical and socio-economic indicators of ecosystem services were refined to make them more precise, objective and measurable. Through this process, three groups of stakeholders who depended on the ecosystem directly were identified. They were categorized as farmers, fishermen and residents living in the vicinity of the wetlands, and tourists visiting the wetlands for recreation activities. The tourists are people who reside away from these ecosystems and do not directly depend on them for livelihood. Thus, there were four stakeholder groups.

A multi-stage random sample of rice farmers, fishermen and neighbourhood residents (120 samples each) were selected from six villages (20 samples each) viz., Alleppey, Muhamma, Thannermukkom, Champakkulam, Ramankary, and Neelamperoor. The tourist stakeholders were interviewed at the tourist boat hub at Alleppey. The method of personal interview was adopted using structured pre-tested interview schedule along with direct observation. The questions on ecosystem valuation were developed by

following the guidelines of The Economics of Ecosystems and Biodiversity (TEEB), South Asian Network for Environmental Economics (SANDEE), and Technical Report on Economic Valuation of Wetlands (Ramachandra and Rajinikanth 2004). Representatives of the government authorities, including wetland specialists and agricultural officers of various agricultural offices of Kuttanad area of Kerala, as well as NGOs, research institutes, and Paadasekhara committee members, and other organizations were also consulted for listing of ecosystem services of the wetland.

Wetland valuation methods: Following the popular valuation taxonomy developed by various environmental economists (Turner et al 2001). The study identified different ecosystem services delivered by the Kuttanad wetland ecosystem, classified them according to the established environmental economic theory into direct and indirect use values and estimated the monetary values.

Valuation of Direct Services

Rice and Fishery resources; The costs associated were collected from the respective stakeholders. The returns from these activities were estimated based on the market price of the produce and net returns were calculated. Based on the average net returns per hectare, the total value of wetlands from the direct uses viz, rice farming and fishing were estimated.

Total value of wetlands from rice farming or fishing;

$$V_i = \sum_{i=1}^n P_i Q_i - C_i$$

Where,

V_i = Net returns from the resource (Rs/annum)

P_i = price of the i^{th} resource (Rs/quintal)

Q_i = quantity of i^{th} resource (quintal)

C_i = cost of harvesting the output (Rs)

Domestic water supply: The economic value of domestic water supply service provided by the Kuttanad wetlands was estimated by cost of alternatives method. The data on average domestic consumption of water by the 120 sample neighborhood resident households were gathered. The total water usage by the Kuttanad household was calculated and valued based on the water tariff charged by the Kerala Water Authority.

Economic value of domestic water supply was calculated by,

$$V_d = P_d * N_h * U_w * P_{KWA}$$

Where,

V_d = Value of water used for domestic purposes (Rs/annum)

P_d = Percentage of households dependent on wetlands for domestic water supply

N_n = Number of households (numbers)

U_w = Average per month usage of water (litres/month)

P_{kwa} = Kerala Water Authority tariff (Alternate cost of water) (Rs/month)

Valuation of Indirect Services

Recreational services: Recreation benefits of Kuttanad wetlands were estimated using the Travel cost model developed under the assumption that the individuals utility depends on the total time spent at the site, the quality of the site and the quantity of private good other than travel consumed (Turpie and Joubert 2001). The fundamental insight that drives this model is that if a consumer wants to use the recreational services of a site he has to visit it. The travel cost to reach the site is considered as the implicit or the surrogate price of the visit, and changes in the travel cost will cause a variation in the quantity of visits. The Individual Travel Cost Method (ITCM) was used in the study. The visitors to sites are invited to provide information on the trip (cost, length, purpose, other sites visited, etc.) as well as on other socio-economic features (income, age, sex, etc.). Then the dependent variable is defined as the visitor rate (the number of visits made by the individual in a period).

In mathematical terms, the trip demand curve will be defined as:

$$V_{ij} = f(C_{ij}, X_i)$$

where:

V_{ij} = number of visits made in the year by individual i to site j ;

C_{ij} = visit cost faced by individual i to visit site j ;

X_i = all other factors determining individual i 's visits (income, time, and other socioeconomic characteristics).

Empirical model: $\ln V = \alpha + \beta_1 \text{AGE} + \beta_2 \text{EDUC} + \beta_3 \text{FINC} + \beta_4 \text{FAMSIZE} + \beta_5 \text{TRAVCO} + \beta_6 \text{SQLTY}$,

Where

V = Number of visits made by individual per year

AGE = Age of the respondent

EDUC = Education

TRAVCO = Individual total cost of visiting the site (Rs)

FINC = Income of the household (Rs/year)

FAMSIZE = Family size

SQLTY = Site quality

Consumer surplus was estimated by the method used in Adamowicz et al (1989).

$$CS = 1/\beta_5$$

Where,

CS = Consumer surplus per visitor (Rs)

β_5 = Estimated co-efficient of travel cost

Total recreational value in Kuttanad wetlands is calculated using the formula,

$$V_R = CS * V_n$$

Where,

V_R = Value of recreational services (Rs per annum), CS = Consumer surplus per visitor (Rs)

V_n = Number of visitors per annum

Erosion control: Erosion control and sediment retention by Kuttanad wetlands have significant economic value. However, since it is too expensive and time consuming to produce primary economic valuation studies on erosion prevention, benefit transfer method was adopted in the present study. Benefit transfer is the 'practice of adapting value estimates from past research to assess the value of a similar, but separate, change in a different resource' (Johnston et al 2015, Boutwell and Westra 2013). The benefit transfer approach was used to value the ecosystems in which a constant unit ecosystem service value per hectare of ecosystem type is multiplied by the area of the wetland to arrive at aggregate value. The total value of wetlands from erosion control was calculated by the formula:

$$V_{EC} = A_w * VC_K$$

Where,

V_{EC} = Total value of wetlands from erosion control (Rs),

A_w = Area of Wetlands (in hectares)

VC_K = Per hectare monetary values of erosion control from another location (Rs/ha).

RESULTS AND DISCUSSION

Kuttanad wetland system provides an array of services and a total of 22 ecosystem services were identified in the study area. Among them five major direct and indirect services were identified, ranked and quantified based on their use by household or ability to sell them in the market for economic returns (Table 1).

Economic Value of Wetlands from Direct Services

Value of rice farming: Rice farming is the major land use in Kuttanad wetlands. Rice cultivation in Kuttanad constitutes 25 per cent of the total rice area of the Kerala state and contributes nearly 37 per cent of rice production of the state. The estimated total area under rice farming in Kuttanad is 50530 hectares (GoK 2017). Rice cultivation is one of the direct provisioning services provided by the Kuttanad wetlands, which was valued by direct market valuation method. The price of a commodity times the marginal product of the ecosystem service is an indicator of the value of the service, consequently, market prices can be good indicators of the value of the ecosystem service (Table 2).

The average cost incurred for rice cultivation was Rs 75,371 per hectare. The average yield of rice was 63 quintals per hectare sold at an average price of Rs 2,150 per quintal with a gross return of Rs 1,35,450 and net return of Rs 60,079 per hectare. The total area of wetlands under the three

seasons of rice (Virippu, Mundakan and Punja) was 50,530 hectares (GoK 2017). The total monetary value of Kuttanad wetlands per annum based on rice farming was Rs 3.04 billion at 2020 prices.

Value of fishery: Fish resources are the most tangible ecosystem services provided by the Kuttanad wetlands. Fishing was ranked as the second most important wetland-dependent economic activity (Table 3). Almost 60000 active fishermen of the Kuttanad area are employed in inland fishing with an average income of Rs 1600 per day, during the peak season of fishing. The market values were estimated based on current market prices for each species of fish (Table 3). The total expenditure incurred by the fishermen is about Rs 2.41 lakhs. The net income from fishing activity is Rs 89,103 per annum. The total number of active fishermen in the Kuttanad was 60590 (GoK 2013). The total monetary value of Kuttanad wetland fishery was Rs 5.4 billion per annum or US\$75.6 million per annum at 2020 price levels. Hema and Indira Devi (2015) reported the economics of fish catch in Kannur and Ernakulam to be Rs 162,860 per fisherman per year.

Economic value of Kuttanad wetlands from domestic water supply: The people of Kuttanad depend on waters of wetlands for domestic consumption, crop production, fishing and transportation. Many areas in Kuttanad are facing severe potable water availability issue. Fresh water supply is limited due to pollution and intensive agricultural run-offs including fertilizer over dose. Still on an average 58.3 per cent of the sample resident households used the water supply from wetlands for domestic purposes. Since the water is of poor quality, the usage is mainly for washing and cleaning purpose alone.

The total number of households dependent on wetland water supply was estimated to be 3, 11,902. With an average water consumption of 285 litres per month, the total water use

Table 2. Monetary value of Kuttanad wetlands based on rice farming

Variable	Rice farming
Variable cost (Rs/ha)	75,371
Average yield (Qtl/ha)	63
Price per quintal	2150
Gross returns (Rs/ha)	1,35,450
Net returns (Rs/ha)	60,079
Area of wetlands under rice* (hectares)	50,530
Annual value per annum in Rs billion	3.04

Note: *Reports from ADA office, Alappuzha

Source: Primary survey

Table 3. Monetary value of Kuttanad wetlands based on fishing

Variable	Fishing
Total expenditure (Rs/ annum)	2,41,477
Total income (Rs/ annum)	3,30,580
Net returns (Rs/ annum)	89,103
Number of active fishermen*	60,590
Annual value per annum (in Rs billion)	5.4

Source: Primary survey

by the residents was 1.1 billion litres per annum (Table 4). For domestic water consumption of less than 5000 litres per annum, the standard tariff was Rs 20 per month. Hence, the annual value of water for domestic consumption from Kuttanad wetlands was estimated to be Rs 6.2 million at 2020 prices. Other studies which valued the economic value of wetlands from domestic water supply are Baral et al (2016) in Nepal (Nepali rupee 1.82 million per annum; TEEB report (2013) on Kala Oya river basin of Sri Lanka US\$1469 per hectare per year.

Economic Value of Wetlands from Indirect Use

Economic value of recreational services of Kuttanad wetlands:

The log-linear trip generating function was formulated using number of visits per year as dependent

Table 1. Ecosystem services, their use and ranking by the stakeholders

Rank	Ecosystem services and category	Uses	Remarks	Socio-economic indicators	Valuation technique used
1	Rice farming (Direct)	Food and market value	70 per cent of the population depend on rice farming as a source of income	Value of output	Market price method
2	Fishing (Direct)	Food and market value	More than 60,000 active fishermen in the area. Average income of Rs 1,600 per day during peak seasons	Value of output	Market price method
3	Recreational (Indirect)	Employment and global recognition	Important tourist destination. Average inflow of tourist is more than two lakh per annum	Amount of tourism earnings	Individual travel cost method
4	Water (Direct)	Irrigation and household purposes	Daily dependence by stakeholders for irrigation, washing and bathing purposes	Duration of water use, replacement cost of providing alternative sources	Cost of alternatives method
5	Sediment retention (Indirect)	Protect and stream banks against erosion action	Act as buffer against run off , also provide drainage and natural irrigation	Amount of sediment retained	Benefit transfer approach

Source: Household Survey (2017)

variable. The independent variables were socio-economic variables such as age, education, family income, family size, travel cost and the quality of site. The estimated trip generation function is summarised in Table 5. The signs of the coefficients were in consistence with the economic theory. The independent variables that significantly affect the trip generating function are travel cost (negative effect), family size (positive effect) and site quality (positive effect). The negative sign of the travel cost and the significance of the travel cost at one per cent level of significance are in accordance with the results of Anoop *et al.*, (2008) and Vijayan & Job (2015). The negative sign of the travel cost indicates that the number of visits to the ecosystem decreases as travel cost increases. Other variables which significantly affect the dependent variable are family income and site quality.

The consumer surplus could be estimated by finding the absolute value of the reciprocal of travel cost coefficient. The consumer surplus is the surrogate value of net social benefit received from the ecosystem. The consumer surplus per visit

Table 4. Economic value of Kuttanad wetlands from domestic water supply

Variable	Water use
Number of households*	5,34,994
Household dependent on wetland water supply**	3,11,902
Average use of water per month (in litres)	285
Water use by all household per year (million litres)	1122.84
Market price (domestic water usage <5000 litre per annum)***	20
Annual value of water for domestic consumption (Rs million)	6.2

Note: * Based on GoI Census 2011, **Estimated based on primary survey, *** GoK 2017 water tariff proposed by Kerala water authority

Table 5. Parameter estimates of trip generating function

Variable	Coefficient	p-value
Constant	0.125 (0.123)	0.311
AGE (β_1)	0.0002 (0.0016)	0.894
EDUC (β_2)	0.0078 (0.0066)	0.245
FAMSIZE (β_3)	0.017** (0.0082)	0.04
FINC (β_4)	0.00002 (0.00003)	0.498
SQLTY (β_5)	0.085*** (0.024)	0.001
TRAVCO (β_6)	-0.0013*** (0.00034)	0.000
n=120		
Log likelihood= 97.28		

Source: Primary survey and authors' own estimation

Note: *** ** and * implies significance at 1%, 5% and 10% respectively Standard errors are presented in parentheses

was estimated to be Rs 769.23 (Table 6). The total recreational value of the wetlands was obtained by multiplying the total number of visitors by the consumer surplus per visit. The estimated total recreational value was Rs 0.24 billion or USD 3.3 million at 2020 prices. Similar studies were conducted in Kerala, and abroad to determine the recreational value of lakes and wetlands. The recreational value of Cochin backwaters was estimated using the zonal travel cost method by Abraham (2006) and the value was estimated to be Rs 3.81 crores. Anoop *et al* (2008) estimated the recreational value of Astamudi Lake in Kerala using travel cost method to be Rs 0.15 crores which is less than the estimated value of the Kuttanad wetlands. The total recreational value of Kuttanad wetlands was estimated to be Rs 0.24 billion. Hence, it is imperative that the recreational services are promoted as well as conserved

Table 6. Recreational value of Kuttanad wetlands

Particulars	Value
Consumer surplus per visit	769.23
No. of visitors per year*	306493
Total consumer surplus (in Rs million)	235.76
Recreational value per annum (in Rs billion)	0.24

Note: * Kerala tourism statistics GoK, 2017

Table 7. Economic value of Kuttanad wetlands from sediment retention

Variable	Erosion control
Value*(0.5*3929 US\$ ha ⁻¹ yr ⁻¹)	137515
Area of wetlands** (hectares)	162125
Gross annual value of erosion control (Rs billion ha ⁻¹ yr ⁻¹)	22.29

Note: * 50 % of value derived from de Groot *et al* 2012 and Costanza *et al* 2014. ** National Wetland Atlas Kerala, SAC ISRO, 2010

Table 8. Quantifying ecosystem services from Kuttanad wetlands

Ecosystem services	Total value in Rs billion yr ⁻¹
Direct values	
Rice farming	3.04
Fishing	5.4
Domestic water supply	0.0062
Sub-Total	8.45 (27.28 %)
Indirect values	
Recreational services	0.235
Erosion control	22.29
Sub-Total	22.52 (72.72 %)

Source: From primary and secondary data collected

Note: * Secondary data from National Wetland Atlas Kerala, SAC ISRO, 2010

without deteriorating the quality of the ecosystem.

Economic value of Kuttanad wetlands from sediment retention: The per hectare value of erosion control from coastal wetlands were adopted from the de Groot et al (2012) and Costanza et al (2014) after calibrating for developing countries (Table 7). The 50 per cent of the unit value was multiplied by the area of wetlands (162125 hectare) to obtain the gross annual value of sediment retention. Gross annual value from sediment retention was estimated to be Rs22.29 billion ha⁻¹ yr⁻¹ or USD 0.31 billion ha⁻¹ yr⁻¹ (2020 prices).

Total annual direct ecosystem services generated from the wetlands Rs. 8.45 billion or USD 0.11 billion per annum at 2020 prices (Table 8). The estimates of the case study indicate that the annual value of indirect ecosystem services (sediment retention and eco-tourism) is usually thrice the estimates of direct provisioning services (Rs 22.52 billion or USD 0.31 billion per annum at 2020 prices). A large part of the economic value is indirect use value which includes regulating services like erosion control, waste treatment and recreational services like ecotourism. The direct provisioning services like food, water and raw materials contribute less than the indirect values in the total economic value of the ecosystems. The significance of indirect use services indicates that Kuttanad wetlands possess value far more than that merely based on the market viewpoint.

CONCLUSION

Segregating the ecosystem services indicate that the annual value of indirect ecosystem services (sediment retention and eco-tourism) is usually thrice the estimates of direct provisioning services. The multiple benefits (both direct and indirect) provided by the Kuttanad wetlands to the different stakeholders implies the relevance of wetlands and hence highlights the necessity of conservation and management of Kuttanad wetlands for sustainable use in the future. The significance of indirect use services indicates that ecosystems possess value for more than that merely based on the exchange or utility viewpoint. These estimated values would help raise awareness among the policy makers about the economic relevance and their sustainable management to benefit the society. Furthermore, the valuation of wetland ecosystem would also improve knowledge and awareness of economic importance of the ecosystems among the various stakeholders as well as the society as whole.

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REFERENCES

- Abraham S 2006. *Economic valuation of coastal wetlands: A study of Cochin backwaters in Kerala*. Ph.D. Dissertation, CUSAT, Kerala, India.
- Adamowicz WL, Graham-Tomasi T and Fletcher JJ 1989. Inequality constrained estimation of consumer surplus *Canadian Journal of Agricultural Economics* **37**(3): 407-420.
- Anoop PS, Suryaprakash KB, Umesh and TS Amjath Babu 2008. "Economic Valuation of Use Benefits of Ashtamudi Estuary in South India" In *Proceedings of the Taal 2007: The 12th World Lake Conference* edited by M Sengupta and R Dalwani 1822-26 <http://moefnicin/modules/recent-initiatives/nlcp/Indian%20Case%20Studies/Q-7pdf>.
- Baral S, Basnyat B, Khanal R and Gauli K 2016. A total economic valuation of wetland ecosystem services: An evidence from Jagadishpur Ramsar Site Nepal. *The Scientific World Journal* **2016**: 1-9.
- Boutwell JL and Westra JV 2013. Benefit transfer: A review of methodologies and challenges. *Resources* **24**: 517-527.
- Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson S J, Kubiszewski I and Turner R K 2014. Changes in the global value of ecosystem services. *Global Environmental Change* **26**: 152-158.
- De Groot R, Brander L, Van Der Ploeg S, Costanza R, Bernard F, Braat L and Hussain S 2012. Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services* **11**: 50-61.
- Hema M and Devi P 2015. Economic Valuation of Mangrove Ecosystems of Kerala India. *Journal of Environmental Professionals Sri Lanka* **4**(1): 1-16.
- Johnston RJ, Rolfe J, Rosenberger RS and Brouwer R 2015. *Introduction to benefit transfer methods In Benefit Transfer of Environmental and Resource Values* pp 19-59 Springer Netherlands.
- Manh NTTD, Manh PBQ and Tuyen TT 2020. Ecosystem services in mountainous area: A case study of Nghe an, Vietnam. *Indian Journal of Ecology* **47**(1): 109-116.
- MEA Millennium Ecosystem Assessment 2005. *Ecosystems and human well-being: wetlands and water* from <http://142.44.210.7/bitstream/123456789/143/1/Millennium%20Ecosystem%20Assessment.%20ECOSYSTEMS%20AND%20HUMAN%20WELL-BEING%20WETLANDS%20AND%20WATER%20Synthesi.pdf>
- Ramachandra TV, Rajinikanth R and Ranjini VG 2005. Economic valuation of wetlands. *Journal of Environmental Biology* 262-439.
- Sarkar P, Das T and Mandal R 2019. Assessing human dependency on the provisioning ecosystem services of Chatla Floodplain Wetland of Barak Valley, Assam, Northeast India. *Indian Journal of Ecology* **46**(3): 516-520.
- TEEB Foundations 2010. *The Economics of Ecosystems and Biodiversity*. Ecological and Economic Foundations Earthscan London and Washington.
- Thomson K T 2003. *Economic and social management of estuarine biodiversity in the west coast of India*. Ph.D. Dissertation. Cochin University of Science and Technology Cochin 1-282.
- Turner RK, van den Bergh JCM, Soderqvist T, Barendregt A, van der Straaten, Maltby E and van Ierland EC 2000. Ecological-economic analysis of wetlands: Scientific integration for management and policy. *Ecological Economics* **35**: 7-23.
- Turpie JK and Joubert AR 2001. Estimating potential impacts of a change in river quality on the tourism value of Kruger National

Park: An application of travel cost contingent and conjoint valuation methods. *Water SA* **27**: 387-398.

Turpie JK, Joubert AR, Van Zyl H, Harding B and Leiman A 2001. *Valuation of open space in the Cape Metropolitan Area Report to*

the City of Cape Town. Cape Town South Africa.

Vijayan A and Job E 2015. Recreational value of Vellayani lake in south India: A travel cost approach. *International Journal of Scientific Research* **4**(11): 156-158.

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A Proposed Role for Zinc Supplementation in Covid-19 Prevention

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Abstract: Covid-19 is a contagious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which was identified in 2020. SARS-CoV-1 infection attack on lungs (particularly airway epithelia), heart, kidneys, small intestine, testes, and vascular endothelia. Enzymatic studies have revealed that zinc directly blocks the activity of the RNA polymerase by inhibiting elongation and reducing template binding. Increasing zinc availability in the body is considered safe, since zinc toxicity is rare and requires the intake of unusually large doses.

Keywords: Covid-19, Human health, Zinc, Life cycle of SARS-CoV-2

Coronaviruses are large, enveloped, single-stranded, positive-sense RNA viruses with a genome of approximately 30 kilobases in length. The genus *Coronavirus* belongs to the family *Coronaviridae* in the order *Nidovirales*. They are classified into three groups. Group 1 contains various mammalian viruses including porcine epidemic diarrhea virus, porcine transmissible gastroenteritis virus, and human coronaviruses 229E and NL63. Group 2 includes canine respiratory corona virus among other mammalian viruses and human corona virus OC43. Human severe acute respiratory syndrome corona virus (SARS-CoV-1) is considered a distant relative of this group. Group 3 contains solely avian corona viruses. Human corona viruses (HCoVs) cause respiratory infections, mainly, but gastroenteritis and neurological disorders may also occur. So far, at least seven human corona viruses have been described including SARS-CoV-2, which was identified in 2020, and two of these corona viruses (OC43 and 229E) are responsible for 10-30% of all common colds. HCoV-HKU1 is mostly associated with bronchiolitis and pneumonia (Keyaerts et al 2009, Wang et al 2020).

Recent molecular studies have revealed that in order to facilitate entry of the virus into a human cell, the "S" spike surface glycoprotein of SARS-CoV-2 binds to the angiotensin-converting enzyme 2 (ACE-2) cellular receptor. Expression of ACE-2 in human tissues correlates with known sites of SARS-CoV-1 infection including lungs (particularly airway epithelia), heart, kidneys, small intestine, testes, and vascular endothelia (Jia et al 2005) and these same tissues overlap with the sites of SARS-CoV-2 infection in humans. Binding of the virus occurs via the S1 subunit of the S protein to a receptor and entry requires S protein priming by the

cellular serine protease in order to allow fusing together of viral and cell membranes, a process which is initiated by the S2 subunit (Hoffman et al 2020). Following the fusion of viral and plasma membranes, the virus RNA undergoes transcription and replication inside the cell cytoplasm and the process is catalyzed by an RNA-dependent RNA polymerase. Viral proteins are synthesized and the new RNA genomes are assembled and packaged in the endoplasmic reticulum, in the Golgi apparatus, and in the endoplasmic reticulum-Golgi intermediate compartment prior to virion release in vesicles.

RNA synthesis occurs in the life cycle of the SARS-CoV-1 virus in order to reproduce its genetic material and is also catalyzed by an RNA-dependent RNA polymerase, which is the core enzyme of a multiprotein replication/transcription complex. In the case of SARS-CoV-1, an excess of intracellular zinc ions has been found to efficiently inhibit the RNA-synthesizing activity of this replication and transcription multiprotein. Enzymatic studies *in vitro* have revealed that zinc directly blocks the activity of the RNA polymerase by inhibiting elongation and reducing template binding. The RNA polymerase core, which is a central component of the coronaviral replication/transcription machinery, is well conserved among the members of the coronavirus family including SARS-CoV-2 (Velthuis et al 2010, Gao et al 2020). Therefore, it is quite possible that zinc treatment would have a similar effect on SARS-CoV-2 and interfere with its ability to replicate at the biochemical level.

Since current research indicates that the mineral, zinc, can inhibit the replication of coronavirus and a variety of other RNA viruses in cell culture, it has become a potentially important and interesting supplement to study at this time. In

the human body, zinc performs a variety of vital antioxidant functions and is required for good health. Inside the cell, the harmful effects of free radicals are balanced by the action of antioxidant enzymes (such as copper-zinc superoxide dismutase) and non-enzymatic antioxidants (such as metallothioneins, which contain zinc) (Ruttkey-Nedecky et al 2013, Siddoo-Atwal 2019a). Thus, low risk ways of increasing zinc bioavailability in the body can be safely considered, especially since zinc toxicity is rare and requires the intake of unusually large doses (Fosmire 1990).

In rats, rice fortified with zinc oxide or zinc carbonate is a feasible vehicle for zinc absorption, although zinc oxide displays lower bioavailability than zinc carbonate (Lucia et al 20014). In young adults, zinc absorption from supplemental zinc citrate is comparable with that from zinc gluconate, but higher than from zinc oxide (Wegmuller et al 2014). It is already known that zinc can be absorbed from topical (non-nano) zinc oxide by human skin in small quantities (nano forms of zinc oxide are not associated with significant zinc absorption) (Agren 1990). One of our recent studies suggests that zinc is absorbed by the human body from our sun care products (all with the same basic formula containing a medicinal form of zinc oxide) in sufficiently large quantities with regular use (Siddoo-Atwal 2019b).

So, recently, when our company received an inquiry from Health Canada regarding any innovations that may benefit Canadian health workers at this critical time during the novel coronavirus pandemic, the answer was that we do have a product that may be useful to medical professionals and health workers in the field. It is a natural, award-winning sun care product specially formulated to block apoptotic sunburn (Skin Protector Plus). Its active ingredient is a non-nano, medicinal form of zinc oxide. The novel thing about this product is that it appears to be an efficient delivery system for

boosting zinc levels in the whole body in a relatively short period of time. There is no toxicity associated with this product due to the use of high grade zinc oxide and natural ingredients. Since it is so safe and contains no harsh chemicals (already tested on human volunteers), no pre-clinical trials would be required to test its efficacy in protecting subjects from COVID-19 in a clinical study. The objective of such a comprehensive study would be to test and confirm the hypothesis outlined above, *in vivo*; namely, if maximum zinc levels are maintained in the human body via percutaneous zinc absorption from a topically applied zinc oxide cream, then it may provide one suitable defense against SARS-CoV-2 infection. This type of topical application on the surface of the skin may be a faster method of ensuring even zinc distribution throughout the body and delivery to the various potential points of viral entry. Moreover, it may actually provide a physical barrier or blockade against entrance of the virus into the body by allowing suffusion and accumulation of zinc pools directly beneath the skin. Furthermore, ingestion of limited oral zinc supplements to protect vulnerable internal organs such as the small intestine, heart, and kidneys and the application of a zinc oxide crème to other susceptible external areas of the body, for example, routes leading to airway epithelia, may provide good coordinated protection from COVID-19. This combination may be particularly relevant now with the advent of new highly contagious virus variants.

The experimental design would involve a test group of ten or more uninfected health workers, who are regularly exposed to COVID-19, using the Skin Protector Plus cream daily. A second group would receive a limited dose of an oral zinc supplement, as well. A third group would receive only a daily zinc supplement. A matching uninfected control group would receive a placebo without zinc oxide crème or zinc supplement. The body zinc levels of all groups would be monitored until they reached maximum levels in the test groups and these levels would be maintained for three to four weeks or for the duration of the trial. At the end of the study, all groups would be tested for COVID-19 infection, once again, and the rate of infection in the three groups would be analyzed statistically and compared.

If the rate of COVID-19 infection were found to be lower in the test groups than in the control group in this study, then these results would indicate that a degree of temporary immunity from the virus could be achieved by rapidly building up the body's zinc reserves with topically applied zinc oxide/oral supplementation. Similar simultaneous studies could prove to be a cost-effective way of finding a possible solution for combatting COVID-19 on the frontlines in the absence of an approved vaccine for coronanavirus variants and as a future method of secondary defense against certain

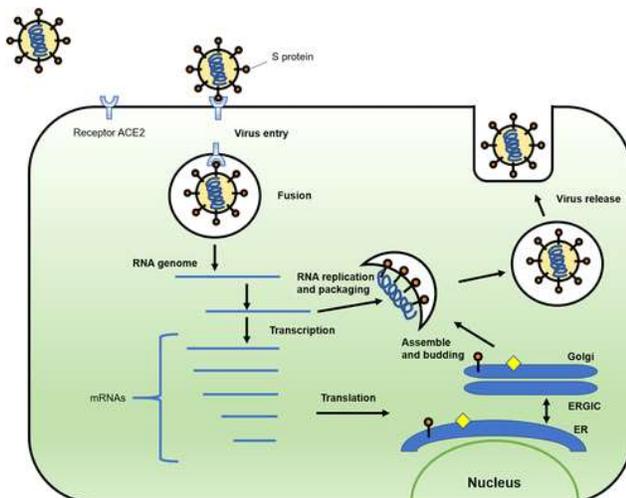


Fig. 1. Life cycle of SARS-CoV-2 (He et al 2020)

RNA viruses. Coating surgical masks with a thin layer of zinc may also be worth considering.

REFERENCES

- Agren MS 1990. Percutaneous absorption of zinc from zinc oxide applied topically to intact skin in man. *Dermatologica* **180**: 36-39. <https://doi.org/10.1159/000247982>.
- Fosmire GJ 1990. Zinc toxicity. *The American Journal of Clinical Nutrition* **51**(2): 225-227. <https://doi.org/10.1093/ajcn/51.2.225>.
- Gao Y, Yan L, Huang Y and Liu FJ. 2020. Structure of the RNA-dependent RNA polymerase from COVID-19 virus. *Science* **368** (6492):779-782. doi: 10.1126/science.abb7498.
- He F, Deng Y and Li W. 2020. Coronavirus disease 2019: What we know? *Journal of Medical Virology* **92**(7): 719-725. DOI.org/10.1002/jmv.25766.
- Hoffmann M, Kleine-Weber H and Schroeder S 2020. SARS-CoV-2 cell entry depends on ACE2 and TMPRSS2 and is blocked by a clinically proven protease inhibitor. *Cell* **181**: 271-280. DOI.org/10.1016/j.cell.2020.02.052.
- Jia HP, Look DC, Shi L, Hickey M, Pewe L, Netland J, Farzan M, Wohlford-Lenane C, Perlman S and McCray PB Jr 2005. ACE2 Receptor Expression and Severe Acute Respiratory Syndrome Coronavirus Infection Depend on Differentiation of Human Airway Epithelia. *Journal of Virology* **79**(23): 14614-14621. DOI: 10.1128/JVI.79.23.14614-14621.2005.
- Keyaerts E, Li S, Vijgen L, Rysman E, Verbeeck J, Van Ranst M and Maes P. 2009. Antiviral activity of chloroquine against human Coronavirus OC43 infection in newborn mice. *Antimicrobial Agents and Chemotherapy* (American Society for Microbiology); doi:10.1128/AAC.01509-08
- Lucia CMD, Santos LLM, da Cruz Rodrigues KC, da Cruz Rodrigues VC, Martino HSD and Sant'Ana HMP 2014. Bioavailability of zinc in wistar rats fed with rice fortified with zinc oxide. *Nutrients* **6**(6): 2279-2289.
- Ruttikay-Nedecky B, Nejdil L, Gumulrc J, Zitka O, Masarik M, Eckschlager T, Stiborova M, Adam V and Kizek R 2013. The role of metallothionein in oxidative stress. *International Journal of Molecular Sciences* **14**(3): 6044-6066.
- Siddoo-Atwal C 2019a. Chapter 17 – Biological Effects of Uranium and Its Decay Products on Soil Microbes, Plants, and Humans; in "Plant Microbe Interface" Springer (edited by Varma A, Tripathi S & Prasad R).
- Siddoo-Atwal C 2019b. A case-study of uranium and heavy metal detoxification. *Indian Journal of Ecology* **46**(2): 427-430.
- Wang H, Li X, Li T, Zhang S, Wang L, Wu X and Liu J 2020. The genetic sequence, origin, and diagnosis of SARS-CoV-2. *European Journal of Clinical Microbiology & Infectious Diseases* **24**: 1-7; doi: 10.1007/s10096-020-03899-4.
- Wegmuller R, Tay F, Zeder C, Brnic M and Hurrell RF 2014. Zinc absorption by young adults from supplemental zinc citrate is comparable with that from zinc gluconate and higher than from zinc oxide. *The Journal of Nutrition* **144**(2): 132-136.
- Velthuis AJW, van den Worm SHE, Sims AC, Baric RS, Snider EJ and van Hemert MJ 2010. Zn²⁺ Inhibits Coronavirus and Arterivirus RNA Polymerase Activity *In Vitro* and Zinc Ionophores Block the Replication of These Viruses in Cell Culture. *PLOS Pathogens*; Published: November 4, 2010 <https://doi.org/10.1371/journal.ppat.1001176>.

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Impact of Seasonal Variations in Physico-chemical Characteristics of Forest Soil under Veerakkal area, Manar Beat, Western Ghats, India

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Abstract: This study observed the seasonal variations in the soil nutrients in Veerakkal forest area, Manar beat, Karamadai Range, Western Ghats, India during March 2018 to February 2019 at variable depth of 0-30 cm for four sites viz., *Pongamia pinnata*, *Terminalia arjuna*, *Gardenia resinifera* and *Celtis phillipensis*. The overall assessment of seasonal observation indicated that in rainy season, the sand and silt particles were maximum (75.03 and 25.5%, respectively) at 0-30 cm depth. The total soil moisture content ranged from 8.85 to 38.62%. The water holding capacity ranged between 15.69 to 41.82%, in particular. The *Pongamia pinnata* exhibited highest water holding capacity (41.82%). The highest bulk density was in *Gardenia resinifera* (1.39 g/ccs) for 0-10 cm depth. The soil porosity on seasonal variation was significantly higher at 20-30 cm depth for all sites. The study site was slightly acidic in the soil of *Pongamia pinnata* and *Terminalia arjuna* and it was alkaline nature of soil in *Gardenia resinifera* and *Celtis phillipensis*. The total soil organic carbon was ranged between 1.04 to 3.20%. The range of highest nitrogen content of the soil was estimated in *Terminalia arjuna* (531.6 kg ha⁻¹) followed by *Pongamia pinnata*, *Gardenia resinifera* and *Celtis phillipensis* in rainy season. Among the seasonal interpretations, the available phosphorous and potassium content under natural forest in winter season was comparatively higher than rainy and summer. In the overall assessment on the impact of seasonal variations on connection with soil depth under physico-chemical characters indicated that significant variations in four study sites.

Keywords: Western Ghats, Physico-chemical properties, Soil depth, Seasons

Soil is a solitary most imperative and precious resource of the nature, composed of particles of broken rocks that have been altered by chemical and environmental processes like weathering and erosion. Soil provide as more reliable key for productivity than water qualities (Mahajan and Billore 2014). Generally in most of the forest areas the rainfall is frequently a factor that determines the plant growth. The increase in organic carbon content of the soil is known to increase the cation exchange capacity of the soil. Similarly any turn down process occur in the soil organic matter content could involve significant loss of nutrients on exchangeable bases and finally alter the soil quality (Atiku and Noma 2011). The natural forest soils are highly enriched with colossal nutrients which happen mainly due to the decomposition processes of the plant litter. Interestingly the soil in mountain regions is very well apposite for the high productivity and sustainability. Besides in forest areas the altitude is often employed to study the impacts of climatic variables on soil organic matter dynamics (Lemenih and Itanna 2004). Generally, the nutrient transformation and its availability in soil depend on pH, clay minerals, cation and anion exchange capacity (Reddy and Reddy 2010). Usually the content of soil organic matter decreases correspondingly

with the bulk density of the soil also decreases. The bulk density and coarse fragments are directly integrated into a soil quality (Neill et al 2009). As a result of the earlier study, the four dominant and associated tree species inhabited in the study area was considered as present collection site because most of the nutrients are generally rich around the plant species. In the present investigation the studies on physico-chemical properties of the soil has been assessed to understand the seasonal variation of soil nutrients along with altitudes.

MATERIAL AND METHODS

Assortment of collection site: The earlier ecological examination under Veerakkal forest area, Karamadai range illustrated the occurrence of pure dominant patches of *Pongamia pinnata*, co-dominant species of *Terminalia arjuna* and associated species like *Gardenia resinifera* and *Celtis phillipensis* with the pedestal on the good IVI value of tree individuals observations. Therefore four dominant and associated tree species inhabited in the study area was considered as present collection site because most of the nutrients are generally rich around the plant species.

Description of the study site: Veerakkal reserve forest is a

type of Tropical moist deciduous forest located in the Manar beat, Karamadai Range, Nilgiris South Division, Western Ghats, Tamil Nadu, India. The study area Karamadai range is bounded on east by Annur, south by Periyayakkanpalayam, Coonoor towards west and finally Kotagiri block towards north. Furthermore the Karamadai range embraces Velliankadu, Nellimarathur, Manar and Pillur beats. Veerakkal area covers around 10.80 hectares constrained in the Manar beat. The natural study area lies between 11° 13.849' of Northern latitude and 76° 45.052' of Eastern longitude with the elevation of 476m.

Meteorological data of the study site: Meteorological data of Karamadai range such as temperature, rainfall, rainy days and relative humidity were collected from District Forest Office, Coimbatore Circle, Tamil Nadu, India and from Karamadai weather source (<https://www.worldweatheronline.com/lang/en-in/karamadai-weather/tamil-nadu/in.aspx>).

Geographical location of the study site: Geographical locations of the selected four study sites viz., *Pongamia pinnata* (site I), *Terminalia arjuna* (site II), *Gardenia resinifera* (site III) and *Celtis philippensis* (site IV) was measured by hand GPS (eTrex 10) which is located in Manar beat, Western Ghats, India (Table 1).

Collection of soil samples: On the basis of altitude the soil samples were collected around the selected tree species from different depths viz., A₁ (0-10 cm), A₂ (10-20 cm) and A₃ (20-30 cm) layers during three successive seasons like summer, rainy and winter (March 2018 to February 2019). In each study site, a total of 15 soil samples were collected by five replicates. Thus, at three different depths (A₁, A₂ and A₃) a total of 60 soil samples were collected from the four study sites on successive seasonal intervals (15 × 4 = 60) and brought into the laboratory in sterile polythene bags aseptically and maintained at the room temperature for further screening.

Physico-chemical Properties of Soil

Soil texture: The percentage of soil texture viz., sand, silt and clay was determined by calculating the proportion of different soil particles using sieves with mesh of different particle size (Piper 1950).

Soil moisture: A known amount of weighed soil samples were dried in an oven at 105°C for overnight (12 hrs.) and

reweighed. The loss of weight of soil denotes the moisture content and was calculated (Misra 1968).

$$\text{Percentage of moisture content} = \frac{\text{Fresh weight of soil} - \text{Dry weight of soil}}{\text{Dry weight of soil}} \times 100$$

Water holding capacity (WHC): Twenty five grams of air dried soil samples were crushed and passed through 0.5 mm sieve. A circular Wattman No.44 filter paper was placed on the perforated bottom of crucible and weighed (W₁). The sieved soil samples were placed in the crucible over the filter paper and the crucibles were kept in water to the depth of 1cm in a Petridish. After 24 hours, the weight of wet soil with crucible and filter paper was determined (W₂). Then it was dried in an oven at 105°C for 48 hours and the dry weights (W₃) of soil samples were recorded. Amount of water absorbed by the filter paper was recorded separately (W₄). Water holding capacity was followed by the method of Piper (1950).

$$\text{WHC (\%)} = \frac{W_2 - W_3 - W_4}{W_3 - W_1} \times 100$$

Where, W₁ = weight of filter paper + crucible; W₂ = weight of crucible + saturated soil + filter paper; W₃ = dry weight of crucible + soil + filter paper; W₄ = amount of water absorbed by the filter paper

Bulk density: This was estimated by taking out a core of undisturbed soil by cutting a small pit. The collected soil samples were oven-dried and weighed. The volume of the soil samples were measured by taking sand in a measuring cylinder and then pouring it down in the pit formed by taking out of the sample until the pit is just full. The volume of the sand used to fill the pit was noted and the bulk density of the study area was calculated (Black 1965).

$$\text{Bulk density (g/ccs)} = \frac{\text{Dry weight of soil taken from the pit}}{\text{Volume of sand packed in the pit}}$$

Soil porosity: The pore size distribution of undisturbed and compacted samples of each subsoil material was determined by porosimetry method (Black 1965).

$$\text{Porosity} = \frac{2.65 - \text{Bulk density}}{2.65} \times 100$$

Where, 2.65 - is the true density of the soil

Chemical properties: Soil pH was measured by using soil and water in the ratio of 1: 2.5. The pH of the soil samples were determined by using a standard dynamic digital pH meter (LMPH-10) (Piper 1950). Soil organic carbon was estimated by using the titration method (Piper 1950). Available nitrogen, phosphorous and potassium were analysed at Tamil Nadu Agricultural University, Coimbatore, India. Available nitrogen was determined using distillation

Table 1. The geographic location of the study area

Location	Geographic's	Elevation (m)
Site I	N11° 13.849' E76° 45.052'	476
Site II	N11° 13.751' E76° 45.073'	465
Site III	N11° 13.780' E76° 45.063'	472
Site IV	N11° 13.847' E76° 45.298'	481

method (Subbiah and Asija 1956). Available phosphorous was measured by colorimeter using the method (Jackson 1958). Available potassium was determined by flame photometric method (Jackson 1973).

Statistical analysis: The significant differences among means were calculated by using Duncan's multiple range test (DMRT) at $p < 0.05$. Multi-factor analysis was used to find out the interaction with species, seasons and their replicates. The statistical analysis was performed using SPSS (version 16.0) software (Duncan 1957).

RESULTS AND DISCUSSION

Meteorological information: Considering the elevation and proximity, the monthly average temperature of the study area was ranged between 23.9°C-30.3°C. The intensity of solar radiation was generally high in March - May. The monthly rainfall ranged from 4.95 to 134.9 mm. The total rainfall for 2018-2019 (March to February) was 536.43 mm. The maximum rainy days was observed in May with moderate rainfall (125.08 mm). The annual relative humidity ranged between 47%-70%. The similar ranges were observed by Ramya et al (2020).

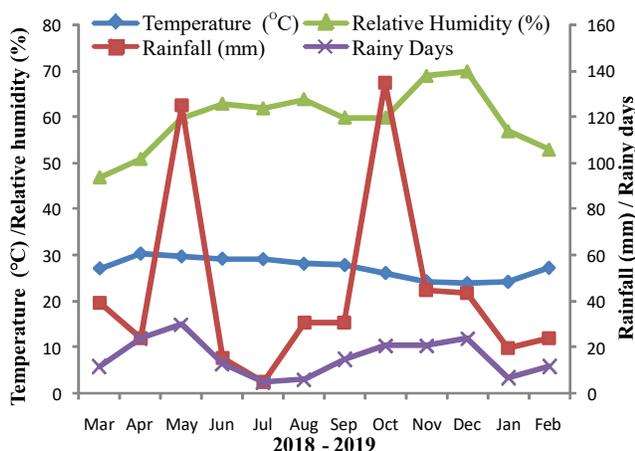


Fig. 1. Omrothermic graphical representation of the study area

Soil texture (%): The texture of soil did not showed any trend with depth. The soil texture was statistically significant in all the three seasons. The total percentage of soil texture ranged between 52.27 to 75.03 % in sand, 12.47 to 25.5 % in silt and 5.32 to 28.64 % in clay for all the three seasons (Figure 2). The current data also indicate that good porosity and high water retaining capacity of soil. Usman et al (2000) analysed sand, silt and clay particle values of *Quercus leucotrichophora* forest in Kumaun Himalaya. The results indicated that 56.1, 25.0 and 18.6% of soil textures like sand, silt and clay particles respectively. However, Khera et al (2001) observed the range of sand particle between 90.9 to

91.3%, silt particle between 3.8 to 4.3% and between in the range of 1.0 to 1.2% in Kumaun mixed broadleaf forests. The nature of soil in the *Pongamia pinnata*, *Terminalia arjuna* was sandy clay loam soil and *Gardenia resinifera*, *Celtis phillipensis* was sandy loam soil. Among the seasonal variations in four study sites, particularly in rainy season the sand and silt particles were registered maximum 75.03% and 25.5%, respectively on 0-30 cm variable depths, while the above suggested values were slightly higher than clay particle. However the clay particle was higher in winter season (28.64 %) and low in summer season.

Soil moisture content (%): The soil moisture content was increased significantly on increasing variable soil depth (0-30 cm) across the study sites for all the three different seasons (Table 2). The total percentage of soil moisture content ranged between 8.85 to 38.62%. For all the three seasons, the species *Pongamia pinnata* showed maximum moisture content (38.62%) followed by *Terminalia arjuna*, *Gardenia resinifera* and *Celtis phillipensis* in 20-30 cm depth. Likewise, Joshi and Negi (2015) were recorded the moisture content of soil, which was ranged from 15-33% in Oak forest of Western Himalaya. This value was closer to the values of current study. The higher moisture content was recorded in the rainy season and it was simultaneously decreased in the summer season and also the sub soil layer possessed higher moisture content than the surface soil. Similarly, Sheikh and Kumar (2010) mentioned that the deep soil rich in organic matter and detritus layer in the forests might have resulted into higher water retention capacity of layers.

Water holding capacity (%): The water holding capacity of four study sites were increased with incremental depth of soil for all the three different seasons and was significant. The total water holding capacity for all sites ranged between 15.69 to 41.82% (Table 2.2). Similar in SMC the water holding capacity also high (41.82%) for *Pongamia pinnata* when compared with other three sites for all the three different seasons followed by *Terminalia arjuna*, *Gardenia resinifera* and *Celtis phillipensis* for 20-30 cm depth. The higher water holding capacity for all the four study sites indicates that the natural forest contains highly rich nutrients and also good physical condition of soil. The similar ranges were observed by Joshi and Negi (2015) and Geeta et al (2016). The high water holding capacity of clay makes it more stable than the other particles. The high stability of soil enables it to hold nutrient cations for nutrient exchange that converts the nutrients in plant acceptable form. Likewise, the higher clay content in the soil shows higher cation exchange capacity and ultimately it increases the fertility of soil (Chinevu et al 2013). Sharma et al (2010) screened the WHC value of 67.17 percentages for *Quercus leucotrichophora* forest, 22.50 to

Table 2. Soil physical parameters in different horizons of four study sites

Seasons Mar. 2018 –Feb. 2019	2.1. Soil moisture (%)											
	<i>Pongamia pinnata</i> (Site-I)			<i>Terminalia arjuna</i> (Site-II)			<i>Gardenia resinifera</i> (Site-III)			<i>Celtis phillypensis</i> (Site-IV)		
Layers	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃
Summer (Mar-May)	12.80	13.42	15.63	10.93	12.12	15.50	9.22	13.44	15.06	8.85	13.68	14.41
Rainy (Jun-Nov)	35.31	38.10	38.62	31.87	35.09	36.90	20.12	22.42	26.85	18.86	20.19	23.17
Winter (Dec-Feb)	22.13	23.85	25.80	17.58	19.86	21.53	16.21	19.33	21.18	17.08	15.95	20.43
F = df _(2,14)	131.212***	159.334**	146.657***	223.434***	254.161***	275.106***	73.051***	13.207*	41.186***	39.669*	26.582***	17.153*
Seasons 2018 – 2019	2.2. Water holding capacity (%)											
Layers	Site-I			Site-II			Site-III			Site-IV		
Summer	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃
Rainy	29.58	29.71	30.97	22.39	26.60	27.91	19.45	22.19	23.58	15.69	17.74	20.10
Winter	36.34	39.36	41.82	32.99	38.89	40.85	27.33	28.02	30.95	23.86	25.97	28.20
F = df _(2,14)	31.31	35.86	38.93	28.90	32.47	36.98	24.89	26.65	28.24	17.11	18.10	25.65
Seasons 2018 - 2019	36.951***	92.087***	64.078***	13.397*	60.296***	29.192*	65.781***	23.335**	55.369***	44.721***	145.426*	28.748***
Layers	Site-I			Site-II			Site-III			Site-IV		
Summer	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃
Rainy	1.23	1.12	0.91	1.28	1.14	0.98	1.39	1.29	1.11	1.33	1.21	1.10
Winter	1.06	1.01	0.92	1.08	1.05	0.87	1.28	1.17	0.98	1.12	1.05	1.03
F = df _(2,14)	1.17	1.07	0.96	1.19	1.06	1.00	1.31	1.19	1.06	1.25	1.14	1.00
Seasons 2018-2019	4.214*	1.407*	0.143*	4.885*	3.279*	14.003***	1.302*	0.251*	1.769*	11.097***	9.915***	5.101*
Layers	Site-I			Site-II			Site-III			Site-IV		
Summer	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃
Rainy	53.74	56.98	65.66	51.62	54.49	62.87	47.70	51.40	58.04	49.96	57.81	58.34
Winter	57.58	61.96	65.36	60.08	60.45	67.02	51.77	55.77	61.21	59.17	60.45	63.09
F = df _(2,14)	55.02	59.62	62.26	55.92	60.15	63.62	50.72	54.94	60.15	52.83	57.06	62.11
Seasons 2018-2019	4.215*	1.407*	0.143*	4.893*	3.284*	13.992***	1.304*	0.251*	1.769*	11.094***	9.913***	5.099*

A₁: 0-10 cm; A₂: 10-20 cm; A₃: 20-30 cm; Values in a column followed by a same letter (s) are significantly (p<0.05) different according to Duncan's Multiple Range Test; * ** *** indicates significant at 0.05 % level; ns - non significant

Table 3. Soil chemical parameters in different horizons of four study sites

3.1. pH												
Seasons	Site-I			Site-II			Site-III			Site-IV		
	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃	A ₁	A ₂	A ₃
2018-2019												
Layers												
Summer	5.59	5.42	5.38	5.48	5.16	4.98	7.08	6.73	6.46	7.31	7.22	7.14
Rainy	5.90	5.71	5.63	5.80	5.53	5.42	7.32	7.05	6.98	8.09	7.90	7.63
Winter	5.68	5.61	5.34	5.56	5.33	5.15	7.17	7.05	6.88	8.06	7.51	7.40
F = df _(2,14)	62.606***	23.436***	15.038***	13.860***	6.002**	16.023***	5.280*	13.993***	44.247***	56.855***	30.090***	10.734***
Seasons												
3.2. Soil organic carbon (%)												
2018 - 2019												
Layers												
Summer	2.72	1.87	1.38	2.53	1.12	1.08	2.02	1.15	1.04	1.78	1.51	1.23
Rainy	2.95	2.51	2.21	2.71	1.31	1.13	2.51	1.52	1.19	1.97	1.78	1.40
Winter	3.20	2.85	2.11	2.86	1.83	1.74	2.78	1.81	1.57	2.32	1.78	1.67
F = df _(2,14)	33.027***	206.163**	128.415**	14.183*	90.735*	71.717*	74.041*	61.851**	38.034*	55.305***	3.229*	29.573***
Seasons												
3.3. Available nitrogen (kg/ha)												
2018 - 2019												
Layers												
Summer	437.4	422	408.2	486.8	482.4	472.6	389.2	355.6	341.6	354.0	348.0	340.4
Rainy	456.8	451	437.4	531.6	520.2	506.8	449.2	426.6	419.4	372.6	365.8	345.8
Winter	388.2	353.2	340.6	426.2	419.4	407.6	354.8	346.4	325.4	325.0	316.4	309.4
F = df _(2,14)	125.300***	483.992*	343.058*	495.530**	591.128**	109.430*	922.825***	920.197*	177.030*	259.213**	408.235***	161.670***
Seasons												
3.4. Available phosphorus (kg/ha)												
2018 -2019												
Layers												
Summer	33.84	32.78	31.44	29.62	28.48	27.68	19.44	16.92	15.50	16.96	15.74	14.98
Rainy	36.54	34.46	32.42	31.80	31.32	28.82	26.80	24.34	21.12	20.80	18.54	15.78
Winter	40.16	37.74	34.68	34.62	33.92	30.88	29.80	27.76	24.72	24.98	23.60	20.54
F = df _(2,14)	191.181*	73.541*	32.816***	102.570**	66.456*	21.728*	127.559**	454.734*	222.752*	263.766***	156.001*	170.048*
Seasons												
3.5. Available potassium (kg/ha)												
2018 -2019												
Layers												
Summer	295.8	286.2	274.6	285.4	277.4	260.4	326.6	309.8	281.4	247.4	234.6	217.8
Rainy	315.8	305.8	285.8	297.2	286.6	277.6	338.0	330.2	318.8	264.8	259.6	236.6
Winter	320.2	316.2	293.2	314.6	307.2	295.0	356.2	349.4	339.2	295.6	289.8	260.4
F = df _(2,14)	45.626***	68.117**	36.846***	84.507**	103.331**	109.231***	155.507***	174.552***	511.484***	272.457*	452.972*	211.659***

A₁: 0-10 cm; A₂: 10-20 cm; A₃: 20-30 cm; Values in a column followed by a same letter (s) are significantly (p<0.05) different according to Duncan's Multiple Range Test; * ** *** indicates significant at 0.05 % level; ns - non significant

38.60% for *Quercus floribunda* forest and 99.91% for *Quercus semecarpifolia* forest in Mandal Chopta under Chamoli Garhwal. The values recorded in the present study also indicated that more or less comparable WHC values.

Bulk density (g/ccs): The soil bulk density of the experimental sites during different seasons is exhibited that the bulk density varied from 0.87 to 1.39 g/ccs (Table 3). Generally the bulk density of four different soil samples was decreased with increasing soil depth which indicates statistically significant differences. Contradictory to the previous result, the highest bulk density (1.39 g/ccs) was in *Gardenia resinifera* as compared with other three species for all the three seasons. In *Gardenia resinifera*, soil bulk density

Table 4. F - value and significance of multi-factor analysis of soil particles under the study area

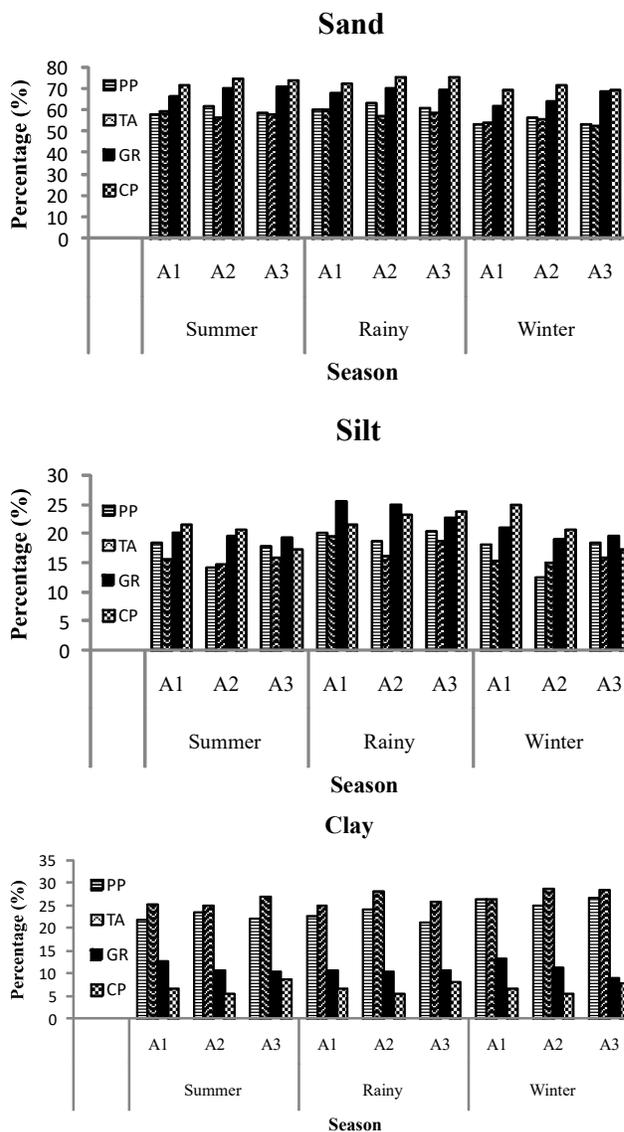
Source	Particles	Factor with significance
4 Species (3,179)	Sand	1.191***
	Silt	192.400***
	Clay	3.344***
3 Seasons (2,179)	Sand	210.161***
	Silt	175.167***
	Clay	21.664***
5 Replicates (2,179)	Sand	23.811***
	Silt	33.700***
	Clay	1.788 ^{ns}
Species* Seasons (6,179)	Sand	3.697***
	Silt	3.060**
	Clay	10.530***
Species* Replicates (6,179)	Sand	16.210***
	Silt	17.335***
	Clay	20.984***
Seasons* Replicates (4,179)	Sand	0.926 ^{ns}
	Silt	0.516 ^{ns}
	Clay	1.832 ^{ns}
Species* Seasons* Replicates (12,179)	Sand	3.432***
	Silt	4.093***
	Clay	3.522***

F: Factor; *, ***, **** indicates significant at 0.05 % level; ns - non significant

Table 5. F - value and significance of multi-factor analysis of the soil characteristics

Source	SM	WHC	BD	SP	pH	OC	N	P	K
4 Species (3,179)	152.714***	632.529***	3.245*	3.249**	3.198***	466.154***	7.072***	5.002***	3.304***
3 Seasons (2,179)	81.099***	163.278***	64.835***	64.847***	141.687***	1.639***	534.985***	492.781***	916.330***
5 Replicates (2,179)	1.029***	466.937***	18.399***	18.401***	43.151***	481.861***	5.037***	1.429***	1.700***
Species* Seasons (6,179)	1.593 ^{ns}	4.525***	2.145*	2.147*	1.612 ^{ns}	73.271***	17.109***	6.174***	7.457***
Species* Replicates (6,179)	73.625***	9.907***	4.198***	4.198***	47.115***	15.372***	215.227***	70.419***	44.830***
Seasons* Replicates (4,179)	0.611 ^{ns}	5.279***	1.006 ^{ns}	1.008 ^{ns}	0.504 ^{ns}	2.070*	1.094 ^{ns}	17.534***	6.234***
Species* Seasons* Replicates (12,179)	1.62 ^{ns}	2.4**	1.016 ^{ns}	1.016 ^{ns}	4.080***	10.097***	12.333***	1.442 ^{ns}	10.732***

SM: Soil Moisture; WHC: Water Holding Capacity; BD: Bulk Density; SP: Soil Porosity; OC: Organic Carbon; N:Nitrogen;P:Phosphorous; K:Potassium; *, ***, **** indicates significant at 0.05 % level; ns - non significant



PP: Pongamia pinnata ; TA: Terminalia arjuna ; GR: Gardenia resinifera ; CP: Celtis philippensis

Fig. 2. Variations in soil particles (%) due to different seasons in variable depths under study sites

was maximum (1.39 g/ccs) and it was followed by *Celtis phillipensis*, *Terminalia arjuna* and *Pongamia pinnata* for 0-10 cm depth. Likewise, the same trend was observed for the depths of 10-20 cm and 20-30 cm for all the sites. The results are in line with the findings of Atiku and Noma (2011) and Chinevu et al (2013) reported that the bulk density ranged from 1.68 to 1.78 g/ccs in Southern Guinea forest of Nigeria, which was quite higher compared to the present study. However, in each site the top soil (A₁) layer recorded significantly higher bulk density and it was maximum in summer season.

Soil porosity (%): Porosity of soil increased with incremental depth of all soil samples (Table 4) and was statistically significant. The total soil porosity ranged between 47.70 to 67.02 %. The summer season expressed highest porosity of the soil which was observed in *Pongamia pinnata* (65.66%) followed by *Terminalia arjuna*, *Celtis phillipensis* and *Gardenia resinifera* for 20-30cm depth. Normally, a high sand particle has no ability to retain water and good water retention capacity of soil finally affects soil fertility. Interestingly the clay soil has the least percentage of porosity which ultimately helpful for good retaining capacity (Chinevu et al 2013). Though in both rainy and summer seasons the species *Terminalia arjuna* was recorded maximum porosity (67.02 and 63.62%) and minimum was in *Gardenia resinifera* (61.21 and 60.15%) for 20-30 cm depth. The soil porosity was significantly higher at sub soil layer in all the four study sites whereas the top soil layer has low porosity which increases the water holding capacity and soil fertility.

Soil pH: The pH decreased with increasing soil depth for all the three seasons (Table 3.1) and significantly varied between the three layers. The total soil pH of the *Pongamia pinnata* ranged from 5.34 to 5.90 followed by *Terminalia arjuna*, *Gardenia resinifera* and *Celtis phillipensis* for all the three seasons in different horizons. Sharma et al (2010) assessed the pH values of *Quercus semecarpifolia* forest as ranged from 5.80 to 6.70 in Pauri Garhwal, Uttarakhand. The determined soil pH was higher in site IV and lower value was considered in site II during all the three seasons. The soil pH was slightly acidic nature in site I and II with decreasing depth wise and it was slightly alkaline nature in study site III and IV observed between the sites of each and also in layers. However the soil pH under all the four different sites followed the same pattern as it was observed higher in rainy season followed by winter and summer season. This may be due to the presence of high organic matter content and undisturbed condition of the natural forest soils. The dissimilar observations were recorded by Uchida and Hue (2000) and Salim et al (2015). Also, Saha et al (2018) screened the seasonal induction of pH level on Garhwal Himalayas that

indicated overall highest range of pH (6.96) during summer season and the minimum pH during rainy season (6.10).

Soil organic carbon (SOC) (%): The organic carbon of four different soil samples was decreased with an increasing soil depth with significant differences. The total organic carbon for ranged between 1.04 to 3.20% during all the three seasons. The highest soil organic carbon (%) was in winter season followed by rainy and summer season (Table 3.2). The soil organic carbon were slightly differed among the three seasons. This is in agreement with the concept of Cancela et al (2002) and Strahm and Harrison (2007) who proved that the nutrient availability in soil varies during the growing seasons when depending on the prevailing environmental conditions and some characteristics of the soil. In winter season the highest percentage of SOC was 3.20% in *Pongamia pinnata* followed by *Terminalia arjuna*, *Gardenia resinifera* and *Celtis phillipensis* secluded in the A₁ surface layer. These findings were similar to the concept of Ogundele (2012) who explained the importance of seasons that are highly significant factor for both organic and nitrogen content availability in the soil.

Available nitrogen (kg ha⁻¹): The available nitrogen content of the four different soil samples were decreased with an increasing soil depth with significant differences. The total available nitrogen content was ranged between 309.4 to 531.6 kg ha⁻¹ for all the three seasons (Table 3.3). Jina et al (2011) observed 0.19% of available nitrogen in Central Himalaya. Comparatively the values represented were much higher than that of already available reports. From the study the higher available nitrogen content was determined in rainy season followed by summer season. The least N content was in the winter season. In rainy season, the highest nitrogen content of the soil was in *Terminalia arjuna* (531.6 kg ha⁻¹) followed by *Pongamia pinnata*, *Gardenia resinifera* and *Celtis phillipensis* for 0-10 cm depth. Generally in all the three seasons the A₁ layer (0-10 cm) registered significantly higher nitrogen content than the A₂ and A₃ layers. The effects of seasons and various altitudinal effects upon nitrogen content accumulation showed significant changes. The reasons for occurrence of more nitrogen in the A₁ layer is due to higher population of nitrogen fixing organism restricted in the surface layer and also due to increased biological nitrogen fixation along with increased mineralization rates. This is in agreement with the results of Bergeron et al (2002) and Saha et al (2018).

Available phosphorous (kg ha⁻¹): The available phosphorous content of four different soil sites were decreased with an increasing soil depth and was differed significantly. The total available phosphorous content ranged from 14.98 to 40.16 kg ha⁻¹ for all the three seasons (Table

3.4). In natural forest in winter season was higher followed by rainy and the least was in summer. During the winter season, highest value of available P was registered in *Pongamia pinnata* (40.16 kg ha⁻¹) followed by *Terminalia arjuna*, *Gardenia resinifera* and *Celtis phillipensis* for 0-10 cm depth. The phosphorus content of PauriGarhwal for *Q. semecarpifolia* forest ranged between 7.20 and 14.30 kg ha⁻¹ (Sharma et al 2010) and 13.80 to 23.20 kg ha⁻¹ for *Q. floribunda* forest and between 11.50 and 31.90 kg ha⁻¹ in Pauri region for *Q. leucotrichophora* forest, Garhwal Himalaya. The values of phosphorous in oak and pine forests were comparatively dominant (14.40 to 21.60 kg ha⁻¹ range) due to more accumulation of minerals in the winter season (Bhandari et al 2000).

Available potassium (kg ha⁻¹): The available potassium content was decreased with an increasing soil depth which was significant (Table 3.5). The total available potassium for all ranged between 217.8 to 356.2 kg ha⁻¹ for all the three seasons. The available potassium content in the soil also followed the same trend as phosphorous, the maximum amount of potassium was observed under natural forest during winter season and also minimum was in the summer season. In winter season, the maximum potassium content in the soil samples were in *Gardenia resinifera* (356.2 kg ha⁻¹) followed by *Pongamia pinnata*, *Terminalia arjuna* and *Celtis phillipensis* for A₁ surface layer. It may be attributed to increase the floristic composition of all the study sites. Semwal (2006) observed that potassium content ranged between 180.9 and 215.7 kg ha⁻¹ in PauriGarhwal for *Quercus leucotrichophora* forest, which are comparably lowest as compared with the present study. Kumar et al (2004) reported potassium ranged from 153.2-408.8 kg ha⁻¹ in TehriGarhwal for *Quercus leucotrichophora* forest, which also showed closer values to the present study.

Multifactor interaction: The experimental results of soil physico-chemical parameters were significant. The multifactor analysis depicted that the species, seasons and replicates of physico-chemical parameters were significantly influenced (Table 4 and 5). The results of two way interactions were more or less significant except in species × replicates in soil moisture, seasons × replicates in texture, soil moisture, bulk density, soil porosity, pH and nitrogen. The results of three way interactions also showed significant result except at species, seasons and replicates in soil moisture, bulk density, porosity and phosphorous. From the data analyzed, it was revealed that the physico-chemical properties of soil in the study area were varied across the sites and significantly varied within the seasons.

CONCLUSION

The species *Pongamia pinnata* in study site I and

Terminalia arjuna in study site II registered more nutrients availability than other two study sites. Therefore dense vegetation of study sites should be protected in future for enrichment of soil nutrient supply. Therefore, it may be recommended that further studies on the aforementioned key point, in order to ascertain the possible consequence of alteration in soil chemical properties on tropical moist deciduous forest vegetation under Veerakkal forest area are needed and thus set priorities in conservation and restoration of undisturbed reserve forest. The study therefore recommends that more strategy should be carried out on the study area so as to clearly understand the nutrient status of soils in the reserve forest.

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REFERENCES

- Atiku M and Noma SS 2011. Physicochemical properties of the soils of Wassaniya forest reserve, Tangaza local Government, Sokoto State. *Nigerian Journal of Basic and Applied Sciences* 19(1): 93-96.
- Bergeron Y, Leduc A, Harvey B and Gauthier S 2002. Natural fire regime: A guide for sustainable management of the Canadian boreal forest. *Silva Fennica* 36(1): 81-95.
- Bhandari BS, Mehta JP and Tiwari SC 2000. Dominance and diversity relation of woody vegetation structure along an altitudinal gradient in a montane forest of Garhwal Himalaya. *Journal of Tropical Forest Science* 12(1): 49-61.
- Black CA 1965. *Methods of soil analysis Part I*. American Society of Agronomy. Inc. Publisher, Madison, Wisconsin, U.S.A. 1185-1187.
- Cancela RC, De Abreu CA, Paz-Gonzalez A 2002. DTPA and Mehlich-3 micronutrient extractability in natural soils. *Communications in Soil Science and Plant Analysis* 33(15): 2879-2893.
- Chinevu CN, Unanaonwi OE and Amonum JI 2013. Physical and chemical characteristics of forest soil in southern Guinea savanna of Nigeria. *Agriculture, Forestry and Fisheries* 2(6): 229-234.
- Duncan BD 1957. Multiple range test for correlated and heteroscedasticity means. *Biometrika* 13(1): 359-364.
- Geeta T, Deepti K, Lata R, Poonam Y, Chitra P, Sunita B, Vinod K, Neeta J and Prasoon KJ 2016. Assessment of physicochemical properties of soils from different land use systems in Uttarakhand, India. *Journal of Chemical Engineering and Chemistry Research* 3(11): 1114-1118.
- Jackson ML 1958. *Soil chemical analysis*. Prentice Hall of India Private Ltd., New Delhi, 498.
- Jackson ML 1973. *Soil chemical analysis*, Prentice Hall of India Pvt. Ltd., New Delhi, 38-56.
- Jina BS, Bohra CS, Lodhiyal LS and Sah P 2011. Soil characteristics in oak and pine forests of Indian Central Himalaya. *International*

- Journal of Science and Research* **3**(1): 19-22.
- Joshi G and Negi GCS 2015. Physico-chemical properties along with soil profiles of two dominant forest types in Western Himalaya. *Current Science* **109**(4): 798-803.
- Khera N, Kumar N, Ram J and Tewari A 2001. Plant biodiversity of assessment in relation to disturbances in mid elevation forest of Central Himalaya, India. *Journal of Tropical Ecology* **42**(1): 83-95.
- Kumar M, Sharma CM and Rajwar GS 2004. Physico-chemical properties of forest soil along with altitudinal gradient in Garhwal Himalaya. *Journal of Hill Research* **17**(2): 60-64.
- Lemenih M and Itanna F 2004. Soil carbon stocks under various vegetation types and its dynamics following deforestation and conservation to arable lands along an elevation gradient in southern Ethiopia. *Geoderma* **123**(2): 177-188.
- Mahajan S and Billore D 2014. Assessment of physico chemical characteristics of the soil of Nagchoon Pond Khandwa, Madhya Pradesh, India. *Research Journal of Chemical Sciences* **4**(1): 26-30.
- Misra R 1968. *Ecology Work Book*. Oxford and IBH Publishing Co., New Delhi. 232-244.
- Neill B, Grossman J, Tsai MT, Gomes JE, Lehmann J, Peterson J, Neves E and Thies JE 2009. Bacterial community composition in Brazilian Anthrosols and adjacent soils characterized using culturing and molecular identification. *Microbial Ecology* **58**(1): 23-35.
- Ogundele AO 2012. Variation in the physico-chemical properties of Badagry and Ikorodu Soils, Lagos Nigeria. *International Journal of Humanities and Social Science* **2**(8): 244-258.
- Piper GS 1950. *Soil and plant analysis*. Adelaide University, Hassell Press, Australia. 368.
- Ramya EK, Sharmila S and Mownika S 2020. Phytosociological Assessment of Tree Vegetation in Tropical Moist Deciduous Forest of Veerakkal area, Nilgiris, Western Ghats, India. *Indian Journal of Ecology* **47**(2): 480-484.
- Reddy TY and Reddy GHS. 2010. *Principles of Agronomy*. Kalyani Publishers, New Delhi. 527.
- Saha S, Rajwar GS and Munesh K 2018. Soil properties along with altitudinal gradient in Himalayan temperate forest of Garhwal region. *Acta Ecologica Sinica* **38**(1): 1-8.
- Salim M, Pramod K, Gupta MK and Saurabh K 2015. Seasonal variation in some chemical characteristics of the soil under different land uses of Jhilmil Jheel Wetland, Haridwar-Uttarakhand, India. *International Journal of Scientific and Research* **5**(10): 1-9.
- Semwal S 2006. *Studies on phytosociology, diversity patterns and competition along an altitudinal gradient in a part of lesser Himalaya in Garhwal, Uttaranchal* (D.Phil. Thesis) HNB Garhwal University, Srinagar (Garhwal), Uttarakhand, India.
- Sharma CM, Baduni NP, Gairola S, Ghildiyal SK and Suyal S 2010. The effect of slope aspects on forest compositions, community structures and soil properties in natural temperate forests in Garhwal Himalaya. *Journal of Forest Research* **21**(3): 331-337.
- Sheikh MA and Kumar M 2010. Nutrient status and economic analysis of soils in oak and pine forests in Garhwal Himalaya. *Journal of American Science* **6**(2): 117-121.
- Strahm BD and Harrison RB 2007. Mineral and organic matter controls on the sorption of macronutrient anions in variable charge soils. *Soil Science Society of America Journal* **71**(6): 1926-1933.
- Subbiah BV and Asija GL 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**(8): 259-260.
- Uchida R and Hue NV 2000. Plant nutrient management in Hawaii's Soils, Approaches for tropical and subtropical agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa, pp. 31-55.
- Usman S, Pratap Singh S and Bargali SS 2000. Fine root decomposition and nitrogen mineralisation patterns in *Quercus leucotrichophora* and *Pinus roxburghii* forests in central Himalaya. *Forest Ecology and Management* **131**(1): 191-199.



Carbon Storage Dynamics of different Forest Types in Central, Nepal

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Abstract: Forest ecosystems are natural carbon sink, and play vital role in sequestering the atmospheric carbon into biomass and soil. A study was carried out to evaluate carbon storage capability of three major forest types, representing different physiographic regions in Makawanpur districts of central Nepal. The inventory for determining above and below ground forest biomass was carried out using systematic sampling. Altogether, 68 circular sample plots were laid out systematically in three different forests. Forest biomass was calculated using standard allometric models. Soil samples were taken from soil profile upto 30 cm depth at the interval of 10 cm. Total biomass carbon in hill sal forest, pine forest and *Schima-Castanopsis* forest was found 121.46 t ha⁻¹, 96.26 t ha⁻¹ and 82.91 t ha⁻¹, respectively. Soil organic carbon stocks in hill sal forest, pine forest and *Schima-Castanopsis* forest was found 53.90 t ha⁻¹, 41.30 t ha⁻¹ and 48.05 t ha⁻¹, respectively. Total carbon stocks in hill sal forest was found 1.27 times higher than pine forest and 1.34 times higher than *Schima-Castanopsis* forest. Hence, forest ecosystems can play an important role on carbon sequestration and sustainable management of such ecosystem is crucial to combat global climate change.

Keywords: Biomass, Carbon, Sal forest, Pine forest, *Schima-Castanopsis* forest

One of the pressing environmental challenges facing human today is climate change on Earth. The reason for this is the increase in human-caused greenhouse gases (GHGs), which has led to health, ecological and humanitarian crises (IPCC 2007). Response to this concern have focused on reducing emissions of GHGs particularly, carbon di-oxide (CO₂) and on estimating carbon absorbed by and stored in forest, soil and other pools. Forests are of critical importance globally; they are an important carbon sink, have a pivotal role for climate regulation and provide many other ecosystem services (Lal 2005, Zhao et al. 2019). Forest vegetation and soils share about 60% of the world's terrestrial carbon, of which terrestrial aboveground carbon storage accounts about 80% of global vegetation carbon and below ground carbon pool accounts for more than 40% of the global soil carbon (Winjum et al. 1992, Kirschbaum 1996). Forest vegetation and soils are therefore viable sinks of atmospheric carbon (C) and may significantly contribute to mitigation of global climate change by sequestering carbon from atmosphere (Bajracharya et al 1998, Lal 2005, Dogra and Chauhan 2016). Thus, estimating stock of carbon under existing forest ecosystem, and their distribution within the soil profile is essential as it enable us to project carbon sequestration overtime.

The carbon stock in forest ecosystem varies according to geographical location, plant species and age of the stand (Van Noordwijk et al 1997). Carbon storage in forest ecosystem can be categorized into vegetation carbon and

soil carbon (Kirschbaum 1996, Lee et al 2014). Globally, deforestation and forest degradation mainly contributes in GHGs emission (IPCC, 2007). It has been estimated that deforestation combined with forest degradation has contributed about 20% of the GHGs emission which is more than emission by the whole transportation system (Stern, 2007). Thus, reducing carbon source and increasing carbon sink can be achieved only by protecting and conserving pools in existing forest ecosystem (Brawn *et al.*, 1996; Hamburg, 2000). It is important that complementary efforts must be made to enlarge the sinks of these gases. One important cost effective approach to sequester atmospheric C in expanding biological sinks is forest (Lal 2005, Chauhan et al 2016a, b, Ghimire et al 2018).

This study focuses on three different forest types viz Hill Sal forest, Pine forest and *Schima castanopsis* forest in three different ecological zones. Forest area in Nepal covers about 45% of the landmass of the country (DFRS 2015). Community Forestry has been accorded the highest priority of Nepal's forestry sector and has been widely acclaimed as a successful forest management approach. More than one third (about 37.5%) of national forests in Nepal is under the community forest management where 2.9 million households are included as beneficiary users (DoF 2017). As reported, Nepalese forests have served as a carbon sink over the past few decades and stores about 1160 million tonnes of total carbon stock (DFRS 2015). More recently the opportunity for management of forests for enhancement of carbon stocks

and as a sink of greenhouse gases (GHGs) has emerged as a potential benefit for local communities participating in carbon trading under REDD agreements (Shrestha et al. 2013, Pandey et al 2016). Accurate estimation of forest ecosystem carbon storage is a major issue that has drawn wider attention of researches in the field of global climate change. In this context, this study intended to analyze the carbon storage capacity of three different forest types by quantifying and evaluating the vegetation and soil carbon representing different ecological regions in central Nepal.

MATERIAL AND METHODS

Study area: The study was conducted in three major forest types of three different community managed forests of Makawanpur district representing two physiographic region of Nepal (Table 1). Located between 27°21' and 27°40' N latitude and between 84°41' and 84°35' E longitude, Makawanpur District lies in the hilly region of Central Nepal. The district broadly divided into two physiographic region i.e. Mahabharata hills in the north and the Churia hills (also called Shiwaliks) in the south. About 75% landmass of the districts is mountainous and rest 25% is dead hills to plain lands (DDC 2018). The total area of the district is 2,418 km² with an altitudinal variation of 166m and 2584m above the mean sea level (CBS 2015). The district exhibits wide range of climate, from lower tropical in the south to temperate in the north, with 21°C mean annual temperature and 2100 mm average annual precipitation (DHM 2015).

