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Detecting the Dynamics: Geospatial Monitoring of the Newly Assigned Ramsar Site, "The Wadhwana Wetland" in Central Gujarat, India

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***Abstract*:** Wetland ecosystems are one of the most important areas that provide various ecosystem services as well as habitat for both aquatic and terrestrial life forms. In spite of multiple functions, like biodiversity conservation, water quality improvement, erosion control and climate regulation through CO_2 sequestration, wetland ecosystems are under threat. This study attempts to analyse the wetland dynamics of the Wadhwana Ramsar site using geospatial techniques. The land use land cover (LULC) and Normalized Difference Vegetation Index (NDVI) were investigated through LANDSAT 5 ETM+ of 1990, 2000, 2010, and LANDSAT 8OLI/TIRS of 2020. The LULC for the study area extent is prepared using the Sentinel-2A 2023 dataset. The LULC is classified using a supervised classification method with a maximum likelihood algorithm. The red and infrared bands of Landsat imagery from three different time periods were used to calculate NDVI. Results show that the wetland ecosystem in the study area decreased by 3.07 km^2 (~45%) with the average rate of ~0.615 km^2/year. In contrast, agricultural land decreased by 5.56 km^2 , at an average rate of ~0.428 km^2/year between 1990 and 2020. About 0.83km^2 of wetland is converted to cultivated land, whereas 1.78 and 3.78km2 of Water bodies and Barren lands are converted into cultivated land, indicating the biotic pressure on the wetland. To minimise the rapid loss of wetlands and water bodies in the study area, proper land use planning and environmental education should be promoted.

***Keywords*:** Wetland, Change detection, Turbidity, Moisture, Vegetation, Ramsar site.

1. INTRODUCTION

Since the beginning of the twentieth century half of the world's wetlands have been lost (Davidson, 2014) and more than 60% of the remaining wetland ecosystems are being used unsustainably (MEA (Millennium Ecosystem Assessment) 2005). The fate of wetlands is determined by human beings who exploit water resources beyond their needs, which may lead to future crises (Murray et al., 2014). Thus, the preservation of wetlands is an important issue to address these days. Information and understanding of environmental changes in wetland are necessary to allow the protection and remediation of ecosystems (Ramachandra & Solanki, 2007). Wetlands are known to provide high-value ecosystem services because of their position in the landscape (Zedler et al., 2006) and allow sediments and other materials to accumulate and settle, providing cleaner water for fish, wildlife and people. However, wetlands worldwide have been intensively modified by various land-use and land-cover (LULC) change activities for more than a century, owing to the ever-increasing population and economy (Hong et al., 2021). LULC have in turn, resulted in changes in the economic and ecological values of various ecosystem services (Leh et al., 2013; Hasan et al., 2020). Changes in land use and their spatial consequences for the wetland ecosystem are a major concern of geographers and environmental conservationists (Cui et al., 2017). Wetlands are diverse and dynamic ecosystems that play a critical role in maintaining ecological balance and supporting a wide range of plant and animal species. They can be found in various forms, such as marshes, swamps, bogs, and mangroves. These ecosystems are often transitional areas between terrestrial and aquatic environments. Wadhwana Wetland, located near the town of Dabhoi in central Gujarat, was designated a Ramsar site in 2021 for its significant ecological, cultural, and socioeconomic value. Wadhwana Wetland, as a Ramsar site, is meant to be conserved and

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managed for the long-term benefit of both nature and people.

Earlier studies and reports indicate that this wetland faces multiple threats, including degradation, pollution, and anthropogenic activity during the dry season (Purandara, 2008). Several studies are carried out at Wadhwana wetland including aquatic bird diversity, water quality and floral diversity (Dabgar, 2012; Soniya et al., 2024; Suthar et al., 2019; Vankar et al., 2019), however, there is a paucity in research data available through which one can understand the dynamics of this wetland with respect to land use and land cover change. for understanding the role of Land Use, Vegetation and other wetland parameters through digital image analysis of remotely sensed data, which serves as a significant marker in the conservation of Wetland or Ramsar sites. Highly functioning wetlands typically have high NDVI values, while disturbed or low-functioning wetlands have lower NDVI values. The aim of the present study is to analyze the wetland dynamics by means of the current and temporal Land Cover, surface vegetation and water cover. The findings of the present study highlight the status of the current situation of the wetland and represent the decadal changes over the years. Understanding these changes is crucial for formulating effective conservation strategies and sustainable management practices to preserve and restore these vital ecosystems.

