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Ecological Health Assessment of Vandiyur Lake, Madurai, India: A Multi-parametric Approach Using Physico-chemical and Planktonic Indicators

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Abstract: Vandiyur Lake, a critical urban wetland in Madurai, faces ecological degradation mainly from encroachment and untreated sewage discharge. This study evaluates the lake's ecological health from December 2023 to March 2024 using physico-chemical profiling and planktonic analyses. Over the study period, both the physico-chemical profiles and planktonic community structures showed significant spatial and seasonal variability. In sampling station II, the highest organic loading was observed, with total alkalinity (321 mg/L), free CO_2 (22.25 mg/L), total nitrogen (1.16 mg/L), total phosphorus (1.01 mg/L), and BOD (6.66 mg/L) coinciding with suppressed dissolved oxygen (6.82 mg/L). A total of 25 phytoplankton and 45 zooplankton species were recorded. Phytoplanktons were dominated by Cyanophyceae and Bacillariophyceae, including *Euglena sp., Microcystis* sp. *Closterium* sp., *Asterionella* sp., and *Anabaena* sp., while Rotifera was the most diverse zooplankton group, including *Brachionus* spp., *Daphnia* sp., and *Diaptomus* sp. These taxa are widely recognized as reliable bio-indicators of eutrophication and organic pollution. Diversity indices indicated that Station I had higher species diversity and evenness, reflecting a relatively stable ecosystem. In contrast, Station II showed high species richness but lower diversity and evenness, suggesting dominance of pollution-tolerant species due to anthropogenic stress. Overall, these findings suggest an ecological imbalance caused by nutrient enrichment and sewage discharge, emphasizing the urgent need for management strategies to restore the lake's ecological health.

Keywords: Bio-indicators, Eutrophication, Shannon-Wiener Index, Vandiyur Lake, Water quality, Zooplankton.

1. INTRODUCTION

Water is the most vital component of the global ecosystem, serving as a fundamental resource for domestic, agricultural, and industrial needs. Historically, lentic water bodies like lakes and ponds have been utilized for diverse purposes ranging from irrigation and fish farming to ritualistic and aesthetic value (Narayan et al., 2007; Bishnoi & Malik, 2008). Bishnoi and Malik (2008) report that rapid industrialization, burgeoning human populations, and intensive use of agrochemicals have been contributing to the significant contamination of these freshwater ecosystems.

The quality of water is defined by its physical, chemical, and biological characteristics (Rajagopal et al., 2010a, 2010b). When these parameters deviate from established safety limits, they pose a direct threat to human health and aquatic biodiversity. Consequently, evaluating the Water Quality Index (WQI) has become a standard method for determining the suitability of water sources for consumption and ecological maintenance (Tyagi et al., 2013). Understanding the biological phenomena of a lake requires a deep dive into its hydro-chemical profile, as the chemistry of water dictates the metabolism of the entire ecosystem (Rajagopal et al., 2010b; Basavaraja et al., 2011).

Recent environmental assessments in India have highlighted nutrient enrichment (eutrophication) and acidification as primary drivers of freshwater degradation. These issues are largely attributed to the discharge of untreated domestic sewage and industrial effluents (Shekhar et al., 2008; Laskar & Gupta, 2009). Biological monitoring or biomonitoring, offers a more holistic view of lake health than chemical testing alone. Aquatic organisms, particularly plankton, are highly sensitive to environmental disturbances. Phytoplankton, as primary producers, form the foundation of the aquatic food web, and their diversity responds rapidly to changes in nutrient levels, particularly silica, nitrates, and phosphates (Chellappa et al., 2008).

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Certain species, such as those identified by Palmer (1969), serve as definitive bioindicators of organic pollution. Similarly, zooplankton communities play a critical role in energy flow and cycling of matter. Their distribution is governed by a complex interplay between climatic conditions and the physico-chemical variables of the aquatic ecosystem (Neves et al., 2003). Despite extensive research on freshwater bodies across India, ecological data regarding the wetlands, specifically the lakes of southern Tamil Nadu, remain relatively sparse (Smitha et al., 2007; Rajagopal et al., 2010b).

Vandiyur Lake, the second-largest lake in Madurai, serves as a crucial lifeline for groundwater recharge. It is primarily used for agricultural irrigation in Anuppanadi, while also supporting the local water supply for residential areas including Gomathipuram, Thendral Nagar, Tahsildar Nagar, and Melamadai. However, over the past two decades, the lake has undergone significant ecological degradation driven by urban encroachment and untreated sewage discharge. While previous studies have documented specific taxonomic groups such as birds, fish, and aquatic flora (Jaffer Ali et al., 2019; Selvamurugan, 2023; Seenivasan, 2024), a comprehensive understanding of the interplay between hydro-chemical properties and planktonic community structures remains elusive (McConnell & Meenakshi, 2024). Consequently, this study was designed to analyze physico-chemical parameters and plankton diversity to provide a baseline assessment of the trophic status and ecological integrity of Vandiyur Lake.