All three community forest lies in Makawanpur district. Sundar CF covers an area of 109.5 ha and lies in Hetauda Sub-Metropolitan city within the altitudinal range of 460-780m. Similarly, Siddhakali CF lies in Daman area and Chandragiri CF in Chitlang area of area of Makawanpur district covering area of 83.33 ha and 492 ha, respectively (Table 1).

Sampling design: Systematic sampling method was used to carry out forest inventory. Sample plots were laid out as per the Community Forestry Inventory Guideline of Government of Nepal (DoF 2004). Concentric circular plots were established systematically to measure forest biomass. Trees (dbh > 30cm) and poles (dbh 10 to 30 cm) were measured within the radiuses 12.61 m and 5.64m, respectively.

Saplings and leaf litters, herbs, and grasses were measured within established circle of radiuses 2.82 m and 0.56 m respectively (Fig. 2). A total of 68 plots were established within the study area for the study.

Biophysical measurement: Systematic sampling with 0.5% sampling intensity was used to measure the forest biomass and carbon. All the forests were found to vary with tree sizes and density. There were 13, 10, and 45 number of sample plots employed in Hill Sal, Pine, and Schima- Castanopsis forest respectively to forest inventory. The plots were circular in shape, and the sizes varied as follows: trees (Size = 500 m²), poles (Size = 100 m²), saplings (Size = 25 m²) and leaf litters, herbs and grass (Size= 1 m²). Diameter at breast height (1.3 m from the ground level) was measured with diameter tape and tree height was measured with the Laser Rangefinder. All the litters, herbs and grasses inside the 0.56 m radius plot were clipped and collected, and the fresh weights of the samples were recorded and representative

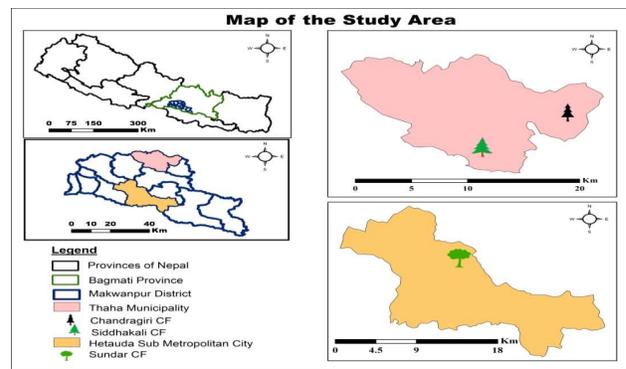


Fig. 1. Map of study area

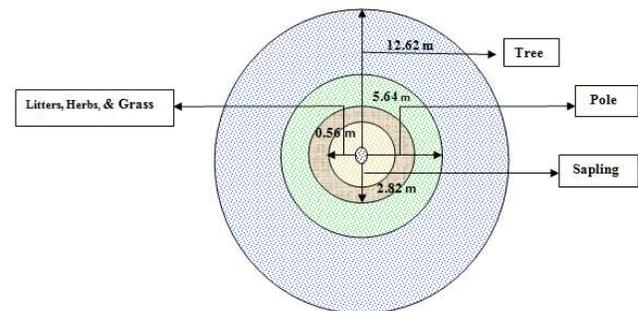


Fig. 2. Sample plot design for the forest inventory

Table 1. District and geographical region wise distribution of studied forest types

Forest types	District	Name of CF	Geographic region/altitude	Major species
Hill Sal (<i>Shorea robusta</i>)	Makawanpur	Sundar CF (109.5 ha)	Mahabharat Foot hills (460-780m)	<i>Shorea robusta</i>
Pine (<i>Pinus roxburghii</i> and <i>Pinus wallichiana</i>)	Makawanpur	Siddhakali CF (83.33 ha)	Mid hills (1231-2300m)	<i>Pinus roxburghii</i> , <i>Pinus wallichiana</i>
<i>Schima-Castanopsis</i>	Makawanpur	Chandragiri CF (492 ha)	Mid hills (900-1700m)	<i>Schima wallichii</i> , <i>Castanopsis indica</i> ,

subsamples were taken to the laboratory for oven drying.

Soil sampling: Soil profile was dug at center part of the each plot up to 30 cm depth of 3 different intervals (0-10 cm, 11-20cm and 21-30 cm). A core ring sampler (10 cm diameter and 5 cm length) was used to take samples of soil for bulk density estimation. All the samples were bagged, labeled and sent to the soil laboratory for further analysis.

Biomass and carbon estimation: Biomass includes all parts such as stem, branch, root, leaves, and undergrowth biomass. The above ground biomass was estimated using the following equation:

Aboveground biomass and carbon estimation: Above ground biomass include above ground tree parts such as stem, branches, leaves and undergrowth biomass. The logarithmic transformation of the allometric formula was used to estimate above ground biomass.

Aboveground tree biomass and carbon estimation: The total above-ground tree biomass was calculated using the equations developed by Chave et al (2005)

$$AGTB = 0.0509 * \rho D^2 H \dots \dots \dots (i)$$

Where,

AGTB = above ground tree biomass (kg)

ρ = Wood specific gravity (g cm^{-3})

D = tree diameter at breast height (cm)

H = tree height (m)

The value of ρ for *Shorea robusta*, *Pinus roxburghii*, *Pinus wallichiana*, *Schima wallichii* and *Castanopsis indica* is 0.880 g cm^{-3} , 0.650 g cm^{-3} , 0.480 g cm^{-3} , 0.690 g cm^{-3} , 0.700 g cm^{-3} , respectively (Jackson 1994).

Above ground sapling biomass and carbon estimation: The following regression model as prescribed by Forest Carbon Measurement Guideline (2010), Ministry of Forest and Environment, Nepal was used to calculate biomass of saplings:

$$\text{Log}(AGSB) = a + b \text{Log}(D) \dots \dots \dots (ii)$$

Where,

Log = natural log (dimensionless)

AGSB = above-ground sapling biomass (kg);

a = intercept of allometric relationship for saplings (dimensionless);

b = slope allometric relationship for saplings (dimensionless); and

D = over bark diameter (cm) at breast height

Leaf litters, herbs and grass (LHG)/ under growth biomass and carbon estimation: To determine the biomass of LHG, samples were taken destructively in the field with in the plot size of 0.56m radius. Collected sample were oven dried for 72 hours at 60°C and oven dry weight was recorded. In the case of leaf litters, herbs, and grass the amount of biomass per unit area was calculated by using the

formula as prescribed Forest Carbon Measurement Guideline (2010), Ministry of Forest and Environment, Nepal:

$$LHG = \frac{W_{\text{field}} * W_{\text{subsample dry}} * 1}{A * W_{\text{subsample wet}} * 1000} \dots \dots \dots (iii)$$

Where,

LHG = biomass of leaf litter, herbs, and grasses (t ha^{-1})

W_{field} = weight of the fresh field sample of leaf litters, herbs and grasses, destructively sampled within an area of size A (g)

$W_{\text{subsample dry}}$ = weight of oven dry sub sample of leaf litter, herb and grasses taken to the laboratory to determine moisture content (g);

$W_{\text{subsample wet}}$ = weight of fresh sub sample of leaf litters, herbs and grasses taken to the laboratory to determine moisture content (g); and

A = size of the area in which leaf litter, herb and grass were collected (ha)

Belowground biomass and carbon estimation:

Below ground biomass includes the roots of trees below the ground. The following relationship was used to estimate the root biomass developed by MacDicken (1997).

$$\text{Below-ground biomass} = 0.15 \times \text{above-ground biomass} \dots \dots \dots (iv)$$

The biomass carbon was calculated using stock method. This value is a typical value of C content in the forest species investigated. The carbon content in biomass (above-ground tree, sapling, leaf litter, herb and grass and below ground) was calculated by multiplying the respective biomass with the IPCC (2006) default carbon fraction of 0.47.

Soil sampling and Soil organic carbon (SOC)

Bulk density: The soil bulk density is the dry weight of soil per unit volume of soil. Soil samples were taken from 0.3 m radius plot. Profile was dug out at the centres of all the plots up to 30 cm depth. For the purpose of estimating bulk density, three individual soil samples of one each from three depths (0-10 cm, 11-20 cm, and 21-30 cm) were collected with the help of a standardized metal Soil Sampling Corer (10cm long and 5cm diameter). Similarly, one composite sample was collected mixing soils from all the three layers in order to determine concentrations of organic carbon.

Oven dry weights of soil samples were determined for moisture correction. The dried soil (for 24 hours at constant temperature of 105°C) was then passed through a 2mm sieve to differentiate stones. The sieved soil was weighed and volume of stones was recorded for stone correction. Following formula was used to calculate the bulk density using stone correction (Pearson et al. 2005).

$$\text{Bulk density} (\text{g cm}^{-33}) = (\text{Oven dry weight of soil in gm}) / (\text{Volume of the soil in cm}^3)$$

Where,

Volume of the soil= Volume of core – Volume of the stone
Soil organic carbon (SOC): Soil Organic carbon (SOC) percent was analyzed using the Walkley-Black wet oxidation method as described by Walkley and Black (1934). This method is based on the oxidation of organic matter by potassium dichromate ($K_2Cr_2O_7$) and sulfuric acid mixture, followed by titration of the excessive dichromate by a ferrous ammonium sulfate ($Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$). SOC was estimated using following formula as reported by (Chhabra et al. 2003).

$$SOC = \rho * d * \%C \dots\dots\dots (V)$$

Where,

SOC = Soil organic carbon stock per unit area (t/ha)

ρ = soil bulk density ($gm\ cm^{-3}$)

d = thickness of horizon (cm)

%C = Organic carbon content %

Estimation of total carbon stock: The carbon stock density of a stratum was calculated by summing the carbon stock densities of the individual carbon pools of that stratum. Total carbon stock is the sum of above-ground vegetation carbon, below ground carbon and soil organic carbon. The following formula was used for computing total carbon stock of the study area:

Total carbon stock = Above ground carbon stock + Below ground carbon stock + Soil organic carbon stock

RESULTS AND DISCUSSIONS

Properties of different forests stand under the study:

Majority of tree size stands were found in all the forest types studied. The total number of trees per hectare of the hill sal

forest stand (123) was higher than the pine forest (109) and *Schima-Castanopsis* Forest (115). Mean dbh of the forest types (including hill sal, pine and *Schima-Castanopsis* forests.) varied from 17.06 cm to 30.14 cm (Table 2). Accordingly mean height of the forest types ranged from 12.35 m to 18.50 m (Table 2). The mean diameter of the forest was higher in hill sal forest (30.14 cm), while it was lower in *Schima-Castanopsis* forests (17.06 cm). However, mean height of the forest was higher in Pine forest (18.50 m) while it was lower in *Schima-Castanopsis* forests (12.35 m). This shows that hill sal forest was denser than both pine and *Schima-Castanopsis* forests. Hill sal forest was also found denser in sapling and regeneration than other two forests.

Aboveground biomass and carbon stock density: Above ground biomass included biomass of trees, saplings, leaf litters, herbs and grasses. Aboveground tree biomass was higher in hill sal forest ($216.45\ t\ ha^{-1}$) than in pine ($175.20\ t\ ha^{-1}$) and *Schima-Castanopsis* forest ($148.36\ t\ ha^{-1}$). Above ground sapling biomass was also found higher in Hill Sal forest ($2.63\ t\ ha^{-1}$) while in Pine and *Schima-Castanopsis* forest it was found $0.78\ t\ ha^{-1}$ and $1.32\ t\ ha^{-1}$, respectively. Accordingly, LHG biomass was found $5.64\ t\ ha^{-1}$, $2.10\ t\ ha^{-1}$ and $3.72\ t\ ha^{-1}$ in hill sal forest, pine and *Schima-Castanopsis* forest, respectively (Table 3).

Total carbon stocks in above ground vegetation was found higher in hill sal forest ($105.62\ t\ ha^{-1}$) than $83.71\ t\ ha^{-1}$ and $72.10\ t\ ha^{-1}$ in pine and *Schima-Castanopsis* forest respectively (Table 4). Higher vegetation carbon stock in hill sal is attributed to the size and height of tree stands and tree density. The tree density and tree size (dbh and height) were higher in hill sal forest compared to pine and *Schima-*

Table 2. Descriptive statistics of measured samples of different forests types

Forest types	Density ha^{-1}	Diameter (cm)			Height (m)		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean
Hill Sal	123	13.00	87.00	30.14	9.00	31.00	17.60
Pine forest	109	11.00	81.00	29.70	10.00	33.00	18.50
<i>Schima-Castanopsis</i>	115	8.00	43.00	17.06	7.00	15.00	12.35

Table 3. Distribution of aboveground biomass in different forests types

Forest types	Above ground tree biomass ($t\ ha^{-1}$)		Above ground sapling biomass		LHG biomass ($t\ ha^{-1}$)		Total above ground biomass ($t\ ha^{-1}$)	p-value ANOVA (test)
	Mean	SD	Mean	SD	Mean	SD		
Hill Sal forest	216.45	31.49	2.63	0.50	5.64	1.13	224.72	0.003*
Pine forest	175.20	28.44	0.78	0.14	2.10	0.40	178.08	0.003*
<i>Schima-Castanopsis</i> forest	148.36	27.67	1.32	0.25	3.72	0.70	153.40	0.003*

* $p < 0.05$ is considered as statistically significant

The mean above ground biomass tree ($t\ ha^{-1}$), sapling biomass and LHG biomass ($t\ ha^{-1}$) area is significantly different for all the forest types with p value 0.003 ($p < 0.05$), 0.003 ($p < 0.05$), and 0.003 ($p < 0.05$) respectively (ANOVA-test)

Castanopsis forest. Various factors affect ecosystem carbon pools, including net primary productivity of plants and biomass decomposition (Shrestha and Lal 2006). Net primary productivity differs according to vegetation type, age of the stand, and the surrounding environment (Shrestha and Singh 2008). Baral et al. (2009) reported that tropical forests of Nepal had higher level of above ground carbon stock than sub-tropical forests. Above ground biomass carbon stock is directly impacted by the condition of the forest (Goetz et al 2009). Oli and Shrestha (2009), Shrestha et al (2009), and Khanal et al (2010) found more or less similar above-ground carbon stocks in the Mid-hills forests of Nepal. The variation in values could be due to other factors such as difference in site quality, stand structure, stand density and intensity of management.

Below ground biomass and carbon stock: Biomass and carbon stock in below-ground (root) vegetation is presented in Table 5. Belowground vegetation biomass stocks were found 32.36 t ha⁻¹, 26.65 t ha⁻¹ and 23.01 t ha⁻¹ in hill sal forest, pine forest and *Schima-Castanopsis* forest, respectively. Accordingly, below ground carbon stock was also found higher in hill sal forest than in pine forest and *Schima-Castanopsis* forest but no significantly different (Table 5). This finding is similar to Khanal et al. (2010) also found more or less similar root carbon stocks in the community-managed forests in the Mid-hills of Nepal. Shrestha et al. (2009) also found similar below ground carbon in the community-managed *Schima Castanopsis* Forests in Palpa district.

Bulk density: The bulk density (BD) depends on various factors such as compaction, consolidation and amount of SOC present in the soil, but it is highly correlated to the organic carbon content (Morisada et al 2004). There was a distinct variation in the BD with respect depth in all three forest types. Accordingly, there was a gradual increase in the

Table 5. Root biomass and carbon sequestration in different forest types

Forest types	Root biomass (t ha ⁻¹)	Root carbon sequestration (t ha ⁻¹)	p-value (ANOVA test)
Hill sal forest	33.70	15.84	0.07
Pine forest	26.71	12.55	
<i>Schima-Castanopsis</i> forest	23.01	10.81	

* p < 0.05 is considered as statistically significant

BD with increase in soil depth in all forests, but it did not differ significantly across the layers of the soil profile (p > 0.05).

The range of bulk density in three different forests based on the entire profile (0-30 cm) depths has been presented in Table 6. The mean BD value ranged from 0.79 to 1.24 gm cm⁻³. Accordingly, the lowest BD (0.79 gm cm⁻³) was found at the top soil (0-10 cm) in the pine forest, whereas highest BD (1.24 gm cm⁻³) was recorded at the depth of 21-30 cm in hill sal forest (Table 6). Ghimire et al. (2018) also reported similar bulk density values for *Shorea robusta* and *Pinus roxburghii* forest of Makawanpur district of Nepal. Khanal et al. (2010) and Shrestha (2009) also reported similar bulk density values in their studies carried out in Palpa district, Nepal.

Soil organic carbon (SOC): Amount of soil organic carbon depends upon various biotic and abiotic factors such as microclimate, forest types, land use and management. Leaf litter and root litter inputs play major roles in forest soil carbon dynamics (Shrestha and Singh 2008). The SOC was found to be higher at the upper layers that gradually decreased as soil depth increased (Table 7). Ghimire et al (2018) also reported that SOC decrease with increase in soil depth in different land uses including forest. Depth-wise distribution of SOC stock in three forest types was shown in Table 8. Accordingly the maximum SOC was found at the top soil (0-10 cm) in Hill Sal

Table 4. Aboveground carbon stock in different forests types

Forest types	Above ground tree carbon stock (t ha ⁻¹)	Sapling Carbon stock (t ha ⁻¹)	LHG carbon stock (t ha ⁻¹)	Total above ground carbon stock (t ha ⁻¹)	p-value ANOVA (test)
Hill Sal forest	101.73	1.24	2.65	105.62	0.009*
Pine forest	82.34	0.37	0.98	83.71	0.009*
<i>Schima-Castanopsis</i> forest	69.72	0.62	1.75	72.10	0.009*

*p < 0.05 is considered as statistically significant

The total above ground carbon stock (t/ha) is significantly different for all the forest types with p value 0.009 (p < 0.05) (t-test).

Table 6. Bulk density in different forest types

Soil depth (cm)	Hill sal forest		Pine forest		<i>Schima Castanopsis</i> forest	
	Mean (gm cm ⁻³)	SD	Mean (gm cm ⁻³)	SD	Mean	SD
0-10	0.99	0.044	0.79	0.050	0.95	0.052
11-20	1.13	0.048	1.04	0.078	1.06	0.055
21-30	1.24	0.052	1.15	0.072	1.18	0.075

forest (23.10 t ha⁻¹) whereas the minimum SOC was reported at the depth of 21-30 cm in the case of Pine forest (10.04 t ha⁻¹) (Table 7). The total SOC was also higher in Hill Sal forest (53.90 t ha⁻¹) than in the case of Pine forest (41.30 t ha⁻¹) and *Schima-Castanopsis* forest (48.05 t ha⁻¹) (Table 7). Total soil organic carbon stock for all forests types is significantly different with *p* value 0.020 (*p*<0.05). The results indicated that with increase in soil depth, bulk density was found to be in increasing trend while the SOC was found to be in decreasing trend. Ghimire et al (2018) reported that the SOC decreased with the increase in soil-depth in both *Shorea robusta* forests and *Pinus roxburghii* of Makawanpur district, Nepal. Similar results were reported by Khanal et al. (2010) and Shrestha (2009). Shrestha and Singh (2008) also reported lower soil carbon pool in Pine mixed forest than in other forest types.

SOC diminishes with the depth of the profile (Trujillo et al 1997). The higher organic carbon percentage in the top layer may be due to rapid decomposition of forest litter in a favorable environment. Soil organic carbon stocks in forest soils fluctuate from 50 to more than 200 Mgha⁻¹, depending on climate and soil conditions, the age and type of the tree stand, and management practices (Ostrowska et al 2010). A soil carbon study in Garhwal Himalayan Region of India revealed 46.07 t ha⁻¹ and 85.67 t ha⁻¹ organic carbon in *P. roxburghii* and *P. wallichiana* forest in 0-30 cm soil layer (Gupta and Sharma 2011). Leaf litter and root inputs play major role in forest carbon dynamics (Shrestha and Singh, 2008). Higher amount of SOC in Hill Sal forest as found in the study could be also due to the higher density of saplings and regenerations and its organic residues.

Total carbon stock: Total carbon stock is the sum of above-ground vegetation carbon, below ground carbon and soil organic carbon. The total carbon stocks in all three forests are shown in Table 8. The total carbon stocks in the Hill Sal forest, Pine forest and *Schima-Castanopsis* forest were found to be 175.36 t ha⁻¹, 137.56 t ha⁻¹ and 130.96 t ha⁻¹, respectively (Table 8).

Total carbon stock was higher in Hill *Shorea robusta* forest than in Pine and *Schima-Castanopsis* forest. Total carbon sequestration in Hill *Shorea robusta* forest was composed of found 59% for above ground, 32% by the soil and 9% by the root/below ground. Similarly, Carbon sequestration in Pine and *Schima-Castanopsis* forests were contributed to 58% and 53% by above ground, 33% and 39% by the soil; and 7% and 8% by the root. A study conducted in the Kusumdanda Community Forest in Palpa District which is also situated in the Hill ecological region of Nepal, showed the carbon stock density in a *Shorea robusta* forest to be 186.95 t ha⁻¹ (Nepal 2006) and later, 235.95 t ha⁻¹ Shrestha (2008), which are almost similar to the findings of this study conducted in the same ecological region. Ghimire et al (2018) also reported more or less similar kind of carbon stock density in *Shorea robusta* and *Pinus roxburghii* forest of Makawanpur district, Nepal. Shrestha and Singh (2008) have reported that the total carbon stock (vegetation and soil) in the Mid-hill forests is 139 t/ha. Similarly, Shrestha (2009) found the total carbon stock in the *Schima-Castanopsis* forest of Palpa district as 178.5 t ha⁻¹. The values are closer and the variation in values could be due to variation in other factors such as diameter, height and stand density. These results were slightly different due to difference

Table 7. Soil organic carbon (t ha⁻¹) in different forests types

Soil depth (cm)	Hill sal forest			<i>Pinus roxburghii</i> forest			<i>Schima Castanopsis</i> forest		p-value (ANOVA test)
	N	Mean	SD	N	Mean	SD	Mean	SD	
0-10	8	23.10	2.06	16	18.24	2.42	20.18	2.50	0.020*
11-20	8	17.30	2.01	16	13.02	1.70	16.35	1.74	
21-30	8	13.50	1.82	16	10.04	1.90	11.52	1.60	
Total		53.90			41.30		48.05		

* *p* < 0.05 is considered as statistically significant

Total soil organic carbon stock for two forests types is significantly different with *p* value 0.010 (*p*<0.05).

Table 8. Total carbon sequestration in different forests types

Forest types	Carbon Stock (t ha ⁻¹)			Total (t/ha)	p-value (ANOVA test)
	Aboveground carbon	Root carbon	Soil carbon		
Hill sal forest	105.62	15.84	53.90	175.36	0.010*
Pine forest	83.71	12.55	41.30	137.56	0.010*
<i>Schima-Castanopsis</i> forest	72.10	10.81	48.05	130.96	0.010*

* *p* < 0.05 is considered as statistically significant

in site quality, stand structure and intensity of management. Baral et al. (2009) also reported that total carbon stock of *Shorea robusta* forest was higher than that of pine forest. The rate of carbon sequestration by different forest types depended on the growing nature of the forest stands. Moreover temperature and moisture, which vary with altitude, are major climatic factors responsible for determining the decomposition rate of organic carbon (Amundson 2001). Litter fall and root turnover are critical components of ecosystem nutrient cycling and carbon sequestration (Gill and Jackson 2000). Total carbon sequestration was sum of aboveground carbon, root carbon and soil organic carbon. Chhabra et al. (2003) reported found 70 Mg ha⁻¹ soil organic carbon stocks (1m depth) in tropical deciduous forest, and 162 Mg ha⁻¹ in montane temperate forest in India. Shrestha and Singh (2008) also reported higher carbon stocks of vegetation and soil in *Shorea robusta* than in the pine forest. The total carbon stock in Nepal's forest has been estimated as 1,054.97 million tons (176.95 t ha⁻¹). Out of this, tree component (live, dead standing, dead wood and below-ground biomass), forest soils, and litter and debris constitute 61.53%, 37.80 %, and 0.67%, respectively (DFRS, 2015). *Shorea robusta*, *Pinus roxburghii*, *Pinus wallichiana* and *Schima-Castanopsis* forest types have contributed in such way to global climate change mitigation.

CONCLUSIONS

The vegetation carbon stock was higher in the Hill Sal forest (121.46 t ha⁻¹) than in the Pine (96.26 t ha⁻¹) and Schima-Castanopsis forest (82.91 t ha⁻¹). The share of undergrowth vegetation carbon was very low. The soil organic carbon in 0-10 cm, 11-20 cm, 21-30 cm soil depths were found to be different. The soil organic carbon was higher in hill sal forest (53.90 t ha⁻¹) than in the pine (41.30 t ha⁻¹) and Schima-Castanopsis forest (48.05 t ha⁻¹). With the increase in soil depth, bulk density was found to have increased, whereas, the carbon content was found to have decreased. The average soil carbon comprised 31% of the total carbon for hill sal forest whereas it accounted for 32% and 37% for Pine and Schima-Castanopsis forest, respectively. The study concluded that forest representing the tropical region of Nepal had higher amount of total carbon stock per hectare compared to sub-tropical region. However, carbon sequestration rate of forest types depended on growing nature of the forest stands. All the forests (including hill sal, pine and *Schima-Castanopsis* forest) are important for sinking carbon, hence contributing to climate change mitigation. Wise use and sustainable management of all forest types are recommended.

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REFERENCES

- Amundson R 2001. The carbon budget in soils. *Annual Review of Earth and Planetary Sciences* **29**(1): 535-562.
- Bajracharya RM, Lal R and Kimble JM 1998. Long-term tillage effect on soil organic carbon distribution in aggregates and primary particle fractions of two Ohio soils. In: Lal R., Kimble JM, Follet RF, and Stewart BA (eds.) *Management of Carbon Sequestration in Soil*, CRC Press, Boca Raton, FL, USA, pp. 68-353.
- Baral SK, Malla R and Ranabhat S 2009. Above ground carbon stock assessment in different forest types of Nepal. *Banko Jankari* **19**(2): 10-14.
- Brown S, Sathaye J, Cannell M and Kauppi PE 1996. Mitigation of carbon emissions to the atmosphere by forest management. *Commonwealth Forest Review* **75**: 80-91.
- CBS 2015. Compendium of Environmental Statistics of Nepal. Central Bureau of Statistics (CBS), Kathmandu, Nepal.
- Chauhan SK, Ritu and Chauhan R 2016a. Carbon sequestration in plantations. *Agroforestry for increased production and livelihood security* (Eds. Gupta SK, Panwar P and Kaushal R). New Indian Publishing Agency, New Delhi, pp. 215-234.
- Chauhan SK, Sharma R, Panwar P and Chander J 2016b. Short rotation forestry: A path for economic and environmental prosperity. In: *Forestry Technologies - A Complete Value Chain Approach*, Vol. 1 (Eds. K.T. Parthiban and R. Seenivasan), Scientific Publishers, Jodhpur, pp.260-288.
- Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ and Eamus D 2005. Tree allometry and improved estimation of carbon stocks. *Oecologia* **145**(1): 87-99.
- Chhabra A, Palria S and Dadhwal VK 2003. Soil organic carbon pool in Indian forests. *Forest Ecology and Management* **173**(1-3): 187-199.
- DDC. 2018. District Development Committee, Hetauda, Makawanpur, Nepal. <http://ddcmakwanpur.gov.np/en/> accessed on 3 September 2018.
- DFRS 2015. *State of Nepal's Forests*. Forest Resource Assessment (FRA) Nepal, Department of Forest Research and Survey (DFRS). Kathmandu, Nepal.
- DHM 2015. *Meteorological Data of Nepal*. Department of Hydrology and Meteorology (DHM), Kathmandu, Nepal.
- DoF. 2004. *Community Forestry Resource Inventory Guideline, 2004*. Department of Forest (DoF). Ministry of Forest and Soil Conservation, Kathmandu, Nepal.
- DoF. 2017. *Hamro Ban*. Annual Report of Fiscal Year 2016-2017, Department of Forest. Kathmandu, Nepal.
- Dogra AS and Chauhan SK 2016. Trees Outside Forests In India: Socio-Economic, Environmental and Policy Issues. In: *Forestry Technologies - A Complete Value Chain Approach - Vol. 1* (Eds. KT Parthiban and R Seenivasan), Scientific Publishers, Jodhpur, pp.84-100.
- Ghimire P, Kafle G and Bhatta B 2018. Carbon stocks in *Shorea robusta* and *Pinus roxburghii* forests in Makawanpur district of Nepal. *Journal of Agriculture and Forestry University* **2**: 241-248.
- Ghimire P, Bhatta B, Pokhrel B, Kafle G and Paudel P 2018. Soil organic carbon stocks under different land uses in Churia Region of Makawanpur District, Nepal. *SAARC J Agri* **16**(2): 13-23.

- Gill RA and Jackson RB. 2000. Global patterns of root turnover for terrestrial ecosystems. *New Phytologist* **147**(1): 13-31.
- Goetz SJ, Baccini A, Laporte NT, Johns T, Walker W, Kellndorfer J and Sun M 2009. Mapping and monitoring carbon stocks with satellite observations: A comparison of methods. *Carbon Balance and Management* **4**(1): 2.
- Gupta MK and Sharma SD 2011. Sequestered carbon: organic carbon pool in the soils under different forest covers and land uses in Garhwal Himalayan region of India. *International Journal of Agriculture and Forestry* **1**(1): 14-20.
- Hamburg SP 2000. Simple rules for measuring changes in ecosystem carbon in forestry offset projects. *Mitigation Adaptation Strategy Global Change* **5**(1): 25-37.
- IPCC. 2006. *Intergovernmental Panel on climate change (IPCC), Guidelines for National Greenhouse Gas Inventories, Volume 4. Agriculture Forestry and other land use*, In Eggleston T, Buendia L, Miwa K, Nagara T, Tanabe K (Eds) Hayanma, Japan; Institute of Global Environmental Strategies (IGES).
- IPCC 2007. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of Intergovernmental Panel on Climate Change.
- Jackson JK 1994. *Manual of Afforestation in Nepal* (Vol. 2). Forest Research and Survey Centre, Ministry of Forest and Soil Conservation, Kathmandu Nepal, pp 631-639.
- Khanal YM, Sharma RP and Upadhyaya CP. 2010. Soil and vegetation carbon in two community forests of Palpa District, Nepal. *Banko Janakari* **20**(2): 34-40.
- Kirschbaum MUF. 1996. The carbon sequestration potential of tree plantations in Australia. In: *Environmental Management: The Role of Eucalypts and Other Fast Growing Species*. (eds.), Eldridge, K.G., Crowe, M.P., Old, K.M. CSIRO, Forestry and Forest Products, pp.77-89.
- Lal R 2005. Forest soils and carbon sequestration. *Forest Ecology and Management* **220**: 242-258.
- Lee J, Yoon TK, Han S, Kim S, Yi MJ, Park GS, Kim C, Son YM, Kim R and Son Y 2014. Estimating the carbon dynamics of South Korean forests from 1954 to 2012. *Bio geosciences* **11**: 4637-4650.
- MacDicken KG. 1997. *A guide to monitoring carbon storage in forestry and agroforestry Projects*. Forest Carbon Monitoring Programme, Winrock International Institute for Agricultural Development, Little Rock, Arkansas, USA.
- MoFSC. (2010). *Forest Carbon Measurement Directives*. The REDD Forestry and Climate Change Cell, Government of Nepal (GoN), Ministry of Forests and Soil Conservation, Kathmandu, Nepal.
- Morisada K, Ono K and Kanomata H 2004. Organic carbon stocks in forest soils in Japan. *Geoderma* **119**: 21-32.
- Nepal S 2006. *A comparative study on carbon sequestration from two forest types in community forestry system (A case study from coniferous and broad-leaved forests in Palpa District)*. B.Sc. Thesis, Tribhuvan University, Institute of Forestry, Nepal.
- Oli BN and Shrestha K 2009. Carbon status in forests of Nepal. *Journal of Forest and Livelihood* **8**(1): 23-38.
- Ostrowska A, Porębska G and Kanafa M 2010. Carbon accumulation and distribution in profiles of forest soils. *Polish Journal of Environmental Studies* **19**(6): 1307-1315.
- Pandey SS, Cockfield G and Maraseni TN. 2016. Assessing the roles of community forestry in climate change mitigation and adaptation: a case study from Nepal. *Forest Ecology and Management* **360**: 400-407.
- Pearson TR, Brown S and Ravindranath NH 2005. *Integrating carbon benefit estimates into gef projects: Guidelines*. Capacity Development and Adaptation Group, Global Environment Facility, United Nations Development Programme, New York, USA.
- Shrestha RK and Lal R 2006. Ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil. *Environment International* **32**: 781-796.
- Shrestha BP 2008. *An analytical study of carbon sequestration in three different forest types of mid-hills of Nepal*. M.Sc. Thesis, Tribhuvan University, Institute of Forestry, Pokhara, Nepal.
- Shrestha BP 2009. Carbon sequestration in *Schima-Castanopsis* forest: A case study from Palpa District. *The Greenery (A Journal of Environment and Biodiversity)* **7**(1): 34-40.
- Shrestha BP, Awasthi KD and Bajracharya RM 2009. *Variation in carbon stock in community forests of mid-hills of Nepal: A case study from Palpa district*. The Natural Resource Management: Reviews and Research in the Himalayan Watershed (Special Publication of NUFU HIMUNET Project): pp.18-29.
- Shrestha BM and Singh BR 2008. Soil and vegetation carbon pools in a mountainous watershed of Nepal. *Nutrient cycling in Agro ecosystems* **81**(2): 179-191.
- Shrestha S, Karky BS, Gurung A, Bista R and Vetaas OR 2013. Assessment of carbon balance in community forests in Dolakha, Nepal. *Small-Scale Forestry* **12**(4): 507-517.
- Stern N 2007. *The Economics of Climate Change: The Stern Review*. Cambridge University Press, Cambridge, U.K.
- Trujillo W, Amezcua E, Fisher MJ and Lal R 1997. Soil organic carbon dynamics and land use in the Colombian Savannas I. Aggregate size distribution. In: Lal R., Kimble J.M., Follett R.F. and Stewart B.A. eds, *Soil Processes and the Carbon Cycle*. CRC Press, Boca Raton, Florida, USA, pp. 267-280.
- Van Noordwijk M, Cerri C, Woomer PL and Bernix M 1997. Soil carbon dynamics in the humid tropical forest zone. *Geoderma* **79**(1-4): 187-225.
- Walkley A and Black IA 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29-37.
- Winjum JK, Dixon RK and Schroeder PE. 1992. Estimating the global potential of forest and agro forestry management practices to sequester carbon. *Water, Air, & Soil Pollution* **64**(1-2): 213-227.
- Zhao M, Yang J, Zhao N, Liu Y, Wang Y, Wilson JP and Yue T 2019. Estimation of China's forest stand biomass carbon sequestration based on the continuous biomass expansion factor model and seven forest inventories from 1977 to 2013. *Forest Ecology and Management* **448**: 528-534.



Floristic Composition, Diversity, and Structure in the Changing Landscape of the Bale Mountains National Park, South-eastern Ethiopia

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Abstract: Bale mountains national park (BMNP) is one of the 34 International Biodiversity Hotspots that comprise a variety of life forms. However, it faces a critical challenge from illegal settlements and livestock grazing. This study aimed to estimate the plant composition and structure in the changing landscape of BMNP. The vegetation and environmental data were collected systematically from 96 plots laid along 24 line transects. Vegetation hierarchical clustering and landscape structural analysis were made using R software version 3.5.2 and FRAGSTATS version 4.2.1, respectively. A total of 205 species that belongs to 153 genera and 71 families were identified. The overall Shannon diversity and evenness index was 4.34 and 0.81, respectively. Both species richness and Shannon diversity index were significantly higher in the edge habitat than the interior at $p < 0.05$. However, the basal area was higher in the interior habitat ($173.79 \text{ m}^2 \text{ ha}^{-1}$) compared to the edge ($64.15 \text{ m}^2 \text{ ha}^{-1}$). This study revealed that BMNP is a biologically diverse and ecologically significant area that provides a variety of ecological and economic benefits to the surrounding communities. Though its habitats are changing alarmingly and urgent restoration and conservation action needs to be taken to reverse this situation.

Keywords: Basal area, Floristic composition, Hierarchical clustering, Illegal settlements

Tropical montane ecosystems are one of the hot spot ecosystems on earth that comprises more than 200,000 species of flowering plants (Aliyi et al 2015, Vergara-Rodríguez et al 2017). The Ethiopian highland encompasses over 50% of the Afromontane vegetation in African (Ahmedin and Elias 2020). A suitable geographical position, a wide range of altitude, a high amount of rainfall, and a wide range of temperature variations equip the country with huge ecological diversity and a wealth of biological resources (Yimer 2007). The ecosystems are highly diverse and it ranges from afro-alpine to desert. However, severe deforestation coupled with the cultivation of steep marginal lands, overgrazing, and socio-political uncertainty, has resulted in rigorous land degradation over large areas of the country (WBISPP 2004). The over dependence of the Ethiopian economy on agricultural production and the existence of 80% of the population in the highlands mainly contribute to the degradation of ecological resources and biodiversity loss (Humi 1998).

The mountainous topography and the mosaic of natural vegetation in the Bale Mountains have substantial economic, recreational, aesthetic, and scientific importance (Yimer 2007). The Bale Mountains National Park (BMNP) is the most important conservation area in Ethiopia that was established in 1969 to conserve the endemic and indigenous floras and

faunas in the area (Mekonnen et al 2010, Stephens et al 2001). It is one of the 34 International Biodiversity Hotspots and qualifies for World Heritage Site and Biosphere Reserve Listing (Tesfaye and Bires 2015). However, the park is facing a critical challenge from subsistence farming and overgrazing due to human settlement and livestock rearing in and around the park. No research provides detailed information about the landscape structure and its potential impact on vegetation composition and structure in the park. Therefore, this research was made to analyze the potential impact of landscape change on floristic composition, diversity and structure in BMNP. Particularly, a comparative analysis was made on the species richness, diversity, and regeneration status as well as the population structure of woody species between edge and interior habitats of the park.

MATERIAL AND METHODS

Study area: BMNP is located at $6^{\circ} 30' - 7^{\circ} 10'$ north and $39^{\circ} 30' - 39^{\circ} 55'$ east and it encompasses 2, 178 km^2 (Fig. 1). It encompasses a broad range of habitats between 1,500m and 4,377m altitude. Rainfall is well distributed throughout the wet season, ranging from 1000 to 2400 mm annually. The park is a globally important center of endemism, harboring 26% of Ethiopia's endemic species, including more than half

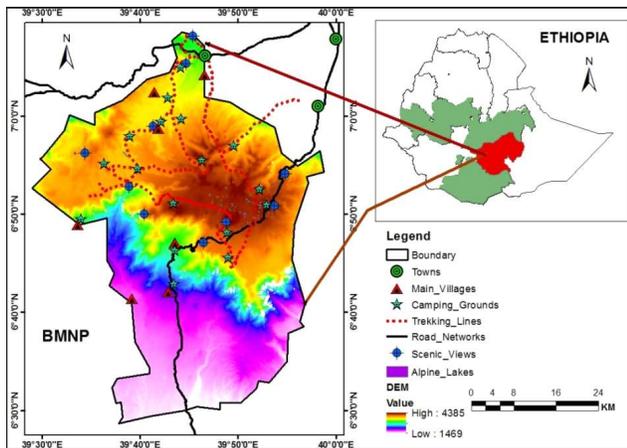


Fig. 1. Location map of the study area

of the global population of the endangered Ethiopian wolf, two-thirds of the global population of the endangered Mountain nyala, and the entire global population of the giant mole-rat (Wakjira et al 2015).

Vegetation sampling design: A reconnaissance survey was carried out from 13 to 20 November 2018 to get an insight into the physiognomy of the vegetation and identify sampling sites in the study area. Subsequently, the actual fieldwork was made in the dry season between November 2019 and January 2020. A 20 x 20 m sample plots were systematically laid on transect lines in 8 directions along the altitudinal gradients at 100 m elevation difference as it maximizes the distance between plots and minimizes spatial correlation among observations (Barry 2008). A total of 96 sample plots (24 transect lines x 4 plots at each transect line) with an area of 3.84 ha were plotted to collect vegetation and environmental data. An equal number of sample plots was laid in the edge and interior habitats to make a comparison among their vegetation data.

Floristic composition and diversity: The most commonly used diversity indices of species richness, Shannon diversity, and evenness index were computed to analyze the patterns of plant diversity at different scales following Okland (1990) and Magurran (2004). The value usually falls between 1.5 and 3.5, and rarely exceeding 4.5. Conversely, the values of evenness lay between 0 to 1 and 1 represents all species are equally abundant (complete evenness) (Magurran 2013).

Floristic structure and plant community analysis: The woody species density, frequency, dominance, and their relative values were computed to obtain the important value index and describe the woody species structure following Mueller-Dombois and Ellenberg (1974) and Martin (2010) and. Moreover, DBH, tree height, and basal area were analyzed to determine the population structure following Van der Maarel (1997) and Kitessa et al (2007). Hierarchical

agglomerative clustering techniques were performed using Euclidean distance and Ward's method to classify plots that produced a dendrogram and cluster IDs (Ahmedin and Elias 2020).

Measurement of landscape structure: Nine landscape indices were analyzed following McGarigal et al (2012), Leitao et al (2012) and Smiraglia et al (2015). The two-way correlation and linear regression between fragmentation indices and species composition and structure parameters were made using PAST software version 4.02 (Hammer et al 2001).

RESULTS AND DISCUSSION

Floristic composition and diversity: A total of 205 species that belongs to 153 genera and 71 families were identified in the BMNP. In terms of life form, 114 were woody species (50 trees, 52 shrubs, and 12 lianas) and 91 were herbaceous species. Asteraceae was the richest family with 31 species and the most species-rich genus was *Helichrysum* with 9 species. Twenty endemic species (9.7% of the total) including *Alchemilla haumanii* Rothm, *Erythrina brucei* Schweinf, and *Kniphofia isoetifolia* Hochst, were identified. The overall Shannon diversity and evenness index of the BMNP were 4.34 and 0.81, respectively and this was higher relative to other similar areas such as Bonga forest (Senbeta et al 2014), Agama forest (Dibaba et al 2020) and Munessa forest (Ahmedin and Elias 2020). The mean species richness and Shannon diversity index of the edge habitat (40 and 2.93) were significantly higher than the interior habitats (25 and 2.43). This was due to the dominance of generalist species in the edge habitat and specialists in the interior habitat. Whereas, the Shannon evenness index in the interior habitats (0.83) was higher, but not significant, than the edge habitat (0.79).

Vegetation classification: The vegetation classification in BMNP at 81-dissimilarity level from hierarchical cluster analysis resulted in five plant community types: *Anthemis tigreensis* - *Alchemilla pedata* (CI), *Alchemilla haumanii* - *Helichrysum gofense* (CII), *Podocarpus falcatus* - *Croton macrostachyus* (CIII), *Croton macrostachyus* - *Syzygium guineense* - *Olea capensis* (CIV), *Solanum marginatum* - *Euphorbia dumalis* - *Rubus steudneri* (CV) (Table 1, Fig. 2).

Floristic structure: The density of woody species with DBH > 2 cm was 1567 individuals' ha⁻¹. This was relatively higher compared to the Wof-Washa forest (Ayalew 2018) and Agama forest (Dibaba et al 2020). The density of woody species in the interior habitat was higher (452 stems ha⁻¹) compared to the edge habitat (320 stems ha⁻¹). This was due to the selective cutting of trees for timber production, house construction, and firewood, which ultimately leads to a

reduced density of large trees and greater canopy openness (Laurance 2004). The frequency of woody species was ranged from 2 to 81%. *Croton macrostachyus* was the most frequent woody species with 81% frequency followed by *Juniperus procera* (79%), *Podocarpus falcatus* (63%) and *Hagenia abyssinica* (60%). The mean DBH and height of woody species in the interior habitat (78.62 cm and 33.63 m) were significantly higher than the edge habitat (44.12 cm and 25.12m) at $p < 0.05$, respectively. The loss of forest structural complexity in the edge causes great differences between the two habitat types in addition to disturbance, forest area reduction, and patch shape complexity (Paciencia and Prado 2005).

The total basal area of woody species with DBH > 2 cm in BMNP was 170.26 m² ha⁻¹ and it was considerably higher compared with the top seven vegetated areas selected in Ethiopia (Table 4). This was due to the presence of relatively larger DBH trees in the study area. About 75 % of the basal area was contributed by five tree species such as *Juniperus procera* (46.71 m² ha⁻¹), *Syzygium guineense* (24.76 m² ha⁻¹), *Cordia africana* (20.95 m² ha⁻¹), *Hagenia abyssinica* (18.47 m² ha⁻¹), and *Ehretia cymose* (15.86 m² ha⁻¹). Conversely, the basal area in the interior habitat (173.79 m² ha⁻¹) was significantly higher than the edge habitat (64.15 m² ha⁻¹) (Fig.

3). This indicates large size trees are predominantly available in the interior habitat than the edge. *Juniperus procera* was the dominant woody species with IVI of 26.43, followed by *Croton macrostachyus*, and *Syzygium guineense*. The species with higher IVI values in the study area were among the characteristic species in the similar vegetation types elsewhere (Sebsebe and Friis 2009, Woldu et al 1999).

Population structure: The population structure of 17 tree species was examined considering their density at various DBH levels and six representative patterns were identified following Teketay 2005b (Fig. 4). These patterns were Inverted-J shaped (a), J shaped (b), Broken Inverted-J shaped (c), Unimodal/bell-shaped (d), the pattern that consists of abundant individuals at the lower DBH classes and the absence of individuals at the intermediate and higher DBH classes (e), and the pattern that comprises fewer matured individuals in the higher DBH classes and lack of individuals at the lower and intermediate DBH classes (f).

Regeneration status of woody species: The total density of seedling, sapling and mature trees in the BMNP was 8751, 4413, and 1567 individuals ha⁻¹, respectively. The ratio of seedling to mature tree, sapling to mature tree and seedling to sapling were 5.58, 2.82, and 1.98, respectively. The mean density of seedling, sapling, and mature trees in the interior

Table 1. Synoptic table based on mean cover-abundance value for species reaching ≥ 1 in at least one community (values in bold refer to characteristic species of the community)

Species	Plant communities				
	CI	CII	CIII	CIV	CV
<i>Alchemilla abyssinica</i>	0.00	3.43	0.00	0.00	0.00
<i>Alchemilla haumanii</i>	0.00	5.07	0.00	0.00	0.00
<i>Alchemilla pedata</i>	2.72	1.36	0.00	0.00	0.00
<i>Anthemis tigreensis</i>	3.03	0.21	0.00	0.00	0.00
<i>Croton macrostachyus</i>	0.00	0.00	3.78	5.38	0.00
<i>Ehretia cymosa</i>	0.00	0.00	2.44	0.25	0.00
<i>Euphorbia depauperata</i>	2.22	1.14	0.00	0.00	0.00
<i>Euphorbia dumalis</i>	1.00	0.00	0.00	0.00	4.34
<i>Helichrysum citrispinum</i>	0.00	2.54	0.00	0.00	0.00
<i>Helichrysum gofense</i>	1.03	3.68	0.00	0.00	0.00
<i>Helichrysum splendidum</i>	0.86	2.50	0.00	0.00	0.00
<i>Juniperus procera</i>	1.17	0.00	0.00	0.50	3.53
<i>Kniphofia foliosa</i>	2.11	0.36	0.00	0.00	0.00
<i>Olea capensis</i>	0.00	0.00	0.34	1.31	0.00
<i>Podocarpus falcatus</i>	0.00	0.00	4.16	0.44	0.00
<i>Rubus steudneri</i>	0.67	0.00	0.56	0.00	4.00
<i>Solanum marginatum</i>	1.78	0.00	0.00	0.00	4.69
<i>Syzygium guineense</i>	0.00	0.00	2.41	1.31	0.00
<i>Triumfetta pentandra</i>	0.00	0.00	2.47	0.94	0.00

habitat was significantly higher (995.42, 509.29, and 187.60 individuals ha⁻¹, respectively) than in the edge habitat (584.61, 353.92, and 121.45 individuals ha⁻¹, respectively). This indicates that the recruitment potential of the interior forest was significantly higher compared to the edge habitat (Ayalew 2018).

Effects of landscape change on floristic composition and structure: From the regression analysis computed PN established strong and negative effect on species richness (with $r = -0.90$,) and diversity (with $r = -0.96$). While the number of fragmented habitats increases, species richness, and diversity, particularly interior dependent species, decreases. However, edge dependent species comfortably flourished. One of the consequences of habitat fragmentation is an increase in the proportional abundance of edge influenced habitat and its adverse impacts on interior sensitive species (Robbins et al 1989). Undoubtedly, while some species (e.g. habitat specialists) may suffer from fragmentation, others may benefit from it (e.g. generalists and edge species) (Henle et al 2004).

Conversely, PN were strong and negatively correlated with AREA_MN ($r = -0.71$, $p < 0.001$). This implies that as the PN increases the area of fragments decreases as a result small fragments contain smaller species richness and lower species density than large fragments (Laurance and Vasconcelos 2009). Large areas of habitat tend to support more individuals, and hence, more species (Rosenzweig 1995). Besides modifying the spatial pattern of the landscape, habitat size reduction and increase of isolation cause an alteration of the dispersal rate, affecting survival, and mortality of individuals (Fahrig and Merriam 1994). Many population and community changes in habitat fragments were commonly attributed to edge effects (Laurance and

Vasconcelos 2009). Interior species may be affected by the size decrease of their habitat, by edge effect, and by competition with generalists (Bolger et al 2001). The most

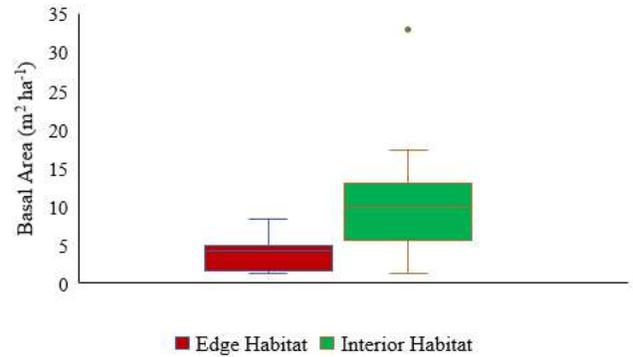


Fig. 3. Box plot showing the basal area in the edge and interior habitats

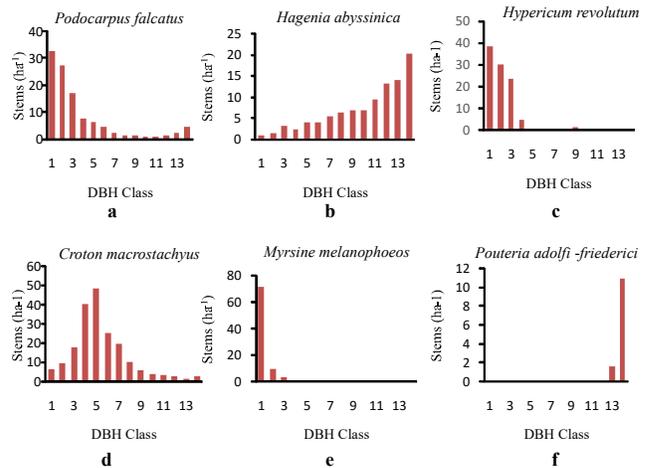


Fig. 4. Representative patterns of woody species population structure along the DBH classes

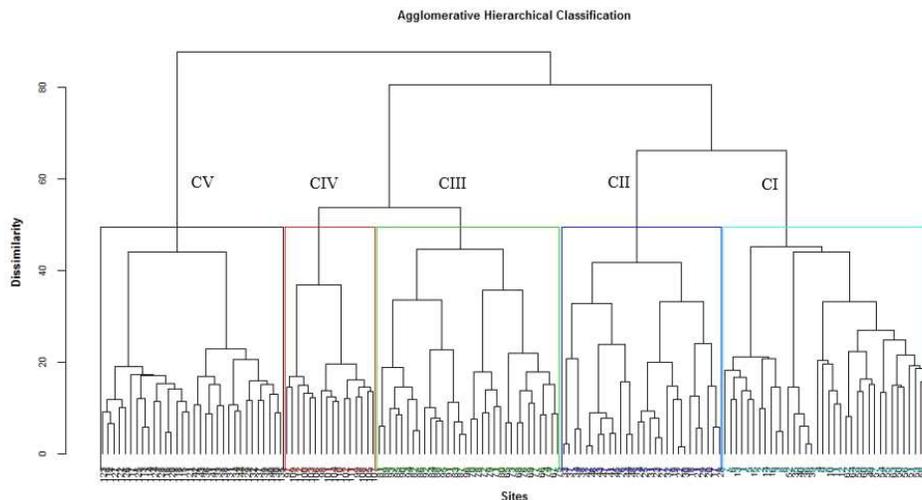


Fig. 2. Dendrogram of sample plots in the plant communities in BMNP

threatened endemic species, due to edge effect, in the BMNP were *Helichrysum harennense* Mesfin, *Kniphofia insignis* Rendle, *Rubus erlangeri* Engl., and *Vepris dainellii* Pichi. Serm. Kokwaro. Conversely, the most common weed species in the study area favored by edge effect was *Achyranthes aspera* L., which is also common in the disturbed forests and forest edges of the dry Afromontane forests and moist Afromontane forests in Ethiopia (Friis et al 2010). The gradual decline of the more sensitive species, caused by changes in the extinction/colonization rates and the proportional increase of edge/generalist species, may induce a species turnover in fragments and cascade effects (Lomolino and Weiser 2001).

Among the landscape indices computed only PN and AREA_MN significantly affected some of the floristic structural properties assessed. Thus, PN was strong and negatively affected woody species density ($r = -0.84$,) and basal area ($r = -0.96$, $p < 0.01$) as well as AREA_MN was strong and positively affected woody species density ($r = 0.71$,) and basal area ($r = 0.82$,). Habitat destruction, isolation, and transformation affect the structure and dynamics of populations, communities, and ecosystems, as well as ecological processes (Soulé and Orians 2001). Generally, as AREA_MN and COA of patches increases, species richness, diversity, evenness, woody species density, basal area, DBH, and height also increases. Whereas, as PN, SHAPE_MN, ED, ENN_MN, and IJI of patches increases, floristic composition, and structural variables decreases. This implies that the landscape composition and configuration change may potentially affect the vegetation composition and structure of a particular area.

CONCLUSIONS

The BMNP is one of the richest ecological areas that comprise of endemic and indigenous plant species in Ethiopia. However, the expansion of settlements and livestock rearing was the most challenging activity performed in the park even in the higher altitudes up to 3900 m asl. The human-induced fire was also the main concern in the ericaceous belt and Afro-alpine region for the expansion of farm and grazing land. These activities are responsible for the occurrence of habitat loss and fragmentation in the park. As a result, the species richness and Shannon diversity index were significantly higher in the edge habitat compared to the interior habitat. This was due to the dominance of generalist species in the edge habitat, which can flourish in the limited resources, and specialist species in the interior habitat, which are sensitive to the limited resources. Moreover, the species in the edge habitat were unevenly distributed and the basal areas of woody species were relatively lower than the interior habitat. This was due to the presence of larger size trees in

the interior habitat than the edge. Therefore, illegal human activities in the park should be banned and the settlements need to be relocated to other areas to avoid their potential impacts on floras and faunas that depend on the park.

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REFERENCES

- Ahmedin A and Elias E 2020. Tree species composition, structure and regeneration status in Munessa natural forest, Southeastern Ethiopia. *Eurasian Journal of Forest Science* 8(1): 35-53.
- Aliyi K, Hundera K and Dalle G 2015. Floristic composition, vegetation structure and regeneration status of Kimphe Lafa natural forest, Oromia Regional State, West Arsi, Ethiopia. *Research & Reviews: Journal of Life Sciences* 5(1): 19-32.
- Ayalew A 2018. *Vegetation Ecology and Carbon Stock of Wof-Washa Forest*, North Shewa Zone, Amhara Region, Ethiopia.
- Barry R 2008. *Mountain Weather and Climate*. Cambridge University Press. New York.
- Bolger D, Scott T and Rotenberry J 2001. Use of corridor-like landscape structures by bird and small mammal species. *Biological Conservation* 102(2): 213-224.
- Dibaba A, Soromessa T, Kefalew A and Addi A 2020. Woody species diversity, vegetation structure, and regeneration status of the moist afromontane forest of Agama in Southwestern Ethiopia. *International Journal of Ecology*, 2020 (accepted).
- Fahrig L and Merriam G 1994. Conservation of fragmented populations. *Conservation Biology* 8(1): 50-59.
- Friis I, Demissew S and Van Breugel P 2010. *Atlas of the potential vegetation of Ethiopia*. Det Kongelige Danske Videnskabernes Selskab.
- Hammer Ø, Harper D and Ryan P 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica* 4(1): 9.
- Hanski I 1994. Patch-occupancy dynamics in fragmented landscapes. *Trends in Ecology & Evolution* 9(4): 131-135.
- Henle K, Davies K, Kleyer M, Margules C and Settele J 2004. Predictors of species sensitivity to fragmentation. *Biodiversity & Conservation* 13(1): 207-251.
- Hurni H 1998. *Agroecological belts of Ethiopia*. Explanatory Notes on Three Maps at a Scale of, 1(1,000,000).
- Laurance W 2004. Forest-climate interactions in fragmented tropical landscapes. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* 359(1443): 345-352.
- Laurance W and Vasconcelos H 2009. Deforestation and forest fragmentation in the amazon. *Tropical Biology and Conservation Management* 2: 23-29.
- Lomolino M and Weiser M 2001. Towards a more general species-area relationship: Diversity on all islands, great and small. *Journal of Biogeography* 431-445.
- Magurran A 2013. *Measuring biological diversity*. John Wiley & Sons.
- Mekonnen A, Bekele A, Hemson G, Teshome E and Atickem A 2010. Population size and habitat preference of the vulnerable bale monkey *Chlorocebus djamdjamensis* in Odobullu Forest and its distribution across the Bale Mountains, Ethiopia. *Oryx* 44(4): 558-563.
- Paciencia M and Prado J 2005. Effects of forest fragmentation on pteridophyte diversity in a tropical rain forest in Brazil. *Plant Ecology* 180(1): 87-104.

- Pimm S, Jenkins C, Abell R, Brooks T, Gittleman J, Joppa L, Raven P, Roberts C and Sexton J 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science* **344**: 6187.
- Robbins C, Dawson D and Dowell B 1989. Habitat area requirements of breeding forest birds of the middle Atlantic states. *Wildlife Monographs*, 3-34.
- Rosenzweig M 1995. *Species diversity in space and time*. Cambridge University Press.
- Schonewald-Cox C and Buechner M 1992. Park protection and public roads. In *Conservation Biology* pp. 373-395. Springer.
- Sebebe D and Friis I 2009. Natural vegetation of the flora area. In *Flora of Ethiopia and Eritrea* **8**: 27–32. National Herbarium, Addis Abeba University.
- Senbeta F, Schmitt C, Woldemariam T, Boehmer H and Denich M 2014. Plant diversity, vegetation structure and relationship between plant communities and environmental variables in the Afromontane Forests of Ethiopia. *SINET: Ethiopian Journal of Science* **37**(2): 113-130.
- Soulé M, and Orians G 2001. Conservation biology research: Its challenges and contexts. *Conservation Biology. Research Priorities for the next Decade*, 271-285.
- Stephens P, Sillero-Zubiri C and Leader-Williams N 2001. Impact of livestock and settlement on the large mammalian wildlife of Bale Mountains National Park, southern Ethiopia. *Biological Conservation* **100**(3): 307-322.
- Tesfaye and Bires Z 2015. Awareness creation at community level towards the conservation of cultural and natural tourism resources of Bale Mountains National Park and Harena Buluk, South East Ethiopia. *Journal of Tourism, Hospitality and Sports* **1**: 14.
- Vergara-Rodríguez D, Mathieu G, Samain M, Armenta-Montero S and Krömer T 2017. Diversity, distribution, and conservation status of Peperomia (Piperaceae) in the state of Veracruz, Mexico. *Tropical Conservation Science* **10**: 1940082917702383.
- Wakjira D, d'Udine F and Crawford A 2015. Migration and Conservation in the Bale mountains ecosystem. *IISD Report*.
- WBISPP (Woody Biomass Inventory and Strategic Planning Project) 2004. A national strategic plan for the biomass energy sector. Federal Democratic Republic of Ethiopia, Ministry of Agriculture, Addis Ababa.
- Woldu Z, Fetene M and Abate A 1999. Vegetation under different tree species in Acacia woodland in the Rift Valley of Ethiopia. *Sinet: Ethiopian Journal of Science* **22**(2): 235-252.
- Yimer F 2007. *Soil properties in relation to topographic aspects, vegetation communities and land use in the south-eastern highlands of Ethiopia*.



Growth, Geographic Concentration and Stability Analysis of Coir Products Export from India

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Abstract: Coir is an important export commodity, giving income and employment opportunity to a number of people across the country. Present study tries to analyse growth and instability of coir products export to major importing countries and also looks into the geographic concentration and stability of direction of trade. Highest growth rate in export quantity (85.66%) and value of export (81.71%) was for China, whereas growth in unit value of export was highest for South Korea (7.47%). High instability in export quantity, value of export and unit value was found for China. Most other importing countries were having low instability, except unit value of export to UK and USA. Geographic concentration was not much high either for quantity or value of export. Markov chain analysis showed China as the most stable importing country with high probability of retention (0.89), whereas, South Korea emerged as the most unstable importer with least probability of retention. Interventions are needed to ensure increasing share of high value coir products in the total export quantity by reducing the share of low value coir products in order to improve the amount of foreign revenue realized through the export of coir products.

Keywords: India, Coir, Export, Geographic concentration, Stability

Indian coir industry is one of the most important agro-based cottage industries contributing significantly to the economy of the country. It is a labour intensive and export oriented traditional cottage industry employing around seven lakhs coir workers of which 80 per cent are women. Processing activities centred on it provide employment opportunities to people in rural areas of coconut producing states of the country *viz.* Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Telangana, Odisha (Coir Board 2018). It is biodegradable, eco-friendly, and can be used for multiple purposes in different forms and, contributes to resource conservation and ecological balancing. Since coir is a labour intensive and export-oriented industry that provide ample employment opportunities and export revenue, government has also played a vital role in reviving the lost fame of this traditional Indian industry by introducing various schemes and programmes to promote it. The opportunities to initiate manufacturing of value-added products and introducing schemes like SFURTI (Scheme of Fund for Regeneration of Traditional Industries) and Coir Udyami Yojana has given wings to this golden industry. With the concerted efforts of the Coir Board and the State Governments, the production of coir and its value-added products in the major coconut producing States have been making a steady progress for the last few years. The promotion of the coir industry in the traditional and non-traditional coir producing states has enhanced

employment opportunities and generation of income in the rural sector (MSME 2019).

India accounts for more than two-thirds of the world production of coir and coir products which are exported to more than 110 countries. China, United States of America (USA), Netherlands and South Korea are the main buyers of coir products from India. China is the principal buyer of coir products from India with market share of nearly 40 per cent of total export quantity. The export of coir and coir products from the country touched an all-time high record of 9,88,996 million tonnes valued at Rs.2757.90 crore during the year 2019-20, which is around Rs.30 crore higher than that of the last year (2018-19). The domestic and international markets for coir and coir products show an increasing trend during this period. Hence, there is further scope for making better returns for the entrepreneurs if they can tap these growing markets (PIB 2020). Since a number of competitors have emerged during the past few years, and are eating into the market share of Indian coir products in many major importing countries, it is important to look into the export performance of Indian coir products at a disaggregate level at each major importing countries. In this backdrop, the present study attempts to analyze the performance of export of coir products from India to major importing countries in terms of growth, instability, geographic concentration and stability of direction of trade.

MATERIAL AND METHODS

Time series data on export of coir products from India during 2003-04 to 2018-19 was used for the analysis. Country-wise yearly export data was collected from Coir Board and Indiastat websites. For better understanding of the scenario at different time periods, the data were divided into two sub-periods viz. Period I: 2003-04 to 2010-11 and Period II: 2011-12 to 2018-19. Analysis were conducted for each of these sub-periods separately, and also for the combined time period. Five major importing countries, namely USA, China, Netherlands, UK and South Korea were considered for the analysis based on the value of exports during the entire period under consideration. All other importing countries were pooled into 'Other countries', and is considered for the analysis along with the major five importing countries.

Analysis of growth in export: Compound annual growth rate (CAGR) was calculated for analyzing the growth in export to different countries over time by fitting exponential function for the variables under consideration (Gujarati et al 2012). Following estimation form was used for the calculation:

$$\ln Y = a + bt$$

Where, 'Y' is the time series data of quantity, value or unit value of coir products export to a particular country for which growth rate is calculated, 't' is the time variable and 'a' is the intercept. The slope coefficient 'b' measures the relative change in Y for a given absolute change in the value of explanatory variable 't'. Compound annual growth rate can be calculated from the value obtained for 'b' as:

$$\text{CAGR} = [\text{Antilog}(b) - 1] \times 100$$

The values of compound growth rates obtained were also tested for their significance using student 't' test.

Analysis of export instability: Apart from growth, stability of exports is an important aspect to look for the risk involved. The instability index as estimated by Raju et al (2014) and Vijayan and Devi (2018):

Instability Index = Standard deviation of natural logarithm (Y_{t+1}/Y_t)

Where, Y_t is the export quantity/ value/ unit value in the current year and, Y_{t+1} is the same in the next year. This index is unit free and very robust. A low value of the index refers to low instability in exports and vice versa.

Geographic concentration in export: Proper understanding on the spread of export destinations is imperative to have an idea on the risks involved. If the exports are concentrated in a few countries only, it increases the chances of instability and thereby risks in export earnings. Hirschman Index as used in Sarada et al (2006) and Indushree and Kuruvila (2019) were used to measure geographic concentration in the export of coir products.

$$\text{Hirschman Index, HI} = 100 \sqrt{\sum_{i=1}^n \left(\frac{X_{it}}{X_t} \right)^2}$$

Where, x_{it} is the value of exports of coir products from India in year t to the i^{th} market, x_t is the total value of coir products exports from India in year t and, n is the number of countries importing coir products from India.

The highest possible value of the coefficient is 100, which indicates that the country exports to only one destination. When the value of the coefficient is lower, the greater is the number of export markets and vice versa.

Changes in the direction of trade: Markov chain analysis, as used in Angles et al (2011), Ganeshkumar et al (2016) and Vivek et al (2019) was used to analyze the changes in the direction of trade. Estimation of a transitional probability matrix P is the major part of Markov chain analysis. The off-diagonal element P_{ij} of this matrix indicates the probability that the export share of a particular country will shift to another country over time. The diagonal elements indicate the probability that the export share of a country will be retained. The average export to a particular country was considered to be a random variable which depends only on its past exports to that country and which could be denoted algebraically as:

$$E_{jt} = \sum_{i=1}^r E_{it-1} P_{ij} + e_{jt}$$

Where,

E_{jt} = Exports from India during the year t to j^{th} country,

E_{it-1} = Exports to i^{th} country during the year t-1,

P_{ij} = The probability that exports will shift from i^{th} country to j^{th} country,

e_{jt} = The error term which is statistically independent of E_{it-1} , and

r = The number of importing countries.

The transitional probabilities can be arranged in a (c x r) matrix, and have the following properties:

$$0 \leq P_{ij} \leq 1$$

$$\sum_{i=1}^n P_{ij} = 1, \text{ for all } i$$

The transitional probability matrix is estimated in the linear programming (LP) framework by a method referred to as minimization of Mean Absolute Deviation (MAD). The LP formulation is stated as:

$$\text{Min OP}^* + l e$$

$$\text{Subject to } X P^* + V = Y. \text{ GP}^* = I, P^* \geq 0$$

Where, P^* is a vector of the probabilities P_{ij} , 0 is a vector of zero, l is an appropriately dimensioned vector of country, e is the vector of absolute errors ($|U|$), y is the vector of exports to each country, x is a block diagonal matrix of lagged values of y, and v is the vector of errors and G is a grouping matrix to add the row elements of P arranged in P^* to unity.

RESULTS AND DISCUSSION

Growth and instability in export: The quantity and value of total coir export from India showed comparatively high growth rate during both the periods under consideration. Whereas growth rate in unit value was negative during the first period, which then improved to a small positive growth - though insignificant- during the second period. The high negative growth rate in the first period compared to the very small positive growth in the second period made the growth in unit value during the overall period negative (-3.06%). This was also reflected in the low growth rate in the value of export compared to growth in export quantity. Higher proportion of low value coir products in the total coir export might be the reason for low growth in unit value/ value of export compared to growth in quantity of export. Raseena (2018) also observed high proportion of comparatively low value products like coir pith and coir fibre in the recent years (starting from the middle of last decade) in India's coir products export, which was earlier dominated by value added products like handloom mats.

While looking into the growth and instability in export of coir products from India to major export destinations (Table 2), China emerged as the top destination with highest growth rate in export quantity (85.66%) and value of exports (81.71%) during the entire period (2002-03 to 2018-19). Though it showed high growth rate in export quantity and value, growth in unit value was found to be negative. Reduction in proportion of value-added products in the export composition and increase in the proportion of low value raw products over time might have caused the negative growth in unit value. Thus, the growth in value of exports might be caused by the high growth in quantity of exports. A glance at the results of growth rate analysis at two time periods gives more insights. Growth in quantity and value was very high in the first period, but both decreased in the second period compared to their earlier values. Just like that in the overall period, growth in export quantity was higher than that of value of export during the first period. But this trend got reversed in the second period. Results of growth rate analysis of unit value of exports during the two periods further strengthens

this observation. Growth in unit value was negative in the first period, but a positive growth rate is evident in the second period.

Highest growth in unit value of exports was for South Korea (7.47%) and was in next position in terms of value of growth rate in export quantity (22.77%) and export value (31.94%) after China. Contradictory to that of growth of coir export to China, South Korea's growth in export value was found higher than growth in export quantity owing to high positive growth rate in unit value. This might have been caused by high proportion of value-added products in the total coir exports to the country. Growth in unit value was found significant increase in the second period compared to that of first period. The growth in export quantity and value of exports was higher in the first period compared to that in the second period. Netherlands and UK also showed positive growth rate in unit value of exports (2.77% and 1.07%, respectively) in the overall period. Owing to this, as expected, growth in export value was higher than that of growth in export quantity for both these countries. USA and other countries showed positive growth rate in export quantity and value, but negative growth in unit value during the overall period. While looking into the instability values, China came with high instability in all three parameters i.e., export quantity, value of export and unit value. Instability in all these three were high during the first period, but were significantly low in the second period. Thus, decreasing instability over time was for China, which is a favorable aspect in export. Instability values of export quantity, value and unit value were found low for all other countries except unit value of UK and USA. Both these countries showed moderate instability (26.61 and 18.20% respectively).

Looking at growth and instability separately may not help to get clear understanding of the entire scenario. Therefore, the combinations of these two is need to be checked thoroughly for proper understanding of the phenomenon under consideration. Different combinations are possible - like, high growth high instability, high growth low instability, low growth high instability and low growth low instability. First two scenarios are not much problematic, but a low growth

Table 1. Growth and instability in total coir export from India

Particulars	Period I		Period II		Overall	
	CAGR	Instability Index	CAGR	Instability Index	CAGR	Instability Index
Total export						
Quantity (tonnes)	17.63 ^{***}	0.91	15.62 ^{***}	0.80	17.70 ^{***}	0.85
Value (Rs.)	10.13 ^{***}	0.82	15.66 ^{***}	0.65	14.09 ^{***}	0.78
Unit Value (Rs.)	-6.38 ^{***}	4.99	0.04	5.04	-3.06 ^{***}	5.86

^{***}Significant at 1 per cent level

(Per Cent)

high instability situation is dangerous. Similarly, combination of low growth and low instability may lead to stagnation, and hence not favorable. Analysis of coir export data showed situation of low growth along with high / moderate instability in unit value of export for countries like China, UK and USA. Making it further worse, apart from being low, growth in unit values of China and USA were negative also. This necessitates immediate attention as these two countries are leading international markets for export of Indian coir products. A decreasing and unstable unit value realization from export to these countries will certainly hamper the export value growth of Indian coir products. Efforts are needed to improve the proportion of more value-added products in the total exports. Proper study on demand scenario of specifications of value-added products in the major export destinations will be helpful to get a stable market by meeting consumer needs in those markets.

Geographic concentration of export: Geographic

concentration was not much high at any time, and it revolved around 40 per cent (Table 3). The index value of geographic concentration of export quantity for the second period (43.08%) was significantly higher than that in the first period

Table 3. Geographic concentration of Indian coir products export (Hirschman Index)

Year	Quantity (%)	Value (%)
2003-04	34.85	40.86
2006-07	31.58	40.20
2009-10	35.80	35.70
2012-13	40.40	33.32
2015-16	43.06	38.15
2018-19	41.65	36.89
2003-04 to 2010-11 (Avg.)	33.67	38.65
2011-12 to 2018-19 (Avg.)	43.08	36.74
2003-04 to 2018-19 (Avg.)	38.37	37.69

Table 2. Growth and instability in export of coir products to major importing countries

Particulars	Period I		Period II		Overall	
	CAGR	Instability index	CAGR	instability index	CAGR	Instability index
USA						
Quantity (tonnes)	8.70 ^{***}	1.22	14.28 ^{***}	2.06	11.28 ^{***}	1.67
Value (Rs.)	4.03 ^ˆ	1.48	16.02 ^{***}	1.06	9.01 ^{***}	1.26
Unit value (Rs.)	-4.30 ^{***}	10.17	1.51	22.56	-2.04 ^{***}	18.20
China						
Quantity (tonnes)	247.14 ^{***}	51.94	20.17 ^{***}	1.67	85.66 ^{***}	34.50
Value (Rs.)	200.00 ^{***}	49.37	22.19 ^{***}	2.15	81.71 ^{***}	33.14
Unit value (Rs.)	-13.58	62.11	1.68	8.98	-2.13	41.19
Netherlands						
Quantity (tonnes)	12.57 ^{***}	1.62	12.78 ^{***}	0.51	11.85 ^{***}	1.14
Value (Rs.)	11.58 ^{***}	1.53	18.36 ^{***}	0.96	14.95 ^{***}	1.22
Unit value (Rs.)	-0.87	5.05	4.95 ^{***}	5.19	2.77 ^{***}	5.06
UK						
Quantity (tonnes)	3.66 ^ˆ	1.61	5.15 ^ˆ	1.84	5.72 ^{***}	2.20
Value (Rs.)	2.83 ^{***}	1.06	5.53 ^{***}	1.00	6.85 ^{***}	1.41
Unit Value (Rs.)	-0.81	15.48	0.36	35.60	1.07 ^ˆ	26.61
South Korea						
Quantity (tonnes)	43.60 ^{***}	5.93	10.20 ^ˆ	2.40	22.77 ^{***}	4.78
Value (Rs.)	47.72 ^{***}	6.83	22.31 ^{***}	2.46	31.94 ^{***}	5.49
Unit value (Rs.)	2.87	5.68	10.98 ^{***}	4.38	7.47 ^{***}	5.26
Other countries						
Quantity (tonnes)	11.48 ^{***}	0.50	14.51 ^{***}	0.89	12.77 ^{***}	0.68
Value (Rs.)	9.54 ^{***}	0.76	11.29 ^{***}	0.87	10.92 ^{***}	0.84
Unit value (Rs.)	-1.75 ^ˆ	6.01	-2.81 ^{***}	6.35	-1.64 ^{***}	6.09

^{***} and ^ˆ corresponds to Significant at 1 per cent, 5 per cent and 10 per cent levels, respectively

(33.67%). But for the value of exports, geographic concentration in the second period (36.74%) was lower than that in the first period (38.65%). Though it is a good sign that geographic concentration of export value decreased, it is important to ensure that proportion of low value products in the export composition of major export destinations need to be reduced and should be replaced with high value products. The comparatively higher value of geographic concentration of export quantity compared to that of value of exports might be pointing to a higher proportion of low value products being exported to the major export destinations like China.

Over time, geographic concentration of export value first increased and then showed gradual declining trend till 2010-11. Then it showed a slight stagnant phase and later started increasing until 2017-18. In the most recent year (2018-19), it decreased further. For the export quantity, geographic concentration slightly increased and then continuously decreased till 2008-09. After that it continuously and significantly increased till 2016-17, and then started decreasing. The geographic concentration of both quantity and value of export started decreasing in the most recent years. This will improve the geographic spread of export and hence the stability of export.

During 2003-04 USA was the single largest export destination for India which accounted for 26.30 per cent and 36.54 per cent of total coir products export quantity and export value, respectively (Table 4). Throughout the years the share of export value was higher than share of export quantity for USA. This indicates the probability to have high proportion of high value coir products in the total coir exports to USA. In China throughout the years the share of export value is less than that of export quantity, indicating chances of high proportion of low value products in the total coir exports to China. The share of export quantity or value is not highly concentrated in a few countries (Though China and USA enjoy slightly higher share). The better distribution among a number of countries thus helps to reduce risk and to provide stability to coir products export from India.

Direction of trade: Transitional probability matrix (Table 5) gives a broad idea on the changes in the direction of trade of coir products export from India. China was the most stable importing country as reflected by highest probability of retention (0.886). This was strengthened by probability of gaining shares from other importing countries like South Korea (1.0) and Netherlands (0.039). China showed only small probability of losing its market share to countries like

Table 4. India's coir products export to major importing countries

Country	2003-04		2008-09		2013-14		2018-19	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
USA	26893.82 (26.30)	14889.48 (36.54)	37819.25 (18.92)	19660.18 (30.72)	55091.03 (10.26)	30026.05 (20.34)	122220.8 (12.68)	60134.19 (22.04)
China	113.60 (0.11)	22.18 (0.05)	18137.24 (9.07)	2199.74 (3.44)	192110.6 (35.77)	36050.66 (24.42)	354267.60 (36.75)	71505.98 (26.21)
Netherlands	17856.19 (17.46)	3204.93 (7.86)	33372.84 (16.69)	4814.41 (7.52)	53786.54 (10.02)	10870.04 (7.36)	96981.75 (10.06)	24841.02 (9.11)
UK	8623.92 (8.43)	4524.6 (11.10)	10819.41 (5.41)	5235.45 (8.18)	11987.01 (2.23)	8600.98 (5.82)	22192.45 (2.30)	11743.33 (4.30)
South Korea	1598.39 (1.56)	126.41 (0.31)	18590.94 (9.30)	1484.12 (2.32)	67042.97 (12.48)	7020.54 (4.76)	75186.43 (7.80)	14251.99 (5.22)
Other countries	47167.56 (46.13)	17982.06 (44.13)	81185.22 (40.61)	30603.51 (47.82)	157022.20 (29.24)	55035.54 (37.29)	293197.50 (30.41)	90328.08 (33.11)
Total export	102253.50 (100.00)	40749.66 (100.00)	199924.9 (100.00)	63997.43 (100.00)	537040.40 (100.00)	147603.80 (100.00)	964046.40 (100.00)	272804.6 (100.00)

Note: Quantity in tonnes, Value in Rs. Lakhs. Digits in parentheses indicate per cent to total

Data source: <http://coirboard.gov.in> and www.indiastat.com

Table 5. Transitional probability matrix of coir products export from India (2003-04 to 2018-19)

Country	USA	China	Netherlands	UK	South Korea	Other countries
USA	0.7034	0.0000	0.0000	0.0924	0.0000	0.2041
China	0.0000	0.8865	0.0094	0.0000	0.1040	0.0000
Netherlands	0.0000	0.0392	0.7815	0.0000	0.1793	0.0000
UK	0.4550	0.0000	0.0000	0.5451	0.0000	0.0000
South Korea	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Other countries	0.0968	0.0000	0.0364	0.0049	0.0137	0.8482

South Korea (0.104) and Netherlands (0.009). China was followed by Netherlands (0.782) and USA (0.703) as stable importers with high probability of retention of their market shares. Netherlands showed probability to lose the market mainly to South Korea (0.179) and China (0.039). USA lost its market mainly to other countries (0.204) and then to UK (0.092). UK showed medium probability of retention (0.545). and was having only low probability of gaining market shares from other countries *viz.* USA (0.092) and other countries (0.0049). It showed probability to lose a good share of its imports to USA (0.455). South Korea was the most unstable importing country for Indian coir products as shown by zero probability of retention. India's coir products export to South Korea exhibit a tendency to shift to China. Though the probability of retention was zero, it showed small probabilities of gaining market shares of some other importing countries like Netherlands, China and other countries.

