

Turbidity-Driven Collapse of Macrophyte Diversity: Physicochemical Forcing in a Central Indian Tropical Pond

Jitendra Kumar Singh

Government PG. College

Saumit Banerjee

Government PG. College

Satendra Kumar

skumar@jnkvv.org

Jawaharlal Nehru Krishi Vishwa Vidyalaya

Dharm Chand Vishwakarma

Digvijai Nath PG College

Abhishek Anand

Government PG. College

Mukesh Kumar

Regional Institute of Education, NCERT

Vijay Kumar Upadhyay

Tula's Institute

Laxmi Prasad

Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go-Anusandhan Sansthan

Astha Dwivedi

Government PG. College

Dinesh Malasiya

Dr. Harisingh Gour University

Ram Manohar Ahirwar

Government PG. College

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Abstract

Small tropical ponds in central India are crucial biodiversity reservoirs, yet the precise mechanism by which turbidity and associated physicochemical stressors trigger macrophyte diversity loss remains understudied. This study evaluated Mahendra Sagar Pond (Tikamgarh, India) across five sites (St-1 to St-5), measuring key water quality parameters alongside standard macrophyte diversity indices such as Shannon-Weiner, Simpson, Margalef, Pielou's evenness, Raunkiaer's frequency, and Importance Value Index.

Water Quality Index (WQI) scores revealed severe degradation, with St-1 and St-3 exhibiting the poorest water quality (> 100%). ANOVA identified turbidity as the primary negative driver of macrophyte collapse ($F = 422.52$), alongside salinity, conductivity, BOD, and TDS. Conversely, dissolved oxygen and pH served as positive stabilizers for plant communities, whereas temperature had minimal effect. Sites St-5, St-4, and St-2 maintained richer, more balanced communities following Raunkiaer's frequency law whereas degraded sites (St-1, St-3) deviated from standard biological distributions and supported fewer species. Shifting transparency dictated species dominance, elevating *Eichhornia crassipes*, *Nelumbo nucifera*, *Pistia stratiotes*, and *Azolla pinnata* as key taxa.

By quantitatively isolating turbidity as the primary physicochemical forcing factor in macrophyte diversity collapse, integrating WQI with ecological diversity metrics, and mapping site-specific vulnerabilities within a single tropical pond. It clarifies the dual role of water quality parameters—negative stressors such as turbidity and eutrophication proxies (BOD, TDS) versus positive stabilizers like dissolved oxygen and pH—and links species dominance to water transparency. Safeguarding these neglected ecosystems requires immediate conservation strategies centered on restoring water transparency.

Highlight

- This work offers the first quantitative proof from central India that the primary physicochemical factor causing the collapse of macrophyte diversity in tropical ponds is turbidity.
- It enhances knowledge of how positive stabilizers (dissolved oxygen, pH) and negative stressors (turbidity, salinity, BOD, TDS) mutually impact community structure by mapping site-specific vulnerabilities and integrating water quality indices with biological diversity measurements.
- These findings highlight the urgent need to restore the optimum water transparency and protect neglected pond ecosystems as vital repositories of biodiversity.

1. Introduction

One of the most precious resources that can be found on the planet is water. Of the water available on the planet, seas and oceans comprise 97% whereas ponds, lakes, rivers, and marshes comprise 1 percent of accessible fresh water (Sogbanmu et al., 2019; Durack, 2015). The fresh waters contain a wide variety of aquatic microscopic and macroscopic life. In the natural environment, pond serve as critical sources of life to most forms of life such as insects, fish, birds, amphibians, mammals and plant species. Pond offers numerous ecological services like purification of water, flood reduction, storage of carbon and biodiversity conservation (Hernandez and Mitsch 2007; Palit and Mukherjee 2012). There has been a sudden drop in the biodiversity of freshwater pond ecosystems across the entire globe (WWF, 2022). The human activities amplified the pollution, habitat destruction, alien species, and disrupted nutrient dynamics, as well as climate change, which adversely affect the populations of the macrophytes, leading to poor ecosystems and loss of biodiversity (Lesiv et al., 2020, Sharma and Singh, 2017). Urbanization is one of the key contributors to this loss as it leads to fragmentation and loss of habitat and represents a continuing threat to freshwater biodiversity (Vehkaoja et al. 2020). Such problems are aggravated by human activities such as improper water management, overexploitation of water resources, siltation, and chemical application in the agricultural sector, which negatively affects macrophytes and their important functions (Sharma and Singh, 2017).

Aquatic vegetation also affects abiotic conditions and aquatic biota in various trophic levels (Norlin et al. 2005). Macrophytes are also big water plants that we can see with our naked eyes and these plants play significant roles in these ecosystems. The hydrophytes are aquatic macrophytes that are adapted to live in different forms (Haroon and Abd Ellah, 2021) and are typically found in fresh water that includes lakes, wetlands, pond, river, streams (Keddy, 2010). Macrophytes, in turn, preserve the quality of water and the abundance of bioresources that make it possible to retain a great relationship between the diversity and ecosystem functioning (Jeppesen et al., 1998; Downing et al., 2014; Duffy et al., 2017; Kuiper et al., 2017). The aquatic plants can provide a quantifiable measurement of the ecological conditions of the surface waters. They are primary producers and the foundational element of the food chain and they transform the inorganic matter into the organic matter via photosynthesis which provides energy to the rest of the ecosystem (Shengnan, et al., 2024). Eutrophication indicators are the submerged macrophytes, which are sensitive to the local environmental condition (Lacoul and Freedman 2006; Sondergaard et al. 2010).

The quality of water resources in any area is a significant issue in the development endeavours of the area (Kumar et al., 2016). The submerged macrophytes could vary because of Physical and Chemical traits of the water column, its depth, and flooding, which was dependent on the source of sediment nutrients (Li et al., 2018). The relationship between water parameters and the submerged macrophytes is crucial in the ecosystem organization in addition to the water quality (Bornette et al., 2011; Swe et al., 2021). The indicators of water quality in lakes and ponds are usually in the form of physico-chemical parameters, namely, pH, Dissolved Oxygen (DO), conductivity, turbidity, Total dissolved solids (TDS), and nutrient concentrations (Nayar, 2020; Jaffar et al., 2020). The physicochemical parameters are used to examine the temperature, salinity, conductivity, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), and pH that prove to be important predictors in all types of water bodies (Chapman, 2021; Xiao et al., 2018; Zhou et al., 2025). Water quality index (WQI) plays a crucial role in giving the complete picture of the health of the water bodies.

Using physico-chemical parameters, it is not difficult to determine the main factors that worsen the water quality, which is paramount to designing effective management approaches. This information assists in the more effective monitoring of water resources in order to ensure they comply with safety

requirements concerning their use as human resources, as agriculture and ecosystem support (Mazengia et al., 2024). Since the bulk of the chemical sources are urban and agricultural and may find their way into the water body, primarily through urban runoff (Kumar et al., 2022) and domestic and industrial effluents (Sousa et al., 2018), domestic and agricultural catchments are to be paid special attention (Tiedeken et al., 2017; Vystavna et al., 2018). The correlation between environmental conditions and macrophyte assemblage and close correlation with the mineralization of the hydro period of an aquatic body were introduced in an analysis conducted recently (Labat et al., 2021).

Though the water bodies and aquatic macrophytes hold ecological significance, there has been no systematic study on the distribution and abundance, frequency, density, variety and ecosystem of the macrophytes in the Central Indian water bodies. Identified research gaps include the lack of comparative studies of species frequency and diversity indices, insufficient data on the distribution and abundance of individual species, and a lack of knowledge on ecosystem. To seal these loopholes, there is need to study the biological patterns of the macrophyte species in these ponds comprehensively. The main objective of the study is to examine vegetation composition, distribution, and dominance of macrophytes in relation to the pond water quality in central India.

2. Materials and methods

2.1 Description of the study area:

The study was conducted at Mahendra Sagar Pond in Tikamgarh district, Madhya Pradesh, India (Fig. 1). The pond is a freshwater ecosystem located between 24.7338271° N latitude and 78.8271775° E longitude situated at a height of 349 meters above sea level, it covers an area of approximately 32 hectares and its maximum depth is estimated to be about 10 meters, while the average depth is about 5.5 meters. This pond is believed to be about two centuries old, it is located on the outskirts of Tikamgarh town, and its water comes mainly from rain. It retains water throughout the year and used by local communities for cattle bathing, washing clothes, grazing, irrigation and fishing. The pond is oval in shape and has concrete stairs on one side and a bypass road on the other side. The surrounding area increasingly influenced by human activities such as agriculture, fishing, and urban expansion, which have begun to degrade the pond water quality and affect its biodiversity. The five study sites (St-1 to St-5) were selected for water sampling and macrophytes plant diversity.

2.2 Water sampling and analysis:

To estimate physicochemical water quality, samples were collected weekly from October 2024 to mid-June 2025, from designated study sites in the east-west direction, at a depth of 20 cm, between 6:00 am and 8:00 am. Physico-chemical parameters (temperature, pH, conductivity, TDS, turbidity and salinity) were measured using a portable microprocessor and soil analysis kit, KMT-1765. Dissolved oxygen (DO) and biological oxygen demand (BOD) were determined by using Winkler's method (APHA, 2012). The basic principle of determining BOD is to measure the amount of dissolved oxygen in a water sample before and after five days of incubation at 250°C. In the study, eight parameters were selected for calculating the water quality index using the drinking water quality standards recommended by BIS (2003) and ICMR (1975). The water quality index of wetland water was calculated using the method proposed by Chatterjee and Razuddin (2002).

2.3 Macrophyte sampling

Water sampling and macrophyte sampling were conducted from October 2024 to June 2025. Study sites were strategically chosen to reflect the ecological variability of the pond. Quadrat sampling was employed to assess macrophyte diversity and abundance (Dotro et al., 2017). At each site, a 1 m x 1 m wooden quadrat was used, with ten quadrats randomly placed and three replicates created at each site. Sampling extended 25 m from the shoreline toward the centre of the pond. A total of 52 quadrats were sampled during the study period. Within each quadrat, macrophyte species were recorded for presence or absence and counted individually (Margalef, 1969). The collected samples were placed in polythene bags and taken to the laboratory for taxonomic identification.

2.4 Identification and nomenclature:

Aquatic macrophytes were identified following standard protocols, work and keys provided by the books of Aquatic and Wetland Plants of India (Cook 1996) and Wetland Flora of West Bengal (Chowdhury and Chowdhury 2022). Valid scientific names were cross-checked using the Plants of the World Online (POWO 2024) and World Flora Online (WFO 2024) databases. The scientific name of macrophytes plant and author citation were checked with the plant list (<http://www.theplantlist.org/>) and International Plant Names Index (IPNI) (<http://www.ipni.org/ipni/plantnamesearchpage.do>). All the aquatic macrophytes were identified using standard protocols published in books and literature (Gupta, 2001; Yadav and Sardesai (2002); Matthew 1991; Saini et al. 2010).

2.5 Data analysis:

Vegetation composition was evaluated by analyzing the frequency, density, abundance, and Importance Value Index (IVI), following the formula given by Misra (1968) and Curtis and McIntosh (1951). The dominance of the macrophyte species was determined using the IVI by summing up relative density (RD), relative frequency (RF) and relative abundance (RA) (Misra, 1968). Species diversity was measured using the Shannon–Wiener diversity index, a widely applied measure of biological diversity in aquatic ecosystems (Ghosh and Biswas, 2015). Phytosociological characteristics were determined according to established protocols (Margalef, 1969). The diversity indicators, including Shannon–Wiener, Simpson's, species richness, and species evenness, were calculated using methods outlined by Magurran (2004). Additionally, according to Raunkiaer (1934), the number of individuals of each species was recorded to obtain phytosociological characteristics such as frequency classes.

