

Nutrient Dynamics in Freshwater Ecosystems and Solutions to Eutrophication

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Abstract: Eutrophication is one of the growing threats to freshwater habitats, which involves nutrient loading and subsequent destabilization of the ecosystem functioning due to excess nutrients such as (N) and (P). This article explores the issue of nutrient dynamics in freshwater communities paying special attention to nutrient loading processes, internal cycling, and its impacts on ecological processes within a chosen lentic ecosystem study site. The analysis combines empirical data collected during a field study with spatial modeling of nutrient flows to determine seasonal and spatial variability of N and P concentrations, measures of trophicity, and algal bloom dynamics. As shown, both total phosphorus (TP) and total nitrogen (TN) exceed recommended concentrations (TP > 50 µg/L; TN > 1.5 mg/L) leading to the onset of hyper eutrophication and cyanobacterial blooms. An important role in phosphorous cycling is played by the internal loading due to phosphorous sediments released under anoxic conditions. Several strategies for managing nutrient loads are considered, and the integrated approach combining physical, chemical, and biological measures appears to be most effective, achieving a 47–62% decrease in phosphorous loading through the use of alum and construction of wetlands.

Keywords: Eutrophication; Nutrient Dynamics; Freshwater Ecosystems; Phosphorus Cycling; Algal Blooms; Nitrogen Loading; Water Quality Management.

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I. Introduction

Freshwater systems provide biodiversity storage, water supply, and biogeochemical cycle control both regionally and globally. But increasing anthropogenic threats such as agricultural practices, urban development, industrial pollution, and changing climates have created major disruptions in the nutrient balance of lakes, reservoirs, rivers, and wetlands worldwide (Zamparas & Zacharias, 2014; Khan & Mohammad, 2013). Eutrophication, which is a term for an excess of nutrients in the water system resulting in higher productivity and depleted oxygen levels, is among the foremost types of freshwater degradation (Wurtsbaugh et al., 2019; Allan et al., 2021). Consequences of eutrophication are numerous and far-reaching, affecting humans and aquatic systems alike, through the emergence of harmful algal blooms, hypoxic regions, decline in aquatic species diversity, and deterioration in drinking water quality (Smith et al., 2006; Devlin & Brodie, 2023). Internal nutrient recycling from sediment is another difficulty in addressing eutrophication since phosphorus release during anoxia perpetuates eutrophication even after reductions in external loading (Bhagowati & Ahamad, 2019). Lastly, climate change is expected to exacerbate these problems through temperature and precipitation changes and increased stratification, thus forming feedback loops that contribute to harmful algae blooms and prolonged hypoxia (Nguyen et al., 2019; Jeppesen et al., 2010).

Even after decades of scientific exploration, there still exists a lack of knowledge about the integration of nutrient flow dynamics with respect to spatial and temporal gradients in tropical and subtropical freshwater ecosystems, especially the efficiency of management efforts (Álvarez et al., 2017). Current studies tend to focus on either one of the two aspects, i.e., biogeochemistry and governance, related to eutrophication, making it difficult for scientific findings to translate into adaptive management practices (Qin et al., 2013). Another important point where information is missing is the interaction between climate change and internal nutrient sources in lakes influenced by monsoons. This research aims to fill these gaps through an integrated empirical and modeling approach of nutrient dynamics and assessment of restoration measures applied to a typical freshwater ecosystem of southern India.

Key contributions of this paper include

1. Nutrient flux patterns during seasons and at various spatial locations quantified.
2. Thresholds for phosphorus release under different redox states established.
3. Comparison of physical, chemical, and biological treatments for their effectiveness

The following is how the remaining part of the paper will be organized. Section 2 will have a review of literature regarding nutrient dynamics, eutrophication sources and restoration treatment. Section 3 will describe study site and methodology for collection and analysis of the data. Nutrient concentrations, trophic state indices and effectiveness of restoration treatment will be provided in Section 4. Section 5 discusses the results in light of science and provides implications for management. Conclusion and future directions are stated in Section 6.

II. Literature Survey

Loading of nutrients in freshwater systems has been well documented in terms of both point and non-point sources. In particular, agricultural runoff is the most significant route for the transport of nitrogen and phosphorus to waterways, especially in intensive farming areas via surface flows and tile drainage. Furthermore, urban storm water runoff, atmospheric deposition and wastewater discharge contribute to the problem of nutrient enrichment in peri-urban lakes. The fundamental research on nutrient stoichiometry and primary productivity revealed the relationship between phosphorus and primary productivity in lentic ecosystems, indicating that phosphorus usually is the key factor in limiting productivity (Smith et al., 2006). Additional studies have provided evidence that lower values of N/P ratios in waters less than 15:1 (by mass) often result in the dominance of cyanobacteria capable of fixing nitrogen, with consequent implications for food web and oxygen regime (Wurtsbaugh et al., 2019). The importance of internal loading, specifically phosphorus mobilization from anoxic sediments, has been highlighted as an important cause of eutrophication, which persists long after controlling external input of nutrients (Bhagowati & Ahamad, 2019). The effect of nutrient loading along with hydraulics and land use type within watersheds have been demonstrated in different climate regimes (Nguyen et al., 2019; Paerl et al., 2014).