2. MATERIALS AND METHODS

2.1 Description of the Study Area and Sampling Site

The study was conducted at the Vandiyur Lake (VL), Madurai, Tamil Nadu (9.93^{O}N, 78.12^{O}E). As the second-largest lake in Madurai, it spans approximately 577 acres (reduced from its original 640 acres due to encroachment). The lake has a catchment area of 96.89 km2, a storage capacity of 107.03 mcft, and a bund length of 2077 m. It primarily receives runoff from the Sathaiyar Dam and surplus channels from the Parasurampatti, Sambakulam, Thallakulam and S. Kodikulam tanks.

Vandiyur Lake serves as a multi-use resource for the local community, primarily supporting agricultural irrigation, cattle grazing, artisanal fishing, and domestic activities. Despite a 2004 Madras High Court directive aimed at curbing industrial and hospital effluent discharge, the lake remains under significant ecological pressure. Current threats include the ingress of untreated domestic sewage, runoff from nearby flower and fish markets, and non-point source pollution from open defecation within the riparian zones.

To assess water quality and plankton diversity, the lake was categorized into four sampling zones based on geographic orientation (Figure 1):

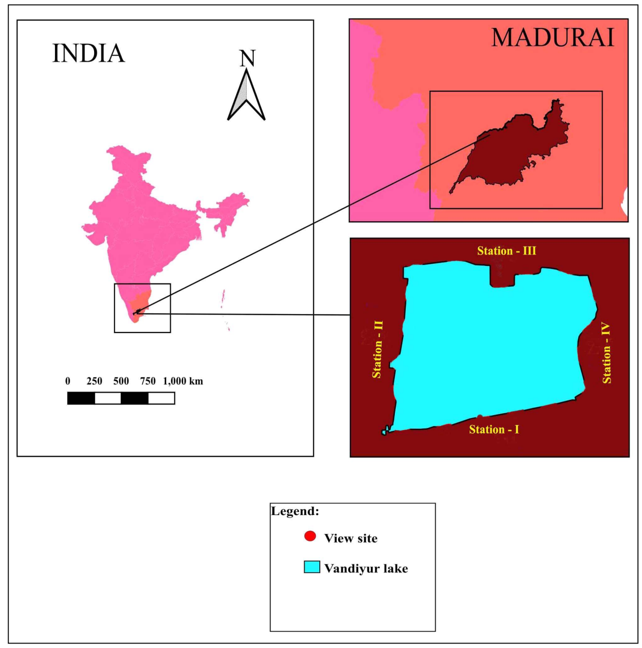

Figure 1. Map showing the location of Vandiyur Lake, Madurai, Tamil Nadu, Indian and specific study stations (I-IV)

1. **Zone I (South site):** Situated near the Gomathipuram residential area, this zone is influenced by urban housing, commercial showrooms, and the local fish market located along the southern banks.
2. **Zone II (West site):** Located adjacent to Sundaram Park, this site is primarily impacted by proximity to the Apollo and Sugapriya hospitals on the western banks.
3. **Zone III (North site):** Positioned near high-traffic landmarks including the Mattuthavani bus stand, flower and fish markets, and Meenakshi Mission Hospital on the northern banks.
4. **Zone IV (East site):** Adjacent to the Pandi Kovil and Madurai Ring Road, this zone is characterized by its proximity to schools, residential apartments, and Guru Hospital on the eastern shores.

2.2 Water Sample Collection

Water samples were collected monthly over a four-month period from December 2023 to March 2024. To ensure consistency, all sampling was performed during the morning hours (08:00 AM to 10:00 AM). Sub-surface water was collected using sterile, wide-mouth, screw-capped glass bottles from a depth of 5–10 cm. The samples were then transported immediately to the departmental laboratory for physicochemical analysis, following the methods described by Rajagopal et al. (2010a).

2.3. Water Quality Analyses

Air and surface water temperatures were recorded on-site using a mercuric centigrade thermometer. Initial pH was screened using pH indicator strips at the site and later confirmed in the laboratory using a digital pH meter. Rainfall data for the 2023–2024 study periods were obtained from the Meteorological Department of the Madurai District Administration Office. Other parameters, including water colour, odour, total solids (TS), salinity, alkalinity, dissolved oxygen (DO), biological oxygen demand (BOD), free CO_2, etc., were analysed following standard protocols prescribed by the American Public Health Association (APHA, 2017).

2.4. Plankton Collection and Identification

For planktonic analysis, 50 litres of water (integrated from surface, middle, and bottom layers) were filtered through a standard plankton net (25 µm mesh size) on-site at each sampling station during the morning hours (08:00 AM to 10:00 AM). The concentrated samples were transferred to polyethylene bottles and preserved immediately with 5% formalin for subsequent qualitative and quantitative analyses:

1. **Qualitative analysis:** Planktonic organisms were identified to the genus or species level under a compound microscope using standard taxonomic keys and manuals (Adoni et al., 1985, Agarker et al., 1994).
2. **Quantitative analysis:** Plankton density was estimated using a Sedgwick-Rafter counting cell, following the methodology described by Rajagopal et al. (2010a).