CONCLUSIONS

The study analyzed the growth rate, instability, geographic concentration and stability of direction of trade aspects of coir products export from India. China showed highest growth rate in quantity and value of export, whereas South Korea topped in the growth rate of unit value of exports. High instability in export quantity, value and unit value of export was found for China. Moderate to high instability coupled with negative growth rate in unit value of export was seen for China and USA – the two major export destinations of Indian coir products. Interventions are needed to address this by improving the share of high value products in the total coir export. Geographic concentration was found not much high for both – quantity and value of export, while geographic concentration in export quantity was comparatively higher. Analysis of Markov chain analysis showed that China was the most stable importer of Indian coir products, as shown by its high probability of retention and also probability to gain from other countries' share. South Korea was found to be the most unstable export destination for Indian coir products. This is a matter of

concern because South Korea was the topper in growth rate of unit value of exports – which might have emerged from increasing proportion of high value products in the total coir export. Stability in export to such important markets is crucial for growth and development of coir industry in a sustainable manner. Interventions are needed to maintain and improve demand for high value products in various export destinations, and also to further decrease geographic concentration of export both in terms of value and quantity.

REFERENCES

- Angles S, Sundar A and Chinnadurai M 2011. Impact of globalization on production and export of turmeric in India: An econometric analysis. *Agricultural Economics Research Review* **24**(2): 301-308.
- Coir Board 2018. *Coir Vikas Yojana: From Waste to Wealth*. <http://coirboard.gov.in/wp-content/uploads/2018/03/coir-final.pdf>
- Ganeshkumar DR, Bhattacharyya K, Narasimhaiah L and Santosh YS 2016. Performance of pomegranate export from India. *Economic Affairs* **61**(4): 1-6.
- Gujarati DN, Porter DC and Gunasekar S 2012. *Basic Econometrics*, Tata McGraw Hill Education Private Limited, New Delhi, p 175.
- Indushree A and Kuruvi A 2019. Performance of small cardamom export from India. *Journal of Tropical Agriculture* **57**(2): 122-131.
- Ministry of Micro, Small & Medium Enterprises, GoI (MSME) 2019. <https://msme.gov.in/coir-board>
- India records all time high export of coir and coir products (Jul 15, 2020), Public Information Bureau (PIB). <https://pib.gov.in/PressReleasePage.aspx?PRID=1638735>
- Raju SS, Chand R and Chouhan S 2014. *Instability In Indian Agriculture: An Inter-State Analysis*. Policy Paper 187, National Centre for Agricultural Economics and Policy Research (NCAEPR), New Delhi. pp. 735-744.
- Raseena KK 2018. Coir industry: trade reforms and the export performance. *Shanlax International Journal of Economics* **6**(S1): 36-42.
- Sarada C, Ravisankar T, Krishnan M and Anandanarayanan C 2006. Indian seafood exports: Issues of instability, commodity concentration and geographical spread. *Indian Journal of Agricultural Economics* **61**(2): 238-252.
- Vijayan A and Devi PI 2018. Risk in agriculture: A spatio-temporal analysis of agricultural income of Kerala. *Journal of Tropical Agriculture* **56**(2):145-152.
- Vivek S, Kumar MCS and Priya V 2019. Rainfall variation and frequency analysis of Tirupur district for crop planning, Tamil Nadu, India. *Indian Journal of Ecology* **46**(3): 610-613.



Reforestation and Features of Forest-Forming Processes in Southeast of Western Siberia. Tomsk region, Russia

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Abstract: Forest is an important renewable natural resource. Natural reforestation preserves the biodiversity of local genotypes and makes natural phytocenoses more resistant to diseases and pests. Natural regeneration is the most important feature of plant formations, which supports the conservation of forests and insures their continuous and sustainable use. Many forestry scientists emphasize biological benefits and cost-effectiveness of natural regeneration of forests. The capability of forest ecosystems for self-regeneration offers unlimited opportunities for forest reproduction. In this study, the renewal of forest stands and formation of young growth on clearings is investigated based on a survey of forest sites, which included laying out sample plots and forest inventory. The sites assigned to wooded lands as a result of artificial regeneration are estimated, and measures to promote natural regeneration are evaluated. The research has shown that over the period (2013-2017), wooded lands in Tomsk region increased by 11,349.44 ha. The areas covered by both young and highly productive middle-aged stands increased.

Keywords: Siberia, Natural regeneration, Biodiversity, Artificial regeneration

Forests are the key component of the natural environment and provide natural regulation of most environmental processes on the earth, which necessitates maximum conservation of the natural capabilities of forests. The ecological and economic potential (Myasnikov 2019, Doddabasawa et al 2020) and biodiversity (Myasnikov 2018, Mouna et al 2019) of forests are affected by geographical conditions of the habitat (Myasnikov 2018, Aditya et al 2018), by species composition and age structure of the forest stand (Myasnikov 2019), and by anthropogenic and natural factors. In contrast to many other natural resources, forests are a renewable natural resource, which enables its rational use and reproduction (Order of the Government of the Russian Federation 2003). Reforestation is carried out by natural, artificial or combined methods in order to restore deforested areas, dead and damaged forests, and to preserve useful functions of forests and biodiversity (Forest Code of the Russian Federation 2006). The main species of woody plants for artificial and combined regeneration in Tomsk region are *Pinus sibirica* Du Tour, *P. sylvestris* L. and *Picea obovata* Ledeb. Zoned seeds of forest stands that meet the requirements established in compliance with the legislation of the Russian Federation are used for cultivation of planting material and growth of artificial stands. The aim of this study was to assess reforestation and features of forest formation in Tomsk region. To achieve the aim, the following objectives to analyze changes in the area of forest fund lands after clear-cutting and reforestation activities fulfilled in the region, to

assess reforestation and formation of young conifers and deciduous species in the region and to evaluate the effectiveness of activities to encourage natural regeneration in Tomsk region.

MATERIAL AND METHODS

The area of Tomsk region is more 314 thousand km², it stretches for 780 km from west to east and for 600 km from north to south. Tomsk region is located in the middle reaches of the Ob river in the southeastern part of the West Siberian Plain, and borders with Kemerovo and Novosibirsk regions in the south, with Omsk region in the south-west, with Khanty-Mansi Autonomous Okrug in the west, north-west and north, and with Krasnoyarsk Territory in the north-east and east. The climate in Tomsk region is moderate continental, and soils are mainly sod-podzolic and peat-bog; in the southeast, soils are gray forest. The study object was forest fund lands of Tomsk region and data of the State Forest Register, which are a systematic set of documented information about forests in the Russian Federation, their use, protection and reproduction, and about forestry and forest parks. During the field survey in 2017, the study objects were forest reproduction sites, which were assigned to wooded lands in Kolpashevsky (Kolpashevo city-N 58°19' E 82°55') and Asinovsky (Asino city-N 57°00' E 86°09') forestries of Tomsk region in 2013-2014. During the survey, sample plots were laid out, where the number and average height of the main, companion and undesirable species were calculated, and the composition of the young growth was determined.

RESULTS AND DISCUSSION

According to the State Forest Register, the area of forest fund lands in Tomsk region occupied by the main forest-forming species as of 01.01.2018 is 19,198.0 thousand ha and all the forests in the region are classified as exploitable and protection forests. The forest cover of Tomsk region is uneven, averages 61.4% and varies in individual areas depending on physical, geographical, climatic and soil conditions. In the forests of Tomsk region, coniferous stands make up 53.7% of the land occupied by the main forest-forming species or 10,309.3 thousand ha. Deciduous stands with the main forest-forming species covers 46.3% (8,888.7 thousand ha) of the land. The main forest-forming species in Tomsk region are the following woody plant species: *Abies sibirica* Ledeb., *P. obovata* Ledeb., *Larix sibirica* Ledeb., *P. sibirica* Du Tour, *P. sylvestris* L., *Betula pubescens* Ehrh., *B. pendula* Roth., *Populus tremula* L., and a small amount of poplars, willows and shrubs. The main objectives of reforestation are timely regeneration of clear-cuts, dead stands, burned-out forests and other non-forested areas, an increase in forest productivity and improvement of species composition. Forest reproduction can be achieved through the following reforestation activities: forest management and creation of favorable conditions for natural regeneration. The most widely used method of reforestation in the region is promotion of natural regeneration, which is ensured by preservation of viable undergrowth of commercially valuable species during logging in mature and over mature forests, and by mineralization of soil in the areas with sources of seeding trees. Figure 1 shows the excess of clear-cuts over reforested areas. However, the areas where reforestation activities were carried out to encourage natural regeneration are several times larger than plantations with artificial regeneration.

Figure 2 shows an increase in reforestation areas in the region mainly due to reforestation activities carried out to encourage natural regeneration and natural overgrowing of areas with economically valuable species. An increase in the areas converted to wooded lands can be observed in forestries located in the regions where logging is mainly carried out in winter. The snow cover protects the hidden undergrowth from damage, while that rising more or less high above the snow can be easily damaged in frosty weather (due to its fragility). Timber skidding in winter causes insignificant damage to litter and soil, while soil disturbance caused by skidding and slash burning in summer has a significant impact on the environment and the process of reforestation (Belyaeva 2013). As part of this study, 7 sites in the Kolpashevsky forestry assigned to wooded lands in 2013-2014 were surveyed where reforestation activities were

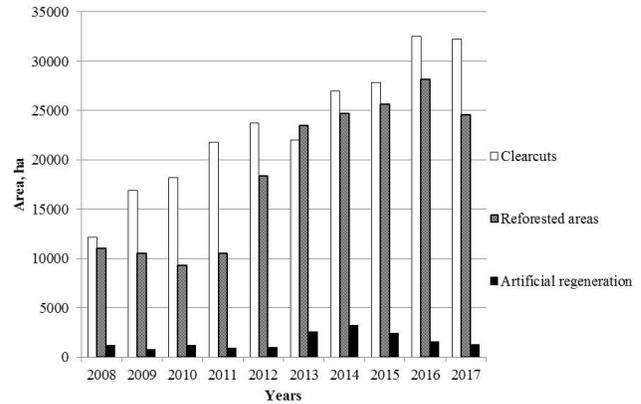


Fig. 1. Clearcutting and reforestation activities

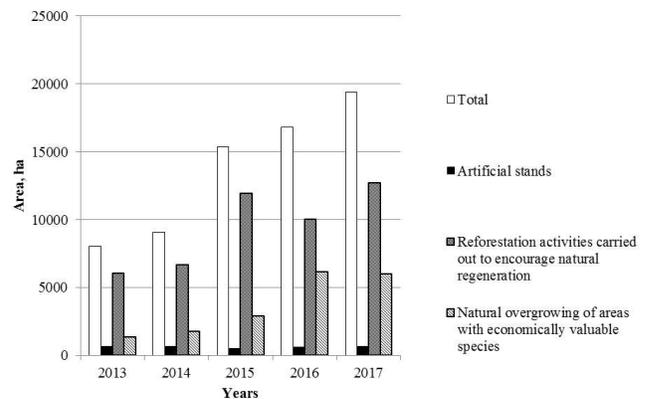


Fig. 2. Conversion to wooded land

carried out to encourage natural regeneration and 3 sites in the Asinovsky forestry, of which 3 sites with a total area of 32.1 ha did not correspond to the young growth system after their assignment to wooded lands, and 1 site of 16.5 ha did not meet the criteria and requirements for reforestation stated in the order of the Ministry of Natural Resources and Ecology and the Russian Federation No. 188 dated March 25, 2019. The first site of 2.7 ha located in the Kolpashevsky forestry was assigned to wooded lands in 2013. In 2017, 20 circular sample plots 20 m² in size were laid out. In the field survey, the species composition of the forest stand was established: aspen (70%); birch (20%); Siberian cedar pine (10%); fir, pine, and spruce occurred sporadically and stand density was 0.7. The second site of 3.8 ha located in the Kolpashevsky forestry was assigned to wooded lands in 2013. In 2017, 20 circular sample plots 20 m² in size were laid out. In the field survey, the species composition of the forest stand was established: aspen (60%); birch (30%); spruce (10%); Siberian cedar pine, fir, and pine occurred sporadically and stand density was 0.5. The third site of 25.6 ha located in the Malo-Yuksinsky forestry was assigned to wooded lands in 2014. In 2017, 60 circular sample plots 20 m² in size were laid

out. In the field survey, the species composition of the stand was established: aspen (60%); birch (10%); pines (30%); larch, Siberian cedar pine, and fir occurred sporadically and stand density was 0.6. The fourth site of 16.5 ha (cleared in 2009) located in the Malo-Yuksinsky forestry was assigned to wooded lands in 2014. In 2017, 40 circular sample plots 20 m² in size were laid out. In the field survey, the species composition of the forest stand was established: fir (50%); Siberian cedar pine (20%); spruce (20%); birch (10%); aspen occurred sporadically and stand density was 0.4.

In addition, surveyed 11 forest sites located in the Asinovskoye forestry and assigned to wooded lands in 2013-2014, of which 2 sites with a total area of 15.0 ha did not correspond to the young growth system after their assignment to wooded lands. In the sites, pine artificial stands were suppressed by soft-leaved species, the height of which was more than two heights of artificial stands. The first site of artificial regeneration with an area of 5.0 ha (artificial stands of common pine planted in 2007), which is located in the Malo-Yuksinsky forestry was assigned to wooded lands in 2014. One sample plot of 780 m² (60 m x 13 m) was laid out. In the field survey, the species composition of the forest stand was established: birch (50%), aspen (30%), pine (20%) and stand density was 0.8. The second site of artificial regeneration with an area of 10.0 ha (artificial stands of common pine planted in 2006) which is located in the Malo-Yuksinsky forestry was assigned to wooded lands in 2014 and. Two sample plots of 1,800 m² (18 m x 100 m) and of 650 m² (10 m x 65 m) were laid out. In the field survey, the species composition of the forest stand was established: aspen (50%); birch (10%); pine (30%); siberian cedar pine (10%); fir, larch, and spruce occurred sporadically and stand density was 0.8. According to paragraph 92, order No. 122 of the Ministry of Natural Resources of Russia dated March 29, 2018 *On the Approval of the Forest Management Instructions*, forest taxation stands are referred to artificial stands if at least 5 tree species of artificial origin are found in the forest plantation. The survey of the sites occupied by artificial stands of coniferous plant species showed that almost everywhere artificial stands were suppressed by deciduous species. Therefore, timely clearcutting is necessary to prevent suppression of artificial stands under the canopy by heliophilous species growing in the first stratum. A lack of timely management causes death of coniferous plants and a change in the species composition.

CONCLUSION

Over the period from 2013 to 2017, wooded lands in the region increased by 11,349.44 ha. The areas covered by both young and highly productive middle-aged stands increased.

Fulfillment of the reforestation activities in Tomsk region exceeded 100%. The area of young growth increased mainly due to reforestation activities carried out to encourage natural regeneration (59.7% of the total area of the young growth), the share of forests with natural regeneration of economically valuable species attained 36.6%, and the share of artificial stands accounted for 3.7%. In 2017, the percentage of fulfillment of the annual volume of field surveys in Tomsk region amounted to 220.0 ha (100%), of which 156.4 ha (71.1%) of the land corresponded to the young growth system after its assignment to wooded lands, and 63.6 ha (28.9%) did not comply with requirements for reforestation, of which 47.1 ha (21.4%) of the land did not correspond to the young growth system after its assignment to wooded lands, and 16.5 ha (7.5%) did not meet the standard (the number of main tree species).

REFERENCES

- Aditya SK, Smitha Asok V and Rajesh Reghunath 2018. Landscape analysis using gis and remote sensing for assessing spatial pattern in forest fragmentation in Shendurney wildlife sanctuary, Western Ghats, India. *Indian Journal of Ecology* **45**(2): 299-304.
- Belyaeva NV 2013. *The patterns of changes in the structure and condition of the young generation of spruce under conditions of intensive economic impact*. Dissertation for the degree of Doctor of Agricultural Sciences. St. Petersburg. 431p.
- Doddabasawa, Chittapur BM and Kammar Shivanand K 2020. Socio-economic evaluation of agroforestry systems. *Indian Journal of Ecology* **47**(1): 129-133.
- Forest Code of the Russian Federation of December 4, 2006 No. 200-FZ (as amended on April 24, 2020).
- Order of the Government of the Russian Federation of January 18, 2003 No. 69-r (as amended on September 28, 2007) On Concept for the Development of Forestry of the Russian Federation in 2003-2010.
- Order of the Ministry of Natural Resources of Russia of March 25, 2019 No. 188 (as amended on August 14, 2019) On Approval of the Reforestation Rules, the Composition of the Reforestation Project, the Procedure for Developing the Reforestation Project and Making Changes to It.
- Order of the Ministry of Natural Resources of Russia of March 29, 2018 No. 122 On Approval of the Forest Management Instructions.
- Mouna S, Jabeen FTZ, Dakshayini J, Haleshi C and Seetharam YN 2019. Carbon Sequestration and Tree Diversity of Thimmalapura Reserve Forest, Tumakuru, Karnataka. *Indian Journal of Ecology* **46**(1): 116-125.
- Myasnikov AG 2018. Biodiversity conservation of the main species of woody and shrubby plants in the forests of Western Siberia (Tomsk region). *Ecology, Environment and Conservation* **24**(3): 1144-1148.
- Myasnikov AG 2018. Zonal forest communities and forest zoning of Western Siberia (Russia). *Iraqi Journal of Agricultural Sciences* **49**(6): 938-943.
- Myasnikov AG 2019. Condition and dynamics of cedar forests of Western Siberia (Tomsk region). *Iraqi Journal of Agricultural Sciences* **50**(5): 1356-1360.
- Myasnikov AG 2019. Ecological and economic assessment of forests and forest zoning of the Republic of Buryatia (Russia). *Annals of Biology* **35**(1): 112-116.



Invasive Alien Flora of Tropical Dry Deciduous Forest of Nauradehi Wildlife Sanctuary, Central India

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Abstract: Biological invasion is a global phenomenon mostly related to trade and travel. Earlier the invasive plant species were commonly observed along the roadside and on the margins of forest communities. With the increasing intensity of invasion, alien invasive species are invading the protected areas. The present study was undertaken to find out the status of alien invasive flora in the protected area network in Madhya Pradesh, India. An intensive floristic survey was carried out in Nauradehi Wildlife Sanctuary covering an area about 1197.042 km², the largest Wildlife Sanctuary of Madhya Pradesh. Enumeration of invasive alien plant species in this area showed the occurrence of 108 species belonging to 82 genera belonging to 31 families. Out of 108 alien species, 81 herbs, 12 climbers, 11 shrubs and 4 trees species were recorded. The data revealed that invasive alien species accessed the core area of Sanctuary and are becoming a threat to the native flora due to their invasive potential traits. It is suggested that early recognition and monitoring of new and naturalized infestations of alien species in Nauradehi Wildlife Sanctuary would help to contain them to conserve the diversity.

Keywords: Biological invasion, Invasive plants, Ecological threats, Nauradehi Wildlife Sanctuary, Madhya Pradesh

The problem of invasive plants has become global and is largely human-aided and (Vitousek et al 1997) observed that invasive plants are responsible for global environmental changes, the biodiversity crisis, species endangerment and disruption of ecosystem processes essential for human welfare. The impact of invasive plants on global biodiversity is the second largest threat after habitat fragmentation and is a major global issue (Drake et al 2003). Invasive alien plants have caused serious economic and ecological damage globally. For effective invasive alien species research, prioritization and management, certain specific data including details of invasive species, pathways of invasion and also the information about the sites that are most sensitive and prone for further invasion are essential (McGeoch et al 2016). The Millennium Ecosystem Assessment (2005) lists invasive alien species as one of the five primary drivers of change in ecosystem composition, structure and function. Moreover, global climate change may further accelerate the rate of introduction and spread of alien species into areas where they were previously absent, or increase their performance relative to indigenous species. Invasive alien species can have large detrimental economic impacts on human enterprises such as fisheries, agriculture, grazing and forestry. It can be regarded as a form of biological pollution and a critical component of human activity processes that lead to the extinction of native species. Over the last few decades, several invasive species have been

introduced whether unintentionally or intentionally as agricultural crops or ornamental plants in India from their native areas. Some frequently cultivated alien species may provide food, medicine, fuel, or livestock to local communities (Kull et al 2007, Roder et al 2007) and some of them are accountable for destruction, extinction of native species, hazardous agricultural production, forest restoration, agricultural land, human and animal health (Sharma et al 2005, Kohli et al 2006). It is reported that as many as 50% of invasive species can typically be listed as environmentally damaging on the basis of their actual effects. (Richardson et al 2000).

The invasive species are well-known to modify the physical habitat as well by intensifying the disturbance regimes such as flooding, soil erosion and forest fires (Lone et al 2019). It is well known that invasive plant species influence the species richness, uniformity and abundance of the native plant species reducing the local species diversity and subsequently drastically modifying the unique characteristics of the original biological community present in the habitat (Olden et al 2003, Pysek et al 2012, Rastogi et al 2015). The present paper deals with the enumeration of invasive flora of a Nauradehi Wildlife Sanctuary, a protected area in the state of Madhya Pradesh, India.

MATERIAL AND METHODS

The study was carried out in Nauradehi Wildlife

Sanctuary. This is the largest wildlife Sanctuary of the Madhya Pradesh. It covers an area of about 1197.042 sq. km. It lies between 23°5' to 23°43' North and 79°5' to 79°25' East and at an average altitude of 600 m above mean sea level. The forest vegetation is a tropical dry deciduous type, with teak (*Tectona grandis*) as predominant species. It comprises the reserved and protected forest of South Sagar forest division, Damoh forest division and Narsingpur forest division. Based on average annual rainfall, temperature and humidity conditions, the climate of the Sanctuary can broadly be termed as seasonal. The year is divisible into three well-marked seasons i.e. rainy, winter and summer. The rainy season starts from mid-June and continues till the end of September. Winter follows the rainy season and extends from mid-October to the end of February. Summer season starts from early March and continues till mid-June. The normal annual rainfall of the area is about 1200 mm. About 90% of the annual rainfall is received during the southwest monsoon period i.e. June to September, only 5.5% and about 4.5% during winter and summer season respectively. January is the coldest month with the temperature as low as 5°C with a maximum up to 30°C. Highest temperature goes up to 48°C during the month of May.

The present study was carried out during February 2018 - February 2020 by surveying each locality of the study area at regular intervals in all seasons of the year. The area was selected based on geographical location and forest community to collect the plant samples in the flowering and fruiting stages. These specimens were dried and pressed in the field and transported to the laboratory and herbarium was prepared and deposited in the Herbarium, Department of Botany, Dr. Harisingh Gour Central University, Sagar, Madhya Pradesh. For the purpose of identification, micro-morphological characters of the plant were detailed. All the specimens were critically examined and identified with the help of different flora and published literature (Verma et al 1993, Mudgal et al 1997, Singh et al 2001). Information on alien invasive plants was compiled from a literature survey. An extensive review of literature on global invasive species was done for the nativity of these plants (Shukla et al 2009, Shukla and Sinha 2012, Wagh and Jain 2015, Reshi et al 2017 and Suman et al 2017). The invasive species are alphabetically addressed in tabular form, accompanied by the author's abbreviations, family name, place of origin, life form, mode of introduction (Table 1).

RESULTS AND DISCUSSION

A number of 108 species were recorded under 82 genera belonging to 31 families (Table 1). Out of the total 106 species, 76 genera belong to 28 dicot families and 6 species

under 6 genera belong to 3 monocot families (Fig. 1). Geographical nativity of their alien invasive species showed that Tropical America (75 species) region contributes the greatest (69 %) followed by tropical Africa (14%). The other regions that contribute little are Afghanistan, Australia, Brazil, Central Asia, Europe, Mediterranean, Mexico, South West Asia, Temperate South America and the West Indies. Most of the alien species are herbs (73%) followed by shrubs (14%), climbers (9%) and trees (4%) (Fig. 2). Out of 30 families having invasive alien species, Asteraceae was the most dominant family (20 species), followed by Fabaceae, Malvaceae, Convolvulaceae and Euphorbiaceae (Fig. 4). The 8 families contributed 71 % of the invasive alien species of Nauradehi Wildlife Sanctuary.

In this study, only the wild invasive species of plants were considered. These species were categorized by different workers into naturalized and noxious (Richardson et al 2000). Out of the total invasive alien species, 10% species were noxious, 26% were interfering and 64% were naturalized

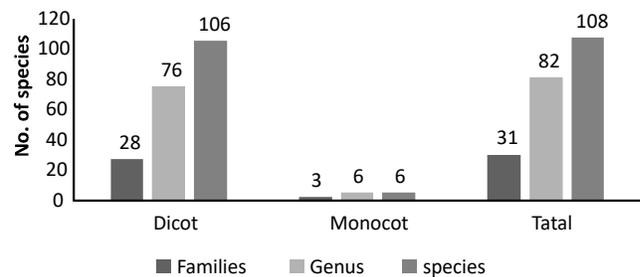


Fig. 1. Status of family, genera and species of invasive alien plant species of Nauradehi Wildlife Sanctuary

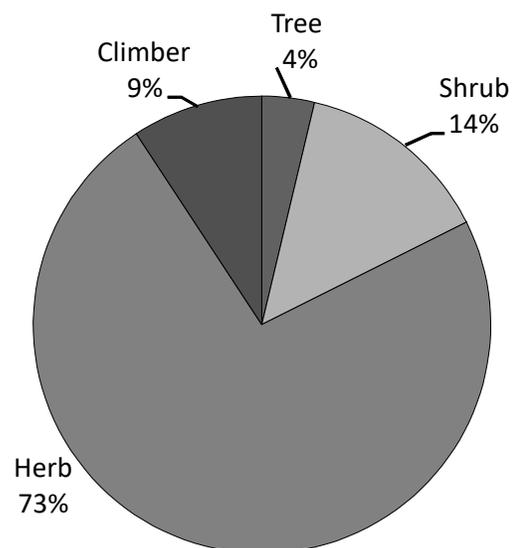


Fig. 2. Life form of invasive alien species in Nauradehi Wildlife Sanctuary

Table 1. List of invasive alien species recorded in Nauradehi Wildlife Sanctuary

Botanical name and family	Specimen No.	Native	LF	Habit	Categories	Mi
<i>Acacia auriculiformis</i> A. Cunn. ex Benth. Fabaceae	NWS- 70	AUS	T	P	Interfering	Uni
<i>Acanthospermum hispidum</i> DC. Asteraceae	NWS- 82	BR	H	A	Naturalized	Uni
<i>Ageratum conyzoides</i> L. Asteraceae	NWS- 10	TAM	H	A	Noxious	Orn
<i>Alternanthera sessilis</i> (L.) R. Br. ex DC. Amaranthaceae	NWS- 99	TAM	H	P	Naturalized	Uni
<i>Amaranthus spinosus</i> L. Amaranthaceae	NWS- 87	TAM	H	A	Naturalized	Uni
<i>Anagallis arvensis</i> L. Primulaceae	NWS- 92	EU	H	A	Naturalized	Uni
<i>Antigonon leptopus</i> Hook. & Arnott Polygonaceae	NWS- 93	TAM	C	P	Noxious	Uni
<i>Argemone mexicana</i> L. Papaveraceae	NWS- 88	TSA	H	A	Noxious	Uni
<i>Argemone ochroleuca</i> Sweet Papaveraceae	NWS- 91	SAM	H	A	Naturalized	Uni
<i>Bidens pilosa</i> L. Asteraceae	NWS- 30	SAM	H	A	Naturalized	Uni
<i>Blainvillea acmella</i> (L.) Philipson Asteraceae	NWS- 113	SAM	H	A	Interfering	Uni
<i>Blumea lacera</i> (Burm. f.) DC. Asteraceae	NWS- 121	TAM	H	A	Interfering	Uni
<i>Calotropis gigantea</i> (L.) R. Br. Apocynaceae	NWS- 123	TAF	S	P	Interfering	Uni
<i>Calotropis procera</i> (Aiton) R. Br. Apocynaceae	NWS- 118	TAF	S	P	Interfering	Uni
<i>Cannabis sativa</i> L. Cannabaceae	NWS- 152	CA	S	P	Interfering	Uni
<i>Cardiospermum halicacabum</i> L. Sapindaceae	NWS- 38	TAM	C	P	Naturalized	Uni
<i>Cassia absus</i> L. Fabaceae	NWS- 143	TAM	H	A	Naturalized	Uni
<i>Cassia occidentalis</i> L. Fabaceae	NWS- 148	TSA	S	P	Naturalized	Uni
<i>Cassia pumila</i> Lam. Fabaceae	NWS- 34	TAM	H	A	Naturalized	Uni
<i>Cassia tora</i> L. Fabaceae	NWS- 162	TSA	H	A	Noxious	Uni
<i>Cassia uniflora</i> Mill. Fabaceae	NWS- 45	SAM	H	A	Interfering	Uni
<i>Catharanthus pusillus</i> (Murr.) G. Don Apocynaceae	NWS- 41	TAM	H	A	Interfering	Orn
<i>Celosia argentea</i> L. Amaranthaceae	NWS- 62	TAF	H	A	Naturalized	Uni
<i>Chloris barbata</i> Sw. Poaceae	NWS- 170	TAM	H	P	Naturalized	Uni
<i>Chrozophora rotleri</i> (Geiseler) A. Juss. ex Spreng. Euphorbiaceae	NWS- 101	TAF	H	P	Interfering	Uni
<i>Cissampelos pareira</i> L. Menispermaceae	NWS- 72	SAM	C	P	Naturalized	Uni
<i>Cleome viscosa</i> L. Cleomaceae	NWS- 186	TAM	H	A	Naturalized	Uni
<i>Convolvulus arvensis</i> L. Convolvulaceae	NWS- 154	TEU	H	A	Naturalized	Uni
<i>Conyza bipinnatifida</i> Wall. Asteraceae	NWS- 83	TAM	H	P	Interfering	Uni
<i>Corchorus aestuans</i> L. Malvaceae	NWS- 161	TAF	H	A	Naturalized	Uni
<i>Corchorus capsularis</i> L. Malvaceae	NWS- 172	TAM	H	A	Naturalized	Uni
<i>Corchorus fascicularis</i> Lam. Malvaceae	NWS- 193	TAM	H	A	Naturalized	Uni
<i>Corchorus olitorius</i> L. Malvaceae	NWS- 208	TAM	H	A	Naturalized	Uni
<i>Corchorus trilocularis</i> L. Malvaceae	NWS- 127	TAF	H	A	Naturalized	Uni
<i>Croton bonplandianus</i> Boill. Euphorbiaceae	NWS- 136	TESA	H	P	Naturalized	Uni
<i>Cuscuta reflexa</i> Roxb. Convolvulaceae	NWS- 141	MD	C	A	Interfering	Uni
<i>Cynodon dactylon</i> (L.) Pers. Poaceae	NWS- 86	AF	H	A	Naturalized	Uni
<i>Cyperus difformis</i> L. Cyperaceae	NWS- 100	TAM	H	A	Naturalized	Uni
<i>Datura innoxia</i> Mill. Solanaceae	NWS- 66	TAM	S	P	Noxious	Uni
<i>Datura metel</i> L. Solanaceae	NWS- 140	TAM	S	P	Interfering	Uni
<i>Digera muricata</i> (L.) Mart. Amaranthaceae	NWS- 164	SWA	H	A	Naturalized	Uni
<i>Dinebra retroflexa</i> (Vahl) Panz. Poaceae	NWS- 156	TAM	H	P	Naturalized	Uni
<i>Echinochloa colonum</i> (L.) Link Poaceae	NWS- 182	TSA	H	A	Noxious	Uni

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Continues Table 1

Botanical name and family	Specimen No.	Native	LF	Habit	Categories	Mi
<i>Echinops echinatus</i> Roxb. Asteraceae	NWS- 401	AFG	H	A	Naturalized	Uni
<i>Eclipta prostrata</i> (L.) L. Asteraceae	NWS- 265	TAM	H	A	Naturalized	Uni
<i>Emilia sonchifolia</i> (L.) DC. Asteraceae	NWS- 287	TAF	H	A	Naturalized	Uni
<i>Euphorbia hirta</i> L. Euphorbiaceae	NWS- 294	TAM	H	A	Naturalized	Uni
<i>Euphorbia hypericifolia</i> L. Euphorbiaceae	NWS- 49	TAM	H	A	Naturalized	Uni
<i>Euphorbia pulcherrima</i> Willd. ex Klotzsch Euphorbiaceae	NWS- 418	TAM	H	A	Naturalized	Orn
<i>Euphorbia thymifolia</i> L. Euphorbiaceae	NWS- 413	SAM	H	A	Naturalized	Uni
<i>Evolvulus nummularius</i> (L.) L. Convolvulaceae	NWS- 404	TAM	H	A	Naturalized	Uni
<i>Galinsoga parviflora</i> Cav. Asteraceae	NWS- 230	TAM	H	A	Naturalized	Uni
<i>Glossocardia bosvallea</i> (L.f.) DC. Asteraceae	NWS- 503	WI	H	A	Naturalized	Uni
<i>Gnaphalium pensylvanicum</i> Willd. Asteraceae	NWS- 160	TAM	H	A	Naturalized	Uni
<i>Hyptis suaveolens</i> (L.) Poit. Lamiaceae	NWS- 463	TAM	H	A	Interfering	Uni
<i>Impatiens balsamina</i> L. Balsaminaceae	NWS- 315	TAM	H	A	Naturalized	Orn
<i>Indigofera astragalina</i> DC. Fabaceae	NWS- 300	TAM	H	A	Naturalized	Uni
<i>Indigofera linifolia</i> (L. f.) Retz. Fabaceae	NWS- 288	TSA	H	A	Naturalized	Uni
<i>Indigofera linnaei</i> Ali. Fabaceae	NWS- 296	TSA	H	A	Naturalized	Uni
<i>Indigofera trita</i> L. f. Fabaceae	NWS- 443	TAF	H	P	Naturalized	Uni
<i>Ipomoea carnea</i> Jacq. Convolvulaceae	NWS- 308	TAM	S	P	Interfering	Uni
<i>Ipomoea eriocarpa</i> R. Br. Convolvulaceae	NWS- 281	TAF	C	A	Interfering	Orn
<i>Ipomoea hederifolia</i> L. Convolvulaceae	NWS- 223	TAM	C	A	Interfering	Uni
<i>Ipomoea nil</i> (L.) Roth. Convolvulaceae	NWS- 311	NAM	C	A	Interfering	Uni
<i>Ipomoea obscura</i> (L.) Ker Gawl. Convolvulaceae	NWS- 444	TSA	C	A	Interfering	Uni
<i>Ipomoea pes-tigridis</i> L. Convolvulaceae	NWS- 126	TEAF	C	A	Interfering	Uni
<i>Jatropha curcas</i> L. Euphorbiaceae	NWS- 124	TAM	S	A	Naturalized	Uni
<i>Jatropha gossypifolia</i> L. Euphorbiaceae	NWS- 128	BR	S	A	Naturalized	Uni
<i>Lagascea mollis</i> Cav. Asteraceae	NWS- 194	TCA	H	A	Noxious	Uni
<i>Lantana camara</i> L. Verbenaceae	NWS- 430	TAM	S	P	Noxious	Orn
<i>Leonotis nepetifolia</i> (L.) R. Br. Lamiaceae	NWS- 61	TAF	S	A	Interfering	Uni
<i>Leucaena leucocephala</i> (Lamk.) De Wit Fabaceae	NWS- 299	TAM	T	A	Noxious	Fo
<i>Ludwigia octovalvis</i> (Jacq.) Raven Onagraceae	NWS- 381	TAM	H	A	Naturalized	Uni
<i>Malvastrum coromandelianum</i> (L.) Gar. Malvaceae	NWS- 11	TAM	H	A	Naturalized	Uni
<i>Martynia annua</i> L. Martyniaceae	NWS- 25	TAM	S	P	Naturalized	Uni
<i>Mecardonia procumbens</i> (Mill.) Small Plantaginaceae	NWS- 309	NAM	H	A	Naturalized	Uni
<i>Melochia corchorifolia</i> L. Malvaceae	NWS- 474	TAM	H	P	Naturalized	Uni
<i>Merremia emarginata</i> (Burm.f.) Hallier f. Convolvulaceae	NWS- 408	TAF	H	P	Naturalized	Uni
<i>Mimosa pudica</i> L. Fabaceae	NWS- 516	BR	H	A	Naturalized	Uni
<i>Ocimum americanum</i> L. Lamiaceae	NWS- 477	TAM	H	A	Naturalized	Uni
<i>Oxalis corniculata</i> L. Oxalidaceae	NWS- 355	EU	H	A	Naturalized	Uni
<i>Oxalis corymbosa</i> DC. Oxalidaceae	NWS- 190	SAM	H	A	Naturalized	Uni
<i>Parthenium hysterophorus</i> L. Asteraceae	NWS- 189	TAM	H	A	Noxious	Uni
<i>Passiflora foetida</i> L. Passifloraceae	NWS- 364	TAM	C	A	Interfering	Orn
<i>Peperomia pellucida</i> (L.) Kunth Piperaceae	NWS- 211	TAM	H	A	Naturalized	Uni
<i>Peristrophe paniculata</i> (Forssk.) Brummitt Acanthaceae	NWS- 361	TAM	H	A	Interfering	Uni

Cont..

Continues Table 1

Botanical name and family	Specimen No.	Native	LF	Habit	Categories	Mi
<i>Physalis minima</i> L. Solanaceae	NWS- 371	TAM	H	A	Naturalized	Uni
<i>Physalis peruviana</i> L. Solanaceae	NWS- 378	SAM	H	A	Naturalized	Uni
<i>Pithecellobium dulce</i> (Roxb.) Benth. Fabaceae	NWS- 514	ME	T	P	Naturalized	Uni
<i>Prosopis juliflora</i> (Swartz) DC. Fabaceae	NWS- 506	ME	T	A	Naturalized	Uni
<i>Ricinus communis</i> L. Euphorbiaceae	NWS- 6	AF	S	A	Interfering	Agr
<i>Ruellia tuberosa</i> L. Acanthaceae	NWS- 489	TAM	H	A	Naturalized	Uni
<i>Scoparia dulcis</i> L. Plantaginaceae	NWS- 284	TAM	H	A	Naturalized	Uni
<i>Sida acuta</i> Burm. f. Malvaceae	NWS- 12	TAM	H	A	Naturalized	Uni
<i>Solanum nigrum</i> L. Solanaceae	NWS- 346	TAM	H	A	Naturalized	Uni
<i>Sonchus asper</i> (L.) Hill. Asteraceae	NWS- 269	MD	H	A	Interfering	Uni
<i>Sonchus oleraceus</i> L. Asteraceae	NWS- 396	MD	H	A	Interfering	Uni
<i>Spermacoce hispida</i> L. Rubiaceae	NWS- 283	TAM	H	A	Interfering	Uni
<i>Spilanthes radicans</i> Jacq. Asteraceae	NWS- 450	TAM	H	A	Naturalized	Uni
<i>Synedrella nodiflora</i> (L.) Gaertn. Asteraceae	NWS- 470	WI	H	A	Naturalized	Uni
<i>Tecoma stans</i> (L.) Juss. ex Kunth Bignoniaceae	NWS- 267	AM	S	P	Naturalized	Uni
<i>Tribulus terrestris</i> L. Zygophyllaceae	NWS- 457	TAM	H	P	Naturalized	Uni
<i>Tridax procumbens</i> L. Asteraceae	NWS- 510	TCA	H	P	Naturalized	Uni
<i>Triumfetta rhomboidea</i> Jacq. Malvaceae	NWS- 231	TAM	H	P	Naturalized	Uni
<i>Typha angustifolia</i> L. Typhaceae	NWS- 89	TAM	H	P	Interfering	Uni
<i>Urena lobata</i> L. Malvaceae	NWS- 461	TAF	S	P	Interfering	Uni
<i>Waltheria indica</i> L. Malvaceae	NWS- 388	TAM	H	A	Noxious	Uni
<i>Xanthium strumarium</i> L. Asteraceae	NWS- 58	TAM	H	A	Naturalized	Uni

Notes: AUS- Australia; BR- Brazil; TAM- Tropical America; EU- Europe; TSA- Tropical South America; SAM- South America; TAF- Tropical Africa; CA- Central Asia; TEU- Temperate Europe; Temperate South America- TESA; MD- Mediterranean; AF- Africa; SWA- South West Asia- SWA; AFG- Afghanistan; WI- West Indies; NAM- North America; TEAF Tropical East Africa; TCA- Tropical Central America; North; Tropical North America- TNA- Mexico- ME; AM- America. LF- Life Form; H- Herb; S- Shrub; T- Tree; C- Climber; A- Annual; P- Perennial. Mi- Mode of introduction; Fo- Fodder; Uni- Unintentional; Orn- Ornamental; Arg- Agroforestry

(Fig. 3). During the field survey, discussion held with local people revealed that 11 species (*Parthenium hysterophorus*, *Lantana camara*, *Ageratum conyzoides*, *Cassia tora*, *Antigonon leptopus*, *Argemone mexicana*, *Datura innoxia*, *Echinochloa colonum*, *Lagascea mollis*, *Xanthium stromarium* and *Leucaena leucocephala*,) were noxious. A few species showed allelopathy effect, e.g. *Leucaena leucocephala*, causes retardation in seedling growth of neighbouring plants. The intervening invasive plants cause disturbance and obstacle in the agriculture field and the undergrowth of the forest. It is a troubling situation to protect local floral diversity. The better viability and resistance to harsh conditions caused by climate change and distinct bounces may result in the predominance of herbs throughout the region. The occurrence of members of family Asteraceae as the major invasive flora may be related to their high reproductive capacity by dividing of reproductive resources into a great amount of minute, light and wind dispersed seeds or propagules. Several invasive species appear to react to

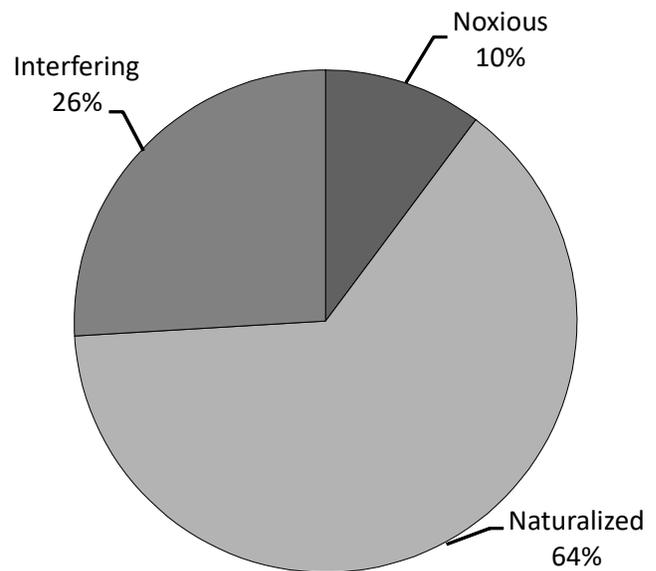


Fig. 3. Status of invasive alien species in Nauradehi Wildlife Sanctuary

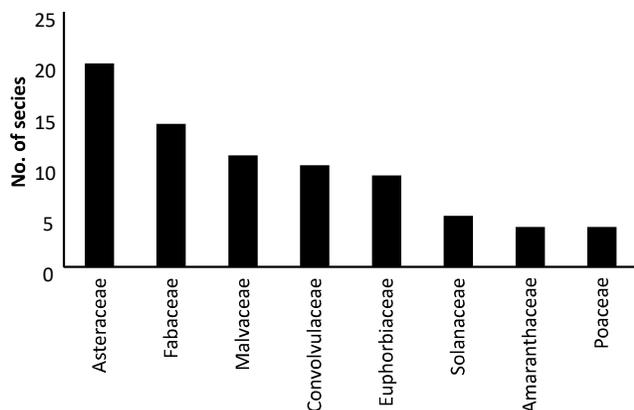


Fig. 4. Dominant families of invasive alien plant species of Nauradehi Wildlife Sanctuary

soil partially supplemented with nutrients and rapidly expand to cover the gaps in disrupted forests. They can destroy agricultural land soil, have a negative effect on orchard production, and can also replace grass in a field, emitting a toxic volatile which prevents grazing (Saxena 1991, Tripathi 1999). Invasive alien species can transform the structure and species composition of ecosystems by dominating the ecosystems and repressing or excluding native species.

CONCLUSION

The present study indicates that Nauradehi Wildlife Sanctuary is facing increasingly severe threats from alien invasive plants from outside. Recent studies of invasive plants in the Nauradehi Wildlife Sanctuary indicate the need for a series of steps to control invasive plants. Early warnings regarding these species may help in managing them well before they damage natural ecosystems. Due to increased globalization, there is a great chance for both unintentional/intentional introductions of species into new environments. Moreover, invasive species are well-known to expand their ranges towards high latitudes and altitudes due to climate change and exacerbated by anthropogenic disturbances. A better planning is required for early detection and monitoring of infestations of the spread of new and naturalized alien species through the creation of plant detection network in Nauradehi Wildlife Sanctuary by establishing communication links among Agriculturist, Botanist, Environmentalist, planting units from forest department or all of them to reduce the invasion and eradication of invaded invasive plant species.

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REFERENCES

- Drake SJ, Weltzin JF and Parr PD 2003. Assessment of non-native invasive plant species on the United States Department of Energy Oak Ridge National Environmental Research. *Castanea* **68**(1): 15-30.
- Kohli RK, Batish DR, Singh HP and Dogra KS 2006. Status, invasiveness and environmental threats of three tropical American invasive weeds (*Parthenium hysterophorus* L., *Ageratum conyzoides* L., *Lantana camara* L.) in India. *Biological Invasions* **8**(7): 1501-1510.
- Kull CA, Tassin J and Rangan H 2007. Multifunctional, scrubby, and invasive forests?. *Mountain Research and Development* **27**(3): 224-231.
- Lone PA, Dar JA, Subashree K, Raha D, Pandey PK, Ray T, Khare PK and Khan ML 2019. Impact of plant invasion on physical, chemical and biological aspects of ecosystems: A review. *Tropical Plant Research* **6**(3): 528-544.
- McGeoch MA, Genovesi P, Bellingham PJ, Costello MJ, McGrannachan C and Sheppard A 2016. Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. *Biological Invasions* **18**(2): 299-314.
- Mudgal V, Khanna KK and Hajra PK 1997. *Flora of Madhya Pradesh Volume II*. Botanical Survey of India, Calcutta, India.
- Olden JD, Poff NL, Olden JD and Poff NL 2003. Toward a mechanistic understanding and prediction of biotic homogenization. *American Society of Naturalists* **162**(4): 442-460.
- Pysek P, Jarosik V, Hulme P, Pergl J, Hejda M, Schaffner U and Vila M 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: The interaction of impact measures, invading species' traits and environment. *Global Change Biology* **18**(5): 1725-1737.
- Rastogi J, Rawat DS and Chandra S 2015. Diversity of invasive alien species in Pantnagar flora. *Tropical Plant Research* **2**(3): 282-287.
- Reshi MI, Chadhar BL and Khare PK 2017. Alien invasive plants of central Indian tropical dry deciduous forests of Sagar district, Madhya Pradesh, India. *Indian Forester* **143**(2): 157-164.
- Richardson DM, Pysek P, Rejmanek M, Barbour MG, Panetta FD and West CJ 2000. Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distribution* **6**(2): 93-107.
- Roder W, Dorji K and Wangdi K 2007. Implications of white clover introduction in East Himalayan grasslands. *Mountain Research and Development* **27**(3): 268-273.
- Saxena KG 1991. Biological invasions in the Indian subcontinent: review of invasion by plants. pp. 53-73. In: Ramakrishnan PS (eds). *Ecology of biological invasion in the tropics*. International Scientific Publications for National Institute of Ecology. New Delhi, India.
- Sharma GP, Singh JS and Raghubanshi AS 2005. Plant invasion: Emerging trends and future implications. *Current Science* **88**(5): 726-734.
- Shukla AN, Singh KP and Singh JS 2009. Invasive alien species of Achanakmar-Amarkantak Biosphere Reserve, Central India. *National Academy of Sciences* **79**(4): 384-392.
- Shukla BK and Sinha GP 2012. An inventory of invasive alien species of Chhattisgarh, India. *International Journal of Biodiversity and Environment* **2**(2): 126-133.
- Singh N, Khanna KK, Mudgal V and Dixit R 2001. *Flora of Madhya*

- Pradesh Volume III*. Botanical Survey of India, Calcutta, India.
- Suman NR, Khare PK, Salunkhe O and Chadhar B 2017. Alien angiospermic plants of Panna Tiger Reserve, Madhya Pradesh, India. *Indian Forester* **143**(1): 19-24.
- Tripathi S 1999. *Plant diversity of grassland of north-eastern U.P. with emphasis on population of Parthenium hysterophorus L.* Ph.D Dissertation, Gorakhpur University, Gorakhpur, India.
- Verma DM, Balakrishnan NP and Dixit RD 1993. *Flora of Madhya Pradesh Volume I*. Botanical Survey of India, Calcutta, India.
- Vitousek PM, D'antonio CM, Loope LL, Rejmanek M and Westbrooks R 1997. Introduced Species: A Significant Component of Human-Caused Global Change. *New Zealand Journal of Ecology* **21**(1): 224-227.
- Wagh VV and Jain AK 2015. Invasive alien flora of Jhabua district, Madhya Pradesh, India. *International Journal of Biodiversity and Conservation* **7**(4): 227-237.

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Phylogenetic Study of Chloroplast Genome of Solanaceae Species

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Abstract: Solanaceae family has many important economic species. Understanding the relationship based on the chloroplast genome for all species belong to this family can develop new cultivars with properties under market needs. 145 chloroplast genomes belong to Solanaceae family has been collected to study the phylogenetic relationship. Three main clades were found which reflects complicated evolution history with essential events during domestication history. Both Bayesian and maximum likelihood analysis agreed with the same topology tree. Group species by genus, simplified the analysis without alteration of the results. It has been identified 339 popular variants across chloroplast genomes, some of them lead to amino acid change, add, terminate, and might lose functions. Two regions were identified the first one is to select unique markers per genus and the second is for family detection.

Keywords: Solanaceae, Genome

Solanaceae family, with around 3000 species, has many economically important species and many species were used as a model plant in research like tomato and tobacco. An enormous study has investigated the fossil evidence as well as molecular information representing some genes from nuclear and plastid genome to organize the position of these genera and species. Recently chloroplast sequencing and characterization of *Lycium ruthenicum* and *Solanum dulcamara* have been investigated, due to importance. Sequences were assembled and annotated to be used as references for further researches. These kinds of work will enrich scientific communities, especially those involved in species evolutionary. Many techniques were utilized for genomic (coding and noncoding) to be amplified and sequenced, to calculate the genetic distance and drawing the relationship among genera, species, and cultivars. However, this produced limited information and was not enough to represent the entire complicated genome which leads to reflect sometimes unrealistic phylogeny. The emergence of high throughput sequencing with affordable cost made it a powerful tool in phylogenomic analysis and relations determine among species. Many researchers were encouraged to perform whole-genome sequence analysis for these kinds of studies. A chloroplast genome sequence is a powerful tool to study the historical evaluation of plant species and has a unique feature as maternally inherited and very conservative, which makes it extraordinary evidence to follow back population evolution. There is an urgent need to implement tools that can handle these amounts of data or simplify the analysis by reducing species numbers by grouping them. This study aims to find the genetic relationship

among *Solanaceae* species using full chloroplast genome and using the shortcut approach to approve these relationships.

MATERIAL AND METHODS

Searching for the Solanaceae chloroplast genome was conducted in the NCBI database. All chloroplasts belong to this family were downloaded in GenBank format (Table 1). All sequences obtained were aligned using MAFFT tools (Auto, 1PAM/K=2 scoring matrix, 1.53 open gap penalty, and 0.123 offset value). Then visual inspection to the entire alignment file to check for errors or misalignment. Two nominated regions were selected to be utilized for markers design, the first one has differentiated marker to the main genus in Solanaceae due to unique patterns per genus, while the second region is to represent common region across the Solanaceae family. To perform phylogenetic analysis two different software packages were used: RaxML, maximum likelihood, (GTR, Gamma and 100 bootstrapping) and MrBayes, Bayesian, (GTR, Gamma and 100 bootstrapping). The full sequence alignment file was utilized to perform the phylogenetic analysis, then to simplify the analysis, the species were grouped by genus then, the aligned consensus sequences were used to represent the genus. The original alignment was used to call variants as SNPs and non-synonymous SNPs using Genious V.11.5 with minimum coverage 14, and minimum variant frequency 0.1 (genious.com). For silent and non-silent SNPs, annotated files were used to identify any changes in translation.

RESULTS AND DISCUSSION

The alignment consensus length was 174,784 for the

Table 1. Solanaceae species and chloroplasts accession IDs were used in this study

Organism Name	Accession ID	Organism Name	Accession ID	Organism Name	Accession ID	Organism Name	Accession ID
<i>Acristusbarborescens</i>	NC_030185.1	<i>Nicotianaattenuata</i>	MF577082.1	<i>S. chomatophilum</i>	NC_041603.1	<i>S. cardiophyllum</i>	NC_041601.1
<i>A. arborescens</i> x <i>lochromacyaneum</i>	NC_030056.1	<i>N. otophora</i>	NC_032724.1	<i>S. commersonii</i> Lz3.2	NC_028069.2	<i>S. pinnatisectum</i>	NC_041626.1
<i>Atropa belladonna</i>	NC_004561.1	<i>N. sylvestris</i>	NC_007500.1	<i>S. dasyphyllum</i>	NC_039607.1	<i>S. spegazzinii</i>	NC_041630.1
<i>Atropanthesinensis</i>	NC_044471.1	<i>N. tabacum</i>	NC_001879.2	<i>S. demissum</i>	NC_041552.1	<i>S. stenophyllidum</i>	NC_041596.1
<i>Capsicum annuum</i>	NC_018552.1	<i>N. tomentosiformis</i>	NC_007602.1	<i>S. dulcamara</i>	NC_035724.1	<i>S. stenotomum</i>	NC_041607.1
<i>C. baccatum</i> var. <i>baccatum</i>	NC_039693.1	<i>N. undulata</i>	NC_016068.1	<i>S. tuberosum</i>	NC_041604.1	<i>S. stenotomum</i> subsp. <i>goniocalyx</i> MH021463.1	NC_039601.1
<i>C. baccatum</i> var. <i>pendulum</i>	NC_039692.1	<i>Petunia x hybrida</i>	NC_040178.1	<i>S. galapagense</i>	NC_026878.1	<i>S. supinum</i>	NC_039601.1
<i>C. baccatum</i> var. <i>praetermissum</i>	NC_039695.1	<i>Physalisangulata</i>	NC_039457.1	<i>S. glabratum</i>	NC_039603.1	<i>S. tarijense</i>	NC_041631.1
<i>C. chacoense</i>	NC_033525.1	<i>P. minima</i>	NC_048515.1	<i>S. gourlayi</i>	NC_041606.1	<i>S. trilobatum</i>	NC_039602.1
<i>C. chinense</i>	NC_030543.1	<i>P. peruviana</i>	NC_026570.1	<i>S. habrochaites</i>	NC_026879.1	<i>S. tuberosum</i>	NC_008096.2
<i>C. eximium</i>	NC_033527.1	<i>P. pruinosa</i>	NC_039458.1	<i>S. hondelmannii</i>	NC_041608.1	<i>S. umtuma</i>	NC_039413.1
<i>C. frutescens</i>	NC_028007.1	<i>P. pubescens</i>	NC_048514.1	<i>S. hypocrarthurum</i>	NC_041611.1	<i>S. usambarense</i>	NC_039415.1
<i>C. galapagoense</i>	NC_033524.1	<i>Physochlainaorientalis</i>	NC_044154.1	<i>S. incamayoense</i>	NC_041612.1	<i>S. venturii</i>	NC_041609.1
<i>C. lycianthoides</i>	NC_026551.1	<i>Przewalskiatanguitica</i>	NC_036733.1	<i>S. incanum</i>	NC_039605.1	<i>S. vernei</i>	NC_041633.1
<i>C. pubescens</i>	NC_039694.1	<i>Sarachapunctata</i>	NC_026694.1	<i>S. jamesii</i>	NC_041613.1	<i>S. verrucosum</i>	NC_041632.1
<i>C. tovarii</i>	NC_033526.1	<i>Scopoliaparviflora</i>	NC_030282.1	<i>S. kurtzianum</i>	NC_041614.1	<i>S. violaceimarmoratum</i>	NC_041634.1
<i>Chromeravella</i>	AB237912.1	<i>Solanum abnancayense</i>	NC_041586.1	<i>S. lanzae</i>	NC_039417.1	<i>S. violaceum</i>	NC_039604.1
<i>Daturastramonium</i>	NC_018117.1	<i>S. acule</i>	NC_041551.1	<i>S. laxissimum</i>	NC_041615.1	<i>S. x blanco-galdosii</i>	NC_041595.1
<i>Dunaliabrachyacantha</i>	NC_026906.1	<i>S. achacachense</i>	NC_041587.1	<i>S. leptophyes</i>	NC_041616.1	<i>S. aethiopicum</i>	NC_039608.1
<i>D. obovata</i>	NC_026563.1	<i>S. acroglossum</i>	NC_041588.1	<i>S. lichtensteinii</i>	NC_039598.1	<i>S. cheesmaniae</i>	NC_026876.1
<i>D. solanacea</i>	NC_027099.1	<i>S. acroscopicum</i>	NC_041589.1	<i>S. limbanense</i>	NC_041617.1	<i>S. lycopersicum</i>	HG975525.1
<i>Eriolarynx fasciculata</i>	NC_030171.1	<i>S. agnewiorum</i>	NC_039416.1	<i>S. linnaeanum</i>	NC_039600.1	<i>S. lycopersicum</i>	AM087200.3
<i>lochromaaustrale</i>	NC_029833.1	<i>S. albornozii</i>	NC_041590.1	<i>S. macrocarpon</i>	NC_039606.1	<i>S. lycopersicum</i>	DQ347959.1
<i>I. cyaneum</i>	NC_030178.1	<i>S. ambosinum</i>	NC_041591.1	<i>S. marinense</i>	NC_041610.1	<i>S. lycopersicum</i>	NC_007898.3
<i>I. ellipticum</i>	NC_030177.1	<i>S. andreaum</i>	NC_041592.1	<i>S. medians</i>	NC_041618.1	<i>S. pennellii</i>	HG975452.1
<i>I. lehmannii</i>	NC_030167.1	<i>S. anguivi</i>	NC_039611.1	<i>S. megistacrolobum</i>	NC_041619.1	<i>S. peruvianum</i>	NC_026881.1
<i>I. loxense</i>	NC_026726.1	<i>S. aureitomentosum</i>	NC_039412.1	<i>S. melongena</i>	NC_030207.1	<i>S. pimpinellifolium</i>	NC_026882.1
<i>I. nitidum</i>	NC_026567.1	<i>S. avilesii</i>	NC_041593.1	<i>S. microdontum</i>	NC_041594.1	<i>S. polhillii</i>	NC_039414.1
<i>I. salpoanum</i>	NC_030168.1	<i>S. berthaultii</i>	NC_034951.1	<i>S. multiinterruptum</i>	NC_041620.1	<i>S. polyadenium</i>	NC_041627.1
<i>I. stananthum</i>	NC_026574.1	<i>S. brevicaula</i>	NC_041597.1	<i>S. neorickii</i>	NC_026880.1	<i>S. richardii</i>	NC_039610.1
<i>I. tingoanum</i>	NC_027177.1	<i>S. bukasovii</i>	NC_041598.1	<i>S. nigrum</i>	NC_028070.2	<i>S. sogarandinum</i>	NC_041628.1
<i>I. umbellatum</i>	NC_030044.1	<i>S. bukasovii</i> f. <i>ultidissectum</i>	NC_041621.1	<i>S. palustre</i>	NC_041622.1	<i>S. sparsipilum</i>	NC_041629.1
<i>Lyciumbarbarum</i>	NC_041110.1	<i>S. bulbocastanum</i>	NC_007943.1	<i>S. pampasense</i>	NC_041623.1	<i>S. cerasiferum</i>	NC_039599.1
<i>L. chinense</i>	NC_042204.1	<i>S. cajamarquense</i>	NC_041599.1	<i>S. paucissectum</i>	NC_041624.1	<i>S. chacoense</i>	NC_041602.1
<i>L. ruthenicum</i>	NC_039651.1	<i>S. campylacanthum</i>	NC_039609.1	<i>S. pennellii</i>	KY887589.1	<i>S. chilense</i>	NC_026877.1
<i>Trompettiacardenasiana</i>	NC_029746.1	<i>S. canasense</i>	NC_041600.1	<i>S. phureja</i>	NC_041625.1	<i>Withaniacoagulans</i>	NC_047176.1
				<i>W. somnifera</i>			NC_047245.1

whole data set 145 species. Identical sites were around 70% while pairwise identity was about 96%. Ungapped length mean was 155,858.4. The minimum and maximum length were 154196 and 157390, respectively. The most extensive phylogenetic analysis of the Solanaceae plant family was done using complete chloroplast sequences of 145 species. Two software packages Bayesian (MrBayes) and maximum likelihood (RAxML) were used. Both produced the same topology tree, which supports the accuracy of the relationship among these species gives high confidence to this analysis. The tree shows (Fig. 1) three main distinct clades. The Solanum genus has been divided into two large clades, by a third internal clade that has several species (mainly *Capsicum* spp., *Nicotiana* spp., *Lycium* spp., *Physalis* spp., *lochroma* spp.). *Solanum* spp. is very popular and widely separate, but chloroplast inheritance shows just two main clades. This could be due to domestication event of this genus. Properly had two vast domestication events or it happened in two different geographically isolated areas, which lead to develop unique chloroplast.

Withania spp., apparently had huge differences as they found far from each other (in two distinct clades), unlikely to be real differences, but possibly due to mistakes in sequence assembly in one or both of them. Grouped species by genus was simplified the analysis, but with slight differences. Figure 2 shows *Solanum* spp. as a sister clade to *Capsicum*, *Physalis*, *Dunalia* and *lochroma* genera. While *Nicotiana* and *Lycium* were out of clads. These results might not reflect the reality of the relationship as with all species analysis.

Visual inspection of the alignment sequences presented several unique regions that can be used as a molecular marker. The selected region in figure 3A and 3B is for genus identification due to their unique sequences compared to other genera in this family which can be utilized as a genus marker. The figure 4 has a nearly uniform region that suite to be a Solanaceae family identification marker. These makers could save time and cost in relationship investigation studies and breeding programs. More than 14000 variants among 145 species were recorded. However, these SNPs were reduced to 399 when minimum coverage was 14 (10% of the population) and were distributed on 147 insertions, 19 deletion and 233 transitions/transversions. Polymorphism has been noticed in 66 genes, sequences variations consequences on translation were different according to its position in the codon. Several impacts were recorded like deletion, insertion, extension, frameshift, start codon loss, substitution, and truncation. The six bases InDel in the *atpF*

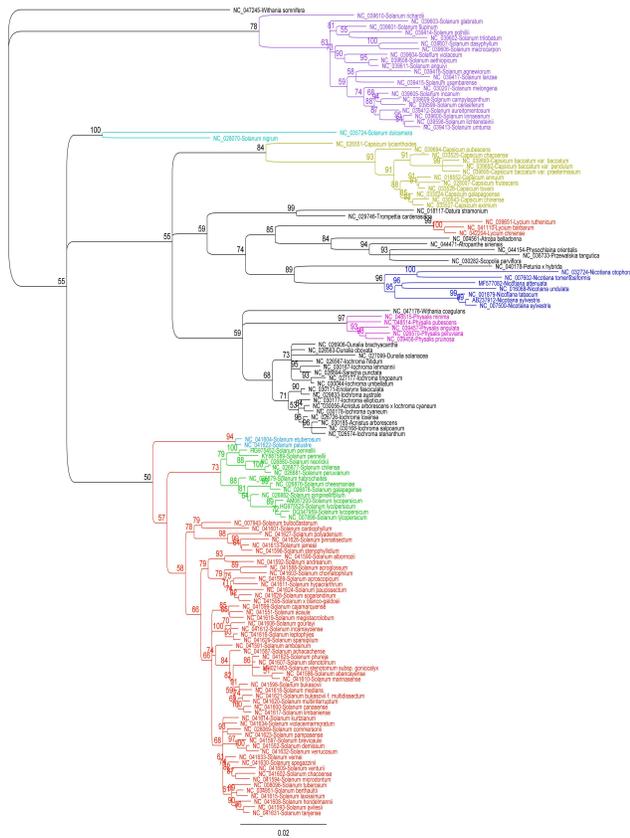


Fig. 1. Phylogenetic analysis of the whole chloroplast genome sequences of the Solanaceae plant family using MrBayes with 100 bootstrapping. The same topology was produced by both MrBayes and RAxML methods

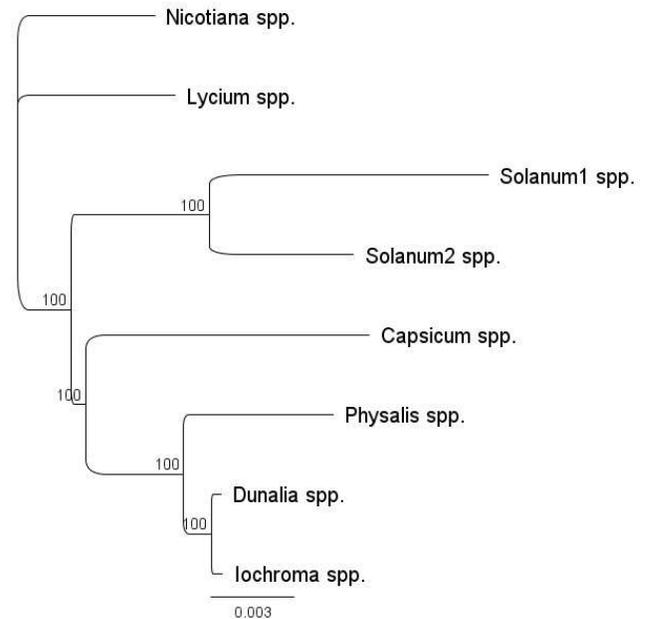


Fig. 2. Phylogenetic analysis shows clearly isolation by genus using MrBayes and RAxML with 100 bootstrapping. The same topology was produced by both methods

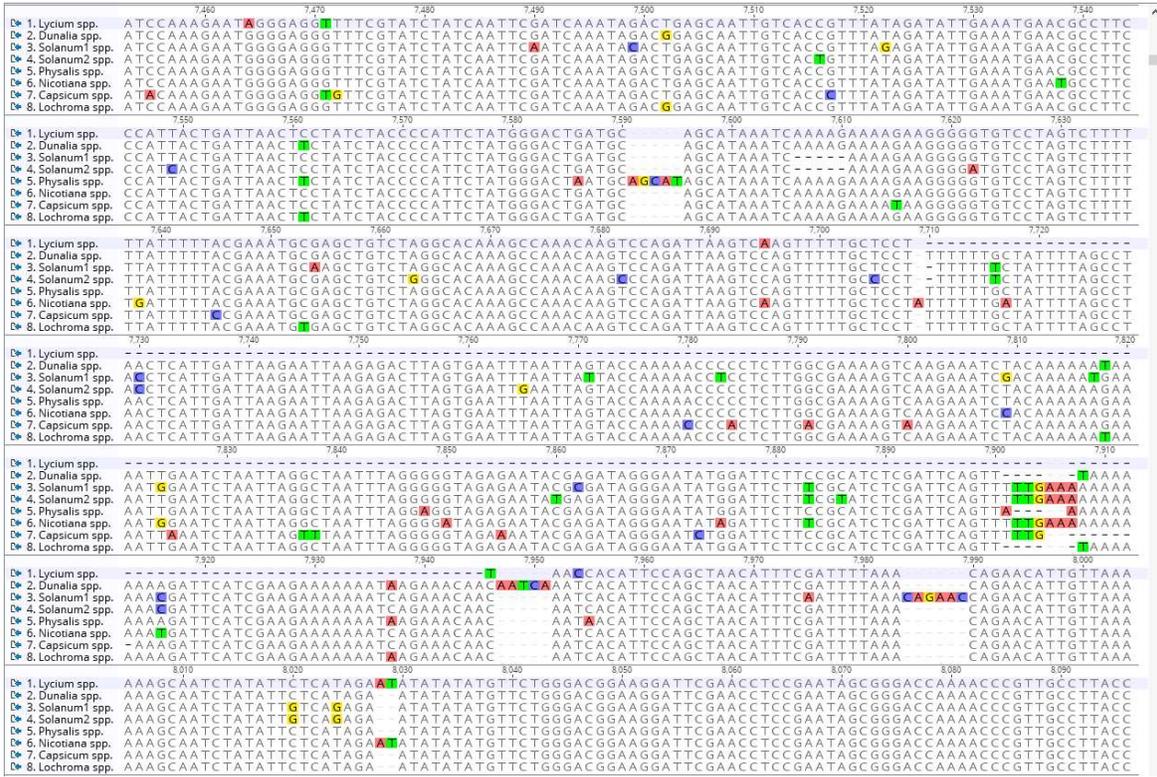


Fig. 3a. Nominated regions to be used for designing unique markers per genus

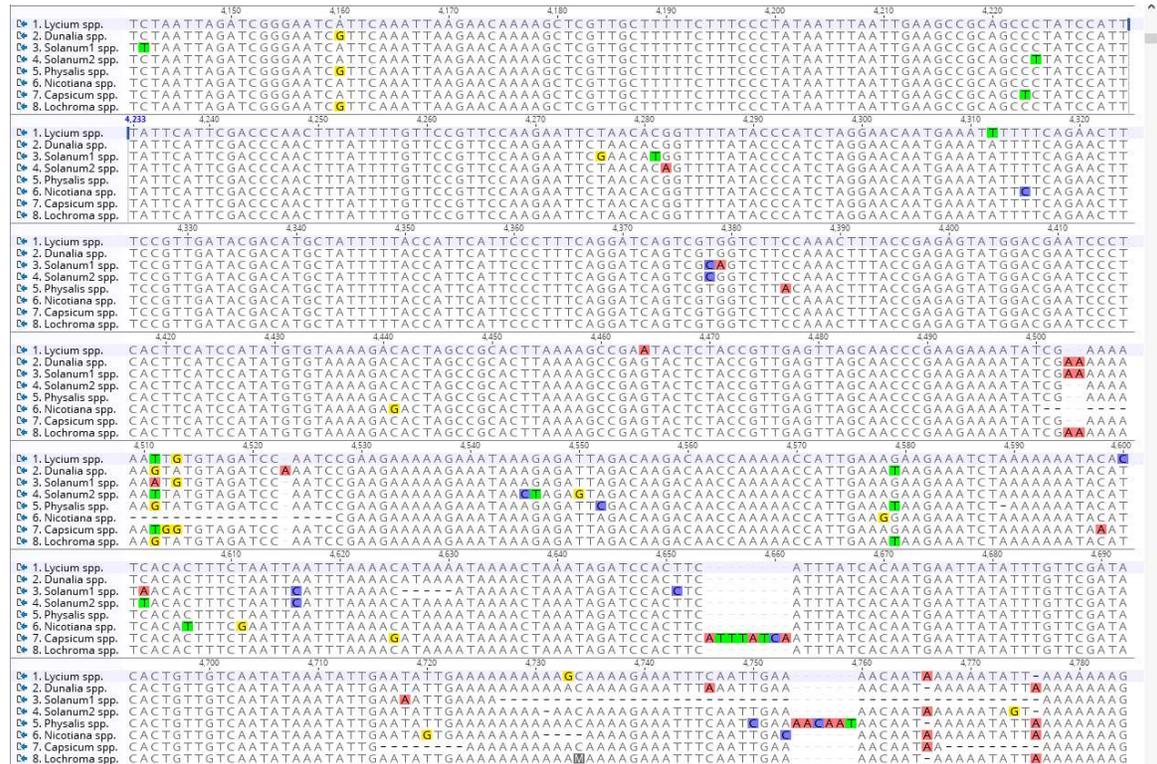


Fig. 3b. Nominated regions to be used for designing unique markers per genus

- Göransson U and Uddin SJ 2020. Ethnobotany and antimicrobial peptides from plants of the solanaceae family: an update and future prospects. *Frontiers in Pharmacology* **11**: 1-23.
- Amiryousefi A, Hyvönen J and Poczai P 2018. The chloroplast genome sequence of bitter melon (*Solanum dulcamara*): Plastid genome structure evolution in Solanaceae. *PLoS ONE* **13**(4): 1-23.
- Brozynska M, Copetti D, Furtado A, Wing RA, Crayn D, Fox G, Ishikawa R and Henry RJ 2017. Sequencing of Australian wild rice genomes reveals ancestral relationships with domesticated rice. *Plant Biotechnology Journal* **15**(6): 765-774.
- Brozynska M, Omar ES, Furtado A, Crayn D, Simon B, Ishikawa R and Henry RJ 2014. Chloroplast genome of novel rice germplasm identified in northern Australia. *Tropical Plant Biology* **7**(3-4): 111-120.
- Cho KS and Park TH 2016. Complete chloroplast genome sequence of *Solanum nigrum* and development of markers for the discrimination of *S. nigrum*. *Horticulture, Environment, and Biotechnology* **57**(1): 69-78.
- Dakal TC, Kala D, Dhiman G, Yadav V, Krokhotin A and Dokholyan NV 2017. Predicting the functional consequences of non-synonymous single nucleotide polymorphisms in IL8 gene. *Scientific Reports* **7**(1): 1-18.
- Gebhardt C 2016. The historical role of species from the Solanaceae plant family in genetic research. *TAG. Theoretical and applied genetics. Theoretische und angewandte Genetik* **129**(12): 2281-2294.
- Huelsenbeck JP and Ronquist F 2001. MRBAYES: Bayesian inference of phylogenetic trees. *Bioinformatics* **17**(8): 754-755.
- Katoh K and Standley DM 2013. MAFFT multiple sequence alignment software version 7: Improvements in performance and usability. *Molecular Biology and Evolution* **30**(4): 772-780.
- Mehmood F, Shahzadi I, Ahmed I, Waheed MT and Mirza B 2020. Characterization of *Withania somnifera* chloroplast genome and its comparison with other selected species of Solanaceae. *Genomics* **112**(2): 1522-1530.
- Melotto-Passarin DM, Berger LJ, Dressano K, De Martin VDF, Oliveira GCX, Bock R and Carrer H 2008. Phylogenetic relationships in Solanaceae and related species based on cpDNA sequence from plastid *trnE-trnT* region. *Crop Breeding and Applied Biotechnology* **8**(1): 85-95.
- Moner AM 2020. Analysis of chloroplast genetic diversity in the Rosaceae family using a new phylogenetic approach. *plant Archives* **20**(2): 7056-7062.
- Moner AM, Furtado A, Chivers I, Fox G, Crayn D and Henry RJ 2018. Diversity and evolution of rice progenitors in Australia. *Ecology and Evolution* **8**(8): 4360-4366.
- Moner AM, Furtado A and Henry RJ 2018. Chloroplast phylogeography of AA genome rice species. *Molecular Phylogenetics and Evolution* **127**: 475-487.
- Särkinen T, Bohs L, Olmstead RG and Knapp S 2013. A phylogenetic framework for evolutionary study of the nightshades (Solanaceae): A dated 1000-tip tree. *BMC Evolutionary Biology* **13**(1): 1-15.
- Shim D, Raveendar S, Lee J, Lee G, Ro N, Jeon Y, Cho G, Lee H, Ma K and Chung J 2016. The complete chloroplast genome of *Capsicum frutescens* (Solanaceae). *Applications in Plant Sciences* **4**(5): 1-6.
- Stamatakis A 2014. RAxML version 8: A tool for phylogenetic analysis and post-analysis of large phylogenies. *Bioinformatics* **30**(9): 1312-1313.
- Wambugu PW, Brozynska M, Furtado A, Waters DL and Henry RJ 2015. Relationships of wild and domesticated rices (*Oryza* AA genome species) based upon whole chloroplast genome sequences. *Scientific Reports* **5**(1): 1-9.
- Yisilam G, Mamut R, Li J, Li P and Fu C 2018. Characterization of the complete chloroplast genome of *Lycium ruthenicum* (Solanaceae). *Mitochondrial DNA Part B: Resources* **3**(1): 361-362.



Forest Floor Diversity, Distribution and Biomass Pattern of Oak and Chir-pine Forest in the Indian Western Himalaya

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Abstract: The present study envisage the dynamics of forest floor vegetation and biomass pattern in selected oak and chir-pine forest, western Himalaya an altitudinal ranged between 1450-1950 m. The herb species richness was slightly higher (26) in the oak forest as compared to the chir-pine (25) forest. Poaceae was the dominant family in both forests represent 5 species in each site. The herb layer density was higher (234.50 m²) in the oak forest as compared to the chir-pine forest (119.85 m²). Species diversity was recorded 3.29 in oak and 4.09 in the chir-pine forest and concentration of dominance was 0.16 in oak and 0.076 in the chir-pine forest stands. Most of the species in both the study sites were showing contagious distribution patterns. The forest floor biomass was 515.52 gm⁻² in the oak and 428.11 gm⁻² in the chir pine stand during the study period (2017-2019). The rainy session account for maximum biomass in both the sites.