2. MATERIALS AND METHODS

2.1. Study Area

Wadhwana Wetland, also known as Wadhwana Lake or Reservoir (22˚ 09' 42.2"N, 73˚ 28' 32.9"E), is located in the state of Gujarat, India (Figure 1). It is situated in the Dabhoi tehsil, in the district of Vadodara, approximately 75 kilometers (47 miles) from the city of Vadodara. It is 45km away from Vadodara city on Vadodara-Dabhoi-Chhota Udepur state highway. Dabhoi town is approximately 15 km from Wadhwana wetland. It was originally created in 1910 by the former King of Baroda State, Maharaja Sayajirao Gaekwad III. Historical records indicate that Shrimant Maharaja Sir Sayajirao Gaekwad III carried out the excavation works between 1909 and 1910 (Suthar et al., 2019), primarily for irrigation purposes. In recent years, the wetland has gained significant ecological recognition and was designated as a Ramsar Site in 2021. The references to more recent development relate not to its initial creation, but to conservation and management initiatives undertaken by the Government of Gujarat. Wadhwana Wetland was officially declared a wildlife sanctuary in 2005, marking a key step in its protection. The wetland covers an area of approximately 5.8 km² with a perimeter of about 11 km (Tatu, 2012).

Wadhwana reservoir is located in Dabhoi tehsil of

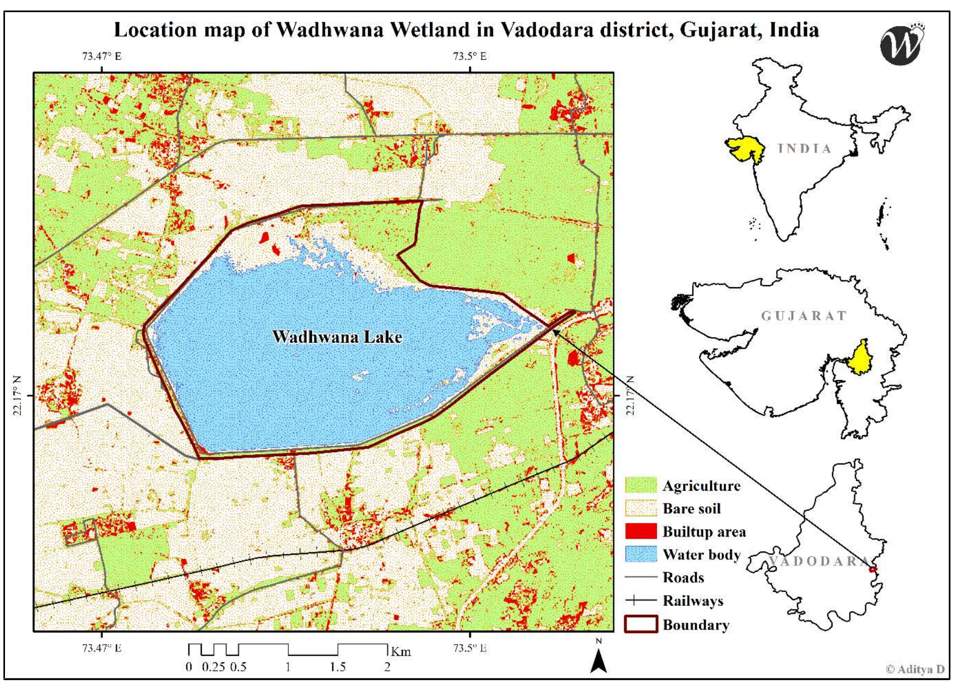

Figure 1. Location map of Wadhwana Wetland, a Ramsar site located in central Gujarat

Vadodara district in central Gujarat. The major inlets of the wetland are the Mahi and Narmada canals, which are feeder canals of the lake. The maximum depth of the wetland measured during the study is 20ft, and the tank area is 1430 acres. It irrigates about 88.15km^2 land of 25 villages in its vicinity (Mudaliar & Pandya, 2023). The wetland is predominantly used for fishing, irrigation, and the supply of drinking water to nearby villages. The climate in the area is characteristic of hot-dry with the precipitation during the south-west monsoon, i.e. June to September. The average temperature in the area ranges from 12°C to 33°C; however, it can reach 40°C during peak summer and drop to 10°C in winter. The precipitation pattern in the region is primarily governed by large-scale monsoonal circulation rather than the wetland itself. However, the presence of the wetland influences local microclimatic conditions, such as enhancing humidity, moderating temperature, and facilitating localized evapotranspiration processes. These factors may contribute to minor local variations in moisture availability and atmospheric conditions, but do not significantly control the overall precipitation regime (Murray et al., 2014).