2.5. Statistical Analysis

The planktonic community structure was assessed through diversity indices calculated using PAST (Paleontological Statistics) software (Hammer et al., 2001). The following indices were determined: (1) Shannon-Wiener Index (H′) to evaluate species diversity, (2) Menhinick's Index (D) to measure species richness and (3) Pielou's Evenness Index (J′) to assess the distribution of individuals among species. Planktonic species abundance data were compiled and managed using SPSS software (Version 11.0). To identify significant differences in mean values across the sampling stations, the data were subjected to Duncan's Multiple Range Test (DMRT) at a significance level of $p<0.05$.

3. RESULTS AND DISCUSSION

3.1. Assessment of Physico-chemical Parameters

Physico-chemical water quality parameters are very important in assessing the constituents of water and also determining the level of pollutants or contaminants. The physico-chemical parameters and plankton diversity variation have been found in Vandiyur Lake; these variations were influenced by both biotic and abiotic components, either directly or indirectly. In the present study, the air temperature (AT) and water temperature (WT) showed a progressive increase from December to March, consistent with the transition from winter to the pre-monsoon season. AT ranged from 29°C to 33°C, while WT remained slightly lower, peaking at 29°C in March. This synchrony is typical of shallow lentic systems, as noted by Welch (1952), who reported that smaller water bodies such as ponds respond rapidly to changes in atmospheric temperature due to their low thermal mass. The peak temperature in March likely accelerated the metabolic rates of the dominant planktonic communities, particularly Cyanophyceae and Rotifera (Naik et al., 2020). According to Ganesh et al. (2015), rising temperatures and nutrient concentrations create the perfect conditions for opportunistic species, shifting the ecosystem from a balanced state to a eutrophic one.

There was a significant peak of rainfall in December (105.1 mm). High precipitation likely reduced nutrient concentrations temporarily and increasing water clarity as a result of this "dilution effect". As rainfall stopped and evaporation increased toward March, dissolved solids accumulation increased as the water level dropped. A similar observation was made by Jhingran (1991), who noted that the post-monsoon drawdown in Indian lakes often leads to nutrients accumulation, resulting in algal blooms (Jargal et al., 2021). Correspondingly, water color shifted from cloudy in December to slightly brown by February/March across all stations. This change is attributed to the accumulation of chromophoric dissolved organic matter (CDOM) and suspended solids during water level recession. Such discoloration is commonly associated with high organic loading and decomposition processes, indicating an advanced trophic state (Hossain et al., 2013; Shampa et al., 2024).

The pH of Vandiyur Lake showed a clear spatio-temporal shift, ranging from slightly acidic/neutral in December (minimum 6.12 at Station IV) to strongly alkaline in March (maximum 8.90 at Station II). While the mean pH (7.10–7.96) remained suitable for aquatic life; however, elevated March values indicate environmental stress. This rise is attributed to intensified phytoplankton photosynthesis during the pre-monsoon period, which increases alkalinity (Wetzel, 2001, Naik et al., 2020). Similar alkaline conditions (pH 8.0–9.0) are typical of eutrophic tropical waters and can enhance phosphorus availability, thereby promoting algal blooms (Verma et al., 2012; Wetzel, 2001). In contrast, the lower pH observed in December (6.12) is likely due to heavy rainfall (105.1 mm), which introduces organic acids and dilutes alkaline salts (Hulyal & Kaliwal, 2011).

The alkaline nature of Vandiyur Lake (ranges pH 7.10 to 7.96) indicates good buffering capacity, supported by the high total alkalinity across stations. Elevated alkalinity at Stations II and III (>300 mg/L) suggests localized nutrient inputs from domestic sewage and agricultural runoff (Kulshrestha et al., 1989). From December to March, a clear concentration effect was observed, with rising temperatures enhancing photosynthetic CO_2 uptake and evaporation, leading increased alkalinity and hardness (Hulyal and Kaliwal, 2011). Higher values at mid-lake stations (II/III) point to possible pollution hotspots or stagnant zones. Total hardness showed a similar trend, peaking in March (80 mg/L at Station II) (Table 1), likely due to evaporative concentration of calcium and magnesium ions (Jargal et al., 2021), consistent with patterns reported in Indian reservoirs (Hulyal & Kaliwal, 2011).

Dissolved oxygen (DO) levels across the four sampling stations ranged from a minimum of 5.5 mg/L at Station II in January to a maximum of 8.8 mg/L at Station I in December. Despite increasing water temperatures, DO levels showed a slight rise toward the month of March, likely due to enhanced phytoplankton photosynthesis activity, which is typical of nutrient-enriched waters (Wetzel, 2001). In contrast, the biological oxygen demand (BOD) ranged from 3.0 mg/L to 8.0 mg/L, with higher mean values at Stations II (6.66 mg/L) and III (5.37 mg/L), indicating greater organic pollution. These values fall within the moderately polluted range (Kulshrestha et al., 1989) and correspond with observations of slightly putrid odour and brownish water, suggesting localised inputs of biodegradable organic matter from domestic sewage or agricultural runoff.