Keywords: Oak forest, Forest floor vegetation, Herbaceous biomass, Western Himalaya

Himalaya is the tallest and youngest mountain systems of the world, repository of biological and cultural diversity (Negi and Dhyani 2012, Chandra et al 2020). It is the home of a unique ecosystem, plants, animal and other organisms and also make the richest biodiversity zone (Rawal et al 2018). Besides forming a large part of the Himalayan global biodiversity hotspot, it has linkage with three other biodiversity hotspots. This region is distributed from sub-tropical to alpine zones (Bhatt and Bankoti 2016). In the mid-montane belt (1000-2000) of this region are dominated by fast growing chir-pine (*Pinus roxburghii*) species and slow growing oak species. These forests differ significantly in structure, functioning and ecosystem services from each other (Joshi and Negi 2011 and Bhatt et al 2020). Oak and pine forest in Uttarakhand occupy 3000.7 km² and 3993.3 km², respectively and provide various ecosystem services to the local inhabitants of this region. Forest floor vegetation is heterogeneous and dynamic habitat; with playing an important role in ecosystem sustenance maintaining the structure and function of forests. Various environmental factors affect the growth and development of forest floor vegetation, which describes the structure, function, and the dynamics of future communities. Forest floor vegetation (Herbaceous layer) makes an important aspect of the forest understory. The ecology of the forest floor vegetation has been the emphasis in many studies (Gilliam and Roberts 2003, Roberts 2004, Gilliam et al 2006). Forest floor vegetation enhanced soil quality and protection efforts

(Tasker and Bradstock 2006), nutrient cycling and energy flow in ground level (Scheller and Mladenoff 2002, Tessema et al 2011), and regulates the spatiotemporal distribution and dynamics of woody seedlings through regeneration (Moktan et al 2009, Tenzin 2010) and controls the recruitment and growth of woody (tree, and shrub) plants directly as well as indirectly. Herbaceous vegetation responds relatively fast to changes in the environment, destruction rates of herbs are three times higher than the tree species and, therefore any threats to forest biodiversity first cause to the forest floor vegetation (Jolls 2014). There are many studies have been conducted in last two century for the ecological assessment of forest floor vegetation. A small number of these previous studies show the response of herbaceous communities to environmental gradients within the forest's ecosystem (Scheller and Mladenoff 2002). It is needed for precise information of herbaceous species is required for the management and conservation of forest. Therefore, in present study assessed the forest floor diversity, distribution pattern and herbaceous biomass pattern of oak and pine forest communities in the Indian western Himalayan region.

MATERIAL AND METHODS

Present study carried out in oak and chir-pine dominated forest stands of Nainital district, (Uttarakhand) western Himalaya at 1450-1950 m altitudinal range. Geographic location, the dominant forest canopy and soil attribute of forest stands are presented in table 1. The soil was sandy

clay in the oak forest and sandy loam in the chir-pine forest. The soil moisture, water holding capacity organic carbon, and nitrogen are higher in the oak forest than the chir-pine forest. The average annual rainfall in the study area during 2017-2019 is 1,702.85mm, which is highly variable. About 78% of rainfall happens in this region during the rainy season. Maximum and minimum temperatures were recorded as 31.67 and 5.3°C, respectively, whereas the average monthly temperature was 19.30°C (Fig. 1) during the study period.

Forest floor vegetation analysis: The vegetation analysis was carried out by placing simple random quadrats in each identified forest stand during the peak growing session in 2017-18. A total of 100, 1x1 m quadrates (50 in each site) were placed for the investigation of forest floor vegetation in both sites. For the assessment of forest floor vegetation i.e. density, frequency, distribution and diversity standard phytosociological methods (Muller-Dombois and Ellenberg 1974) were used. Grasses species were analysed through tiller analysis and each tiller of grass was counted as an individual plant (Singh 1974). The distribution pattern (Random, regular and contagious distribution) ascertained by calculating abundance to frequency (A:F) ratio; if A/F ratio is <0.025 shows regular distribution, between 0.025 and 0.05 shows random distribution and >0.05 shows contagious distribution (Curtis and Cottam 1956).

Species diversity for each forest was determined with the Shannon and Wiener (1963).

$H = - \sum (Ni/N) \log_2 (Ni/N)$; where, Ni is the total number of individuals of species and N is the total number of individuals of all species in that stand.

The concentration of dominance was using following

formula; $H = - \sum (Ni/N)^2$; where, Ni and N were the same as Shannon and Wiener Index

Species Evenness is calculated by using Pielou evenness Index (1975)

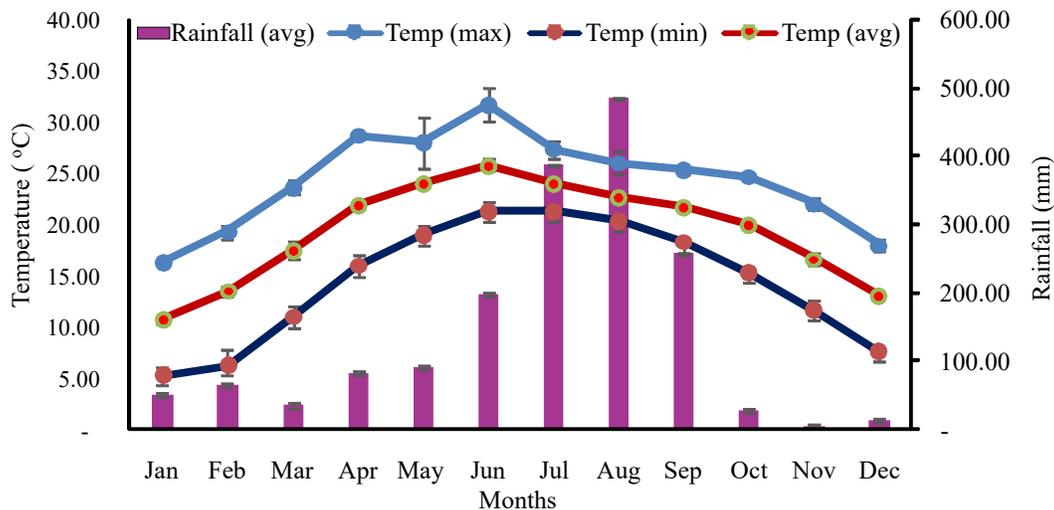
$SE = H'/\ln(S)$; Where, H' = Shannon Wiener Index, S = Total No of species

Forest floor Biomass estimation: Herbaceous Biomass (included grass and forest ground flora) determined by harvesting quadrats. Total Biomass is measured by harvesting 5, 1x1m quadrats in every month. Cut all herbaceous vegetation within the quadrat at 2 cm above the ground, and sort into live (green) biomass and standing biomass then oven dry of these sample for 24 to 48 hours to till constant weight.

RESULTS AND DISCUSSION

Composition and diversity pattern of Forest floor vegetation: The oak forest consists of a total of 26 species distributed in 15 families; Poaceae was the largest family with 5 species and 20% contribution in total forest species.

In the chir-pine forest a total of 29 species recorded belonging to 16 families; Poaceae was also dominant family with 17% contribution in total species (Fig. 2). Species density was 234.50 ind m⁻¹ in oak and 119.84 ind m⁻¹ in the pine forest. Species diversity (H') varied from 3.29 (oak stand) and 4.09 (pine stand). Higher species diversity and richness are the consequence of compact competition because of grazing which resulting in an improved light interference on the forest floor vegetation (Darabant et al 2007, Harrison et al 2008) and the formation of habitat opportunities for higher species diversity and richness. Species evenness) was 0.63 for oak



Source: <http://www.indiawaterportal.org/metdata/>

Fig. 1. Rainfall and temperature patterns of the study areas in Nainital, Uttarakhand, India

and 0.85 for the pine forest (Table 2). Similar results have been found in many other studies conducted in other parts of the Himalayas (Tynsong and Tiwari 2011, Gupta and Kumar 2014). Most have been observed that the species diversity was observed maximum in the herb layer among all forest strata. The concentration of dominance (CD) and Shannon Species diversity (H') was recorded 0.16 and 0.83 in the oak forest and 0.076 and 0.93 in the pine forest. The diversity of forest floor vegetation indicated same trend as observed by earlier workers (Jhariyal et al 2014, Sinha et al 2015, Joshi and Chandra 2020). The species compositions of two different communities are differ with the local environmental condition. The forest was 18.51% similar in their composition, due to different ecological and environmental conditional variations.

Species distribution pattern: The distribution pattern of species was investigating by calculating abundance to frequency (A:F) ratio. The maximum species were distributed contagiously 92 and 100% in oak and pine forest respectively. However, only few species (8%) in the oak forest distributed randomly (Table 3). Similarly, earlier workers described that the maximum of the herb species in a forest ecosystem distributed contagiously and randomly, however regular distribution almost absent or negotiable in the herb strata (Jhariya et al 2012, Kittur et al 2014).

Forest floor biomass pattern: The average annual forest floor biomass of oak and pine stands varied 428.11 to 515.52 gm⁻², maximum during rainy seasons in all stands. In the temperate banj-oak stand total forest phytomass was 429.29 gm⁻² in 2017-18, 601.79 gm⁻² in 2018-19 and average 515.52 gm⁻² during 2017-2019. It was varied from 9.9 to 82.46 gm⁻² in 2017-18, being maximum in August and minimum in April. In 2018-19 ranged from 13.46 to 121gm⁻², being maximum in July and minimum in April. Of the total herbaceous biomass maximum 56% recorded during rainy, 14% during winter and 16% during summer sessions. In the subtropical chir-pine stand total annual herbaceous biomass was 397.76 gm⁻² in

2017-18, 458.45 gm⁻² in 2018-19. It was varied from 8.36to 51.20 gm⁻² in 2017-18, having a maximum in October and minimum in April. In 2018-19 it was varied from 11.54to 67.31gm⁻², being maximum in September and minimum in April (Fig. 3). Of the total herbaceous biomass maximum 51% was during rainy, 28% during winter and minimum 21% during the summer.

Correlation between herbaceous biomasses and the herbaceous vegetation parameter:

The total, forest floor biomass of herbaceous species generally increased with increasing species density, however it decreased with

Table 2. Comparisons of species diversity parameter among oak and pine forest stands

Parameter	Oak forest	Pine forest
Density (ind m ⁻²)	234.50	119.85
Species richness	26.00	25.00
Shannon Species diversity (H')	3.29	4.09
Concentration of dominance (CD)	0.16	0.076
Species Evenness (SE)	0.63	0.85
Simpson Diversity Index (D)	0.83	0.93
Dominant herb species	<i>Cymbopogon distans</i>	<i>Arundinella prunella</i>

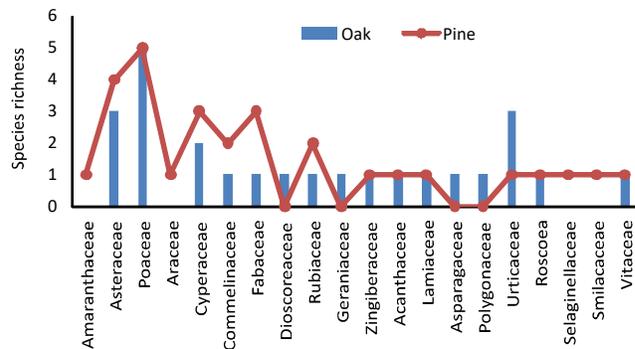


Fig. 2. Family wise distribution of species in the oak and chir-pine forest

Table 1. Descriptions and attribute of selected oak and chir-pine forest sites

Parameter	Oak stand	Chir-pine stand
Forest location	Kailakhan	Baldiyakhan
Altitude (m)	1850-1950	1450-1600
Latitude	29°22.404'	29°20.929'
Longitude	79°28.583'	79° 26.766'
Dominant canopy species (Tree)	<i>Quercus leucotrichophora</i>	<i>Pinus roxburghii</i>
Dominant shrub species	<i>Daphne cannabina Wall</i>	<i>Eupatorium adenophorum Sprengel</i>
Soil moisture (%)	25.35±3.65	20.75±3.14
Water holding capacity (%)	58.68±4.29	51.96±1.25
Soil Nitrogen (N%)	0.38±0.02	0.21±0.008

Table 3. Vegetation composition, relative density and distribution pattern of species in selected oak and pine forest, western Himalaya

Species	Family	Oak forest		Chir-pine forest	
		RD (%)	DP	RD (%)	DP
<i>Achyranthes bidentata</i> Blume	Amaranthaceae	4.07		-	-
<i>Anaphalis cinnamomea</i> , C.B Clarke	Asteraceae	2.77	0.18*	-	-
<i>A. busa</i> L	Asteraceae	-	-	1.97	0.17*
<i>Apluda mutica</i> , Linn	Poaceae	7.98	0.26*	-	-
<i>Arisaema serratum</i> (Thunb.) Schott	Araceae	0.58	0.08*	-	-
<i>Artemisia vulgaris</i> L	Asteraceae	-	-	0.28	0.35*
<i>Arundinella nepalensis</i> , Trin	Poaceae	0.75	0.35*	-	-
<i>A. prunella</i> , Linn	Poaceae	-	-	32.4	0.66*
<i>Aster thomsonii</i> C.B Clerk	Asteraceae	2.39	0.19*	-	-
<i>Bidens pilosa</i> L	Asteraceae	0.98	0.16*	2.16	0.15*
<i>Capillipedium parviflorum</i> (R. Br.)	Poaceae	1.65	0.90*	-	-
<i>Carex filicina</i> Nees	Cyperaceae	-		7.00	0.09*
<i>Carex nubigena</i> , D. doon	Cyperaceae	19.0	0.97*	-	-
<i>Commelina caroliniana</i> . Walter	Commelinaceae	4.91	0.17*	-	-
<i>Commelina paludosa</i> , Blume.	Commelinaceae	-		4.75	0.05*
<i>Chrysopogon serrulatus</i> , Clarke	Poaceae	-		6.34	0.09*
<i>Cymbopogon distans</i> Linn.	Poaceae	27.4	1.02*	-	-
<i>Cyperus iria</i> L	Cyperaceae	-		2.84	0.12*
<i>Desmodium triflorum</i> (L.) DC	Fabaceae	-		3.38	0.50*
<i>Dioscorea deltoidea</i> Wall. ex Griseb	Dioscoreaceae	0.11	0.18*	-	-
<i>Trifolium pratense</i> L	Fabaceae	5.0	0.12*	1.42	0.12*
<i>Flemingia fruticosa</i> , Wall	Fabaceae	-		4.77	0.98*
<i>Galium aparine</i> Linn	Rubiaceae	1.0	0.14*	-	-
<i>Geranium wallichianum</i> D.Don ex Sweet	Geraniaceae	-		0.89	0.14*
<i>Hedychium spicatum</i> Buch. -Ham. Ex Sm	Zingiberaceae	0.86	0.17*	-	-
<i>Imperata cylindrica</i> (L.) P.Beauv.	Poaceae	-		12.94	0.98*
<i>Justicia simplex</i> , D. Doon	Acanthaceae	3.13	0.04**	-	-
<i>Micromeria biflora</i> Benth.	Lamiaceae	1.89	0.33*	2.80	0.29*
<i>Murdannia divergens</i> , (C.B Clarke)	Commelinaceae	-		0.14	0.36*
<i>Ophiopogon intermedius</i> , D. Doon	Asparagaceae	0.05	0.12*	-	-
<i>Oplismenus composites</i> (L.) P. Beauv.	Poaceae	-		3.22	0.18*
<i>O. hirtellus</i> (L.) P. Beauv.	Poaceae	3.69	0.27*	-	-
<i>Persicaria capitata</i> (Buch.-Ham. ex D.Don)	Polygonaceae	1.40	0.27*	-	-
<i>Pilea scripta</i> Linn	Urticaceae	1.61	0.37*	-	-
<i>P. umbrosa</i> Linn	Urticaceae	1.09	0.15*	-	-
<i>Pouzoltzia herta</i> , Weed	Urticaceae	2.84	0.26*	2.84	0.11*
<i>Roscoea alpine</i> , Royle	Roscoea	1.0	0.12*	-	-
<i>R. procera</i> , Wall.	Roscoea	-		0.46	0.12*
<i>Rubia cardifolia</i> L.	Rubiaceae	-		0.43	0.07*
<i>Cynodon dactylon</i> L.	Poaceae	0.98	0.11*	-	-
<i>Selaginella selaginoides</i> (L.) Beauv. ex Mart. & Schrank	Selaginellaceae	-		0.52	0.20*
<i>Setaria megaphylla</i> , (Linn.) P. Beauv.	Poaceae	-		5.78	0.25*
<i>Smilax parvifolia</i> , Wall.	Smilacaceae	-		0.28	0.15*
<i>Strobilanthus dalhausianus</i> , Clarke.	Acanthaceae	-		1.37	0.16*
<i>Taraxacum officinale</i> Wigg.	Asteraceae	-		0.68	0.27*
<i>Vitis himalayana</i> Br.	Vitaceae	3.0	0.03**	0.30	0.17*

* Contagious distribution, ** Random distribution

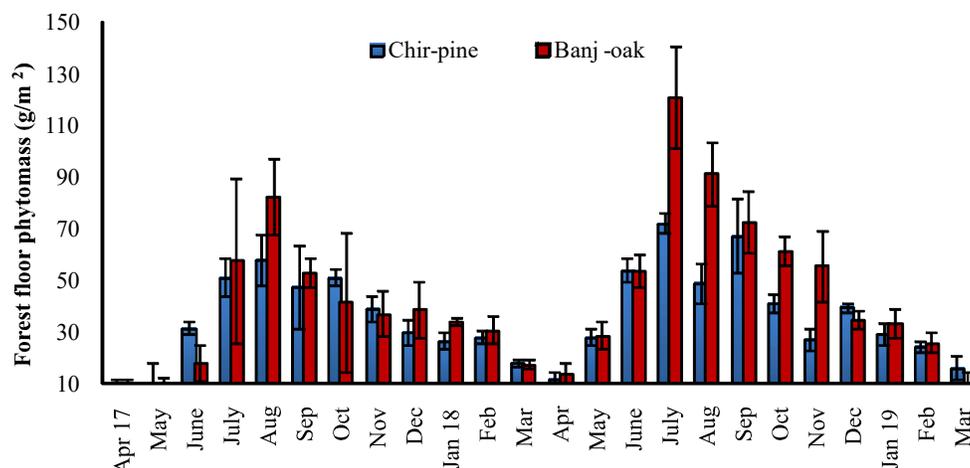


Fig. 3. Monthly variation of forest floor biomass in the oak and pine forest (2017-2019)

Table 4. Correlations among different vegetation parameter and herbaceous biomass

Parameter	Density	SR	H'	CD	SE	Biomass
Density	1.000					
SR	-0.618	1.000				
H'	-1.000	0.610	1.000			
CD	-1.000	0.610	1.000	1.000		
SE	-0.975	0.429	0.977	0.977	1.000	
Biomass	0.659	0.185	-0.666	-0.666	-0.809	1.000

SR=Species richness, H'=Species diversity, CD=Concentration of dominance, SE= Species evenness

increasing species diversity, richness, and evenness. The total dry biomass of herb species had a positive significant relationship with species density and positive not significant with species richness, however negative significant correlation with species diversity, evenness and concentration of dominance. Furthermore, species richness had a positive significant correlation with species diversity, species evenness and the concentration of dominance of the species (Table 4).

CONCLUSION

The herbaceous vegetation and biomass of selected oak and chir-pine forest varied significantly. Pine forest was slightly richer in terms of species diversity whereas in terms of forest floor biomass oak forest has higher potential to store biomass. The higher biomass of both forest during rainy sessions shows the optimum growth of species is depending upon rainfall, soil properties (soil moisture, soil texture, the water holding capacity). Higher nutrient retention in soil and litter in the oak forest facilitated to storage of higher biomass.

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REFERENCES

- Bhatt A and Bankoti NS 2016. Analysis of forest vegetation in Pithoragarh Kumaun Himalayas, Uttarakhand, India. *International Journal of Current Microbiology and Applied Sciences* 5(2): 784-793.
- Chandra N, Joshi VC and Mishra AP 2020. Ecological status of fodder and fuel wood species in Banari Devi Sacred grove of Kumaun Himalaya, Uttarakhand. *Indian Journal of Ecology* 47(4):1044-1048.
- Cottam G and Curtis JT 1956. The use of distance measures in phytosociological sampling. *Ecology* 37(3): 451-460.
- Darabant A, Rai PB and Tenzin K 2007. Cattle grazing facilitates tree regeneration in a conifer forest with palatable bamboo understorey. *Forest Ecology and Management* 252: 73-83.
- Gilliam FS and Roberts MR 2003a. *The Herbaceous Layer in Forests of Eastern North America*. New York: Oxford University Press.
- Gilliam FS 2006. Response of the herbaceous layer of forest ecosystems to excess nitrogen deposition. *Journal of Ecology* 94: 1176-1191.
- Harrison M, Evans JR and Moore A 2008. Grazing induced changes in light interception and radiation-use efficiency of winter wheat. *Proceedings of 14th Agronomy Conference* 2008, 21-25 September 2008, Adelaide, South Australia.
- Jhariya MK, Bargali SS, Swamy SL and Kittur B 2012. Vegetational Structure, Diversity and Fuel Load in Fire Affected Areas of Tropical Dry Deciduous Forests in Chhattisgarh. *Vegetos* 25(1): 210-224.
- Jhariya MK, Bargali SS, Swamy SL, Kittur B, Bargali K and Pawar GV 2014. Impact of forest fire on biomass and Carbon storage pattern of Tropical Deciduous Forests in Boramdeo Wildlife Sanctuary, Chhattisgarh. *International Journal of Ecology and Environmental Science* 40(1): 57-74.
- Jolls Claudia L and Whigham DF 2014. Populations of and threats to rare plants of the herb layer: Still more challenges and

- opportunities for conservation biologists. In *the herbaceous layer in forests of Eastern North America*. Oxford University Press.
- Joshi G and Negi GCS 2011. Quantification and valuation of forest ecosystem services in the western Himalayan region of India. *International Journal of Biodiversity Science, Ecosystem Services & Management* **7**(1): 2-11.
- Joshi VC and Chandra N 2020. Pattern of diversity and regeneration potential along altitudinal gradient in selected forest stands of Kumaun Himalaya. *Indian Forester* **146**(4): 301-305.
- Kittur BH, Swamy SL, Bargali SS and Jhariya MK 2014. Wild land fires and moist deciduous forests of Chhattisgarh, India: Divergent component assessment. *Journal of Forestry Research* **25**(4): 857-866.
- Moktan MR, Gratzer G, Richards WH, Rai TB, Dukpa Dand Tenzin K 2009. Regeneration of mixed conifer forests under group tree selection harvest management in western Bhutan Himalayas. *Forest Ecology and Management* **257**(10): 2121-2132.
- Mueller-Dombois D and Ellenburg H 1974. *Aims and Methods of vegetation Ecology*. John Wiley and Sons. Inc., New York. 547pp.
- Negi GCS and Dhyani PP (Eds.) 2012. *Glimpses of Forestry Research in the Indian Himalayan Region: Special Issue in the International Year of Forest-2011*. ENVIS Centre on Himalayan Ecology, GB Pant Institute of Himalayan Environment and Development.
- Pielou EC 1975. *Ecological diversity*, John Wiley and Sons, New York.
- Rawal RS, Rawal R, Rawal B, Negi VS and Pathak R 2018. Plant species diversity and rarity patterns along altitude range covering treeline ecotone in Uttarakhand: conservation implications. *Tropical Ecology* **59**(2): 225-239.
- Roberts MR 2004. Response of the herbaceous layer to disturbance in North American forests. *Canadian Journal of Botany* **82**: 1273-1283.
- Scheller RM and Mladenoff DJ 2002. Understorey species pattern in old growth and managed northern hardwood forests. *Ecological Applications* **12**: 1329-1343
- Shadangi DK and Nath V 2005. Impact of seasons on ground flora under plantation and natural forest in Amarkantak. *Indian Forester* **131**(2): 240-250.
- Shannon CE and Weaver W 1963. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, Illinois, USA, 117 pages.
- Singh JS and Yadava PS 1974. Seasonal variation in composition, plant biomass, and net primary productivity of a tropical grassland at Kurukshetra, India. *Ecological Monographs* **44**(3): 351-376.
- Sinha R, Yadav DK and Jhariya MK 2014. Growth performance of Sal in Mahamaya central forest nursery (Ambikapur), Chhattisgarh. *International Journal of Scientific Research* **3**(11): 246-248.
- Struik GJ and Curtis JT 1962 Herb distribution in an Acer saccharum forest. *American Midland Naturalist* **23**: 285-296.
- Tasker EM and Bradstock RA 2006. Influence of cattle grazing practices on forest understorey structure in north-eastern New South Wales. *Austral Ecology* **31**(4): 490-502.
- Tenzin K 2010. *Regeneration and gap dynamics in mixed conifer forests of the Bhutan Himalayas*. Ph.D. Dissertation, University of Natural Resources and Life Sciences, Vienna, Austria.
- Tessema ZK, DeBoer WF, Baars RMT and Prins HHT 2011. Changes in soil nutrients, vegetation structure and herbaceous biomass in response to grazing in a semiarid savanna of Ethiopia. *Journal of Arid Environment* **75**: 662-670.
- Tynsong H and Tiwari BK 2011. Diversity and population characteristics of woody species in natural forests and arecanut agroforests of south Meghalaya, Northeast India. *Tropical Ecology* **52**(3): 243-252.



Assessment of above Ground Biomass and Carbon Stock of Tropical Rain-forest Tree Species from Java, Yogyakarta, Indonesia

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Abstract: The study was conducted in the mixed plantation of tropical rain-forest species of Java Island, Special Region of Yogyakarta, Indonesia. Forests act as a source or sinks for atmospheric CO₂ to store from the atmosphere in different carbon pools by trees in a forest stand. The objectives of the study were to evaluate tree biomass, carbon stock, and absorb carbon dioxide and to expose the impacts of the basal area on biomass, carbon stocks, and absorb CO₂. The sample was selected by a simple random sampling method in the study site. Tree diameter at breast height point, height, and the crown cover were measured as primary source data. The tree basal area showed a strong positive correlation on tree biomass, carbon stocks and absorb CO₂, and value of R² is closed to 1, although when the basal area was increases with an increase in biomass, carbon stocks and absorb CO₂ of both sample trees. Average basal area was 1.850 m², total biomass is 4.276-ton, carbon stocks was 2.13 tons and CO₂ absorptions were 7.84±61.21 tons in *Spondias dulcis* and more as compared to *Monoon lingifolium* which shows suitability and its quality of the site. Proper scientific management and proper utilization of the forest stand can be significant measures to enhance the potential of the forest to be stored and sink more carbon and can be included for CDM and REED++ under Kyoto protocol.

Keywords: Basal area, Biomass, Carbon stocks, Absorbed carbon dioxide

Carbon occurs in the atmosphere as a form of gas-carbon dioxide. About 0.04% approximately in the atmosphere. However, it plays an important role in supporting life on earth, as plants make themselves from it. During the process of photosynthesis, plants consumed carbon dioxide from the atmosphere, change it into carbohydrates, and releasing oxygen into the atmosphere. When these plants trees die and burnt, the stored carbon in them is released back into the atmosphere. Among the greenhouse gases, carbon dioxide is a more responsible gas to cause global warming/climate change. Global climate change is an important issue among the scientific community because of accelerating carbon dioxide concentration in the atmosphere due to different human activities. Various human activities like land-use change, fossil fuel burning, and deforestation increase the concentration of carbon dioxide in the atmosphere and cause the problem of climate change and global warming. The concentration of carbon dioxide increased from 280 to 398.79 ppm. The IPCC in its fourth assessment report recommended for serious measures to check the problem of climate change/global warming to coup the serious ecological, social, and economic consequences.

In a terrestrial ecosystem, oceans, atmosphere, and geological reservoirs are the main components of the global carbon cycle. The forest ecosystem has the significant

potential to store/accumulate and sink carbon and therefore globally forests are considering a potential tool to mitigate global climate change. Forest ecosystem stores 20 to 50 % more carbon as compared to other ecosystems due to its woody character and long-life span covers 31% of the total land area, about 4 billion ha of the land is covered by the forest. The total estimated growing stock of the world forest is 527 billion m³, while the total stored carbon in the world forest is 650 billion tons. For the estimation of above ground biomass in a forest the growing stock volume is the required parameter. Being a member of the Key to protocol the store carbon in the different forest types of Pakistan will be evaluated. In Pakistan the forest department conducts inventory on regular basis for the measurement of the growing stock in the shape of working plan and can be used to assessed carbon stock, but these estimates can be error prone.

The study was carried out in the mixed plantation of *Spondias dulcis* and *Monoon lingifolium* with other tropical specie in Java Special Region of Yogyakarta, Indonesia. Less scientific study has been conducted in Indonesia regarding the growing stock, biomass and carbon stocks measurement of the tropical rain-forest. The present study provides useful information and field protocol regarding growing stock, biomass and carbon stock assessment in the tropical rain-forest. The aim and objectives of the study were

to estimate basal area, biomass, carbon stock and carbon dioxide absorb by trees, to expose the impacts of basal area on total biomass of trees and basal area impacts on total carbon stocks and carbon dioxide absorb by trees in stand of tropical rain-forest in Special region Yogyakarta.

MATERIAL AND METHODS

Study site: The research site was located in foot hill of Java island but outside from the main City of Special region of Yogyakarta, Indonesia. The site had mixed plantation of *Spondias dulcis* and *Monoon lingifolium* with others tropical rain-forest species and the soil is generally fertile and favorable for forestry and agriculture practices. The elevation of the study site was 205 meters (7°46, 1 S an 110°23, 13 E). The mean annual temperate was 22°C while the maximum temperatures of 28°C and the minimum was 28°C respectively were recorded. The area receives 2200 to 22100 mm annually average precipitation was also recorded by a metrological station in Yogyakarta city.

Research design: The sample trees were selected by simple random sampling method. Each sample tree height was measured by using Abnize level and Haga altimeter, while diameter at (DBH) point and the crown cover were measured by using measuring tape of the sample trees. The diameter was measured at two different point's diameters at breast height point and diameter at mid-point. GPS was used for taking the location and to find out the elevation of the study site. Diameter at the midpoint were measured by climbed the tree by using diameter tape and calipers. Diameter at breast point was measured for to cylindrical tree volume and diameter at mid-point was measured to estimate actual volume.

Calculation basal area and biomass: Diameter at breast height was measured to calculate cylindrical tree volume while diameter at midpoint was measured to estimate actual tree volume. To calculate stem volume (m³), tree height (m) and diameter of the tree (cm) at DBH were estimated. The height of the tree was measured by Abney's level. Basel area was calculated from diameter at breast height point and the following formula was used to find basal area of trees.

$$B.A = 1/4\pi D^2$$

Tree volume was estimated by the following formula;

$$V (m^3) = 1/4\pi D^2 \times H \times FF$$

Whereas V = Volume of stem (m³), H = Height of tree in meter, B.A = Cross-sectional Basel area at DBH point and FF = form factor. For the present study, the form factor for each tree in the respective diameter class was calculated.

Biomass of stem (tons) was estimated from (BWD) basic wood density (kg m⁻³) and stem volume (m³). The value of (BWD) was taken from the literature. The stem biomass was

estimated as.

$$\text{Biomass of stem (tons)} = \text{Volume of the stem (m}^3\text{)} \times \text{Basic wood density (kg m}^{-3}\text{)}$$

Measurements of total biomass were estimated by using the biomass expansion factor. The biomass expansion factor is the ratio between stem biomass and total biomass. It means the contribution in making the total biomass of a tree by different parts of the tree i.e., leaves, root, stem, and twigs, etc. To calculate the total biomass, the stem biomass is multiplied with the BEF and the formula used under given below:

The Biomass expansion factor (BEF) was taken as from literature. The biomass (tons) of other tree components (leaves, branches, and roots) were estimated from stem biomass using published Biomass Expansion Factors (BEF) for these tree species.

$$\text{Total biomass (Tons)} = \text{BEF} \times \text{stem biomass (Tons)}$$

Estimation of carbon stock and absorb carbon dioxide:

For the estimation of total carbon stock, used conversion factor 0.5. For the calculation of total carbon stock, we multiplied the conversion factor with total biomass. The total carbon stock estimated. The conversion factor is constant (0.5) in the formula. This conversion factor has been globally used by (Khan et al 2015, Ahmad & Nizami 2015, Sajad 2020).

$$\text{Total carbon stock} = \text{Conversion factor} \times \text{Total biomass}$$

The total absorbs the carbon dioxide of the sampled trees was calculated from the value of total carbon stock with the atomic mass of carbon dioxide (3.67) as it was taken from the literature .

$$\text{Absorb carbon dioxide} = \text{Total carbon stock (ton/tree)} \times \text{Atomic mass of carbon dioxide (3.67)}$$

Data analysis: The collected primary data from the filed were analyzed in Microsoft, Excel and specified formulas were used to find out the results of tree parameters basal area, biomass, carbon stock and absorb carbon dioxide. In regression models (Simple linear regression model) were applied in software Sigma Plot version 10.0 for the correlation to describe the impacts of tree basal area on total tree biomass, carbon stock, and absorb carbon dioxide and tables were composed in MS office Excel.

RESULTS AND DISCUSSION

Biomass and carbon stock of *Spondias dulcis*: The minimum basal area range between 1.850 and 3.961 with mean of 0.66 m². The sum of the total basal area was 55.501 m². The average total biomass was 4.276 tons while the maximum was 11.012 tons minimum 0.508 tons, and the sum of the total biomass of all sample trees was 128.298 tons (Fig. 3). The maximum total carbon stock was 5.506 tons

estimated in a sample tree, while the average was 2.138 with 0.254 and 2.138 as a minimum and maximum. The sum of the total carbon stocks was 64.149 tons of all sample trees estimated. The total minimum absorbs carbon dioxide was 0.933 tons, while the maximum was 20.207 tons in another sample tree, although the average absorbs carbon stocks was 7.84±4.804 tons in all sample's trees estimated. The coefficient variance and standard deviation were calculated for carbon stocks and absorb carbon dioxide which is given in (Fig. 3).

The correlation between the basal areas with total biomass in individual sample trees was calculated from the minimum to maximum level as well as total biomass which are dependent on the basal area of sample trees. The basal area increases with an increase in total biomass of sample trees which shows have a strong positive correlation in between basal area and biomass by using the polynomial cubic equation in the simple linear regression model in sigma plot 10.0 version and value of R² is 0.9710 (Fig. 1).

The basal area was calculated from the minimum to maximum amount and also total carbon stock because which is depended on the basal area of sample trees. The basal area is increases with an increase in total carbon stocks amount of sample trees which shows have a strong positive correlation in between basal area and carbon stock by using the polynomial quadratic equation in the simple linear regression model in sigma plot 10.0 version and value of R² is 0.9740 (Fig. 2).

The impacts of the basal area on absorb carbon dioxide and correlation in between basal area with total absorb carbon dioxide in individual sample trees. The basal area was calculated from minimum to maximum range as well as total absorb carbon dioxide because which is depended on the basal area of sample trees. When basal area is increases with an increase in total absorb carbon dioxide amount of sample trees which shows have a strong positive correlation in between basal area and absorb carbon dioxide by using the polynomial linear equation in the simple linear regression model in sigma plot 10.0 version and value of R² is 0.9677 (Fig. 3).

Biomass and carbon stocks of *Monoon longifolium*: The basal area 0.061137 and 0.00099 m² with the average of 0.15871 m². The sum of the total basal area in all 30 sample trees was 4.76129 m². The average total biomass was 0.413084 tons with range of maximum was 0.755584 tons, although the minimum was 0.092325 tons, and some of the total biomass of all sample trees was 12.39252 tons, and its coefficient variance and standard deviation were also calculated shown in as in Figure 6. The maximum total carbon stock was 0.377792 tons estimated in a sample tree,

while the average total carbon stock was 0.206542±0.103386 tons of all sample trees estimated, however, the minimum was 0.046162 tons, and sum of the total carbon stocks was 6.196258 tons of all sample trees estimated. The total minimum absorbs carbon dioxide was 0.169416 tons in a sample tree estimated, while the maximum was 1.86496 tons in another sample tree, although the average absorbs carbon stocks was 0.758009±0.79427 tons in all sample's trees estimated. The coefficient variance

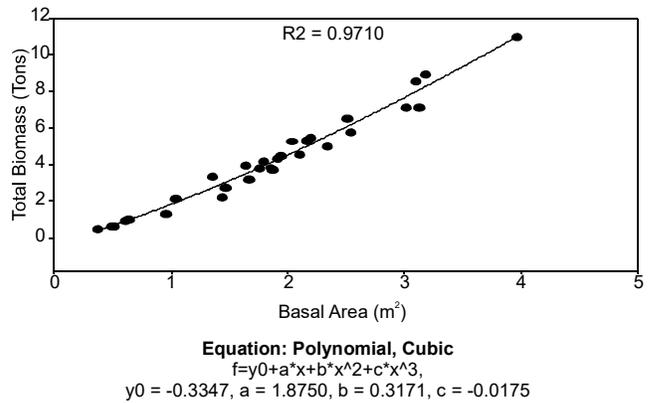


Fig. 4. correlation between basal area with total biomass

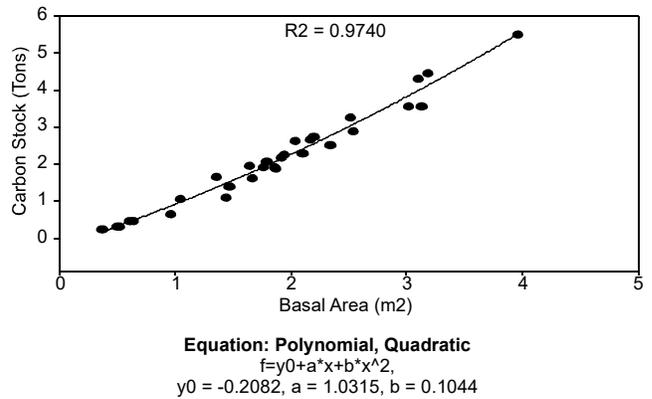


Fig. 5. relation between basal area with carbon stocks

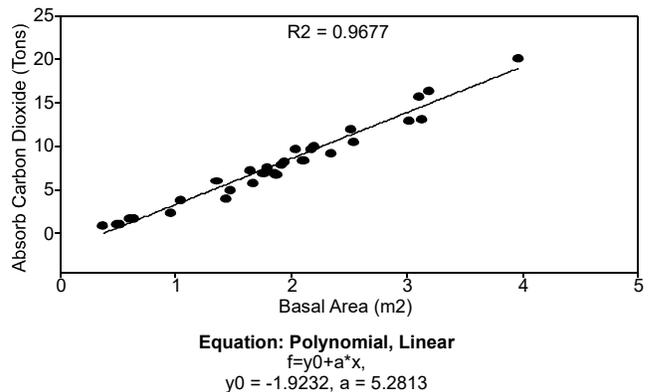


Fig. 6. Basal area impact on absorbing carbon dioxide

and standard deviation was calculated for carbon stocks and absorb carbon dioxide which is given in (Table 2). Correlation between basal area with total biomass in individual sample trees. the basal area was calculated from the minimum to maximum level as well as total biomass which is dependent on the basal area of sample trees. When basal area is increases with an increase in total biomass of sample trees which shows have a strong positive correlation in between basal area and biomass by using the polynomial cubic equation in the simple linear regression model in sigma plot 10.0 version and value of R² is 0.8996 as in (Fig. 4).

The basal area was calculated from the minimum to maximum amount and also total carbon stock because which is depended on the basal area of sample trees. When the basal area is increases with an increase in total carbon stocks amount of sample trees which shows have a strong positive correlation in between basal area and carbon stock by using the polynomial quadratic equation in the simple linear regression model in sigma plot 10.0 version and value of R² is 0.9275 as in (Fig. 5).

The basal area was calculated from minimum to maximum range as well as total absorb carbon dioxide because which is depended on the basal area of sample trees. When basal area is increases with an increase in total absorb carbon dioxide amount of sample trees which shows have a strong positive correlation in between basal area and

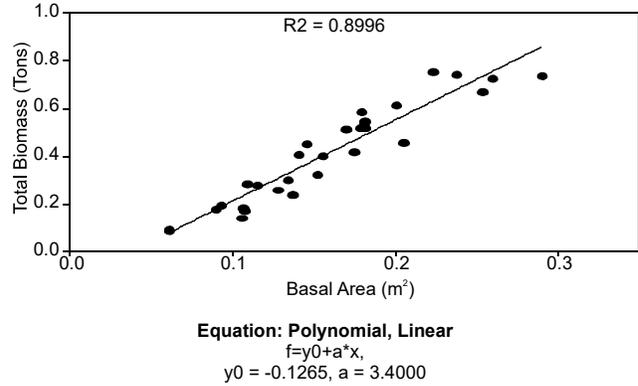


Fig. 8. The relation between the basal area with total biomass

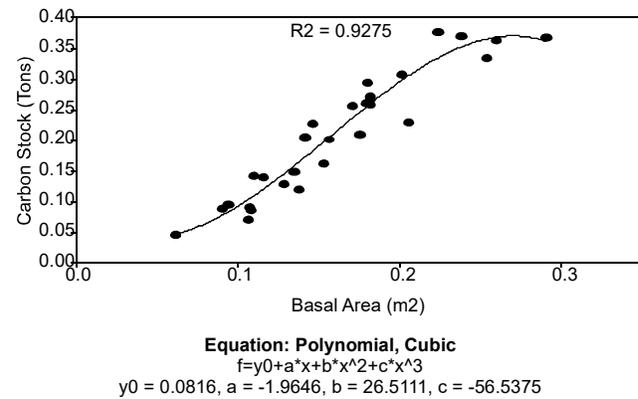


Fig. 9. Shows impacts between basal area on carbon stocks

Table 1. Statistics of *Spondias dulcis*

Variable	Unit	N	Min	Max	Mean	Sum	SD	CV (%)
Basle area	M ² /Tree	30	0.366	3.961	1.850	55.501	0.894	48.365
Total biomass	Tons/Tree	30	0.508	11.012	4.276	128.298	2.617	61.216
Carbon stock	Tons/Tree	30	0.254	5.506	2.138	64.149	1.308	61.216
Absorb CO ₂	Tons/Tree	30	0.933	20.207	7.847	235.427	4.804	61.216

Table 2. Statistics of *Monoon longifolium*

Variable	Unit	N	Min	Max	Mean	Sum	SD	CV (%)
Basle area	M ² /Tree	30	0.061137	0.290099	0.15871	4.761297	0.057681	36.34345
Total biomass	Tons/Tree	30	0.092325	0.755584	0.413084	12.39252	0.206772	50.05573
Carbon stock	Tons/Tree	30	0.046162	0.377792	0.206542	6.196258	0.103386	50.05573
Absorb CO ₂	Tons/Tree	30	0.169416	1.386496	0.758009	22.74027	0.379427	50.05573

Table 3. Comparison of biomass and carbon stock between two trees

Names of trees specie	<i>Spondias Dulcis</i>			<i>Monoon longifolium</i>
	Unit	N	Mean	Mean
Basle area	M ²	30	1.850+48.36	0.15871+36.34
Total biomass	Tons	30	4.276+61.21	0.413084+50.05
Carbon stock	Tons	30	2.138+61.21	0.206542+50.05
Absorb CO ₂	Tons	30	7.84+61.21	0.758009+50.05

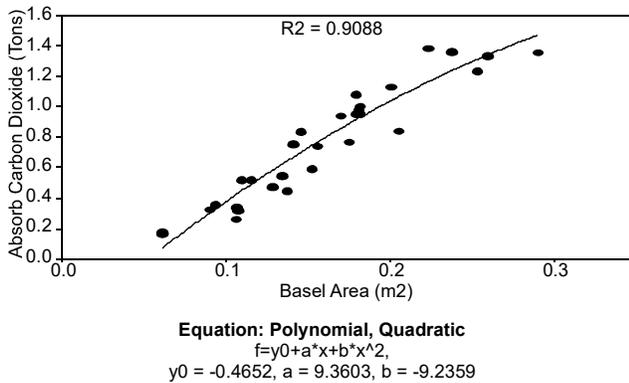


Fig. 10. Relationship between basal area with absorb carbon dioxide

absorb carbon dioxide by using the polynomial linear equation in the simple linear regression model in sigma plot 10.0 version and value of R^2 is 0.9088 as in (Figure 6).

Comparisons of biomass and carbon stock between trees species: In *Sponduas dulcis* the average basal area, biomass, carbon stocks, and absorb carbon more as compared to *Monoon lingifolium* (). Because the tree growth mostly depended on site suitability and its quality which means edaphic as well depends on climatic factors of the site.

CONCLUSIONS

The study was conducted in the mixed plantation of tropical rain-forest trees (*Sponduas dulcis* and *Monoon lingifolium*) from the low foothill of Java island but outside from the main City of Special Region of Yogyakarta, Indonesia. The tree basal area showed a strong positive correlation with total biomass, carbon stocks, and absorb carbon dioxide and the value of R^2 was close to 1. When the basal area was increases with an increase in biomass, carbon stocks and absorbs carbon dioxide for both sample trees which are shown in different figures the mixed plantation of tropical rain-forest trees (*Sponduas dulcis* and *Monoon lingifolium*) is a valuable sink for carbon sequestration. Improper utilization, unscientific management and illegal activities were carried out and its needs the proper scientific management plan and proper utilization. By rehabilitation of degraded forest stand, afforestation, and reforestation can increase the potential of the mixed plantation of tropical rain-forest trees to sorted more carbon from the atmosphere and acts as a sink for carbon.

REFERENCES

- AbarquezA, Bush D, Ata J, Tolentino EL and Gilbero D 2015. Early growth and genetic variation of mahogany (*Swietenia Macrophylla*) in progenyttests Planted in Northern Mindanao, Philippines. *Journal of Tropical Forest Science* **27**(3): 314-324.
- Achmad B 2017. *Estimation of Carbon Stock of Red Meranti (Shorea leprosula Miq.) Stands at Natural Forests Applying Intensive Silviculture in Indonesia.*
- Ahmad A and Nizami SM 2015. Carbon stocks of different land use in the Kumrat valley, Hindu Kush Region of Pakistan. *Journal of Forestry Research* **26**(1): 57-64.
- Alessandri S 2019. A learning pathway to an integrated approach involving natural, applied and social science, humanities, and arts to face climate change. *Sustainability* **12**(4): 199-214.
- Ekoungoulou R, Liu X, Loumeto JJ and lfo SA 2014. Tree above- and below-ground biomass allometries for carbon stocks estimation in secondary forest of Congo. *IOSR Journal of Environmental Science, Toxicology and Food Technology* **8**(4): 09-20.
- Global Forest Resources Assessment 2010.* (n.d.). IPCC — Intergovernmental Panel on Climate Change. (n.d.). Retrieved October 18, 2020, from <https://www.ipcc.ch/>
- Jabłoński M and Budniak P 2014. Estimating aboveground woody biomass of forests in Poland for FAO/ECE and UNFCCC reporting. *Forest Research Papers* **75**(3): 277-289.
- Kaul M, Mohren GMJ and Dadhwal VK 2010. Carbon storage and sequestration potential of selected tree species in India. *Mitigation and Adaptation Strategies for Global Change* **15**(5): 489-510.
- Khan A, Ahmad A, Rahman Z, Qureshi R and Muhammad J 2015. The assess-ment of carbon stocks in the oak scrub forest of Sheringal Valley Dir Kohistan. *Open Journal of Forestry* **5**: 510-517.
- Kumar A and Sharma M P 2015. Estimation of carbon stocks of Balganga reserved Forest, Uttarakhand, India. *Forest Science and Technology* **11**(4): 177-181.
- Nizami SM 2012. The inventory of the carbon stocks in sub tropical forests of Pakistan for reporting under Kyoto Protocol. *Journal of Forestry Research* **23**(3): 377-384.
- Oki Widhanarto G, Hadi Purwanto R and Maryudi A 2016. *Assessing carbon pool of forest plantation to support REDD+ implementation in Indonesia* <https://doi.org/10.1063/1.4958552>
- Pharma D, Sharma A, Prashar B and Arora P 2018. *PCHHAX Cedrus deodara: A Medicinal Herb* **10**(4). www.derpharmachemica.com
- Phongkrathung R, Vajrodaya S and Kermanee P 2016. Wood anatomy and properties of three species in the genus *Spondias lakonensis* (Anacardiaceae) found in Thailand. *Agriculture and Natural Resources* **50**(1):14-19.
- Raqeeb A, Nizami SM, Saleem A and Hanif M 2014. Characteristics and growing stocks volume of forest stand in dry temperate forest of Chilas Gilgit-Baltistan. *Open Journal of Forestry* **04**(03): 231-238.
- Sajad AN and J 2020. *Evaluation of Biomass and Carbon Stocks by Inventory Method in Pure Pinus* **8**(June): 371-377.
- Sharma CM, Baduni NP, Gairola S, Ghildiyal SK and Suyal S 2010. Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. *Forest Ecology and Management* **260**(12): 2170-2179.
- Sharma R, Chauhan SK and Tripathi AM 2016. Carbon sequestration potential in agroforestry system in India: An analysis for carbon project. *Agroforestry Systems* **90**(4): 631-644.
- VashumTK 2012. Methods to estimate above-ground biomass and carbon stock in natural forests: A review. *Journal of Ecosystem & Ecography* **02**(04): 1-7.
- US Department of Commerce, N. G. M. L. (n.d.). *Global Monitoring Laboratory - Global Greenhouse Gas Reference Network.*
- Yogyakarta, Indonesia - Detailed climate information and monthly weather forecast | Weather Atlas.* (n.d.). Retrieved September 29, 2020, from <https://www.weather-atlas.com/en/indonesia/yogyakarta-climate>



Urban Tree Species Diversity and Related Carbon Contribution: A Case Study of the Legon Botanical Garden (LBG), University of Ghana Main Campus

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Abstract: The present study was carried out to record tree diversity and estimate their related carbon input at the Legon Botanical Garden. Using non-destructive sampling approach in 1.56-hectare area, biophysical parameters of trees species was carried out and appropriate allometries used to convert these measures to total biomass and potential carbon dioxide values. 146 diverse live tree species belonging to 32 different plant families were inventoried. The Fabaceae constitutes the dominant plant family. A total count of 289 individual trees belonging to 44 genera made up of 51 different species and 16 plant families was enumerated. The average tree height and girth measured ranged between 6.4 to 45.2 m and 0.2 to 3.8 m respectively. Potentially, these wood species contributed a total biomass weighting of 546.2 t ha⁻¹ and 273.1 t C ha⁻¹ carbon storage with *Ceiba pentandra*, *Gliricidia sepium*, and *Antiaris toxicaria* recording the highest values. The findings in this study, represents the current status of tree stands in the Legon Botanical Garden.

Keywords: Urban trees, Legon botanical garden, Tree diversity, Biomass and carbon storage

Trees act as major CO₂ sink, capturing carbon from the atmosphere and storing that carbon in the form of fixed biomass during their growth process. The more trees grow and their biomass increase, the more carbon they absorb from the atmosphere and store in their tissues (Matthews et al 2000). Significant roles played by forests in combatting the elevated atmospheric carbon levels across the globe are well defined and documented (FAO 2010). Apart from forests, the so called 'green pockets' in urban communities made up of avenue trees, trees in home gardens, orchards, arboretum, botanical gardens, etc. also act as hotspots in urban landscapes (Kulkarni et al 2001), hence urban green diversity also play a major role in lowering atmospheric carbon levels. Many urban development policies, continue to promote tree-planting, preservation of urban green spaces, and green architecture. Green roofs and facades (Pataki et al 2011, Demuzere et al 2014, Mahajan et al 2018, Nandal et al 2019) to mitigate carbon. However, not many attempts have been made to document the potential contribution of urban trees to carbon storage and sequestration. In urban green areas, carbon is stored in the form of above and below ground biomass. Above-ground, trees and shrubs contribute to the major part of vegetation biomass compared to turf grass, lawns, and herbaceous garden plants. Below ground, tree roots and litter are identified as the relevant soil carbon pools in urban areas (Brown et al 2012). The numerous

environmental benefits of urban trees include influence of air quality, air temperatures on local climate, carbon cycles, energy use and climate change, filtering and retaining storm water, sequestering carbon, and contributing to healthier and more beautiful cities (Nowak and Crane 2002, McPherson and Simpson 2003, Gill et al 2007, Nowak et al 2008) cannot be overemphasized. In addition, urban trees also provide essential habitat and food sources for wildlife in urban landscapes, local and migratory birds (Rega et al 2015). Therefore, carbon sink occurs when sequestered carbon is greater than total carbon released into the atmosphere over some time period. According to Watson (2008), carbon sequestration is a way to mitigate the accumulation of greenhouse gases in the atmosphere released by the burning of fossil fuels and other anthropogenic activities.

According to the IPCC (2006) on climate change, when information on tree biomass due to structural and functional features is evaluated, that provides one of the ways of monitoring greenhouse gas emissions measured as the average carbon stocks per unit area. For forest and urban trees, approximately 50% of dry biomass consists of carbon that is sequestered (Losi et al 2003, Montagu et al 2005, Sheikh and Kumar, 2010). Ecologically, this implies that biomass assessments in any landscape provide measure of the amount of carbon that may be sequestered. The region of Ghana is endowed with rich tropical vegetation (Asante

and Benefoh 2013) of which the University of Ghana (UG) main campus landscape that has a beautiful land use pattern and rich floral diversity including urban trees as a green hub Legon Botanical Garden (LBG), is a prototype of the original vegetation of the Accra plains. Hence, this work makes an attempt to provide a first-hand estimate of the contribution of urban tree species in the Accra plains to biomass accumulation, carbon storage and sequestration, as the functional components of the species diversity adaptation and climate change mitigation of the Accra plains.

MATERIAL AND METHODS

Study area: The study was conducted at the Legon Botanical Garden (LBG) of University of Ghana's main Campus situated at latitude $5^{\circ}19'32.82''N$ and longitude $0^{\circ}11'12.20''W$ at an altitude of 61 m above msl and lies north-east of the University main campus. The demarcation of the LBG extends approximately thirty-six hectares (Fig. 1). Given that the LBG lies within the coastal savannah belt, the area experiences a daily minimum and maximum temperature that range between $21.0-24.0^{\circ}C$ and $26.5-32.0^{\circ}C$ respectively with average minimum temperatures ranging $24.0-27.6^{\circ}C$ that is characterized by 787 mm annual total precipitation. In terms of sunshine hour per annum, 2377 hours is notable with average sunlight hour per day recording 6.4 hours. The LBG is rich in floral diversity made up of tropical and semi-tropical tree species and comprise of grassland, herbs and shrubs vegetation areas with impenetrable thickets, palmatum, wood land, a dam (known as Vaughan Dam), an agricultural experimental farm, a plant nursery, recreational area, a canopy walk, children's playground and restaurants as shown in (Fig. 1).

Sampling technique: A reconnaissance survey was initially carried out in the study area to identify and inventorize all standing tree species.

Plot sampling: The area of $625m^2$ ($25m \times 25m$ sampled plots) was demarcated and live tree species measurement using non-destructive approach was carried out to obtain datasets on biophysical parameters such as tree height (H) and girth at breast height (GBH) for each tree species in a sampled quadrat. In all, 25 sampled plots were assessed.

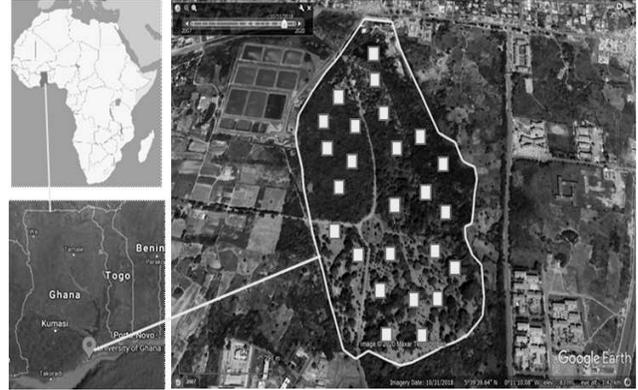
Species diversity: The Shannon diversity (H) measure was used to describe the vegetation of the sampled area in terms of richness of species and plant family distribution.

$$\text{Shannon Diversity (H)} = -\sum P_i \times \ln P_i \dots \text{Eqn.-1,}$$

where $P_i = n/N$ and n , N are individual and total count numbers respectively (Shannon 1948).

Shannon-Weaver diversity value usually ranges from as low as 1.5 to as high as 3.5 and rarely exceeding 4.5.

Biomass: Derived allometric equations were employed for



Source: Google Earth Map Pro

Fig. 1. 2018 Landsat imagery showing LBG location in the University of Ghana, Accra and 25 sample plot demarcations

estimating biomass pool, organic carbon storage and carbon dioxide sequestered. Using appropriate ecological tools, bio-physically measured tree values: height (H) and girth at breast height (GBH) were obtained for the aforementioned estimations. Tree girth value ($2\pi r$) was also converted to diameter values (D).

Tree bio-volume: This equation was established by multiplying the estimated diameter (D) (i.e., DBH) and height (H) of tree species to a factor of 0.4

$$\text{Tree Bio-volume (TBV)} = 0.4 \times (D)^2 \times H \text{ (Brown 1997, Chavan and Rasal 2010, 2012)...Eqn. -2}$$

Above ground biomass estimation: $AGB = \text{Wood density} \times TBV$ (Brown 1997, Negi et al 2003)...Eqn. -3

The wood density values were obtained from the global wood density database (Zanne et al 2009).

Below ground biomass estimation: $BGB = AGB \times 0.26$ (Brown 1997, Negi et al 2003)...Eqn. -4

Total biomass estimation: $\text{Total Biomass (TB)} = AGB + BGB$ (Brown 1997, Negi et al 2003)...Eqn. -5

Carbon storage estimation: $\text{Carbon Storage} = \text{Biomass} \times 50\%$ or $\text{Biomass} / 2$ (Brown 1997, Negi et al 2003)...Eqn.-6

Estimation of carbon dioxide sequestered: $CO_2 \text{ sequestered} = \text{Carbon storage} \times 3.67$ (Brown 1997, Negi et al 2003, Pearson et al 2007)...Eqn.-7

RESULTS AND DISCUSSION

A total of 146 species belonging to 32 different plant families in 36 ha area (appx. four species/ ha or one plant family ha⁻¹) constituted tree diversity in LBG (Table 1). The 51 different tree species belonging to 16 plant families were measured for tree height and girth values. In all a total of 289 individual tree species count in 25 quadrats (appx. 1.56 ha) area were measured. The Fabaceae is the most dominant plant family with 35 different tree species followed by

Table 1. Checklist of standing tree diversity at the LBG

Number	Tree species
Family Anacardiaceae	
1.	<i>Anacardium occidentale</i>
2.	<i>Mangifera indica</i>
3.	<i>Lannea acida</i>
4.	<i>Sclerocarya birrea</i>
5.	<i>Spondias mombin</i>
Family Annonaceae	
6.	<i>Annona squamosa</i>
7.	<i>Cananga odorata</i>
8.	<i>Polyalthia longifolia</i>
Family Apocynaceae	
9.	<i>Allamanda cathartica</i>
10.	<i>Alstonia boonei</i>
11.	<i>Carissa spinarum</i>
12.	<i>Holarrhena floribunda</i>
13.	<i>Nerium oleander</i>
14.	<i>Plumeria rubra</i>
15.	<i>Strophanthus gratus</i>
16.	<i>S. hispidus</i>
17.	<i>Thevetia neriifolia</i>
18.	<i>Voacanga africana</i>
Family Arecaceae	
19.	<i>Borassus aethiopicum</i>
20.	<i>Cocos nucifera</i>
21.	<i>Elaeis guineensis</i>
22.	<i>Hyphaene dichotoma</i>
23.	<i>Phoenix reclinata</i>
24.	<i>Roystonea oleracea</i>
Family Bignoniaceae	
25.	<i>Crescentia cujete</i>
26.	<i>Kigelia africana</i>
27.	<i>Millingtonia hortensis</i>
28.	<i>Spathodea campanulata</i>
29.	<i>Stereospermum kunthianum</i>
30.	<i>Tabebuia microphylla</i>
31.	<i>Tecoma stans</i>
Family Bixaceae	
32.	<i>Bixa orellana</i>
Family Cannabaceae	
33.	<i>Celtis integrifolia</i>
34.	<i>C. iguanaea</i>
Family Casuarinaceae	
35.	<i>Casuarina equisetifolia</i>

Cont...

Continues Table 1

Number	Tree species
Family Combretaceae	
36.	<i>Anogeissus leiocarpus</i>
37.	<i>Combretum fragrans</i>
38.	<i>Terminalia brownii</i>
39.	<i>T. catappa</i>
40.	<i>T. glaucescens</i>
41.	<i>T. mantaly</i>
42.	<i>T. ivorensis</i>
Family Dichapetalaceae	
43.	<i>Dichapetalum madagascariense</i>
Family Ebenaceae	
44.	<i>Diospyros abyssinica</i>
45.	<i>D. mespiliformis</i>
Family Euphorbiaceae	
46.	<i>Bridelia ferruginea</i>
47.	<i>Croton</i> sp.
48.	<i>Euphorbia drupifera</i>
49.	<i>Hura crepitans</i>
Family Fabaceae	
50.	<i>Acacia auriculiformis</i>
51.	<i>A. mangium</i>
52.	<i>Adenanthera pavonina</i>
53.	<i>Afzelia africana</i>
54.	<i>Albizia lebbbeck</i>
55.	<i>A. zygia</i>
56.	<i>Baphia nitida</i>
57.	<i>Bauhinia tomentosa</i>
58.	<i>Brownea coccinea</i>
59.	<i>Caesalpinia pulcherrima</i>
60.	<i>Cassia fistula</i>
61.	<i>C. sieberiana</i>
62.	<i>Dalbergia sissoo</i>
63.	<i>Delonix regia</i>
64.	<i>Dialium guineense</i>
65.	<i>Erythrina senegalensis</i>
66.	<i>Erythrophleum suaveolens</i>
67.	<i>Gliricidia sepium</i>
68.	<i>Griffonia simplicifolia</i>
69.	<i>Guibourtia copallifera</i>
70.	<i>G. demeusei</i>
71.	<i>Leucaena leucocephala</i>
72.	<i>Lonchocarpus cyanescens</i>
73.	<i>L. sericeus</i>

Cont...

Continues Table 1

Number	Tree species
75.	<i>Myroxylon balsamum</i>
76.	<i>Parkia biglobosa</i>
77.	<i>Peltophorum linnaei</i>
78.	<i>P. pterocarpum</i>
79.	<i>Pterocarpus erinaceus</i>
80.	<i>Samanea saman</i>
81.	<i>Senna pallida</i>
82.	<i>S. siamea</i>
83.	<i>Tamarindus indica</i>
84.	<i>Tetrapleura tetraptera</i>
Family Gentianaceae	
85.	<i>Anthocleista djalonenis</i>
Family Lamiaceae	
86.	<i>Vitex doniana</i>
87.	<i>Tectona grandis</i>
Family Lauraceae	
88.	<i>Cinnamomum verum</i>
89.	<i>Persea americana</i>
Family Lecythidaceae	
90.	<i>Lecythis zabucajo</i>
Family Malvaceae	
91.	<i>Adansonia digitata</i>
92.	<i>Bombax buonopozense</i>
93.	<i>Ceiba pentandra</i>
94.	<i>Cola gigantea</i>
95.	<i>C. millenii</i>
96.	<i>Gossypium sp.</i>
97.	<i>Hildegardia barteri</i>
98.	<i>Mansonia altissima</i>
99.	<i>Pachira insignis</i>
100.	<i>P. sessilis</i>
101.	<i>Sterculia foetida</i>
102.	<i>Theobroma cacao</i>
103.	<i>Triplochiton scleroxylon</i>
Family Meliaceae	
104.	<i>Azadirachta indica</i>
105.	<i>Entandrophragma angolense</i>
106.	<i>Khaya senegalensis</i>
Family Moraceae	
107.	<i>Antiaris toxicaria</i>
108.	<i>Artocarpus altilis</i>
109.	<i>Ficus americana</i>
110.	<i>F. elastica</i>

Continues Table 1

Number	Tree species
111.	<i>F. grabhamii</i>
112.	<i>F. lutea</i>
113.	<i>F. natalensis</i>
114.	<i>F. platyphylla</i>
115.	<i>F. religiosa</i>
116.	<i>Millicia excelsa</i>
Family Moringaceae	
117.	<i>Moringa oleifera</i>
Family Myrtaceae	
118.	<i>Eucalyptus cerasiformis</i>
119.	<i>Psidium cattleianum</i>
120.	<i>P. glaziovianum</i>
Family Oxalidaceae	
121.	<i>Averrhoa bilimbi</i>
Family Poaceae	
122.	<i>Bambusa burmanica</i>
Family Rhamnaceae	
123.	<i>Ziziphus mauritiana</i>
Family Rubiaceae	
124.	<i>Gardenia ternifolia</i>
125.	<i>Ixora coccinea</i>
126.	<i>Morinda lucida</i>
127.	<i>Pavetta corymbosa</i>
128.	<i>Rothmannia longiflora</i>
129.	<i>Sarcocephalus latifolius</i>
Family Rutaceae	
130.	<i>Afraegle paniculata</i>
131.	<i>Murraya paniculata</i>
132.	<i>Zanthoxylum zanthoxyloides</i>
Family Salicaceae	
133.	<i>Dovyalis caffra</i>
134.	<i>Flacourtia flavescens</i>
Family Sapindaceae	
135.	<i>Blighia sapida</i>
136.	<i>B. unijugata</i>
137.	<i>Lecaniodiscus cupanioides</i>
Family Sapotaceae	
138.	<i>Chrysophyllum albidum</i>
139.	<i>C. cainito</i>
140.	<i>Malacantha alnifolia</i>
141.	<i>Mimusops elengi</i>
142.	<i>Synsepalum dulcificum</i>
143.	<i>Vitellaria paradoxa</i>
Family Zamiaceae	
144.	<i>Encephalartos barteri</i>
Family Zygophyllaceae	
145.	<i>Balanites aegyptiaca</i>
146.	<i>Guaiaicum officinale</i>

Cont...

Malvaceae with thirteen and, Apocynaceae & Moraceae with ten plant species each inventoried. The families as Dichapetalaceae, Oxalidaceae and Casuarinaceae recorded single species. Similarly, some other families namely the Bignoniaceae and Combretaceae, recorded equal number of species count.

Similar finding of the dominance of the Fabaceae is reported by Kuma and Shibru (2015) in the Oda forest, Addis Ababa-Ethiopia and Mouna et al (2019) in the Reserve Forest, Tumakuru, Karnataka. Some of the Fabaceae members in this study include species such as *Cassia fistula*, *Senna siamea*, *Cassia spectabilis*, *Erythrophleum suaveolens*, *Leucaena leucocephala*, *Tamarindus indica*, *Millettia thonningii*, *Pterocarpus tetraptera*, *Samanea saman*, etc. The dominance of this plant family is a clear indication of the suitability of similar ecological conditions and therefore adaptation of the Fabaceae to such plant communities: the dry woodland forest type in the Oda forest being similar to the 'forest-like' vegetation of the LBG. However, in relation to other plant species and family diversities of the sampled area, the Shannon diversity (H) measure for $H_{species}$ and H_{family} was 1.8 and 0.7, respectively. This implies that the sampled area is rather low in terms of species and plant family diversity. In terms of relative frequency of sampled species distribution, five different tiers or rank orders were observed (Fig. 3). The highest tier or rank of tree species are *Khaya senegalensis*, *Azadirachta indica*, *Gliricidia sepium* and *Antiaris toxicaria* recording values of 7.27, 5.45, 5.45 and 4.55%, respectively. The lowest rank order included species such as *Cola gigantea*, *Anacardium occidentale*, *Lecaniodiscus cupanioides*, *Dalbergia sissoo*, *Terminalia glaucescens* with the relative frequency 0.91% (Fig. 3).

Similarly, in terms of relative density distribution of tree species *Ceiba pentandra* recorded the highest value per unit area (22.49%) followed by *Gliricidia sepium*, *Azadirachta indica*, *Leucaena leucocephala* and *Adansonia digitata* with

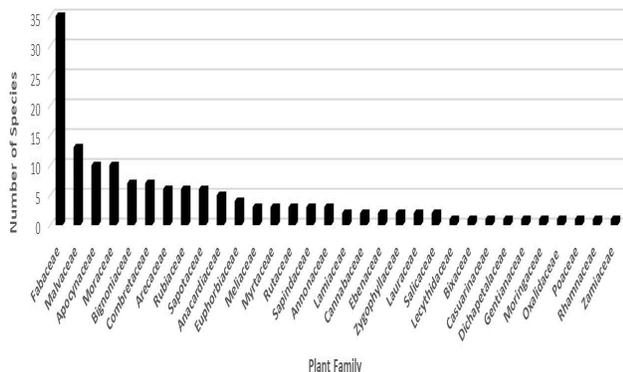


Fig. 2. Plant families and species count in the LBG

the remaining species such as *Celtis integrifolia*, *Millettia thonningii*, *Delonix regia*, *Albizia lebbek*, *Peltophorum pterocarpum*, *Moringa oleifera*, *Mimusops elengi* and *Bombax buonopozense* ranging between 0.3 to 3.8% which assumes an inverted 'J' shaped pattern (Fig. 4). This pattern is an indication that the vegetation of tree species in the sampled area is 'forest-like' and conforms to findings of Kuma and Shibru (2015) on dry woodland forest of the Oda in Addis Ababa, Ethiopia. This distribution pattern is indicative of a well-spaced reproduction and recruitment potential of different species in this tree community.

For tree biomass accumulation, a total of 852.05 tons is estimated for the sampled area. This implies 546.19 t ha⁻¹ biomass with *Ceiba pentandra* (244.9 t ha⁻¹), *Antiaris toxicaria* (53.14 t ha⁻¹) and *Gliricidia sepium* (43.06 t ha⁻¹). Additionally, thirteen different tree species namely *Triplochiton scleroxylon*, *Ficus platyphylla*, *Lecaniodiscus cupanioides*, *Moringa oleifera*, *Cassia spectabilis*, *Terminalia catappa*, *Terminalia glaucescens*, *Polyalthia longifolia*, *Ficus americana*, *Mimusops elengi*, *Acacia auriculiformis*, and *Pachira insignis* measured less than 1.0 t ha⁻¹ of biomass with the remaining other woody tree species measuring between >1.00 to 21.15 t ha⁻¹ biomass (Fig. 5).

Numerous studies on biomass have been done on different vegetation types including urban forest, evergreen forest, deciduous forest, tropical rain forest and University Campuses. Bhat et al (2003) reported that tree biomass in

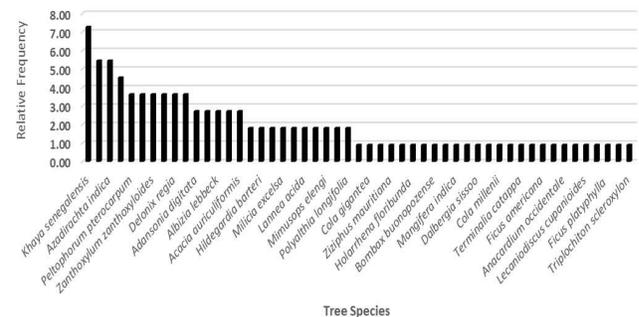


Fig. 3. Relative frequency distribution of sampled species

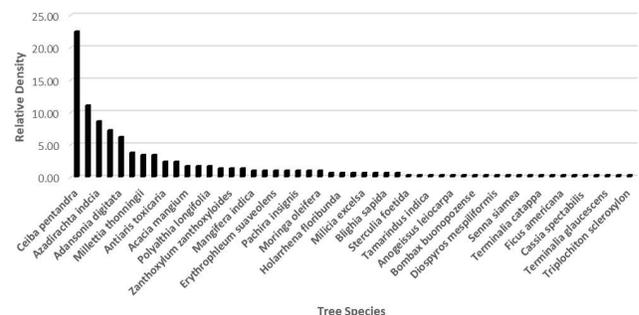


Fig. 4. Relative density distribution of sampled tree species

Table 2. Bio-physical parameters, biomass and carbon input of sampled tree species

Tree species	Count No.	Ave. height/ M	Ave. GBH/ M	Rel. density	Rel. freq.	Biomass/ tons	C storage/ tons	CO ₂ sequestration/ tons	Potential CO ₂ sequestration/ tons per tree
<i>Acacia auriculiformis</i>	3	16.66	0.45	1.0	2.73	0.76	0.38	1.40	0.30
<i>A. mangium</i>	5	17.27	0.87	1.7	3.64	3.66	1.83	6.72	0.86
<i>Adansonia digitata</i>	18	25.91	1.1	6.2	2.73	17.22	8.61	31.60	1.13
<i>Afraegle paniculata</i>	1	19.2	2.03	0.3	0.91	5.25	2.62	9.63	6.18
<i>Albizia lebbbeck</i>	5	13.32	0.7	1.7	2.73	2.19	1.10	4.02	0.52
<i>Anacardium occidentale</i>	1	15.5	0.65	0.3	0.91	0.32	0.16	0.59	0.38
<i>Anogeissus leiocarpa</i>	1	37.2	2.34	0.3	0.91	18.02	9.01	33.07	21.20
<i>Antiaris toxicaria</i>	7	25.61	2.64	2.4	4.55	82.90	41.45	152.12	13.93
<i>Azadirachta indica</i>	25	11.52	0.61	8.7	5.45	7.58	3.79	13.92	0.36
<i>Blighia sapida</i>	2	18.6	0.75	0.7	1.82	1.73	0.86	3.17	1.02
<i>Bombax buonopozense</i>	1	45.2	1.9	0.3	0.91	5.85	2.92	10.73	6.88
<i>Cassia fistula</i>	1	14.9	0.95	0.3	0.91	1.07	0.53	1.96	1.26
<i>C. spectabilis</i>	1	15	0.51	0.3	0.91	0.21	0.10	0.38	0.24
<i>Ceiba pentandra</i>	65	39.08	2.2	22.5	3.64	382.04	191.02	701.03	6.91
<i>Celtis integrifolia</i>	11	11.85	1.1	3.8	0.91	10.46	5.23	19.20	1.12
<i>Cola gigantea</i>	1	32.3	2.94	0.3	0.91	14.82	7.41	27.19	17.43
<i>C. millenii</i>	1	21	1.13	0.3	0.91	1.78	0.89	3.26	2.09
<i>Dalbergia sissoo</i>	1	19.6	1.3	0.3	0.91	2.41	1.21	4.43	2.84
<i>Delonix regia</i>	7	14.28	1.15	2.4	3.64	7.81	3.90	14.32	1.31
<i>Diospyros mespiliformis</i>	1	15.7	1.46	0.3	0.91	2.60	1.30	4.77	3.06
<i>Elaeis guineensis</i>	3	15.46	1.04	1.0	1.82	3.33	1.66	6.11	1.31
<i>Erythrophleum suaveolens</i>	3	14.6	1.06	1.0	2.73	3.97	1.98	7.28	1.56
<i>Ficus americana</i>	1	15.2	0.91	0.3	0.91	0.56	0.28	1.02	0.65
<i>F. platyphylla</i>	1	6.4	0.43	0.3	0.91	0.08	0.04	0.14	0.09
<i>F. religiosa</i>	2	26.45	3.57	0.7	1.82	33.03	16.51	60.61	19.42
<i>Gliricidia sepium</i>	32	18.06	1.37	11.1	5.45	67.17	33.59	123.26	2.47
<i>Hildegardia barteri</i>	2	20.25	1.8	0.7	1.82	8.71	4.35	15.98	5.12
<i>Holarrhena floribunda</i>	2	29.9	2.27	0.7	0.91	15.98	7.99	29.33	9.40
<i>Khaya senegalensis</i>	10	13.73	0.67	3.5	7.27	4.33	2.16	7.94	0.51
<i>Lannea acida</i>	2	19.95	0.98	0.7	1.82	2.54	1.27	4.67	1.50
<i>Lecaniodiscus cupanioides</i>	1	7.46	0.44	0.3	0.91	0.10	0.05	0.18	0.11
<i>Leucaena leucocephala</i>	21	12.6	0.4	7.3	0.91	2.83	1.42	5.20	0.16
<i>Malacantha alnifolia</i>	1	12.64	1.89	0.3	0.91	3.00	1.50	5.50	3.52
<i>Mangifera indica</i>	3	12.83	1.78	1.0	0.91	7.23	3.61	13.26	2.83
<i>Milicia excelsa</i>	2	25.4	1.38	0.7	1.82	6.15	3.08	11.29	3.62
<i>Millettia thonningii</i>	10	11.9	1.45	3.5	3.64	16.60	8.30	30.46	1.95
<i>Mimusops elengi</i>	2	12.7	0.56	0.7	1.82	0.73	0.37	1.34	0.43
<i>Moringa oleifera</i>	3	8.8	0.44	1.0	1.82	0.15	0.07	0.27	0.06
<i>Pachira insignis</i>	3	13.43	0.68	1.0	2.73	0.79	0.40	1.45	0.31
<i>Peltophorum pterocarpum</i>	4	23	2.22	1.4	3.64	28.33	14.16	51.98	8.33
<i>Polyalthia longifolia</i>	5	10.55	0.41	1.7	1.82	0.53	0.26	0.97	0.12
<i>Tetrapleura tetraptera</i>	4	16.1	0.87	1.4	0.91	3.23	1.62	5.93	0.95
<i>Samanea saman</i>	3	17.5	1.71	1.0	1.82	10.19	5.09	18.69	3.99
<i>Senna siamea</i>	1	17	1.17	0.3	0.91	1.54	0.77	2.83	1.82
<i>Sterculia foetida</i>	1	42.7	3.25	0.3	0.91	22.34	11.17	41.00	26.28
<i>Tamarindus indica</i>	1	21.74	2.74	0.3	0.91	15.41	7.71	28.28	18.13
<i>Terminalia catappa</i>	1	8.4	1	0.3	0.91	0.43	0.21	0.79	0.50
<i>Terminalia glaucescens</i>	1	29	0.43	0.3	0.91	0.43	0.22	0.80	0.51
<i>Triplochiton scleroxylon</i>	1	10.5	0.21	0.3	0.91	0.02	0.01	0.03	0.02
<i>Zanthoxylum zanthoxyloides</i>	4	16.74	1.92	1.4	3.64	16.38	8.19	30.05	4.82
<i>Ziziphus mauritiana</i>	1	15.15	2.65	0.3	0.91	7.27	3.64	13.34	8.55
Total	289			100.00	100.00	852.05	426.02	1563.51	

the tropical rain forest of Uttara Kannada in the Western Ghat of India ranges from 92 t ha⁻¹ to 268.49 t ha⁻¹ accumulation. Haripriya (2003) observed tree biomass accumulation in evergreen, semi-evergreen and deciduous forest in India to be 183.06 t ha⁻¹, 181.73 t ha⁻¹ and 105.20 t ha⁻¹, respectively. For the Amazon forest in Southern America Laurance et al (2002), also reported as much as 397.7 t ha⁻¹ biomass accumulation. Bdoor (2018) reported 236 Mg C ha⁻¹ in Mawlong sacred forest and 158 Mg C ha⁻¹ in Ramjadong forest in Meghalaya, India whereas, Biswas et al (2020) reported tree biomass of 329.96 t ha⁻¹ in the dry deciduous Sal forest of West Bengal. Therefore, based on appx. 185 trees ha⁻¹ for this LBG studies, a biomass measure of 546.19 t ha⁻¹ is a comparatively high measure. This pattern influences carbon accumulation and carbon dioxide sequestration that are all in agreement with Pandya et al (2013), Timilsina et al (2013), Marshet (2015), Nagar and Rawat (2016), Rai and Gupta (2018) on the biophysical status of many tree communities. Earlier workers in related studies documented that healthy, large and older aged trees stands store several times more biomass and absorb more carbon from the atmosphere than young and smaller trees (Nowak et al 2001, Nowak and Crane 2002, Thornton et al 2002, Maco and McPherson 2003, Nowak and Dwyer 2007, Gough et al 2008, Escobedo et al 2010 a, b, Timilsina et al 2013). Thus, this

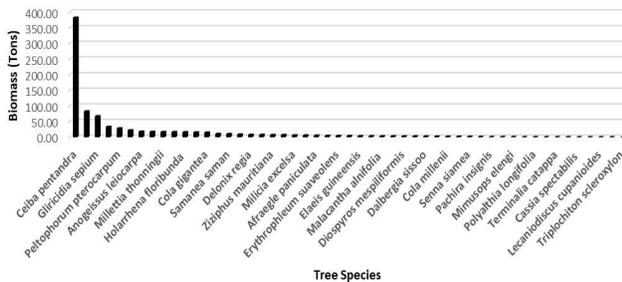


Fig. 5. Estimated biomass accumulation of tree species in the study area

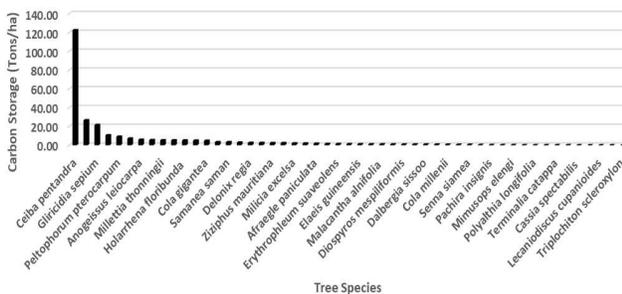


Fig. 6. Estimated total carbon storage accumulation of tree species in the study area

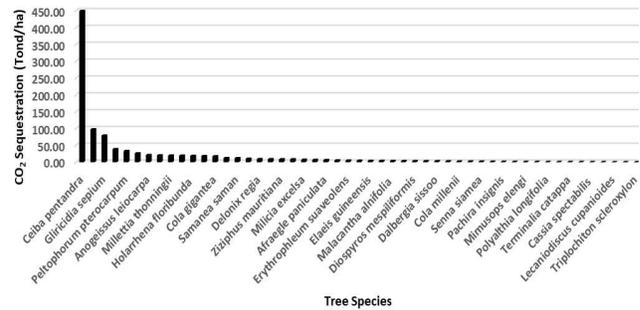


Fig. 7. Estimated total CO₂ sequestration of tree species in the study area

LBG study finding is comparative to the aforementioned (Fig. 6).