Suthar et al. (2019) have recorded six species of hydrophytes viz, *Hydrilla verticillata*, *Potamogeton nodosus*, *Ipomoea aquatica*, *Nelumbo nucifera*, *Nymphoides indica* and *Typha domingensis*. Dabgar (2012) studied floral diversity and recorded 73 genera and 82 species of flora belonging to 43 families. Wadhvana wetland provides wintering ground to many migratory bird species such as Dalmatian Pelican (*Pelecanus crispus*), Greater spotted Eagle (*Clanga clanga*), Pallas's fish-eagle (*Haliaeetus leucoryphus*), Grey-headed fish-eagle (*Ichthyophaga ichthyaetus*), Common Pochard (*Aythya ferina*) and Ferruginous Duck (*Aythya nyroca*).

2.1.1. Soil type: The wetland soil is a mixture of black cotton soil and clay with abundant organic matter. It also contains sporadic deposits of calcareous Kankar. This suggests the presence of areas with accumulated calcium carbonate (Prasad et al., 2014). The wetland includes alluvial tracts, implying influence from nearby water sources, enriching the soil with nutrients. Clay aids water retention, benefiting aquatic life and vegetation.

2.2. Data Acquisition

The satellite datasets of LANDSAT 5TM/+ETM, LANDSAT 8 OLI/TIRS and Sentinel 2A along with Cartosat 1 DEM were used to carry out the interpretation and analysis of the study. LANDSAT, SENTINEL, and Cartosat datasets were acquired from USGS Earth explorer, ESA (European Space Agency) and Bhuvan ISRO's data portal, respectively (Banerjee et al., 2020: Ghayour et al., 2021). Other vector land-use layers, such as roads and railways, were directly digitised from the OpenStreetMap (OSM) server in QGIS. The LANDSAT datasets were acquired over a 10-year time interval (1990, 2000, 2010, 2020) and were further used to prepare the Land Use Land Cover (LULC) map. The LANDSAT data has the spatial resolution of 30 m and the SENTINEL data has that of 10-60 m. All satellite images used in this study were acquired during the post-monsoon season (October-November), when vegetation cover is at its peak due to adequate soil moisture availability following southwest monsoon rainfall. This period was specifically selected to enhance spectral separability among land-cover classes, particularly vegetation, agricultural land, and barren surfaces. During this season, edaphic factors such as soil moisture retention and soil characteristics play a significant role in controlling vegetation growth patterns, thereby improving the accuracy of LULC classification. The use of consistent seasonal imagery across different years ensures comparability and minimizes misclassification arising from seasonal variability. The Data sources are briefly listed in Table 1. The preprocessing and analysis were carried out using ArcGIS® 10.8.

2.3. Data Set and Classification

For the analysis of LULC change, satellite images (Landsat 5 and 8) of 30 years is procured from the Earth Explorer USGS website (https://earthexplorer.usgs.gov/).

Table 1. Data sources and their descriptions

Data type	Sensor	Acquisition year & Period	Path and row	Resolution	Source
LANDSAT 5	ETM+	1990 (Oct-Nov) Post-Monsoon	148 & 45	30 m	USGS
LANDSAT 5	ETM +	2000 (Oct-Nov) Post-Monsoon	148 & 45	30 m	USGS
LANDSAT 5	ETM+	2010 (Oct-Nov) Post-Monsoon	148 & 45	30 m	USGS
LANDSAT 8	OLI	2020 (Oct-Nov) Post-Monsoon	148 & 45	30 m	USGS
SENTINEL 2A	MSI	2023 (Not for analysis, only for general study area LULC)	N/A	10 – 60 m	ESA

The composite band images are prepared for the downloaded satellite images, and the masking tool in the ArcGIS® 10.8 is used to extract the study area. Supervised classification is used to identify the temporal LULC changes. The features of the LULC classification on the images are verified using Google Earth Pro. The change detection method is used to calculate per cent changes in LULC of analyse land transformation across various categories. The Normalised Difference Vegetation Index (NDVI) is generated using Sentinel-2 MS data along with False Colour Composite (FCC).