Total dissolved solids (TDS) ranged from 1.0 to 3.8 mg/L and salinity from 0.21 and 3.0 mg/L, indicating a predominantly freshwater environment. Station II recorded comparatively higher salinity (mean: 0.55 mg/L), reflecting greater input of dissolved salts. A slight rise in TDS toward March suggests a concentration effect driven by increased evaporation (Promilton et al., 2025). Free CO_2 values increased markedly from December to March, with higher mean values at Stations II (22.25 mg/L) and III (18.75 mg/L), likely due to enhanced microbial decomposition of organic matter (Shi et al., 2025). This is supported by the elevated BOD at these stations. Despite rising CO_2 levels, the pH remained alkaline, indicating strong buffering capacity, possibly maintained by concurrent photosynthetic activity (Shi et al., 2025).

Total nitrogen (TN) and total phosphorus (TP) were consistently highest at Station II, with peak values of 1.55 mg/L and 1.13 mg/L in December, likely due to nutrient-rich runoff during heavy rainfall. Both parameters remained elevated at Station II throughout the study period, indicating substantial human activity in this area of Vandiyur Lake (Hulyal & Kaliwal, 2011). Such nutrient enrichment, coupled with rising temperatures, promotes high primary productivity (Wetzel, 2001). Notably, the average phosphorus concentration (~1.0 mg/L) far exceeds the eutrophication threshold of 0.1 mg/L (Li et al., 2024), confirming that Vandiyur Lake is in a highly eutrophic state and requires urgent management intervention.

3.2. Assessment of Planktonic Community Structure

The planktonic assessment of Vandiyur Lake recorded 25 phytoplankton species across six major classes with a total density of 961 individuals. Cyanophyceae (9 species) was the most diverse group, followed by Bacillariophyceae (8 species) and Chlorophyceae (4 species), reflecting typical dominance patterns in nutrient-rich or eutrophic waters (Baba & Pandit, 2014). These groups exhibit broad ecological tolerance across salinity gradients (Stanca et al., 2013; Pratiwi et al., 2018), with Cyanophyceae favoring warm, stable conditions and Bacillariophyceae thriving in cooler, well-mixed, nutrient-rich environments (Guedes et al., 2018). Station I showed the highest species diversity (n=24 species) but lowest species density (219 individuals), whereas Station II had the highest density (329 individuals) despite lower diversity (16 species). Seasonally, phytoplankton density was lowest in January (range: 21–51 individuals) and peaked in March, reaching 140 individuals at Station II. Dominant genera included *Microcystis*, *Anabaena*, *Closterium*, *Nitzschia*, *Navicula*, *Asterionella*, and *Skeletonema*, whose proliferation particularly at Station II indicates organic pollution and advanced eutrophic conditions, as supported by earlier and recent studies (Shekhar et al., 2008; Nikolopoulou et al., 2025; Maire et al., 2025). This finding confirms that Vandiyur Lake's is in an advanced eutrophic state, necessitating urgent conservation and management measures to protect its ecological integrity.

Table 1. Physico-chemical parameters of the various sampling stations of Vandiyur Lake from December 2023 to March 2024

Parameters	Sampling station-I					Sampling station-II					Sampling station-III					Sampling station-IV				
	D	**J**	**F**	**M**	**MV**	**D**	**J**	**F**	**M**	**MV**	**D**	**J**	**F**	**M**	**MV**	**D**	**J**	**F**	**M**	**MV**
Colour	C	C	SB	SB	--	SB	SB	SB	**SB**	--	SB	SB	SB	SB	**--**	C	C	SB	SB	**--**
Odour	N	N	N	N	--	N	N	**SR**	SR	--	N	N	**SR**	**SR**	**--**	No	N	N	N	**--**
AT (°C)	29	30	31	33	30.75	29	30	31	33	30.75	29	30	31	33	30.75	29	30	31	33	30.75
WT (°C)	27	27	28	29	27.75	27	27.2	28	29	27.75	27	27	27	28	27.75	27	27	27	29	27.75
Rainfall (mm)	105.1	8.9	13.2	24.2	133.32	105.1	8.9	13.2	24.2	133.32	105.1	8.9	13.2	24.2	133.32	105.1	8.9	13.2	24.2	133.32
pH	6.5	7.2	7.5	7.8	7.25	6.85	7.5	8.5	.9	7.96	6.55	7.25	8.1	8.5	7.6	6.12	7	7.5	7.8	7.10
TDS (mg/L)	1.0	3.2	3.2	3.8	2.80	2.03	2.71	3.33	3.45	2.88	2.05	2.4	3.02	3.05	2.63	1.8	2.0	2.5	2.58	2.22
Total alkalinity (mg/L)	180	188	220	212	200	289	304	355	336	321	280	300	316	327	305.75	211	220	233	276	235
Salinity (mg/L)	0.22	0.25	0.3	0.32	0.27	3.0	0.5	0.6	0.8	0.55	0.25	0.31	0.61	0.72	0.47	0.21	0.23	0.25	0.3	0.24
DO (mg/L)	8.8	6.4	7.5	8	7.67	8	5.5	6.3	7.5	6.82	8	5.8	6.5	7.5	6.95	8.1	6.5	7.5	7.9	7.5
BOD (mg/L)	3	3.2	3.5	4.1	3.45	5	6.45	7.2	8	6.66	4	4.5	6.2	6.8	5.37	3.1	3.5	4	4.75	3.83
Total Hardness (mg/L)	9	60.5	63	75	64.37	65	75	76	80	74	63	73	73	78	71.75	60	62	68	73	65.75
Free CO_2 (mg/L)	8	10	12	15	11.25	14	22	25	28	22.25	10	18	22	25	18.75	10	12	15	18	13.75
Total nitrogen (mg/L)	0.91	0.75	0.85	0.98	0.62	1.55	0.94	1.03	1.12	1.16	1.23	0.75	0.92	1.01	0.97	0.94	0.65	0.71	0.78	0.77
Total phosphorous (mg/L)	0.97	0.68	0.74	0.92	0.82	1.13	0.93	0.98	1.02	1.01	1.02	0.85	0.91	0.98	0.94	0.95	0.75	0.78	0.91	0.85

