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Ecological Assessment of Water Quality and Aquatic Biodiversity in Macferson Lake, Prayagraj, Uttar Pradesh

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A B S T R A C T

In this study, the physico-chemical parameters as well as the biological diversity of Macferson Lake, Allahabad (Prayagraj), Uttar Pradesh, India was studied during the period June, 2022 to May 2023. Seasonal sampling covered the inspecting of temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolve solids (TDS), electrical conductivity (EC), hardness and alkalinity and other parameters. Simultaneous biological studies determined phytoplankton, zooplankton, benthic macro invertebrates, fishes and aquatic macrophytes. The outcomes showed moderate and poor quality of water, demonstrating the eutrophication process, and the presence of *eichhornia crassipes* as well as fish and invertebrates resistant to pollution. Possible strategies of conserving and restoring lakes are then mentioned.

1 Introduction

Lakes are the key ecosystems which maintain ecological balance, protect biodiversity, and provide essential resources to human civilization. They serve as natural water reservoirs that help regulate local microclimates, recharge groundwater, control floods, and offer habitats for diverse aquatic flora and fauna (Gopal, 2016). In addition, lakes contribute to economic development, recreation, and cultural traditions across both urban and rural areas (Trisal & Kumar, 2008). However, rapid urbanization, uncontrolled discharge of wastes, and increasing anthropogenic activities have led to severe degradation in water quality and the loss of habitat diversity in many Indian urban lakes (Kumar & Chopra, 2012; Reddy & Char, 2006). These impacts highlight the urgent need for sustainable lake management and conservation practices (Singh & Mathur, 2005). Macferson Lake, located in the urban area of Allahabad (presently Prayagraj), Uttar Pradesh, represents a typical example of an urban freshwater ecosystem. In the past, this lake served as a source of recreation and aesthetic beauty while supporting migratory birds and diverse aquatic life (Singh et al., 2010). However, over the last few decades, it has been subjected to continuous pollution, encroachment, and biological invasion, primarily due to rapid urbanization, human settlement expansion, and the discharge of untreated sewage (Kumar & Chopra, 2012). Such anthropogenic pressures have severely affected the ecological integrity of the lake, resulting in nutrient enrichment, excessive algal blooms, and the proliferation of invasive species such as *Eichhornia crassipes* (water hyacinth) (Reddy & Char,

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2006). Consequently, these activities have further deteriorated the overall water quality and ecological health of Macferson Lake (Gopal, 2016).

The physico-chemical parameters measured included dissolved oxygen (DO), pH, biochemical oxygen demand (BOD), total dissolved solids (TDS), and nutrient concentrations, which are essential indices for the ecological assessment of lake ecosystems (Wetzel, 2001). A comprehensive understanding of aquatic health is achieved when these parameters are evaluated alongside biological variables such as plankton diversity, benthic fauna, and fish populations (APHA, 2017). Aquatic macrophytes and higher trophic-level organisms respond sensitively to environmental changes, thereby serving as effective bio-indicators for assessing ecosystem integrity and trophic status (Mishra & Saksena, 1993; Rai & Hill, 2012).

The growing challenges associated with modern water-resource management have emphasized the importance of a sound and comprehensive assessment of freshwater ecosystems (Wetzel, 2001). To address this, the present study adopts a multifactor characterization approach for Macferson Lake, integrating analyses of both physico-chemical properties and biotic composition. The primary objectives of the study are: (1) to map the seasonal trends in water quality, (2) to inventory and document the aquatic flora and fauna, and (3) to evaluate the biodiversity status using ecological indices (APHA, 2017; Mishra & Saksena, 1993). The resulting dataset aims to provide a scientific foundation for policymakers, conservation experts, and local stakeholders to develop evidence-based strategies for the restoration and sustainable management of the lake (Rai & Hill, 2012).

2 Materials and Methods

2.1 Study Area

The Macferson Lake is located at latitude 25.45° N and longitude of 81.85° E. The lake having a size of about 2.5 hectares is enclosed on all its sides by a combination of residential and institutional development. The reservoir is fed by runoff of other landscapes and the levels and concentration of nutrients in the water changes seasonally.