The estimated carbon storage is directly proportional to the carbon dioxide sequestered (Pearson et al 2007). Jithila and Prasad (2018) reported a significant positive relation between the tree DBH and CO₂ sequestration which supports the findings of present study. From a related urban forest studies by Nandini et al (2009) within a sampled plot of 4.49 hectares at the Jananabharathi Campus of the Bangalore University in India, an estimated amount of 11.72 tCO₂ to 505.75 tCO₂ was sequestered. In this study, the total estimated CO₂ sequestered in the LBG is 1002.25 tCO₂ in a 1.56 ha sampled plot (Fig. 7).

The potential contribution of individual trees as the major carbon sink include such tree species as *Sterculia foetida* (26.28 tCO₂ tree⁻¹) followed by *Anogeissus leiocarpa*, *Ficus religiosa*, *Tamarindus indica* and *Cola gigantea*. *Triplochiton scleroxylon* (0.02 tCO₂/tree), *Moringa oleifera* (0.06 tCO₂ tree⁻¹) and *Ficus platyphylla* (0.09 tCO₂ tree⁻¹) recorded low carbon sequestration potential. Whereas the potential contribution of some other important tree species includes *Ceiba pentandra* (1.18 tCO₂ tree⁻¹), *Antiaris toxicaria* (13.93t CO₂), *Gliricidia sepium* (2.47 tCO₂ tree⁻¹), *Peltophorum pterocarpum* (8.33 tCO₂ tree⁻¹) (Table 2).

CONCLUSION

The natural vegetation of the University of Ghana is experiencing disturbances of various magnitudes due to prevailing anthropogenic pressures. LBG foremost serves as a refugia for valuable mature woody tree species of varied sizes such as *Sterculia foetida*, *Anogeissus leiocarpa*, *Ficus religiosa*, *Tamarindus indica*, *Cola gigantean*, *Ceiba pentandra*, *Antiaris toxicaria*, *Gliricidia sepium* *Peltophorum pterocarpum*, etc. that have high potential of sequestering reasonable amounts carbon emissions from the atmosphere that must be considered. The massive tree sizes are suggestive of a long life span and have contributed

immensely to the local environment, hence must be conserved. This vegetative cover also serves to intercept heavy downpour of rain thereby preventing soil erosion along the topo gradient. In terms of prioritizing future climate change mitigation efforts, it is recommended that selection criterion of tree plant efforts by the University of Ghana Physical Development and Municipal Services Directorate (PDMSD) must be based on the ability of trees to sequester more carbon based on this research finding as a reference point. Finally, apart from the aforementioned values, the vegetation also serves as hotspot for supporting biodiversity within the coastal savanna.

REFERENCES

- Asante WA and Benefoh DT 2013. *Potential REED+ project types in off-reserved areas, Agroforestry and secondary forests in various ecological zones of Ghana*. ITTO, SECO, FC, CSIR Ghana, p 44.
- Bdoor BS 2018. Organic carbon stocks in various land-use types of karst landscape in Northeastern India, *Indian Journal of Ecology* **45**(1): 77-83.
- Bhat DM, Murali, KS and Ravindranath NH 2003. Carbon stock dynamics in the tropical rain forest of Uttara Kanada District, Western Ghats, India. *International Journal of Environment and Pollution* **19**(2): 139-149.
- Biswas S, Banerjee S and Biswas A 2020. Study on carbon sequestration potential of sal forest in dry tropics: Allometric biomass assessment approach. *Indian Journal of Ecology* **47**(4): 959-964.
- Brown S 1997. Estimating biomass and biomass change of tropical forest. *A primer FAO Forestry*, paper no. 134. Food and Agricultural Organization of the United Nation, Rome, Italy.
- Brown S, Miltner E and Cogger C 2012. Carbon Sequestration Potential in Urban Soils. In Book: *Carbon Sequestration in Urban Ecosystem*, Springer, pp. 173-196.
- Chavan BL and Rasal GB 2010. Sequestered standing carbon stock in selective tree species grown in University campus at Aurangabad, Maharashtra, India. *International Journal of Engineering Science and Technology* **2**(7): 3003-3007.
- Chavan BL and Rasal GB 2012. Carbon sequestration potential of young *Annona reticulata* and *Annona squamosa* from University campus of Aurangabad. *International Journal of Physical and Social Sciences* **2**(3): 193-198.
- Demuzere M, Orru K, Heidrich O, Olazabal E, Geneletti D, Orru H, Bhawe AJ, Mittal N, Feliu E and Faehnle M 2014. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management* **146**: 107-115.
- Escobedo FJ, Kroeger T and Wagner JE 2010b. Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. *Environmental Pollution* **159**(8-9): 2078-2087.
- Escobedo F, Varela S, Zhao M, Wagner JE and Zipperer W 2010a. Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. *Environmental Science Policy* **13**(5): 362-372.
- FAO 2010. Carbon Finance Possibilities for Agriculture, Forestry and other Land Use Projects in a Smallholder Context. *Environment and Natural Resource Management Working Paper* 34. Rom, Italy.
- Gill SE, Handley JF, Ennos AR and Pauleit S 2007. Adapting cities for climate change: the role of the green infrastructure. *Built Environment* **33**(1): 115-133.
- Gough CM, Vogel CS, Schmid HP and Curtis PS 2008. Controls on annual forest carbon storage: lessons from the past and predictions for the future. *BioScience* **58**(7): 609-622.
- HariPriya GS 2003. Carbon budget of the Indian Forest Ecosystem. *Climate Change Science* **263**: 185-190.
- IPCC 2006. *Guidelines for national greenhouse gas inventories*. Vol. 4, Agriculture, Forestry and other land use AFLOLU. Institute for Global Environmental strategies, Hayama, Japan.
- Kulkarni M, Dighe S, Sawant A, Oswal P, Sahasrabudhe K and Patwardhan A 2001. Institutions: Biodiversity hotspots in urban areas. In *Tropical Ecosystems: Structure, Diversity and Human Welfare* Oxford and IBH: New Delhi, India, 693-695.
- Jithila PJ and Prasadani PK 2018. Carbon sequestration by trees-a study in the western ghats, Wayanad Region. *Indian Journal of Ecology* **45**(3): 479-482.
- Kuma M and Shibru S 2015. Floristic composition, vegetation structure and regeneration status of the woody plant species of Oda forest of Humbo Carbon Project, Wolaita, Ethiopia. *Journal of Botany* **15**(2): 1-9.
- Laurance WF, Lovejoy TE, Vasconcelos HL, Bruna EM, Didham RK, Stouffer PC, Gascon C, Bierregaard RO, Laurance SGW and Sampaio E 2002. Ecosystem decay of Amazon forest fragments: A 22-year investigation. *Conservation Biology* **16**: 605-618.
- Losi CJ, Siccama TG, Condit R and Morales JE 2003. Analysis of alternative methods for estimating carbon stock in young tropical plantations. *Forest Ecology and Management* **184**(1-3): 355-368.
- Maco S and Mcpherson EG 2003. A practical approach to assessing structure, function and value of street tree populations in small communities. *Journal of Arboriculture* **29**(2): 84-97.
- Mahajan V, Raina NS and Gupta LM 2018. Biomass and Carbon Stocks in Agroforestry Landuse System in Sub-tropics of J&K. *Indian Journal of Ecology* **45**(2): 276-280.
- Marshet TW 2015. Carbon stock potentials of woody plant species in Bihersitige and central closed public parks of addis ababa and its contribution to climate change mitigation. *Journal of Environment and Earth Science* **5**(13): 1-14.
- Matthews E, Payne R, Rohweder M and Murray S 2000. Carbon sequestration in soil. *Global Climate Change Digest* **12**: 20-25.
- Mcpherson EG and Simpson JR 2003. Potential energy savings in buildings by an urban tree planting programme in California. *Urban Forestry Urban Greening* **2**(2): 73-86.
- Montagu KD, Duttmer K, Barton CVM and Cowie AL 2005. Developing general allometric relationships for regional estimates of carbon sequestration: An example using *Eucalyptus pilularis* from seven contrasting sites. *Forest Ecology and Management* **204**(1): 115-129.
- Mouna S, Jabeen FTZ, Dakshayini J, Haleshi C and Seetharam YN 2019. Carbon sequestration and tree diversity of Thimmalapura Reserve Forest, Tumakuru, Karnataka. *Indian Journal of Ecology* **46**(1): 116-125.
- Nagar B and Rawat S 2016. Carbon mitigation potential of biomass and soil under different density of *Eucalyptus camaldulensis* in Arid Region of India. *Indian Journal of Ecology* **43**(2): 431-435.
- Nandal A, Singh N, Yadav SS, Rao AS and Yadav VS 2019. Carbon stock assessment of selected tree species in Maharshi Dayanand University Campus, Rohtak (Haryana) India. *Indian Journal of Ecology* **46**(2): 330-334.
- Nandini N, Kumar M and Tandon S 2009. Assessment of carbon sequestration in trees of Janabharathi Campus. Bangalore University, Bangalore, India. *Ecology, Environment and Conservation* **15**(3): 503-508.
- Negi JDS, Manhas RK and Chauhan PS 2003. Carbon allocation in different components of some tree species of India: A new approach for carbon estimation. *Current Science* **85**: 101-104.
- Nowak DJ and Dwyer JF 2007. Understanding the benefits and costs of urban forest ecosystems. *Urban and Community Forestry in*

- the Northeast*. In J.E. Kuser Ed., pp. 25-46: Springer Netherlands.
- Nowak DJ and Crane DE 2002. Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution* **116**(3): 381-389.
- Nowak DJ, Crane DE, Stevens JC, Hoehn RE, Walton JT and Bond J 2008. A ground-based method of assessing urban forest structure and ecosystem services. *Arboriculture and Urban Forestry* **34**(6): 347-358.
- Nowak DJ, Noble MH, Sisinni SM and Dwyer JF 2001. People and trees: assessing the US urban forest resource. *Journal of Forestry* **99**: 37-42.
- Pandya IY, Salvi H, Chahar O and Vaghela N 2013. Quantitative analysis on carbon storage of 25 valuable tree species of Gujarat. *Indian Journal of Scientific Research* **41**: 137-141.
- Pataki DE, Carreiro MM, Cherrier J, Grulke NE, Jennings V, Pincetl S, Pouyat RV, Whitlow TH and Zipperer WC 2011. Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment* **9**(1): 27-36.
- Pearson TR, Brown SL and Birdsey RA 2007. *Measurement guidelines for the sequestration of forest carbon*. Gen. Tech. Rep. NRS-18. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station, 42 p.
- Pearson T, Walker S and Brown S 2005. *Guidebook for the formulation of afforestation and reforestation projects under the clean development mechanism*. ITTO Technical series 25.
- Rai P and Gupta B 2018. Estimation of biomass and carbon stock variations in vegetation of differently managed *Quercus leucotrichophora* forests along an elevation gradient in western Himalaya, India. *Indian Journal of Ecology* **45**(1): 100-106.
- Rega CC, Nilon CH and Warren PS 2015. Avian Abundance Patterns in Relation to the Distribution of Small Urban Greenspaces. *Journal of Urban Planning and Development* **141**(3): A4015002.
- Shannon CE 1948. A mathematical theory of communication. *The Bell System Technical Journal* **27**: 379-423.
- Sheikh MA and Kumar M 2010. Carbon sequestration potential of trees on two aspects in sub-tropical forest. *International Journal of Conservation Science* **1**(3): 143-148.
- Thornton PE, Law BE, Gholz HL, Clark KL, Falge E, Ellsworth DS and Sparks JP 2002. Modeling and measuring the effects of disturbance history and climate on carbon and water budgets in evergreen needle leaf forests. *Agricultural and Biological Research* **4**(4): 169-175.
- Timilsina N, Escobedo FJ, Cropper Jr WP, Abd-Elrahman A, Brandeis TJ, Delphin S and Lambert S 2013. A framework for identifying carbon hotspots and forest management drivers. *Journal of Environmental Management* **114**: 293-302.
- Watson C 2008. *Forest Carbon Accounting: Overview and Principles CDM Capacity Development in East and Southern Africa*, London School of Economics and Political Science, UK, pp 39.
- Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J and Lopez-Gonzalez G 2009. *Global Wood Density Database*. Dryad Identifier. <http://hdl.handle.net/10255/dryad.235>



Bio-herbicidal Potential of Essential Oil of *Callistemon* - A Review

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Abstract: *Callistemon* is an aromatic genus of family Myrtaceae. It possesses essential oil in almost all parts of the plant body. The oil is characterized by the dominance of monoterpenes viz. 1,8-cineole, α -pinene and α -terpineol. It has been reported to inhibit germination and early growth of many agricultural and wasteland weeds by altering the photosynthetic and respiratory metabolism of target plants. There are many scientific reports which confirm its antimicrobial, insecticidal, anti-inflammatory and antioxidant properties. This review discusses the morphological, physicochemical and allelopathic properties of essential oil of *Callistemon* with a view to explore its bio-herbicidal potential.

Keywords: Bio-herbicide, *Callistemon*, Essential oil, Monoterpenes, Weed management

Bio-herbicides are natural plant products derived from living organisms that suppress weed populations (Glare et al 2012, Bailey 2014). These are secondary metabolites derived from phytotoxic plant residues or microbes such as fungi, bacteria or protozoa (Souza et al 2016). Recently, Aneja et al (2017) have defined these as the formulations of host-specific plant pathogens that are applied at high inoculum rates in a similar way as chemical herbicides for the management of weeds. Chemical control of weeds started in 1944 with the discovery of 2,4-D as a landmark in herbicide usage in agroecosystems (Walia et al 2011). However, increased use of chemical herbicides has polluted the environment, adversely affected the soil microbes and caused herbicide resistance among weeds (Bhullar et al 2017). Till date, globally 514 unique cases of herbicide resistant weeds, with 262 species (152 dicots and 110 monocots) have been identified (International Survey of Herbicide Resistance Weeds 2020). Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 167 different herbicides. There are 94 crops in 71 countries suffering from continuously evolving herbicide resistant weeds (International Survey of Herbicide Resistance Weeds 2020).

In view of these facts, use of natural compounds provides a great field for the discovery of new environmentally safe herbicides, called "bioherbicides". Till date many commercial bioherbicides are available in market having essential oil as their main constituents. List of bioherbicides having essential oils as major components being used successfully in organic agriculture, have been listed below in Table 1.

Essential Oils

Essential oils (EOs) are volatile, natural compounds characterized by a strong odour and synthesized in almost all organs of aromatic plants as secondary metabolites (Bakkali et al 2008). These increase the fitness of plants and help to interact with pathogens, herbivores and symbiotic insects (Kennedy and Wightman 2011). Ecologically, they are important to attract biotic agencies for pollination and seed dispersal (Prins et al 2010). Commercially, EOs are the most important raw materials of the fragrance and aroma industry (Prins et al 2010). They are also used in the food and pharmaceutical industries due to their therapeutic, antimicrobial and antioxidant activities (Prins et al 2010).

EOs are complex mixture of chemical compounds mainly monoterpenes, diterpenes and sesquiterpenes hydrocarbons and their oxygenated derivatives. These are chemically isoprenoids having five carbon structure isopentenyl diphosphate (Bano et al 2016). The chemical composition of EOs depends on the place of origin, climatic conditions and plant species (Eslahi et al 2017). Two factors that influence the EOs composition are planting time and mineral fertilization (Eslahi et al 2017). The EOs components can be categorized into four groups defined by chemical structures namely terpenes (mono- and sesquiterpene), terpenoids (alcohols, esters, aldehydes, ketones, ethers, phenols and epoxides), phenylpropenes and sulfur or nitrogen sulfur-containing compounds (thioesters, sulfides, isothiocyanates, nitriles and others) (Burchul et al 2017). These are synthesized in the plastids and cytoplasm of plant cells via methyl-D-erythritol-4-phosphate, mevalonic acid and malonic acid pathways (Eslahi et al 2017). In this review, we

Table 1. Commercial Weed killer in market

Brand	Active Ingredients	Nature of oil	Company/ Country	Phytotoxicity on test Weed	Authors
BurnOut Weed & Grass Killer - Concentrate (Clove oil)	Citric Acid- 24%, Clove Oil- 8% and Inert ingredients 68%	Non-selective, broad spectrum	BONIDE® (BND7464) USA	<i>Stellaria media</i> , <i>Chenopodium album</i> , <i>Brassica</i> spp., <i>Oxalis</i> spp., <i>Amaranthus</i> spp., <i>Taraxacum officinale</i> , <i>Linaria vulgaris</i> , <i>Vicia cracca</i> , <i>Digitaria</i> spp., <i>Setaria</i> spp., <i>Poa annua</i> , <i>Elymus repens</i>	David Chinery (2001), Dayan et al (2009), Islam et al (2018) and Gared Shaffer (2019)
Weed Slayer Organic Herbicide (Clove oil)	Eugenol (essential oil of Clove): 6.0%, Water and Molasses: 94.0%, Bio Surfactant 35%	Non-selective, broad spectrum	ANDAMAN AG Agro Research International LLC 29203, USA	Grass and weeds	Deac Jones (2018) and Islam et al (2018)
Eco-Exempt® HC (Clove oil)	Eugenol (Clove Oil) - 24.0%, 2-Phenethyl Propionate -24.0% & Water and Lecithin - 52.0%	Non-selective, broad spectrum	HC Company, Inc. US(EcoSMART Technologies, GA)	Annual and perennial broadleaf and grass weeds.	Dayan et al (2009), Dayan & Duke (2010), Duke & Dayan (2018) and Islam et al (2018)
Eco SMART® Organic Weed & Grass killer (Clove oil)	Eugenol (5%), 2-Phenethyl Propionate (5%), Sodium lauryl sulfate (0.5%) and other ingredient (water, potassium oleate, sodium bicarbonate, lecithins)	Non-selective	Zoecon (Mfg. Number: 33122)	<i>Echinochloa crus-galli</i> , <i>Elymus repens</i> , <i>Elytrigia repens</i> and <i>Cyperus esculentus</i>	Dayan et al (2009)
Bioganic safety brands™ weed & grass killer (Clove oil +Thyme Oil)	Clove Oil (2.0%), Thyme Oil (2.0%), Sodium Lauryl Sulfate (1.0%), Acetic Acid (10.0%) and other Ingredients (85.0%)	Non-selective	Bioganic Safety Brands, Inc. 318 Seaboard Lane, Suite 202. Franklin, TN 37067	<i>Echinochloa crus-galli</i> , <i>Elymus repens</i> , <i>Elytrigia repens</i> and <i>Cyperus esculentus</i>	Dayan et al (2009, 2011)
Weed Zap (Clove oil% + Cinnamon oil)	Clove oil 45% + cinnamon oil 45%	Non-selective, post-emergent weed killer	JH Biotech, Inc., USA	<i>Amaranthus</i> spp., <i>Digitaria</i> spp. and <i>Echinochloa crus-galli</i> , <i>Phalaris canariensis</i> , <i>Chenopodium album</i> etc.	Dayan et al (2009), Dayan and Duke (2010), Duke & Dayan (2018), Islam et al (2018) and Gared Shaffer (2019)
Matran II (Clove oil% + wintergreen oil)	50% clove oil, wintergreen oil, butyl lactate, lecithin	Non-selective, post-emergent weed killer	Eco SMART Technologies, GA	<i>Amaranthus</i> spp., <i>Digitaria</i> spp. and <i>Echinochloa crus-galli</i>	Avila-Adame et al (2008), Dayan et al (2009), Dayan & Duke (2010), Islam et al (2018) and Gared Shaffer (2019)
Green Match EX™ (Lemongrass oil + Corn oil)	lemongrass oil 50% and a mixture of water, corn oil, glycerol esters, potassium oleate and lecithin	Non-selective, broad spectrum, foliar herbicide.	Marrone Organic Innovations, Inc.	<i>Amaranthus</i> spp., <i>Digitaria</i> spp. and <i>Echinochloa crus-galli</i>	Dayan et al (2009, 2011), Islam et al (2018) and Gared Shaffer (2019)
WO2009/049153 A2 (Lemongrass oil + Corn oil)	Lemongrass oil (50%), corn oil, surfactant, emulsifier	Non-selective	Marrone Organic Innovations, Inc. (us)	<i>Stellaria media</i> , Annual bluegrass and <i>Poa annua</i>	Campbellet al (2009)
Organic Weed & Grass killer™ (Citrus oil)	Citrus oil (70%)	Non-selective	(EcoSMART Technologies, GA)	All types of weeds and grasses	Dayan et al (2009)
Avenger® weed killer	Citrus oil (17.5%)	Non-selective, post-emergence herbicide	Avenger Products, LLC	<i>Amaranthus retroflexus</i> , <i>Amaranthus albus</i> , <i>Stellaria media</i> , <i>Capsella bursa-pastoris</i> , <i>Digitaria sanguinalis</i> , <i>Taraxacum officinale</i> , <i>Chenopodium album</i>	Duke and Dayan (2018)
Organic Intceptor™ (Pine oil)	Pine oil (10%)	Non-selective	Biocoat Australia Pty Ltd	<i>Echinochloa crus-galli</i> , <i>Elymus repens</i> , <i>Elytrigia repens</i> , <i>Cyperus esculentus</i>	Dayan and Duke (2010)
Weed Blitz® Organic Weed Blitz	Pine oil (13.6%)	Pre-emergent weed control.		<i>Poa annua</i> , <i>Hypochaeris radicata</i> , <i>Sporobolus africanus</i> , <i>Romulea rosea</i> , <i>Medicago polymorpha</i>	Duke and Dayan (2018)

are discussing the botanical description of various species of *Callistemon* cultivated in India, chemical composition of their essential oil and various reports related to use of essential oils in weed management.

Genus *Callistemon*

Callistemon (Myrtaceae) was first described by Robert Brown in 1814 as a genus formed of those species of *Metrosideros* that have inflorescence similar to that of *Melaleuca* and distinct elongated filaments and transferred to the genus *Callistemon* in 1913 by botanist Homer Collar Skeels from the United States Department of Agriculture, Bureau of Plant Industry Bulletin ((Maria et al 2015, Sumitra Singh and Shiva 2014). It belongs to family myrtaceae under order myrtales. Plant is a native of Australia and has approximately 34 species around the world, out of which 10 species of *Callistemon* were introduced in the National Botanical Gardens in India (Srivastava et al 2001, Ahmad and Athar 2017). Plant is represented by species that are mostly shrubs or small trees which can attain a height of 1.5 meter. The plants bear evergreen persistent foliage and brush-like flowering spikes that provide them the common name of bottlebrush (Spencer et al 1991). These are planted as a windbreak and for shelter-belts. Flowers are a good source of nectar and pollen for bees during the summers (The Wealth of India 1992).

Species of *Callistemon* in India: In India, *Callistemon* species were introduced as ornamental plants throughout the country, except in extremely dry and cool places. These mainly includes *Callistemon lanceolatus* (Crimson Bottlebrush), *C. viminalis* (Weeping Bottlebrush), *C. rigidus* (Stiff Bottlebrush), *C. linearis* (Narrow-leaved Bottlebrush) *C. macropunctatus* (Scarlet Bottlebrush), *C. phoeniceus* (Fieri Bottle brush) and *C. salignus* (White Bottlebrush) (Wealth of India 1992).

***Callistemon lanceolatus* D.C. (Syn. *Callistemon citrinus*):** It is an evergreen plant of 10-15 feet height with bright red flower spikes. Leaves are simple, lanceolate, alternate, entire, pinnate and evergreen (Gilman and Watson 1993). The tree grows in clay, sandy, acidic and well-drained soil (Maria et al 2015, Kumar et al 2020).

***Callistemon viminalis* (Sol. ex. Gaertn.) G. Don (syn. *Melaleuca viminalis*):** It is an evergreen multi-trunk tree of 4-8 m height and 3-5 m width with pendulous branches. Flowers with bright red spikes and stamens fused into a ring at the base with persistent woody capsules (Australian Plants Society North Shore Group 2013). Leaves are light green, lanceolate, up to 7 cm long. Species have high tolerance for drought and low soil oxygen (Australian Plants Society North Shore Group 2013).

***Callistemon rigidus* R. Br.:** It is stiff shrub which grows up to

the height of 3 m approximately. Leaves are 5-7 cm long, 3-4 mm wide, with thickened margins. The spikes are up to 10 cm long with dark anthers. Fruits are globular about 7 mm in diameter with a narrow aperture (Islaki et al 2002, Australian Plants Society North Shore Group 2013).

***Callistemon linearis* (Schrad. & J.C. Wendl.):** It is a narrow leaved *Callistemon* which favors rocky, riverside and wet sandy soils. It grows as open spreading shrub up to 3 m long. Leaves are sharply pointed, rigid, up to 12 cm long and less than 1-3 mm wide. Spikes are up to 11 cm long. Capsules are depressed globular, about 8 mm in diameter (Brophy et al 2012, Australian Plants Society North Shore Group 2013).

***Callistemon macropunctatus* (Dum. Cours.) Court (syn. *Callistemon rugulosus*):** It is a shrub growing to 5 m height with an open, straggling habit with grey bark. Leaves are arranged alternately and are 3-8 cm long, 2.5-8.5 mm wide, flat, thick, rigid, narrow elliptic to egg-shaped with the narrower end near the base. The stamens are rosy-red with yellow anthers. The young leaves and branches are often covered with dense, silky hairs. (Maurya et al 2009, Brophy et al 2012).

***Callistemon phoeniceus* Lindl.:** It is a large bushy shrub growing to 3 m height with a spread of about 2 m. The rich scarlet flower brushes, 10-5 cm long, are dark tipped and borne terminally on the slender stems. The narrow leaves, 3-7 cm long, are thick and rigid, tipped with a short spine. Their blue-green colour provides a striking contrast to the brilliant coloration of the flowers (Brophy et al 2012).

***Callistemon salignus* (Smith) Colvill ex Sweet:** It is a small tree of height 10 m, with pendulous branches and papery bark. Leaves are narrow-elliptical, soft, 6-9 cm long, 5-14 mm wide with creamy-yellow spikes up to 5 cm long. Capsules are about 5 mm wide in diameter. The tree is further ornamented with bright pink new foliage growth and creamy-white bottle-brush flowers (Brophy et al 1998 and Australian Plants Society North Shore Group 2013).

Essential Oil Composition of *Callistemon* Species in India

Many researchers have reported composition of essential oil of *Callistemon* species analysed through GC-MS. Information related to major components has been provided here as follows:

***Callistemon lanceolatus* D.C. (Syn. *Callistemon citrinus*):** The chemical composition of essential oil from leaves of *C. lanceolatus* revealed that 1,8- cineole, α -terpineol, terpine-4-ol, eugenol, α -pinene, limonene, β -pinene, thujene, linalyl acetate, p-cymene, α -phellandrene and (E)-caryophyllene are the most commonly identified compounds (Oyedegi et al 2009, Abdelhady et al 2012, Sohani et al 2013, Kumar et al 2015, Shrestha et al 2015, Larayetan et al 2017). Most of researchers have

reported that EO of *C. lanceolatus* is dominated by oxygenated monoterpenes (Abdelhady et al 2012, Jamzad et al 2014, Shrestha et al 2015, Aweke and Yeshanew 2016, Larayetan et al 2017, Gad et al 2019). However, Kumar et al (2015) have reported higher amount of monoterpene hydrocarbons (52.1%) and sesquiterpenoids (14%) predominated by α -pinene (32.3%), limonene (13.1%) and α -terpineol (14.6%) in essential oil extracted from leaves. From literature review, it could be concluded that chemical composition of EO of *C. lanceolatus* vary from place to place (Table 2). It can be distinguished into chemical forms namely (i) oil with abundance of monoterpene hydrocarbons from Western Himalayas region (Kumar et al 2015), (ii) oils with abundance of oxygenated monoterpenes from South Africa, Iran, lower region of Himalayas and other parts (Srivastava 2003, Oyedeji et al 2009, Sohani et al 2012, Jamzad et al 2015, Larayetan et al 2017, Gad et al 2019).

***Callistemon viminalis* (Sol. ex. Gaertn.) G. Don (syn. *Melaleuca viminalis*):** The chemical composition of EO oil of *C. viminalis* from leaves revealed the presence of 1,8-cineole, α -pinene, β -pinene, trans-geraniol, D-limonene, α -terpineol, myrcene, p-cymene, γ -terpinene, terpinolene, transpinocarveol, borneol, α -humulene, alloaromadendrene, spathulenol, 2-methylpropyl isobutyrate, globulol, ocimanol, eugenol, isoamylacetate, ocimene, 2-methylpropylisobutyrate and linalool (Ndomo et al 2010, Gohar et al 2014, Vishwakarma et al 2017, Fall et al 2017, Ahmad and Athar 2017). Major composition of the oil from the leaves of *C. viminalis* species showed 1, 8-cineole (eucalyptol) as the main component (Ndomo et al 2010). Pino et al (2010), Silva et al (2010), Gohar et al (2014), Vishwakarma et al (2017), Fall et al (2017), Bali et al (2017) and Gad et al (2019) have reported that 1,8-cineole content was higher in South Africa and Egypt samples than the Equatorial region samples collected from India, Cameroon and Australia. However, α -Pinene (31.4%) was found as a major component in EO of species found in the southern parts of Australia (Brophy et al 1997) and Pakistan (Siddique et al 2017). The difference in composition of essential oil could be attributed to environmental factors i.e. latitude, geographical distribution, etc. (Ahmad and Athar 2017).

***Callistemon rigidus* R. Br.:** The chemical composition of essential oil of *C. rigidus* revealed the presence of 1, 8-cineole, α -pinene, β -pinene, α -thujene, limonene, terpineol, myrcene, eugenol (Jazet et al 2009, Gad et al 2019). Oxygenated monoterpenes dominated EO composition with 1, 8-cineole as a major component (Brophy et al 1998, Jazet et al 2009, Gad et al 2019).

***Callistemon linearis* (Schrad. & J.C. Wendl.):** The chemical composition of essential oil of *C. linearis* from

Table 2. Major components of volatile oil of *Callistemon* species from various parts of the world

Origin	Major components	Reference
<i>C. lanceolatus</i>		
Egypt	Eucalyptol (81.63%) Linalool (7.61%) α -Terpineol (2.84%)	Gad et al (2019)
Ethiopia	1,8- Cineole (76.9%) α -Terpineol (15.3%) Terpinen-4-ol (1.9%) 2-Methylbutyl Isobutyrate (1.2%)	Aweke and Yeshanew (2016)
Iran	Eucalyptol (67.60%) α -Pinene (9.40%) β -Pinene (4.70%)	Jamzad et al (2015)
Iran	Eucalyptol (34.20%) α -Pinene (29.0%) α -Terpineol (16.70%) α -Phellandrene (9.0%)	Sohani et al (2013)
Lower Region of Himalaya	Eucalyptol (66.30%) α -Pinene (18.70%)	Srivastava et al (2003)
South Africa	Eucalyptol (48.98%) α -Pinene (20.02%) α -Terpineol (8.10%)	Larayetan et al (2017)
South Africa	Eucalyptol (61.20%) α -Pinene (13.40%) β -Pinene (4.70%)	Oyedeji et al (2009)
Western Himalayas	α -Pinene (32.30%) Limonene (13.1%) α -Terpineol (14.6%)	Kumar et al (2015)
<i>C. viminalis</i>		
Brazil	1,8-Cineole (65%) α -Terpineol (13.0%) α -Pinene (12.0%)	Silva et al (2010)
Cameroon (Western highlands)	1,8-Cineole (58.49%) 3-Carene (8.61%) α -Terpinol (7.83%) Limonene (7.01%)	Ndomo et al (2010)
Colombia	1,8-Cineole (39.4%) α -Pinene (8.9%) α -Phellandrene (8.6%) α -Terpineol (6.1%)	Pino et al (2010)
Egypt	1,8-Cineole (66.3%) α -Pinene (20.43%) α -Terpineol (6.65%)	Gohar et al (2014)
India (Bathinda)	1,8-cineole (64.5%) α -Terpineol (19.7%) + (-)-Limonene (4.7%) Trans-geraniol (2.0%) Linalool (1.43%)	Vishwakarma et al (2017)
India	1,8-Cineole (64%) α -Pinene (17%) α -Terpineol (10%)	Bali et al (2017)
South Africa	1,8-Cineole (83.2%) α -Pinene (6.4%) α -Terpineol (4.9%)	Ahmad and Athar (2017)
West Africa (Dakar, Senegal)	1,8-Cineole (58.12%) Limonene (9.72%) α -Terpineol (9.56%) Geraniol (6.02%) δ -Elemene (3.53%) Myrcene (2.96%) α -Pinene (2.49%)	Fall et al (2017)

Cont...

Table 2. Major components of volatile oil of *Callistemon* species from various parts of the world

Origin	Major components	Reference
<i>C. rigidus</i>		
Australia	1,8-Cineole (62.4%) α-Terpineol (13.0%) Limonene (7.7%) α-Pinene (6.6%)	Brophy et al (1998)
Cameroon	1,8-cineole (79.1%), α-Pinene (12.9%) α-Terpineol (4.1%)	Jazet et al (2009)
Egypt	Eucalyptol (80%) α-Pinene (9.18%) α-Terpineol (5.69%)	Gad et al (2019)
<i>C. linearis</i>		
Australia	1,8-Cineole (61.9%) β-Caryophyllene (29%) Limonene (8.1%) α-Pinene (7.3%)	Brophy et al (1998)
India	1,8-cineole (58.3%) γ-Terpinene (25.3%) 3-Carene (10.7%) n-Dec-3-ene (5.4%)	Daset al (2009)
<i>C. macropunctatus</i>		
India (Northern plains)	1,8-Cineole (74.7%) α-Pinene (8.5%) (E)-β-terpineol (11.4%),	Mauya et al (2009)
<i>C. phoeniceus</i>		
Australia	1,8-Cineole (74%) α-Terpineol (4.3%) Limonene (3.5%) β-Pinene (1.3%)	Brophy et al (1998)
<i>C. salignus</i>		
South Africa Zululand, KwaDlangezwa campus (Sample A)	1,8-Cineole (63.4%) α-Pinene (17.8%) E-(b)-Ocimene (6.7%)	Oyedjeji et al (2010)
Empangeni (Sample B)	1,8-Cineole (85.4%) α-Pinene (6.2%) Terpinen-4-ol (1.5%)	
Johannesburg (Sample C)	1,8-Cineole (44.4%) α-Pinene (27.8%) α-Terpineol (6.8%)	

leaves revealed the presence of 1,8-cineole, γ-terpinene, sabinene, limonene, myrcene, β-pinene, α-phellandrene, α-terpineol, 3-carene and n-dec-3-ene. Like other species, EO of *Callistemon linearis* also had 1,8-cineole as a major component (Brophy et al 1998, Das et al 2009).

***Callistemon macropunctatus* (Dum.Cours.) Court syn.**

***Callistemon rugulosus*:** Qualitative analysis revealed that the presence of 1,8-cineole, terpineol, α-pinene, camphene, β-myrcene, terpinolene, linalool caryophyllene oxide and viridiflorene (Mauya et al 2009) in EO of *Callistemon macropunctatus*. The leaf oil from the northern plains of India had a higher content of 1,8-cineole but a lower content of α-pinene and isobutyl acetate.

***Callistemon phoeniceus* Lindl.:** Chemical components of essential of *C. phoeniceus* were reported by Brophy et al (1998). 1,8-cineole, α-pinene, α-terpineol, β-pinene, linalool, α-phellandrene were detected in EO of its leaves and 1-8 cineole was the major component.

***Callistemon salignus* (Smith) Colvill ex Sweet:** The chemical components reported in EO of *C. salignus* were 1,8-cineole, α-pinene, α-terpineol, limonene, linalool etc. out of which 1,8-cineole was maximum in percentage (Oyedjeji et al 2010). Various reports on chemical composition of EO of *Callistemon* species found that 1, 8-cineol as the most abundant monoterpene. The composition was species specific however, geographical and environmental factors has been reported as the major regulators of variation in composition shown in Table 2.

Use of Essential Oil in Weed Management

Weeds are unwanted plants which interfere with the growth and nutritional resources of crop and thus adversely affect human welfare (Rao 2000). Overall, weeds produce the highest potential loss (34%), with animal pests and pathogens being less important (losses of 18 and 16%) (Oerke 2006). From the beginning of agriculture, weed management has depended on crop rotation, soil cultivation and seed cleaning (Radicetti 2012). The problem with conventional methods of weed control is the requirement of more frequent treatments than chemical weed management (RASK and Kristoffersen 2004). The development of new herbicides had been progressing steadily since 1900. However, the discovery of the weed killing properties of the phenoxy acetic herbicides in Britain and the United States during 1942 to 1944 marked the real beginning of the herbicide phase of the Chemical Era of Agriculture (Timmons 2005). Peterson (1967) presented the complete story of 2,4-D beginning in 1935 with related growth regulating chemicals. Hence, the use of chemical herbicides gained popularity in 1943 after the discovery of DDT by Paul Muller. Since then synthetic herbicides are being used widely in agriculture and wastelands for weed management. However, their use is posing threat to environment and human health and is also enhancing herbicidal resistance among many weed species (Grichi et al 2016).

Therefore, agricultural scientists are looking for environment friendly options of weed control viz. natural plant products examples triketone herbicides and *p*-hydroxyphenylpyruvate dioxygenase (*Callistemon* spp. and *Leptospermum scoparium*), cineole herbicide (essential oils), benzoxazoline (grass species e.g. wheat, rye and maize), sarmentine and fatty acids (*Piper longum* L.) and citral & microtubules (*Cymbopogon citratus* Stapf.) (Dayan et al 2012). Amongst these, essential oils have been reported

Table 3. Literature review depicting herbicidal potential of essential oils present in *Callistemon* sp.

Species	Target weed	Organs	Allelochemicals	References
<i>Callistemon viminalis</i> (Sol. ex. Gaertn.) G. Don.	<i>Echinochloa crus-galli</i> (L.) Beauv., <i>Amaranthus viridis</i> L. and <i>Phalaris minor</i> Retz.	Leaves	1, 8-cineol, α -terpineol, linalool and limonene, trans-geraniol	Vishwakarma et al (2017)
<i>Callistemon viminalis</i> (Sol. ex. Gaertn.) G. Don.	<i>Bidens pilosa</i> Linn., <i>Cassia occidentalis</i> L., <i>Echinochloa crus-galli</i> (L.) P.Beauv. and <i>Phalaris minor</i> Retz.	Leaves	1, 8-cineol and α -pinene	Bali et al (2017)
<i>Callistemon lanceolatus</i> DC	<i>Echinochloa crus-galli</i> (L.) P.Beauv.	leaves	1,8-cineole, α -pinene and α -terpineol	Bunkoed et al (2017)
<i>Callistemon viminalis</i> (Sol. ex. Gaertn.) G. Don.	<i>Lactuca sativa</i> L.	Flowers	1,8-cineole, α -pinene, methyl acetate and α -terpineol	Ahmad and Athar(2017)
<i>Callistemon viminalis</i> (Sol. ex. Gaertn.) G. Don	<i>Ageratum conyzoides</i> L., <i>Sorghum halepense</i> (L.) Pers, <i>Leptochloa chinensis</i> (L.) Nees. and <i>Commelina benghalensis</i> L.	Leaves	1, 8-cineol and α -pinene	Bali et al (2016)
<i>Callistemon viminalis</i> (Sol. ex. Gaertn.) G. Don.	<i>Lactuca sativa</i> L	Flowers	1, 8-cineole, α -pinene and limonene	Oliveira et al (2014)
<i>Callistemon citrinus</i> L. and <i>Cymbopogon citratus</i> (DC) Stapf	<i>Alternaria padwickii</i> (Ganguly)M.B. Ellis and <i>Bipolaris oryzae</i> (Breda de Haan) Shoemaker	-	-	Nguefack et al (2013)
<i>Callistemon viminalis</i> (Sol. ex. Gaertn.) G. Don.	<i>Silybum marianum</i> L.	Aerial parts	1, 8-cineole	Saad and Abdelgaleil et al (2014)
<i>Callistemon citrinus</i> L.	<i>Arabidopsis thaliana</i> (L.) Heynh., <i>Xanthium strumarium</i> L., <i>Abutilon theophrasti</i> (L.) Medic., <i>Ambrosia trifida</i> L., <i>Chenopodium album</i> L., <i>Amaranthus retroflexus</i> L. and <i>Echinochloa crus-galli</i> (L.) P. Beauv.	-	Mesotrione	Mitchell et al (2001)

quite promising as bioherbicides (Amri et al 2013). Volatile essential oils have attracted much consideration due to their rich phytochemistry, allelopathic properties and relatively quicker degradation in the environment (Singh et al 2003 Dayan et al 2009, Grichi et al 2016). The first ever report of use of EO in weed management appeared in 1965 by Muller (1965). He reported phytotoxic effects of *Salvia leucophylla* essential oil on seedling growth in radicles and hypocotyls of germinating *Cucumis sativus* seeds.

Nowadays, natural plant products are receiving attention as potential bioherbicides for weed management owing to their allelopathic properties. Natural phytotoxins are also a source of discovery of new herbicide target sites that can serve as the focus of traditional herbicide discovery (Dayan et al 2012). Among different natural plant products, allelochemicals are being explored as an important tool in weed management because of their structural and chemical diversity (Singh et al 2003, Dayan et al 2009). It is primarily because these plants-based products are environmentally safer, biodegradable, possess low mammalian toxicity than the synthetic. Various reports related to herbicides which are expensive too (Dayan et al 2012). Bio-herbicide potential of essential oils of *Callistemon* sp. against weeds have been listed in Table 3.

CONCLUSION

The present review describes the bio-herbicide potential of essential oil of *Callistemon* sp. against weeds. *Callistemon* EO is characterized by the dominance of 1, 8-cineole, α -pinene and α -terpineol which shows maximum phytotoxicity against weeds. EO of *Callistemon* reported to have the bio-herbicide potential against different weeds viz. *Ageratum conyzoides*, *Sorghum halepense*, *Leptochloa chinensis*, *Commelina benghalensis*, *Amaranthus viridis*, *Echinochloa crus-galli* and *Phalaris minor*. They have strong inhibitory effects on germination and seedling growth of weeds and can be used for manufacturing the products for weed control. Several studies have reported the phytotoxicity of essential oils among the most widely found weeds. In general, the results showed that oxygenated monoterpenes as well as aromatic compounds are responsible for the main phytotoxic effects. Bioherbicide technology could be used as a component in integrated weed management strategies to help avoiding herbicide resistance, reduce production costs and increase crop yield in organic horticulture. While there have been significant efforts to develop bioherbicides, few have been registered for use. Future research should focus on the development of more cost-effective and efficient

bioherbicides from *Callistemon sp.*, as well as the optimization of their use in production systems.

REFERENCES

- Abdelhady MI, Motaal AA and Beerhues L 2011. Total phenolic content and antioxidant activity of standardized extracts from leaves and cell cultures of three *Callistemon* species. *American Journal of Plant Sciences* **2**(6): 847.
- Ahmad K and Athar F 2017. Phytochemistry and pharmacology of *Callistemon viminalis* (Myrtaceae): A review. *The Natural Products Journal* **7**(3): 166-175.
- Amri I, Hamrouni L, Hanana M and Jamoussi B 2013. Reviews on phytotoxic effects of essential oils and their individual components: new approach for weeds management. *International Journal of Applied Biology and Pharmaceutical Technology* **4**(1): 96-114.
- Aneja KR, Khan SA and Aneja A 2017. Bioherbicides: strategies, challenges and prospects, pp. 449-470. In: Satyanarayana U, Deshmukh S K and Johri B N (eds). *Developments in Fungal Biology and Applied Mycology*. Springer, Singapore
- Anonymous 1992. *The Wealth of India*, Raw Materials and Industrial Products, CSIR, New Delhi, India, Vol- 3, pp 63-66.
- Australian National Botanic Gardens and Centre for Australian National Biodiversity Research, Canberra.
- Australian Plants Society NORTH SHORE GROUP <https://www.scribd.com/document/372132019/Topic-29-Callistemons-2013>.
- Avila-Adame C, Fernandez L, Campbell B, Tan E, Koivunen M and Marrone P 2008. Field evaluation of Green Match EX: A new broad spectrum organic herbicide pp.129. In: Proceedings of the 60th Conference of the California Weed Science Society, January 28-30, 2008, California, USA.
- Aweke N and Yeshanew S 2016. Chemical composition and antibacterial activity of essential oil of *Callistemon citrinus* from Ethiopia. *European Journal of Medicinal Plants* **21**: 1-7.
- Bailey KL 2014. The bioherbicide approach to weed control using plant pathogens, pp. 245-266. In: Dharam PA (eds). *Integrated Pest Management*. Academic Press, Canada.
- Bakkali F, Averbeck S, Averbeck D and Idaomar M 2008. Biological effects of essential oils: A review. *Food and Chemical Toxicology* **46**(2): 446-475.
- Bali AS, Batish DR and Singh HP 2016. Phytotoxicity of *Callistemon viminalis* essential oil against some weeds. *Annals of Plant Sciences* **5**(10): 1442-1445.
- Bali AS, Batish DR, Singh HP, Kaur S and Kohli RK 2017. Chemical characterization and phytotoxicity of foliar volatiles and essential oil of *Callistemon viminalis*. *Journal of Essential Oil-Bearing Plants* **20**(2): 535-545.
- Bano U, Khan AF, Mujeeb F, Maurya N, Tabassum H, Siddiqui MH, Haneef M, Osama K and Farooqui A. 2016. Effect of plant growth regulators on essential oil yield in aromatic plants. *Journal of Chemical and Pharmaceutical Research* **8**(7): 733-739.
- Brophy JJ, Craven LA, Forster PI, Goldsack RJ and Lepschi BJ 2012. The leaf essential oil of the Australian members of the genus *Callistemon* (Myrtaceae), *Journal of Essential Oil Research* **10**(6): 595-606.
- Brophy JJ, Forster PI, Goldsack RJ, Hibbert DB and Punruckvong A 1997. Variation in *Callistemon viminalis* (Myrtaceae): New evidence from leaf essential oils. *Australian Systematic Botany* **10**(1): 1-13.
- Brophy JJ, Goldsack RJ, Forster PI, Craven LA and Lepschi BJ 1998. The leaf essential oils of the Australian members of the genus *Callistemon* (Myrtaceae). *Journal of Essential Oil Research* **10**(6): 595-606.
- Bunkoed W, Wichittrakarn P and Laosinwattana C 2017. Allelopathic potential of essential oil from bottle brush (*Callistemon lanceolatus* DC.) on the germination and growth of *Echinochloa crus-galli* L. *International Journal of Agricultural Technology* **13**(7.3): 2693-2701.
- Burcul F, Blazevic I, Radan M and Politeo O 2017. Terpenes, phenylpropanoids, sulfur and other essential oil constituents as inhibitors of cholinesterases. *Current Medicinal Chemistry*, pp. 1-54.
- Chinery D 2001. Evaluation of acetic acid-based herbicides for use in broad-spectrum turfgrass and weed control. *New York State IPM Program*
- Das A, Zaman K and Singh AV 2009. Phytochemical and chemical composition evaluation of volatile oil of *Callistemon linearis* DC leaf. *Advances in Natural and Applied Sciences* **3**(1): 56-60.
- Dayan FE and Duke SO 2010. Natural products for weed management in organic farming in the USA. *Outlooks on Pest Management* **21**(4): 156-160.
- Dayan FE, Cantrell CL and Duke SO 2009. Natural products in crop protection. *Bioorganic and Medicinal Chemistry* **17**(12): 4022-4034.
- Dayan FE, Howell JL, Marais JP, Ferreira D and Koivunen M 2011. Manuka oil, a natural herbicide with preemergence activity. *Weed Science* **59**(4): 464-469.
- Dayan FE, Owens DK and Duke SO 2012. Rationale for a natural products approach to herbicide discovery. *Pest management Science* **68**(4): 519-528.
- de Oliveira CM, das Graças Cardoso M, da Silva Figueiredo AC, de Carvalho ML, de Miranda CA, Albuquerque LR, Nelson DL, de Souza Gomes M, Silva LF, de Andrade Santiago J and Teixeira ML 2014. Chemical composition and allelopathic activity of the essential oil from *Callistemon viminalis* (Myrtaceae) blossoms on lettuce (*Lactuca sativa* L.) seedlings. *American Journal of Plant Sciences* **5**(24): 3551.
- Deac Jones 2018. Weed Slayer Organic Herbicide. *Agro Research International* <https://andaman-ag.com/products/weed-slayer-organic-herbicide>.
- Duke SO, Owens DK and Dayan FE 2018. Natural product-based chemical herbicides, pp. 153-165. In: Korres NE, Burgos NR and Duke SO (Eds). *Weed Control: Sustainability, Hazards and Risks in Cropping Systems Worldwide*. Taylor and Francis, USA.
- Eslahi H, Fahimi N and Sardarian AR 2017. Chemical composition of essential oils, pp. 119-171. In: Hashemi SMB, Khaneghah AM and Sant'Ana ADS (eds). *Essential Oils in Food Processing: Chemistry, Safety and Applications*. Wiley Blackwell, UK.
- Fall R, Ngom S, Sall D, Sembène M and Samb A 2017. Chemical characterization of essential oil from the leaves of *Callistemon viminalis* (DR) and *Melaleuca leucadendron* (Linn.). *Asian Pacific Journal of Tropical Biomedicine* **7**(4): 347-351.
- Fernandez L, Campbell B, Huang H, Koivunen M and Marrone PG 2009. Marrone Organic Innovations Inc, assignee. Natural herbicide containing lemongrass essential oil. *United States patent application US 12/249,312*.
- Gad HA, Ayoub IM and Wink M 2019. Phytochemical profiling and seasonal variation of essential oils of three *Callistemon* species cultivated in Egypt. *PLoS ONE* **14**(7): e0219571.
- Gared Shaffer 2019. SDSU Extension. <https://extension.sdstate.edu/organic-herbicides>
- Gilman EF and Watson DG 1993. *Callistemon citrinus*: Red Bottlebrush. *Fac Sheet ENH269*. University of Florida.
- Glare T, Caradus J, Gelernter W, Jackson T, Keyhani N, Kohl J, Marrone P, Morin L and Stewart A 2012. Have biopesticides come of age? *Trends in Biotechnology* **30**(5): 250-258.
- Gohar AA, Maatooq GT, Gadara SR and Aboelmaaty WS 2014. The profile and antimicrobial activity of the essential oil from *Callistemon viminalis* (Sol. Ex Gaertner) G. Don Ex Loudon leaves. *E3 Journal of Biotechnology and Pharmaceutical Research* **12**(1): 7-11.

- Grichi A, Nasr Z and Khouja ML 2016. Phytotoxic effects of essential oil from *Eucalyptus lehmannii* against weeds and its possible use as a bioherbicide. *Bulletin of Environment, Pharmacology and Life Sciences* **5**: 17-23.
- Heap I 2020. The International Herbicide-Resistant Weed Database. <https://www.anbg.gov.au/gnp/gnp9/callistemon-phoeniceus.html>.
- Islaki AO, Nureni OO, Adeleke AK, Ekundayo O and Wilfred AK 2002. Essential oil of the leaves of *Callistemon rigidus*. *Journal of Essential Oil-Bearing Plants* **5**(2): 55-59.
- Islam AM, Yeasmin S, Qasem JRS, Juraimi AS and Anwar MP 2018. Allelopathy of medicinal plants: current status and future prospects in weed management. *Agricultural Sciences* **9**(12): 1569-1588.
- Jamzad M, Kazembakloo A, Tehrani AD and Rostami F 2015. Essential oil composition and antioxidant activity of hydromethanolic extract from the flowers, leaves and stems of *Callistemon citrinus* (Curtis) Skeels. *Indian Journal of Natural Products and Resources (IJNPR) [Formerly Natural Product Radiance (NPR)]* **5**(4): 308-312.
- Jazet PM, Tatsadjieu LN, Ndongson BD, Kuete J, Zollo PH and Menut C 2009. Correlation between chemical composition and antifungal properties of essential oils of *Callistemon rigidus* and *Callistemon citrinus* of Cameroon against *Phaeoramularia angolensis*. *Journal of Medicinal Plants Research* **3**(1): 009-015.
- Kennedy DO and Wightman EL 2011. Herbal extracts and phytochemicals: plant secondary metabolites and the enhancement of human brain function. *Advances in Nutrition* **2**(1): 32-50.
- Kumar D, Sukapaka M, Babu GK and Padwad Y 2015. Chemical composition and in vitro cytotoxicity of essential oils from leaves and flowers of *Callistemon citrinus* from western Himalayas. *PLoS ONE* **10**(8): e0133823.
- Kumar R, Gupta A, Singh AK, Bishayee A and Pandey AK 2020. The antioxidant and antihyperglycemic activities of bottlebrush plant (*Callistemon lanceolatus*) stem extracts. *Medicines* **7**(3): 11-17.
- Larayetan RA, Okoh OO, Sadimenko A and Okoh AI 2017. Terpene constituents of the aerial parts, phenolic content, antibacterial potential, free radical scavenging and antioxidant activity of *Callistemon citrinus* (Curtis) Skeels (Myrtaceae) from Eastern Cape Province of South Africa. *BMC Complementary and Alternative Medicine* **17**(1): 292.
- Maria S, Kuppast IJ, Virupaksha JH, Vanajakshi M and Prasad K 2015. Glossary of *Callistemon lanceolatus* DC: An ornamental plant with Marvellous Properties. *Research Journal of Pharmacology and Pharmacodynamics* **7**(4): 165-170.
- Maurya A, Shrivastava K, Gupta S, Srivastava SK, Luqman S, Saxena M, Kumar A, Syamsundar KV, Darokar MP, Ram T and Gupta S 2009. Antimicrobial activity and chemical composition of *Callistemon macropunctatus* leaf essential oil from the northern plains of India. *International Journal of Essential Oil Therapeutics* **3**: 9-12.
- Mitchell G, Bartlett DW, Fraser TE, Hawkes TR, Holt DC, Townson JK and Wichert RA 2001. Mesotrione: A new selective herbicide for use in maize. *Pest Management Science: formerly Pesticide Science* **57**(2): 120-128.
- Muller WH 1965. Volatile materials produced by *Salvia leucophylla*: Effects on seedling growth and soil bacteria. *Botanical Gazette* **126**(3): 195-200.
- Ndomo AF, Tapondjou LA, Ngamo LT and Hance T 2010. Insecticidal activities of essential oil of *Callistemon viminalis* applied as fumigant and powder against two bruchids. *Journal of Applied Entomology* **134**(4): 333-341.
- Nguefack J, Wulff G E, Dongmo J B, Fouelefack F R, Fotio D, Mbo J and Torp J 2013. Effect of plant extracts and an essential oil on the control of brown spot disease, tillering, number of panicles and yield increase in rice. *European Journal of Plant Pathology* **137**(4): 871-882.
- Orke EC 2006. Crop losses to pests. *The Journal of Agricultural Science* **144**(1): 31-43.
- Oyedeki OO, Lawal O, Shode F and Oyedeki A 2009. Chemical composition and antibacterial activity of the essential oils of *Callistemon citrinus* and *Callistemon viminalis* from South Africa. *Molecules* **14**(6): 1990-1998.
- Oyedeki OO, Oyedeki AO, Shode FO and Lawal OA 2010. Volatile constituents of the leaf oils of *Callistemon salignus* from two provinces in South Africa. *Journal of Essential Oil Research* **22**(6): 613-615.
- Peterson GE 1967. The discovery and development of 2, 4-D. *Agricultural History* **41**(3): 243-254.
- Prins CL, Vieira IJ and Freitas SP 2010. Growth regulators and essential oil production. *Brazilian Journal of Plant Physiology* **22**(2): 91-102.
- Quijano-Celis C, Gaviria M and Vanegas-Lopez C and Pino JA 2010. Chemical composition and antibacterial activity of the essential oil of *Callistemon viminalis* (Gaertn.) G. Don leaves from Colombia. *Journal of Essential Oil-Bearing Plants* **13**(6): 710-716.
- Radicetti E 2012. *Ecological weed management* Ph.D. Dissertation, Tuscia University, Viterbo (VT), Italy.
- Rao VS 2000. *Principles of Weed Science*. CRC Press.
- Rask AM and Kristoffersen P 2007. A review of non-chemical weed control on hard surfaces. *Weed Research* **47**(5): 370-380.
- Saad MM and Abdelgaleil SA 2014. Allelopathic potential of essential oils isolated from aromatic plants on *Silybum marianum* L. *Global Advanced Research Journal of Agricultural Science* **3**(9): 289-297.
- Shrestha S, Poudel A, Satyal P, Dosoky NS, Chhetri BK and Setzer WN 2015. Chemical composition and biological activity of the leaf essential oil of *Callistemon citrinus* from Nepal. *American Journal of Essential Oils and Natural Products* **2**(5): 29-33.
- Siddique S, Parveen Z, Firdaus-e-Bareen, Mazhar S, Chaudhary MN and Saeed K 2017. Chemical composition, antioxidant and antimicrobial activities of essential oil from *Callistemon viminalis* (Gaertn.) G. Don leaves. *Journal of Essential Oil-Bearing Plants* **20**(2): 524-534.
- Silva CJ, Barbosa LC, Demuner AJ, Montanari RM, Pinheiro AL, Dias I and Andrade NJ 2010. Chemical composition and antibacterial activities from the essential oils of Myrtaceae species planted in Brazil. *Quimica Nova* **33**(1): 104-108.
- Singh HP, Batish DR and Kohli RK 2003. Allelopathic interactions and allelochemicals: New possibilities for sustainable weed management. *Critical Reviews in Plant Sciences* **22**(3-4): 239-311.
- Singh M, Bhullar MS and Chauhan BS 2017. Relative time of weed and crop emergence is crucial for managing weed seed production: A study under an aerobic rice system. *Crop Protection* **99**: 33-38.
- Souza ARCD, Baldoni DB, Lima J, Porto V, Marcuz C, Machado C, Ferraz RC, Kuhn RC, Jacques RJ, Guedes JV and Mazutti MA 2017. Selection, isolation, and identification of fungi for bioherbicide production. *Brazilian Journal of Microbiology* **48**(1): 101-108.
- Spencer RD and Lumley PF 1991. *Callistemon*. *Flora of New South Wales* **2**: 168-173.
- Srivastava SK, Ahmad A, Syamsunder KV, Aggarwal KK and Khanuja SP 2003. Essential oil composition of *Callistemon viminalis* leaves from India. *Flavour and Fragrance Journal* **18**(5): 361-363.
- Sumitra S 2014. Genus *Callistemon*: an update review. *World Journal of Pharmacy and Pharmaceutical Sciences* **3**(7): 291-307.
- Timmons FL 2005. A history of weed control in the United States and Canada. *Weed Science* **53**(6): 748-761.
- Vishwakarma GS, Sharma S and Mittal S 2017. Herbicidal potential of *Callistemon viminalis* Essential oil against *Echinochloa crus-*

- galli* L., *Amaranthus viridis* and *Phalaris minor*. *Current Agriculture Research Journal* **5**(3): 312-317.
- Walia US, Walia SS, Kler DS and Singh D 2011. *Science of Agronomy*. Scientific Publishers, Jodhpur, India.
- Zandi-Sohani N, Hojjati M and Carbonell-Barrachina AA 2012. Volatile composition of the essential oil of *Callistemon citrinus* leaves from Iran. *Journal of Essential Oil-Bearing Plants* **15**(5): 703-707.

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Influence of Invasive Alien Plants on Vegetation of Hailakandi District, Assam, North-East, India

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Abstract: The invasive alien plants are introduced to an ecosystem and extend their geographical occupancy with the potential to perturb the native vegetation. Aim of the present study was to study the vegetation analysis of Katlicherra block in the Hailakandi district (Barak valley) of North-East (NE) India to assess the diversity of invasive alien plants (IAPs). In this study, the vegetation analysis was done in agriculture systems, roadside, and railway side to delineate the impacts of anthropogenic disturbance on phytosociology. In vegetation analysis random quadrat methods were used. Phyto-sociological analysis revealed that the recorded plants belonged to 23 different families, 36 genera and 44 species. Further, habitat-wise, 27 herbs and 17 shrubs were recorded and the Asteraceae was noted as the dominant family. Among the recorded plants *Ageratum conyzoides*, *Chromolaena odorata*, *Lantana camara* and *Mikania micrantha* were noted as the aggressive and noxious invaders. Therefore, further ecological investigations are warranted to provide an insight into underlying invasion mechanisms. The results of such invasive-native interactions are prerequisite for formulating management strategies to safeguard the biodiversity of this study area lying in an Indo-Burma hotspot region.

Keywords: Invasive alien plants, *Ageratum conyzoides*, *Chromolaena odorata*, *Lantana camara*, *Mikania micrantha*

Plant invasion is an important component of ongoing global change and can potentially alter the structure and /functions of the recipient ecosystem (Rai 2015a, Ricciardi et al 2017, Zhang et al 2019). The invasive alien plants (IAPs) perturb the agriculture sustainability and food security. The IAPs can be introduced in pristine geographical landscapes either accidentally or intentionally due to easy dispersal by the pollinators and the human interference. Human mediated biotic invasions can result from dispersion roads, highways, railways, and other anthropogenic perturbations leading to habitat fragmentation (Mararakanye et al 2017). After the transportation, IAPs establish, colonize, and reproduces in the new habitat due to aggressive ecological traits/allelochemical, out-competing the native (Ratnayake 2014, Rai and Singh 2020). Several workers have studied, documented, and provided catalogue of the IAPs in a different parts of the world (Srivastava et al 2014, Singh et al 2015, Debnath and Debnath 2017, Singh et al 2018, Rajasekaran et al 2020). Such studies provide the unique opportunities for the researchers to understand on the impact of plant invasion (Debnath and Debnath 2017). Further, 17 per cent global land area noted vulnerable to invasion (Early et al 2016), however, the mechanism that make the species more vulnerable to the ecosystem are poorly understood (Sharma et al 2005, Srivastava et al 2014).

Needs for the better data and technologies to support more accurate empirical assessments of IAPs damages and

control costs are required (Olson 2006). Therefore, the present study aimed to investigate the influence of IAPs on the diversity of native plants. It is worth mentioning that early detection and management needs can be prioritized only after-vegetation analysis and the evaluation of phyto-sociological status of the invasive plants in Katlicherra block of Hailakandi district, Assam, North East India.

MATERIAL AND METHODS

Katlicherra block of Hailakandi district, Assam has been selected for the study site. Initially, the district of Hailakandi had five developmental blocks viz. Aglapur, Hailakandi, Lala, Katlicherra and the south Hailakandi block. Whereas, south Hailakandi is the largest and the Katlicherra is the smallest block of the district. The total area of Katlicherra block is 674 km². The altitude is 45 meters above the sea level and falls under 24.46721° N and 92.5572° E. The average rainfall of district is 2993mm and the average temperature ranges from 30°C- 36°C during summer and 10°C- 20°C during winter (Anonymous 2013).

Vegetation analysis: The phyto-sociological analysis is to understand the floristic vegetation characteristics, to estimate the species richness and diversity (Curtis and McIntosh 1950). For the vegetation analysis, 30 quadrats laid down for herbs (1×1m) and shrubs (5×5m) randomly in Katlicherra. The quantitative/phyto-sociological analysis has been done by the density, percentage of frequency,

abundance (Curtis and McIntosh 1950) and Basal Area (BA), Relative Density (RD), Relative Frequency, Relative Abundance (RA), and Important Value Index (IVI) (Mueller-Dombois and Ellenberg 1979). Vegetation was further analyzed by the variety of indices such as Shannon's diversity index, Evenness index (Pielou's index), Margalef's index of species richness and Simpson's index of dominance computed by the following formulas:

Shannon diversity index (Shannon 1949)

$$H' = \sum_{i=1}^s \left(\frac{n_i}{N} \right) \ln \left(\frac{n_i}{N} \right)$$

Evenness index (Pielou's index 1975)

$$E = \frac{H'}{\ln S}$$

Margalef's index of species richness (Margalef 1958)

$$R = \frac{(S-1)}{\ln N}$$

Simpson's index of dominance (Simpson 1949)

$$D = \sum \frac{n_i (n_i - 1)}{N (N - 1)}$$

Where, S= Total number of species, N= total number of individuals of all the species, and n_i = number of individuals of the i^{th} species.

RESULTS AND DISCUSSION

Quantitative/ phyto-sociological analysis recorded plants from 23 different families, 36 genera and 44 species (27 herbs and 17 shrubs) (Table 1). Asteraceae was noted as the most dominant family with 8 species followed by Caesalpiniaceae, Solanaceae, Lamiaceae, and Amaranthaceae. The present study revealed that 61.36 per cent of the alien plant species in the study site were native to the American continent. The origin of the plant species recorded in the present study was in accordance with the published literatures (Singh et al 2010, Srivastava et al 2014, Kumar and Bihari 2015, Debnath et al 2015, Singh and Mohammed 2015, Debnath and Debnath 2017, Singh and Kumari 2019). More than 58 per cent of the invasive plants introduced in India are from the American continent (Singh 2012) and are classified as noxious species (Srivastava et al 2014).

Further, in quantitative/ phyto-sociological analysis *Ageratum conyzoides* (IVI= 35.12) was reported to be most dominant among the herbs (Table 2). *A. conyzoides* competes with the native vegetation/ food crops for the soil nutrient and demonstrate aggressive allelochemic/ pathogenic attributes (Ekleme et al 2005, Kaur et al 2014). It has been noted in studies that *Mikania micrantha* infestation

in agriculture systems reduced the crops productivity by 10-15% depending upon the intensity of weed growth (Vijay 2015).

Among the shrubs *Chloromolaena odorata* (IVI=69.42) and *Lantana camara* (IVI=31.34) were among the dominant shrubs (Table 3). *C. odorata*, (Asteraceae family) and *L. camara* (Verbanaceae family) native to tropical America tends to compete with the native plants for space, light, water and soil nutrient and thereby adversely impact on their diversity. Lantana is noxious weed of agro and forest ecosystems; aggressively forms dense thicket (Rai 2015, Rai and Singh 2015). Also it has allelopathic potential that suppress germination, growth, and development due to secretion of allelochemical to the rhizosphere of neighboring crop plants (Qasem 2006, Mishra 2015). *C. Odorata* is a serious problem in pastures, forest, orchards and commercial plantations in the south and Northeast India (Singh 1998). In present ecological investigation, *Clerodendrum infortunatum* (IVI=28.07), *Ipomoea carnea*

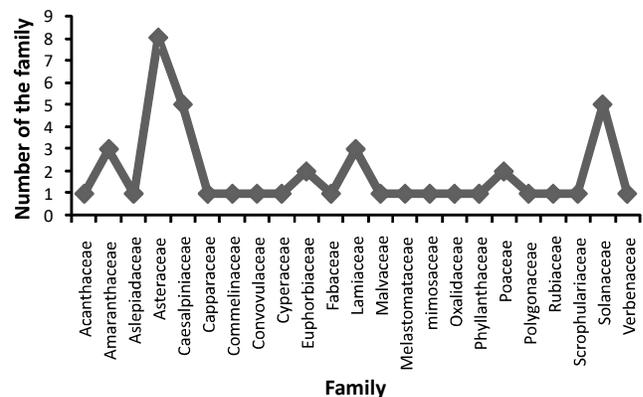


Fig. 1. Family distribution of the species

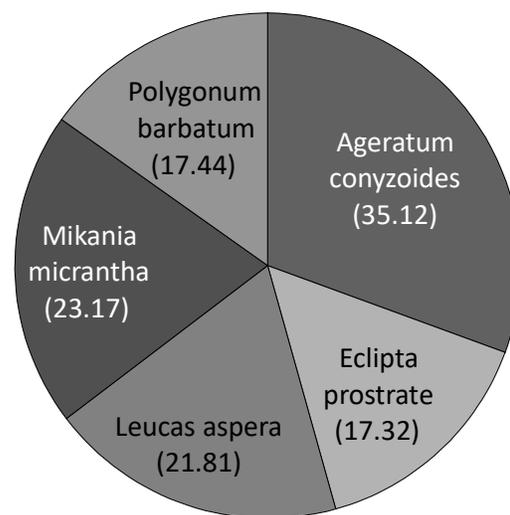


Fig. 2. Five predominant herbs in Katlicherra, Hailakandi district, Assam

Table 1. List of the plant species reported from the study site

Name of the species	Family	Nativity	Habitat
<i>Acanthospermum hispidum</i> DC.	Asteraceae	Brazil	H
<i>Achyranthes aspera</i> L.	Amaranthaceae	Australia	H
<i>Ageratum conyzoides</i> L.	Asteraceae	Tropical America	H
<i>Alternanthera paronychioides</i> A. St. -Hil.	Amaranthaceae	Tropical America	H
<i>Amaranthus viridis</i> L.	Amaranthaceae	Tropical east America	H
<i>Blumea lacera</i> (Burm.f.) DC.	Asteraceae	Tropical America	H
<i>Calotropis gigantea</i> (L.)W. T. Aiton	Asclepiadaceae	Tropical Africa	S
<i>Cassia alata</i> L.	Caesalpiaceae	South America	S
<i>Cassia floribunda</i> (Cav.) H.S. Irwin & Barneby	Caesalpiaceae	Mexico	S
<i>Cassia occidentalis</i> L.	Caesalpiaceae	Tropical South Africa	H
<i>Cassia sophora</i> L.	Caesalpiaceae	Tropical America	S
<i>Cassia tora</i> L.	Caesalpiaceae	South America	H
<i>Chloris barbata</i> (L.)Sw.	Poaceae	Tropical America	G
<i>Chromolaena odorata</i> L.	Asteraceae	South America	S
<i>Cleome gynandra</i> L.	Capparaceae	Tropical America	H
<i>Clerodendrum glandulosum</i> Lindl.	Lamiaceae	India	S
<i>Clerodendrum infortunatum</i> L.	Lamiaceae	Tropical Asia	S
<i>Commelina erecta</i> L.	Commelinaceae	America, Africa, Western Asia	H
<i>Crotalaria pallida</i> Ait.	Fabaceae	Tropical America	H
<i>Crassocephalum crepidioides</i> (Benth.) S. Moore	Asteraceae	Tropical America	H
<i>Cyperus rotundus</i> L.	Cyperaceae	Europe	G
<i>Datura innoxia</i> P. Mill.	Solanaceae	Tropical America	S
<i>Datura metel</i> L.	Solanaceae	Tropical America	S
<i>Eclipta prostrata</i> (L.) L.	Asteraceae	Tropical America	H
<i>Euphorbia hirta</i> L.	Euphorbiaceae	Tropical America	H
<i>Imperata cylindrica</i> (L.) Raeusch.	Poaceae	Tropical America	H
<i>Ipomoea carnea</i> Jacq.	Convolvulaceae	Tropical America	S
<i>Justicia adhatoda</i> L.	Acanthaceae	Asia	S
<i>Lantana camara</i> L.	Verbenaceae	Tropical America	S
<i>Leucas aspera</i> (Willd.) Link	Lamiaceae	India	H
<i>Melastoma malabathricum</i> L.	Melastomataceae	Asia and Australia	S
<i>Mikania micrantha</i> Kunth	Asteraceae	Tropical America	C
<i>Mimosa pudica</i> L.	Mimosaceae	Brazil	H
<i>Oxalis corniculata</i> L.	Oxalidaceae	Europe	H
<i>Parthenium hysterophorus</i> L.	Asteraceae	North America	H
<i>Phyllanthus urinaria</i> L.	Phyllanthaceae	Asia	H
<i>Polygonum barbatum</i> L.	Polygonaceae	India	H
<i>Ricinus communis</i> L.	Euphorbiaceae	South America	S
<i>Scoparia dulcis</i> L.	Scrophulariaceae	Tropical America	H
<i>Solanum anguivi</i> L.	Solanaceae	India	S
<i>Solanum nigrum</i> L.	Solanaceae	Tropical America	H
<i>Solanum torvum</i> Sw.	Solanaceae	West Indies	S
<i>Spermacoce ocymoides</i> Burm.f.	Rubiaceae	Tropical America	H
<i>Urena lobata</i> L.	Malvaceae	Tropical America	S

* C= Climber, G=Grass, H=Herb and S=Shrub

Table 2. Quantitative/ phytosociological analysis of herbs in Katlicherra, Hailakandi district, Assam

Name of the species	Density	Frequency	Abundance	Relative density	Relative frequency	Relative abundance	Important value index
<i>Acanthospermum hispidum</i> DC.	0.43	16.67	2.60	5.94	4.35	5.47	15.75
<i>Achyranthes aspera</i> L.	0.03	3.33	1.00	0.46	0.87	2.10	3.43
<i>Ageratum conyzoides</i> L.	1.23	50.00	2.47	16.89	13.04	5.19	35.12
<i>Alternanthera paronychioides</i> St. -Hill.	0.07	3.33	2.00	0.91	0.87	4.20	5.99
<i>Amaranthus viridis</i> L.	0.07	6.67	1.00	0.91	1.74	2.10	4.75
<i>Blumea lacera</i> (Burm.f.) DC.	0.33	13.33	2.50	4.57	3.48	5.26	13.30
<i>Cassia occidentalis</i> L.	0.17	13.33	1.25	2.28	3.48	2.63	8.39
<i>Cassia tora</i> L.	0.07	3.33	2.00	0.91	0.87	4.20	5.99
<i>Chloris barbata</i> Sw.	0.10	6.67	1.50	1.37	1.74	3.15	6.26
<i>Cleome gynandra</i> L.	0.23	13.33	1.75	3.20	3.48	3.68	10.35
<i>Crassocephalum crepidioides</i> (Benth.) S. Moore	0.10	10.00	1.00	1.37	2.61	2.10	6.08
<i>Commelina erecta</i> L.	0.23	13.33	1.75	3.20	3.48	3.68	10.35
<i>Crotalaria pallida</i> Ait.	0.47	23.33	2.00	6.39	6.09	4.20	16.68
<i>Cyperus rotundus</i> L.	0.03	3.33	1.00	0.46	0.87	2.10	3.43
<i>Eclipta prostrata</i> (L.) L.	0.50	20.00	2.50	6.85	5.22	5.26	17.32
<i>Euphorbia hirta</i> L.	0.33	16.67	2.00	4.57	4.35	4.20	13.12
<i>Imperata cylindrica</i> (L.) Raeusch.	0.20	16.67	1.20	2.74	4.35	2.52	9.61
<i>Leucas aspera</i> (Willd.) Link	0.60	40.00	1.50	8.22	10.43	3.15	21.81
<i>Mikania micrantha</i> Kunth	0.70	36.67	1.91	9.59	9.57	4.01	23.17
<i>Mimosa pudica</i> L.	0.20	10.00	2.00	2.74	2.61	4.20	9.55
<i>Oxalis corniculata</i> L.	0.07	6.67	1.00	0.91	1.74	2.10	4.75
<i>Parthenium hysterophorus</i> L.	0.27	6.67	4.00	3.65	1.74	8.41	13.80
<i>Phyllanthus urinaria</i> L.	0.10	6.67	1.50	1.37	1.74	3.15	6.26
<i>Polygonum barbatum</i> L.	0.50	23.33	2.14	6.85	6.09	4.50	17.44
<i>Scoparia dulcis</i> L.	0.10	6.67	1.50	1.37	1.74	3.15	6.26
<i>Solanum nigrum</i> L.	0.07	6.67	1.00	0.91	1.74	2.10	4.75
<i>Spermacoce ocymoides</i> Burm.f.	0.10	6.67	1.50	1.37	1.74	3.15	6.26

Table 3. Quantitative/phytosociological analysis of shrubs in Katlicherra, Hailakandi district, Assam

Name of the species	Density	Frequency	Abundance	Relative density	Relative frequency	Relative abundance	Important value index
<i>Calotropis gigantea</i> (L.) W. T. Aiton	0.03	3.33	1.00	0.83	1.41	4.09	6.33
<i>Cassia alata</i> L.	0.13	6.67	2.00	3.31	2.82	8.19	14.31
<i>Cassia floribunda</i> (Cav.) H.S. Irwin & Barneby	0.07	6.67	1.00	1.65	2.82	4.09	8.56
<i>Cassia sophera</i> L.	0.07	6.67	1.00	1.65	2.82	4.09	8.56
<i>Chromolaena odorata</i> L.	1.33	66.67	2.00	33.06	28.17	8.19	69.42
<i>Clerodendrum glandulosum</i> Lindl.	0.07	6.67	1.00	1.65	2.82	4.09	8.56
<i>Clerodendrum infortunatum</i> L.	0.43	20.00	2.17	10.74	8.45	8.87	28.07
<i>Datura innoxia</i> P. Mill.	0.07	6.67	1.00	1.65	2.82	4.09	8.56
<i>Datura metel</i> L.	0.07	6.67	1.00	1.65	2.82	4.09	8.56
<i>Ipomoea carnea</i> Jacq.	0.40	20.00	2.00	9.92	8.45	8.19	26.56
<i>Justicia adhatoda</i> L.	0.10	10.00	1.00	2.48	4.23	4.09	10.80
<i>Lantana camara</i> L.	0.50	26.67	1.88	12.40	11.27	7.68	31.34
<i>Melastoma malabathricum</i> L.	0.30	16.67	1.80	7.44	7.04	7.37	21.85
<i>Ricinus communis</i> L.	0.17	13.33	1.25	4.13	5.63	5.12	14.88
<i>Solanum anguivi</i> L.	0.03	3.33	1.00	0.83	1.41	4.09	6.33
<i>Solanum torvum</i> Sw.	0.13	10.00	1.33	3.31	4.23	5.46	12.99
<i>Urena lobata</i> L.	0.13	6.67	2.00	3.31	2.82	8.19	14.31

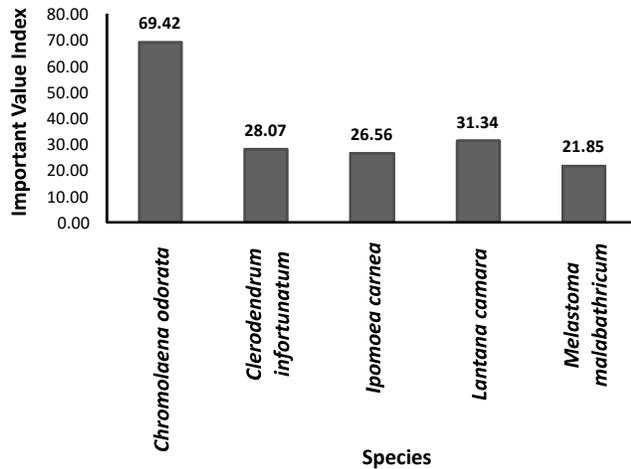


Fig. 3. Five predominant shrubs in Katlicherra, Hailakandi district, Assam

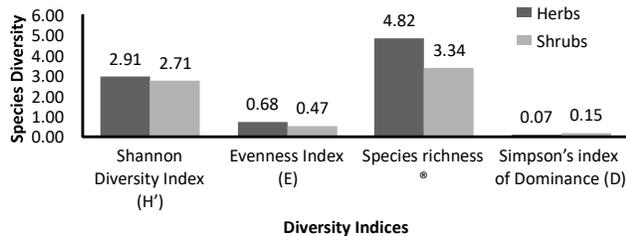


Fig. 4. The biological indices of herbs and shrubs in Katlicherra, Hailakandi district Assam

(IVI=26.56) and *Melastoma malabathricum* (IVI=21.85) were the other three dominant plants from the vegetation analysis.