Note: Abbreviation: SB: Slightly brown; SRS: Slightly putrid smell; C: Cloudy; N: None; AT: Air Temperature; WT: Water Temperature; TSC: Total dissolved Solid Content; DO: Dissolved Oxygen; BOD: Biological Oxygen Demand; D: December; J: January; F: February; M: March; MV: Mean value

Table 2. Phytoplankton species diversity at various sampling stations in Vandiyur Lake from December 2023 to March 2024

Phytoplankton	Sampling station-I					Sampling station-II					Sampling station-III					Sampling station-IV				
	D	J	F	M	DE	D	J	F	M	DE	D	J	F	M	DE	D	J	F	M	DE
CLASS: CHLOROPHYACEAE																				
Closterium sp.,	5	2	4	5	4	5	8	5	15	8.25	5	5	6	8	6	4	3	6	3	4
Spirogyra sp.,	-	-	5	4	2.25	2	2	4	4	3	-	-	2	2	1	-	5	3	4	3
Stigeoclonium sp.,	-	-	1	2	0.75	-	-	-	-	-	1	1	4	2	2	5	5	4	5	4.75
Zygnema sp.,	-	-	3	5	2	-	-	-	-	-	4	3	4	3	3.5	5	4	2	3	3.5
CLASS: CYANOPHYACEAE																				
Gonium sp.,	-	-	1	-	0.25	-	-	1	2	0.75	-	-	-	-	-	-	-	-	2	0.5
Oscillatoria sp., 1	4	4	4	4	4	1	-	4	4	2.25	5	2	2	4	3.25	5	4	7	5	5.25
Oscillatoria sp., 2	-	-	5	5	2.5	-	-	-	-	-	-	-	-	-	-	-	-	2	10	3
Oscillatoria sp., 3	-	-	1	5	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.5
Oscillatoria sp., 4	-	-	3	10	3.25	-	-	-	-	-	-	-	-	-	-	-	-	1	2	0.75
Microcystis sp.,	3	2	3	2	2.5	10	12	8	25	13.75	6	4	14	18	10.5	3	-	2	2	1.75
Anabaena sp.,	-	2	1	5	2	8	8	10	16	10.5	5	3	6	10	6	-	3	2	4	2.25
Merismopedia glauca	1	-	-	2	0.75	2	-	-	4	1.5	-	-	-	2	0.5	-	-	-	-	-
Nostoc caeruleum	1	-	-	1	0.50	-	-	-	-	-	-	-	-	-	-	-	-	1	1	0.5
CLASS: BACILLAROPHYCEAE																				
Skeletonema sp.,	-	-	1	25	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphora sp.,	-	-	3	5	2	-	-	-	-	-	-	2	1	-	0.75	-	-	-	-	-
Synedra sp.,	3	2	3	3	2.75	-	-	-	-	-	2	2	2	4	2.5	5	3	1	1	2.5
Nitzschia sp., 1	-	-	1	10	275	3	3	4	10	5	-	-	-	-	-	-	-	1	1	0.5
Nitzschia sp., 2	3	2	2	3	2.5	5	4	4	5	4.5	4	2	1	1	2	2	2	-	-	1
Navicula sp.,	1	2	3	3	2.25	4	3	4	8	4.75	1	-	8	6	3.75	3	-	3	3	2.25
Cyclotella sp.,	4	4	-	4	3	-	-	-	3	0.75	-	-	-	-	-	2	2	-	5	2.25
Asterionella sp.,	-	-	3	3	1.5	6	6	8	12	8	3	5	3	8	4.75	-	-	2	2	1
CLASS: PENNALES																				
Thalassiothrix sp.,	-	-	-	-	-	-	-	1	1	0.5	-	-	-	4	1	-	-	-	-	-
CLASS: TREBOUXIOPHYCEAE																				
Chlorella sp.,	-	-	3	3	1.5	5	3	10	12	7.5	3	3	8	10	6	-	1	2	2	1.25
CLASS: EUGLENOPHYCEAE																				
Euglena sp.,	2	1	4	4	2.75	5	3	7	12	6.75	5	-	-	8	3.25	-	-	3	5	2
Phacus sp.,	-	-	2	2	1	3	-	5	8	4	3	3	5	5	4	-	-	1	3	1
TNI-MW	**27**	**21**	**56**	**115**		**59**	**51**	**75**	**140**		**43**	**35**	**66**	**95**		**34**	**32**	**43**	**65**	
TNS-MW	**10**	**9**	**21**	**23**		**13**	**11**	**15**	**17**		**13**	**12**	**15**	**17**		**9**	**10**	**17**	**20**	
TNS-SW			**24**					**16**					**17**					**21**		
TNI-SW			**219**					**329**					**239**					**174**		