2.4. Pre-processing

The LANDSAT 5 & 8 and SENTINEL 2A datasets are pre-processed to improve the accuracy of the outcomes. Geo-referencing is done of the study area using the extraction tool to clip the satellite imagery with respect to the Area of Interest (AOI). The next step involves Radiometric Calibration, conversion of Digital Numbers (DN) to Top of Atmosphere (TOA) and Surface Reflectance, for which the Calibration technique is implied to convert DN to Radiance values. Surface reflectance or TOA is only processed when the influence of the atmosphere is removed from the imagery, thus, radiometric and atmospheric corrections are processed (Chander et al., 2009; Richards, 1999). The pixel values indicate the Surface reflectance values instead of DN, after atmospheric correction.

2.5. LULC Classification and Change

The changes that are observed over the years represent a serious threat to the ecosystem's sustainability, as the vegetation developed naturally gives way to man-made vegetation, for example (Gouda et al., 2021). In order to carry out the classification of the year 1990, 2000, 2010, and 2020, all the bands of imageries of the LANDSAT 5& 8 satellites were stacked using the Band Composite tool and thus, a False Color Composite (FCC) (Figure 2) was created using the combinations of red, blue and green bands of the visible spectrum. Specifically, for LANDSAT 8 OLI imagery, the stacked imagery was Pan-Sharpened, thereby converting the 30 m resolution to 15 m, as it includes a Panchromatic Band (Band 8) with a spatial resolution of 15 m. So, the image Pan-Sharpening was carried out in LANDSAT 8 in order to generate accuracy in the classification (Rahaman et al., 2017).

Classification is the process of assigning each pixel to an individual class based on a set of criteria. Maximum Likelihood Classification (MLC) is one of the most widely used methods of classification algorithms, in which a pixel is assigned to the class with the highest probability. This is a basic pixel method which relies by assuming the data of each class from each band has a normal distribution (Mondal et

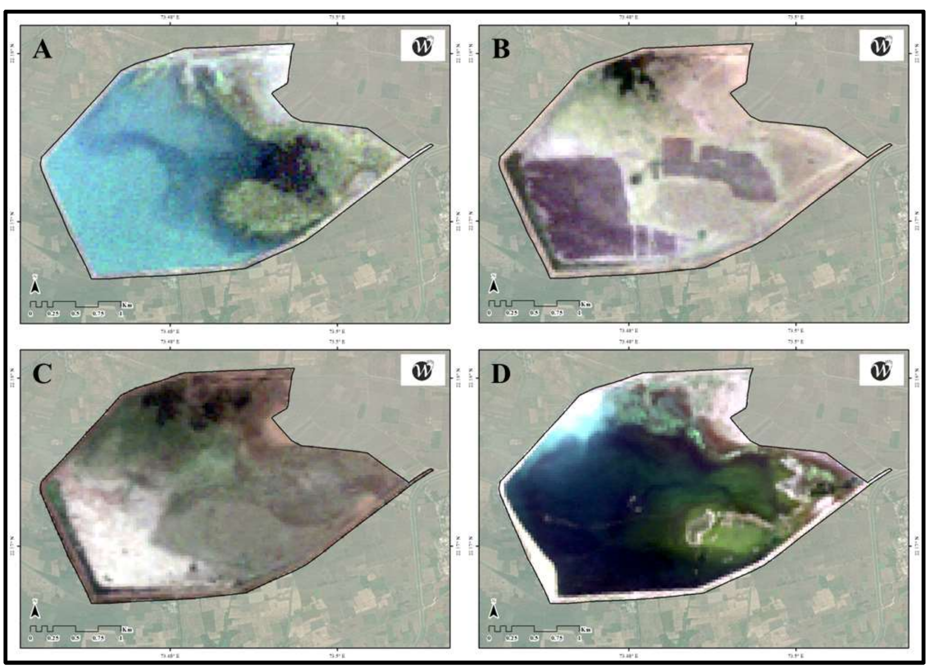

Figure 2. The figure shows the False Color Composite (FCC) required to generate the maps (A=1990; B=2000; C=2010; D=2020)

al., 2013). The training classes were assigned to the imagery, which assigns a value to each pixel based on similar spectral signatures, and 4 to 5 classes are classified in the imagery. After creation of LULC, the rasters of all the 4 imageries were converted to polygons using the polygonization tool and the Stratified Random Sampling technique was used, and around 50 points were generated for proving the accuracy of the classification statistically using the Kappa coefficient method of Error matrices (Fal et al. 2019; Miranda et al. 2016). Furthermore, this method of accuracy assessment was applied to all the classified layers of the years 1990, 2000, 2010 and 2020, along with the subsequent imageries (1990 - 2000), (2000 - 2010), (2010 - 2020), and (1990 - 2020) was subtracted from each other using the Intersect tool. Then, the attribute table of the resulting layer was processed to create a new field, changed classes using the expression (1990 + " - " + 2000) and so on, to interpret in such a way that a particular class has been changed into another class during this 10-year interval (Anderson et al. 1976; Banerjee et al., 2020). The area of each class, along with the change in each area of all four years, was also calculated in km^2.