2.6 Statistical analysis:

To compare macrophyte diversity and associated factors among the five study sites (St-1 to St-5), statistical analysis was performed using SPSS (version 21.0). Physiochemical parameters of water and number of macrophyte species richness graphs are prepared by Origin 8.0. The relationships between water physicochemical parameters and macrophyte diversity were evaluated at the 0.05 significance level. Statistical tools such as ANOVA, correlation and water quality index (WQI) of physicochemical parameters were used. Pearson correlation (r) was used to assess association between pairs of variables, including study sites and the number of macrophyte species. Principal component analysis (PCA) was performed with 8 environmental variables measured at each study site, St-1 to St-5; temperature, pH, salinity, conductivity, TDS, DO, BOD and turbidity and species number. Since the variables were expressed in different units, PCA was performed on the standardized values obtained by dividing each variable by its standard deviation.

3. Result

A total 35 aquatic macrophyte plant species were noted which belong to 23 different families and 26 genera (Table 3). The observed macrophytes, based on their nature were classified as free floating, rooted leaf floating, submerged and emergent macrophytes. Figure 2 represented the some macrophytes species images observed during the study period of Mahendra sagar pond. A total of 7 free floating, 7 rooted with leaf floating, 7 submerged, and 14 emergent macrophyte species were identified which contributed 25.71%, 20%, 14.28%, and 40%, respectively (Fig. 3). Comparatively among different study sites, highest species diversity was observed in St-5 with 29 plant species, followed by St-4 with 26 plant species, St-2 with 24 plant species and St-3 and St-1 with 20 and 15 species, respectively.

3.1 Dominant families:

To determine the dominant families across the study sites of pond, a quantitative method was employed. Dominant families were identified by calculating the proportion of species in each family relative to the total number of species expressed as percentage (Mahato and Ghosh, 2025).

$$\text{Percentage of Family} = \frac{\text{Number of Species in a Particular Family}}{\text{Total number of Species across all Families}} \times 100$$

The family that was found to have the highest percentage was considered to be the dominant family, providing the best contribution to the multiplicity of macrophytes in the pond. Cyperaceae became the most dominant family with 5 species, which comprise 16.66 percent of total species. The various microhabitats are indicated by the existence of all four growth forms that make up a structurally complex ecosystem necessary to support aquatic fauna and ensure the ecosystem functions (Jeppesen et al., 2012). Hydrocharitaceae (11.43%), Nymphaeaceae (5.71%), and Potamogetonaceae (5.71) were other dominant families. These families can be varied and they can be supplemented by other families, which are an indicator of a rich wetland flora that serves as an indicator of aggregate ecosystem health and sustainability under environmental change (Mitsch and Gosselink, 2015). Lal and Lal (2021) have also reported similar results; they reported 36 macrophyte species in Kanke Dam and 17 species in Ranchi Lake. Wetlands in the Ranchi district have also been reported to have macrophyte diversity; in broader floristic surveys (Verma and Pandeya, 2008; Mukherjee and Kumar, 2020).

3.2 Physicochemical analysis of water:

Physicochemical parameters are key variables that impact the aquatic environment. Table 1 gives the statistical variances in physiochemical characteristics of water for the five analyzed sites (St-1 to St-5). The temperatures were consistent between the pond study sites, St-1 to St-5; it was ranged from Mean $\pm$ SD value, 24.64 ± 0.91 to $24.42 \pm 0.82^\circ\text{C}$ with the minimum and maximum recorded in St-1 and St-3, respectively. In the study sites, St-2, St-4 and St-5 it was ranged from Mean $\pm$ SD value, 24.62 ± 0.83 , 24.54 ± 0.69 and $24.48 \pm 0.73^\circ\text{C}$, respectively.

Table 1
Physicochemical characteristics of Mahendra sagar pond at selected study sites

Parameters	St-1 Min	St-1 Max	St-1 (Mean ± SD)	St-2 Min	St-2 Max	St-2 (Mean ± SD)	St-3 Min	St-3 Max	St-3 (Mean ± SD)	St-4 Min	St-4 Max	St-4 (Mean ± SD)	St-5 Min	St-5 Max	St-5 (Mean ± SD)	F value
Temperature (°C)	23.4	25.8	24.64 ± 0.91	23.5	25.7	24.62 ± 0.83	23.3	25.5	24.42 ± 0.82	23.7	25.6	24.54 ± 0.69	23.6	25.6	24.48 ± 0.73	0.0674
pH	6.5	7.6	6.94 ± 0.43	7.1	8.1	7.4 ± 0.41	6.6	7.7	7 ± 0.42	7	8.2	7.48 ± 0.51	7.1	7.9	7.5 ± 0.35	2.0522
Salinity (ppt)	1.4	2.7	2.04 ± 0.57	1.2	1.7	1.48 ± 0.19	1.3	2.6	1.92 ± 0.56	1.3	2.1	1.7 ± 0.32	0.9	1.6	1.22 ± 0.26	3.25
Conductivity (mS/cm)	460	626	519.4 ± 69.37	162	254	204.6 ± 38.02	470	630	534.2 ± 63.83	146	272	207 ± 54.71	154	265	216.8 ± 48.33	48.301
TDS (mg/l)	645	855	762.8 ± 84.96	575	670	581.4 ± 70.16	618	790	713.6 ± 72.51	485	657	559.8 ± 77.64	418	504	459 ± 34.94	15.236
DO (mg/l)	2.2	2.6	2.36 ± 0.18	5.2	6.5	5.82 ± 0.54	2.7	3.1	2.86 ± 0.15	4.8	7.4	6.42 ± 1.19	5.4	7.6	6.5 ± 0.97	37.32
Turbidity (NTU)	76.5	84.7	80.38 ± 3.06	26.4	32.7	29.46 ± 2.65	54.2	65.1	60 ± 4.41	15.2	22.6	18.94 ± 3.13	12.5	16.4	14.7 ± 1.42	422.52
BOD (mg/l)	26.42	36.2	31.752 ± 4.47	8.8	12.6	10.652 ± 1.53	18.6	28.5	24.368 ± 3.86	4.52	6.88	5.69 ± 0.93	4.46	5.74	5.296 ± 0.51	92.366

The level of acidic or alkaline nature of a solution is represented by pH, which is the negative logarithm of hydrogen ion concentration. The pH of the water affects aquatic plants and animal's ability to survive and prosper. At certain circumstances, greater pH levels can have an impact on aquatic life; however, BIS (2003) recommends an ideal pH level of 7-8.5. In the present study, the pH was ranged from Mean ± SD value, 6.64 ± 0.43 to 7.0 ± 0.42 with lowest and highest being recorded in St-1 and St-3, respectively. In the study sites, St-2, St-4 and St-5, the pH ranges from Mean ± SD value, 7.4 ± 0.41, 7.48 ± 0.51 and 7.5 ± 0.35 respectively. The study sites, St-1 and St-3 showed the low pH in comparison of St-2, St-4 and St-5, this is due to water pollution and anthropogenic disturbance. Bala and Mukherjee (2010) reported similar results of pH levels ranging from 5.34 to 8.67 in West Bengal's Nadia wetlands. These changes occur as a result of photosynthesis and respiration of aquatic biota (Kumar, 2017).

The minimum concentration of salinity (ppt) of study sites, St-5, St-2 and St-4 was recorded Mean ± SD value, 1.22 ± 0.26, 1.48 ± 0.19 and 1.7 ± 0.32, respectively. The maximum salinity of water Mean ± SD value, 2.04 ± 0.57% was recorded in St-1 and Mean ± SD value, 1.92 ± 0.56 at St-3.

The conductivity (mS/cm) of water is the important factor, that can show how much dissolved substances, chemicals, and minerals are present in the water. Higher amounts of these impurities will lead to higher conductivity. In this study, conductivity was found to be lowest of Mean ± SD value, 204.6 ± 38.02 mS/cm in St-2 and highest of Mean ± SD value, 534.2 ± 63.83 mS/cm in St-3. Other study sites, St-1, St-4 and St-5 have recorded Mean ± SD value, 519.4 ± 69.37, 207.0 ± 54.71 and 216.8 ± 48.33, respectively. The study clearly showed that the polluted and disturbed study sites, St-1 and St-3 have more electrical conductivities due to heavy metals ions and various other ionic form of substances. Study of Bala and Mukherjee (2010) supported present study results. The conductivity was recorded maximum at St-1 and St-3 with a maximum value of 534.2 ± 63.83 and 519.4 ± 69.37 mS/cm in the pond which is due to the enormous human activities enhancing the ionization of additional chemical compounds that entered into the ecosystem. Our study results are, supported by Oboh and Agbala, (2017), human disturbances enhance the ionization of chemical materials which enters in water ecosystem.

Total dissolved solids (TDS) are materials that dissolve in water, such as bicarbonate, sulfate, phosphate, nitrate, calcium, magnesium, sodium, and organic ions. In the present study, TDS values ranged from 459 ± 34.94 to 762.8 ± 84.96 mg/l with the minimum recorded at St-5 and maximum at St-1, respectively. At the other study sites Mean ± SD values of TDS were 581.4 ± 70.16 mg/l at St-2, 713.6 ± 72.51 mg/l at St-3, and 559.8 ± 77.64 mg/l at St-4. The results clearly indicate that the study sites located close to human settlements and roads (St-1 and St-3) exhibit higher TDS levels, which are mainly influenced by urbanization, agricultural runoff and domestic wastewater. The Present findings are consistent with Bala and Mukherjee, (2010).

Dissolved oxygen (DO) regulates ecosystem health by determining the amount of oxygen present in water bodies. In the present study the lowest DO concentration was reported at St-1 (2.36 ± 0.18 mg/l), while the highest was observed at St-5 (6.5 ± 0.97 mg/l). At the other study sites, St-2, St-3 and St-5, the recorded Mean ± SD values of DO were, 5.82 ± 0.54 mg/l at St-2, 2.86 ± 0.15 mg/l at St-3 and 6.42 ± 1.19 mg/l at St-5. While the DO level in drinking water should exceed 6.0 mg/l, but more than 5.0 mg/l is recommended for fisheries, recreation, and irrigation purposes (Munni et al., 2013). The results show that the DO levels in St-1 and St-3 are very low, mainly due to the direct discharge of urban sewage, making these sites poor in terms of water quality.

Turbidity (NTU) is a measure of water's ability to scatter light, which reduces light penetration and limits photosynthesis. The turbidity was recorded as maximum at St-1 (80.38 ± 3.06 NTU) and lowest at St-5 (14.7 ± 1.42 NTU). At the other study sites, St-2, St-3, and St-4, the recorded Mean ± SD values are 29.46 ± 2.65, 60.00 ± 4.41, and 18.94 ± 3.13 NTU, respectively. Turbidity is the observation of the optical property of water by which light is scattered by the colloidal particles present in the water.