Note: Abbreviation: D: December; J: January; F: February; M: March; DE: Density; TNI-MW: Total Number of Individual in Month-wise; TNS-MS: Total Number of Species in Month-wise; TNI-SW: Total Number of Individuals in Site-wise; TNS-SW: Total Number of Species in Site-wise

Table 3. Zooplankton species diversity at various sampling stations in Vandiyur Lake from December 2023 to March 2024

Zooplankton	Sampling station-I					Sampling station-II					Sampling station-III					Sampling station-IV				
	D	J	F	M	DE	D	J	F	M	DE	D	J	F	M	DE	D	J	F	M	DE
CLASS: ROTIFERA																				
Brachionus rubens	2	3	3	5	3.25	4	6	6	5	5.25	5	3	6	6	5	4	2	2	5	3.5
Brachionus calyciflorus	4	3	4	3	3.5	7	3	5	10	6.25	7	3	4	5	4.75	5	3	2	3	3.25
Brachionus kostei	-	-	-	-	-	-	-	2	2	1	2	-	1	3	2	3	2	2	1	2
Brachionus urceolaris	2	2	2	2	2	5	7	10	10	8	5	4	8	8	6.25	-	-	2	2	1
Brachionus uadridentatus	4	2	3	3	3	8	6	8	12	8.5	4	2	6	8	5	2	4	4	2	3
Brachionus durgae	2	-	-	2	1	-	-	-	-	-	2	2	2	3	2.25	-	-	-	-	-
Brachionus bidentatus	4	2	2	4	3	8	3	5	7	5.75	4	5	5	5	4.75	-	-	2	2	1
Brachionus plicatilis	3	2	4	3	3	5	6	6	6	5.75	-	-	-	-	-	3	5	5	6	4.75
Brachionus forficula	5	5	5	5	5	2	2	4	3	2.75	-	-	-	-	-	2	4	4	3	3.25
Brachionus durgae isigakiensis	4	3	2	3	3	-	-	-	-	-	1	3	2	1	1.75	-	-	-	-	-
Brachionus sp., 1	13	9	9	7	9.5	7	8	6	6	6.75	8	7	7	6	7	8	4	7	8	6.75
Brachionus sp., 2	-	-	-	1	0.25	-	-	2	2	1	1	2	-	2	1.25	-	-	1	2	0.75
Brachionus sp., 3	-	-	1	2	0.75	-	-	-	-	-	-	-	1	1	0.5	-	-	1	2	0.75
Brachionus sp., 4	-	-	-	-	-	1	1	1	1	1	-	-	2	2	1	-	-	3	3	1.5
Brachionus sp., 5	-	-	1	2	0.75	3	2	2	5	3	1	-	1	1	0.75	-	-	2	5	1.75
Brachionus sp., 6	-	-	1	2	0.75	1	-	1	1	0.75	-	-	-	1	0.25	-	-	10	5	4
Brachionus sp., 7	-	-	1	5	1.5	2	-	2	2	1.5	-	-	2	1	0.75	-	-	2	2	1
Brachionus sp., 8	-	-	-	-	-	-	-	-	-	-	1	-	2	2	1.25	-	-	1	1	0.5
Filinia longiseta	2	2	1	2	1.75	3	-	2	3	2	3	-	3	-	1.5	-	2	1	2	1.25
Monostyla sp.,	1	-	-	2	0.75	5	3	8	8	6	2	-	3	5	2.5	-	-	1	2	0.75
Lepadella sp.,	-	-	2	2	1	4	1	3	5	3.25	3	-	3	3	2.25	1	1	1	1	1
CLASS: CLADOCERANS																				
Alonella sp.,	-	-	2	2	1	3	2	2	2	2.25	4	6	2	4	4	3	2	2	4	2.75
Diaphanosoma sarsi	1	-	-	1	0.5	7	5	5	6	5.75	5	7	5	4	5.25	4	2	2	2	2.5
Daphnia magna	2	-	2	2	1.5	5	4	6	10	6.25	6	3	2	2	3.25	1	-	1	2	1
Daphnia sp.,	3	2	2	3	2.5	7	9	9	7	8	5	3	3	3	3.5	-	-	1	2	0.75
Moina brachiata	-	2	5	-	1.75	-	-	-	1	0.25	-	2	5	-	1.75	4	2	3	2	2.75
Moina sp., 1	7	10	6	6	7.25	1	3	3	2	2.25	6	9	5	5	6.25	9	6	3	4	5.5

Cont...