2.6. Normalized Difference Vegetation Index (NDVI)

Spectral indices are dimensionless variables derived from the reflectance of two or more bands. NDVI was developed for quantifying vegetation conditions over broad areas and was shown to have a strong correlation with green biomass (Karnieli et al. 2010; Rouse et al. 1974)The NDVI is essential to identify different land cover types in the study area, and it ranges from -1.0 to +1.0 (Kriegler et al. 1969). The NDVI is calculated on a per-pixel basis as the normalized difference between the red band (0.64-0.67 μm) and near infrared band (0.85-0.88 μm) using the formula as follows (Eq.1):

NDVI = ρNIR - ρRED / ρNIR + ρRED…………(1)

According to the LANDSAT 5 and 8 satellite imagery, the NIR, which is the Near Infrared Band, refers to Bands 4 and 5, and the visible band, which is the RED band, refers to Bands 3 and 4. So, the formula used in the raster calculator is as follows (Eqs. 2 and 3):

NDVI = float (Band 4 - Band 3) / float (Band 4 + Band 3), for LANDSAT 5 TM/+ETM….(2)

NDVI = float (Band 5 - Band 4) / float (Band 5 + Band 4), for LANDSAT 8 OLI……(3)

3. RESULTS AND DISCUSSIONS

3.1. Analysis of Land Use and Land Cover (LULC)

The study area was classified into five classes, viz., water body, shallow water, bare soil, sparse vegetation, and dense vegetation, over of 10-year temporal range (1990, 2000, 2010, and 2020). In the year 1990, it was observed that the shallow water covered the maximum area of 3 km2, while the bare soil covered the minimum area of 0.5 km^2. In the year 2000, a sudden increase in the area of bare soil was observed (4 km2) and a corresponding decrease in the area of shallow water (0.5 km^2). This can be understood from the rate of change in area, as shown in Table 3.

In the year 2010, a new class of dense vegetation was observed, whereas on the other hand, the class of bare soil had disappeared, and the maximum area was covered by the sparse vegetation or grassland of 3 km^2. Alongside, the water body and dense vegetation cover the least area of approximately. 1.5 km^2. Finally, in the year 2020, the class water body disappeared, and bare soil and shallow water were observed accordingly. Here, the maximum area is covered by shallow water (4 km^2), and the least area is covered by vegetation (0.5 km^2).

From the overlay analysis, change detection maps of LULC of the corresponding ten-year intervals and the reference year to the final year (1990 - 2020) were prepared (Figure 4). These maps reveal the change that occurred in the LULC pattern in the respective ten years of interval along with the change from 1990 to 2020, say, the class such as water body, shallow water, bare soil, etc., has changed to bare soil, sparse vegetation, etc., or remained as it is,

Table 2. LULC change in the study area in the last three decades

LULC type	1990		2000		2010		2020	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Bare soil	0.463	7	4.015	63	-	-	1.349	21
Deep water	0.635	10	1.298	20	1.486	23	-	-
Dense vegetation	-	-	-	-	1.697	27	0.754	12
Shallow water	3.045	48	0.461	7	-	-	3.972	63
Sparse vegetation	2.201	35	0.572	9	3.159	50	0.233	4