The Biochemical oxygen demand (BOD) is the amount of oxygen consumed during the microbial consumption of organics in water. Thus, BOD signals the presence of microbial activity and dead organic matter that microorganisms can consume. BOD indicates the level of pollution in water sources based on the

levels of DO and organic matter accessible for oxygen-consuming bacteria (Tao et al., 2019). The maximum demand of oxygen in the water was recorded at St-1, Mean $\pm$ SD value, 31.752 ± 4.47 mg/l and St-3 has Mean $\pm$ SD value, 24.386 ± 3.86 in the studied pond. The other study site, BOD was recorded in the pond St-2, St-4 and St-5 was also considerably high Mean $\pm$ SD value, 10.652 ± 1.53 , 5.69 ± 0.93 , 5.296 ± 0.51 mg/l, respectively.

Table 2
Pearson correlation coefficients matrix between the physicochemical parameters of study area.

Parameters	Temperature (°C)	pH	Salinity (ppt)	Conductivity (mS/cm)	TDS (mg/l)	DO (mg/l)	Turbidity (NTU)	BOD (mg/l)	Species No.
Temperature (°C)	1								
pH	0.70641*	1							
Salinity (ppt)	0.6464*	0.24534	1						
Conductivity (mS/cm)	0.23489	-0.2637	0.71538*	1					
TDS (mg/l)	0.39547	-0.08	0.85379*	0.87786*	1				
DO (mg/l)	0.21122	0.72413*	-0.3615	-0.80128*	-0.66328*	1			
Turbidity (NTU)	0.12123	-0.44942*	0.61886*	0.91545*	0.87824*	-0.89486*	1		
BOD (mg/l)	0.19284	-0.386	0.67766*	0.93418*	0.89832*	-0.87963*	0.98769*	1	
Species No.	-0.1454	0.38596	-0.53676*	-0.86048*	-0.78339*	0.86199*	-0.90413*	-0.88423*	1
* Correlation is significant at the 0.05 level (two tailed)									

Table 2 displays the correlation matrix of mean water quality metrics, which assesses the correlations between environmental factors at sampling sites. Salinity had a substantial positive correlation with conductivity ($r = 0.71538$), TDS ($r = 0.89832$), and turbidity ($r = 0.98769$) ($p < 0.05$). Conductivity was significantly favorably connected with TDS ($r = 0.87824$) and turbidity ($r = 0.98769$) at the 0.05 level. Conversely, conductivity was inversely correlated with species distribution ($r = -0.86048$) at the $p < 0.05$ level. Total dissolved solids showed significant correlations with salinity ($r = 0.85379$) and conductivity (0.87786) at the $p < 0.01$ level, as well as a negative correlation with the distribution of species numbers ($r = -0.53676$). Turbidity was negatively linked with the number of species ($r = -0.90413$), which was statistically significant at the 0.05 level (Table 2). A one-way analysis of variance (ANOVA) was used to investigate the association between physiochemical water quality measures in the several study sites of the analyzed pond. Temperature, pH, and DO showed significant differences ($p < 0.05$) across the five study sites. However, there was no significant difference ($p > 0.05$) in salinity, TDS, conductivity, BOD, and turbidity across all pond study sites (Table 1).

Principal Component Analysis (PCA) analysis of physiochemical parameters and macrophyte species richness revealed a clear correlation with increased pH, DO, and temperature levels. The pond had 35 macrophyte species. Multidimensional scaling revealed significant differences in macrophyte composition and physiochemical parameters among aquatic plants. The PCA's first two components explained 66.8% of the variation in the original data (Fig. 4). The strongest variations were in the physiochemical parameters, with the turbidity, BOD, conductivity, TDS and salinity increasing on the first PCA. The second PCA accounted for 25.8% defined a gradient with higher values of DO, and pH. On the contrary, turbidity, BOD and conductivity did not result significantly in studied pond. The PCA found significant relationships between some physiochemical parameters and species richness of macrophytes. The physiochemical parameters factors related to plant species richness were related to, DO and pH in the studied pond water (Fig. 4).

3.6 Water quality index:

The water quality index (WQI) is used to assess the status of water characteristics. The range of the quality index and their status are shown in Table 4. The graphs showed in Fig. 4 which revealed the relationship between macrophyte species richness and physiochemical parameters of studied pond. In the study site St-1, the values of the parameters are, temperature $23.4\text{--}25.8^\circ\text{C}$; pH $6.5\text{--}7.6$; salinity $1.4\text{--}2.7$ ppt; conductivity $460\text{--}626$ mS/cm; TDS $645\text{--}855$ mS/cm; DO $2.2\text{--}2.6$ mg/l; turbidity $76.5\text{--}84.7$ NTU and BOD $26.42\text{--}36.2$ mg/l with minimum of 15 species were recorded, and the WQI (100.25) evident that the water of the site was unfit for drinking (Table 5). This may be due to increase of waste water sewage discharged at study site, St-1 which might be increased the physiochemical parameters of pond water. This is conformed from the results of turbidity which was found to be higher in St-1 than that of other study sites. In this study site, 5 rooted with leaf floating, 4 free floating, and 6 emergent plants are reported and the submerged macrophytes are absent (Table 3). The absence of submerged macrophytes showed that this study site is very strongly polluted and disturbed. Shannon Wiener index ($H = 2.1202$) at this study site which is lowest among all study sites of pond. Shannon Wiener index ($H = 2.74 \pm 0.36$) indicates moderate pollution status of lake as reported by Biswas et al., (2015). The free floating species such as *Pistia stratiotes* L., *Eichhornia crassipes* (Mart.) Solms and *Lemna minor* L. were highly dominant in terms of IVI value such as 19.24, 22.45 and 24.45, respectively.

Table 4
WQI and status of water quality.

Water quality index	Water quality
0–25	Excellent water quality
26–50	Good water quality
51–75	Poor water quality
76–100	Very poor water quality
More than 100	Unfit for drinking

Table 5
WQI of Mahendra sagar pond at different study sites.

S. No.	Parameters	Standard value (Sn)	Unit Weight (Wn)	St-1		St-2			St-3			St-4	
				Observed value	Quality rating (qn)	Wn*qn	Observed value	Quality rating (qn)	Wnqn	Observed value	Quality rating (qn)	Wnqn	Observed value
1	pH	6.5–8.5	0.219	6.94	81.65	17.88	7.4	87.06	19.07	7	82.35	18.04	7.48
2	DO (mg/l)	5	0.3723	2.36	47.2	17.57	5.82	116.4	43.34	2.86	57.2	21.30	6.42
3	Conductivity (mS/cm)	300	0.371	519.4	173.13	64.23	204.6	68.2	25.30	534.2	178.07	66.06	207
4	TDS (mg/l)	500	0.0037	762.8	152.56	0.56	581.4	116.28	0.43	713.6	142.72	0.53	559.8
WQI				100.25			88.13			105.92			

In the study site St-2, 24 macrophyte species were recorded, with the temperature ranged from 23.5–25.7°C; pH 7.1–8.1; salinity 1.2–1.7 ppt; conductivity 162–254 mS/cm; TDS 575–670 mg/l; DO 5.2– 6.5 mg/l; turbidity 26.4– 32.7 NTU; and BOD 8.8–12.6 mg/l. The estimated WQI was around 88.13 (Table 5), which means it has very poor water quality. Moreover, this difference in the WQI of St-2 can be explained by the fact that more vegetation was submerged in the same site where 5 out of 7 submerged aquatic macrophyte were counted. In total, St-2 had 5 submerged, 6 rooted leaf floating, 7 free-floating and 6 emergent macrophytes. The IVI index at this study site of macrophytes species are *Hygroryza aristata* (Retz.) Nees ex Wight & Arn. (3.44), *Hydrilla verticillata* (L.f.) Royle (11.24), and *Nelumbo nucifera* Gaertn. (20.62). The Shannon-Weiner index at this study site is higher (3.2431) than St-1 (2.1202) and St-3 (2.3224), which clearly indicates the St-2, have less pollution and have more macrophytes species diversity. This study sites followed the Raunkiaer's frequency class law $A < B > C > D < E$, this means distribution of macrophytes species is less affected from water quality.

At the study site St-3, 20 macrophyte species were recorded, with the temperature ranged from 23.3–25.5°C; pH 6.6–7.7; salinity 1.3–2.6 ppt; conductivity 470–630 mS/cm; TDS 618–790 mg/l; DO 2.7– 3.1 mg/l; turbidity 54.2– 65.1 NTU; and BOD 18.6–28.5 mg/l. The WQI, at this study site is found which is about 105.92 and not fit to drink. At this site, 2 submerged, 6 free floating, 6 rooted leaf floating, and 6 emergent macrophyte species are found. The Shannon and Weiner species diversity ($H = 2.3224$) is higher than St-1 but lower than St-2, St-4 and St-5, which revealed that St-3 is partially more polluted and have free floating macrophyte species in comparison of St-1. The 6 free floating dominant macrophytes species are *Lemna minor* L., *Pistia stratiotes* L., *Ludwigia adscendens* (L.) H. Hara, *Hydrocharis morsus-ranae* L., *Trapa natans* L. and *Azolla pinnata* R. Br., these free floating macrophyte have more capacity to remove nutrient concentration from the polluted water, and this is the region for higher species diversity at the site, than the St-1, even though St-3 have more WQI which is observed 105.92. The similar observation is found in the study of Greenway, 1997. The IVI value at this study site showed *Cyperus rotundus* L. (2.65), *Nymphoides indica* (L.) Kuntze (12.55) and *Pistia stratiotes* L. (25.12) as low, intermediate and high IVI value, respectively. Raunkiaer's frequency class law ($A < B < C > D > E$) not followed by this study site due to very high WQI which is about 105.92. At this study site, urban sewage water is mixed into the pond water, due to which the physicochemical parameters of the water increase, and hence, the WQI is high, hence the dead macrophyte species.

At the study site St-4, 26 macrophytes were recorded, with the temperature ranged from 23.7 to 25.6°C; pH 7.0–8.2; salinity 1.3–2.1 ppt; conductivity 146–272 mS/ cm; TDS 485–657 mg/l; DO 4.8– 7.4 mg/l; turbidity 15.2–22.6 NTU; and BOD 4.52–6.88 mg/l. The estimated value of WQI at this site is 93.09 which is also very poor, but showed rich macrophyte species. The Shannon-Weiner index at this study site, St-4 ($H = 3.2872$) which is less compares to St-5 and higher than St-2 (Table-5). Here, 6 submerged, 5 rooted leaf floating, 7 free floating and 9 emergent macrophytes are reported. The IVI values of this site are *Limnophila sessiliflora* (Vahl) Blume (5.58), *Polygonum glabrum* Roxb. (11.33) and *Azolla pinnata* L. (22.58), low IVI value, intermediate IVI value and high IVI value, respectively. This study site, followed Raunkiaer's frequency class law $A < B > C > D = E$ which means the dominance of macrophytes is low and evenly distribution.

However, 29 macrophytes species were reported in study site St-5, due to water quality conditions with temperature ranged from 23.6–25.6°C; pH 7.1–7.9; salinity 0.9–1.6 ppt; conductivity 154–265 (mS/cm); TDS 418–504 mg/l; DO 5.4–7.6 mg/l; turbidity 12.5–16.4 NTU and BOD 4.46–5.74 mg/l. At this site, the estimated WQI are about 94.87, which is also poor water quality but sustain more macrophyte species. The maximum macrophyte species found at this study site which is 5 submerged, 6 rooted leaf floating, 5 free floating and 12 emergent. The IVI value of macrophyte species are found as *Typha angustifolia* L. (5.58), *Potamogeton nodosus* Poir (12.98) and *Nelumbo nucifera* Gaertn. (24.32). The Raunkiaer's frequency class law for this site is $A < B > C > D = E$ which showed normal frequency distribution of all classes of macrophyte species distribution.