Table 3. Zooplankton species diversity at various sampling stations in Vandiyur Lake from December 2023 to March 2024

Zooplankton	Sampling station-I					Sampling station-II					Sampling station-III					Sampling station-IV				
	D	**J**	**F**	**M**	**DE**	**D**	**J**	**F**	**M**	**DE**	**D**	**J**	**F**	**M**	**DE**	**D**	**J**	**F**	**M**	**DE**
Moina sp., 2	-	-	2	5	1.75	2	-	2	2	1.5	-	-	2	2	1	-	-	-	-	-
Simocephalus sp.,	2	-	-	1	0.75	-	-	-	-	-	-	-	-	-	-	3	2	-	1	1.5
CLASS: COPEPODS																				
Cyclops sp.,1	6	4	4	1	3.75	5	3	6	6	5	7	2	4	10	5.75	7	4	2	2	3.75
Cyclops sp.,2	-	-	2	10	3	-	-	-	-	-	-	-	-	-	-	-	-	1	1	0.5
Heliodiaptomus sp.,	4	-	-	2	1.5	-	-	-	-	-	-	-	1	-	0.25	4	1	-	-	1.25
Rhinediaptomus indicus	3	-	-	-	0.75	-	-	-	-	-	-	-	-	1	0.25	-	-	-	2	0.5
Sinodiaptomus sp.,	3	3	3	1	2.5	-	-	-	-	-	-	-	-	-	-	3	-	4	-	1.75
Diaptomus sp., 1	6	2	2	3	3.25	8	5	6	12	7.75	4	3	8	8	5.75	6	4	2	5	4.25
Diaptomus sp., 2	-	-	-	2	0.5	-	-	2	2	1	1	-	3	3	1.75	-	-	-	-	-
Mesocyclops leuckarti	5	4	5	2	4	8	5	3	10	6.5	4	1	6	8	4.75	-	-	2	2	1
Nauplius sp.,	4	2	5	2	3.25	-	-	1	1	0.5	2	-	2	-	1	2	2	5	1	2.5
Acartia sp.,	-	-	-	1	0.25	5	2	5	8	5	3	-	3	5	2.75	-	-	-	-	-
CLASS: OSTRACODA																				
Cypris sp.,1	5	2	2	3	3	3	3	2	5	3.25	-	-	-	-	-	3	2	1	1	1.75
Cypris sp.,2	-	-	4	10	3.5	-	-	1	2	0.75	-	-	-	-	-	-	-	-	1	0.25
Cypris sp.,3	-	-	2	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.5
Strandesia elongate	1	-	-	-	0.25	-	-	-	-	-	1	1	-	1	0.75	-	3	3	3	2.25
Cypris protubera	3	1	4	-	2	-	-	-	-	-	4	2	2	2	2.5	-	-	-	-	-
Heterocypris dentatomarginatus	2	-	-	1	0.75	2	-	1	2	1.25	-	-	-	-	-	-	-	-	-	-
TNI-MW	103	65	93	115		121	89	126	165		101	70	111	121		77	57	85	94	
TNS-MW	**28**	**20**	**31**	**38**		**27**	**22**	**31**	**33**		**28**	**20**	**32**	**32**		**20**	**20**	**32**	**36**	
TNS-SW			**42**					**33**					**36**					**38**		
TNI-SW			**376**					**503**					**403**					**313**		

Note: Abbreviation: D: December; J: January; F: February; M: March; DE: Density; TNI-MW: Total Number of Individual in Month-wise; TNS-MS: Total Number of Species in Month-wise; TNI-SW: Total Number of Individuals in Site-wise; TNS-SW: Total Number of Species in Site-wise

The zooplankton community of Vandiyur Lake exhibited high taxonomic diversity, comprising 45 species across four major groups: Rotifera, Copepoda, Cladocera, and Ostracoda, with a total abundance of 1,595 individuals. Rotifera (21 species) was the most diverse group, followed by Copepoda (10 species), Cladocera (8 species), and Ostracoda (6 species). Their dominance is consistent with their high ecological adaptability and rapid reproductive capacity, enabling them to thrive in nutrient-rich and eutrophic environments (Phan et al., 2021; Montemezzani et al., 2015). Station I recorded the highest species richness (42 species) but the lowest species abundance (n=376 individuals), whereas Station II showed the highest species abundance (503 individuals) despite lower species richness (33 species), indicating ecological imbalance. Seasonally, zooplankton density was lowest in January and peaked in March, with a maximum of 165 individuals at Station II. The community was dominated by *Brachionus* spp. (e.g., *B. calyciflorus*, *B. rubens*, *B. plicatilis*), along with *Daphnia magna*, *Diaphanosoma sarsi*, *Cyclops* sp., *Diaptomus* sp., and *Cypris* sp. The proliferation of *Brachionus* spp., particularly at Station II, indicates high organic loading and advanced eutrophication, as these taxa are well-known saprobic indicators tolerant of low dissolved oxygen and elevated nutrient levels (Sampaio et al., 2002). The occurrence of *Brachionus plicatilis* further suggests elevated total dissolved solids and alkaline conditions (Sládeček, 1983), consistent with observations from polluted tropical waters (Sampath et al., 2000).