The biodiversity indices in the study sites reported in Figure 3 pertain to two different habitat i.e., the herbs and the shrubs layer. The Shannon diversity index (H') was calculated 2.91 in herbs and 2.27 in shrubs category. Species Evenness Index (E), and the Species Richness Index (R) are reported in (Fig. 3) as a measure of the vegetation level. Increase/ or higher value of these indices represent the increase in species diversity. Simultaneously, from the present study, it has been reported that the Simpson's Index of Dominance (D), ranged in herbs and shrubs layer are 0.07 and 0.15 respectively. Higher the value of dominance greater is the homogenous nature of the species community, which indicates that the community is dominated by the single species. Thus, the displacement and an imbalance in ecosystem exerted due to the impact of the invasive plants in the present study site was as per Pimental et al (2001).

CONCLUSION

Present vegetation analysis revealed the presence of IAPs such as *C. odorata*, *L. camara*, and *M. micrantha* at the

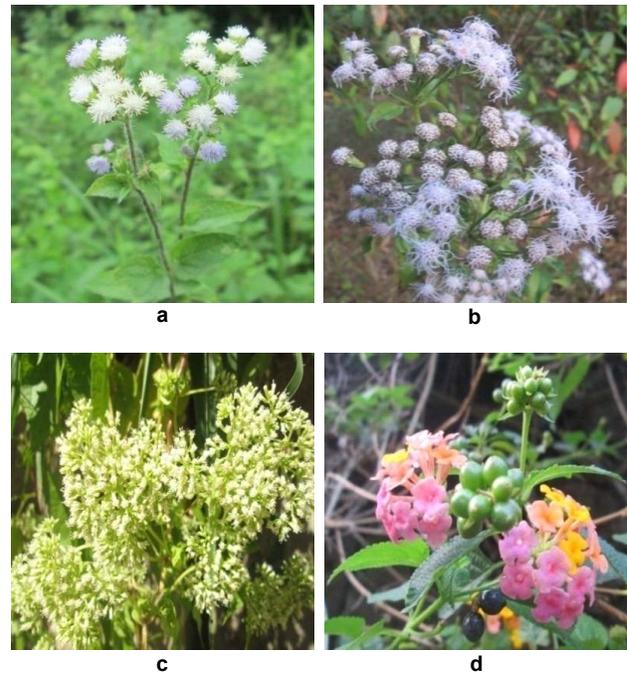


Fig. 5. Dominant IAPs in the study site (a) *Ageratum conyzoides* (b) *Chromolaena odorata* (c) *Mikania micrantha* and (d) *Lantana camara*

selected site in Assam, North East India. Some of the recorded IAPs are included among 100 worst invaders list. Further, these aggressive invasive alien plant species like *A. conyzoides*, *C. odorata*, *L. camara* and *M. micrantha* across the study site expand and respond fast to occupy the habitat as compared to the other native plant species. From the study, it can be concluded that even though the diversity of the invasive plants are moderate at this point but the precaution for the control, management, and the eradication of the IAPs need to be taken in consideration. Henceforth, in the early stage, IAPs spread needs to be checked regularly to avoid native biodiversity loss of this Indo-Burma hot spot region.

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REFERENCES

Anonymous 2013. *Ministry of Water Resources*, Guwahati.
Curtis JT and McIntosh RP 1950. The inter-relations of certain

- analytical and synthetic phytosociological characters. *Ecology* **31**: 434-455.
- Debnath B, Debnath A and Paul C 2015. Diversity of invasive plants species in Trishna wildlife sanctuary, Tripura, Northeast India. *Life Sciences Leaflets* **70**: 9-21.
- Debnath A and Debnath B 2017. Diversity, Invasion status and usages of Alien plant species in Northeast hilly state of Tripura: A confluence of Indo- Barman hotspot. *American Journal of Plant Sciences* **8**(2): 212-235.
- Early R, Bradley BA, Dukes JS, Lawler JJ, Blumenthal DM, Gonzalez P, Grosholz ED, Ibanez I and Miller LP 2016. Global threats from invasive alien species in the twenty-first century and national response capacities. *Nature Communications* **7**: 12485.
- Ekleme F, Forcella F, Archer DW, Akobundu O and Chikoye D 2005. Seedling emergence model for tropic ageratum (*Ageratum conyzoides*). *Weed Science* **53**: 55-61.
- Kaur B, Bhatia S and Sharma KK 2014. Diversity and impact of invasive alien species of family Asteraceae in Jammu district of Jammu and Kashmir, India. *International Journal of Interdisciplinary and Multidisciplinary Studies* **1**(8): 51-62.
- Kumar NS and Bihari SK 2015. Diversity, uses and origin of invasive alien plants in Dhenkanal district of Odisha, India. *International Journal of Biological Sciences* **4**(2): 21-27.
- Mararakanye N, Magoro MN, Matshaya NN, Rabothata MC and Ncobeni SR 2017. Railway side mapping of alien plant distributions in Mpumalanga, South Africa. *Bothalia* **47**(1): 1-11
- Margalef R 1958. Temporal succession and spatial heterogeneity in phytoplankton. In: A.A. Buzzati-Traverso, (eds). *Perspective in marine biology*. Berkeley: University of California Press, pp 323-347.
- Mishra A 2015. Allelopathic properties of *Lantana camara*. *International Research Journal of Basic and Clinical Studies* **3**(1): 13-28.
- Mueller-Dombois D and Ellenberg H 1974. *Aims and Methods of Vegetation Ecosystem*. Wiley and sons. New York. 547pp.
- Olson L 2006. The economics of terrestrial invasive species: A reviews of the literature. *Agricultural and Resource Economic Review* **35**: 178-194.
- Pielou EC 1975. *Ecological Diversity*. John Wiley and Sons. New York. 165pp.
- Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zem J, Aquino T and Tsomondo T 2001. Economic and environmental threats of alien plant, Animal, and Microbe invasions. *Agriculture, Ecosystems and Environment* **84**: 1-20.
- Qasem JR 2006. Response of onion (*Allium cepa* L.) plants to fertilizers, weed competition duration and planting time in the central Jordan Valley. *Weed Biology and Management* **6**: 212-220.
- Rai PK 2015. Plant invasion ecology of an Indo-Burma hot spot region along the disturbed gradient: in case study. *International Research Journal of Environmental Sciences* **4**: 108-114.
- Rai PK 2015a. Paradigm of plant invasion: multifaceted review on sustainable management. *Environmental Monitoring and Assessment* **187**: 759.
- Rai PK and Singh MM 2015. *Lantana camara* invasion in urban forests of and Indo- Burma hotspot region and its eco-sustainable management implication through biomonitoring of particulate matter. *Journal of Asian-Pacific Biodiversity* **8**: 375-381.
- Rai PK and Singh 2020. Invasive alien plants species: Their impact on environment, ecosystem services and human health. *Ecological Indicators* **21**: 1-20.
- Rajasekaran A, Salunkhe P and Singh M 2020. *Documentation and status of invasive alien plant species in India: A handbook*. Indian Council of Forestry Research and Education (ICFRE), Dehradun, pp 1-16.
- Ratnayake RMCS 2014. Why plant species become invasive? Character related to successful biological invasion. Proceedings of the *National symposium on invasive alien species*. Colombo, Sri Lanka. 1.
- Ricciardi A, Blackburn TM, Carlton JT, Dick JTA, Hulme PE and Iacarella JC 2017. Invasive science: A horizon scan of emerging challenges and opportunities. *Trends in Ecology and Evolution* **32**(6): 464-474.
- Shannon CE and Wiener W 1949. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana Illinois. 1-117.
- Sharma GP, Singh JS and Raghubanshi AS 2005. Plant invasions: Emerging trends and future implications. *Current Science* **88**(5): 726-734.
- Simpson EH 1949. Measurement of Diversity. *Nature* **163**: 688.
- Singh A and Mohammed I 2015. Diversity of invasive alien plant species in district Yamuna Nagar of Haryana, India. *Biological Forum- An International Journal* **7**(2): 1051-1056.
- Singh SP 1998. A review of biological suppression of *Chromolaena odorata* K&R in India. In Fessar et al, eds. *Proc, 4th International Workshop On Biological Control and Management Chromolaena odorata*, pp. 86-92. USA, University of Guam.
- Singh MK, Verma P, Bharti A and Kumar R 2018. Forest invasive species: A serious threat to native species in the forest habitat of Assam, India. *Archive of Life Science and Environment* **2**(1): 97-104.
- Singh PS and Kumari B 2019. Distribution and beneficial uses of invasive alien angiosperms in the roadside area of JP. Nagar, Uttar Pradesh. *Journal of Medicinal Plant Studies* **7**(3): 08-11
- Singh KP, Shukla AN and Singh JS 2010. State-level inventory of alien plants, their sources regions and use potential. *Current Sciences* **99**(1): 107-114.
- Singh TB, Das AK and Singh PK 2015. Study of alien and invasive flora of valley district of Manipur and their control. *International Journal for Innovative Research in Sciences and Technology* **1**(2): 616-626.
- Srivastava S, Divedi A and Shukla RP 2014. Invasive alien species of terrestrial vegetation of North-eastern Uttar Pradesh. *International Journal of Forestry Research* **14**: 1-9.
- Vijay B 2015. Invasive plants *Mikania micrantha* a major threat to biological diversity- A review. *International Journal of Advanced Research in Science and Engineering* **4**: 48-52.
- Zhang P, Li B, Wu J and Hu S 2019. Invasive plants differentially affect soil biota through litter and rhizosphere pathway: Meta-analysis. *Ecology Letters* **20**: 200-210.



Application of Sunflower Seed Oil in Preparation of Novel Low-Fat Kefir

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Abstract: The objectives of this research were focused on preparing Kefir with skimmed milk and sunflower seed oil and studying its compositional, rheological, and textural properties as well as its microstructure characteristics. Rheological and textural properties of Kefir samples containing 2-4% sunflower seed oil (SMK) did not differ significantly from the standard Kefir made from whole milk (WMK). The substitution of milk fat by sunflower seed oil improved the chemical composition of Kefir. In addition, the microstructure of Kefir made from skimmed milk and sunflower seed oil was similar to that of Kefir made from whole milk.

Keywords: Kefir, Sunflower seed oil, Rheological and textural properties, Microstructure

Milk is a liquid secreted by the mammary glands of females and differs in terms of components according to its source (Ceballos et al 2009). Kefir is a traditional popular beverage originated from Middle Eastern and can be prepared from several kind of milk (cow, goat, sheep, coconut, rice or soybeans). There are many choices for milk such as pasteurized, unpasteurized, full-fat, low-fat, non-fat and fat-free (Ottes and Cagindi 2003). Kefir nutritional values differ greatly and depend on milk source and content, starter culture composition and fermentation processing. (Bensmira et al 2010, Bensmira and Jiang 2012a, 2012b). Little information is available on Kefir containing vegetable oil. Therefore, the objectives of this research were focused on preparing Kefir with skimmed milk and sunflower seed oil and studying its compositional, rheological, and textural properties.

MATERIAL AND METHODS

This study was conducted at State Key Laboratory of Food Science and Technology, Jiangnan University, Wuxi, China. Analytical reagent grade chemicals were provided by the Chemical Store of Jiangnan University. The Kefir starter culture used in this study was obtained from Wilderness Family Naturals (Finland, USA). Skimmed milk powder and refined sunflower seed oil were taken from a local Supermarket in Wuxi (China).

Kefir working-culture preparation: The working-culture was prepared as described by Bensmira et al (2010).

Kefir production: The reconstitution of skimmed milk powder was to 12% (w/w), as mentioned by Bensmira et al (2010) and divided into five batches. Sunflower seed oil was

added as reported by Barrantes et al (1996a) into four batches at 1, 2, 3 and 4% (w/w), while the other batch not containing sunflower seed oil served to prepare the control Kefir sample. All batches were mixed and kept at 4°C overnight. Bovine fresh milk was used to prepare the standard Kefir sample. Each milk sample was homogenized at 15 MPa after a pre-heat to 60°C, pasteurized for 15 min at 92°C, cooled down to 25°C, and inoculated with 3% (v/v) of starter-culture. Kefir samples were incubated at 24°C during 18 h, and ripened at 4°C for 24 h before measurements (Bensmira et al 2010). All analysis was evaluated for duplicate samples.

Analysis of Kefir rheology: The variation of complex modulus (G^*) was recorded as described by Bensmira et al (2010) using a Physica MCR 301 rheometer (Anton Paar, TruGop Ready, Österreich).

Analysis of Kefir texture: Texture profile analysis (TPA) of Kefir samples was carried out using the Universal TA-XT2 Texture Analyser (Stable Micro Systems, Ltd., UK).

Proximate analysis of Kefir: The moisture and ash content of Kefir were investigated by vacuum oven method and dry ash method, respectively (James 1995). Kefir fat content was analyzed using the Gerber method James (1995). Total protein content of samples was measured by the Kjeldahl method (James 1995) with 6.38 as conversion factor. The content in available carbohydrates of Kefir was measured by the DNS colorimetric method.

Microstructure: Kefir samples were prepared for microstructure analysis following the method illustrated by Puvanenthiran et al (2002), Madadlou et al (2005) and Bensmira and Jiang (2012b). Several images were taken by

a scanning electron microscope (Quanta 200, AFEI Co., Holland) from different sections of each sample.

Statistical analysis: The variance of the mean values was analyzed using Duncan Multiple Range Test (DMRT) with SAS software (The SAS System for Windows, Version 8.1, 1999).

RESULTS AND DISCUSSION

Effect of sunflower seed oil addition on Kefir rheology:

The complex modulus (G^*) exhibited a little dependence on the increase of frequency and sunflower oil content (Fig. 1). The statistical study showed a significant distinction (among Kefir sample made from whole milk (WMK) and that made from skimmed milk alone (SMK), with no important variation (within Kefir samples containing sunflower seed oil and Kefir sample made from whole milk (WMK). Peng et al (2009) also reported that at low strains full-fat yoghurt had higher values of G^* in comparison with the low-fat yoghurt. Similarly, Bensmira and Jiang (2012a) observed the rigidity of Kefir made from peanut milk is affected by the fat content.

Effect of sunflower seed oil addition on Kefir texture: The behavior of firmness and adhesiveness as function of sunflower seed oil seed content is illustrated in Figure 2. Firmness values increased with the increase of sunflower seed oil content in Kefir samples. However, adhesiveness values decreased with the increase of sunflower seed oil concentration in Kefir. The results are comparable to Bensmira and Jiang (2012a) in Kefir made from peanut milk. The statistical analysis showed a major variation () among whole milk Kefir, skimmed milk Kefir and Kefir containing 1% sunflower seed oil (1% SOK). Nevertheless, no significant distinction was noted between the other samples containing sunflower seed oil (2% SOK, 3% SOK and 4% SOK) and the standard Kefir made from whole milk.

Effect of sunflower seed oil addition on the proximate composition of Kefir: The water content in Kefir made from skimmed milk and sunflower seed oil (2%) was slightly higher than that in Kefir made from whole milk (Table 1). However, Kefir containing sunflower seed oil exhibited higher content in total solids than Kefir made from skimmed milk alone. In addition, Kefir made from whole milk had the highest ash content, which was lowest in Kefir prepared from skimmed milk only. The fat and protein contents in Kefir made from whole milk were higher than those in Kefir containing sunflower seed oil (2%). Fat content was decreased in samples prepared from 2% sunflower seed oil and that is due to milk fat lipolysis by the starter culture used. Reguła (2007) observed that lactic acid bacteria have enzymes capable to hydrolyze mono-, di- and triacylglycerols. The pre-treatment of the milk is also essential, since all the technical handlings

(cooling, homogenization and stirring) that demolish the membrane of milk fat globules can carry the risk of too much lipolysis (Evers 2004). The amount of available carbohydrates was highest in Kefir containing sunflower seed oil (2%), while being lowest in Kefir made from skimmed milk alone. Kefir composition is variable and not clear (Zubillaga et al 2001). According Kefir nutritional values and chemical composition depend on the source and composition of milk, the kind of starter and the technological process (Otles and Cagindi 2003, Bensmira et al 2010, Bensmira and Jiang 2012a, 2012b). Results observed in this study are comparable with those other researchers (Wszolek et al 2001, Bensmira and Jiang 2011).

Effect of sunflower seed oil addition on Kefir microstructure:

Scanning electron microscopy (SEM) illustrate that Kefir prepared from whole milk and Kefir made from skimmed milk with sunflower seed oil had similar microstructures (Fig. 3). All are formed by a protein network consisting of chains and aggregates of interconnected casein micelles, the spherical shape of which is still visible and separated by uniformly distributed voids filled with milk serum (Fig. 3 a,c). The protein network of Kefir made from

Table 1. Proximate composition of whole milk Kefir (WMK), skimmed milk Kefir (SMK) and skimmed milk with sunflower seed oil Kefir (2% SOK) (% w/w)^a

Components	WMK	SMK	2% SOK
Moisture	88.38±0.01	90.45± 0.01	90.07±0.01
Total solids	11.62±0.01	9.55±0.00	9.93±0.01
Ash	0.90± 0.00	0.67± 0.00	0.89±0.01
Total protein	3.26±0.00	2.23± 0.00	2.68±0.00
Fat	3.35±0.03	0.02±0.01	0.28±0.01
Carbohydrate	4.81±0.04	4.22±0.05	4.36±0.05

^a Data are means of values expressed on a fresh weight basis

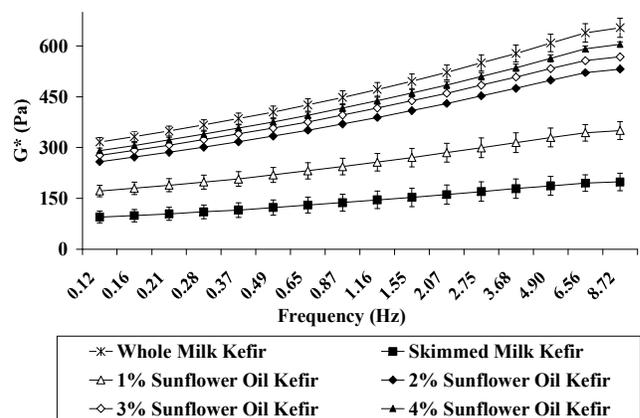


Fig. 1. Effect of sunflower seed oil addition on the complex modulus (G^*) of Kefir

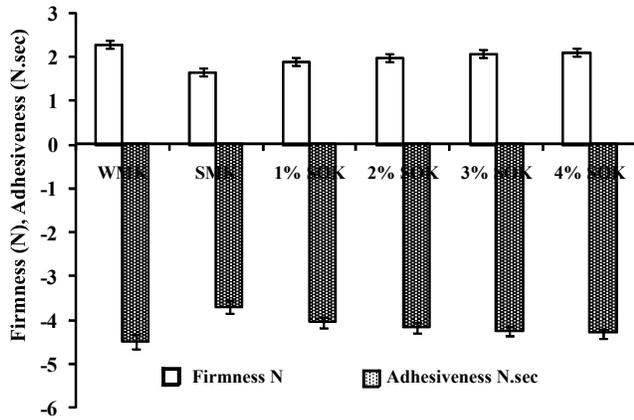


Fig. 2. Effect of sunflower seed oil addition on Kefir Firmness and Adhesiveness

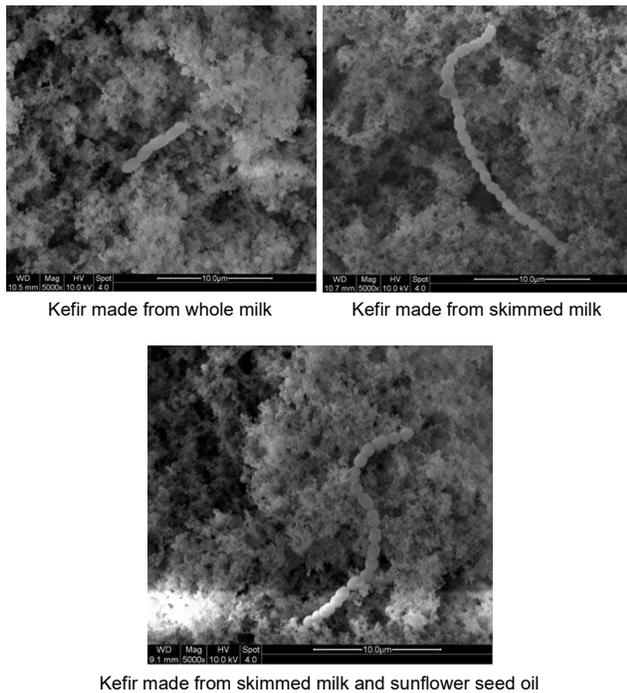


Fig. 3. Effect of sunflower seed oil addition on the microstructure of Kefir

skimmed milk alone (Fig. 3b) was less thick, more released, and have further void comparatively to that of Kefir made from whole milk as result of smaller complex casein micelles aggregates, possibly due to fewer fat globules acting as linking protein factors. This arrangement develops in homogenized milk heated to at least 85°C). At this temperature, a complex is formed between β -lactoglobulin and κ -casein at the casein micelle surface (Sharma and Dalgleish 1994, McCrae et al 1994).

CONCLUSION

In the present work, the substitution of milk fat by sunflower seed oil to prepare a novel Kefir beverage was investigated. Results showed that the processing of low-fat Kefir could be optimized using 2% sunflower seed oil.

REFERENCES

- Asgar A and Tompkinson DK 1994. Influence of composition and processing parameters on curd tension of fruit flavoured field bio-yoghurt. *Indian Journal of Dairy Science* **47**(10): 875-879.
- Barrantes F, Tamime AY, Sword AM, Muir DD and Kalab M 1996a. The manufacture of set-type natural yoghurt containing different oils-1. Compositional quality, microbiological evaluation and sensory properties. *International Dairy Journal* **6**(8-9): 811-826.
- Barrantes F, Tamime AY, Sword AM, Muir DD and Kalab M 1996b. The manufacture of set-type natural yoghurt containing different oils-2. Rheological properties and microstructure. *International Dairy Journal* **6**(8-9): 827-837.
- Bensmira M, Nsabimana C and Jiang B 2010. Effects of fermentation conditions and homogenization pressure on the rheological properties of Kefir. *LWT-Food Science and Technology* **43**(8): 1180-1184.
- Bensmira M and Jiang B 2011. Organic Acids Formation during the production of a novel peanut-milk Kefir beverage. *British Journal of Dairy Science* **2**(1): 18-22.
- Bensmira M and Jiang B 2012a. Rheological characteristics and nutritional aspects of novel peanut-based kefir beverages and whole milk kefir. *International Food Research Journal* **19**(2): 647-650.
- Bensmira M and Jiang B 2012b. Effect of some operating variables on the microstructure and physical properties of a novel Kefir formulation. *Journal of Food Engineering* **108**(4): 579-584.
- Ceballos LS, Morales ER, Adarve GDT, Castro JD, Martínez LP and Sampelayo MRS 2009. Composition of goat and cow milk produced under similar conditions and analyzed by identical methodology. *Journal of Food Composition and Analysis* **22**: 322-329.
- Evers JM 2004. The milk fat globule membrane compositional and structural changes post secretion by the mammary secretory cell. *International Dairy Journal* **14**(8): 661-674.
- James CS 1995. *Analytical Chemistry of Foods*. Chapman & Hall Oxford.
- Madadlou A, Khosroshahi A, Mousavi SM and Djome ZE 2005. Microstructure and rheological properties of iranian white cheese coagulated at various temperatures. *Journal of Dairy Science* **89**(7): 2359-2364.
- McCrae CH, Hirst D, Law AJR and Muir DD 1994. Heat stability of homogenized milk: role of interfacial protein. *Journal of Dairy Science* **61**(4):507-516.
- Otles S and Cagindi O 2003. Kefir: A probiotic dairy-composition, nutritional and therapeutic aspects. *Pakistan Journal of Nutrition* **2**(2): 54-59.
- Peng Y, Serra M, Horne DS and Lucey JA 2009. Effect of fortification with various types of milk proteins on the rheological properties and permeability of nonfat set yogurt. *Journal of Food Science* **74**(9): 666-673.
- Puvanenthiran A, Goddard SJ and Augustin MA 2002. Gelation of mixed gels containing κ -carrageenan and skim milk components. *Journal of Food Science* **67**(2): 573-577.
- Regula A 2007. Free fatty acid profiles of fermented beverages made from ewe's milk. *Lait* **87**(1): 71-77.
- SAS 1999. *System for Windows, Version 8.01*. SAS Institute Inc Cary NC.
- Sharma SK and Dalgleish DG 1994. Effect of heat treatments on the

incorporation of milk serum proteins into the fat globule membrane of homogenized milk. *Journal of Dairy Science* **61**(3): 375-384.

Wszolek M, Tamime AY, Muirs DD and Barclay MNI 2001. Properties of Kefir made in Scotland and Poland using Bovine, Caprine and

ovine milk with different starter cultures. *LWT -Food Science and Technology* **34**(4): 251-261.

Zubillaga M, Weill R, Postaire E, Goldman C, Caro Rand Boccio J 2001. Effect of probiotics and functional foods and their use in different diseases. *Nutrition Research* **21**(3): 569-579.

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Modeling Rainfall-Runoff using Artificial Neural Network (ANNs) and Wavelet based ANNs (WANNs) for Haripura Dam, Uttarakhand

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Abstract: The main objective of this study was to estimate runoff using rainfall as input variable on daily basis by developing models using artificial neural network (ANNs) and wavelet based ANNs (WANNs). This study deals with location and climate of study area, collection of rainfall-runoff data, standardization of data, input selection using Gamma test and methodology adopted for runoff estimation and modeling using ANNs and WANNs for Haripura dam located in U.S. Nagar district of Uttarakhand. As the numbers of neurons are increased, correlation between rainfall and runoff first increase and then decrease. So at an optimum number of neurons there exists a best correlation. WANNs models give better correlation coefficient, lesser root mean square error and more Nash Shutcliff coefficient of efficiency as compared to ANNs models. These results can be useful for runoff forecasting for various purpose such as irrigation purpose.

Keywords: Artificial Neural Networks (ANNs), Wavelet, Nash Shutcliff coefficient of efficiency (NSCE)

Water resources of the world in general are under heavy stress due to increased demand and limitation of available quantity. Proper water management is the only option that ensures a squeezed gap between the demand and supply. Sustainable water management of a river basin is required to ensure a long-term stable and flexible water supply to meet crop water demands. Worldwide many attempts have been made to model and predict rainfall behaviour using various empirical, statistical, numerical and deterministic techniques (Meher and Jha 2011a,b). Water resources structures need appropriate planning to ensure the fulfillment of the goals of water management. It requires a system approach that includes not only all of the hydrological components, but also the links, relations, interactions, consequences, and implications among these components. It is necessary to forecast the runoff for planning and management of available surface water. Artificial intelligent techniques are more popular amongst researchers because of ease in operation, time effectiveness and good results. Although these data driven models are widely applied in hydrologic studies but still some space is present which reduce its prediction performance (Tayyab et al 2017). Levenberg-Marquardt algorithm is commonly adopted method for modeling various earth system and environmental processes (Vidyarthi and Jain 2020). The main objectives of this study are to select the best input combination using gamma test (GT), to develop rainfall-runoff models using ANNs and WANNs techniques and to evaluate the performance and adequacy of the developed models.

MATERIAL AND METHODS

The Haripura dam is an earthen dam, built on Bhakhara river in Udham Singh Nagar district of Uttarakhand at 29° 8' N latitude and 79° 20' E longitude. The catchment area of Haripura dam is 294.4 sq. km. which is hilly and partially plain. Reduced level of cut in between Baur and Haripura dams is 238.81 m. River Ganga is the basin area of this dam. Dam has a maximum height of 10.98 meters and length of 7.90 kilometers. Dead storage level is 236.22 m and full reservoir level is 242.32 m. Reservoir capacity at full storage level is 28.317 million cubic meter. Data is obtained from the Irrigation division Rudrapur. Daily rainfall and corresponding runoff data for four months of monsoon season i.e. June, July, August and September were obtained for 20 years starting from 1996 to 2015. This data is taken for analysis of rainfall runoff modeling. Rainfall and runoff time series is shown in Figure 1.

For obtaining an optimum and efficient training between input and output data, all input and output data were normalized using a standard normal variable (z). It provide simple and fast training convergence within a small range during model development and also eliminate dimensions, thus give equal weightage to all variables. The standard normal variable is defined as eq. (1) as,

$$Z = \frac{x - \mu}{\sigma} \quad (1)$$

The 2440 sets of rainfall-runoff data were distributed as 1708 samples (70%) for training and 732 samples (30%) for testing purpose using artificial neural network (ANNs) and

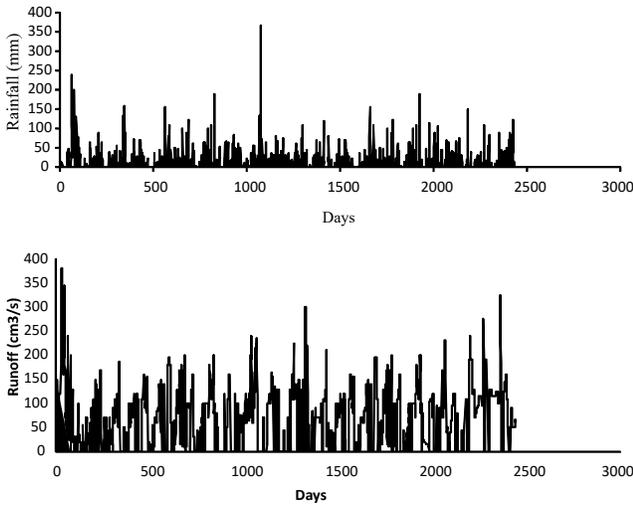


Fig. 1. Rainfall and runoff time series data of Haripura dam

wavelet with ANNs (WANNs). Models have been developed using MATLAB R2018a software for ANN and WANN. Gamma test is a non-parametric test. Main assumption in this test is that if two variables are close together in a given input space then their corresponding output variables should be close in a given output space. Gamma distribution function has three different types i.e. one, two and three parameter gamma distributions. ANN has been developed from a generalization of mathematical model of human cognition or neural biology. The activation function is taken as tan sigmoidal function and gives in a range of -1 to 1 and mathematically expressed as eq. (2).

$$tansig(x) = \frac{2}{1 + e^{-2x}} - 1 \dots (2)$$

Wavelets are used to analyze hydrologic models according to scale. The Haar sequence is known as the first known wavelet basis function used in present study and is defined as in equation (3).

$$f(x) = \begin{cases} 1 & \text{if } 0 < t < 0.05 \\ -1 & \text{if } 0.5 < t < 1 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

In this study wavelet based ANN models are developed using Haar function.

RESULTS AND DISCUSSION

Gamma test: Using gamma test it can be concluded that out of various input combinations, the model having inputs as $R_t, R_{t-1}, Q_{t-1}, Q_{t-2}, Q_{t-3}$ has minimum value of gamma i.e. 0.0312 is considered as best input combination on the basis of which all the results are calculated.

ANN: RMSE varies from 34.76 cusec to 72.87 cusec and correlation coefficient from 0.805047 to 0.836780. Values of

NSCE vary from 0.6450 to 0.6986. Model ANN-08 having architecture 5-24-24-1 shows the best performance as it consist minimum value of RMSE (34.76 cusec), max correlation coefficient ($r=0.8367$) and max value of NSCE (0.6986).

For testing data, RMSE varies from 42.27 to 44.56 cusec, correlation coefficient from 0.7051 to 0.734643 and NSCE from 0.4747 to 0.5274. It can be concluded that model ANN-03 having architecture 5-9-9-1 shows the max value of correlation coefficient ($r=0.7346$), model ANN-14 having architecture 5-42-42-1 shows the min value of RMSE (42.27 cusec) and max value of NSCE (0.5274) (Table 2) It has also a large value of correlation coefficient (0.7304). So the best performance model can be taken as ANN-14.

RMSE varies from 24.16 cusec to 33.80 cusec correlation coefficient from 0.8486 to 0.9246 and NSCE from

Table 1. Performance indicators for ANN (training) based runoff prediction models of Haripura dam

Model	Architecture	RMSE	r	NSCE
ANN-04	5-12-12-1	35.33	0.8301	0.6887
ANN-05	5-15-15-1	35.22	0.8311	0.6906
ANN-06	5-18-18-1	35.46	0.8296	0.6864
ANN-07	5-21-21-1	35.66	0.8275	0.6829
ANN-08	5-24-24-1	34.76	0.8367	0.6986
ANN-09	5-27-27-1	35.09	0.8327	0.6928
ANN-10	5-30-30-1	36.38	0.8194	0.6699
ANN-11	5-33-33-1	37.73	0.8050	0.6450

Table 2. Performance indicators for ANN (testing) based runoff prediction models of Haripura dam

Model	Architecture	RMSE	r	NSCE
ANN-02	5-6-6-1	42.35	0.7305	0.5256
ANN-03	5-9-9-1	42.30	0.7346	0.5266
ANN-04	5-12-12-1	43.48	0.7193	0.4999
ANN-05	5-15-15-1	42.96	0.7250	0.5119
ANN-06	5-18-18-1	42.65	0.7262	0.5189
ANN-07	5-21-21-1	42.42	0.7319	0.5240
ANN-08	5-24-24-1	42.65	0.7345	0.5188
ANN-09	5-27-27-1	44.56	0.7051	0.4747
ANN-10	5-30-30-1	44.03	0.7173	0.4873
ANN-11	5-33-33-1	42.73	0.7315	0.5170
ANN-12	5-36-36-1	43.25	0.7317	0.5054
ANN-13	5-39-39-1	43.18	0.7213	0.5069
ANN-14	5-42-42-1	42.27	0.7304	0.5274
ANN-15	5-45-45-1	43.30	0.7240	0.5040
ANN-16	5-48-48-1	42.59	0.7238	0.5202

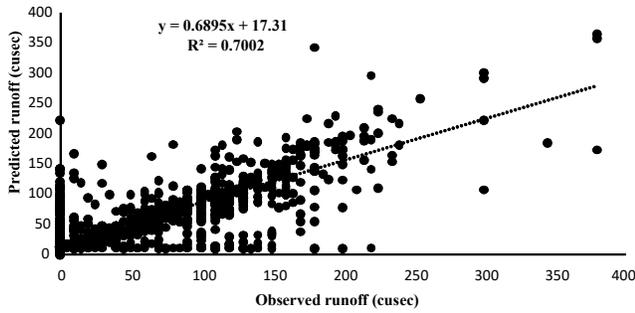


Fig. 2. Time series and scatter plot of predicted versus observed runoff for ANN-08 (5-24-24-1) model during training period

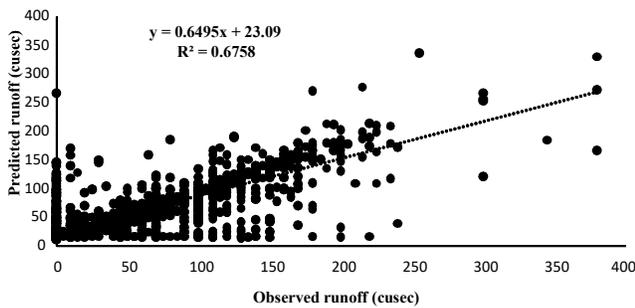


Fig. 3. Time series and scatter plot of predicted versus observed runoff for ANN-14 (5-42-42-1) model during testing period

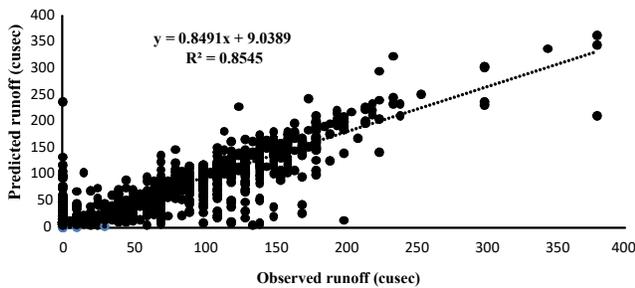


Fig. 4. Time series and scatter plot of predicted versus observed runoff for WANN-11 (5-33-33-1) model during training period

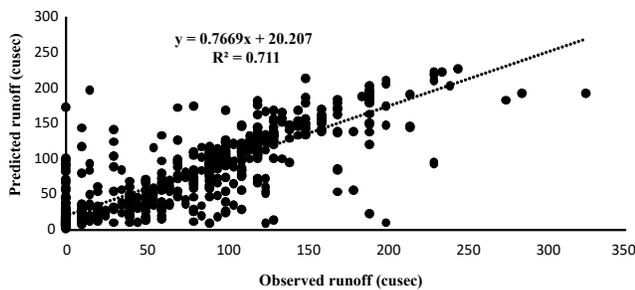


Fig. 5. Time series and scatter plot of predicted versus observed runoff for WANN-1 (5-3-3-1) model during training period

Table 3. Performance indicators for WANN (training) based runoff prediction models of Haripura dam

Model	Architecture	RMSE	r	NSCE
WANN-09	5-27-27-1	25.50	0.9169	0.8378
WANN-10	5-30-30-1	27.83	0.9022	0.8069
WANN-11	5-33-33-1	24.16	0.9243	0.8544
WANN-12	5-36-36-1	25.09	0.9186	0.8429
WANN-13	5-39-39-1	24.18	0.9246	0.8541
WANN-14	5-42-42-1	26.39	0.9097	0.8262
WANN-15	5-45-45-1	27.07	0.9078	0.8172
WANN-16	5-48-48-1	25.57	0.9153	0.8367
WANN-17	5-51-51-1	26.35	0.9132	0.8268

Table 4. Performance indicators for WANN (testing) based runoff prediction models of Haripura dam

Model	Architecture	RMSE	r	NSCE
WANN-01	5-3-3-1	33.38	0.8432	0.7053
WANN-02	5-6-6-1	34.05	0.8336	0.6934
WANN-03	5-9-9-1	80.35	0.6655	0.7073
WANN-04	5-12-12-1	38.58	0.7923	0.6063
WANN-05	5-15-15-1	34.37	0.8349	0.6874
WANN-06	5-18-18-1	34.65	0.8279	0.6824
WANN-07	5-21-21-1	35.72	0.8212	0.6625
WANN-08	5-24-24-1	36.52	0.8046	0.6472

0.7150 to 0.8544. It can be concluded that model WANN-11 having architecture 5-33-33-1 shows the best performance as it consist minimum value of RMSE (24.16 cusec), sufficiently large value of correlation coefficient ($r=0.9243$) and max value of NSCE (0.8544). Model WANN-13 having architecture 5-39-39-1 shows maximum value of correlation coefficient ($r=0.924608$) (Table 3).

For testing data, RMSE varies from 33.38 cusec to 80.35 cusec, correlation coefficient from 0.6655 to 0.8432 and NSCE from 0.5276 to 0.7073. It can be concluded that model WANN-01 having architecture 5-3-3-1 shows the min of RMSE (33.38 cusec) and max of correlation coefficient ($r=0.8432$) and sufficiently large value of NSCE (0.7053). Model WANN-03 shows max value of NSCE (0.7073) (Table 4).

CONCLUSION

ANN with architecture 5-24-24-1 provide optimum result for training and 5-42-42-1 for testing. WANN with architecture 5-33-33-1 provide optimum result for training and 5-3-3-1 for testing. On an average, WANNs models give better correlation coefficient, lesser root mean square error and more Nash Shutcliff coefficient of efficiency value as compared to ANNs models. These results can be useful for

runoff forecasting for various purpose like irrigation, flood control etc.

REFERENCES

- Benzaghta MA, Mohammed TA, Ghazali AH and Soom MAM 2012. Prediction of evaporation in tropical climate using artificial neural network and climate based models. *Scientific Research and Essays* **7**(36): 3133-3148.
- Benzaghta MA 2014. Estimation of evaporation from a reservoir in semi-arid environments using artificial neural network and climate based models. *British Journal of Applied Science & Technology* **4**(24): 3501-3518.
- Dumka BB, Kashyap PS and Saran B 2018. Modeling reference evapotranspiration of Pantnagar using various training functions in artificial neural network, *Indian Journal of Ecology* **45**(1): 19-24.
- Feng Y, Jia Y, Cui N, Zhao N, Li C and Gong D 2017. Calibration of Hargreaves model for reference evapotranspiration estimation in Sichuan basin of southwest China. *Agricultural Water Management* **181**(2): 1-9.
- Gulay Tand Meral B 2015. Monthly evaporation forecasting using artificial neural networks and support vector machines. *Applied Climatology* **66**(2): 205-219.
- Hassan M, Shamim MA, Sikandar A, Mehmood L, Ahmed L, Ashiq SZ and Khitab A 2015. Development of sediment load estimation models by using artificial neural networking techniques. *Environmental Monitoring and Assessment* **187**: 11.
- Heng S and Suetsugi T 2013. Using artificial neural network to estimate sediment load in ungauged catchments of the tonle sapriver basin, Cambodia. *Journal of Water Resource and Protection* **5**(2): 54-56.
- Meher J and Jha R 2011a. Analysis of spatio-temporal variability of rainfall over Mahanadi river basin, International conference "Sustainable water resources management and climate change adaptation", NIT Durgapur.
- Meher J and Jha R 2011b. Time series analysis of rainfall data over Mahanadi River basin. *Emerging Science* **3**(6): 22-32.
- Malik A and Kumar A 2015. Co-active neuro-fuzzy inference system (CANFIS) and multiple linear regression (MLR) based suspended sediment modeling. *Journal of Indian Water Resources Society* **35**(2): 43-48.
- Tayyab M, Zhou J, Adnan R and Zeng X 2017. Application of artificial intelligence method coupled with discrete wavelet transform method. *Procedia Computer Science* **107**: 212-207.
- Vidyarthi VK and Jain A 2020. Modeling rainfall-runoff process using artificial neural network with emphasis on parameter sensitivity. *Modeling Earth Systems and Environment* **6**: 2177-2188.

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Intensity Duration Frequency Curve Generation using Historical and Future Downscaled Rainfall Data

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Abstract: Intensity–duration–frequency curves are used extensively in engineering to assess the return periods of rainfall events. The estimation and use of IDF curves rely on the hypothesis of rainfall series stationarity, namely that intensities and frequencies of extreme hydrological events remain unchanged over time. However, changes in the hydrologic cycle due to the increase in greenhouse gases are projected to cause variations in intensity, duration, and frequency of precipitation events. Quantifying the potential effects of climate change and adapting to them is one way to reduce vulnerability. Since rainfall characteristics are often used to design water management structures, reviewing and updating rainfall characteristics for future climate scenarios is necessary. In this study, IDF curves relationship is determined to utilize statistical analysis of rainfall data for a record of 38 years. The methods used are Log-Normal, Normal, and Gumbel (EV-I). The distributions were carried out with return periods of 2, 5, 10, 25, 50, and 100 years with durations of 1, 2, 3, 6, 12, and 24 hours. Highest intensity values were observed for the Gumbel method and the values obtained from other methods were close to each other.

Keywords: IDF, Hydrologic, Statistical, Empirical, Hypothesis, Vulnerability

Precipitation is a crucial component of Hydrological cycle through which ground water recharges and surface water rejuvenates in the form of rivers, ponds, wells, stream networks etc (Agarwal and Kumar 2019). Due to inadequacy and severity of precipitation, numerous risks and hazard prevailing in the society (Bezak et al 2017, Asadi et al 2017a). Thus, knowledge of extreme precipitation events of different intensities is required for designing various Hydraulic structures which regulates storm runoff viz. flood detention reservoirs, sewer systems etc (Kumar et al 2018, Agarwal 2019). Such information is of enormous importance to hydrology, which is expressed as an association with intensity, duration and return period of rainfall (inverse of probability of exceedance). Quantification of rainfall is of utmost importance in designing and risk analysis pertaining to various hydrologic and hydraulic studies (Asadi et al 2017b, Sujatha et al 2019). Precipitation data is generally used for numerous assessment and exploration related to climate, environment, drainage etc (Kesanapalli 2018). Using these data Intensity-duration-frequency curves can be prepared for a region, which proclaim the alliance between rainfall intensity, duration and return period for a specified duration. In this IDF plot duration of rainfall is taken along abscissa, intensity of rainfall along ordinate while return period as third component. Application of this plot or curve can be observed in LULC planning, soil protection schemes, sewer and storm water management (Ahamed and Agarwal

2019). To determine flow carrying capacity of channels and pumping stations for managing, planning and designing of water resources projects, this IDF curve is helpful in many aspects. Statistical methods pertaining to water resource assessment can be more prominent to manage intense or severe rainfall events. These methods play a crucial role by analyzing the extreme weather scenario like floods; thus, suitable measures can be adopted to mitigate the risk of loss of life and property. Hence, utmost precipitation events evaluation gives direction in various civil engineering works like reservoir management, flood forecasting, hydraulic structure designs etc.

Numerous studies (Mailhot et al 2007, Paola et al 2014, Kumar et al 2019) have been carried to establish interrelation between different places across the globe to incorporate IDF curve applications in various domains. For developing countries like India, Pakistan, Afghanistan, Myanmar, Bhutan, Nepal etc. these relationships are not done accurately for many regions. Some research studies are conducted using design IDF curves where water resources projects are existing while the area is ungauged. Three methods for probability distribution analysis is used by (AlHassoun 2011) to approximate the intensity of rainfall in Riyadh, Saudi Arabia. These methods are namely Log Pearson Type III, Gumbel and Log Normal which were used for IDF curve generation alternatively of Mechanics, Energy and Environment. Similarly, IDF relations and its governing

equation is formulated for Hafr and Al Batin Najran, Saudi Arabia using Log Pearson Type III and Gumbel (Elsebaie 2012). Using goodness of fit technique, the most accurate method among these is determined for the region. For Eskisehir region, Turkey four methods for probability distribution analysis is done to develop IDF relationship and its governing equation (Hailegeorgis et al 2013). Various studies to create IDF curve using Gumbel method of probability distribution is done by (Singh and Zhang 2007) to compare results derived from empirical relationships. These relationships are mainly based on areas and thus, IDF curves can be made separately for different regions (Mirhosseini et al 2013, Marta et al 2009, Rodríguez et al 2014). The purpose of this study is mainly to produce IDF-curves for precipitation using three different statistical methods for Krishna district region.

MATERIAL AND METHODS

Krishna District is a district of India's Andhra Pradesh state among the nine districts of Coastal Andhra region. It is named after the Krishna River which flows through the district. Machilipatnam is the administrative headquarters of the district. The district is situated between 80° 01' E and 81° 33' E, of the eastern longitudes and 15° 45' N and 17° 10' N, of northern latitudes (Fig. 1). The boundaries of this district are West Godavari district in the East, Bay of Bengal in the South, Guntur and Nalgonda districts in the West and Khammam district in the North directions. In the study area small and medium sized hillocks are present which are mostly rocky and lacks vegetation cover. The surrounding plain areas are covered with red and sandy soil. The sandy clay loams are formed along Krishna river. There are four types of soils in the area, viz., black cotton soils (58%), sandy clay loams (23%), red loamy soils (17%), and sandy soils (2%). The sandy soils form a fringe along the coast. The black cotton soil is most extensive and occurs in Western part. With increasing growth of population, the people are moving towards the foot of the hills which later led to expansion on the hill slopes. The sandy clay loams are formed along Krishna river (Akhila Manne et al 2010).

Meteorological characteristics: Extreme hot and moderate winter is predominating the area during Summer and Winter seasons. The maximum temperature rises to 47°C during summer and minimum temperature drops to 20°C during winter. From April to June month hottest conditions prevail, thus, days are much longer than normal during this period. Hence, the atmospheric conditions and weather characteristics of the district prove it to be Tropical region. The average precipitation occurring annually in the region is about 1028 mm and routine wetness or dampness is

78%. The rainfall is occurring generally from June to September which is mainly dependent on Southwest monsoon. Nearly 30% of gross rainfall volume is contributed by North-East monsoons from October to December. During December to February month the cold and dry conditions exists. The monthly extremes of average temperature and precipitation is shown in (Table 1). Temperature and Rainfall data on daily basis for last 30 years is collected from State Disaster Management Authority (APSDMA), A.P. The Spatio - Temporal variability of climatic parameters of the region is shown in (Fig. 2). The maximum variability of precipitation is observed in coastal region while temperature is seen to be increased in Urban area due to Urban Heat Island effects. The general methodology adopted in downscaling the future rainfall values is shown in (Fig. 3) to produce future IDF curves of the region.

Future downscaled rainfall time series: Due to low bias and variability in uncertainty, Global Climate Models can give better results than Regional Climate model. Generally bias-correction is done for RCM variables for any regional studies related to hydrological applications. It has proficiency to incorporate Orographic and Cyclonic rainfall which is more capable than models developed by CMIP5 projects. The precipitation record of year 2017 to 2040 is accessed from Earth System Grid Federation which is a database of South Asian region. These data belong to CORDEX-GCM and NOAA-GFDL-ESM2M climatic model which are used under Representative Concentration Pathway 4.5. RCPs are based on growth of population, sources of energy and various pivotal socio-economic activities. RCP 4.5 utilizes the force of radiation at 4.5 W/m² and prolonged emission of

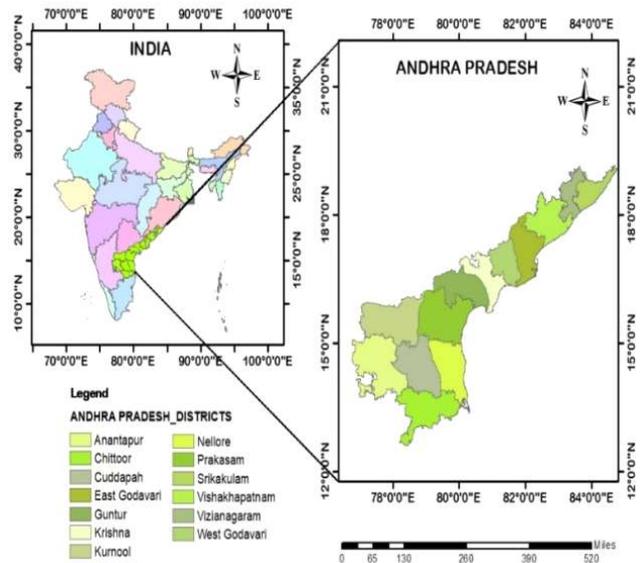


Fig. 1. Study area map of the region

greenhouse gases and LULC changes in global economic framework (Kumar et al 2020).

Estimation of short-duration rainfall: An empirical reduction equation is being used by the Indian meteorological department (IMD) to estimate the values of rainfall from the annual maximum values for durations like 1-2-3-5- and 8-hours rainfall values.

$$P_t = P_{24} \sqrt{\frac{t}{24}}$$

where P_t is the required rainfall depth in mm at 't' hr duration of rainfall for which the rainfall depth is required in an hour and P_{24} is the daily rainfall in mm.

Constructing of IDF Curves

General: For approximating the intensities of rainfall for different time periods and recurrence intervals the IDF can be used for developing the relationship between precipitation and storm frequency. Storm Design for different water system projects are mainly done through IDF curves and without determining the approximate rainfall intensity hydrologic analyses is not possible and it is not possible to obtain the IDF data for one particular storm but by collecting the data for large number of storms relationship can be

determined with reference to large number of data collected for storms. A three-step procedure is adopted to develop the IDF curves for a specific time period such as 1 hour, 2-hour, 3-hour, 6-hour, 12-hour, 24 hour records to fit any of the probability distribution functions. To determine the intensity of rainfall for the specific period, probability distribution function is utilised in earlier step and already defined return period like 2, 5, 10, 25,50, 100 years, etc.

PDF fitting using frequency distribution method: Around the globe few of theoretical probability distribution functions

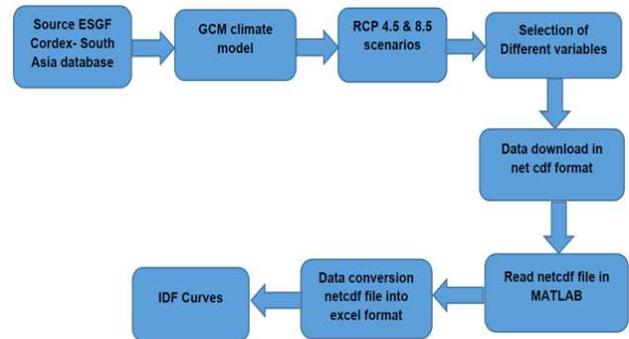


Fig. 3. Flowchart of methodology

Table 1. Historical average of climatic data for Krishna district (IMD)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Avg high (°C)	30	32.7	35.4	37.4	39.8	37.2	33.2	32.4	32.6	31.8	30.7	29.6	33.6
Avg low (°C)	18.7	20.1	22.4	25.5	27.5	27	25.4	25.1	25.1	24	21.3	19.1	23.4
Avg precipitation (mm)	0.9	5.3	9.6	14.3	51.3	131.9	218.4	185.6	163.5	142	51.3	6.7	998.2
Avg precipitation (days)	0.1	0.4	0.5	1	3.1	7.6	12.6	11.5	8.8	7.1	2.8	0.6	56.1

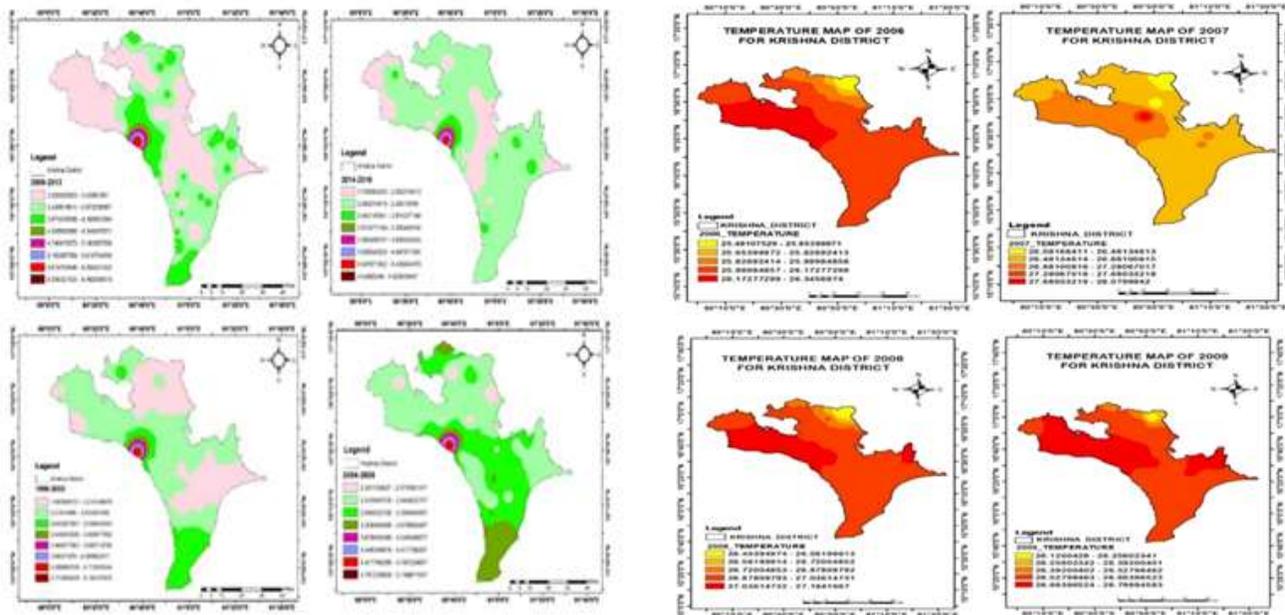


Fig. 2. Spatiotemporal variability of rainfall and temperature in Krishna district

were very often utilized and applied, e.g. GEV (Generalized Extreme Value Distribution), Gumbel (Extreme Value Distribution type 1), Normal Distribution, log-Normal Distribution, Pearson and log Pearson Type III Distribution, etc. To develop the IDF curves from rainfall data for study area three common probability distribution functions were used, which are mainly Normal, Log-Normal and Gumbel.

Normal function: In statistics the Normal (Gaussian) distribution is most prominent method. For obtaining the rainfall intensities for a specified return periods and every storm time period many calculations need to be carried out, i.e. like all other methods, this method also calculates the rainfall intensities. Below mentioned is the equation to determine the P_T (in mm) using a specified time (T in years) and specific duration (t):

$$P_T = P + K_T S \text{-----(1)}$$

Here, ' K_T ' is the frequency factor and is equal to 'z' for log-normal and normal distribution which is calculated by:

$$Z = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189629w^2 + 0.001308w^3} \text{ (2)}$$

Here, 'w' is given as:

$$w = [\ln(1/p^2)]^{0.5} \text{-----(3)}$$

In the above equation P is the probability of occurrence in a specified return period. And p is given as:

$$P = 1/T \text{-----(4)}$$

For the case of $p > 0.5$, 'p' in Eq. (3) is substituted by (1-p) and z gives a negative value. Considering Eq. (1), For a single time 'p' is the arithmetic average of the rainfall records. Moreover, 'S' is the standard deviation. On multiplication of the 'S' and 'K' give the output as departure of a return period.

To develop IDF calculation of precipitation and rainfall intensity I (in mm/hr) with respect to a period T is calculated.

$$I_t = P_t/t$$

Here, t represents the duration in hours.

The following procedure utilised to find the intensity for fourteen durations and 6 return periods the calculations were made.

Log-normal function: Using the log normal method with the interference of logarithm variables the frequency precipitation can be calculated which is like normal method. Calculations for average precipitation and standard deviations are done through logarithmically transformed data.

$$P^* = \text{Log}(P_i)$$

$$\bar{P}^* = \frac{1}{n} \sum_{i=1}^n P_i^*$$

$$S^* = \left[\frac{1}{n} \sum_{i=1}^n (P_i^* - \bar{P}^*)^2 \right]^{0.5}$$

The Frequency precipitation is calculated as:

$$P_T^* = P + K_T S^*$$

The intensity can be calculated by:

$$I_t = P_T^*/t$$

Here P_T is the antilogarithm of P_T^* calculated by equation.

Gumbel Function (EV1): After the name of developer Gumbel, the functionality is termed and it is also called as type 1 distribution of maxima. Utilising the Gumbel distribution, the IDF curves are studied and assessed as fitting of maxima attain appropriateness. Utilisation of the maximum rainfall values and extreme data with ease is done by the Gumbel method. Likely to Normal function this method can also be used to determine the frequency precipitation, but with a different frequency factor K_T which is given by:

$$K_T = -\frac{\sqrt{6}}{\pi} \left\{ 0.5772 + \ln \left[\ln \left(\frac{T}{T-1} \right) \right] \right\}$$

The Gumbel distribution uses the following equation proposed by chow:

$$X_T = (X_{ave} + K_T S)$$

Where X_T is the intensity in mm/hr, X_{ave} is the Mean, S is the standard deviation and K_T is the frequency factor.

$$\bar{X} = \frac{1}{m} \sum_{i=1}^m x_i$$

$$S = \frac{1}{m-1} \sum_{i=1}^m (x_i - \bar{X})^2$$

The frequency intensities that are calculated using Gumbel methods.

RESULTS AND DISCUSSION

The IDF curve obtained based on the chosen methodology, links the relationship between duration of rainfall (mins), intensity (mm/hr) and return period (years). The return intervals in the Table 2 are describes as frequency factor for different functions of probability distribution functions. There are three different methods namely Normal, Log-Normal and Gumbel which is proposed to be adopted for rainfall intensity calculations for different return period.

The intensity of rainfall and its return duration is directly proportional to each other as shown in Figures 4, 5 and 6 which is a combination of three methods. Hence, if return

Table 2. Value of frequency factor for different return periods

Probability distribution methods	Frequency factor (K_T)					
	Return period (Years)					
	2	5	10	25	50	100
Gumbel	0.16	0.71	1.30	2.04	2.59	3.13
Normal	0.11	0.84	1.28	1.75	2.05	2.32
Log normal	0.13	0.78	1.27	1.70	2.46	2.73

interval increases, then, duration of storm also increases and vice versa. It is depicted from the plots that rainfall intensity and storm duration are inversely proportional to each other in each case. A major change of return period is observed with variation of rainfall intensity when it reaches 3 to 6 hours

duration which gradually decreases. The Intensity Duration Curve shows that Gumbel method give highest rainfall intensity values among the three methods for higher return period and remaining values deducted from rest of the methods are close to each other.

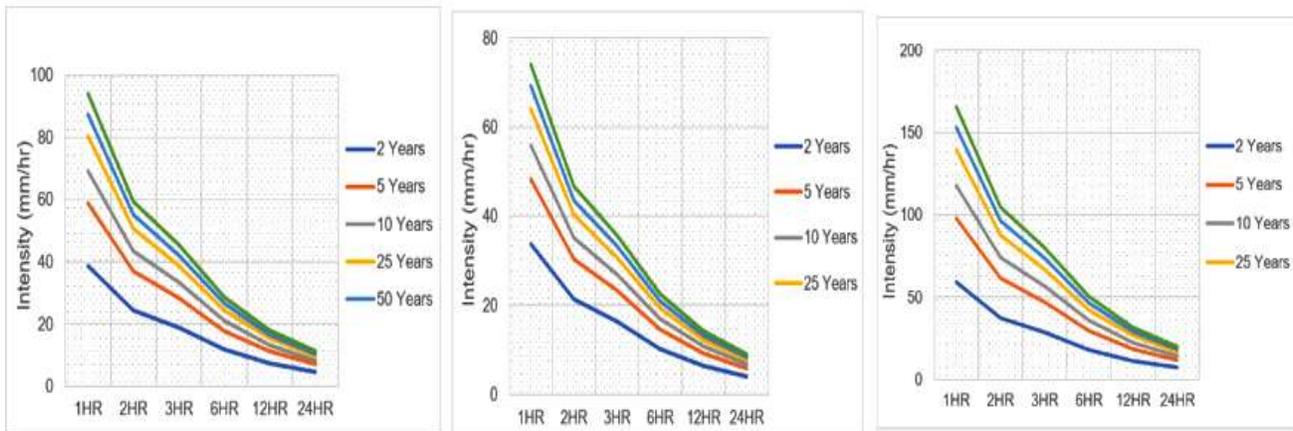


Fig. 4. IDF Curve using normal method for historical, RCP 4.5 and RCP 8.5 rainfall events

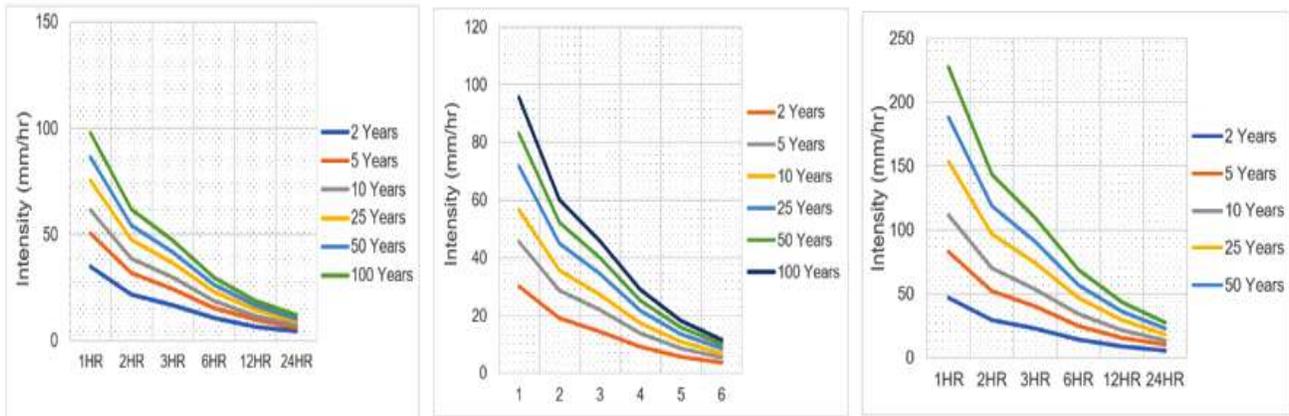


Fig. 5. IDF Curve using log-normal method for historical, RCP 4.5 and RCP 8.5 rainfall events

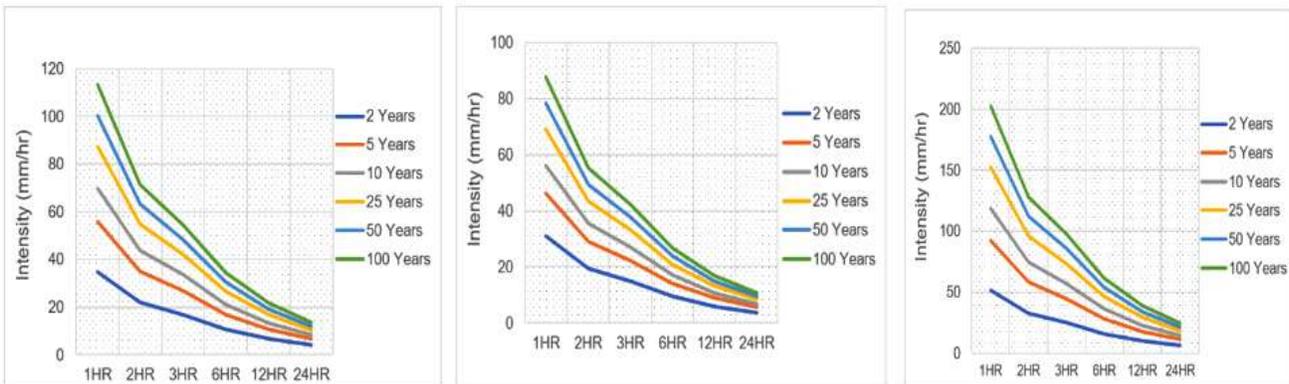


Fig. 6. IDF Curve using gumbel method for historical, RCP 4.5 and RCP 8.5 rainfall events

CONCLUSION

The aim of the study is to develop the IDF curves to calculate the intensity using the specific storm duration and return period. For this purpose, three different distribution methods have been used in the study for fitting the data. After the development of the IDF curves, Log-Normal method indicated some abnormality in this study because the value of intensities using this method are found to be very high while low intensities are observed in the case of Log-Pearson III and Gumbel method. Gumbel distribution and those from the empirical equations were the same. The floods with higher return period were severe when compared to that of lower return period. The intensity duration frequency curve for the Krishna region of Andhra Pradesh were analyzed using the Daily rainfall data obtained from Andhra Pradesh State Development Planning Society (APSDPS). Results obtained amongst all the method's highest rainfall intensity was calculated for the Gumbel method and the rest has almost similar values. The floods with higher return period were severe when compared to that of the lower return period.

REFERENCES

- Agarwal S and Kumar S 2019a. Applicability of SWMM for semi urban catchment flood modeling using extreme rainfall events. *International Journal of Recent Technology and Engineering* **8**(2): 245-251.
- Agarwal S, Patil JP, Goyal VC and Singh A 2019b. Assessment of water supply-demand using water evaluation and planning (WEAP) model for ur river watershed, Madhya Pradesh, India. *Journal of The Institution of Engineers (India): Series A* **100**(1): 21-32.
- Ahamed SMF and Agarwal S 2019. Urban flood modeling and management using SWMM for new R.R. Pet region, Vijayawada, India. *International Journal of Recent Technology and Engineering* **7**(6C2): 317-322.
- AlHassoun SA 2011. Developing an empirical formulae to estimate rainfall intensity in Riyadh region. *Journal of King Saud University-Engineering Sciences* **23**(2): 81-88.
- Asadi SS, Kumar MS, Kumar NV and Rajyalakshmi K 2017a. Estimation of runoff for agricultural utilization using geoinformatics: A model study from Telangana state. *International Journal of Civil Engineering and Technology* **8**(10): 472-483.
- Asadi SS, Kumar MS, Sree BR and Sujatha M 2017b. Remote sensing and GIS based water quality estimation for Thimmapally watershed. *International Journal of Civil Engineering and Technology* **8**(8): 1626-1635.
- Bezak N, Šraj M and Mikoš M 2016. Copula-based IDF curves and empirical rainfall thresholds for flash floods and rainfall-induced landslides. *Journal of Hydrology* **541**: 272-284.
- Elsebaie IH 2012. Developing rainfall intensity-duration-frequency relationship for two regions in Saudi Arabia. *Journal of King Saud University - Engineering Sciences* **24**(2): 131-140.
- Hailegeorgis TT, Thorolfsson ST and Alfredsen K 2013. Regional frequency analysis of extreme precipitation with consideration of uncertainties to update IDF curves for the city of Trondheim. *Journal of Hydrology* **498**: 305-318.
- Kesanapalli SK, Konda RR and Pitta SK 2018. Planning and estimation of water grid in sub basin of Gundlakamma River, Andhra Pradesh, India: A model study. *International Journal of Civil Engineering and Technology* **9**(6): 162-171.
- Kumar MR, Naveen M, Pravalika MS and Kumar S 2019. Variability and time series trend analysis of rainfall over Krishna District of Andhra Pradesh: A case study. *International Journal of Recent Technology and Engineering* **7**(6C2): 720-726.
- Kumar PS, Praveen TV, Prasad MA and Rao PS 2018. Identification of critical erosion prone areas and computation of sediment yield using remote sensing and GIS: a case study on Sarada river basin. *Journal of The Institution of Engineers (India): Series A* **99**(4): 719-728.
- Kumar PVA, Agarwal S and Ramanamurthy PV 2020. Forecasting regional scale rainfall and temperature using statistical downscaling model. *Test Engineering and Management* **83**(9226): 9226-9235.
- Marta BARA, Kohnová S, Ladislav GAÁL, Szolgay J and Hlavčová K 2009. Estimation of IDF curves of extreme rainfall by simple scaling in Slovakia. *Contributions to Geophysics and Geodesy* **39**(3): 187-206.
- Mirhosseini G, Srivastava P and Stefanova L 2013. The impact of climate change on rainfall Intensity–Duration–Frequency (IDF) curves in Alabama. *Regional Environmental Change* **13**(1): 25-33.
- Mailhot A, Duchesne S, Caya D and Talbot G 2007. Assessment of future change in intensity–duration–frequency (IDF) curves for Southern Quebec using the Canadian Regional Climate Model (CRCM). *Journal of hydrology* **347**(1-2): 197-210.
- Paola FD, Giugni M, Topa ME and Bucchignani E 2014. Intensity-Duration-Frequency (IDF) rainfall curves, for data series and climate projection in African cities. *Springer Plus* **3**(1): 133.
- Rodríguez R, Navarro X, Casas MC, Ribalaygua J, Russo B, Pouget L and Redaño A 2014. Influence of climate change on IDF curves for the metropolitan area of Barcelona (Spain). *International Journal of Climatology* **34**(3): 643-654.
- Singh VP and Zhang L 2007. IDF curves using the Frank Archimedean copula. *Journal of Hydrologic Engineering* **12**(6): 651-662.
- Sujatha M, Satyanarayana T and Asadi SS 2019. Spatial distribution analysis on groundwater quality of Sarada river basin, Visakhapatnam, AP India. *International Conference on Advances in Civil Engineering* **7**(6C2): 747-751.



Bias Correction of Climate Model Outputs for Climate Change Impact Assessment in Central Kashmir

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Abstract: The impacts of climate change are often quantified by impact models whereas impact models typically require high resolution unbiased input data, global and regional climate models are in general biased, their resolution is often lower than desired. Thus, many users of climate model data apply some form of bias correction and downscaling. In this study two correction functions using two methods viz. modified difference approach and linear scaling method were applied for local bias correction of maximum temperature (T_{max}), minimum temperature (T_{min}) and precipitation data at monthly scales and validated to minimize the bias between the modelled (HAD GEM2-ES-GCM) and observed climate data for the Central Kashmir of great Himalayas. Correction functions derived using linear scaling method at monthly time scale for T_{max} , T_{min} and precipitation were found to be better than modified difference approach for bias correction of the climate data to bring it to close to observed data.

Keywords: Bias correction, Climate change, GCM, RCM, Modified difference approach, Linear scaling

The Regional Climate Models (RCMs) provide a new opportunity for climate change effect analysis since they have a higher spatial resolution and more reliable results on a regional scale compared to General Circulation Models (GCMs) (Buonomo et al 2007, Chen et al 2013, Turco et al 2017). Numerous studies have shown that RCM outputs improve the representation of climate change information at the mesoscale by providing spatially and physically coherent outputs with observations (Chen et al 2013, Turco et al 2017). However, the original RCM outputs still contain considerable bias, which is inherited from the forcing of GCMs or produced by systematic model error which may prevent their direct application for the analysis of the behavior of the climate system and eventual changes and their local impacts. (Durman et al 2001, Herrera et al 2010). Therefore, bias correction of RCM data is the prerequisite step to the data being used in any climate change effects analysis. Many possible impacts of future climate change will be experienced at the regional scale (Barros et al 2014). These impacts may be quantified by impact models, which often require high resolution meteorological input data that are for present conditions, unbiased compared to observations (Wilby et al 2000). The errors in modelled daily rainfall and temperature may afflict the monthly or annual time trends and magnitude. Andreasson et al (2004) pointed out that these biases are particularly pronounced for Precipitation than temperature. There are two distinct approaches to downscaling GCM outputs dynamic downscaling using a Regional Climate

Model (RCM) and statistical downscaling. Dynamic downscaling is computationally expensive. It is therefore not always feasible to perform dynamic downscaling at the required spatial resolution, especially if predictions from multiple models are desired. In contrast, statistical downscaling is computationally efficient and can be suitably used to perform the spatial downscaling and bias correction for a large amount of GCM outputs, and has become a commonly used tool in impact studies. Various studies demonstrated that the overall performance of statistical and dynamic downscaling were similar in reproducing the present-day climate for the respective regions (Murphy 1999, Wilby et al 2000).

There are also statistical downscaling methods primarily for the purpose of bias correction which involve some form of transfer function derived from cumulative distribution functions (CDFs) of observations and model simulations (Ines and Hansen 2006, Piani et al 2010, Wood et al 2004). The advantages and disadvantages of both approaches have been thoroughly documented (Fowler et al 2007, Wilby et al 2009). The key advantage of the statistical approach is the lower computational requirement compared to the dynamical model-based alternative, and thus, statistical downscaling approaches are widely used in climate impact-related research work. A number of statistical bias correction methods have been developed and successfully applied in climate change impact studies (Grillakis et al 2013). Their main task is to adjust the statistical properties of

climate simulations to resemble those of observations, in a common climatological period. Hence, the statistical outcome of an impact model run using observational data is likely to be reproduced by the adjusted data. Several bias correction methods have been developed to downscale meteorological variables from the RCMs, ranging from the simple scaling approach to sophisticated distribution mapping (Teutschbein and Seibert 2012) and their applicability in the Central Kashmir has not been investigated; therefore, evaluating and finding the appropriate bias correction method is necessary for the climate change impact studies.