Table 3
List of aquatic macrophyte species recorded in the studied pond.

S. No.	Scientific name	Family	Common Name	Type	St-1	St-2	St-3	St-4	St-5
1.	<i>Nymphaea nouchali</i> Burm.f.	Nymphaeaceae	Red or blue water lily	RFL	✓	✓	✓	✓	✓
2.	<i>Nymphaea alba</i> L.	Nymphaeaceae	White water lily	RFL	✓	✓	✓	✓	✓
3.	<i>Nelumbo nucifera</i> Gaertn.	Nelumbonaceae	Indian lotus	RFL	✓	✓	✓	✓	✓
4.	<i>Ottelia alismoides</i> (L.) Pears.	Hydrocharitaceae	Duck lettuce	S	X	✓	X	✓	✓
5.	<i>Najas indica</i> (Willd.) Cham.	Hydrocharitaceae	Slender naiad	S	X	✓	✓	✓	✓
6.	<i>Pistia stratiotes</i> L.	Araceae	Water lettuce	FF	✓	✓	✓	✓	✓
7.	<i>Ludwigia adscendens</i> (L.) H. Hara	Onagraceae	Water Primrose	FF	X	✓	✓	✓	✓
8.	<i>Azolla pinnata</i> R. Br.	Salvinaceae	Water velvet	FF	X	✓	✓	✓	✓
9.	<i>Polygonum glabrum</i> Roxb.	Polygonaceae	Denseflower Knotweed	E	X	X	✓	✓	✓
10.	<i>Potamogeton crispus</i> L.	Potamogetonaceae	Curled pondweed	S	X	✓	X	✓	✓
11.	<i>Ceratophyllum demersum</i> L.	Ceratophyllaceae	Rigid hornwort	S	X	✓	X	✓	✓
12.	<i>Lemna minor</i> L.	Lemnaceae	Common duckweed	FF	✓	✓	✓	✓	✓
13.	<i>Eichhornia crassipes</i> (Mart.) Solms	Pontederiaceae	Water hyacinth	FF	✓	✓	X	X	X
14.	<i>Typha angustifolia</i> L.	Typhaceae	Narrow leaf cattail	E	X	X	✓	✓	✓
15.	<i>Hydrilla verticillata</i> (L.f.) Royle	Hydrocharitaceae	Indian star grass	S	X	✓	✓	✓	X
16.	<i>Hydrocharismorsus-ranae</i> L.	Hydrocharitaceae	Common frogbit	FF	✓	✓	✓	X	X
17.	<i>Trapa natans</i> L.	Trapaceae	Water chestnut	FF	X	✓	✓	✓	✓
18.	<i>Hygroryza aristata</i> (Retz.) Nees ex Wight & Arn.	Poaceae	Asian watergrass	E	X	✓	✓	X	X
19.	<i>Marsilea quadrifolia</i> L.	Marsileaceae	Water clover	RFL	✓	✓	✓	X	✓
20.	<i>Ipomoea aquatica</i> Forrsk.	Convolvulaceae	Water spinach	E	X	X	✓	✓	✓
21.	<i>Ipomoea carnea</i> subsp. <i>Fustulosa</i> (Mart. Ex Choisy) D. F. Austin	Convolvulaceae	Pink Morning Glory	E	X	X	X	✓	✓
22.	<i>Alternanthera sessilis</i> (L.) DC.	Amaranthaceae	Dwarf Copperleaf	E	✓	✓	X	X	✓
23.	<i>Utricularia aurea</i> Lour.	Lentibulariaceae	Golden Bladderwort	S	X	X	X	✓	✓
24.	<i>Hygrophila auriculata</i> (Schumach.) Heine	Acanthaceae	Talimkhana	RLF	X	✓	X	✓	✓
25.	<i>Limnophila sessiliflora</i> (Vahl) Blume	Plantaginaceae	Asian marshweed	E	X	✓	X	✓	✓
26.	<i>Nymphoides cristata</i> (Roxb.) Kuntze	Menyanthaceae	Crested Floating Heart	E	✓	✓	✓	X	✓
27.	<i>Cyperus iria</i> L.	Cyperaceae	Rice Flat Sedge	E	✓	X	X	✓	✓
28.	<i>Cyperus rotundus</i> L.	Cyperaceae	Nut grass	E	X	X	✓	✓	✓
29.	<i>Cyperus difformis</i> L.	Cyperaceae	Small flower umbrella sedge	E	✓	✓	X	X	✓
30.	<i>Cyperus compressus</i> Jacq.	Cyperaceae	Annual sedge	E	✓	X	X	✓	✓
31.	<i>Cyperus polystachyos</i> Rottb.	Cyperaceae	Many-spiked flatsedge	E	✓	✓	X	X	X
32.	<i>Nymphoides indica</i> (L.) Kuntze	Menyanthaceae	Water Snowflake	RFL	X	X	✓	✓	✓
33.	<i>Typha latifolia</i> L.	Typhaceae	Common cattail	E	X	X	X	✓	✓
34.	<i>Oxalis corniculata</i> L.	Oxalidaceae	Indian sorrel	RFL	✓	✓	✓	X	X
35.	<i>Potamogeton nodosus</i> Poir.	Potamogetonaceae	Longleaf pondweed	S	X	X	X	✓	✓
Total number of species in each station					15	24	20	26	29
(Abbreviations: G. F= Growth form, E = Emergent, S = Submerged, RFL = Rooted with floating leaves, FF = Free floating.)									

3 Raunkiaer's Frequency Analysis:

The frequency distribution of macrophyte plant species within each study site of pond was calculated using Raunkiaer's law of frequency classes (1934). The results are presented in Table 6. By analyzing and comparing them to Raunkiaer's law of frequency classes ($A > B > C \geq D < E$, where value of frequency class comprises class A = 53%, B = 14%, C = 9%, D = 8% and E = 16%). In the studied pond, across all study sites (St-1–St-5), significant perceptions were gained into the spatial distribution and diversity of macrophytes. This analysis highlights the varying patterns of species diversity, their spatial distribution, and the ecological status of the studied pond. The St-1 displayed higher disturbance with lower frequencies in Classes C and E (8.10% and 1.50%, respectively), indicating the dominance of macrophyte species. The evenness is high and species richness is low. The St-2 had the highest percentage in Class B (47.00%), indicating a heterogeneous vegetation structure, study site, St-3 had the highest percentage in Class A (47.12%), indicating a homogeneous vegetation structure, In St-4, Class B was again the most frequent at 42.30%, with moderately high macrophyte diversity overall. The site St-5 recorded Class B at 45.15% and Class A at 36.23%, reflecting a consistent distribution pattern across the pond.

Table 6
Raunkiaer's frequency classes (%) of the study sites (St-1-St-5).

Study sites	Class A	Class B	Class C	Class D	Class E	Raunkiaer's Frequency
St-1	55.00	30.15	5.25	8.10	1.50	$A > B > C < D > E$
St-2	15.60	47.00	24.32	5.44	7.64	$A < B > C > D < E$
St-3	47.12	20.46	28.88	9.12	1.42	$A < B < C > D > E$
St-4	23.30	42.30	25.50	4.45	4.45	$A < B > C > D = E$
St-5	36.23	45.15	12.46	7.25	7.25	$A < B > C > D = E$

2.4 Diversity Indices and Evenness Analysis:

The current study investigates macrophyte diversity and evenness across the pond under study site (St-1-St-5) using several established biodiversity indices (Table 7), including the Shannon and Weiner diversity index (H), Simpson's index of diversity (1-D), Margalef diversity index, and Pielou's evenness index (J). These biodiversity indices offer a perspective on the composition, richness and evenness of macrophyte communities, offering a comprehensive view of their biodiversity status (Fig. 3).

Table 7
Values of different diversity Indices

Index	St-1	St-2	St-3	St-4	St-5
Shannon and Weiner Diversity Index (H)	2.1202	3.2431	2.3224	3.2872	3.7849
Simpson's Index of Diversity (1- D)	0.7324	0.9325	0.7845	0.9112	0.9563
Margalef Diversity Index	3.152334	4.120751	3.112310	4.657378	5.152545
Pielou's Evenness (J)	0.902658	0.954278	0.912679	0.957784	0.963371

The Shannon-Weiner diversity index (H) showed that St-5 exhibited the most richness ($H = 3.7849$), indicating a diverse and equally dispersed macrophyte species assemblage. The study sites, St-2 and St-4 are also having high H value which showed the high species richness and evenness of macrophyte species. In contrast, the study site, St-1 and St-3 exhibited the lowest biodiversity ($H = 2.1202$ and 2.3224 , respectively), suggesting reduced species richness and evenness. Macrophytes were more evenly distributed at St-3 than St-2 similar to Bhattapokhari (Niroula and Singh 2010). The diversity index (H) revealed varying levels of species complexity, with St-5 exhibiting the highest biodiversity (3.4968) and St-1 the lowest (2.9512). This pattern aligns with studies on the water bodies, which demonstrated varied H values based on plant community structure and human impact (Li et al., 2022). High values of H could suggest a more diversified community. A community with a single species yields a H value of 0. If species are uniformly distributed, the H value increases. As a result, the H value indicates how a species' abundance is spread throughout all species in a community. Simpson's (1-D), which also considers species richness and evenness, showed high values for St-2, St-4, and St-5, with scores values 0.9325, 0.9112 and .9563, respectively. These high values indicate that these study sites, St-2, St-4 and St-5 of pond have diverse and stable ecosystems. However, St-1 and St-3 had lower (1-D) values (0.7324 and 0.7845), consistent with their lower H scores, reflecting reduced biodiversity or dominance by certain macrophyte species. Simpson's index of diversity (1-D) corroborated these findings, showing high values (0.9112 to 0.9563) for St-2, St-4 and St-5 indicating diverse and stable ecosystems. However, St-1 and St-3 displayed slightly lower (1-D) values (0.7324 and 0.7845, respectively), suggesting potential biodiversity reduction or species dominance, consistent with findings on the impact of urbanization in the Bamenda Municipality (Asongwe et al., 2022). The Margalef diversity index (DMg), which focuses on species richness, highlighted that St-2 (4.120751), St-4 (4.657378), and St-5 (5.152545) had relatively high species richness. Study site St-5 had the highest richness overall, while St-1 exhibited the lowest species richness. The lower DMg values in St-1 (3.152334) and St-3 (3.112310) suggest that these pond study sites experience reduced species richness, likely due to waste water discharged which causes pollution and human activities. The Margalef Diversity Index (DMg) provided insights into species richness, with St-2, St-4, and St-5 showing relatively high values (4.120751 to 5.152545), indicating rich species diversity and favourable conditions for macrophytes growth forms. Conversely, St-1 (3.152334) and St-3 (3.112310) exhibited lower DMg values, suggesting reduced species richness, possibly due to environmental stressors such as pollution, human activities, or invasive species (Saluja and Garg, 2017). These findings mirror challenges faced by ecosystems impacted by anthropogenic influences, similar to observations in the tropical lakes of the Central Ganga Plain (Dubey

et al., 2022). Pielou's Evenness index (J), which measures species distribution and ecological balance, showed high evenness found in pond St-2, St-4, and St-5, indicating more stable environmental conditions in comparison of St-1 and St-3. The study site, St-5 had the highest evenness score (0.963371), whereas St-1 (0.902658) and St-3 (0.912679) displayed the lowest evenness, possibly due to the influence of environmental or anthropogenic activities. Evenness index (J) analysis revealed high evenness values for St-2, St-4, and St-5 (0.954278 to 0.963371), indicating stable environmental conditions with minimal species dominance. Interestingly, while St-1 showed lower values in other indices, it maintained high evenness, suggesting a relatively balanced distribution of species despite potential reductions in overall diversity. St-1 (0.92904) and St-3 (0.91683) displayed lower evenness, aligning with their performance in other indices.