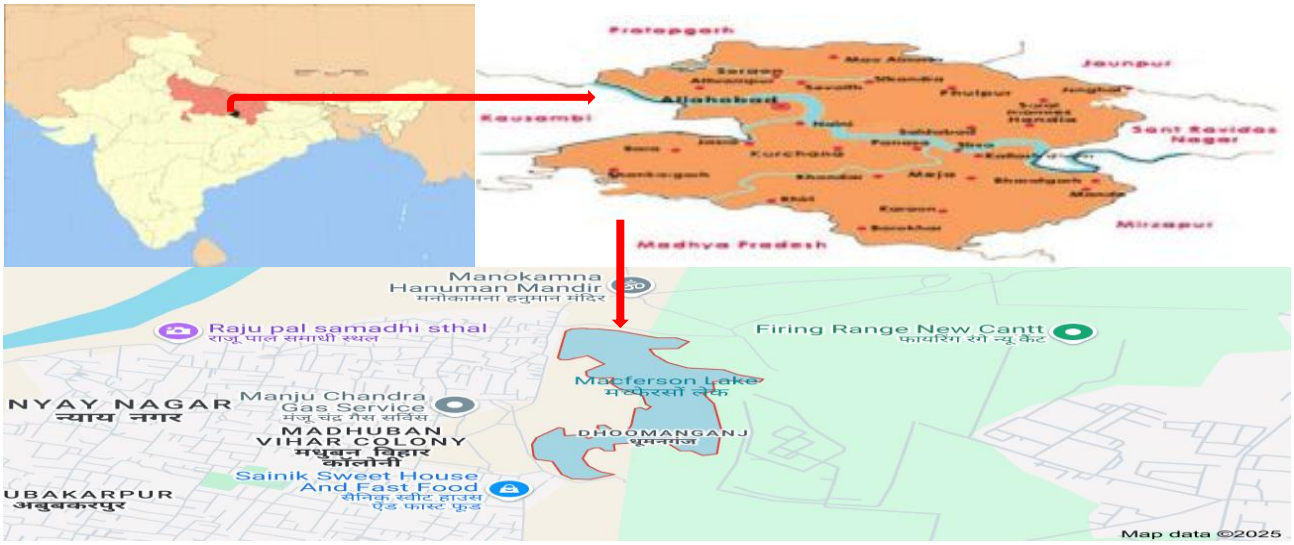

Fig.1: Map of Macferson Lake Pryagraj, Uttar Pradesh, India

2.2 Sample Collection

Water and biological samples were collected from five designated sampling sites distributed around Macferson Lake during the pre-monsoon, monsoon, and post-monsoon seasons. Water samples were stored in sterile containers and analyzed within twenty-four hours of collection to ensure accuracy and prevent degradation (APHA, 2017). Plankton communities were sampled using standard plankton nets, while benthic macroinvertebrates were collected with an Ekman

dredge following standard limnological procedures (Wetzel, 2001). Fish population data were obtained through cast-net sampling, supplemented by structured interviews with local fishermen to validate species occurrence and abundance (Jhingran, 1991) Standard methods (APHA, 2017) were used to analyze.

2.3 Physico-chemical Analysis

Table: 2.1 Physico-chemical Parameter to be analyzed for Macferson Lake Prayagraj, Uttar Pradesh, India

S. No.	Parameters	Unit	Methods
1.	**Temperature**	°C	Digital thermometer (APHA, 2017)
2.	**EC**	µS/cm	Digital conductivity meter (APHA, 2017)
3.	**pH**	-------	Digital pH meter (APHA, 2017)
4.	**DO**	mg/L	Winkler method (Trivedy & Goel ,1986)
5.	**BOD**	mg/L	5-day incubation (APHA, 2017)
6.	**TDS**	mg/L	Digital conductivity meter (APHA, 2017)
7.	**Total hardness**	mg/L	Titration methods (APHA, 2017)
8.	**Alkalinity**	mg/L	Titration methods (APHA, 2017)
9.	**Chloride**	mg/L	Titration methods (NEERI, 1986)

2.4 Biological Analysis

In the present study, aquatic macrophytes were identified using standard floristic keys and manuals (Subramanyam, 1962; Cook, 1996). Plankton samples were collected using plankton nets with mesh sizes of 20 µm for phytoplankton and 60 µm for zooplankton, respectively. Benthic macroinvertebrates and fish communities were identified and classified following standard taxonomic literature and field guides (Ward & Whipple, 1959; Talwar & Jhingran, 1991). The Shannon–Wiener Diversity Index (Shannon & Wiener, 1963) and Simpson's Diversity Index (Simpson, 1949) were employed to quantify the community diversity and assess the biological health of the ecosystem

3 Results

3.1 Physico-chemical Parameters

Table: 3.1 Physico-chemical Parameters of Macferson Lake Prayagraj, Uttar Pradesh, India