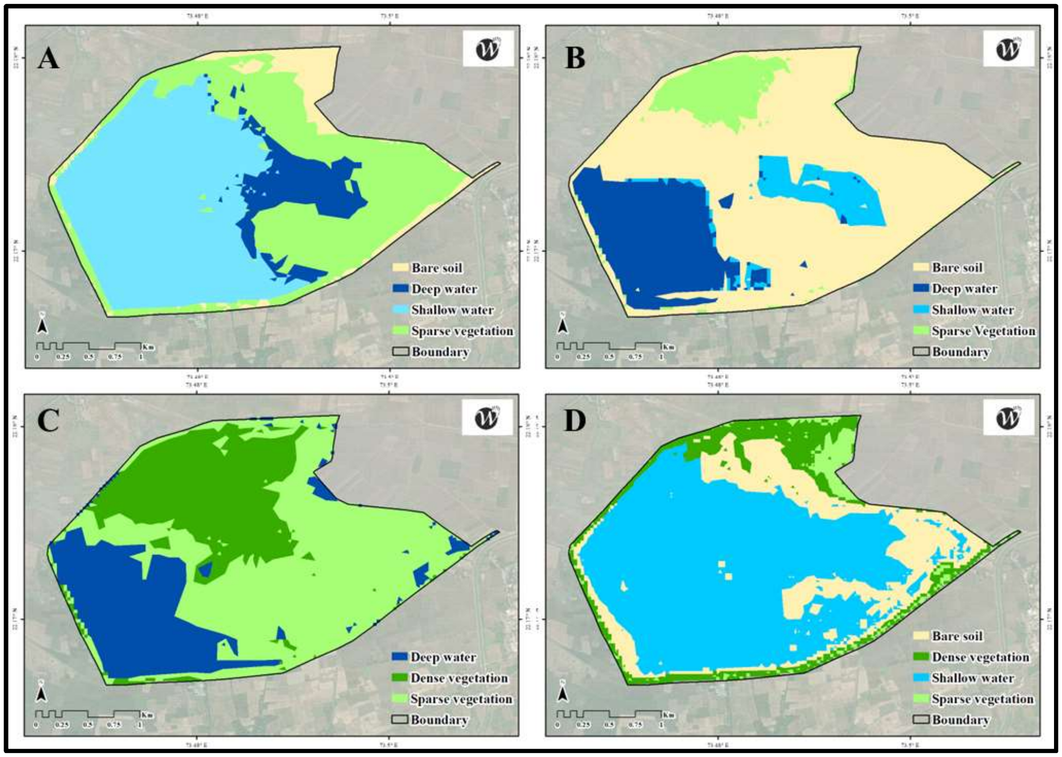

Figure 3. The figures show the land use and land cover from the year 1990-2020 in Wadhwana Wetland (A=1990; B=2000; C=2010; D=2020)

Table 3. Description of the rate of change in the area of LULC types in the past three decades

LULC type	1990-2000 area (km^2/year)	2000-2010 area (km^2/year)	2010-2020 area (km^2/year)
Bare soil – Bare soil	0.393	-	-
Bare soil – Deep water	0.004	0.255	-
Bare soil – Sparse vegetation	0.050	2.665	-
Bare soil – Dense vegetation	-	1.068	-
Deep water – Bare soil	0.323	-	0.191
Deep water – Deep water	0.004	1.185	-
Deep water – Shallow water	0.293	-	1.186
Deep water – Sparse vegetation	0.015	0.108	0.048
Deep water – Dense vegetation	-	0.005	0.051
Dense Vegetation – Dense vegetation	-	-	0.285
Dense Vegetation – Shallow water	-	-	1.054
Dense Vegetation – Bare soil	-	-	0.339
Shallow water – Bare soil	1.424	-	-
Shallow water – Deep water	1.266	0.025	-
Shallow water – Shallow water	0.126	-	-
Shallow water – Sparse vegetation	0.230	0.307	-
Shallow water – Dense vegetation	-	0.130	-
Sparse Vegetation – Bare Soil	1.854	-	0.817
Sparse Vegetation – Deep water	0.023	0.015	-
Sparse Vegetation – Shallow water	0.042	-	1.732
Sparse Vegetation – Sparse vegetation	0.271	0.063	0.169
Sparse Vegetation – Dense vegetation	-	0.490	0.401

respectively (Figure 3). Alongside, the calculation of area change reveals the increase or decrease in the area of each class in the temporal range (Table 2).

The confusion matrix or error matrix resulting from the random sampling technique reveals the overall accuracy and Kappa statistics, which are a vital part of post-classification accuracy assessment (Table 4). The Kappa statistic, often known as the value, contrasts observed accuracy with expected accuracy (random chance). The value range of Kappa, which quantifies the variety of the two classifiers, is between -1 and 1 (Carletta, 1996). The overall accuracy of the LULC for the years 1990, 2000, 2010, and 2020 are 90.38%, 90.38%, 94.12% and 90.38%, respectively. Moreover, it can be inferred that the overall accuracy of classifying all four images is nearly 90%. Similarly, the Kappa coefficient of all four images is 0.87, 0.87, 0.91, and 0.88, respectively, ranging from 0.8 to 0.9; the level of agreement between the classifiers is interpreted as Strong or basically, it infers that the classifiers are highly accurate (McHugh, 2012; Miranda et al., **2016**).