3.5 Analysis of IVI:

The analysis of important value index (IVI) values across pond study sites, (St-1–St-5) revealed distinct patterns in the distribution of species based on their ecological significance. The IVI serves as an indicator of a species role within the community, considering its abundance, frequency, and dominance. The IVI value of macrophytes species of studied pond are given in the Table 8. The Table 9 illustrates the macrophytes species distribution with their IVI values for each study site of pond, highlighting species as low, intermediate, and high IVI values. The percentage of species among low, intermediate, and high IVI values varied among the study sites of pond, highlighting the diverse ecological roles and dominance of macrophyte species. Macrophytes species with low IVI values such as *Cyperus iria* L., *Hygroryza aristata* (Retz.) Nees ex Wight & Arn., *Cyperus rotundus* L., *Limnophila sessiliflora* (Vahl) Blume., *Typha angustifolia* L., exhibit low abundance, frequency, or dominance across study sites, St-1–St-5, indicating their modest roles in pond macrophytes structure and functioning. Intermediate IVI species, which dominate most of the study sites (St-1–St-5), make up 52–75% of the total macrophyte species community. These species such as *Alternanthera sessilis* (L.) DC. *Nymphoides indica* (L.) Kuntze., *Polygonum glabrum* Roxb., *Potamogeton nodosus* Poir., and *Hydrilla verticillata* (L.f.) Royle., contribute significantly to the stability of pond ecosystems by maintaining biodiversity, habitat provisioning, and food supply for various organisms. High IVI species, like *Nelumbo nucifera* Gaertn., *Eichhornia crassipes* (Mart.) Solms., *Azolla pinnata* R. Br., and *Pistia stratiotes* L., are the most frequent and dominant, playing crucial roles in nutrient cycling, sediment retention, and habitat structuring. The highest IVI (Table 9) was achieved by free floating; *Eichhornia crassipes* (Mart.) Solms (24.45) *Pistia stratiotes* L. (25.12), *Azolla pinnata* R. Br. (22.58) *Ludwigia adscendens* (L.) H. Hara (22.25), followed by rooted with floating leaf; *Nelumbo nucifera* Gaertn. (24.32), *Nymphaeaceae nouchali* Burm.f. (18.24), and emergent; *Ipomoea aquatica* Forrsk. (23.45), *Alternanthera sessilis* (L.) DC. (14.673) whereas, the least IVI scores were attained by emergent *Cyperus difformis* L. (14.55) at different study sites of studied pond.

Table 8
Distribution of macrophyte species with IVI at different sites of studied pond.

S.N.	Name of species	IVI				
		St-1	St-2	St-3	St-4	St-5
1.	<i>Nelumbo nucifera</i> Gaertn.	23.26	20.62	23.54	22.25	24.32
2.	<i>Lemna minor</i> L.	19.24	15.24	20.54	21.54	19.14
3.	<i>Nymphaea nouchali</i> Burm.f.	8.75	15.25	7.25	18.24	22.33
4.	<i>Nymphaea alba</i> L.	3.45	7.12	6.26	8.14	10.88
5.	<i>Pistia stratiotes</i> L.	22.45	15.23	25.12	17.56	16.48
6.	<i>Najas indica</i> (Willd.) Cham.	-	6.12	8.25	14.58	18.25
7.	<i>Trapa natans</i> L.	-	16.14	8.95	18.56	23.45
8.	<i>Ludwigia adscendens</i> (L.) H. Hara	-	16.24	4.58	22.25	25.66
9.	<i>Azolla pinnata</i> R. Br.	-	18.34	6.12	22.58	21.24
10.	<i>Ottelia alismoides</i> (L.) Pears.	-	12.45	-	15.23	17.24
11.	<i>Potamogeton crispus</i> L.	12.45	14.23	-	20.14	-
12.	<i>Ceratophyllum demersum</i> L.	-	3.47	-	6.58	8.46
13.	<i>Hydrilla verticillata</i> (L.f.) Royle	-	11.24	7.66	18.24	-
14.	<i>Hygroryza aristata</i> (Retz.) Nees ex Wight & Arn.	-	3.44	4.65	4.58	-
15.	<i>Hydrocharismorsus-ranae</i> L.	3.46	5.88	7.21	10.25	-
16.	<i>Ipomoea aquatica</i> Forrsk.	-	-	23.45	22.45	22.58
17.	<i>Eichhornia crassipes</i> (Mart.) Solms	24.45	15.46	-	-	-
18.	<i>Typha angustifolia</i> L.	-	-	8.46	9.78	5.58
19.	<i>Polygonum glabrum</i> Roxb.	-	-	15.45	11.33	18.56
20.	<i>Nymphoides cristata</i> (Roxb.) Kuntze	11.34	21.56	22.75	-	21.25
21.	<i>Alternanthera sessilis</i> (L.) DC.	12.45	10.85	-	-	15.46
22.	<i>Ipomoea carnea</i> subsp. <i>Fustulosa</i> (Mart. Ex Choisy) D. F. Austin	-	-	-	8.55	12.45
23.	<i>Utricularia aurea</i> Lour.	-	-	-	9.12	6.30
24.	<i>Hygrophila auriculata</i> (Schumach.) Heine	-	6.45	-	8.14	9.47
25.	<i>Limnophila sessiliflora</i>	-	3.45	-	5.63	6.12
26.	<i>Cyperus iria</i> L.	2.77	-	-	7.33	8.45
27.	<i>Cyperus rotundus</i> L.	-	-	2.65	12.47	14.33
28.	<i>Cyperus difformis</i> L.	11.05	14.55	-	-	10.23
29.	<i>Cyperus compressus</i> Jacq.	11.40	-	-	14.22	12.66
30.	<i>Cyperus polystachyos</i> Rottb.	5.49	4.33	-	-	-
31.	<i>Nymphoides indica</i> (L.) Kuntze	-	-	12.55	20.31	21.22
32.	<i>Potamogeton nodosus</i> Poir.	-	-	-	14.21	12.98
33.	<i>Typha latifolia</i> L.	20.55	-	-	22.44	25.45
34.	<i>Oxalis corniculata</i> L.	7.25	8.33	10.22	-	-
35.	<i>Marsilea quadrifolia</i> L.	8.55	12.25	14.54	-	16.55

Table 9
Categorization and ranges of IVI value of macrophytes in the study sites (St-1 to St-5).

Study sites	Ranges of IVI value	Low IVI value	Intermediate IVI value	High IVI value
St-1	2.77–24.45	<i>Cyperus iria</i> (IVI-2.46)	<i>Alternanthera sessilis</i> (IVI-12.45)	<i>Eichhornia crassipes</i> (IVI-24.45)
St-2	3.44–20.62	<i>Hygrorhiza aristata</i> (IVI-3.44)	<i>Hydrilla verticillata</i> (IVI-11.24)	<i>Nelumbo nucifera</i> (IVI-20.62)
St-3	2.65–25.12	<i>Cyperus rotundus</i> (IVI-2.65)	<i>Nymphoides indica</i> (IVI-12.55)	<i>Pistia stratiotes</i> (IVI-25.12)
St-4	5.63–22.58	<i>Limnophila sessiliflora</i> (IVI-5.63)	<i>Polygonum glabrum</i> (IVI-11.33)	<i>Azolla pinnata</i> (IVI-22.58)
St-5	5.58–24.23	<i>Typha angustifolia</i> (IVI-5.58)	<i>Potamogeton nodosus</i> (IVI-12.98)	<i>Nelumbo nucifera</i> (IVI-24.32)

Discussion

The Physicochemical records of the pond water and macrophyte sample collection at study sites have been able to receive the support of study conducted by Das and Sharma (2022). Our results highlight that there is considerable variability in the aquatic habitat of studied pond. Physicochemical parameters that alter the habitat structures differences among study sites of pond are recognized, as are physiochemical parameters significant that structuring pond macrophytes communities on broad spatial scales (Brazner and Beals, 1997; Loughheed et al., 2001). The strong relations between common macrophyte species and physiochemical parameters of water, potentially impact the changes in aquatic ecosystems (Naiman et al., 1993). The influence of physiochemical parameters of water on aquatic macrophytes plant richness was analyzed in several studies (Oertli et al., 2002, Gee et al., 1997; Jeffries, 1998; Brose, 2001). In general, the availability of physiochemical factors was identified as a primary predictor of species distributions, with pond habitats having the highest macrophyte diversity (Vestergaard and Sand-Jensen, 2000, Heegaard et al., 2001; Murphy, 2002). In the present study, a total of 35 macrophyte species were recorded; these species belong to 23 families, 26 genera and 35 species. A total of 7 submerged macrophytes, namely *Ceratophyllum demersum* L., *Ottelia alismoides* (L.) Pears, *Najas indica* (Willd.) Cham, *Potamogeton crispus* L., *Potamogeton nodosus* Poir., *Hydrilla verticillata* (L.f.) Royle., *Utricularia aurea* Lour and 7 rooted with floating leaf, namely, *Nelumbo nucifera* Gaertn., *Nymphaea nouchali* Burm.f., *Nymphaea alba* L., *Marsilea quadrifolia* L., *Hygrophila auriculata* (Schumacher) Heine., *Nymphoides indica* (L.) Kuntze and *Oxalis corniculata* L.; 7 free floating, namely, *Eichhornia crassipes* (Mart.) Solms, *Lemna minor* L., *Pistia stratiotes* L., *Azolla pinnata* R. Br., *Ludwigia adscendens* (L.) H., *Hara Hydrocharis-morsus-ranae* L. and *Trapa natans* L. and 14 emergent macrophytes species were recorded in Mahendra sagar pond (Table 3). Dennison et al. (1993) supported this finding by studying water quality in the Chesapeake Bay utilizing aquatic submerged plants and reporting that submerged aquatic vegetation serves as an indication of water clarity and pollution level. Physiochemical water parameters regulate the distribution of aquatic macrophytes plants species. Our findings are related to study of Adhishwar and Choudhary (2013) observed 137 macrophytes species related to 50 families in Gogabil wetland, Bihar, India. These free floating species are having a higher capacity to remove large amount of nutrient and fastest growing plant in waste water (Sooknah and Wilkie 2004). It has positive and negative effect on ecosystem and water quality which degrades the water quality and greatly reduced the DO in water bodies. Hence, these free floating species replace the other macrophytes species in pond ecosystem due to better utilization of nutrient present in pond water.

Temperature is another significant physicochemical factor that balances the distribution of macrophytes by affecting the productivity, the species composition, and the ecosystems functioning. It is also dependent on depth, season and geographical position. The water temperature has direct influence on growth and dispersal of aquatic vegetation and aquatic fauna (Jalal and Sanalkumar, 2012; Tank and Chippa, 2013). The results are consistent with the studies by Das et al. (2021). Macrophyte diversity and processes in the ecosystem are directly associated with water quality, so even slight changes in temperature can have an ecological impact (Rameshkumar et al., 2019).