Parameter	Pre-monsoon	Monsoon	Post-monsoon	CPCB Limits
Temperature (°C)	28.5	26.0	22.7	-
pH	7.8	7.5	7.6	6.5–8.5
DO (mg/L)	4.2	5.0	4.6	>5
BOD (mg/L)	8.1	6.5	7.3	<3
TDS (mg/L)	480	400	450	<500
EC (uS/cm)	670	580	630	-
Hardness (mg/L)	220	210	215	200-600
Alkalinity (mg/L)	190	180	185	200

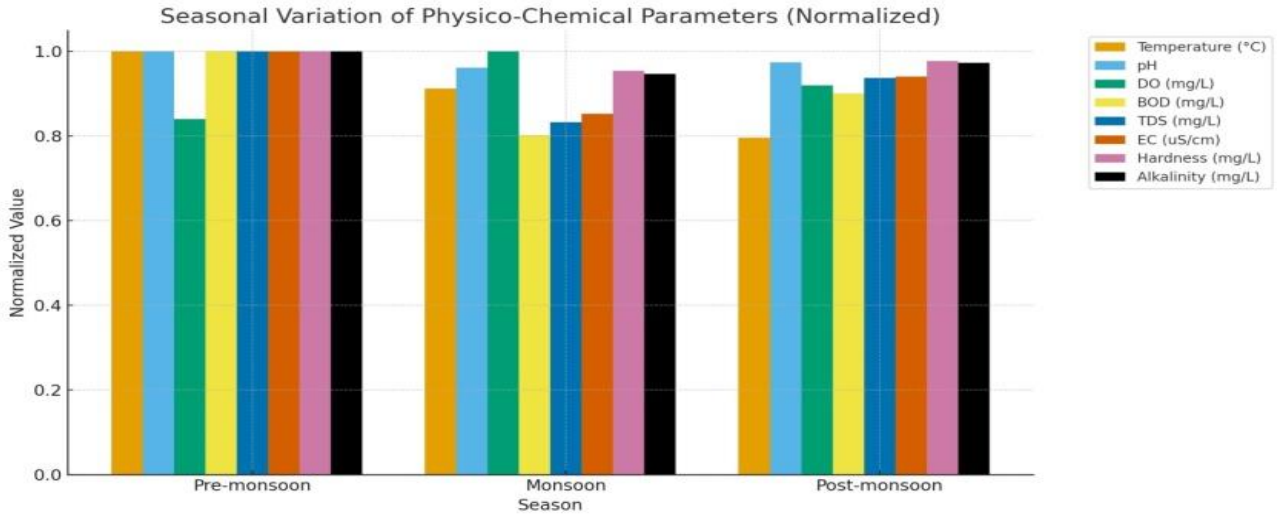

Fig.2. Seasonal Variation of Physico-Chemical Parameter

The findings obtained in the present study indicate moderate levels of pollution in Macferson Lake. The recorded biochemical oxygen demand (BOD) values exceeded the standard permissible limits, suggesting the presence of organic pollution likely originating from domestic sewage and anthropogenic runoff. Although the dissolved oxygen (DO) concentrations were observed to be near the threshold levels required for sustaining aquatic life, the decline in oxygen availability is sufficient to stress sensitive aquatic organisms and alter community composition (Trivedy & Goel, 1986; Wetzel, 2001). These results highlight the progressive deterioration of water quality and the onset of eutrophication, a process that may worsen without effective management and restoration measures. The aquatic animal in lake was also responsible for higher BOD which is also consuming DO for respiration (Mishra et al. 2017).

3.2 Biological Indicators

3.2.1 Plankton Diversity

Plankton constitute invaluable ecological indicators in assessing the quality of aquatic ecosystems due to their fundamental role in energy transfer and nutrient cycling, forming the base of the aquatic food web (APHA, 2017). Monitoring of planktonic communities in Macferson Lake revealed higher species diversity and density during the monsoon and post-monsoon periods, which can be attributed to increased nutrient inflow and eutrophication processes. A notable dominance of cyanobacteria (blue-green algae) and rotifers was recorded, groups typically associated with nutrient-enriched and polluted systems (Mishra et al., 2015). These findings suggest that the lake exhibits characteristics of a eutrophic water body, where excessive nutrient loading stimulates algal blooms and disrupts ecological balance.