3.2. Normalized Difference Vegetation Index (NDVI)

The NDVI were calculated for all four years, 1990, 2000, 2010, and 2020, from the LANDSAT spectral regions of NIR and Visible Red Bands. The NDVI values of the year 1990 range from -0.35 to 0.4. Correspondingly, the NDVI values of the year 2000, 2010, and 2020 range from -0.2 to 0.47, -0.1

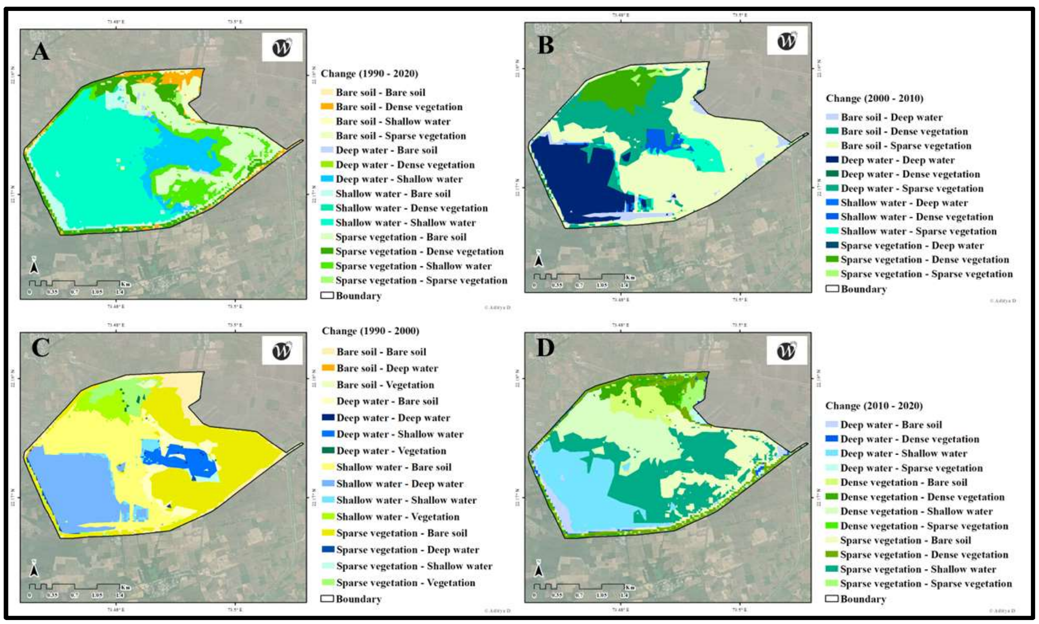

Figure 4. The figures show the change in land use and land cover from the year 1990-2020 in Wadhwana Wetland (A=1990; B=2000; C=2010; D=2020)

Table 4. Error (Confusion) matrix for the accuracy assessment of LULC for 1990, 2000, 2010, and 2020

LULC type	1990		2000		2010		2020	
	Producer accuracy (%)	User accuracy (%)	Producer accuracy (%)	User accuracy (%)	Producer accuracy (%)	User accuracy (%)	Producer accuracy (%)	User accuracy (%)
Bare soil	100	92	91	84	-	-	90	76
Deep water	76	100	100	84	94	94	-	-
Dense vegetation	-	-	-	-	100	88	85	92
Shallow water	100	76	81	100	-	-	92	100
Sparse vegetation	92	92	92	92	89	100	92	92