The pH, which regulates the acidic or basic features, is a critical property of any aquatic ecosystem considering all the biochemical functions and retention of physicochemical properties of the water are strongly dependent on the pH of the surrounding environment (Jalal and Sanalkumar, 2013). The majority of such investigations suggested that water samples are somewhat alkaline (Tank and Chippa, 2013; Gopalkrushna, 2011; Verma et al., 2012). When the pH falls below the low level, it can be hazardous and have an impact on the pond water quality. In this study St-1 and St-3 have low pH among the all studied sites this might be cause of low number of macrophyte species in both studied sites. Germ et al., (2021) stated that water body with higher pH of 8.4 supported less macrophyte against the present value of pH (6.1–6.9) could draw certain debate. The pH ranges 6.5–8.2 in studied pond might be within the acceptable limit for the maintenance of an ecosystem as per the work of Bala and Mukherjee 2010; Rameshkumar et al., 2019 and Ljevanak-Masic et al., 2020.

Salinity is the main physical attribute given to biological diversity, which works as a limiting factor and determines the spread of aquatic species (Balasubramanian and Kannan, 2005). The salinity (2.14 ppt) assigned to the biological diversity particularly the distributions of plant species (Sridhar et al., 2006). As per the results of this study higher salinity study sites, St-1 and St-3, effects the macrophytes species diversity and community structure might be significantly alters in concentration of maximum salinity.

In study sites, St-1 and St-3 have higher concentration of conductivity due to these study sites are polluted through urban waste water discharged and human disturbances. Conductivity is an index of the total ionic content of water, and therefore indicates whether the water is pure or not (Acharya et al., 2008). Conductivity measures an aqueous solution's ability to carry an electric current in aquatic surroundings (Lodh et al., 2014).

TDS enters the aquatic systems mainly through various human activities, which explain the highest values observed at St-1 and St-3 and lowest at St-2, St-4 and St-5. The researchers (Bharathi and Krishnamoorthy, 1990; Tripathy and Adhikary, 1990) reported that TDS is proportional to the degree of pollution.

The study clearly revealed that St-1 and St-3 were the most polluted and disturbed sites, with very low dissolved oxygen levels due to two urban sewage drains flowing directly into the pond. However, in this study, the dissolved oxygen levels at the study sites, St-2, St-4, and St-5, were found to be higher than the permitted limit, which has a favorable impact on these pond ecosystems. Oxygen enters the water via aerial diffusion and as a photosynthetic byproduct of aquatic plants (Kotadiya Nimesh and Acharya, 2014). The DO is determined by the temperature, salinity, and depth of the water. DO levels suggest contamination in aquatic bodies (Gopalkrushna, 2011). The BIS/ICMR recommends a minimum DO of 5 mg/l.

Das and Shrivastva (2003) stated that the composition of microscopic organisms, clay, and other organic matter makes a lake turbid. In the present study, the minimum concentration (14.7 ± 1.42 NTU) was recorded at St-5, and the maximum (80.38 ± 3.06 NTU) was recorded at St-1. This finding was supported by Bala and Mukherjee (2010). Thus, the study sites, St-1 and St-3, record maximum turbidity conditions across all the study sites, and this is due to the wastewater discharged and human activities at both study sites.

An inverse relationship was found between the dissolve oxygen concentration and BOD value (Cosgun et al., 1989). It is an indicator parameter to know the presence of biodegradable matter in the wastes water and express degree of contamination. BOD is lower in unpolluted water while it is high in case of polluted water. It depends on temperature, the extent of biological activity, the concentration of organic matter and microbial population such as bacteria and fungi (Yadav et al., 2013). The study highlighted that the environment was reducing due to very low amount of dissolved oxygen at St-1 and St-3 with considerably high amount of BOD at both St-1 and St-3. The values of BOD in pond water ranged from Mean $\pm$ SD value, 5.296 ± 0.51 to 31.752 ± 4.47 mg/l (Table 1). The maximum demand of oxygen in the water was recorded at St-1 and St-3, which is possibly due to addition of high amount of urban waste water containing high amount of organic content in both study sites along with rainwater from the surrounding agricultural fields. Human activities that bring organic waste to ponds may also contribute to a rise in BOD levels. Our study concurred with other studies, particularly when water contamination concerns developed as a result of land use activities, discharged waste water, and urbanization (Mei et al. 2014; Tao et al., 2018). BOD is a key indicator of water quality in Thailand's major rivers (Singkran 2017).

Thus, studied pond has critical water pollution levels at study sites, St-1 and St-3, indicating high organic matter content and oxygen depletion where waste water sewage meet to pond water, which is very harmful for macrophytes species in pond ecosystem. The low pH (< 7) suggested that acidic water conditions at study sites, St-1 and St-3, potentially due to effluents of urban waste water discharged. The higher BOD (> 6) at study site, St-1 and St-3, indicates excessive organic pollutants, likely from untreated sewage effluents, agricultural runoff. The study sites, St-1 and St-3 were recorded very low value DO (Table 1) reflects oxygen depletion, threatening aquatic life such as culturing of fish and other fauna, frequently caused by organic waste decomposition. The Pond show low DO level and higher BOD which indicates organic pollution at study sites, St-1 and St-3. According to study of, Achieng et al., (2017) found that urban waste water sewage, particularly in crowded areas located along the water source, are often directly discharged into water sources and deteriorate water quality. The discharges of domestic effluents, sewage, and agricultural runoff have the main cause of unsuitable water qualities of pond in present study. Padmanabha (2017) reported that the WQI of lentic ecosystem is higher than the lotic ecosystem in general indicated that water quality of standing water to be deteriorated more than the running water in Mysuru, India. This is in corroborated with our findings in present study.

Several researchers (Penning et al., 2008; Sondergaard et al., 2010; Poikane et al., 2015) reported that macrophyte species are important structural components and indicators of freshwater water bodies, and their presence and species composition depend on the physicochemical parameters of the water. Variations in macrophyte species is affected by changing environmental conditions (Rooney and Kalff, 2000; Silva et al., 2010). Aquatic macrophytes not only play a crucial role in ensuring the longevity of aquatic ecosystems, but they also absorb various dissolved nutrients such as nitrogen and phosphorus from polluted water, which helps to maintain ecosystem resilience. The study of macrophytes provides useful knowledge while also maintaining a healthy aquatic environment. The estimated WQI was around 100.25, 88.13, 105.92, 93.09 and 94.87 for study sites, St-1, St-2, St-3, St-4 and St-5, respectively. The study sites, St-1 and St-3, have very low macrophyte species diversity due to the presence of urban wastewater, sewage and anthropogenic activities. The study sites, St-1 and St-3 has very poor water quality due to very high WQI which are 100.25 and 105.92, respectively. This finding was confirmed by other observation of Thakor et al., (2011); Jena et al., (2013) and Korgaonkar et al., (2014). In the WQI variation analysis, it was found that submerged macrophyte species were absent in ST-1, where only 2 out of 7 expected species were recorded. Denison et al. (1993) stated that submerged aquatic vegetation is an indicator of water clarity and nutrient levels in a pond ecosystem. A statistical analysis was conducted using correlation analysis of the water quality parameters. The findings demonstrated that the dissolved oxygen (DO) and pH are strongly correlated and, hence, organic pollutants play a significant role in determining oxygen demand in the pond ecosystem. Furthermore, the total dissolved solids (TDS) and the conductivity had a significant positive relationship meaning that it was contaminated by the agricultural runoff and household wastes. Generally, this study has demonstrated that statistical techniques are helpful in the provision of meaningful information concerning the trends of pollution patterns and therefore, it is significant in effective monitoring and management of water quality. The distribution, abundance and diversity of macrophytes presented a positive association with the water turbidity (Dar et al., 2014), pH and DO (Ondiba et al., 2018) as well as conductivity (Dorotovicova, 2013) also evident in this study. Enhanced conductivity (Table 2) at St-1 and St-3 could be evaluated as an integration of several factors, which might be the reflection of human activities (Epele et al., 2018). A positive correlation between the water temperature, pH and DO with species like *Potamogeton crispus* L. (S), *Lemna minor* L., *Azolla pinnata* L., *Cyperus compressus* Jacq. are shown in (Table 2 and Fig. 4).

In comparison to Raunkiaer's law of frequency classes (1934), the pond study sites St-2, St-4, and St-5, revealed heterogeneous vegetation structures, consistent with similar research conducted in the Hokersar wetland in the Kashmir Himalaya (Mir et al., 2009). The study site, St-5 displayed an even species

distribution, suggesting a more stable ecosystem likely resulting from balanced environmental conditions and minimal extreme of disturbances. Similarly, study sites, St-4 and St-2 showed better degree of balance, contributing to ecological resilience. The importance of species distribution and evenness for ecosystem stability in pond is further emphasized by the work of Malson et al. (2008). Their study on rich fens vegetation revealed that sewage drainage significantly reduced biodiversity, while the slow recovery observed to make wet the critical role of maintaining evenness for ecosystem resilience. On the contrary, the study sites, St-1, and St-3 exhibited complex patterns of species dominance and potential instability, with deviations from Raunkaier's normal frequency class law. Exceptionally, study sites St-1 and St-3 exhibited notable species dominance, with St-1 showing a higher frequency in class B than Raunkaier's normal frequency, while St-3 displayed a decrease in class A, increases in classes B and C, and a very minute of class E. These patterns suggest less stable ecosystems facing extreme conditions and competitive interactions. The analysis reveals the complex interplay of environmental factors, competitive interactions, and ecosystem stability in these water bodies, emphasizing the utility of Raunkaier's frequency classes in understanding pond ecosystems and the importance of conservation efforts to maintain species evenness for long-term ecosystem stability. The high-frequency species like *Eichhornia crassipes* (Mart.) Solms, *Alternanthera sessilis* (L.) DC., and *Azolla pinnata* R. Br. demonstrate adaptability to various conditions. The abundance of *Nymphoides cristata* (Roxb.) Kuntze and *Nymphoides indica* (L.) Kuntze aligns with study of Preston and Croft's (2022) findings on species with effective reproductive strategies. The high frequencies of *Pistia stratiotes* L. and *Potamogeton crispus* L. may indicate nutrient enrichment (Guntenspergen et al., 2020), potentially due to waste water sewage discharge. The species range reflects pond ecosystem complexity, with high-frequency species shaping habitats and supporting ecosystem functions, while low-frequency species contribute to biodiversity and resilience (Mishra et al., 2016).

The diversity indices revealed distinct patterns of species diversity and ecological dynamics within this pond ecosystem. The analysis of four different biodiversity indices across five study sites, St-1 to St-5 of pond provides a comprehensive understanding of ecosystem health, species richness, and distribution patterns. The high diversity index represents the positive condition of pond as because of lower pollution percentage at St-2, St-4 and St-5 and fewer disturbances in compared to urban waste water discharged at St-1 and St-3. The St-1 and St-3 DMg higher values likely reflect optimal environmental conditions and effective conservation efforts, aligning with the diverse and healthy ecosystems observed in Lake Alakol (Zaparina et al., 2024). This gives an opportunity to the macrophytes for better growth and development but dominance of free floating macrophyte species which reduce the biodiversity (Qi et al., 2021; Li et al., 2021). These findings are consistent with Zhao et al. (2021), who reported that farmland abandonment positively influences evenness by transitioning plant communities from annual to perennial species. The combined analysis of these four biodiversity indices explores complexities of the five study sites of pond ecological health. The study site, St-5 emerges as the most diverse and stable ecosystem due to St-5 is comparably away from study site, St-1 and St-3, followed closely by St-4, and St-2. So, study site, St-2, St-4 and St-5 is not polluted very much. The St-1 and St-3 consistently show signs of ecological stress across all indices, indicating they are prime candidates for intensive conservation and restoration efforts. These results support study findings indicating that macrophyte management improves biodiversity by regulating water temperature, pH, and DO (Molnár et al. 2011; Chen et al. 2020; Dimitrov and Mollov 2022). The relatively low diversity in St-1 and St-3 is probably due to their proximity to urban settlements, where wastewater and sewage enter the pond. This will likely lead to pollution and disturbance, reducing the availability of suitable habitats for macrophyte colonization in these sections. Similar observations were reported in related studies by da Silva et al., 2020 and Stoler et al., 2018.