Table: 3.2 Different types of Groups and Dominant Species found in Macferson Lake Prayagraj, Uttar Pradesh, India

Group	Dominant Species	Ecological Significance
Phytoplankton	*Oscillatoria*	Cyanobacteria; nitrogen fixer; blooms
	Anabaena	Cyanobacteria; indicator of eutrophication
	Scenedesmus	Green algae; found in organic-rich water
	Microcystis	Toxin-producing; indicative of pollution
Zooplankton	*Brachionus*	Rotifer; pollution tolerant
	Cyclops	Copepod; intermediate pollution level
	Keratella	Rotifer; moderately tolerant

The abundance of *Oscillatoria* and *Microcystis* species within the phytoplankton community, along with the dominance of rotifer species among the zooplankton, clearly indicates a highly eutrophic and organically polluted condition of the lake. The proliferation of cyanobacteria such as *Microcystis* and *Oscillatoria* is typically associated with nutrient enrichment (particularly nitrogen and phosphorus), leading to oxygen depletion and anoxic zones in the water column (Wetzel, 2001; Edmondson, 1991). The dominance of rotifers further supports the organic pollution status and signifies the alteration of the trophic structure due to excessive nutrient load.

Although moderate eutrophication can enhance fish recruitment and primary productivity, excessive eutrophication disrupts ecosystem stability, leading to decline in biodiversity, fish kills, and loss of ecological integrity in the aquatic environment (Schindler, 2006).

3.2.2 Benthic Macroinvertebrates

Table: 3.3 Benthic Macroinvertebrates found in Macferson Lake Prayagraj, Uttar Pradesh, India

Species	Group	Indicator Role
Tubifex tubifex	Oligochaete worms	High pollution tolerance
Chironomus larvae	Dipteran insect	Moderate pollution
Lymnaea spp.	Gastropod	Moderate tolerance

3.2.3 Fish Diversity

Table: 3.4 Fish Diversity found in Macferson Lake Prayagraj, Uttar Pradesh, India

Species	Common Name	Abundance	Tolerance Level
Oreochromis mossambicus	Tilapia	High	Tolerant
Cyprinus carpio	Common Carp	Moderate	Tolerant
Catla catla	Catla	Low	Sensitive

3.2.4 Aquatic Macrophytes

Table: 3.5 Aquatic Macrophytes found in Macferson Lake Prayagraj, Uttar Pradesh, India

Species	Type	Abundance (%)
Eichhornia crassipes	Floating	45
Typha angustata	Emergent	25
Hydrilla verticillata	Submerged	15
Lemna minor	Floating	5
Pistia stratiotes	Floating	10

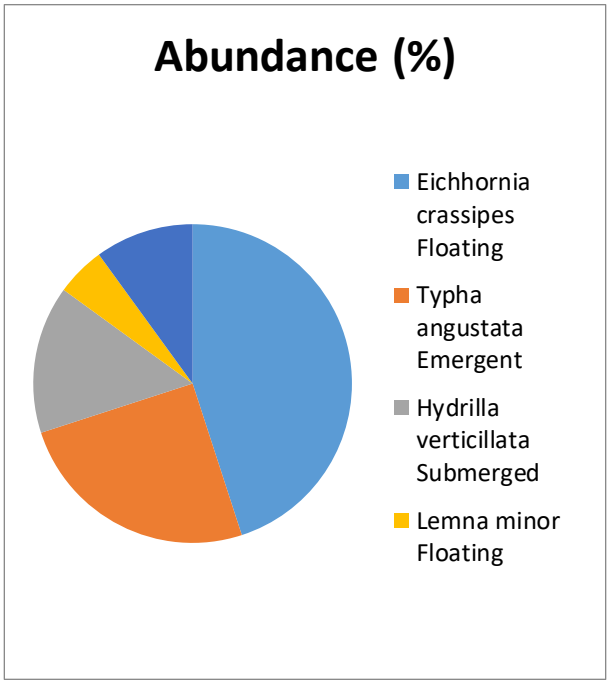

Fig.3: Abundance of Species in Aquatic Macrophytes

The ecological conditions are deteriorating as they are characterized by the wide spreading of Eichhornia crassipes as well as introduction of fish and invertebrate species which are pollution tolerant.

3.2.5 Biodiversity Indices

Biodiversity indices are quantitative measures that help assess the variety and abundance of species in an ecosystem. Two commonly used indices in this study are:

Table: 3.6 Biodiversity Index are found in Macferson Lake Prayagraj, Uttar Pradesh, India

Index	Formula	Value	Interpretation
Shannon-Wiener Index (H')	H' = -Σ(pi * ln pi)	1.87	Low diversity, dominance by few species
Simpson's Index (D)	D = 1 - Σ(pi²)	0.62	Moderate dominance, reduced evenness

Where ***pi*** = proportion of individuals of species ***i*** = relative to total individuals.