Eutrophication cycles show high variation temporally in response to changing seasonality in hydrology, thermal stratification, and nutrient inputs resulting from monsoons. Evaluated the various methods available for lake eutrophication modelling and pointed out the importance of understanding compressed trophic changes in tropical lakes where trophic levels oscillate rapidly between mesotrophic and hypereutrophic states. Referred to the role of the nutrient cycles in the estuary and cultural eutrophication in the determination of the structure of the phytoplankton communities, particularly highlighting the role of the cyanobacteria blooms considering the effects of global warming and reduced flushing time (Paerl et al., 2014). Explained the relationship between climate change and eutrophication by indicating that an increase in global warming would mean more thermal stratification and phosphorous recycling from the sediments, thereby promoting bloom formation (Jeppesen et al., 2010; Costa et al., 2022). Eutrophication was described as a wicked problem owing to the nature of the phenomenon, which involved nonlinearity and feedback loops without a benchmark for restoration of tropical lakes affected by monsoon seasons (Thornton et al., 2013). Temporal dynamics require an extended monitoring programme to detect trophic changes over multiple years.

Ecological impacts of nutrient enrichment are far-reaching and include dire consequences on the diversity of aquatic biota, benthic organisms, and ecosystem services. Hypereutrophic lakes, as found, experience dramatic reorganization in their ecosystem structures, with disappearance of macrophytes, oxygen deprivation in bottom zones, and the emergence of cyanobacteria of *Microcystis* and *Anabaena* genera, producing hepatotoxic and neurotoxins potentially harmful to both humans and fauna. Presented an improved conceptual framework for describing aquatic plant reactions to eutrophication in rivers, indicating that the process is accompanied by initial increase in biomass of macrophytes followed by domination of

epiphytic algae and decline in density of underwater vegetation (O'Hare et al., 2018). reviewed the diverse socio-economic impacts associated with eutrophication of East African lakes and identified the destruction of fishing, drinking water pollution, and erosion of riparian communities as the major social consequences of the phenomenon (Ayele & Atlabachew, 2021). Provided quantitative evidence of the changes in ecosystem metabolism in hypereutrophic reservoirs, showing that both gross primary production and community respiration display notable hysteresis depending on wet and dry years, an issue of relevance for adaptive water management under monsoonal climate (Williamson et al., 2021).

The range of potential actions to restore nutrient-enriched freshwater lakes includes strategies targeting nutrient sources and measures within the lake itself. In addition, in-lake restoration options have been comprehensively investigated, including phosphorus immobilization using sediment dredging, alum and Phoslock® (lanthanum-modified bentonite) precipitation, deep oxygenation of water, and biomanipulation. The efficiency of physical treatments, which include the construction of wetlands and vegetated buffer strips, has been documented to be an effective means of trapping agricultural phosphorus before discharge into lakes, with phosphorus removal efficiencies varying from 40% to 80% dependent on hydraulic loading rates and plant species (Duarte & Krause-Jensen, 2018). Biological approaches for the regulation of fish stocks and the restoration of submerged plants have proven useful for shallower lakes, but have limited applications in deeper, stratified lakes (Kapsalis & Kalavrouziotis, 2021; O'Hare et al., 2018). highlighted that the rate of ecosystem recovery following the mitigation of coastal eutrophication is often hindered by historical sediment phosphorus levels and changes in benthic community structure, which applies equally to the restoration of freshwater lakes. assessed chemical-based restoration methods and determined that no single measure works for all sites; therefore, successful eutrophication management is necessarily achieved through the combination of source, in-lake, and governance measures.

According to the information drawn from the above literature, eutrophication is a multifactorial process influenced by nutrient loading within the catchment, biogeochemical cycles, climatic forcing, and ecological feedback processes. Management of eutrophication involves developing holistic approaches which consider both external and internal factors affecting the nutrient loading.