The IVI of each macrophyte species of the studied pond reveals significant patterns in species composition and ecological importance (Mori et al., 2015). The findings indicate a clear stratification of species based on their IVI values: Low IVI species, such as *Cyperus iria* L., *Hygroryza aristata* (Retz.) Nees ex Wight & Arn., *Cyperus rotundus* L., and *Limnophila sessiliflora* (Vahl) Blume, exhibit limited ecological roles but contributed to overall biodiversity (Junk et al., 2013). The majority of species, comprising 52–75% across study sites (St-1-St-5), demonstrated intermediate IVI values. These species, including *Ipomoea aquatica* Forrsk., *Hydrilla verticillata* (L.f.) Royle, *Alternanthera sessilis* (L.) DC., *Polygonum glabrum* Roxb. and *Nymphoides indica* (L.) Kuntze, play crucial roles in maintaining ecological stability and highlight the complexity of pond wetland ecosystems. The main particular concerns are the high IVI species, approximately 15 in total, including *Alternanthera sessilis* (L.) DC., *Eichhornia crassipes* (Mart.) Solms, and *Pistia stratiotes* L., which emerge as key invasive components of the pond ecosystems (Zedler and Kercher, 2005). These dominant species, while indicative of successful adaptation to the pond environment, raise concerns about their potential negative impacts on native biodiversity and ecosystem functions, required careful monitoring and management strategies. Emergent species dominated the wetland, followed by submerged, rooted floating-leaves, and free-floating growth types, consistent with previous studies (Junk et al., 2013). This pattern suggests possible modification of pond, water bodies into terrestrial habitat (Mitsch and Gosselink, 2015). While IVI provides valuable insights, it has limitations in capturing the functional roles of less abundant species (Frieswyk et al., 2007). The study emphasizes the need for balanced management approaches that consider both high and low IVI species to maintain biodiversity and ecosystem resilience (Zedler and Kercher, 2005). This analysis provides a comprehensive understanding of pond wetland plant community structure and species importance, highlighting the need for accurate, adaptive management approaches. The IVI value of macrophytes species is necessary to monitoring and integration of functional trait analyses with IVI data to gain deeper insights into ecosystem processes and community assembly mechanisms in these pond ecosystems. For instance, rare submerged species such as *Ottelia alismoides* (L.) Pears. are noteworthy, as they are often easily affected by water quality and habitat changes (Carpenter and Lodge, 1986). Their low abundance could indicate ecosystem stress, possibly from urbanization and sewage disposal pollution in pond study sites, St-1 and St-3. Elo et al. (2018) examined how environmental parameters and human activities affect aquatic macrophyte diversity and rarity. Salgado et al. (2023) found that conservation area enhances native aquatic macrophyte biosecurity and prevent spread of invasive species. Monitoring and managing impact of invasive species like *Eichhornia crassipes* (Mart.) Solms on rare species populations is crucial for maintaining ecological balance.

A site-specific analysis of pond macrophytes in the investigated pond (number of species) depending on habitat conditions found that the greatest number of species (35 species) were seen during the study period. The study found a greater number of macrophyte species at St-5. Although comparative research on the plant community makeup of different sites within ponds are sparse, they appear to support our findings. However, the majority of studies similar to this one are not site-specific and do not provide a complete picture of species diversity, abundance, or distribution across many places. In contrast, the current work provides a more comprehensive understanding of species distributions and diversity in the examined pond ecosystem through multi-site investigation of physicochemical variables and aquatic macrophyte communities.

Conclusions

Based on communities' structure, emergent macrophytes are dominant with Cyperaceae family, followed by the Hydrocharitaceae and other families. The physiochemical characteristics of water at analyzed sites showed a positive correlation with temperature, pH, and DO, but a negative correlation with salinity, turbidity, conductivity, pH, BOD, and TDS. Water quality parameters have a direct impact on aquatic macrophytes or vegetation, as evidenced by the pond's water quality index. Urban waste water sewage discharge and human activities at study sites St-1 and St-3 also contribute to varying water quality levels. High-frequency species such as *Eichhornia crassipes* (85.71% in St-1) and *Pistia stratiotes* (57.14% in St-3) demonstrated resilience across diverse habitats, while low-frequency species like *Limnophila sessiliflora* (14.29% in St-4) were limited to specific areas due to habitat sensitivity. Raunkiaer's frequency analysis indicated a dominance of Class B species in most pond study sites, particularly St-1 (64.52%), while St-3 exhibited signs of disturbance with a higher proportion of Class A species (52%) and fewer in Classes C and E. The pond study site, St-5 had the highest biodiversity ($H = 3.4968$) and richness ($DMg = 5.08069$), while St-1 had the lowest values, and St-4 showed the highest evenness ($J = 0.96965$), indicating ecological stability. Intermediate IVI species dominated most study sites (52–75%), with *Eichhornia crassipes* ($IVI = 20.72$) prominent in St-1, and *Cyperus iria* ($IVI = 2.46$) less so. This study provides essential baseline data for developing targeted conservation strategies to address ecological stress in urban pond (St-1 and St-3). Furthermore, this study demonstrates that underwater aquatic vegetation is an indicator of water quality parameters, despite the need for specific adaption methods to preserve water quality for long-term domestic purposes. It emphasizes macrophytes' critical role in maintaining ecosystem services, as well as their usefulness in wetland conservation and biodiversity management. The current work provides vital new insights on macrophyte diversification in urban aquatic ponds by shedding light on differences in species richness, abundance, and ecological features. It emphasizes the significance of urban aquatic ponds in sustaining and expanding biodiversity.

Declarations

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Author's contributions:

Conceptualization, JKS, SB and SK; methodology, DCV; data collection, JKS, AA and SK; formal analysis, JKS, SB and SK; manuscript preparation—original draft preparation, JKS, DM and SK; supervision, VKU, MK and LP; visualization; writing—review and editing, VKU, MK, and DM; Correlation coefficient; AD and RMA. All authors have read and agreed to the published version of the manuscript.

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Data availability:

Data collected for this manuscript is in this research cannot be accessed publicly due to privacy concerns. However, interested person or authority can request access to the data from corresponding author and such requests will be reasonably considered.

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Figures

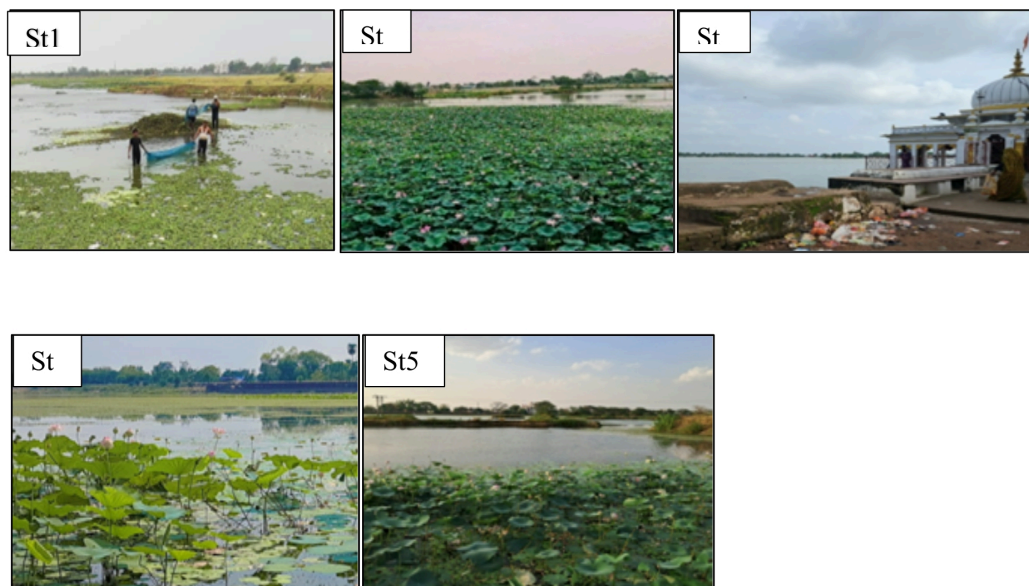
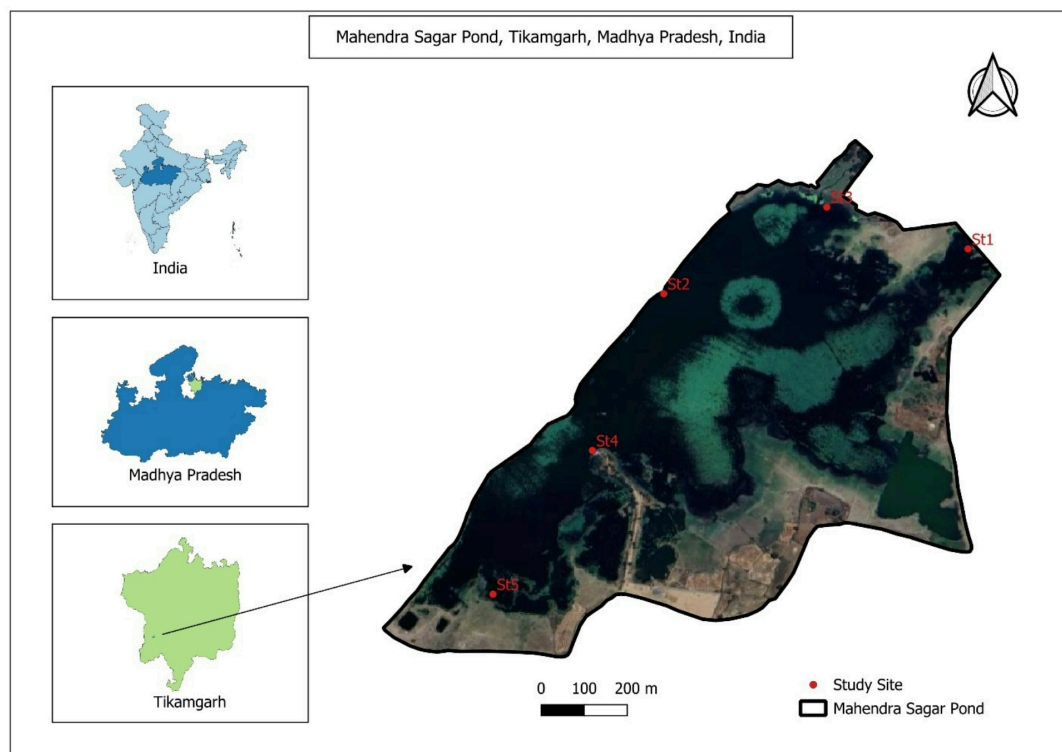