Shannon-Wiener Index (H'): The diversity index value reflects both the number of taxa present and the evenness in their relative abundance. A higher index score generally indicates greater species richness and higher ecosystem stability, while a lower score implies ecological stress or imbalance. In the present study, the Shannon-Wiener diversity index value of 1.87 suggests a low level of species diversity, which may be attributed to pollution-induced stress and the dominance of a few pollution-tolerant species. Such low diversity levels are typical in eutrophic or organically enriched systems, where only resistant taxa can survive and proliferate under degraded water quality conditions (Magurran, 2004; Odum & Barrett, 2005).

Simpson's Diversity Index (D): The P_1P_2 index represents the probability that two randomly selected individuals from a given population belong to different species. It is an important measure of species diversity and dominance within an ecosystem. In the present study, the calculated value of P_1P_2 = 0.62 indicates a moderate level of dominance, suggesting the presence of a few dominant species and a reduced overall diversity—a condition typically observed in stress-strained or eutrophic ecosystems. In contrast, a low P_1P_2 value (e.g., 0.02) signifies that most species are evenly represented, reflecting a stable, oligotrophic environment with minimal ecological disturbance (Pielou, 1975; Wilhm & Dorris, 1968).

In addition to the fact that biological indices can be useful in comparing biodiversity over seasons or between places, the indices are critical tools in ecological monitoring, including restoration design.

4. Recommendations

Results of the current research make it necessary to draw up a set of recommendations that may be introduced to optimize the ecological state of the Macferson Lake and restore its integrity. To begin with, it is necessary to establish a long-term monitoring programme that will allow following temporal changes in water quality and biotic characteristics. This comes at a time when such a programme must be aligned with a larger regional monitoring network to enable the provision of contextual information and allow cross-site comparisons. Second, the processes that determine the functioning of lentic ecosystems can also be better explained by using quantitative models ideally in conjunction with observations made on field. Models which directly take into account hydrological, trophic and discharge-induced processes would be specifically useful. Third, there is a need to carry out specific measures aimed at reducing anthropogenic stressors, namely, a decrease in phosphorus loads and the minimization of nutrient loads. The ones that will have the greatest impact are strategies that involve the stakeholders and rewards pro-environmental behaviors.

Pollution Control Measures:

Stop the discharge of untreated domestic sewage and urban runoff into the lake.

Establish decentralized wastewater treatment systems near the lake's catchment area.

Aquatic Weed Management:

Mechanical removal and biological control of invasive species like *Eichhornia crassipes* and *Pistia stratiotes*.

Encourage the growth of native submerged and emergent macrophytes to restore ecological balance.

Aeration and Desiltation:

Install aeration units to improve dissolved oxygen levels.

Periodic desilting to remove nutrient-rich sediments and enhance water holding capacity.

Biodiversity Conservation:

Protect and restore habitats for native fish, plankton, and benthic species.

Monitor populations of sensitive species as indicators of recovery.

Community Participation and Awareness:

Engage local residents, schools, and NGOs in lake monitoring and clean-up drives.

Launch awareness campaigns on the ecological importance of the lake.

Regular Monitoring and Research:

Conduct seasonal biodiversity and water quality assessments.

Develop a long-term lake management plan based on scientific data.

The guidance provided in the current report is an important guideline in ensuring the future restoration of the ecological integrity at the Macferson lake to ensure that the site could be sustainable in the future generations. All the aforementioned interventions are anticipated to have significant improvement in the quality of the habitat, ability to store water, prevent over-enrichment of nutrients and the physical strength of the lakeshore.

5. Conclusion

The study at hand gives an overall examination of the conditions prevailing physico-chemical, biological, and even ecological conditions of Macferson Lake at Allahabad. Results denote that there is moderate pollution, eutrophic nature, and impoverished biodiversity especially the dominance of tolerants. These indicators are manifestations of the negative effects of unregulated anthropogenic forces, nutrient enrichment and exotic species. However, due to the occurrence of native species and a strategic position of the lake in an urban setting, the possibilities of ecological restoration are available.

By employing well-planned management activities, i.e., pollution control action, invasive species eradication, badly damaged habitats restoration, and involvement of local populations, the ecological status of the Macferson Lake can be brought up to the healthy level. This is impossible without continuity of monitoring and conducting research that will be required to identify and measure ecological changes as well as allow improvement of conservation methods. Thus, conservation and reconstruction of Macferson Lake is necessary not only in order to ensure biodiversity but also to improve the environmental conditions and the condition of the communities. The work is a foundation of further ecological strategy and contributes to the overall discussion of the sustainable city water-resources management.

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Conflict of interest: As a Author I Declare that there is no conflicts of Interest.

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