MATERIAL AND METHODS

The present study focuses on Central Kashmir of the Indian western Himalayas. In this study two simple methods (1) Modified difference approach and (2) Linear scaling method have been used for local bias correction of temperature and precipitation. There is often a clear bias from observations in the statistics of variables produced by GCMs such as temperature and precipitation due to limitations in, among others as a result of the incorporation of local topography and non-stationary phenomena within the GCMs. The daily data was obtained from Marksim DSSAT weather file generator under GCM (HAD GEM2-ES-GCM) for the period of 2010-2018. The observed data was obtained from Agro-meteorological station SKUAST-Kashmir.

Modified difference approach: In the modified difference method some statistical parameters were added to improve the correction function. For example in temperature correction, mean (μ) and standard deviation (σ) were added which aimed at shifting and scaling to adjust the μ and variance σ^2 (Leander and Buishand 2007). The corrected daily temperature T (cor) is obtained as:

$$T(\text{cor}) = T(\text{obs}) + \frac{\sigma(\text{obs})}{\sigma(\text{mod})} \times (T(\text{uncor}) - T(\text{obs})) + T(\text{obs}) - T(\text{mod}) \quad (1)$$

Where $T(\text{uncor})$ is the uncorrected daily temperature for a scenario, $T(\text{obs})$ and $T(\text{mod})$ is the observed and modelled daily temperature obtained from the baseline scenario. In this equation an over bar denotes the average over the considered period. Similarly in case of precipitation correction, the resulting precipitation from different methods was multiplied by $\sigma RF_{\text{obs}} / \sigma RF_{\text{mod}}$ as:

$$RF \text{ model}_{\text{cor}} = (RF \text{ model}_{\text{uncor}} + (dx) \times \left(\frac{\sigma RF_{\text{obs}}}{\sigma RF_{\text{mod}}} \right)) \quad (2)$$

Where (dx) is the average daily difference of observed and modelled values.

Linear scaling method: The linear scaling (LS) method aims to perfectly match the monthly mean of corrected values

with that of observed ones (Lenderink et al 2007). It operates with monthly correction values based on the differences between observed and raw data (raw GCM simulated data in this case). Precipitation is typically corrected with a multiplier and temperature with an additive term on a monthly basis. The multipliers and additives are based on the formulas given under linear scaling which are:

$$P_{\text{cor},m,d} = P_{\text{raw},m,d} \times \frac{\mu(P_{\text{obs},m})}{\mu(P_{\text{raw},m})} \quad (3)$$

$$T_{\text{cor},m,d} = T_{\text{raw},m,d} + \mu(T_{\text{obs},m}) - \mu(T_{\text{raw},m}) \quad (4)$$

Where $P_{\text{cor},m,d}$ and $T_{\text{cor},m,d}$ are corrected precipitation and temperature on the d th day of m th month, and $P_{\text{raw},m,d}$ and $T_{\text{raw},m,d}$ are the raw precipitation and temperature on the d th day of m th month. $\mu(\dots)$ represents the expectation operator e.g. $\mu(P_{\text{obs},m})$ represents the mean value of observed precipitation at given month (m).

RESULTS AND DISCUSSIONS

Maximum and minimum temperature: Monthly averages of 9 years (2010-2018) of the observed and GCM-HAD GEM2 ES modelled maximum temperature (T_{max}) and minimum temperature (T_{min}) for the location showed that the modelled temperature approximately represented the observed seasonal cycle. However, the modelled values of T_{max} were higher than that of the observed in May, June, August, September, October and December. Modelled T_{min} also followed the trend similar to that of T_{max} but the modelled values were higher for May, June, July, August, September, October and December and less for November (Fig. 1-2). The analysis of the statistical parameters i.e., annual mean (μ), standard deviation (σ) and variance (σ^2) of T_{max} showed that the μ of the modelled T_{max} was 3 per cent more than that of the observed while as σ of modelled T_{max} was 20 per cent more than that of observed T_{max} data. In T_{min} μ of modeled was 43 per cent more than observed and σ was 31 per cent more in the modelled data (Table 1).

Precipitation: In precipitation, the modelled precipitation was less during January, February, March, April, June, August, September and November. The model predicted higher precipitation than observed in the remaining months of year (Fig. 3). The analysis of the statistical parameters revealed that in case of precipitation, μ of the modelled precipitation was 33 per cent less than that of the observed and σ for the same was 31 per cent less (Table 1).

Climate data correction: The observed data from SKUAST-Kashmir Agrometeorology station was available from 1985-2018, but the modelled climate data was available from 2010-2018. So for calibration, data from 2010-2018 was used and

randomly validated for two years. For correcting, biases in the climate data, two different approaches viz. modified difference approach and linear scaling for generating correction factors were used.

Modified Difference Approach

Temperature: Correction functions based on modified difference (Leander and Buishland 2007) were developed (equation 1) for each of the calendar months (Table 2). The use of these correction functions for the correction of the modelled data to make it close to observed data for both T_{max} and T_{min} is shown in (Fig. 4-5). The computed statistical parameters of T_{max} and T_{min} are presented in Table 3. The differences in μ values were comparable in model corrected T_{max} and T_{min} at monthly time scale compared to that of modelled and observed data after correction, but differences in σ , σ^2 values in model

corrected T_{max} and T_{min} were higher than that of the modelled and observed data by 33 and 38 per cent, respectively.

Precipitation: Correction functions based on modified difference approach were developed based on Equation 2, for monthly basis and these functions for each calendar month (Table 2). With modified difference approach (Equation 2) the variation in cumulative model corrected to that of the observed precipitation was increased (Fig. 6). The variation was of 12 mm more in corrected model data than observed precipitation data at monthly time scale. The variation in μ value was more in corrected modelled and observed precipitation compared to that of modelled and observed while as σ and σ^2 values were less in corrected modelled and observed precipitation compared to that of modelled and observed (Table 4).

Table 1. Statistical parameters of modelled and observed temperatures and precipitation

Parameter	T_{max} (°C)		T_{min} (°C)		Precipitation (mm)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	20.09	20.79	6.42	8.58	80.11	54.03
Standard deviation	8.73	10.51	7.29	9.58	8.39	5.83
Variance	76.15	110.45	53.21	91.75	70.39	34.03

Table 2. Correction functions using modified difference approach for modelled daily temperature and precipitation

Month	Correction factors		
	T_{max} (°C)	T_{min} (°C)	Precipitation (mm)
January	$T_{cor} = 8.34 + 0.821 * (T_{mod} - 14.45)$	$T_{cor} = -2.71 + 0.757 * (T_{mod} + 1.39)$	$P_{cor} = (P_{mod} - 0.88) * (1.425)$
February	$T_{cor} = 10.23 + 0.829 * (T_{mod} - 11.08)$	$T_{cor} = -0.066 + 0.759 * (T_{mod} + 0.142)$	$P_{cor} = (P_{mod} + 0.26) * (1.456)$
March	$T_{cor} = 16.01 + 0.826 * (T_{mod} - 18.17)$	$T_{cor} = 3.34 + 0.760 * (T_{mod} - 2.7)$	$P_{cor} = (P_{mod} + 2.59) * (1.448)$
April	$T_{cor} = 19.39 + 0.828 * (T_{mod} - 18.9)$	$T_{cor} = 6.45 + 0.761 * (T_{mod} - 5.41)$	$P_{cor} = (P_{mod} + 1.26) * (1.467)$
May	$T_{cor} = 24.43 + 0.827 * (T_{mod} - 20.44)$	$T_{cor} = 9.43 + 0.759 * (T_{mod} - 2.85)$	$P_{cor} = (P_{mod} - 2.13) * (1.429)$
June	$T_{cor} = 28.11 + 0.829 * (T_{mod} - 25.4)$	$T_{cor} = 13.02 + 0.761 * (T_{mod} - 8.63)$	$P_{cor} = (P_{mod} + 0.60) * (1.424)$
July	$T_{cor} = 29.98 + 0.832 * (T_{mod} - 29.43)$	$T_{cor} = 16.97 + 0.766 * (T_{mod} - 14.11)$	$P_{cor} = (P_{mod} - 1.43) * (1.422)$
August	$T_{cor} = 29.43 + 0.832 * (T_{mod} - 26.43)$	$T_{cor} = 16.55 + 0.765 * (T_{mod} - 12.64)$	$P_{cor} = (P_{mod} + 1.58) * (1.436)$
September	$T_{cor} = 27.27 + 0.834 * (T_{mod} - 25.89)$	$T_{cor} = 11.67 + 0.763 * (T_{mod} - 9.65)$	$P_{cor} = (P_{mod} + 1.71) * (1.432)$
October	$T_{cor} = 22.87 + 0.833 * (T_{mod} - 19.79)$	$T_{cor} = 5.06 + 0.762 * (T_{mod} - 0.16)$	$P_{cor} = (P_{mod} - 0.52) * (1.427)$
November	$T_{cor} = 15.17 + 0.833 * (T_{mod} - 15.18)$	$T_{cor} = 0.4 + 0.759 * (T_{mod} - 2.44)$	$P_{cor} = (P_{mod} + 0.64) * (1.446)$
December	$T_{cor} = 9.89 + 0.839 * (T_{mod} - 7.58)$	$T_{cor} = -3.04 + 0.767 * (T_{mod} + 5.87)$	$P_{cor} = (P_{mod} + 0.43) * (1.446)$

*Symbol for multiplication

Table 3. Statistical parameters of model, corrected model and observed temperature as a result of modified difference approach

Parameter	T_{max} (°C)			T_{min} (°C)		
	Observed	Modelled	Model corrected	Observed	Modelled	Model corrected
Mean	20.09	20.79	21.34	6.42	8.58	9.80
Standard deviation	8.73	10.51	11.59	7.29	9.58	10.09
Variance	76.15	110.45	134.37	53.21	91.75	101.87

Linear Scaling Method

Temperature: Correction functions based on linear scaling method were developed based on equation 4 for each of the calendar month (Table 5). The use of these correction functions matched the time trends and magnitude of the model corrected and observed temperature for both T_{max} (Fig. 7) and T_{min} (Fig. 8) respectively. The differences in μ values were comparable in corrected modelled and observed T_{max} and T_{min} at monthly time scale. The differences in σ, σ^2 values in corrected and observed T_{max} and T_{min} were lesser than that of the modelled and observed data by 1 and 11 per cent respectively (Table 6).

Precipitation: Correction functions based on linear scaling

Table 4. Statistical parameters of model, corrected model and observed precipitation as a result of modified difference approach

Parameter	Precipitation (mm)		
	Observed	Modelled	Model corrected
Mean	80.11	54.03	3.03
Standard deviation	8.39	5.83	8.25
Variance	70.39	34.03	68.13

Table 5. Correction functions using linear scaling for correcting modelled daily temperature and precipitation

Month	Correction factors		
	Precipitation (mm)	T_{max} (°C)	T_{min} (°C)
January	0.75	6.11	1.32
February	17.57	0.85	-0.076
March	2.15	2.16	-0.64
April	10.48	-0.49	-1.04
May	0.51	-3.99	-6.58
June	1.43	-2.71	-4.39
July	0.68	-0.55	-2.86
August	1.83	-3.00	-3.91
September	4.82	-1.38	-2.02
October	0.61	-3.08	-4.90
November	2.84	0.01	2.04
December	2.06	-2.31	-2.83

Table 6. Statistical parameters of model, corrected model and observed temperature as a result of linear scaling method

Parameter	T_{max} (°C)			T_{min} (°C)		
	Observed	Modelled	Model corrected	Observed	Modelled	Model corrected
Mean	20.09	20.79	20.11	6.42	8.58	6.47
Standard deviation	8.73	10.51	8.83	7.29	9.58	8.13
Variance	76.15	110.45	77.99	53.21	91.75	66.06

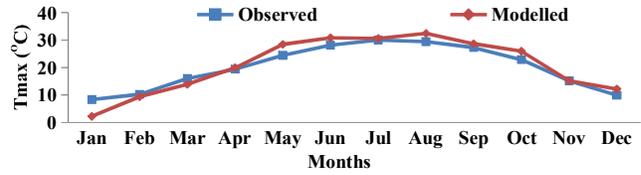


Fig. 1. Biases in average modelled data of T_{max}

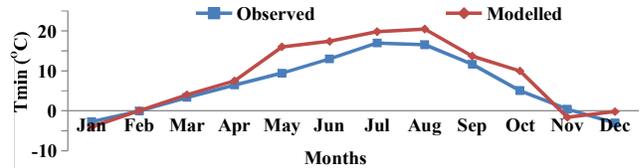


Fig. 2. Biases in average modelled data of T_{min}

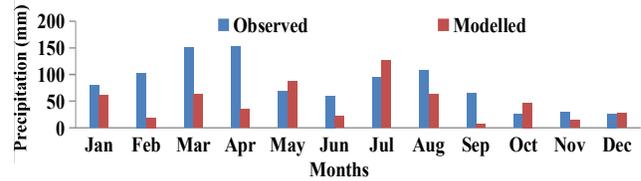


Fig. 3. Biases in average modelled data of precipitation

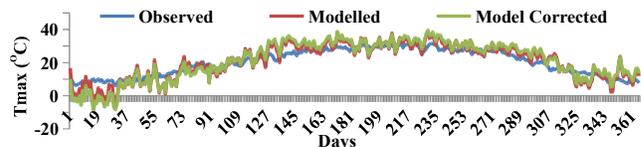


Fig. 4. Observed, modelled and model corrected maximum temperature by modified difference approach

Table 7. Statistical parameters of model, corrected model and observed precipitation as a result of linear scaling method

Parameter	Precipitation (mm)		
	Observed	Modelled	Model corrected
Mean	80.11	54.03	2.01
Standard deviation	8.39	5.83	7.24
Variance	70.39	34.03	52.37

Table 8. Statistical parameters of observed, modelled and model corrected Tmax, Tmin and precipitation by modified difference and linear scaling method

Parameter	Observed	Modelled	Modified difference approach	Linear scaling method
T_{max} (°C)				
Mean	20.09	20.79	21.34	20.11
Standard deviation	8.73	10.51	11.59	8.83
Variance	76.15	110.45	134.37	77.99
CV (RMSE) %	-	5.86	6.41	5.31
NRMSE	-	0.30	0.33	0.27
T_{min} (°C)				
Mean	6.42	8.58	9.80	6.47
Standard deviation	7.29	9.58	10.09	8.13
Variance	53.21	91.75	101.87	66.06
CV (RMSE) %	-	5.67	6.08	4.57
NRMSE	-	0.44	0.47	0.35
Precipitation (mm)				
Mean	2.63	1.78	3.03	2.01
Standard deviation	8.39	5.83	8.25	7.24
Variance	70.39	34.03	68.13	52.37
CV (RMSE) %	-	9.54	10.75	9.53
NRMSE	-	0.15	0.17	0.15

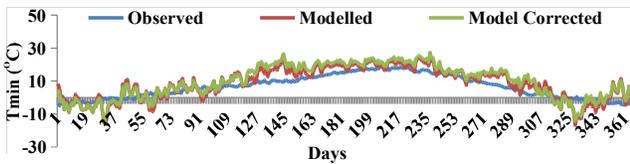


Fig. 5. Observed, modelled and model corrected minimum temperature by modified difference approach

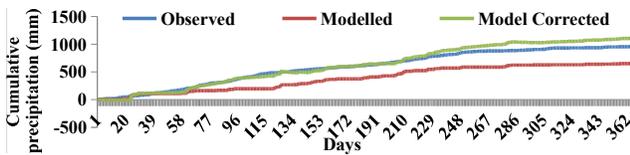


Fig. 6. Observed, modelled and model corrected precipitation by modified difference approach

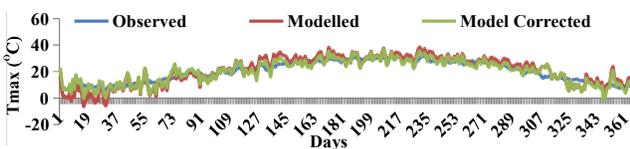


Fig. 7. Observed, modelled and model corrected maximum temperature by linear scaling

method of bias correction were developed based on (equation 3) for monthly basis and these functions for each calendar month (Table 5). With linear scaling method, variation in cumulative model corrected to that of the observed precipitation was decreased (Fig. 9). The variation was of 19 mm at monthly time scale. The variation in μ , σ and σ^2 values were less in corrected modelled and observed precipitation compared to that of modelled and observed (Table 7).

Best estimate: The minimum coefficient of variation was

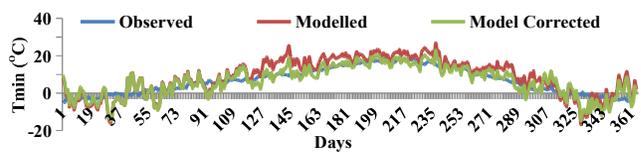


Fig. 8. Observed, modelled and model corrected minimum temperature by linear scaling

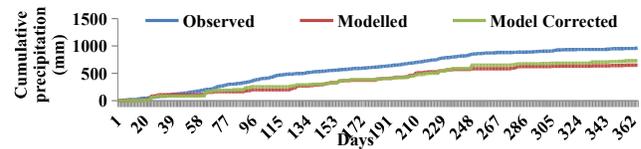


Fig. 9. Observed, modelled and model corrected precipitation by linear scaling method

observed with monthly correction function of linear scaling in both T_{\max} and T_{\min} . The RMSE for the modelled T_{\max} was 5.86 per cent, which was increased to 6.41 per cent by modified difference approach but was reduced to 5.31 per cent by linear scaling method on monthly time scale (Table 8). The corresponding value for modelled T_{\min} was 5.67 per cent, which was increased to 6.08 per cent by modified difference approach but was reduced to 4.57 per cent by linear scaling method on monthly time scale. The RMSE for the modelled cumulative precipitation was 9.54 per cent. It was increased to 10.75 per cent by modified difference approach while as it was reduced to 9.53 per cent by linear scaling method. Summing all these linear scaling method performed better than modified difference approach.

CONCLUSION

This paper compares the performances of (precipitation and temperature bias) RCM correction methods in Central Kashmir of Great Himalayas. Original RCM outputs are very biased, and this precludes their direct use in the analysis of climate change effects. The representation of the RCM simulations is highly dependent upon the region and season. All bias correction methods have the potential to improve the performance of reproducing precipitation and temperature, although the bias correction method greatly influences their final results. Downscaled data showed that temperature was having more bias than precipitation data using the GCM HAD GEM2 ES Model. Correction functions derived using linear scaling method at monthly time scale for T_{\max} , T_{\min} and precipitation were found to be better than modified difference approach for bias correction of the climate data.

REFERENCES

- Andreasson J, Bergstrom S, Carlsson B, Graham LP and Lindstrom G 2004. Hydrological change-Climate change impact simulation for Sweden. *AMBIO: A Journal of the Human Environment* **33**(4): 228-234.
- Barros V, Field C, Dokke D, Mastrandrea M, Mach K, Bilir T, Chatterjee M, Ebi K, Estrada Y and Genova R 2014. Climate change 2014: Impacts, adaptation, and vulnerability. Part B: regional aspects. *Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change, volume 5*. Cambridge University Press Cambridge, United Kingdom and New York, NY, USA.
- Buonomo E, Jones R, Huntingford C and Hannaford J 2007. On the robustness of changes in extreme precipitation over Europe from two high resolution climate change simulations. *Quarterly Journal of the Royal Meteorological Society* **133**(622): 65-81.
- Chen J, Brissette FP, Chaumont D and Braun M 2013. Performance and uncertainty evaluation of empirical downscaling methods in quantifying the climate change impacts on hydrology over two North American river basins. *Journal of Hydrology* **479**: 200-214.
- Durman C, Gregory JM, Hassell DC, Jones R and Murphy JA 2001. Comparison of extreme European daily precipitation simulated by a global and a regional climate model for present and future climates. *Quarterly Journal of the Royal Meteorological Society* **127**(573): 1005-1015.
- Fowler HJ, Blenkinsop S and Tebaldi C 2007. Linking climate change modelling to impacts studies: Recent advances in downscaling techniques for hydrological modelling. *International Journal of Climatology* **27**(12): 1547-1578.
- Grillakis MG, Koutroulis AG and Tsanis IK 2011. Climate change impact on the hydrology of Spencer Creek watershed in Southern Ontario, Canada. *Journal of Hydrology* **409**(1-2): 1-19.
- Herrera S, Fita L, Fernández J and Gutiérrez J 2010. Evaluation of the mean and extreme precipitation regimes from the ensembles regional climate multimodel simulations over Spain. *Journal of Geophysical Research: Atmospheres* **115**: D21117.
- Ines AVM and Hansen JW 2006. Bias correction of daily GCM rainfall for crop simulation studies. *Agricultural and Forest Meteorology* **138**(1-4): 44-53.
- Leander R and Buishand T 2007. Resampling of regional climate model output for the simulation of extreme river flows. *Journal of Hydrology* **332**(3-4): 487-496.
- Lenderink G, Buishand A and Van Deursen W 2007. Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. *Hydrology and Earth System Sciences* **11**(3): 1145-1159.
- Murphy J 1999. An evaluation of statistical and dynamical techniques for downscaling local climate. *Journal of Climate* **12**(8): 2256-2284.
- Piani CJO, Haerter and Coppola E 2010. Statistical bias correction for daily precipitation in regional climate models over Europe. *Theoretical and Applied Climatology* **99**(1-2): 187-92.
- Teutschbein C and Seibert J 2012. Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods. *Journal of Hydrology* **456**: 12-29.
- Turco M, Llasat MC, Herrera S and Gutiérrez JM 2017. Bias correction and downscaling of future rcm precipitation projections using a mos-analog technique. *Journal of Geophysical Research: Atmospheres* **122**(5): 2631-2648.
- Wilby RL and Wigley TML 2000. Precipitation predictors for downscaling: observed and general circulation model relationships. *International Journal of Climatology* **20**(6): 641-661.
- Wilby RL, Troni J, Biot Y, Tedd L, Hewitson BC, Smith DM and Sutton RT 2009. A review of climate risk information for adaptation and development planning. *International Journal of Climatology* **29**(9): 1193-1215.
- Wood AW, Leung LR, Sridhar V and Lettenmaier DP 2004. Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climatic Change* **62**(1-3): 189-216.



Multivariate Analysis in Two Rowed Genotypes of Barley (*Hordeum vulgare* L.)

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Abstract: This study aimed to determine the genetic variation among barley (*Hordeum vulgare* L.) genotypes by using principal component method of factor analysis. A total of 47 two rowed genotypes were evaluated for 10 metric traits at CCS Haryana Agricultural University, Hisar during *Rabi* 2016-17. First four principal components had eigen values more than one and have explained altogether 70.76 % of the total variation in 10 metric traits which were mainly associated with harvest index; days to heading and maturity; biological yield, grain yield and number of tillers per meter; and spike length, number of grains per spike, plant height and 1000-grain weight. The remaining principal components made very little contribution towards total variation and thus could not be considered of much practical value to barley improvement. The genotypes DWRUB 52, BH 14-07, BH 14-40, BH 13-26, BH 14-17, BH 14-25 and BH 15-05 were identified as most superior genotypes that might be considered desirable parents for hybridization. The results of the present study provide evidence of variability in barley and thus prove the adequacy of the principal component method in biological investigations.

Keywords: Principal component analysis, Factor analysis, Barley, Genotypes, Variation

Barley is an autogamous plant and one of the oldest members of family *Poaceae*, belongs to the genus *Hordeum* in the Tribe *Triticeae*. It is the most widely grown crop than any other cereals because of its hardiness to harsh environments like drought, cold, salinity/alkalinity and marginal lands. Currently, barley is the world's fourth most produced and marketed cereal. In India, 1.59 million tonnes barley was produced from an area of 0.62 million hectare with average productivity of 25.73 q ha⁻¹ during the crop season 2019-20 (ICAR-IIWBR 2020). In Haryana, barley was cultivated on 12,200 hectares with a production level of 44,000 tons. Punjab (3767 kg ha⁻¹) ranks first in average productivity followed by Haryana (3607 kg ha⁻¹), Uttar Pradesh (2956 kg ha⁻¹) and Rajasthan (2884 kg ha⁻¹).

Multivariate analysis refers to all statistical methods that simultaneously analyze multiple measurements on each individual or object under study. More explicitly, any simultaneous analysis of more than two variables can be considered as multivariate analysis. Multivariate data analysis facilitates a graphic display of the underlying latent factors and interface between individual samples and variables. Due to lack of knowledge regarding relative importance and usefulness of variables, the investigator tried to include all possible variables which made the data matrix perceivably large, complicated, unmanageable and beyond comprehension. Therefore, the investigator required a technique for systematic reduction and summarization of

data. Principal component analysis offers solution to this complex problem by transforming the original set of variables into a smaller set of linear combinations that account for most of the variability of the original set. It is basically a data reduction technique, where the total variation contained in a set of variables is considered. Factor analysis, also a data reduction technique, where no distributional assumption is required and interest centre on that part of variance which is shared by the common factors. In view of the immense importance of principal component and factor analysis in plant breeding, these techniques were applied to 47 genotypes of two rowed barley.

MATERIAL AND METHODS

The experimental was conducted at CCS Haryana Agricultural University, Hisar during *rabi* 2016-17. The experimental location is situated at latitude of 29°10'N, longitude of 75°46'E and altitude of 215.2 m above sea level in subtropical region of North Western Plain Zone of India. A set of 47 two rowed barley genotypes (Table 1) were evaluated in randomized block design with three replications. The plot size used was six rows with 5.0 m length and 0.23m between rows. Recommended package of practices were applied to raise the good crop. The observations were recorded for 10 metric traits *viz.*, days to heading, days to maturity, plant height (cm), spike length (cm), number of tillers per meter, number of grains per spike, 1000-grain

weight (g), harvest index (%), biological yield (kg/plot) and grain yield (kg plot⁻¹). Five randomly selected competitive plants in each replication were recorded for all the traits under study except of days to heading and maturity, biological yield and grain yield which were recorded on plot basis. Further, the value of harvest index was calculated as per the formula given by Donald and Humblin (1976).

The principal component analysis was computed to reduce the number of variables into a few correlated components that can explain much of the variability. It was performed using the correlation matrix to define the pattern of variation in the experimental material based on the mean of metric traits and also helps to identify traits that load the most in explaining the observed variability. SPSS Statistics v. 19.0 was used for principal component analysis. Those principal components having correlation matrix with eigen roots more than one were retained. Principal factor analysis was carried out using principal component method, which does not require assumption of multivariate normal distribution of population (Jaiswal 2000). As the initial factor loading was not clearly interpretable, the factor axes were rotated using

varimax method of orthogonal rotation which is the most popular method of which corresponded to spreading out of the squares of loading on each factor as much as possible. It made possible to obtain groups of large and negligible coefficients in different columns of the rotated factor loading.

RESULTS AND DISCUSSION

The first four principal components had eigen values more than one and altogether explained 70.76% of cumulative variability (Table 2). Rest of the principal components accounted for a little amount of the total variation. This indicated that these components are not of much practical value to the barley improvement. However, these components may provide good information if studied in more detail. The first principal component explained 28.457% of the total variation. The second, third and fourth principal components exhibited 18.386, 12.918 and 11.003% variation, respectively. The relative contribution of various traits to the total variability has also been reported by Zakova and Benkova (2006), Manjunatha et al (2007), Rahal-Bouziane et al (2015), Dyulgerova et al (2016), Saroei et al (2017), Amezrou et al (2018) and Kumar et al (2018a) in barley. Mekonnon et al (2014) also showed the presence of high genetic variation among barley genotypes based on principal component analyses for breeding strategies.

Initially, principal factor analysis was carried out without any rotation (Table 3) which revealed that three variables, viz., plant height, days to maturity and number of grains per spike had high loading on first factor, while biological yield, grain yield and number of tillers per meter were found to have high loading on second factor. Similarly, harvest index on fourth have high loading. None of the variables was highly loaded on third factor. Factor loading of different variables indicated that three out of 10 variables were left without high

Table 1. List of two rowed barley genotypes used in the study

Sr. No.	Genotypes	Sr. No.	Genotypes
1	BH 10-30	25	BH 16-05
2	BH 12-29	26	BH 16-08
3	BH 13-20	27	BH 16-09
4	BH 13-26	28	BH 16-12
5	BH 14-06	29	BH 16-14
6	BH 14-07	30	BH 16-15
7	BH 14-25	31	BH 16-16
8	BH 15-17	32	BH 16-19
9	BH 14-17	33	BH 16-21
10	BH 14-40	34	BH 16-22
11	BH 14-43	35	BH 16-23
12	BH 15-05	36	BH 16-24
13	BH 15-11	37	BH 16-25
14	BH 15-12	38	BH 16-26
15	BH 15-24	39	BH 16-27
16	BH 15-38	40	BH 16-28
17	DWRB 101	41	BH 16-31
18	BH 885	42	BH 16-32
19	DWRUB 52	43	BH 16-34
20	DWRB 92	44	BH 16-35
21	BH 16-01	45	BH 16-36
22	BH 16-02	46	BH 16-39
23	BH 16-03	47	BH 16-46
24	BH 16-04		

Table 2. Total variance explained by different principal components

Principal components	Eigen values	Per cent variability	Cumulative % variability
1	2.846	28.457	28.457
2	1.839	18.386	46.843
3	1.292	12.918	59.760
4	1.100	11.003	70.764
5	0.915	9.148	79.912
6	0.848	8.483	88.395
7	0.536	5.361	93.756
8	0.374	3.742	97.498
9	0.243	2.430	99.928
10	0.007	0.072	100.000

loading on any of the principal factors. The failure of principal factor analysis without rotation to draw reasonable conclusions incited to go for analysis with rotation. All the 10 variables showed high loading on different principal factors and none of them was left after rotation of the principal factor axes (Table 4). Moreover, it grouped the similar type of variables by loading them together on a common principal factor. The first principal factor was associated with harvest index. Days to heading and maturity showed relation with second factor. The association of third principal factor was very high with biological yield, grain yield and number of tillers per meter. Spike length, number of grains per spike, plant height and 1000-grain weight were correlated with fourth factor.

Table 3. Factor loading of different characters with respect to different principal factors (unrotated)

Characters	PF 1	PF 2	PF 3	PF 4
Plant height (cm)	0.718	-0.121	0.484	-0.036
Days to maturity	0.642	0.232	-0.408	0.119
No. of grains per spike	0.588	0.498	0.102	0.286
Spike length (cm)	0.544	-0.008	0.131	0.594
Days to heading	0.474	0.473	-0.485	0.003
Biological yield (Kg plot ¹)	-0.038	0.733	0.514	-0.331
Grain yield (Kg plot ¹)	-0.662	0.624	0.174	0.133
No. of tillers per meter	-0.258	0.427	0.161	0.321
1000-grain weight (g)	-0.088	-0.425	0.459	0.443
Harvest index (%)	-0.734	0.084	-0.312	0.473
Explained variability	2.846	1.839	1.292	1.100
Proportion of total (%)	28.457	18.386	12.918	11.003

PF: Principal factor

Table 4. Factor loading of different characters with respect to different principal factors (Varimax rotation)

Characters/ Principal factors	PF 1	PF 2	PF 3	PF 4
Harvest index (%)	0.915	-0.162	0.032	-0.041
Days to heading	-0.019	0.809	0.018	0.168
Days to maturity	-0.150	0.685	-0.185	0.348
Biological yield (Kg plot ¹)	-0.269	0.096	0.904	-0.119
Grain yield (Kg plot ¹)	0.547	-0.101	0.740	-0.134
No. of tillers per meter	0.342	-0.042	0.465	0.207
Spike length (cm)	-0.122	0.071	-0.111	0.797
No. of grains per spike	-0.218	0.440	0.300	0.597
Plant height (cm)	-0.759	-0.049	-0.003	0.432
1000-grain weight (g)	0.010	-0.653	-0.118	0.393
Explained variability	1.988	1.799	1.733	1.557
Proportion of total (%)	19.875	17.986	17.333	15.569

PF: Principal factor

The clear cut grouping of similar types of variables by getting loaded on common principal factor elaborates the successful transformation of 10 interrelated variables into four independent factors explaining 70.76% of the variability of the original set. Ebrahim et al (2015) also studied 20 barley varieties for 10 traits and reported 84.22% contribution of the total variation by first three principal components having eigen value greater than one. In the findings of Abebe et al (2010), the first three principal components with eigen values greater than unity, explained about 73% of the total variation among barley accessions for nine quantitative traits. Principal component analysis revealed 83.40 % contribution of the total variation in barley by five principal components having eigen values greater than unity (Zaheer et al 2008).

Principal factor scores were calculated for all the genotypes using Anderson-Rubin method and were utilized to find out genotypes superior for different factors, *i.e.* for all characters cumulatively ascribed to that factor. A high value of score of a particular genotype in a particular factor denotes high value for those variables in that genotype, which that factor is representing. Thus, the genotypes BH 16-35, BH 16-36 and BH 10-30, which were having high score in PF 1 denotes that they are having high harvest index. The correlation of early maturing genotypes *viz.*, BH 16-09, BH 16-15, BH 16-23, BH 15-11 and BH 15-17 with PF 2, suggest that early heading and maturing genotypes may result in higher grain yield. Similarly, genotypes DWRUB 52, BH 14-07, BH 14-40, BH 13-26, BH 14-17, BH 14-25 and BH 15-05 had high score in PF 3, therefore, have high yield potential. Likewise, genotypes BH 14-40, BH 16-24, BH 16-05, BH 16-08, BH 16-19 and BH 16-28 for PF 4 have high score, hence, performed good for the characters to which the factor associated. Our results corroborated the study by Kumar et al (2018b) who also reported 81.37% of cumulative variability explained by five principal components and also selected promising genotypes plotted on different graphs based on various principal factors.

Further, all the genotypes were plotted on graph utilizing their scores based on two factors simultaneously. The genotypes which found place towards the better end of both the factors were also superior for those two factors and hence superior for all the characters, which are defined by these two factors. Thus, the genotype DWRB 92, BH14-17, BH 14-07 and BH 10-30 were better for PF 3 and PF1 (Fig. 1); DWRUB 52 and BH 14-07 for PF 3 and PF 2 (Fig. 2); and BH 14-07, BH 13-26 and BH 14-40 exhibited superiority for PF 3 and PF 4 (Fig. 3), meaning hereby that these genotypes are better for characters for which principal factors ascribed.

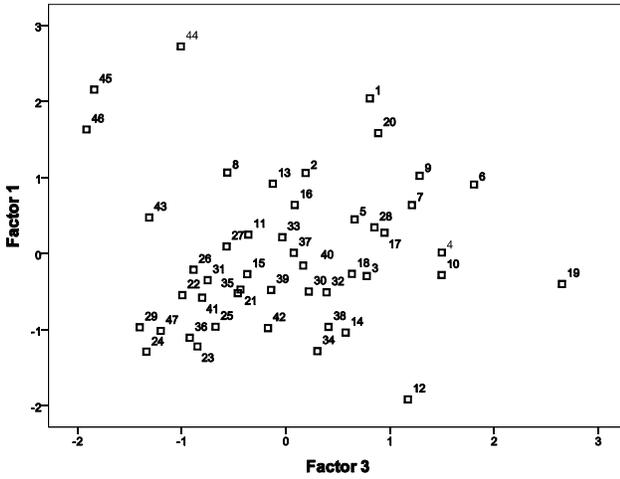


Fig. 1. Location of genotypes based on PF scores w.r.t. factors 3 & 1

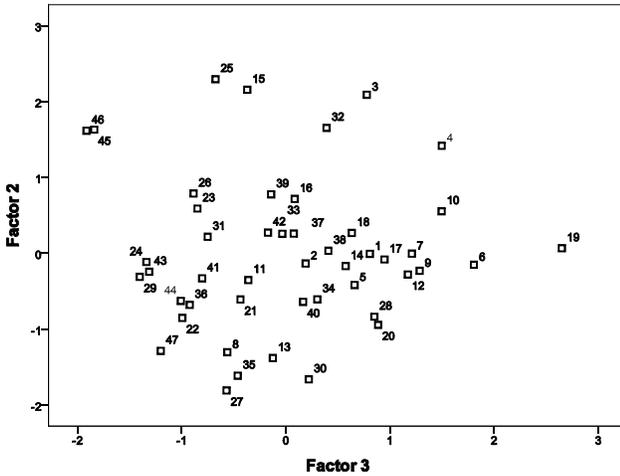


Fig. 2. Location of genotypes based on PF scores w.r.t. factors 3 & 2

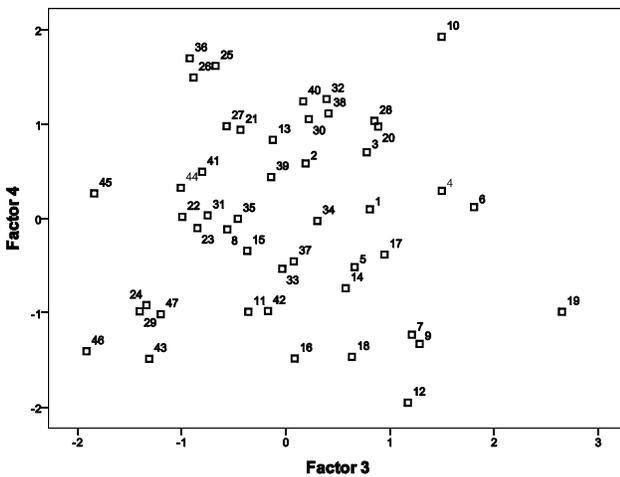


Fig. 3. Location of genotypes based on PF scores w.r.t. factors 3 & 4

CONCLUSION

The genotypes DWRUB 52, BH 14-07, BH 14-40, BH 13-26, BH 14-17, BH 14-25 and BH 15-05 were identified as most superior genotypes that might be considered desirable parents for hybridization. However, for improvement of a particular component trait, the promising donors thus identified based on principal factors could be used in crossing programme to obtain high heterotic response and thus better segregants in subsequent generations for higher grain yield in barley. The present study can be used as a stepping stone for developing well defined approach based on evaluation and characterization of genetic variation in barley and can be utilized in various breeding programme to suit their specific objective.

REFERENCES

Abebe TD, Bauer AM and Leon J 2010. Morphological diversity of Ethiopian barleys (*Hordeum vulgare* L.) in relation to geographic regions and altitudes. *Hereditas* **147**: 154-164.

Amezrou R, Gyawali S, Belqadi L, Chao S, Arbaoui M, Mamidi S, Rehman S, Sreedasyam A and Verma RPS 2018. Molecular and phenotypic diversity of ICARDA spring barley (*Hordeum vulgare* L.) collection. *Genetic Resources and Crop Evolution* **65**: 255-269.

Donald CM and Humblin J 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Advances in Agronomy* **28**: 361-405.

Dyulgerova B, Dimova D and Valcheva D 2016. Genetic diversity in six rowed winter barley (*Hordeum sativum* Jess., ssp. *vulgare* L.) genotypes. *Bulgarian Journal of Agricultural Sciences* **22**: 114-118.

Ebrahim S, Shiferaw E and Hailu F 2015. Evaluation of genetic diversity in barley (*Hordeum vulgare* L.) from Wollo high land areas using agro-morphological traits and *hordein*. *African Journal of Biotechnology* **14**: 1886-1896.

ICAR-IIWBR 2020. *Director's Report of AICRP on Wheat and Barley 2019-2020*, Ed: G.P. Singh. ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana, India, pp. 76.

Jaiswal UC 2000. Principal component analysis and its interpretation. II. Factor analysis and its application in social sciences. In: Course Compendium of "Use of Statistical Methods in Agricultural and Applied Fields". Academy of Agricultural Research and Management, CCS HAU, Hisar. pp: 166-81.

Kumar Y, Kumar N and Devi S 2018a. Genetic diversity for yield and its attributes in barley (*Hordeum vulgare* L.) under irrigated condition. *Indian Journal of Ecology* **45**(2): 425-429.

Kumar Y, Niwas R, Bishnoi OP and Kumar N 2018b. Principal component and factor analysis in six rowed barley (*Hordeum vulgare* L.) genotypes. *Forage Research* **44**(1): 38-42.

Manjunatha T, Bisht IS, Bhat KV and Singh BP 2007. Genetic diversity in barley (*Hordeum vulgare* L. ssp. *vulgare*) landraces from Uttaranchal Himalaya of India. *Genetic Resources and Crop Evolution* **54**: 55-65.

Mekonnen B, Lakew B and Dessalegn T 2014. Genotypic diversity and interrelationship of characters in Ethiopian food barley (*Hordeum vulgare* L.) landraces. *International Journal of Plant Breeding and Genetics* **8**: 164-180.

Rahal-Bouziane H, Berkani S, Merdas S, Nait Merzoug S and Abdelguerfi A 2015. Genetic diversity of traditional genotypes of barley (*Hordeum vulgare* L.) in Algeria by pheno-morphological and agronomic traits. *African Journal of Agricultural Research* **10**(31): 3041-3048.

Saroei E, Cheghamirza K and Zarei L 2017. Genetic diversity of characteristics in barley cultivars. *Genetika* **49**(2): 495-510.

Zaheer A, Saif UA, Muhammad M, Muhammad Z and Muhammad SM 2008. Genetic diversity for morpho-genetic traits in barley

germplasm. *Pakistan Journal of Botany* **40**: 1217-1224.

Zakova M and Benkova M 2006. Characterization of spring barley accessions based on multivariate analysis. *Communications in Biometry and Crop Science* **1**: 124-134.

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Floristic and Ecological Analysis of Weeds in Citrus Groves in the Oranian Phytoecological Sector (Western Algeria)

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Abstract: The weeds in agro ecosystem are known as a critical problem which is associated with severe economic loss. There is a lacking in the information about biology and ecology of weeds communities in agro ecosystems of the north-western tell of Oranie (western Algeria), particularly citrus farms. The study of citrus weeds in this region during the 2015-2016 crop years included 200 phytoecological surveys according to the round-field sampling method. They were distributed in five sites the study area in order to take into account the variability of ecological and Agronomic factors. The flora recorded at all the sites includes 101 weed species belonging to 31 families and 87 genera. The dominant families were Asteraceae, Poaceae and Fabaceae this weeds flora was dominated by the Mediterranean elements (43%) and the therophytes (74.5%) reflecting unfavourable climatic conditions. The results obtained by Principal Component Analysis shows the existence of three distinct groups of study sites for both weed families and biological types. Correspondence Factor Analysis revealed two groups of species with different correlations to the study sites and the ecological parameters considered these results explain the distribution of citrus weeds in Oranian region according to climate edaphic conditions.

Keywords: Weeds, Citrus groves, Phyto-ecological surveys, North Oranian, Biological types

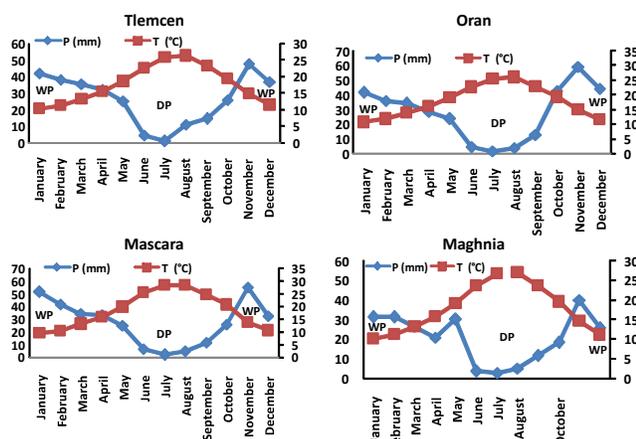
Good management of the weeds flora certainly depends on good knowledge of the flora and its member species. For this purpose, several studies have been conducted in different regions in Algeria (Abdelkrim 2004, Kazi Tani et al 2010). In general, the presence of a weed has both an ecological (soil and climate) and an agronomic (cultural practices) dimension. It is through the change of this environment that it is possible to quantify the impacts on agriculture (Fried et al 2008). Changes on agricultural practices influence the composition and evolution of weed communities (Fried and Reboud 2007, Chafik et al 2014). The impact of humans on the weed communities causes some characteristic species to disappear from poor environments (oligotrophiles) in favour of nitrophilic species. Specialist species also disappear in relation to generalist species and the massive decline in species and species diversity affects even common species (Fried 2010). Weeds compete with the plants and in some cases; their seeds contaminate the crop and reduce its value. Losses caused by these weeds are estimated at 9.7% of global agricultural production and are in the order of 10 to 56 in Africa (Traoré and Mangara 2009). However, much research carried out to highlight the influence of weeds on crops has shown that the relationship between weeds and crops is constantly evolving and depends on climatic conditions cultivation techniques,

used crop type and above all type of infestation and weed emergence period (Traoré and Mangara 2009). The objective of our work is to inventory the weeds of citrus groves in the phytoecological sector of Oran and to characterize them botanically, ecologically and agronomically.

MATERIAL AND METHODS

The study area is part of the Oranian (western Algeria) phytoecological sector where five sampling sites were selected: Oran, Mohammadia, Sig, Tlemcen and Maghnia. The biogeographical and climatic characteristics of these sites are shown in Table 1. Bioclimatic data correspond to the period 1982-2017 (ONW 2015). In general, the climate of the five study sites is characterized by a semi-arid to temperate winter climate with mean annual precipitation ranging from 246.5 to 332mm. The mean annual maximum temperature (M) is 34.2°C; the mean annual temperature is 18°C. The hottest month is August with 32.1°C and 33.53°C for Oran and Tlemcen and July with 34.87°C and 36.38°C for Maghnia and Mascara respectively. The coldest month is January with 5.4°C for Oran, 5.33°C for Tlemcen, 4.23°C for Maghnia and 4.12°C for Mascara. The dry season lasts more than 7 and 8 months from spring to autumn (Fig. 1).

Inventory and characterization of adventitious flora: For



DP: dry period; WP: wet period; P: monthly average precipitations; T: monthly average temperatures; mm: millimetre; °C: degree Celsius

Fig. 1. Omrothermal diagrams of study sites

the inventory of the weed flora, 200 phyto-ecological surveys were carried out over the entire study area (Oran, Mascara, Mohammadia, Sig and Tlemcen) in citrus orchards during the spring period of 2015-2016. They were distributed throughout the study area to take into account the variability of ecological and agronomical factors. The floristic survey technique used was that of the field tour, which provides information on the various species in the plot (Lebreton et al 2005). Surveys are carried out on floristically homogeneous and representative areas of about 100 m². Some sites are partially or completely weeded where it was difficult for to choose the surface location. For this considered the irrigation basin (under the tree) as the smallest area in which almost all species are represented (minimum area). Each species inventoried is assigned a coefficient of abundance-dominance (from + to 5) in the sense of Braun Blanquet (Fenni 2003). The inventoried species were distributed according to their botanical families. Biological and biogeographic types using the new flora of Algeria and the southern desert regions of Quezel and Santa (1962-1963) and also crop weeds (Mamarot and Rodriguez 2014).

Soil analysis: The physico-chemical parameters were determined from soil samples taken at a depth of approximately 10 cm from each study site which includes: texture, pH, electrical conductivity, organic matter content, active limestone content and total nitrogen content.

Weed diversity analysis: For the analysis and evaluation of the phyto-diversity of the study sites, the similarity index of Sørensen (1948) and the diversity index of Shannon (Shannon and Weaver 1949) were used. The purpose of using the Sørensen similarity index (Si) was to compare sites from the absent-presence point of view of botanical families. The Shannon's index (Ish) provides information on the diversity of

species in a studied environment and the Sørensen similarity index (Si) on the diversity of species.

Data analysis: The data obtained was processed by correspondence factor analysis (CFA) to highlight possible correlations between the species identified in our study sites (ecological and pedological parameters). These parameters make it possible to specify the ecological and pedological conditions that contribute to the composition of weed groups in the study area. Hierarchical ascending classification (HAC) was used to identify the different species groups and their relationships with parameters: altitude, structure and texture, electrical conductivity, soil organic matter, nitrogen and active soil limestone. Principal component analysis (PCA) was carried out to show the correlations between biological types and species families with the above parameters.

RESULTS AND DISCUSSION

Specific richness and taxonomic families identified: The site richest of weeds are in Tlemcen (89 species) and Mohammadia (88 species) followed by Oran (74 species) and Maghnia (71 species). The Sig site is the least rich with 45 species. The main families recorded were Asteraceae, Fabaceae and Poaceae (Fig. 2, Table 2). These same families also dominate in Oranian weed flora (Kazi Tani 2010). The presence of Poaceae in the middle of an annual crop determines a more complex competition phenomena in terms of water, nutrient and space factors and also makes possible chemical or cultural control of these weeds difficult (Fenni 2003). The *Poaceae* family is represented by 16, 15, 12, 11 and 9 species, respectively for Mohammadia, Tlemcen, Maghnia, Oran and Sig. The Asteraceae family is represented by 12, 11, 09, 07 and 11 species consecutively for Tlemcen, Mohammadia, Oran, Maghnia and Sig sites. Hseini et al (2007) observed that the Asteraceae family always occupies the first ranks. The Fabaceae family is represented by 09, 08, 07 and 03 species accordingly for Tlemcen, Mohammadia, Maghnia, Oran and Sig. The *Fabaceae* have a strong competition for water towards the crop due to their deep root system, and allows a high availability of nitrogen in the soil (Fenni 2003). For the Brassicaceae family 09, 08, 07, 06 and 03 species respectively in Oran, Mohammadia, Tlemcen, Maghnia and Sig. However, some families participate in the weed flora much more than their rank in the overall flora would suggest. Papaveraceae, Polygonaceae, Chenopodiaceae and Amaranthaceae are represented in agrosystems. These are families containing a large number of anthropophilic species favoured by disturbances induced by human activities in biocenoses and on habitat conditions (nitrogenous manures,

Table 1. Biogeographic and climatic characteristics of study sites

Sites	Geographic coordinates	Seasonal pattern	Bioclimatic stage	Number of surveys
Mohammadia (Province of Mascara)	Altitude 47m N: 35 ° 23'47.90 " E: 0 ° 08'24.97 "	WSAS	Semi-arid to temperate winter	94
Sig (Province of Mascara)	Altitude : 67m N: 35 ° 31'41.95 " W: 0 ° 11'37.28 "	WSAS	Semi-arid to temperate winter	16
Maghnia (Province of Tlemcen)	Altitude 444 m N: 34 ° 51 '12.4' ' W 1 ° 44'6 "	WSAS	Arid to temperate Winter	30
Tlemcen	Altitude : 326m N: 34 ° 52 '54.5' W: 1 ° 19 '13.7' '	WSAS	Semi-arid to temperate winter	50
Oran	Altitude : 110 m N: 35 ° 39'51 " W: 0 ° 35'34 "	WASS	Semi-arid to temperate winter	30

Winter -Spring- Autumn-Summer (WSAS)

Table 2. Number of species listed by botanical family in the study sites

Families	Maghnia	Mohammadia	Sig	Tlemcen	Oran
Poaceae	12	16	9	15	11
Asteraceae	9	11	7	12	11
Fabaceae	7	8	3	9	7
Brassicaceae	6	8	3	7	9
Apiaceae	5	6	4	5	4
Convolvulaceae	3	2	1	2	1
Boraginaceae	2	1	1	2	2
Caryophyllaceae	2	2	1	2	2
Malvaceae	2	3	1	2	3
Polygonaceae	2	5	1	4	2
Rubiaceae	2	2	1	2	1
Amaranthaceae	1	2	0	2	1
Araceae	1	0	0	1	1
Araliaceae	1	2	0	1	0
Aristolochiaceae	1	0	0	1	0
Cucurbitaceae	1	2	1	1	1
Euphorbiaceae	1	1	1	1	1
Fumariaceae	1	2	1	2	2
Geraniaceae	1	2	1	2	1
Labiaceae	1	1	0	1	1
Liliaceae	1	0	0	1	1
Oxalidaceae	1	1	1	1	1
Papaveraceae	1	1	0	1	1
Plantaginaceae	1	1	1	1	1
Portulacaceae	1	1	1	1	1
Primulaceae	1	1	1	1	1
Resedaceae	1	1	1	1	1
Scrophulariaceae	1	0	0	1	0
Solanaceae	1	1	1	2	2
Urticaceae	1	1	1	1	1
Chenopodiaceae	0	4	2	4	2

accumulation of organic waste, household waste, irrigation etc.). Moreover, Amaranthaceae are almost all of American origin (kenophytes) and have naturalized in Algeria in cultivated environments (Kazi Tani 2010). The studies enabled us to identify the factors influencing the evolution of the weed flora and to explain the distribution of species in the five study sites. Over the entire study area, 101 weed species belonging to 87 genera and 31 families were identified. The family *Poaceae* is the most species-rich with 16 species. followed by Asteraceae, Brassicaceae, Fabaceae and Apiaceae.

Biogeographic and biological spectra of the species surveyed: The inventoried weed flora is characterized by a heterogeneous set of elements of very diverse origin. For all the sites, the biogeographical spectrum of the species was dominated by the Mediterranean element with percentages of 25.35, 28.09, 17.78, 24.72 and 25.68 respectively for Maghnia, Mohammadia, Sig, Tlemcen and Oran (Fig. 3, Table 3). The Mediterranean-Irano-Turanian element is represented with a percentage between 11.24 and 14.86% for the five sites. The cosmopolitan element retains an important place in the vegetation with a percentage that varies between 8.45 and 13.33% in the different sites. The European-Mediterranean, European-Siberian-Mediterranean and Paleo-Temperate. Eurasian, North American and Thermocosmopolite elements are moderately represented. The remaining elements are poorly presented. The 101 species in the floristic list of our study region are divided into 28 characteristic phyto-geographic types. The Mediterranean element is dominant with 27 Mediterranean species or 26.73% of the total number of species. This rate is close to that obtained in a previous study for weed communities of phytogeographic crops Oranian in which 58% of the taxa are Mediterranean (Kazi Tani et al 2010). 62% for the weed flora of western Morocco agrosystems

Table 3. Biogeographic diagram of number of species surveyed at the stations studied

Families	Maghnia	Mohammadia	Sig	Tlemcen	Oran
Méd.	25.35	28.09	17.78	24.72	25.68
Méd.-lr.-Tour.	11.27	13.48	13.33	11.24	14.86
Cosm.	8.45	10.11	13.33	10.11	10.81
Euro-Méd.	7.04	5.62	8.89	5.62	8.11
Euras.	5.63	5.62	8.89	4.49	5.41
Euro-Sib.-Méd.	5.63	6.74	4.44	4.49	5.41
Paléo-Temp.	5.63	4.49	4.44	5.62	5.41
Thermocosm.	4.23	3.37	4.44	3.37	4.05
Circumbor.	2.82	2.25	4.44	2.25	2.70
Af.S.	1.41	1.12	2.22	1.12	1.35
Circumméd.	1.41	0	0	1.12	0
Euras.-Af.	1.41	1.12	0	1.12	0
Euras.-Macar.	1.41	1.12	2.22	1.12	1.35
Euro-Sib.	1.41	1.12	2.22	1.12	1.35
Eurosib.-Méd.-lr.-Tour.	1.41	2.25	2.22	4.49	2.70
Ibéro-Maur.	1.41	0	0	1.12	0
Méd.-Macar.	2.82	0	0	2.25	0
Méd.-W.As.	1.41	1.12	2.22	1.12	0
Nord Trop-Temp.	1.41	1.12	0	1.12	0
Paléo-Néotrop.	1.41	1.12	0	1.12	0
Paléo-Subtrop.	1.41	1.12	0	1.12	0
Subcosm.	1.41	2.25	4.44	2.25	2.70
Subméd.	1.41	0	2.22	1.12	1.35
Trop.-Subtrop.	1.41	1.12	2.22	1.12	1.35
W.Méd.	1.41	1.12	0	1.12	0
N.Am.	0	2.25	0	2.25	2.70
Sah.-Arab.-Méd.-lr.-Tour.	0	2.25	0	2.25	1.35
Asie	0	0	0	0	1.35

(Zidane et al 2010) and 59% for the weeds of eastern Morocco (Chafik et al 2013) followed by the Mediterranean-Irano-Turanian species which number 15 (14.85 %) and 9 cosmopolitan species represented by 8.91 % of the total number of species. The European-Mediterranean element represented by 5.94% of species, the European-Siberian-Mediterranean and Paleo-Temperate elements represented by 4.95% of species, the Eurasian elements represented by 3.96% of species. North American and Thermocosmopolite represented by 2.97% of species. The other biogeographic elements are very poorly represented (Fig. 3). The dominance of the Mediterranean type and the relative importance of Eurasian, palaeotemperate and cosmopolitan elements in the weed flora of the crops of the Mediterranean basin have also been observed by Fenni (2003).

For all the sites, the dominant biological type is therophyts with percentages occupying more than half of the vegetation studied: 75, 78.41, 75.56, 76.40 and 78.38% respectively for Maghnia, Mohammadia, Sig, Tlemcen and Oran (Table 4). This contribution is lower than that previously established at 69% for citrus flora in eastern Morocco (Chafik et al 2013). The therophytes are 75 % in Oranian and 45% in Rachgoune and Oulhassa region of Tlemcen (Kazi Tani et al 2010, Ghalem and Hassani 2020). Despite the dominance of therophyts, geophyts also retain a very important place with a percentage that varies between 11.11 and 12.50% for the five sites. Hemicryptophyts occupies the third position in all sites with percentages ranging from 8.11 to 13.33%, while

Table 4. Percentage of species distribution by biological type in study stations

	Maghnia	Mohammadia	Sig	Tlemcen	Oran
Therophyts	75.00	78.41	75.56	76.40	78.38
Geophyts	12.50	11.36	11.11	11.24	12.16
Hemicryptophyts	11.11	7.95	13.33	10.11	8.11
Nanophanerophyts	1.39	1.14	0	1.12	0
Chamephyts	0	1.14	0	1.12	1.35

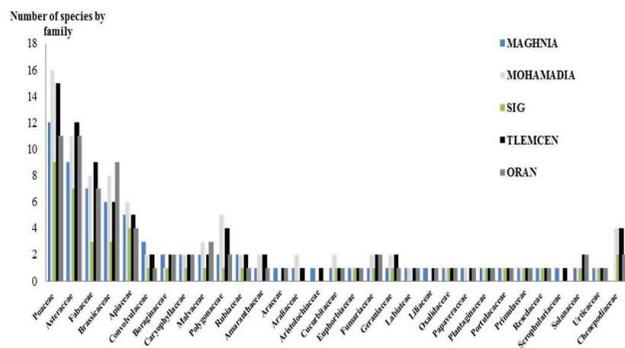


Fig. 2. Diagram of number of species listed by botanical family in the study sites

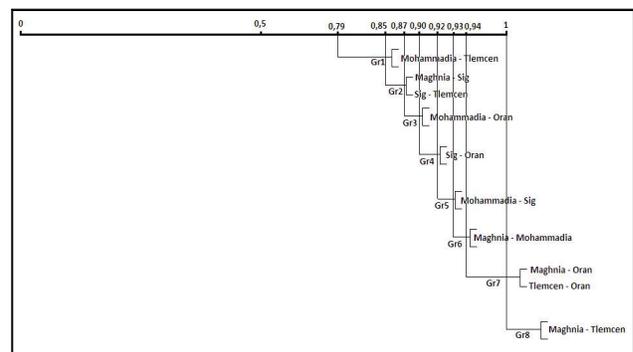


Fig. 3. Similarity dendrogram

nanophanerophytes are less represented with a rate of 1% in Maghnia, Mohammadia and Tlemcen. The same rate characterizes the chamephytes at Mohammadia, Tlemcen and Oran.

Pedological study: The granulometric composition of the different soil samples in clay, silt and sand and its projection on the triangle of textures shows that the Sig site is of silty texture; the Oran and Mohammadia sites are of fine silty texture; the Tlemcen site is of silty-clay texture and Maghnia site is of fine silty-clay texture. The soil pH at the different sites is generally moderately alkaline, between 7.4 and 7.9 with very little difference between the different samples analysed. Our study soil is very salty since its electrical conductivity (CE) varied between 2.37 and 3.39 ds/m at Oran, Maghnia, Mohammadia and Sig. except for Tlemcen where it is not salty with an electrical conductivity of 0.2 ds/m. The organic matter contents always remain low in all the sites; the lowest rate is was at Maghnia with mean 2.77% and low 4.09% for the Sig site. The rate of active limestone (CaCO_3) varied between 7.94% and 15.57%. By the standards established by Mouffak (2014) these percentages showed the existence of two classes of soils: Class 1: medium calcareous soil for Sig. Oran and Tlemcen where the rate varies from 11.64 % to 15.67 %;

Class 2: low calcareous soil for Maghnia where the rate is 7.94%. The total nitrogen rate achieved in all sites is the same with a very insignificant difference between the different samples analyzed (0.13% and 0.20%).

Shannon Specific Diversity Index (Shannon index): The results obtained indicate the existence of a slightly variable specific diversity between the study sites. A high Ish value characterizes the Tlemcen site (3.96 bit individual⁻¹). The lowest diversity was at the Oran site (3.3 bit individual⁻¹). The other sites show intermediate values of 3.62, 3.77 and 3.80 bit/individual respectively for Sig, Mohammadia and Maghnia. This variability in species diversity is certainly related to the ecological and pedological parameters of the explored sites.

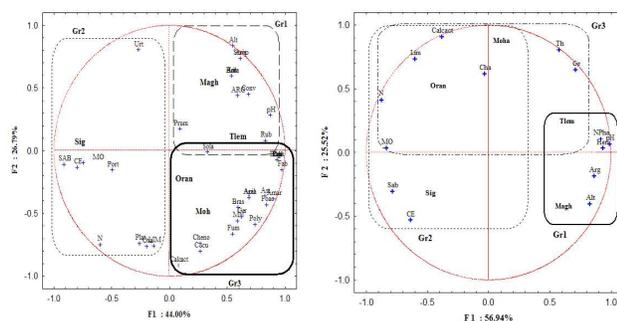


Fig. 4. The principal component analysis of botanical families (A) and biological types (B)

Sorensen similarity index (Si): The similarity dendrogram (Fig. 3) revealed 8 groups of study sites. The Gr 8 group indicates a strong similarity between the Maghnia and Tlemcen sites ($\text{Si} = 1$). On the other hand, the Gr1 group represented by the Mohammadia-Tlemcen pair shows a weak similarity ($\text{Si} = 0.79$). Intermediate values between 0.85 and 0.94 characterize the other groups of sites. These are the groups Gr2. Gr3. Gr4. Gr5. Gr6. and Gr7. These groups correlate with ecological and pedological conditions (altitude, salinity, limestone, texture).

Correlation between botanical families and study sites: The principal component analysis performed for the botanical families (Fig. 4 A). On the factorial plan (F1/F2), the F1 axis which provides the most information in the PCA ($F1 = 44\%$ inertia) compared to the F2 axis ($F2 = 26.79\%$), opposes groups G1 and G3 to group G2. The groups are constituted based on the contributions taken by the botanical families. The first group G1 is on the positive side of the F1 axis, it is represented by the sites of Tlemcen (Tlem) and Maghnia (Magh). It essentially groups the following families with their correlation coefficients: *Scrophulariaceae* (Scro) (0.612), *Convolvulaceae* (Conv) (0.681), *Aristolochiaceae* (Aristo) (0.612) and *Rubiaceae* (Rub) (0.831). The latter are correlated with the altitude factor (Alt) (0.545) and a silty-clay substratum (La).

The second group G2: is located on the negative side of the F1 axis and is represented by the Sig site. It essentially includes the following families: *Oxalidaceae* (Oxal) (-0.195), *Plantaginaceae* (plant) (-0.257), *Portulacaceae* (Port) (-0.492) and *Urticaceae* (Urti) (-0.268). The latter are correlated with environmental factors (organic matter MO) (-0.743); sands (S) (-0.911); electrical conductivity (EC) (-0.795); silt (L) (-0.132) and nitrogen (N) (-0.598). The third group G3 is on the positive side of the F1 axis, it is represented by the two sites Oran and Mohammadia. It includes a large number of families: *Asteraceae* (0.824), *Poaceae* (0.842), *Fabaceae* (0.973), *Brassicaceae* (0.592), *Apiaceae* (0.687), *Boraginaceae* (0.538), *Caryophyllaceae* (0.927), *Malvaceae* (0.591), *Polygonaceae* (0.739), *Amaranthaceae* (0.902), *Araceae* (0.538), *Araliaceae* (0.687), *Cucurbitaceae* (0.268), *Euphorbiaceae* (0.927), *Fumariaceae* (0.547), *Geraniaceae* (0.621), *Labiaceae* (0.927), *Liliaceae* (0.538), *Papaveraceae* (0.927), *Primulaceae* (0.09), *Resedaceae* (0.927), *Scrophulariaceae* (0.612), *Solanaceae* (0.328), *Chenopodiaceae* (0.269). These are correlated with a rate of active limestone (calcaire or CaCO_3) (0.07). So we can deduce that these families are well tolerant of calcareous soils reflecting degraded sites.

Correlation between biological types and study sites: The principal component analysis performed for the

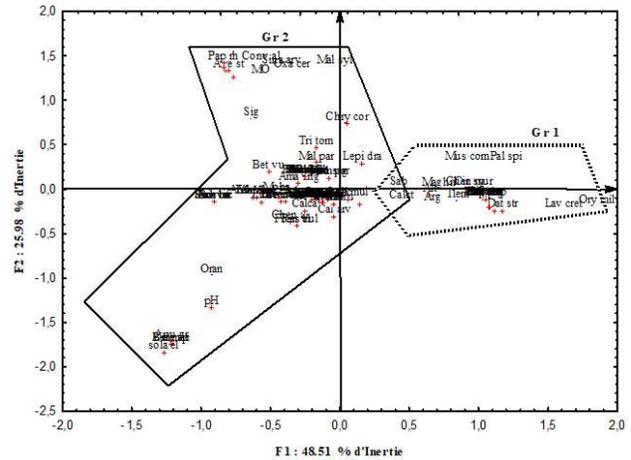
biological types is shown in Figure 4B. On the factorial plan (F1/F2), the F1 axis provides the most information (F1= 56.94% inertia) compared to the F2 axis (F2= 25.52%). This PCA highlighted three groups on axis 1. taking into account the contributions made by biological types. The first group Gr1: is represented by the Tlemcen (Tlem) and Maghnia (Magh) sites where nanophanerophyts (Nph) (0.917) and hemicryptophyts (hem) (0.933) dominate. These biological types are particularly related to the altitude factor (Alt) (0.828) with a soil with a basic pH (0.988) and clay texture (Arg) (0.863).

The second group Gr2: is represented by two sites. Oran and Mohammadia (Moha) where chamephyts (Ch) (-0.03) dominate. This biological type is associated with a high rate of active limestone (calcact or CaCO₃) (-0.382), an average content of organic matter (Mo) (-0.835). the rate is average in nitrogen (N) (-0.877), the rate of electrical conductivity is average (EC) (-0.641), the rate of sand is average (S) (-0.788) and on the other hand the rate of silt is medium (L) (-0.602). Chamephyts (Ch) characterize degraded environments and are better adapted to summer drought (Cherifi et al 2011, 2017).

The third group Gr3: is represented by the three sites: Tlemcen, Oran and Mohammadia where the Therophyts (Th) (0.577), the Geophyts (Geo) (0.712) and the Chamephyts (Cha) dominate. This ensemble is positively correlated on the F2 axis to some edaphic parameters such as the active limestone rate is high (Calcact) (0.908) and the organic matter content is medium (Mo) (0.03), the nitrogen rate is medium (N) (0.412) and the silt rate is high (L) (0.734), the installation of therophyts (Th) and chamephyts (Cha) in the above-mentioned sites can be explained by their good adaptation to the environmental conditions.

Correspondence factor analysis: On the factorial plan (F1/F2), the F1 axis provides the most information in the correspondence factorial analysis (F1= 48.51% inertia) compared to the F2 axis (F2= 25.98%). The correspondence factorial analysis allowed us to identify two groups (Fig. 5). The first group Gr1: is represented by the Tlemcen (Tlem) and Maghnia (Magh) sites where the following species dominate: *Datura stramonium* L., *Pallenis spinosa* L., *Oryzopsis miliacea* L., *Lavatera cretica* L., *Cichorium intybus* L. These species are linked in particular to the factors altitude (Alt), sand (Sab), clay (Ag) and active limestone (calcact or CaCO₃).

The second group Gr2: is represented by the sites Oran, Mohammadia (Moh), Sig where dominating species were: *Amaranthus angustifolius* Lamk (AMAAN), *Avena sterilis* (AVEST), *Beta vulgaris* L. (BETVG), *Chenopodium album* L. (CHEAL), *Convolvulus althaeoides* L. (CONAL), *Calendula*



Tlem :Tlemcen; **Magh** : Maghnia; **Scro** :Scrophulariaceae; **Conv** : Convolvulaceae; **Aristo** : Aristolochiaceae; **Rub** : Rubiaceae; **Alt** : altitude; **La** : silt-clay; **Oxal** : Oxalidaceae; **plant** :Plantaginaceae; **Port** : Portulacaceae; **Urti** : Urticaceae; **MO** : organic matter; **S** : sands; **CE** : electric conductivity; **L** : limons; **N** : nitrogen; **Aste** : Asteraceae; **Poac** : Poaceae; **Fab** : Fabaceae; **Brass** : Brassicaceae; **Apia** : Apiaceae; **Bora** : Boraginaceae; **Car** : Caryophyllaceae; **Malv** : Malvaceae; **Pol** : Polygonaceae; **Amar** : Amaranthaceae; **Ara** : Araceae; **Aral** : Araliaceae; **Cucu** : Cucurbitaceae; **Eupho** : Euphorbiaceae; **Fuma** : Fumariaceae; **Gera** : Geraniaceae; **Lab** : Labiaceae; **Lil** : Liliaceae; **Papav** : Papaveraceae; **Prim** : Primulaceae; **Res** : Resedaceae; **Scrop** : Scrophulariaceae; **Sola** : Solanaceae; **Chen** : Chenopodiaceae; **calcact or CaCO₃** : active limestone; **NPha** : nanophanérophytes - **Hem** : hémicryptophytes; **Arg** : argile; **Moha** :Mohammadia; **Ch** : chaméphytes; **Th** : Thérophytes; **Geo** : Géophyte; **Da str** : *Datura stramonium* L.; **Pasp** : *Pallenis spinosa* (L.) ; **Ory mi** : *Oryzopsis miliacea* L.; **Lavcr** : *Lavatera cretica* L.; **Cic in** : *Cichorium intybus* L.; **Aman** : *Amaranthus angustifolius* Lamk; **Avest** : *Avena sterilis*; **Betvg** : *Beta vulgaris* L.; **Cheal** : *Chenopodium album* L.; **Conal** : *Convolvulus althaeoides* L.; **Calar** : *Calendula arvensis* L.; **Lepdra** : *Lepidium draba*; **Malpa** : *Malva parviflora* L.; **Paprh** : *Papaver rhoeas* L.; **Sinar** : *Sinapis arvensis* L.; **Malsi** : *Malva sylvestris* L.; **Oxapc** : *Oxalis cernua* Thumb; **Trfto** : *Trifolium tomentosum* L.; **Solel** : *Solanum eleagnipholium*; **Betmc** : *Beta macrocarpa*

Fig. 5. The correspondence factor analysis

arvensis L. (CALAR). *Lepidium draba* (CADDR). *Malva parviflora* L. (MALPA). *Papaver rhoeas* L. (PAPRH). *Sinapis arvensis* L. (SINAR), *Malva sylvestris* (MALSI), *Oxalis cernua* Thumb (OXAPC), *Trifolium tomentosum* L. (TRFTO), *Solanum eleagnipholium* (SOLEL) and *Beta macrocarpa* Guss (BETMC). These species are correlated with organic matter (Mo), sand (Sab), active limestone (calcact or CaCO₃) and pH. The analysis of the factor maps relating to species, ecological and soil parameters allows us to specify the ecological and soil conditions that contribute to the composition of the weed groups. The intensity of tillage leads to a change in the composition of the weed flora: frequent and intense disturbance generally leads to low diversity favouring the selection of species with cycles that match the rhythm of cultivation. According to Traoré and Mangara (2009), climate is the predominant abiotic factor in species distribution followed by soil type. They add that about rainfall, substrate type, texture, *Papaver rhoeas* is classified by Fried et al (2008) as an indicator species of cultural practices and not of

soil-climatic conditions. The presence of *Plantago* indicates clay heavy, acidic and poorly draining soil. The development of appropriate weed control techniques requires knowledge of the composition of the weed flora (Lebreton and Le Bourgeois 2005). Rauber et al (2018) in pointed out that agricultural practice are the main driver for weed diversity and abundance in agro-ecosystems. In general, four species occupied the first places. They are the most common perennial weeds present in Algeria: *Oxalis pescaprae* L., *Convolvulus arvensis* L., *Cynodon dactylon* (L.) Pers. and *Cyperus rotundus* (Chemouri et al 2019). *Solanum elaeagnifolium* Cav is new rare species. This species was not reported earlier from Rajasthan in India (Jeph and Khan 2019).

CONCLUSION

The weed flora in the study area is diversified and that its distribution is conditioned by two major factors, climate and soil type. The inventory consisted of 101 weed species belonging to 31 families and 87 genera. The dominant families were *Asteraceae*, *Poaceae* and *Fabaceae*. The majority of the species had a distinctly Mediterranean character (43%). The biological spectrum revealed a dominance of therophytes (74.5%) reflecting unfavourable climatic conditions. The results obtained by Principal Component Analysis (PCA) shows the existence of three distinct groups of study sites for both weed families and biological types. Correspondence Factor Analysis revealed two groups of species with different correlations to the study sites and the ecological parameters considered these results explain the distribution of citrus weeds in Oranian region according to climate, edaphic conditions. Weeds are often considered undesirable to the eye of farmers, especially in annual crops. In citrus growing areas these species do not only have a harmful aspect, because they have many advantages related to their presence. in addition to the enrichment of the flora of the cultivated plots which contributes to the maintenance of the biodiversity. This work will add to the body of knowledge we have built upon the weeds of the Oranian region. It would be advisable to extend the sampling area by increasing the number of surveys and to explore different crops (olive groves. fruit trees. vines. cereals. market garden crops in the field as well as greenhouse crops) and fallow land.

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REFERENCES

- Abdelkrim H 2004. Contribution à l'Étude Écologique et Phytosociologiques des Adventices des Cultures et des Jachères dans le Secteur Phytogéographique de l'Algérie (Algérie). *Phytocoenologia* **34**(2): 287–326.
- Chemouri S, Ainad Tabet M, Kechairi R, Tefiani C, Megharb Ai, Roca-Fernandez A and Larid M 2019. Impact of mechanical and chemical weeding on the floristic diversity of citrus orchards in Tlemcen (Northwestern Algeria). *International Journal of Environmental Studies* **77**(4): 602-612.
- Cherifi K, Mehdadi Z and Bachir Bouiadjra SE 2011. Impact de l'Action Anthropozoogène sur l'Ecosystème Forestier du Mont de Tessala (Algérie occidentale). *Sécheresse* **22**(3): 197-206.
- Cherifi K, Mehdadi Z, Elkhiahi NA and Latreuch R 2017. Floristic composition of the Mountainous Massif of Tessala (Algerian West): biodiversity and regressive dynamics of the forest ecosystem. *Journal of Materials and Environmental Science* **8**(9): 3184-3191.
- Chafik Z, Taleb A, Bouhache M and Berrichi A 2013. Weed flora of western Morocco agro systems: Case of the Moulouya perimeter. *Revue Marocaine de Protection des Plantes* **4**: 27-44.
- Chafik Z, Bouchache M, Taleb A and Berrichi A 2014. Actualisation de la Flore Adventice des Cépages du Périmètre Irrigué de la Moulouya. *Revue Marocaine de Protection des Plantes* **5**: 47-65.
- Fenni M 2003. *Etude des mauvaises herbes des céréales d'hiver des hautes plaines constantinoises. Ecologie. dynamique. phénologie et biologie des bromes*. Thèse doctorat d'état. Université de Sétif. Algérie.
- Fried G and Reboud X 2007. Évolution de la Composition des Communautés Adventices des Cultures de colza sous l'Influence des Systèmes de Culture. *Oléagineux. Corps Gras. Lipides* **14**(2): 130-138.
- Fried G, Chauvel B et Reboud X 2008. Évolution de la Flore Adventice des Champs Cultivés au Cours des Dernières Décennies : vers la Sélection de Groupes d'Espèces Répondant aux Systèmes de Culture. *Innovations Agronomiques* **3**: 15-26.
- Fried G 2010. Variations Spatiales et Temporelles des Communautés Adventices des Cultures Annuelles en France. *Acta Botanica Gallica* **157**(1): 183–192.
- Ghalem S and Hassani F 2020. Phytobiological and morphological diversity of a *Malvaceous Lavatera* Maritima in Rachgoune and Oulhassa Region of Tlemcen Algeria. *Indian Journal of Ecology* **47**(2): 575-578.
- Hseini S, Kahouadji A, Lahssissene H and Tijane M 2007. Analyses Floristique et Ethnobotanique des Plantes Vasculaires Médicinales Utilisées dans la Région de Rabat (Maroc occidental). *Lazaroa* **28**: 93-100.
- Jeph A and Khan JB 2019. Study on some threatened rare and endangered plant's species in reserve forest area of Jhunjhunu District. Rajasthan. Department of Botany. Govt. Lohia College. Churu-331 001. India. *Indian Journal of Ecology* **46** (4): 755-759.
- Kazi Tani C 2010. *Contribution à l'étude des communautés d'adventices des cultures du secteur phytogéographique oranais (Nord-Ouest algérien): Aspects botanique. agronomique et phyto-écologique*. Thèse Doctorat d'Etat. Université de Tlemcen. Alegria.
- KaziTani C, Le Bourgeois T. and Munoz F 2010. Floristic aspects of weed flora of the oranian phytogeographic territory (North-West Algeria) and persistency of rare and/or endemic species. *Flora Mediterranea* **20**: 29–46.
- Lebreton G and Le Bourgeois T 2005. Analyse de la Flore Adventice de la Lentille à Cilaos. *Cirad-Ca / 3P. UMR PVBMT*. p 9-10.
- Mouffak A 2014. *Effets des procédés de revégétalisation des sablières sur les aspects édaphiques des sols dégradés de l'ouest algérien*. Thèse de Doctorat de l'Université d'Oran. Algeria.