Figure 1

Study area map and sampling sites (St1-St5) of Mahendra Sagar Pond



Figure 2
Some macrophyte species of Mahendra Sagar Pond, **a.** *Azolla pinnata*, **b.** *Pistia stratiotes*, **c.** *Trapa natans*, **d.** *Ipomoea carnea*, **e.** *Ludwigia adscendens*, **f.** *Nelumbo nucifera*, **g.** *Cyperus difformis*, **h.** *Nymphoides indica*, **i.** *Polygonum glabrum*, **j.** *Najas indica*, **k.** *Nymphaea alba*, **l.** *Nymphaea nouchali*, **m.** *Lemna minor*, **n.** *Potamogeton crispus*, **o.** *Hydrilla verticillata*

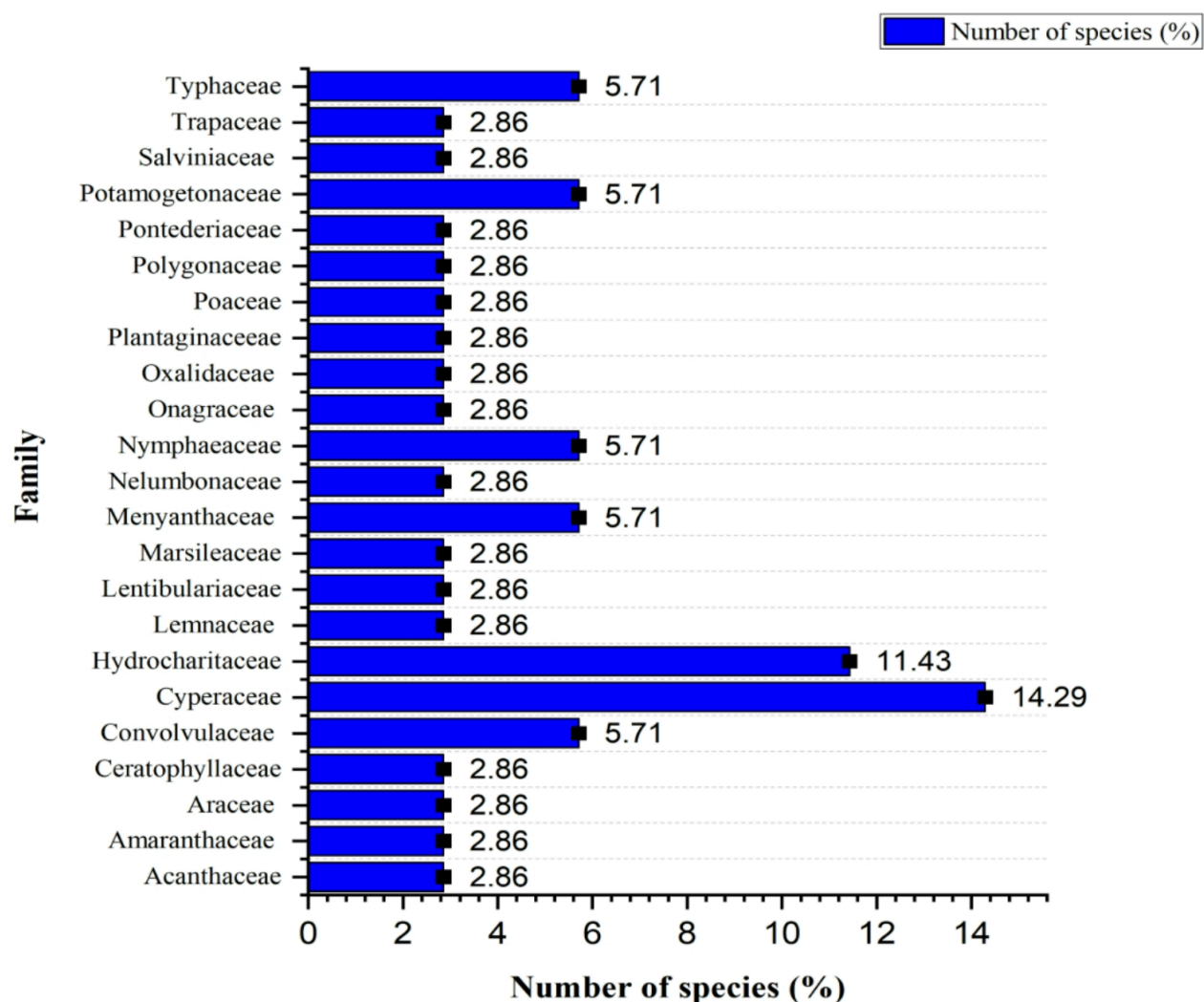


Figure 3

The dominant plant families of Mahendra Sagar Pond

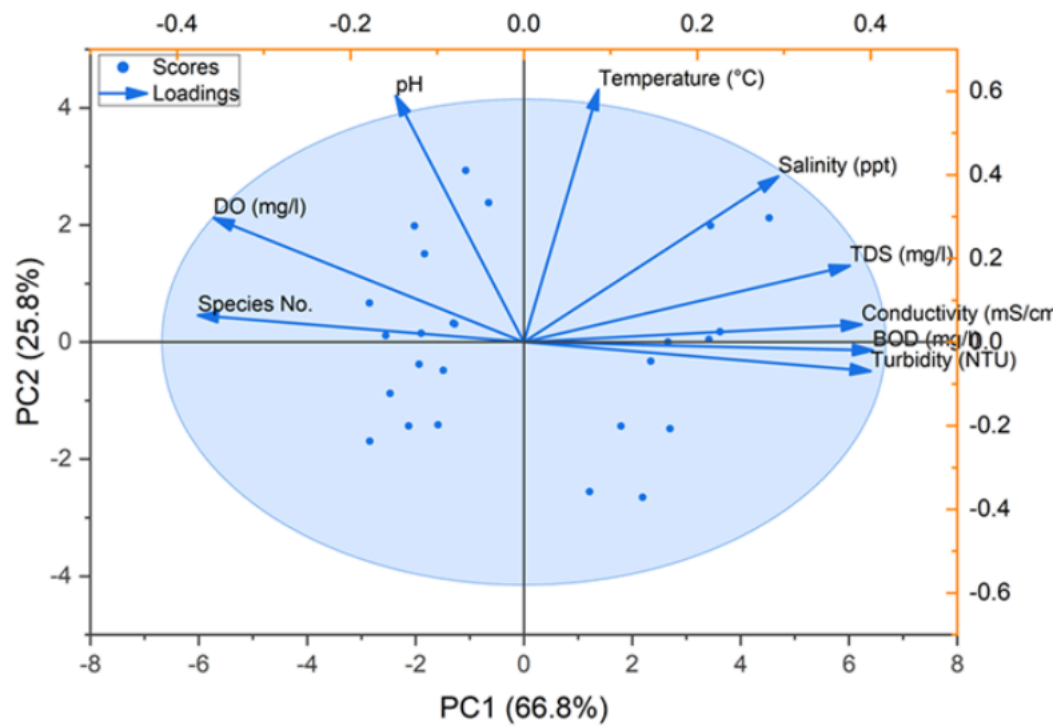


Figure 4

Principal component analysis of physiochemical parameters and macrophytes species richness.

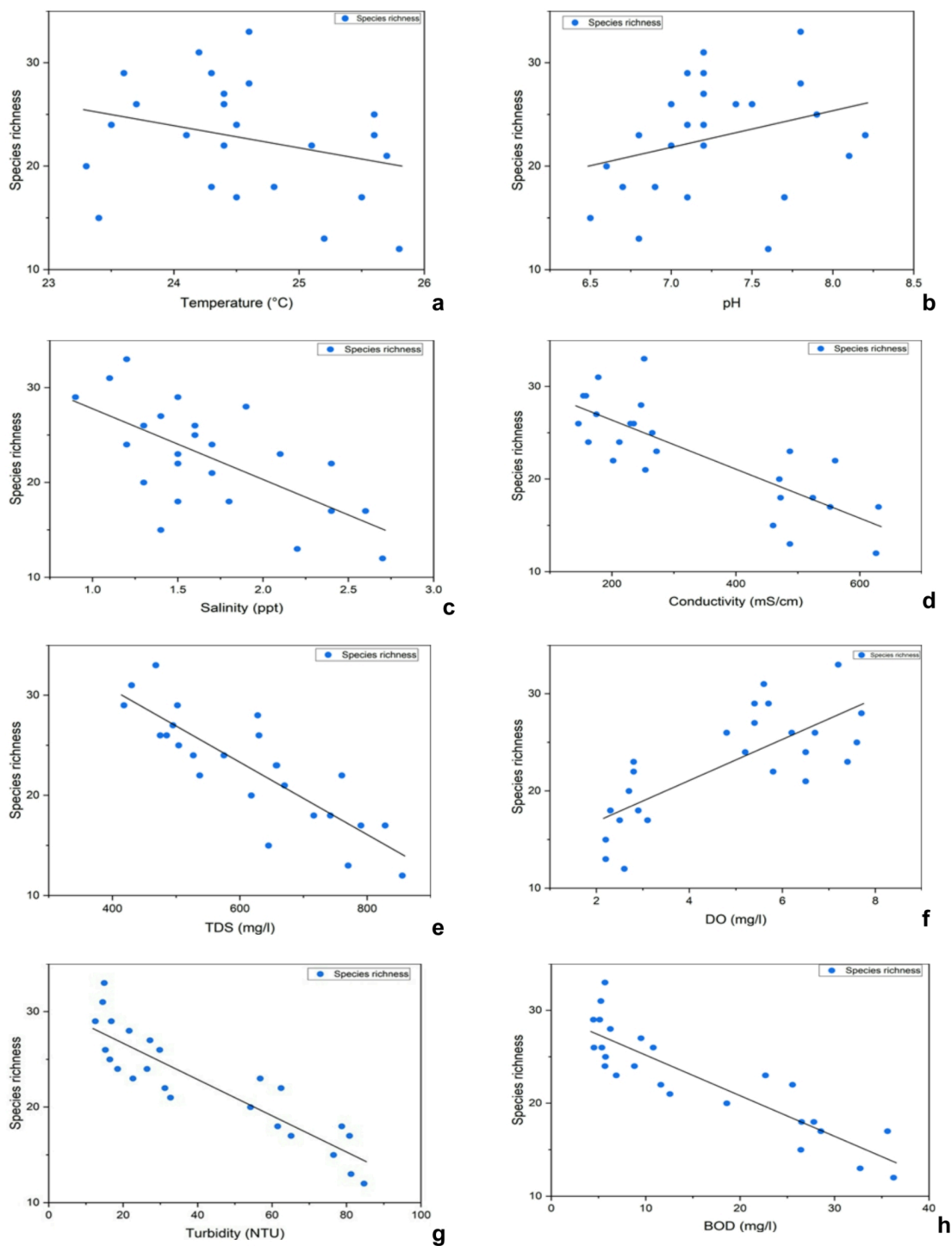


Figure 5

Figure 4: Graphs showing the relation between macrophytes species richness and water parameters; **a**-Temperature vs macrophyte species, **b**-pH vs macrophyte species richness, **c**-Salinity vs macrophyte species richness, **d**-Conductivity vs macrophyte species richness, **e**-TDS vs macrophyte species richness, **f**- DO vs macrophyte species richness, **g**-Turbidity vs macrophyte species, **h**-BOD vs macrophyte species richness.