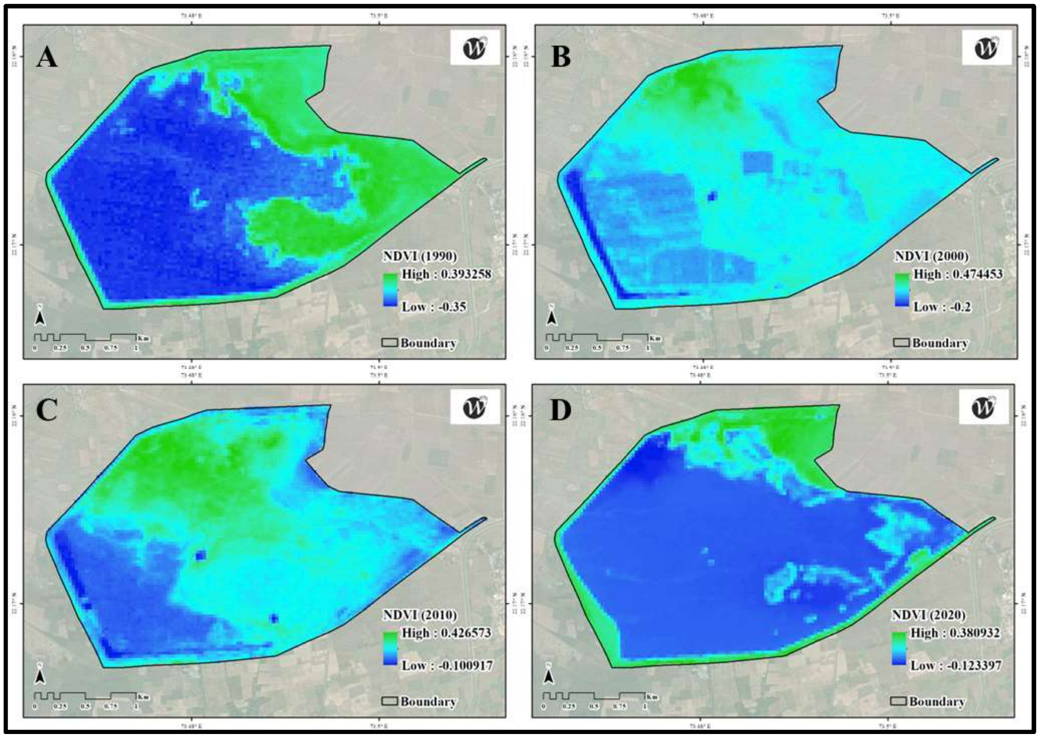

Figure 5. The figures show the change in vegetation through NDVI from the year 1990-2020 in Wadhwana wetland (A=1990; B=2000; C=2010; D=2020)

to 0.42, and -0.12 to 0.38, respectively. Here, the negative values indicate the water bodies, and the positive values (average ranging from 0.18 to 0.47) indicate the presence of vegetations (Ashok et al., 2021). From all four images, the positive NDVI values range from 0.47. According to Pettorelli (2013), shrubs, grasslands, and senescing crops are represented by NDVI values ranging from 0.2 to 0.5.

4. CONCLUSION

In conclusion, this comprehensive study examined the dynamic shifts in the Wadhwana Ramsar wetland ecosystem over four decades, using a combination of geospatial techniques and remote sensing data. The analysis has clearly established the interrelationship between LULC transitions and vegetation dynamics, where a significant decline in wetland extent (~45%) and the conversion of water bodies and barren land into cultivated areas reflect increasing anthropogenic pressure. The observed variations in NDVI values further indicate shifts in vegetation health and density, collectively demonstrating how these factors have altered the hydrological and ecological balance of the wetland over time. The findings underscore the challenges faced by wetlands globally, as they grapple with anthropogenic pressures, climate fluctuations, and urban expansion.

The results unveiled a compelling narrative of transformation - a story of shrinking wetland areas and evolving vegetation patterns. The transition from water bodies to barren lands, from lush vegetation to cultivated fields, paints a vivid picture of the multifaceted impact of human activities. Amid these changes, the study identified strategic land-use planning and environmental education as pivotal tools to safeguard the fragile wetland ecosystem.

Furthermore, the application of the Normalised Difference Vegetation Index (NDVI) provided a quantitative lens to observe the ebb and flow of green cover. The positive NDVI values, indicative of flourishing vegetation, accentuated the ecological richness of the wetland when human intervention was minimised. These findings amplify the importance of preserving wetlands not only for their inherent biodiversity but also for their role in climate regulation, water purification, and the intricate web of ecosystem services they offer. As Wadhwana Wetland takes on its new designation as a Ramsar site, this study's insights serve as a beacon for responsible conservation and management practices.

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CRediT Authorship Contribution Statement

Aditya Dharaiya: Conceptualization, Data collection, Data curation, Methodology, Software, Writing - original draft. **Shalu Mesaria**: Conceptualization, Data collection, Data curation, Formal analysis. **Pratikkumar Desai**: Conceptualization, Data collection, Data curation, Formal analysis, Project Administration, Resources, Validation. **Ravirajsinh Rathod**: Investigation, Resources, Supervision, Validation, Visualization. **Sasi Kumar K**: Investigation, Resources, Supervision, Validation, Visualization. **Nishith Dharaiya**: Conceptualization, Investigation, Resources, Supervision, Validation, Visualization.

Conflict of Interests

The authors declare that they have no known competing financial or personal relationships that could have influenced the work reported in this paper.

Declaration about the use of AI tools

The authors declare that no AI tools have been used in the writing process, except for grammar and spelling checks.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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