- Mamarot J and Rodriguez A 2014. *Mauvaises herbes des cultures*. 4eme Edition Acta. Paris. France. p 569.
- ONW 2015. *Office National Weather*. Oran. Algeria.
- Quézel P and Santa S 1963. *New flora of Algeria and southern desert regions*. CNRS. Paris. France. p 603.
- Rauber R B. Demaría M R. Jobbágy EG. Arroyo D N and Poggio SL 2018. Weed communities in semi-arid rainfed croplands of Central Argentina: Comparison between corn (*Zea mays*) and soybean (*Glycine max*) crops. *Weed Science* **66** (3): 368-378.
- Shannon CE and Weaver W 1949. *The mathematical theory of communication*. Urbana. Chicago Ill. Univ. Illinois Press. p 125.
- Sørensen T 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. *Det Kongelige Danske Videnskabernes Selskab. Biologiske Skrifter* **5**(4): 1-34.
- Traoré K and Mangara A 2009. Étude Phyto-Écologique des Adventices dans les Agro Écosystèmes Élaeicoles de la Mé et de Dabou Traore Karidia. *European Journal of Scientific Research. UFR Sciences de la Nature*. Université. d'Abobo-Adjamé. Côte d'Ivoire. pp 519-533.
- Zidane L. Salhi S, Fadli M. El Antri M. Taleb A. and Douira A 2010. Study of the weeds groupings in western Morocco. *Biotechnologie. Agronomie. Société et Environnement* **14**(1): 153-166.

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Weed Composition and Nutrient Uptake by Weeds in Sole and Intercrops during *Rabi* Season

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Abstract: The field experiment was conducted to study weed composition and status of nutrient removal by weeds in sole and intercrops. Weed flora studies were recorded in four sole crops- wheat, mustard, potato, radish and four intercrops- wheat + mustard, wheat + linseed, gram + mustard, pea + mustard along with fallow land as control. In total, 18 weed species were recorded with dominance of Poaceae family. The total dry weight of weeds was maximum in fallow land ($2516.6 \text{ kg ha}^{-1}$) among all systems, whereas in sole crops, maximum dry weight was recorded in wheat ($1973.3 \text{ kg ha}^{-1}$) and in intercrops was in wheat + mustard ($1659.1 \text{ kg ha}^{-1}$). The nutrient uptake (N, P and K) by weeds was higher in sole crops as compared to intercrops. The highest total nutrient (N, P and K) uptake by weeds was in the fallow land, which was 4644.7, 558 and 2880.5 kg ha^{-1} , respectively in March.

Keywords: Sole crops, Intercrops, Dry weight, Nutrient uptake

Weeds are important component of biodiversity in agricultural field and compete with cultivated food crops for resources such as water, nutrients and light (Oudhia 2004). Weed plants usually grow faster than crop plants, thus they absorb nutrients earlier, resulting in lack of nutrients for growth of plants. Weeds not only reduce the amount of nitrogen available to the crops but also suppress the crop growth at the early stage of their growth (Blackshaw 2003). The competition for nutrients (N, P and K) constitutes an important aspect of weed crop relation, which we need to minimize to harvest good yield. The crop rotation significantly increase total nutrient uptake by the crop, but decrease total nutrient uptake by weeds (Mohammaddoust- E-Chamanabad et al. 2007). This study was conducted to understand the relationship of crop weed diversity and nutrient uptake to effect the winter crops yield. This study will act as base line for the future observations to record changes in different cropping systems.

MATERIAL AND METHODS

The present investigation was carried out at the Punjab Agricultural University, Ludhiana from November to March during 2015-16 in *rabi* season. The study area was divided into different study plots on randomized plot bases for different crops which include four sole crops i.e., wheat, mustard, potato, radish and four intercrops i.e., wheat+mustard, wheat+linseed, pea+mustard, gram+mustard and fallow land (control). During experiment no herbicide or weedicide spray was done. The treatments were replicated thrice and in each treatment three fixed quadrats

(1m x1m) were laid down in each plot. The weed composition was recorded for every system and along with its emergence time. For dry weight measurement the weeds, they were uprooted from the quadrats and sundried, kept in oven at 60°C for drying purpose and dry weight was recorded at monthly interval for the sole, intercrops and fallow land. Nitrogen, phosphorous and potassium were estimated from the dry weight as per standard procedures. Nitrogen was estimated by Kjeldahl's method (Bradstreet 1954), phosphorus by Vanado- molybdo-phosphoric yellow color method (Jackson 1987) and potassium by Flame photometer (Chapman and Pratta 1961). Data recorded were suitably analysed.

RESULTS AND DISCUSSION

Weed composition: Twenty one weed species were recorded during *Rabi* season in crop fields. Weed species, *Anagallis arvensis*, *Avena ludoviciana*, *Cannabis sativa*, *Chenopodium album*, *Coronopus didymus*, *Cyperus rotundus*, *Erigeron canadensis*, *Fumaria parviflora*, *Gnaphalium purpureum*, *Medicago denticulata*, *Melilotus alba*, *Oenothera laciniata*, *Phalaris minor*, *Poa annua*, *Polypogon monspeliensis*, *Rumex dentatus*, *Silene conoidia*, *Sonchus arvensis*, *Sorghum halepense*, *Stellaria media* and *Veronica agrestis* were recorded. Among them, nineteen were annual and two were perennial in their life cycle six were monocot and fifteen were dicot weed species. These weeds belonged to thirteen different families. The Poaceae family was found dominating among them. The detail of weeds in each system is presented separately. In wheat, eighteen weed species were observed, six were

monocot and thirteen were dicot. The five weed species belonged to dominating family Poaceae. Thirteen weed species were found recorded in mustard, four were monocot and nine were dicot. The three weed species belonged to dominating family Poaceae, whereas,

In potato, there were eleven weed species, three were monocot and eight were dicot. The two weed species belonged to dominating family Poaceae. Twelve weed species were found in radish, among which, three were monocot and nine were dicot. The species recorded were *A. arvensis*, *C. album*, *C. didymus*, *C. rotundus*, *F. parviflora*, *M. denticulata*, *O. laciniata*, *P. annua*, *R. dentatus*, *S. halepense*, *S. media*, *V. agrestis*. The two weed species belonged to dominating family Poaceae. The weed composition was also recorded in mixed cropping and results are presented under different crops separately.

Wheat+Mustard: Seventeen weed species were recorded in wheat+mustard intercropping system. Five weeds were monocot and twelve were dicot (*A. arvensis*, *C. album*, *C. didymus*, *C. rotundus*, *F. parviflora*, *M. denticulata*, *M. alba*, *O. laciniata*, *P. minor*, *P. annua*, *P. monospeliensis*, *R.*

dentatus, *S. conoidia*, *S. arvensis*, *S. halepense*, *S. media* and *V. agrestis*). The four weed species belonged to dominating family Poaceae.

Wheat+Linseed: Fifteen weed species, *A. arvensis*, *C. album*, *C. didymus*, *C. rotundus*, *M. denticulata*, *M. alba*, *O. laciniata*, *P. minor*, *P. annua*, *P. monospeliensis*, *R. dentatus*, *S. conoidia*, *S. halepense*, *S. media* and *V. agrestis* were found in this intercropping system, among which five belonged to monocot and ten were dicot. The four weed species belonged to dominating family Poaceae.

Gram+Mustard: Total thirteen weed species were found in this intercropping system, five were monocot and eight were dicot (*A. arvensis*, *C. album*, *C. didymus*, *C. rotundus*, *M. denticulata*, *O. laciniata*, *P. minor*, *P. annua*, *P. monospeliensis*, *R. dentatus*, *S. arvensis*, *S. halepense* and *V. agrestis*). The four weed species belonged to dominating family Poaceae family.

Pea+Mustard: Eleven weed species were noticed in pea+mustard intercropping system, three were monocot and eight were dicot (*A. arvensis*, *C. album*, *C. didymus*, *C. rotundus*, *M. denticulata*, *O. laciniata*, *P. annua*, *R. dentatus*,

Table 1. Weed composition in different cropping systems

Weed species	T1	T2	T3	T4	T5	T6	T7	T8	T9	Group	Family
<i>Anagallis arvensis</i>	*	*	*	*	*	*	*	*	*	D	Primulaceae
<i>Avena ludoviciana</i>	*	-	-	-	-	-	-	-	-	M	Poaceae
<i>Cannabis sativa</i>	-	-	-	-	-	-	-	-	*	D	Cannabaceae
<i>Chenopodium album</i>	*	*	*	*	*	*	*	*	*	D	Amaranthaceae
<i>Coronopus didymus</i>	*	*	*	*	*	*	*	*	*	D	Brassicaceae
<i>Cyperus rotundus*</i>	*	*	*	*	*	*	*	*	*	M	Cyperaceae
<i>Erigeron canadensis</i>	-	-	-	-	-	-	-	-	*	D	Asteraceae
<i>Fumaria parviflora</i>	*	-	-	*	*	-	-	-	-	D	Fumariaceae
<i>Gnaphalium purpureum</i>	-	-	-	-	-	-	-	-	*	D	Asteraceae
<i>Medicago denticulata</i>	*	*	*	*	*	*	*	*	*	D	Fabaceae
<i>Melilotus alba</i>	*	-	-	-	*	*	-	-	-	D	Fabaceae
<i>Oenothera laciniata</i>	*	*	*	*	*	*	*	*	*	D	Onagraceae
<i>Phalaris minor</i>	*	*	-	-	*	*	*	-	-	M	Poaceae
<i>Poa annua</i>	*	*	*	*	*	*	*	*	*	M	Poaceae
<i>Polypogon monospeliensis</i>	*	-	-	-	*	*	*	-	-	M	Poaceae
<i>Rumex dentatus</i>	*	*	*	*	*	*	*	*	*	D	Polygonaceae
<i>Silene conoidea</i>	*	*	-	-	*	*	-	*	*	D	Caryophyllaceae
<i>Sonchus arvensis</i>	*	-	-	-	*	-	*	-	*	D	Asteraceae
<i>Sorghum halepense*</i>	*	*	*	*	*	*	*	*	*	M	Poaceae
<i>Stellaria media</i>	*	*	*	*	*	*	-	-	*	D	Caryophyllaceae
<i>Veronica agrestis</i>	*	*	*	*	*	*	*	*	*	D	Plantaginaceae

*and - presence and absence of weed species; * perennial and rest annual

A- Annual, P- Perennial, D- Dicot and M- Monocot, T1- Wheat, T2- Mustard, T3- Potato, T4- Radish, T5- Wheat+Mustard, T6- Wheat+Linseed, T7- Gram+Mustard, T8- Peas+Mustard, T9- Fallow land (control)

S. conoidia, *S. halepense*, and *V. agrestis*). Only two weed species belonged to dominating family Poaceae, rest belonged to ten different families.

In the uncultivated fallow land, total sixteen weed species were recorded (*A. arvensis*, *C. sativa*, *C. album*, *C. didymus*, *C. rotundus*, *E. canadensis*, *G. purpureum*, *M. denticulata*, *O. laciniata*, *P. annua*, *R. dentatus*, *S. conoidia*, *S. arvensis*, *S. halepense*, *S. media* and *V. agrestis*) Only two weed species belonged to family Poaceae and remaining fourteen belong to different families. This study indicated that dicots were dominating among all the treatments. Sharma et al. (2010) also reported dicot dominance in cultivated area. Weed species, *A. arvensis*, *C. album*, *C. didymus*, *C. rotundus*, *M. denticulata*, *O. laciniata*, *P. annua*, *S. halepense* and *V. agrestis* were common in all the systems, whether

cultivated or fallow, whereas, *A. ludoviciana* was recorded in wheat only and *E. canadensis*, *F. parviflora* and *G. purpureum* in uncultivated fallow land. The maximum eighteen weed species were recorded in wheat crop and minimum eleven in potato and pea+ mustard. Hyvonen and Salonen (2002), Jafari et al. (2013) also reported sixteen weed species with maximum belonging to Poaceae family.

Dry weight of weeds: The variations in dry weight were highly significant in different cropping systems. The total dry weight of weeds was 2516.6 kg ha⁻¹ for fallow land followed by wheat (1973.3 kg ha⁻¹) and mustard (1694 kg ha⁻¹) among the sole crops (Table 2), whereas, wheat+mustard (1659.1 kg ha⁻¹), wheat+linseed (1575.7 kg ha⁻¹) and wheat+linseed (1236.7 kg ha⁻¹) among the intercrops. The monthly dry weight was more in fallow land in January, February and March (591.7,

Table 2. Dry weight of weeds in different cropping system (kg ha⁻¹)

Treatments	December 2015	January 2016	February 2016	March 2016	Total dry weight
Wheat	255.0	493.3	545.0	680.0	1973.3
Mustard	280.0	416.7	484.0	513.3	1694.0
Potato	306.7	356.7	-	-	663.4
Radish	386.7	420.0	-	-	806.7
Wheat + Mustard	212.4	353.3	486.7	606.7	1659.1
Wheat + Linseed	185.0	281.7	323.3	446.7	1236.7
Gram + Mustard	246.7	373.3	402.4	553.3	1575.7
Pea + Mustard	263.3	316.7	351.7	-	931.7
Fallow land (control)	146.7	591.7	641.5	1136.7	2516.6
CD (P=0.05)	0.02	0.63	0.55	0.67	-

Table 3. Nutrient uptake by weeds in different months (kg ha⁻¹)

Treatments	Months												Total uptake			Total nutrient
	December, 2015			January, 2016			February, 2016			March, 2016			N	P	K	
	N	P	K	N	P	K	N	P	K	N	P	K				
Wheat	533.1	88.2	276.2	902.4	112.0	493.3	976.6	126.8	454.2	1218.6	117.6	504.3	3630.7	444.6	1728.0	5803.3
Mustard	671.6	95.2	326.7	836.2	115.8	694.5	1088.6	114.7	645.3	1058.8	66.10	453.4	3655.2	391.8	2119.9	6166.9
Potato	615.4	46.9	485.6	679.2	51.40	445.9	-	-	-	-	-	-	1294.6	98.30	931.5	2324.4
Radish	776.0	62.0	451.2	760.5	94.61	280.0	-	-	-	-	-	-	1536.5	156.61	731.2	2424.3
Wheat + Mustard	438.1	32.2	141.6	629.8	68.30	353.3	849.5	70.25	365.0	1075.9	99.30	444.9	2993.3	270.05	1304.8	4568.2
Wheat + Linseed	352.2	26.4	107.9	441.7	92.96	234.8	594.4	59.49	350.2	1017.3	86.31	428.8	2405.6	265.16	1121.7	3792.5
Gram + Mustard	534.2	72.5	287.8	710.8	104.7	684.4	436.2	101.1	503.0	800.5	62.24	409.5	2481.7	340.54	1884.7	4706.9
Pea + Mustard	530.8	76.4	197.5	682.8	75.69	422.3	604.0	69.51	615.5	-	-	-	1817.6	221.6	1235.3	3274.5
Fallow land (control)	297.1	49.4	244.5	1143	165.7	936.9	1146.4	151.0	695.0	2058.2	191.9	1004.1	4644.7	558.0	2880.5	8083.2
CD (p=0.05)	76.15	32.7	141.6	130.3	36.38	117.9	193.6	44.49	174.2	379.99	51.25	273.7	-	-	-	-

641.5, 1136.7 kg ha⁻¹, respectively). It was correlated with higher density and abundance of weed species during these months, whereas, dry weight was lowest in in December (146.7 kg ha⁻¹) among all the systems. Similar results had been found by Azizi et al (2015). Sharma and Banik (2013) also observed that weeds were densely populated in sole crops and had higher dry weight as compared to intercrops.

Nutrient uptake: The highest total nutrient uptake (N+P+K) was in fallow land (8083.2 kg ha⁻¹) followed by mustard (6166.9 kg ha⁻¹) and wheat (5803.3 kg ha⁻¹) among sole crops (Table 3), whereas, gram+mustard (4706.9 kg ha⁻¹) and wheat+mustard (4568.1 kg ha⁻¹) had highest values for total nutrients among intercrops. Similar trend was observed in N, P and K individually.

CONCLUSION

Weeds of poaceae family dominated in the winter crops and 18 different species were recorded in different cropping systems. Obviously, uncultivated area had more weed diversity and biomass but crops were also invaded by the weeds and requires proper management to avoid nutrient loss for the crops.

REFERENCES

- Adensina GO, Akinyemiju OA and Ola OT 2012. Assessment of frequency, density and abundance of weed species in different cropping systems. *Journal of Natural Science and Research* **2**(9): 107-119.
- Azizi E, Koocheki A, Rezvani-Moghadam P, Nassiri-Mahallati M and Sharifi-Noori MS 2015. Evaluation of plant diversity and nutrient resource on weed diversity and soil microbial respiration. *Agricultural Biological Sciences Journal* **1**(5): 197-205.
- Blackshaw RE, Brandt RN, Janzen HH, Entz T, Grant CA and Derksen DA 2003. Differential response of weed species to added nitrogen. *Weed Science* **51**: 532-539.
- Borah N, Deka NC, Deka J, Barua IC and Rajkhowa DJ 2008. Nutrient removal by crop and weeds under different weed and nutrient management practices in transplanted autumn rice-winter rice cropping sequence. *Proceeding Biennial Conference of Indian Society of Weed Science* Pp 179, Bihar Veterinary College, Patna.
- Bradstreet RB 1954. Kjeldahl method for organic nitrogen. *Analytical Chemistry* **26**(1): 185-187.
- Chapman HD and Pratta PF 1961. Methods of analysis for soil, plants and water. University of California, U.S.A.
- Hyvonen T and Salonen J 2002. Weed species diversity and community composition in cropping practices at two intensity levels - a six-year experiment. *Plant Ecology* **159**: 73-81.
- Jackson ML 1987. Soil chemical analysis, Prentice Hall of India, New Delhi.
- Jafari R, Vesanlo F and Javan R 2013. Weeds associated with potato (*Solanum tuberosum*) crops. *International Journal of Agricultural Crop Science* **6**(20): 1403-1406.
- Kour P, Sharma BC, Kumar AK and Kour P 2013. Nutrient uptake by chickpea + mustard intercropping systems as influenced by weed management. *Indian Journal of Weed Science* **45**(3): 183-188.
- Lima filho DA, Revilla J, Amaral IL, Matos FD, Coelho LS, Ramos JF, Siliiva GB and Guedes JO 2004. Floristic composition of 13 hectares in Cachoeira Porteira, Para State. *Acta Amazonica* **34**(3): 415-423.
- Mohammaddoust- E-Chamanabad HR, Asghari A and Tulikoy AM 2007. The effects of weed-crop competition on nutrient uptake as affected by crop rotation and fertilizers. *Pakistan Journal of Weed Science* **10**(22): 4128-4131.
- Oudhia P 2004. Phyto-sociological studies of rainy wastelands weed with special reference to *Parthenium hysterophous* L. In Repair District <http://www.iprng.org/IPRNG-and-w-15.Htm>.
- Sharma RC and Banik P 2013. Baby corn-legumes intercropping system: II weed dynamics and community structure. *Wageningen Journal Life Science* **67**: 11-18.
- Sharma LN, Chaudhary RP and Gupta VNP 2010. Weed diversity in Trans-Himalayan wheat fields of Upper Manag, Nepal. *Sustainable Biological Research Nepal* **21**: 72-78.
- Sher Z, Haussain F, Badshah L and Wahab M 2011. Floristic communication, communities of weeds of wheat fields of Lahore, district Swabi, Pakistan. *Pakistan Journal of Botany* **43**(6): 2817-2820.
- Sinha MK and Banerjee A 2016. Studies on weed diversity and its phyto-sociological under direct dry seeded rice systems. *Community Plant Science* **6**: 47-54.
- Van Elsen T 2000. Species diversity as a task for organic agriculture in Europe. *Agricultural Ecosystem Environment* **77**: 101-109.



Energy Input-Output Analysis in Wheat, Barley and Oat Production

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Abstract: The consumed energy, energy input-output relation of wheat, barley, and oat production in was analysed in Al-Qarneh al-Ghamayj (31° 1' 5.5956" N and 47° 25' 23.4192" E.). The irrigation consumed 32.99, 31.83 and 31.96% of the total energy inputs on wheat, barley and oat, respectively. Fuel is the second source of consumed energy in tractors, harvesting engines, pumps being 8466.21 (27.84%), 9415.03 (28.45), and 8757.33 (28.41) for wheat, barley, and oats, respectively. The fertilizers consumed energy (Nitrogen especially) were 7291.94 (23.98%), 7658.35 (23.14%), and 7444.72 (24.15%) MJ ha⁻¹ for wheat, barley, and oats respectively. The average energy output for grain wheat, barley and oat was 60469.63, 71960.66 and 70017.61 MJ ha⁻¹. Barley was the most energy-efficient crop (1.9 %) followed by wheat and oat (1.71 and 1.59 %). Barley yield was 4945.75 Kg ha⁻¹ with input energy of 37776.46 MJ ha⁻¹ while wheat yield was 4113.58 Kg ha⁻¹ with input energy of 38095.52 MJ ha⁻¹.

Keywords: Input and output energy, Energy efficiency, Wheat, Barley, Oats

Reduced energy consumption in cereal production leads to lower production costs. The use of traditional means of agricultural production increases the cost of agricultural production particularly in developing countries. Most developing countries rely mainly on fossil fuels to produce energy for agricultural production. These countries still use a modest percentage of renewable energy in production compared to the developed world. The agricultural production cannot increase except if sufficient fertilizers and water for irrigation are available in an appropriate time and utilized with scientifically methods. With increasing the world population, the energy consumption required efficient planning. This means the input components need to be specified to prescribe the methods most efficient for dominating them. Crop food and yields provisions to consumers are straight linked to energy and adequate energy is needed in the appropriate form at the suitable time to increase productivity. One method for improving the consumption of energy in agricultural production is to determine the competence of manners and techniques used (Safa and Tabatabaefar 2002). The energy input had an influence directly on crop yield. Fossil fuel and fertilizers (N and P) account for the greatest share (>75%) of overall energy spent in a mixed cropping system (Safa et al 2010). Agricultural practices contain all crops processes that happen after its land reclamation such as plowing, seeding, fertilizing, weed control, combating insects, irrigation, harvest, and transportation. The energy needed for

agricultural production was roughly 3% of the total in the developed countries national consumption. The percentage of energy consumption in developing countries increased to 6% of the total national consumption. There must be a plan for energy consumption, on the other hand, with the existing population increasing the current lifestyle will be unsustainable (Sahabi et al 2013). The energy used in agricultural production can be classified into direct and indirect energy. The essential means of direct energy used on the farm include fossil fuel consumption such as diesel, gasoline, furnace oil, electro power and coal. The energy consumed as indirect for transportation agricultural input, like pesticides, fodder, equipment, cereals, and the organic and chemical fertilizers. Indirect energy consumption is 70 percent in dairy farms and around 49.97 percent in arable fields (Saunders et al 2006). This investigation aimed to determine the energy consumption in wheat, barley and oat development based on farm operations and semi-arid farmland energy sources.

MATERIAL AND METHODS

Study site: A field experiment was conducted during seasons 2017 and 2018. The field experiments were carried out in the district of Al-Qarneh al-Ghamayj (65 km north of the city center of Basrah, 31° 1' 5.5956" N and 47° 25' 23.4192" E.). Average annual rainfall in spring of 2017 and 2018 was 100 mm and 180 mm respectively, with average temperatures of 21 ° C and 23 ° C for the same period's. Soil

moisture content and bulk densities were 18.75% and 1.32 Mg m⁻³ respectively. Soil texture was clay content 52 %; silt 35 %; sand 13 %.

Methodology: The investigation has considered only the energy used in wheat, barley, and oat production, without considering natural sources of energy such as solar radiation, rain, wind. The equivalent input and output energy indicators for wheat, barley and oat production were determined depending on experimental field and ASAE standards (ASAE 2006). All farms are considered irrigated land and the rainfall rate in winter does not reach 180 mm, therefore, using the pumps for irrigation the crops. The irrigation for all growing season was between 5 to 20 times according to rainfall. Direct energy requires human labour, electricity, and fuel to have a reasonable estimate of energy consumption in wheat, barley, and oat output. Indirect resources, include pesticides, fertilizers, machinery, and crops. This research, therefore, examines the two significant portions of energy that use processes and energy sources.

Operations: The energy consumption in the production of barley, wheat and oat, include plowing, seeding, fertilizer distribution, irrigation, spraying, harvesting and transportation (Table 1). Direct energy means human effort, nourishment and electricity. Human labour-power is low, and the use of electricity in irrigation operations is slight. In other processes, the more substantial workable energy is a fossil fuel. The power comes from fuel use in tractors engines, pumps, and harvesters, the fuel also use in generating electricity in some farms.

Equipment, vehicles, and tractors: Several measures were taken in calculating this energy: first, the energy needed to produce raw materials; second, the energy used in industrial operations; third, the energy used to move machines to and from consumers; the energy used to upgrade and maintain them (from Ziaei et al (2015). In order to estimate the energy input for tractors and other machines, knowledge of the weight and work life span is essential. Determining life has been used from ASAE criteria in this analysis (ASAE 2006).

Human labour: The male and female energy outputs were about 1.96 and 0.8 MJ ha⁻¹, respectively (Khan et al 2010). The approach used in these studies to determine human labour energy usage has been to estimate the number of hours of the fieldwork to achieve a task by human labour. Energy consumption was estimated by multiplying overall hours of human activities by the energy coefficient of labourers.

Pesticide: The energy consumption was determined by multiplying the energy coefficients of the pesticides by the overall value of the herbicides, insecticides and fungicides

concerned.

Fertilizer: In this analysis, the quantity of each fertilizer was manually measured by scanning phosphate, and the nitrogen content of the different fertilizers. Nitrogen and phosphate have a production energy content of 78.1 and 17.4 MJ kg⁻¹, respectively (Mohammadi and Omid 2010). The addition of chemical fertilizers with quantities increasing or decreasing leads to energy waste and a negative impact on the yield, as fertilizers must be given to the plant within the appropriate times depending on the stage of plant growth.

Fuel: Fuel consumption was measured for the tractor engine by determination for a distance of 10 m which represented the test run. The graduated tube was filled by diesel fuel for each operation. The fuel consumption was measured for each operation(10m) by registering the difference between the level of fuel in the graduated tube at the starting and the finish of the operation. The unit of fuel consumed was converted from cubic centimeter to liter The energy output for this study was estimated from fuel consumption, as shown in the following equation for each operation of 1 hectare of land times the fuel equivalent energy per liter:

$$FC = \frac{Vfc * 1000}{W * d} \quad (1)$$

Where:

FC: Fuel consumption (L h⁻¹), Vfc: Volume of fuel consumed (L), W: Effective plow width (m), d: Tillage depth (m).

Seeds: There are many certified seed producers, but the majority of farmers use their seeds. Different types of seeds are used for each crop for the geographical patch under study. Seed quantities (seeding rate) and seeding methods are different where some farmers use the machines seeding and the other uses manual seeding. For these reasons, there is difficulty in determining the exact bases of energy consumption. However, the recommended seed quantities can be adopted as the seed quantity for wheat, barley and oats are 135, 155 and 145 kg ha⁻¹, respectively.

Energy efficiency: Energy efficiency, energy productivity, energy intensity and energy gain for wheat, barley and oat was calculated, based on the energy equivalents of the inputs and output For wheat, barley and oat energy efficiency, productivity, intensity and gain was measured, based on the input and output energy equivalents.

$$\text{Energy efficiency} = \frac{\text{Output energy (MJ h}^{-1}\text{)}}{\text{Input energy (MJ h}^{-1}\text{)}} \quad (2)$$

$$\text{Energy productivity (MJ kg}^{-1}\text{)} = \frac{\text{Crop yield (kg ha}^{-1}\text{)}}{\text{Input energy (MJ h}^{-1}\text{)}} \quad (3)$$

$$\text{Energy intensity (kg MJ}^{-1}\text{)} = \frac{\text{Input energy (MJ h}^{-1}\text{)}}{\text{Crop yield (kg ha}^{-1}\text{)}} \quad (4)$$

$$\text{Energy gain (kg MJ}^{-1}\text{)} = \text{Output energy (Mj h}^{-1}\text{)} - \text{input energy (MJ h}^{-1}\text{)}$$

RESULTS AND DISCUSSION

Energy sources: The water irrigation recorded the highest energy consumption among direct energy consumption for wheat, barley and oat production (Table 3). It was 12568.88 (32.99%), 13104.38 (31.96%), and 12024.43 (31.83%) MJ ha⁻¹, respectively. These results can be attributed to replicating times of irrigation every two weeks, particularly when rainfall is low. The second source for energy consumption is diesel fuel used in most agricultural operations such as using it in tractors, harvesting engines, pumps, etc. It was 8466.21 (27.84%), 9415.03 (28.45), and 8757.33 (28.41) for wheat, barley, and oats, respectively. The fertilizers consumed energy (nitrogen especially) were 7291.94 (23.98%), 7658.35 (23.14%), and 7444.72 (24.15%) MJ ha⁻¹ for wheat, barley, and oats respectively. The energy consumed by wheat is more than barley and oat crops, and this includes all the fertilizers studied. The wheat yield needs energy higher than that of barley and oat yield. Energy consumption in sowing operations often the same for wheat, barley and oat. However, in the wheat crop, more seed energy was consumed due to this crop's higher seed rate compared to the barley and oat crops. Herbicide, pesticide and fungicide consumed energy the lower than that of other input energy for all three crops. These results agree with the findings of Safa et al (2010) and Ziaei et al (2015).

Consumed energy in operations: The same processes were applied in crop production (wheat, barley, oats). The energy consumed in the production process includes tillage, drilling, irrigation, fertilizer distribution, spraying, harvesting. The irrigation operations had the highest energy consumption of 1956.80 MJ ha⁻¹ (70%), followed by plowing, drilling, fertilizer distribution, and harvesting operations by recording energy consumption by 503.18 (18%), 83.86 (3%), 27.95 (1%) and 167.73 (6%), respectively (Table 4). Irrigation operations consume high energy because of need for water irrigation continuously every other week. In contrast, the other operations consumed energy lower because of was conducted one time or twice in the growing season. Irrigation operations can be reduced by using recent technologies such as pivotal irrigation where the surface irrigation is squandering much water. If the growing season has a high rainfall rate, the percentage for consumed energy by irrigation will be reduced to lower than 70% (Safa et al 2010).

Energy efficiency: Barley recorded the maximum value of energy efficiency 1.9, followed by oat and wheat (1.71, and 1.59) (Table 4). This was mainly because of increasing the output energy (71960.66 MJ ha⁻¹) in case barley. Oat had the highest energy productivity of 0.12, and the lowest was 0.07 for barley. If the field output energy value is lower than the

Table 1. Energy consumption depending on operations in wheat, barley and oat production

Operations	Consumed energy (%)	Consumed energy (MJ ha ⁻¹)
Tillage	18	503.18
Drilling	3	83.86
Spraying	2	55.91
Fertilizer distributor	1	27.95
Harvesting	6	167.73
Irrigation	70	1956.80
Total	100	2795.43

Table 2. Inputs and outputs equivalent energy into the production of wheat, barley, and oat

Energy input	Unit	Energy equivalent (MJ unit ⁻¹)
Human labour	H	1.96
Machinery	H	62.72
Diesel fuel	L	56.31
Chemical fertilizers		
Nitrogen (N)	Kg	66.14
Phosphate (P ₂ O ₅)	Kg	12.44
Potassium (K ₂ O)	Kg	11.15
Herbicide	L	238
Pesticide	L	199
Fungicide	L	92
Water for irrigation	M3	1.02
Seeds (Wheat)	Kg	20.1
Seeds (Barley)	Kg	14.7
Seeds (Oat)	Kg	16.25
Total energy input		
Outputs energy		
Wheat grain yield	Kg	14.48
Barley grain yield	Kg	14.7
Oat grain yield	Kg	14.55

energy value within the field, energy is therefore ineffective. Generally, barley achieved the maximum energy gain of 34184.2 MJ ha⁻¹ followed by oat and wheat (29016.56 and 22374.11 MJ ha⁻¹ respectively).

Grains yield: The barley had a high output (grain yield) although consumed input energy is low (Table 4). Barley yield was 4945.75 Kg ha⁻¹ when input energy of 37776.46 MJ ha⁻¹ while the wheat yield was 4113.58 Kg ha⁻¹ with input energy of 38095.52 MJ ha⁻¹. The barley achieved a higher yield than that of oat and wheat in lower consumption energy, and this can be attributed to natural factors such as ability the barley to bear for the salinity of soil or irrigation water, cold weather and also barley more resistant to disease than wheat and oat

Table 3. Input and output energy in wheat, barley and oat production

Energy input	Quantity per unit (ha)			Total energy equivalent (MJ)		
	Wheat	Barley	Oat	Wheat	Barley	Oat
Human labor (h)	226.20	230.73	237.50	443.35 (1.16)	452.23 (1.20)	465.5 (1.14)
Machinery (h)	40.56	42.47	44.57	2543.92 (6.68)	2663.72 (7.05)	2795.43 (6.82)
Diesel fuel (liter)	150.35	155.52	167.20	8466.21 (22.22)	8757.33 (23.18)	9415.03 (22.96)
Chemical fertilizers (kg)						
Nitrogen (N) (kg)	110.25	112.56	115.79	7291.94 (19.14)	7444.72 (19.71)	7658.35 (18.68)
Phosphate (P ₂ O ₅) (kg)	55.36	58.85	63.48	799.4 (2.10)	849.79 (2.25)	916.65 (2.24)
Potassium (K ₂ O) (kg)	50.08	52.78	50.55	558.39 (1.47)	588.5 (1.56)	563.63 (1.37)
Herbicide (l)	2.06	1.97	2.10	490.28 (1.29)	468.86 (1.24)	499.8 (1.22)
Pesticide (l)	1.41	1.48	1.5	280.59 (0.74)	294.52 (0.78)	298.5 (0.73)
Fungicide (kg)	0.33	0.33	0.34	30.36 (0.8)	30.36 (0.8)	31.28 (0.8)
Water for irrigation (m ³)	4787.65	4971.60	5100.15	12568.88 (32.99)	12024.43 (31.83)	13104.38 (31.96)
Seeds (Wheat) (kg)	220	200	250	4622.2 (12.13)	4202 (11.12)	52525 (12.81)
Total energy input (MJ)				38095.52	37776.46	41001.05
Outputs energy						
Grain yield (kg)	4113.58	4945.75	4835.47	60469.63	71960.66	70017.61

The values between parentheses are the percentage of total energy input (%)

Table 4. Energy efficiency within one hectare of the production of wheat, barley and oat

Parameters	Wheat	Barley	Oat
Energy input (MJ ha ⁻¹)	38095.52	37776.46	41001.05
Energy output (MJ ha ⁻¹)	60469.63	71960.66	70017.61
Energy efficiency (%)	1.59	1.90	1.71
Energy gain (MJ ha ⁻¹)	22374.11	34184.2	29016.56
Yield (kg ha ⁻¹)	4113.58	4945.75	4835.47
Energy productivity (kg MJ ⁻¹)	0.11	0.07	0.12
Energy intensity (MJ kg ⁻¹)	9.26	7.64	8.48

These results agree with the findings of Ziaei et al (2015) and Strnad and Miša (2016).

CONCLUSION

Barley achieved a higher yield than that of oat and wheat in lower consumption energy. The production of barley exceeded in terms of output energy, energy efficiency and energy gain from wheat and oat production. Barley recorded the lowest values of input energy and energy productivity and barley achieved a higher yield than that of oat and wheat in lower consumption energy.

REFERENCES

- ASAE. ASAE D497.5 FEB 2006. Agricultural Machinery Management Data. *St. Joseph, Mich.: ASAE.*
- FAO, 2008. < <http://www.fao.org/faostat/en/#home> >.
- Khan S, Khan MA and Latif N 2010. Energy requirements and economic analysis of wheat, rice and barley production in Australia. *Soil Environment* **29**(1): 61-68.
- Mohammadi A and Omid M 2010. Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. *Applied Energy* **87**(1): 191-196.
- Safa M, Mohtasebi SS and Lar MB 2010. Energy use in wheat production (A case study for Saveh, Iran). *World Journal of Agricultural Sciences* **6**(1): 98-104.
- Safa M and Tabatabaeefar A 2002, November. Energy consumption in wheat production in irrigated and dry land farming. *In Proceeding of International Agricultural Engineering Conference, Wuxi, China.*
- Sahabi H, Feizi H and Amirmoradi S 2013. Which crop production system is more efficient in energy use: Wheat or barley?. *Environment, Development and Sustainability* **15**(3):711-721.
- Saunders CM, Barber A and Taylor GJ 2006. Food miles-comparative energy/emissions performance of New Zealand's Agriculture Industry. Agribusiness & Economics Research Unit
- Strnad L and Miša P 2016. Energy Use of Different Farming Systems in Long-Term Trial. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **64**(5): 1667-1674.
- Ziaei SM, Mazloumzadeh SM and Jabbari M 2015. A comparison of energy use and productivity of wheat and barley (case study). *Journal of the Saudi Society of Agricultural Sciences* **14**(1): 19-



Gender Differentials in Occupational Structure and Employment Pattern in Agriculture in Punjab

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Abstract: This paper studies gender differentials in crop production in the villages of Punjab under different crops. The specific objectives addressed in the study were to: analyze the extent of female employment across cropping systems in Punjab; to examine the gender differentials in employment across various cropping systems in Punjab and to identify the factors affecting the rural women employment in agriculture. The primary data were collected using a structured questionnaire administered to 300 rural households in Punjab. Frequency and percentage methods were used to analyze the socio-economic characteristics of women and their level of participation in agricultural production. The participation of female labour in agriculture varies depending on the number of factors viz. education level, size of the family, employment opportunities, access to land and credit, cultural and religious norms etc. Analysis of the data showed that more than two-thirds of the households in the agricultural households belonged to general category whereas the scheduled caste and the backward class were very few. The proportion of uneducated males (23.75%) and uneducated females (41.25%) was the highest among the landless category of rural households. The labour and workforce participation rates of sampled rural households on their involvement in various occupations showed that the overall LFPR of males was 88.66% and female LFPR, 29.07 per cent. The total labour use per hectare for wheat, rice, maize, cotton, chilli, peas and kinnow of the state on an average worked out to be the highest, 1155.5 hours per hectare for chilli, constituting 561.9 hours per hectare (48.62%) of males and 593.6 hours per hectare (51.37%) of females. Crop wise analysis showed that wheat occupied the minimum labour hours 271.7 per hectare offering the amount of female labour use for this crop to only 41.3 hours per hectare (13.4%) of the total labour used. More female labour was used for chilli, cotton and peas as these crops are less mechanized in contrast to other crops thus there is a tendency among the farmers to employ male labour for the mechanized and skilled operations and female labour for unskilled operations.

Keywords: Female labour, Mechanization, Agriculture operations, Labour hours

Women contribute considerably in agricultural development and allied fields including the primary crop production, livestock production, horticulture, post-harvest operations, forestry and fisheries etc. The nature and extent of participation of women in agriculture vary widely among different farming systems, classes and castes. But despite these variations, there is hardly any activity in agricultural production, where women are not actively involved. In some of the farm activities like processing and storage, women predominate so strongly that male workers are numerically insignificant (Agarwal 2003). Various studies conducted in India and other developing countries proved that women contribute more to agricultural production, but they have not been acknowledged either by the planners or the policymakers. They constitute a large group of landless labourers who work in the fields with their counterparts and also do the household work.

Women constitute more or less half of any country's population, but their labour force participation rate is low as compared to that of men. Social norms restrict their availability and location of work, leading to lower labour force participation rate (NCEUS 2007). Goldin (1990) analyzed the

employment pattern in the United States and suggested that there is a long run 'U- Shaped' pattern of female workforce participation due to urbanization. The downward-sloping part of this U-Shape is due to the sociological process, i.e. social restrictions on the lifestyle of women which tend to become more rigid as households move up in the caste hierarchy (Chen and Dreze 1992). Women's work is a complex task not only in India but also elsewhere in the world, as the issues related to women work and employment is qualitatively different from those of male workers (Beneria 1982). The participation of women in rural areas is often led by poverty rather than by choice. They move in the labour force only during a crisis or when their household conditions are not better. Various studies have shown that females tend to cross their household boundary and enter into the labour force if there is a fall in the income of the households (Srivastava and Srivastava 2010). Rate of participation of female, on the one hand, is due to reproductive roles, household and care responsibilities, cultural sanctions, patriarchal hierarchies (Sudarshan and Bhattacharya 2009) and other factors as caste, religion, marital status, adequate education and skills, forms of discrimination in the labour market and occupational

segregation. These constraints push women not to explore employment in the market (Ghosh 2009, Thomas 2012). These constraints have entrenched the women in a vicious circle of poverty that placed them at a less advantageous vantage of income and resource empowerment (Damisa, Samndi and Yohanna 2007). Damisa et al (2007) highlighted in their study that despite various social, economic and other constraints, women have a high level of participation in agriculture, and they are very committed in their agricultural activities. Access to credit and land ownership also determine the extent of female participation in agricultural production. It is a pity that agriculture sector in many developing economies is underperforming, because women who represent a crucial resource in agriculture and the rural economy through their roles as farmers, labourers and entrepreneurs, face more severe constraints than men in access to productive resources (Ahmed et al 2008).

Women in contemporary India do not enjoy equal status with men in all the fields of society, particularly in the agriculture sector. Agriculture is the primary occupation in the rural areas, which engages 64.5 per cent, 0.5 per cent and 35 per cent of the rural female workers as self-employed, regular workers and casual labourers respectively (NSSO 2004-05). In wheat-growing areas of Haryana, women's direct contribution to agriculture was not less than 50 per cent of all agricultural work (Chakravarty 1975). They contributed not only in terms of physical output but also in quality and efficiency. Over the years, women played a chief role in the field of food security, horticulture, fisheries etc. The UN Report of International conference on Women 1985 concluded that apart from the household jobs, women perform so many other roles. Though the household activities are termed as non-economic and not rewarded with payments but the importance of their work cannot be neglected/overlooked. Over the years, women cultivators are typically and wrongly characterized as economically inactive, and women cultivator plays only a supportive role in agriculture as farmer's wives (Samanta 1994). They remain invisible workers. Also, they do not get any recognition, and their contribution to the national income is not considered. There is hardly any agricultural activity where women are not actively involved. All the farming jobs are productive, and the contribution of female workers must be recognized; however, their work has been overlooked by the policymakers. Hence, generally, men are labelled as farmers and women as homemakers and child raisers. Many reforms have taken place, and women are moving closer to equality. Now agriculture is recognized as a female activity. Nearly 48 per cent of India's self-employed persons are women. There are almost 75 million women engaged in dairying as compared to

15 million men and 20 million women in animal husbandry as against 1.5 million men (Ghosh and Ghosh 2009). Women play a critical role in various operations as crop production, livestock production, horticulture, sericulture, post-harvest operations etc. But it is dismal that as things change newer forms of inequality emerge.

Punjab, known as the granary of India, was at the forefront in reaping the benefits of green revolution technologies. As per 2001 census, nearly 38.9 per cent were dependent on agriculture and allied activities. Out of the total agricultural workforce cultivators and labourers accounted for 58.09 and 41.91 per cent, respectively (Statistical Abstract, Punjab 2001). It has been contributing around 50 per cent of the rice and 65 per cent of wheat to the central pool for more than five decades. There was a significant shift in the cropping pattern. The area under maize, oilseeds and pulses showed a substantial decline, but the area under rice and wheat increased from about 50 per cent in 1960-61 to about 80 per cent of the gross cropped area. In the late 1960s and early 1970s, the introduction of modern production technology for wheat and rice unleashed the forces of change that influenced productivity, production and employment. Increase in production was accompanied by more excellent labour absorption in the process through an increase in cropping intensity and use of fertilizers, expansion in irrigated area and higher land productivity (Raju 1976, Bisliah 1978). However, the seed-irrigation-fertilizer technology necessitated mechanization of farm operations through the introduction of tractors and tractor-operated threshers in a big way in the late 1970s, to realize higher returns through precision farming and vertical expansion of the land area, mechanization of farm operations led to a fall in labour intensity. Due to an increase in the use of combine harvesters and weedicides, the demand for human labour in the farm sector in Punjab decreased significantly since the late 1980s. Based on per hectare labour use in the crop sector, demand for human labour is estimated to have fallen from 479.3 million man-days in 1983-84 to 421.93 million man-days in 2000-01.

Female employment in the agriculture sector has also undergone significant changes over time. While almost 83 per cent of rural females in India were engaged in agriculture, such proportion was even higher in Punjab agriculture (GOI 2006). More than 90 per cent of the female workers belonging to farming families and about 52 per cent of those belonging to landless households were engaged in agriculture and allied activities including the rearing of milch animals (Vatta 2006). However, the employment of female workers is expected to differ significantly across various crops and farming systems. While, due to massive

mechanization in rice and wheat, the opportunities for female employment in these crops reduced significantly. Crops such as cotton, vegetables and fruits, which are quite labour intensive, usually employ a large number of women workers in picking, harvesting and packing, etc. Agriculture mechanization is generally planned by men and aims to benefit men leaving behind women's burden unrelieved or even increased.

Agriculture is the largest sector in the economy, and women constitute a challenging part of this sector. It is necessary to understand their nature of work because they have to face many problems. Women's role in agricultural development and allied fields, including the primary crop production, livestock, horticulture, post-harvest operations etc. have been taken for granted and ignored. No doubt the work of women varies from region to region and is also different in different zones, but, there is hardly any activity where women are not actively involved. In some of the activities like processing and storage, women predominate men workers. Since independence, a large number of women are seeking employment in this sector, but a need is felt to analyze whether this employment has in real terms increased their capabilities, autonomy, qualities of life and reduced their restrictions prevailing from gender relations. This study attempts to analyze the pattern and determinants of female employment opportunities in Punjab agriculture. The study concentrates on the following objectives to study the extent of female employment across cropping systems in Punjab; examine the gender differentials in employment across various cropping systems in Punjab and identify the factors affecting the rural women employment in agriculture

MATERIAL AND METHODS

The multistage stratified random sampling procedure was used for the selection of the study sample. At the first stage, the three divisions of the state were considered based on the cropping pattern. Six districts, two from each cropping pattern were selected for the study to ensure sufficient representative sample, keeping in mind the time constraints. From each district, two blocks were selected and then from each block, one village was selected randomly. At the next stage of sampling, 25 household respondents were selected from each village which was involved in the cultivation of rice, wheat, maize, cotton, fruit, vegetable and dairy activities. The cross-section data pertaining to crop-wise labour utilization and participation in various operations were collected for the year 2016-17 and 2017-18.

RESULTS AND DISCUSSION

The socio-economic characteristics of the selected

respondents are presented in Table 1. The average size of operational holdings ranges between 1.51 hectares for small farmers and 17.33 hectares for large farmers. Overall households belonging to the general category, scheduled caste and backward caste were 68 per cent, 27 per cent and 15 per cent respectively. More than two-thirds of the households in the agricultural households belonged to general category whereas the scheduled caste and the backward class were very few. The proportion of uneducated males (23.75%) and uneducated females (41.25%) was the highest among the landless category of rural households. Landless rural households represent the people having very low-income and no land, which is the most valuable asset in rural areas. Such households have little access to education. Moreover, the proportion of uneducated females was more than educated males in all the category of landholdings, but this gap was the maximum among large farm households. Amongst the educated population, the level of education for most of the rural households for both males and females was primary to matric. The proportion of rural households above matric was more only large farm households.

The labour and workforce participation rates of sampled rural households were discussed based on their involvement in various occupations. The households in the rural areas

Table 1. Socio-economic characteristics of the respondents N = 300 (Percentage)

Socio-economic characteristics				
The average size of land holdings	Landless	Small	Medium	Large
Total operated area (in hectares)	-	1.51	5.62	17.33
Educational Level	Male		Female	
Uneducated	13.48		31.16	
Primary/Secondary	34.86		29.81	
Matriculate	41.74		27.92	
Graduate	9.42		8.68	
Post Graduate	0.5		2.43	
Type of family				
Joint	45.56			
Nuclear	54.44			
Labour Force Participation Rate	Male		Female	
Agriculture	60.47		18.44	
Non-agriculture	28.19		10.63	
Others	11.34		70.93	
Caste				
General	68.00			
Schedule caste	27.00			
Backward caste	5.00			

were engaged in multiple domains like agriculture, animal husbandry, casual labour, agricultural labour, business, MGNREGA worker, government job and private job. Among these occupations, it is worth mentioning that some of the professions, on the one hand, maybe primary for one household member and secondary for the other member. Regarding the occupational pattern of the rural households, the results based on principal status (PS) of the household member depicted that the overall LFPR of males was 88.66 per cent and female LFPR, 29.07 per cent.

With the ushering of the Green Revolution in the late nineteen sixties, agriculture sector made rapid progress in the wake of new technology. The strategy for increasing the agricultural production in Punjab was followed by putting a sizeable cultivated area under wheat and rice by using high yielding variety seeds. It brought significant changes in the cropping pattern of Punjab agriculture. An attempt has been made to study labour employment under various crops such as wheat, rice, maize, cotton, chilli, peas and kinnow. The analysis was done to examine the hours per hectare and the use of male and female labour under these crops.

Table 2 shows that the total labour use per cropped hectare for wheat, rice, maize, cotton, chilli, peas and kinnow of the state on an average worked out to be the highest, 1155.5 hours per hectare for chilli, constituting 561.9 hours per hectare (48.62%) of males and 593.6 hours per hectare (51.37%) of females followed by cotton which showed 847.1 hours per hectare utilization of both males and females. Crop wise analysis showed that wheat occupied the minimum labour hours 271.7 per hectare offering the amount of female labour use for this crop to only 41.3 hours per hectare (13.4%) of the total labour used. It was so because the

Table 2. Extent of labour used in different crops/enterprises

Crops	Labour use (Hours/hectare)		
	Male	Female	Total
Wheat	230.4 (84.7)	41.3 (15.2)	271.7
Rice	324.7 (68.3)	150.4 (31.6)	475.1
Maize	245.1 (64.9)	132.5 (35.1)	377.6
Cotton	398.0 (46.9)	449.2 (53.0)	847.1
Vegetables			
Chilli	561.9 (48.6)	593.6 (51.3)	1155.5
Peas	319.0 (48.2)	341.5 (51.7)	660.5
Fruits			
Establishment of a new kinnow orchard	288.9 (60.6)	187.3 (39.3)	476.1
Established kinnow orchard > 10 years	322.9 (45.2)	391.1 (54.7)	713.9

Figure in parenthesis indicate percentages of the total

production of wheat had become highly mechanized. The analysis showed that crops such as chilli, cotton and kinnow are labour intensive, whereas wheat and rice are mechanized.

The comparison between labour hours of male and female showed that in cotton crop female labour use was 449.2 hours per hectare (53%), and that of male labour was 398 hours per hectare (46.%), and also in the production of peas more female hours per hectare, i.e. 51.7 per cent were used in comparison to 48.2 per cent of males. More female labour use for these crops shows that these crops are less mechanized in contrast to other crops thus there is a tendency among the farmers to employ male labour for the mechanized and skilled operations and female labour for unskilled operations.

Table 3 shows the crop-wise male and female labour employment pattern under the different size of landholdings. The females belonging to the category of landless and small households work more in the fields in comparison to medium and large farm households. Among the medium and large holding, there was a decline in family labour. It was the hired female labour who worked in the farms of medium and large farmers. The female family labour worked only in household activities. On small farms, female labour was highest in case of chilli, followed by cotton and fruits. Among all the crops, the least female labour was employed in wheat. Among different landholdings, more female of small holdings were used on wheat in comparison to the other farms. It is because the farmers on the small farms do not hire any casual labour to do any additional work in the fields and the female of the house is doing this work; In other words, the females help the male member of the family in various activities although which remain invisible. Overall, in the crops as mentioned above, wheat and rice are the crops which are more mechanized and thus requires less amount of female labour in all the farms in comparison to cotton, fruits and vegetables which are more labour intensive.

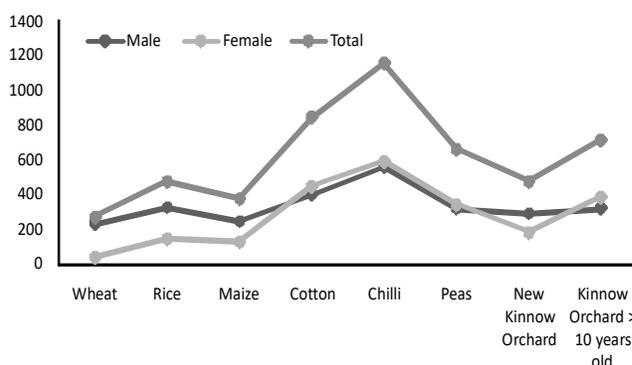


Fig. 1. Extent of labour used in different crops/enterprises

Women contributed to agricultural activities as cultivators or as agricultural labourers in several farm operations, either independently or jointly with men. The participation of women varied in different agrarian operations. This variation varied from region to region or crop to crop depending upon the agro-climatic conditions. In Table 4, the comparison of the employment of labour used in accordance to the variation in the different agricultural operations among other crops such as wheat, rice, maize, cotton, vegetables and fruits is analyzed. Regarding wheat,

out of the total labour hours, 271.7 hours contributed in the cultivation of this crop, of which female labour hours were only 15.2 per cent (41.31 hours), which were relatively less as compared to 230.4 hours of male labour. Out of the total female participation of 41.31 hours, weeding and hoeing were the operations where the involvement of female labour hours (20.9 hours) was in a more considerable extent in comparison to other operations. The production of wheat showed female labour displacement in the operations of sowing, harvesting and threshing.

Table 3. Distribution of crop-wise female labour employment pattern of male/ female labour under different landholdings (Hours per hectare)

Crops	Landless			Small			Medium			Large		
	Male	Female	Total									
Wheat	255.9 (86.3)	40.6 (13.6)	296.5	248.1 (82.1)	52.3 (17.2)	302.5	211.9 (88.1)	28.6 (11.9)	240.5	218.7 (90.6)	22.5 (9.4)	241.2
Rice	315.7 (66.9)	155.5 (33.1)	471.2	325.4 (68.8)	147.0 (31.2)	472.4	334.9 (69.1)	150.1 (30.9)	485.0	324.8 (68.4)	149.5 (31.5)	474.3
Maize	249.7 (67.4)	120.4 (32.6)	370.1	227.9 (63.4)	131.5 (36.6)	359.6	255.2 (70.3)	107.8 (29.7)	363.0	248.5 (60.8)	124.3 (39.2)	408.8
Cotton	418.7 (48.6)	441.3 (51.4)	860.0	375.7 (44.3)	471.9 (55.7)	847.6	424.2 (49.2)	437.7 (50.8)	861.9	375.3 (45.6)	446.1 (54.3)	821.4
Chilli	575.7 (49.3)	592.0 (50.6)	1167.7	536.8 (47.2)	599.9 (52.7)	1136.7	560.3 (49.1)	582.9 (50.9)	1143.2	586.4 (49.8)	589.9 (50.1)	1176.3
Peas	328.3 (48.4)	348.8 (51.6)	677.1	317.2 (48.9)	331.2 (51.1)	648.4	299.1 (48.5)	316.7 (51.4)	615.8	316.4 (47.9)	343.0 (52.1)	659.4
New kinnow orchard	293.0 (60.3)	192.6 (39.7)	485.6	274.3 (65.6)	143.8 (34.4)	418.1	292.2 (62.1)	178.7 (37.9)	470.9	297.0 (62.4)	178.3 (37.6)	475.3
Old kinnow orchard	420.3 (52.4)	382.5 (47.6)	802.8	433.3 (52.1)	397.6 (47.9)	830.9	418.2 (51.9)	386.2 (48.1)	804.4	421.2 (51.4)	397.9 (48.6)	819.1

Figure in parenthesis indicate percentages of the total

Table 4. Operation wise details of male and female labour utilization hours per hectare of different crops

Particulars	Crop operations									
	Land preparation	Sowing	Irrigation	Fertilizers	Weeding and hoeing	Spraying	Harvesting/ Picking	Threshing/ packing and loading	Transportation	
Wheat Male	55.5	20.2	29.9	8.9	8.7	10.0	32.8	22.5	41.9	
Female	-	0.71	-	-	20.9	-	9.7	6.2	3.8	
Rice Male	48.7	72.3	121.9	16.6	-	31.9	16.8	-	16.7	
Female	-	129.5	-	-	16.27	-	-	-	4.77	
Maize Male	31.7	11.2	54.8	16.4	34.2	31.8	15.4	33.7	15.8	
Female	-	7.4	8.1	-	42.2	-	65.1	-	9.7	
Cotton Male	58.8	16.3	48.2	15.5	52.2	80.1	118.5	-	15.4	
Female	1.05	1.1	-	-	102.4	-	327.7	-	10.5	
Chilli Male	51.2	66.9	66.9	14.1	155.1	-	115.7	76.8	15.2	
Female	4.8	73.5	16.1	-	242.1	-	204.1	42.9	10.1	
Peas Male	39.5	16.7	28.9	8.3	82.1	-	110.8	32.8	-	
Female					117.6	-	183.4	40.5	-	

The production of rice crop involved a total of 475.3 labour hours, out of which the engagement of male labour was 324.9 hours (68.3 per cent) and of females was 150.4 hours (31.6%). Most of the female labour hours for rice were only on those operations where there was no mechanization, i.e. transplantation (129.5 hours) and weeding (16.27 hours). Operation wise details of labour on maize showed that out of the total labour hours (377.6 hours) involved the maximum amount of labour was on plucking (80.5 hours per hectare) followed by weeding (76.4 per hectare). For maize, weeding was the process which was performed collectively by male labour (34.2 hours) and female labour (42.2 hours); hence the variation in the labour hours in this process was found to be insignificant. However, there was a significant difference in plucking, where 65.1 labour hours (80.1 %) of females were involved as compared to 15.4 hours (19.1%) of males.

Cotton is more of a labour-intensive crop in which 847.2 labour hours per hectare of both male and female were utilized. Out of the total labour hour utilization, more than half of the total labour hours (449.2 hours) were of females. Operation wise details of labour on cotton showed that the maximum amount of labour was on picking (446.2 hours per hectare) followed by weeding and inter-row tillage (154.6 hours per hectare). The operation wise average male labour use of chilli was 561.9 hours per hectare and 593.6 hours per hectare of females comprising of 48.6 per cent and 51.3 per cent, respectively. For chilli, the maximum amount of labour was on weeding and crop supporting by soil (397.2 hours) followed by picking (319.8 hours). However, in transplantation, both male, 66.9 hours (47.6%) and female labour, 73.5 hours (52.3%) were used in equal proportion. For peas, female labour was utilized mainly for plucking, 183.4 hours (62.3%) followed by weeding 117.6 hours (58.8%) and packing and loading, 40.5 hours (55.3%), whereas male labour was involved in land preparation (39.5 hours), sowing (16.7 hours), irrigation (28.9 hours) and fertilizer application (8.3 hours). The results highlighted that operations such as weeding, plucking and packing and loading were quite laborious and not mechanized; hence utilized more of female labour as compared to males.

CONCLUSION

The participation of female labour decreased in various operations in agriculture. Mechanization has resulted in the displacement of female labour from the agriculture sector. Priorities of women are different from men. Their needs also vary depending on the number of factors viz. education level, size of the family, employment opportunities, access to land and credit, cultural and religious norms etc. Rice, cotton, chilli and peas are the crops where women are mostly involved

while weeding and hoeing, harvesting/ picking and plucking were the significant operations which absorbed female labour. With the advent of the green revolution, there was an increase in the yields of rice and wheat. The development and advancement of new technology entailed a shift in inputs from human to technical. Women play a significant and crucial role in development by getting themselves involved in various operations as crop production, livestock production, horticulture, sericulture, post-harvest operations etc. But it is sad to say that as things change newer forms of inequality emerge.

REFERENCES

- Ahmed SM, Islam S, Islam MB, Aktar S and Rahma ML 2008. Effects of intervention of integrated farming system technology on the livelihood improvement of resources poor farm household. *International Journal of BioResearch* 4(1): 47-55.
- Agarwala B 2003. *Agricultural modernisation and the third world women: Pointers from the literature and empirical analysis*, ILO, Geneva, 2003.
- Beneria L 1982. Accounting for Women's work, in Lourdes Beneria (ed): *Women and Development: The Sexual Division of labour in the rural societies* (New York, Praeger), pp. 119-147
- Bisliah S 1978. Decomposition analysis of employment change under new production technology in Punjab Agriculture, *Indian Journal of Agricultural Economics* 33: 70-80.
- Chakravarty S 1975. Farm women labour: waste and exploitation. *Social Change* 5(1-2): 9-16.
- Chen M and Drèze J 1992. *Widows and well-being in rural North India*, mimeo, London School of Economics.
- Damisa MA, Samandi R and Yohana M 2007. Women participation in agricultural production: A probit analysis. *Journal of Applied Sciences* 7(3): 412-416.
- Damisa MA and Yohanna M 2007. Role of rural women in farm management decision making process: Ordered probit analysis. *World Journal of Agricultural Sciences* 3(4): 543, IDOSI publication.
- Ghosh J 2009. *Never done and poorly paid: Women's work in globalizing India* (New Delhi, Women Unlimited Press).
- GOI 2006. *Employment and unemployment situation in India, 2004-05*. NSSO Report No. 515, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.
- Goldin C 1990. *Understanding the gender gap: an economic history of american women*, Oxford University Press, New York.
- NCEUS 2007. *Conditions of work and promotion of livelihood in the unorganized sector*, National Commission for Enterprises in the unorganized sector, Government of India and New Delhi, Academic Foundation.
- NSSO 2004-2005. *Employment-unemployment situation in India, 61st Round*, Ministry of Statistics and Programme Implementation, New Delhi.
- Raju VT 1976. The impact of new farm technology on human labour employment. *Indian Journal of Industrial Relations* 11: 493-510.
- Samanta RK 1994. *The Reap less Than Show*. The Hindu (April) no. 7, Chennai, India.
- Srivastava N and Srivastava R 2010. Women work and employment outcomes in rural India. *Economic and Political Weekly* 45: 49-63.
- Statistical Abstract of Punjab, 2001.
- Sudarshan, Ratna M and Bhattacharya S 2009. *Through the magnifying glass: Women's work and labour force participation*

in urban Delhi. *Economic and Political Weekly*, Vol XLIV no.48
November 28-December 4, 2009.

Thomas JJ 2012. India's Labour market during the 2000s: Surveying
the changes. *Economic and Political Weekly* 47: 39-51.

UN Report of International Conference on Women, 1985.

Vatta Kamal 2006. *Non-farm Employment, Poverty and Inequality in
Rural Punjab*. Ph.D. Dissertation (unpublished), Punjab
Agricultural University, Ludhiana.

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Effect of Sedimentary Source on the Properties of Sphericity and Roundness of Feldspar Minerals in Some Soils of the Alluvial Plain

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Abstract: This study was conducted on the effect of the sedimentary source (the sediments coming from both the Iraqi-Iranian borderline and the Tigris river) on the optical and textural features, especially sphericity and roundness of feldspar minerals (potassium and plagioclase types) in soils of the southern part of the alluvial plain. Eight pedons were selected to represent the study area, five of them represented sediments coming from the borderline, which included pedons of (Badra, Taj Al-Din, Al-Shihabi, Jassan, and Galati), while two of them represent the sediments of the Tigris River (Essaouira, Al-Dabouni), the pedon of Ali Al-Gharbi was represented the mixing area of sediments of all the floods coming from the borderline and the sediments of the Tigris River. The roundness degree for the particles of potassium feldspar minerals was concentrated between the sub-angular (SA) and well- roundness (WR), as a well- roundness category was in Ali Al-Gharbi pedon and percentage reached 14. Particles of Plagioclase feldspar minerals showed the same pattern in the distribution of roundness categories. The sphericity degree for particles of Potassium Feldspar and Plagioclase minerals were compatible with the distribution of the roundness degree for those particles. The sphericity degree concentrated between the medium sphericity and the high sphericity.

Keywords: Sedimentary source, Sphericity, Roundness, Feldspar minerals

Feldspar is of great importance in studying the development of soils as it is considered an important genetic ring in the mineral weathering processes development. However, it is a group of tectosilicates minerals with three dimensions, which is one of the important mineral light group and forms about 60% of the earth's crust. The transport and sedimentary conditions affect the formal characteristics of many minerals including feldspar. As these properties varied according to the conditions that accompany the transfer and sedimentation process, where the sediments exist in the nature as a mixture of both clastic and non- clastic sediments, which consists of a natural mixture of minerals and rocks crumbs, as well as some colloidal materials such as clay, chemical and biological sediments (Merina 2017). Therefore, it is necessary to determine the formal characteristics of each species separately, and the relationship of each to the other, as analyzing the texture of the rocks crumbs to understand the media whether it is water or wind for the crumbs sediments. In general, the texture of the particles is determined directly by the hydrodynamics of sediments media (Hou and Frakes 2004), while for the distinction between roundness and sphericity, the shape of the mineral granule is defined by its roundness or its proximity to the spherical shape (Boggs 2006). Thus, a granule sharp edge can be spherical in shape and on the contrary, a long one can be far from the spherical shape at the same time, are completely round and free from any sharp

corners. Generally, roundness and sphericity depend largely on the mechanical abrasion of the crumbs during transportation before sedimentation, as well as the physical properties of the transported crumbs for the source rock. Current study intends to study the effect of transferred sedimentary source on the texture properties of feldspar minerals, especially sphericity and roundness.

MATERIAL AND METHODS

The study was conducted within the lands located in the provinces of Wasit and Maysan, and this region represents a part of the southern alluvial plain of Iraq, which is crossed by the Tigris river passing through the Kut Dam, at the latitude (-33.06) and (-2.08) northward and longitude (-44.40) and (-46.56) eastward. Three study transects were chosen perpendicular to the left bank of the Tigris River and within the area between the left bank of the Tigris river and the mountainous at the Iraq-Iranian borderline in the east. The first transect extends from the Iraqi-Iranian borderline eastwards towards the Tigris river westwards, which includes three soil pedons sites, starting from the east towards the west and they are Badra (1), Taj Al-Din (2) and Essaouira (3). The second transect located to the south of the first transect and parallel to it, which includes three soil pedons sites, according to the first sequence (from east eastwards west), and represented by pedons of Al-Shihabi (4), Jassan (5), and Al-Dabouni (6). Finally, the third transect located to the south

of the second transect and parallel to it, it includes two soil pedons sites, as follows: Galat (7), Ali Al-Gharbi (8). The pedon sites were chosen according to the topographical location, which they were divided into sites flooded with torrents coming from the borderline including the pedons sites (1, 2, 4, 5, 7 and 8), while the sites that are the sediments of the Tigris river included the pedons (3,6 and 8).

The sand particles were separated with a wet-sieving method through sieve of a 50 µm diameter and the sand particles were examined with a petrographic microscope. Light minerals were separated from the heavy minerals of the sand using a promoform liquid (HBR₃) with specific weight (2.89) (Milner 1962). Sand fraction (light and heavy minerals) was scattered after being air-dried on a glass slide of (7.5 x 7.5 cm) using the Canda balsam with a refractive index (1.54). The glass slides were examined microscopically (Brewer 1976) and the minerals were identified and diagnosed according to the optical properties of each mineral (Kerr 1977). The samples were photographed using a German-made Lietz microscope. Furthermore, the Visual comparison chart proposed by Krumbein and Sloss (1963) was used to study the properties of roundness and sphericity of feldspar particles (Fig. 2).



Fig. 1. Pedons sites of the study

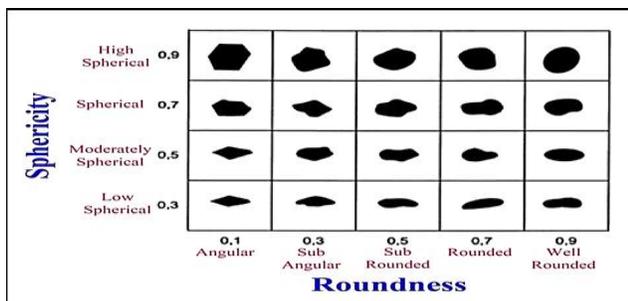


Fig. 2. Visual comparison chart proposed by Krumbein and Sloss (1963)

RESULTS AND DISCUSSION

Degree of Feldspars Roundness

The degree of roundness of the K-Feldspar minerals particles within the pedons affected by the torrents sediments that come from the borderline, where increase in two directions: the first vertically starting from the borderline pedons (Badra, Al-Shihabi, Galat) and toward the Iraqi territories within pedons (Taj Al-Din, Jassan, Ali Al-Gharbi). The second direction horizontally towards the south with the land slope, starting from the soil pedons (Badra and Taj Al-Din) to reach its maximum in the soil pedons of Ali Al-Gharbi (Table 1). However, the roundness categories for particles of feldspar minerals were concentrated between the angular (A) category and the well- roundness (WR). The highest percentage of the angular was in the Galat pedon (20%), also the well- roundness category did not appear except in a few sites of study soil pedons, where the highest value was in Ali Al-Gharbi soil pedon(30%). In the rest of the study soil pedons, the degree of sphericity of the feldspar particles ranged between the sub angular (SA) and the roundness (R) in different percentages (Table 1).

The higher percentages of the roundness degree for the particles of the potassium feldspar minerals within the soil pedon of Essaouira were concentrated within the roundness categories (R), and sub-angular (SA) (67, 33%) (Table 1). Moreover, the degree of roundness for these particles increased within the Al-Dabouni soil pedon, to be concentrated in the sub-roundness (SR) and roundness (R) categories, by percentages of 33 and 33 respectively, with the appearance of a well- roundness category (WR) by 17% in that soil, which increased to 30% in Ali Al-Gharbi soil. The roundness degree for the particles of potassium feldspar minerals was increased with the flow of Tigris River towards the south.

In general, the results showed that the roundness degree for the particles of potassium feldspar minerals in the soil pedons of sites affected by the Tigris river sediments was concentrated between the roundness - sub roundness groups (R- SR), and was exceeded the degree of roundness of those particles within the pedons of sites affected by torrents coming from the borderline. The degree of roundness was concentrated in the low roundness groups, which are angular and sub-angular (A-SA). This may be due to the high distance of sedimentation sources, as well as the distance that particles move during the transportation process in those locations. The particles within the sediments of the Tigris river pass through longer distances (about 1,800 km) from their sources to sedimentation sites, while the particles within the transported sediments by torrents coming from the Iranian lands are pass through shorter distance

(about 200-300 km) until they reach the sedimentation sites. Thus, the particles within the sediments of the Tigris River are more exposed to the abrasion during transportation compared to the particles within the sediments transported by the torrents coming from the Iranian lands. Szabo et al (2013) observe that the far distance of which the transported minerals particle traveled by water were exposed to high abrasion operation and reflected on their degree of roundness and sizes. The degree of roundness for the particles was taking the same pattern as that of the particles of potassium feldspar minerals within the soil pedons affected by the torrents coming from the borderline. The particles maintained their concentration in the same categories of the roundness degree that the potassium feldspar minerals particles were in those soils, except for a slight increase in the roundness degree of particles in the soil of Taj Al-Din pedon. The roundness degree of particles was concentrated in the sub-angular (SA) and roundness (R) categories at percentages of 67, 33%), respectively. The roundness degree of particles soil of Al-Shihabi pedon was concentrated in the sub-angular categories (SA) and roundness (R).

The roundness degree for particles of Plagioclase feldspar minerals within the soil pedons affected by the sediments of Tigris River. There were no clear differences with the roundness degree for particles of Plagioclase feldspar minerals and particles of potassium feldspar minerals (Figs. 3 d). The degree of roundness for the particles of potassium feldspar minerals within the soils of Essaouira, Al-Dabouni, Ali Al-Gharbi pedons was concentrated among the sub roundness - roundness (SR- R) categories (33.67%). In addition, the roundness degree for particles of Plagioclase feldspar minerals for the same sites was also concentrated among the sub roundness-roundness (SR- R) (44 and 30%). There were no clear differences in the degree of roundness for mineral particles of potassium feldspar and Plagioclase feldspar, while their a variation in the intensity of weathering resistance, as well the far distance of sedimentation sources, and the long-distance that those mineral particle move (about 1,800 km) during transport till their sedimentation at these locations. It may be due to the combined effect of these factors on the degree of roundness of the feldspar minerals in general as the long transport distance has affected the surfaces of these minerals, which led to the convergence of the degree of their roundness. Crundwell (2015) pointed out that the mineral particles during the transfer process are exposed to continuous abrasion processes, which leads to the continuous change in the properties of their surfaces. These formal characteristics for the particle of these minerals

become completely contrary to their properties from the source, which is accompanied by its small size wherever the distance of transport between the source and the sedimentation sites been longer.

Degree of Feldspars Sphericity

The degree of sphericity for the particles of potassium feldspar minerals within the soil pedons affected by the torrents sediments coming from the borderline (Table 2). The degree of sphericity increased in the vertical directions starting from the borderline towards the Iraqi territories, and horizontally to the south with the land slope in this distribution was consistent with the distribution of the sphericity degree for those particles. The degree of sphericity was concentrated between the two categories, medium sphericity (MS) and the high sphericity (HS), where the low sphericity (LS) for particles of potassium feldspar minerals appeared in the soil of Galat pedon by 14%. The increase in the degree of sphericity for the particles of potassium feldspar minerals in the vertical and horizontal directions, within the soil pedons affected by the torrents coming from the Iranian lands.

Its increases consistent with the sphericity degree increasing of these particles in the same direction reflected

Table 1. Roundness percentages for potassium feldspar minerals (%)

Region	Angular	Sub angular	Sub rounded	Rounded	Well rounded
Badra	33	17	16	17	16
Taj Al-Din	0	29	43	14	14
Al-Shihabi	0	25	50	25	0
Jassan	33	0	33	34	0
Essaouira	0	33	0	67	0
Al-Dabouni	0	17	33	33	17
Galat	20	0	40	20	20
Ali Al-Gharbi	0	20	30	20	30

Table 2. Roundness percentages for Plagioclase feldspar minerals

Region	Angular	Sub angular	Sub rounded	Rounded	Well rounded
Badra	43	29	28	0	0
Taj Al-Din	0	67	0	33	0
Al-Shihabi	0	67	0	33	0
Jassan	20	20	40	20	0
Essaouira	0	30	40	30	0
Al-Dabouni	0	11	44	23	22
Galat	0	75	0	25	0
Ali Al-Gharbi	0	25	30	20	25

Table 3. Sphericity percentages for potassium feldspar minerals (%)

Region	Low spherical	Moderately spherical	Spherical	High spherical
Badra	17	50	33	0
Taj Al-Din	29	28	15	28
Al-Shihabi	25	50	25	0
Jassan	17	33	17	33
Essaouira	67	0	0	33
Al-Dabouni	20	20	40	20
Galat	14	29	29	28
Ali Al-Gharbi	20	0	40	40

Table 4. Sphericity percentage for Plagioclase feldspar minerals (%)

Region	Low spherical	Moderately spherical	Spherical	High spherical
Badra	15	71	14	0
Taj Al-Din	0	44	56	0
Al-Shihabi	0	56	33	11
Jassan	20	20	40	20
Essaouira	0	30	50	20
Al-Dabouni	11	34	22	33
Galat	25	0	50	25
Ali Al-Gharbi	10	25	25	40

the combined effect of the transport and sedimentation conditions in the two properties within those soils, which confirmed the increasing better-sorted process towards Iraqi territories. As for the soil pedons affected by the sediments of the Tigris river, degree of sphericity for the particles of potassium feldspar minerals within the soil of Essaouira pedon was concentrated in the two low- sphericity (LS) and high- sphericity (HS) by 67 and 33%, respectively. The degree of sphericity for those particles was concentrated in the soil pedon within the sphericity (S) and high- sphericity (HS) categories by 40 and 20% respectively, then increasing again to reach the maximum within the soil of Ali Al-Gharbi pedon, and concentrated in the sphericity (S) and high sphericity (HS) categories by 40 and 40%, respectively. The degree of sphericity for the particles of potassium feldspar increased with the advance of the Tigris river flow southward.

The degree of sphericity for the particles of Plagioclase feldspar minerals in pedons soil affected by the torrents coming from the Iraqi-Iranian borderline. It takes the same

pattern as the potassium feldspar minerals were, as the degree of sphericity increased towards the lands in the vertical-horizontal direction to the south with the land slope. The particles for Plagioclase feldspar minerals of the soil pedons (Essaouira, Al-Dabouni, Ali Al-Gharbi) affected by the sediments of the Tigris river and by transport and sedimentation processes, which in turn affected the abrasion, thus their degree of sphericity was variable. It was between the two categories of medium sphericity (MS) and sphericity (S), while the Ali Al-Gharbi site is considered a mixing area between the torrents sediments coming from the Iraqi-Iranian borderline. As it receives its sediments from the area of Galat and from the Al-Shihabi and Jassan sits, as well as affected by the sediments of the Tigris River, and therefore the degree of sphericity for its particles is high if the percentage of this category is 40%.

CONCLUSIONS

The textural inspections showed that the degree of roundness of feldspar minerals in affected soils by torrents were increased in two directions, vertically from pedons located at borderline towards the Iraqi territories and horizontally towards the south with the slope, while the roundness of feldspar minerals in soils. This was affected by the sediment of Tigris river and increased with the flow of the river to the south. The degree of sphericity of feldspar minerals was indicated same trend of roundness degree in both groups of soils.

REFERENCES

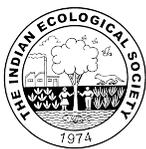
- Boggs SJ 2006. *Principles of sedimentology and stratigraphy*, 4th ed, Upper Saddle River, Pearson NJ, Prentice Hall p. 662.
- Brewer R 1976. *Fabric and mineral analysis of soils*. Robert E. Krieger publishing company. Huntington N.Y. p. 282.
- Grundwell FK 2015. The mechanism of dissolution of the feldspars: Part I. Dissolution at conditions far from equilibrium. *Hydrometallurgy* 151-162
- Hou B and Frakes LA 2004. *Tertiary sea levels and heavy mineral deposition in the eastern Eucla Basin* Roach I.C. ed. Regolith.CRC LEME, p 140-143
- Kerr PF 1977. *Optical mineralogy*. 4th ed. McGraw-Hill Book Co. Inc. New York, U.S.A.p492.
- Krumbein WC and Sloss LL 1963. *Stratigraphy and Sedimentation*, 2nd Edition. San Francisc, p 660.
- Milner HB 1962. *Sedimentary Petrography*. 4th. Ed. Murby and Co. London.
- Merina RN 2017. Evaluation of sediment using GIS approach in southern Tamilnadu, *Indian Journal of Ecology* 44(2): 179-184
- Szabó T, Fityus S and Domokos G 2013. Abrasion model of downstream changes in grain shape and size along the Williams River, Australia. *Journal of Geophysical Research: Earth Surface* 118(4): 2059-2071.

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