Despite predation pressure, the persistence of Cladocerans such as *Daphnia magna* and *Diaphanosoma sarsi* is likely supported by abundant phytoplankton, including *Microcystis* and *Anabaena* (Jeppesen et al., 2011). The presence of *Cyclops* and *Diaptomus* species reflects a resilient community adapted to fluctuating environmental conditions, with cyclopoids known to tolerate polluted habitats (Radhika et al., 2004). Overall, the dominance of Rotifera, particularly *Brachionus* spp., indicates a shift toward an advanced trophic state driven by both nutrient enrichment (bottom-up control) and ecological stress, which is characteristic of urbanized lake ecosystems (Mageed, 2008).

3.3. Assessment of Ecological Diversity Indices

Comparative analysis of ecological indices Margalef richness (D_{mg}), Shannon–Wiener diversity (H′), and Pielou evenness (J′) revealed significant spatial variation across the four stations for both phytoplankton and zooplankton (Table 4). Station II exhibited the highest species richness (D_{mg}: 3.18 for phytoplankton; 6.91 for zooplankton), while Station IV recorded the lowest values. In contrast, Station I showed the highest species diversity (H′: 4.27 for phytoplankton and 5.74 for zooplankton), indicating a more stable and heterogeneous community. Despite high species richness and abundance observed at Station II, the lower species diversity (Shannon–Wiener index) values reflect poor species distribution, further supported by reduced species evenness (Pielou Index). Station I also showed the highest species evenness (0.65 and 0.80 phyto-zooplankton, respectively), whereas Stations II and III recorded lower species diversity (H') and evenness (J'), suggesting dominance by a few taxa. Such reduced species evenness typically indicates environmental stress and community

Table 4. Comparative analysis of diversity indices for Phytoplankton and Zooplankton across four sampling stations in Vandiyur Lake

Category	Sampling station	No. of species	No. of individuals	Diversity Indices		
				Margalef (D_{mg})	Shannon (H′)	Pielou (J′)
Phytoplankton	I	24	219	2.88^{bc}	4.27^{a}	0.65^{a}
	II	16	329	3.18^{a}	2.59^{d}	0.22^{b}
	III	17	239	2.92^{b}	2.83^{c}	0.20^{bc}
	IV	21	174	1.88^{c}	3.04^{b}	0.61^{ab}
Zooplankton	I	42	376	5.53^{bc}	5.74^{a}	0.80^{a}
	II	32	501	6.91^{a}	3.88^{c}	0.55^{d}
	III	36	403	5.95^{b}	4.15^{bc}	0.68c
	IV	38	313	4.35^{c}	4.64^{b}	0.72^{b}

For all diversity indices, values within the same column followed by different superscript letters are significantly different (P<0.05) across sampling stations, based on Duncan's Multiple Range Test (DMRT)

imbalance, often associated with bloom-forming or pollution-tolerant species.

The biological diversity indices indicate that Station I maintains the most stable and diverse ecosystem for both phytoplankton and zooplankton. In contrast, Station II, despite its high abundance, exhibited lower Shannon (H′) and Pielou (J′) values, reflecting dominance by a few opportunistic species and suggesting localized organic enrichment or anthropogenic stress. DMRT analysis confirmed that spatial variations among stations were statistically significant ($P < 0.05$). Plankton communities (phytoplankton and zooplankton) are widely recognized as sensitive indicators of water quality (Singh et al., 2013). Overall, relatively high values of Shannon, Margalef, and Pielou indices across the lake indicate good species diversity; however, localised reductions in H′ (Shannon's index) may be attributed to factors such as heavy rainfall and associated environmental fluctuations (Dash, 1996).

4. CONCLUSION

Based on a multi-parametric assessment, Vandiyur Lake is undergoing advanced eutrophication. Although elevated nutrient levels support high planktonic productivity, the dominance of pollution-tolerant taxa and reduced species evenness indicate ecological imbalance and environmental stress, primarily driven by untreated sewage inflow. Despite this degradation, the lake retains significant biological potential; with effective sewage control and proper screening for contaminants, it could support sustainable inland aquaculture. To restore the ecological integrity of Vandiyur Lake, immediate management interventions are essential, including: (1) Sewage diversion: Implementing infrastructure to prevent the direct ingress of domestic and market effluents into the lake basin. (2) Riparian buffers: Establishing biological filters and green belts along the lake margins to mitigate nutrient-rich surface runoff. (3) Holistic management: Developing a long-term, sustainable conservation plan that balances the lake's ecological restoration with its multi-use functions for the local community.

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Thangavel Rajagopal: Conceptualization, Data curation, Supervision, and Writing original draft, Review and editing.preparation, Formal analysis and validation. **Ponnirul Ponmanickam** Conceptualization, Writing, review and editing. **Selvam Kaviya** Resources, investigation, and methodology, Formal analysis and validation. **Pandiyarajan Seenivasan** Resources, investigation, and methodology.

Conflict of Interest

The authors declare no competing interests.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors declare that no artificial intelligence tools were used to write this manuscript.

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All results are published in this article; raw data can be made available from the authors upon reasonable request.

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