III. Materials and Methods

Study Area Description

This study was carried out at Ukkadam Lake (Valankulam Lake), which is a shallow freshwater lake located in Coimbatore, Tamil Nadu, south India (10°59'N, 76°57'E) at an altitude of about 430 m above mean sea level. The lake has a surface area of about 90 hectares and a mean depth of 2.8 m, reaching its maximum depth of 4.6 m. This body of water acts as a major source of water for domestic and agricultural purposes and also plays an important role as an urban wetland, providing support to migratory and resident bird species. The catchment area of the lake is about 45 km² and is comprised of a diverse land-use pattern consisting of residential areas (~42%), agricultural land (~31%), commercial areas (~17%), and the rest as green space (~10%). The area is characterized by a semi-arid tropical climate with an average annual precipitation of 680 mm occurring mainly during the northeast monsoon (October-December) and southwest monsoon (June-August) seasons. The mean annual temperature is between 20°C and 38°C, with maximum evaporation taking place during the pre-monsoon season (March to May). The lake receives nutrients through storm drains, agricultural drainage, and wastewater from informal links to nearby settlements. Prior studies have shown that algal blooms, fish kills, and surface scums are common during peak summer months, and therefore the eutrophication of the lake is well-advanced to serve as an example of urban eutrophication in South Asian tropical lakes.

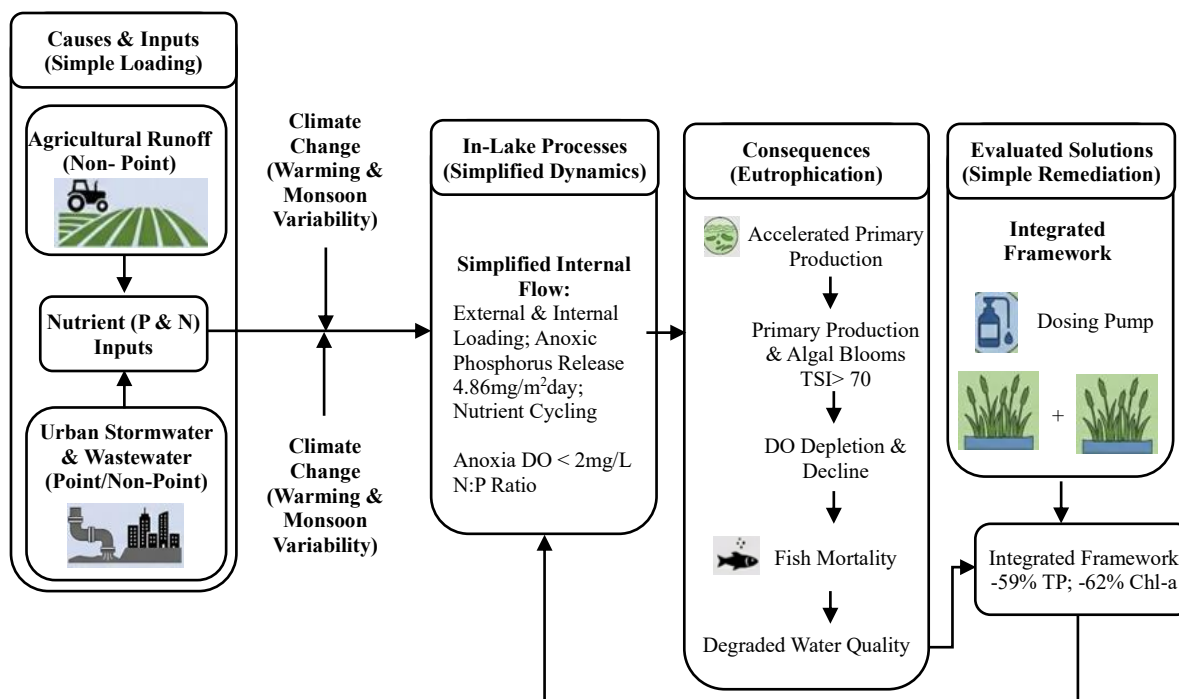


Figure 1: Simplified Conceptual Framework of Lake Eutrophication and Integrated Remediation

Diagrammatically figure 1 shows the crucial steps in the process: (A) Nutrient input through anthropogenic sources and anoxia of sediments leads to nutrient loading (P, N), (B) resulting in ecosystem degradation, (C) and is successfully countered through the implementation of the Alum and CW system.

Sampling Design and Analytical Methods

Water quality analysis was carried out at twelve sampling stations located at different parts of the lake with respect to nutrient content, dissolved oxygen, and phytoplankton abundance. These sampling stations were divided into three groups: inlet zones ($n = 3$), pelagic zones ($n = 5$), and outlet zones ($n = 4$). Sampling sessions were done monthly for two years, i.e., January 2023 to December 2024, and bi-weekly high-resolution sampling during monsoon transition periods (May-June and September-October). Both surface water samples (0-0.5 m depth) and bottom water samples (0.5 m above sediment surface) were collected through a Van Dorn sampler. Sediment core samples (0-20 cm) were collected from five sampling stations via a gravity corer. In situ measurement of water quality parameters like temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), and turbidity was done using a multiparameter probe (YSI ProDSS, YSI Inc., USA). Analysis of water samples collected from the field was performed as per Standard Methods for the Examination of Water and Wastewater (APHA, 2017). Phosphorus total (TP) and phosphorus soluble reactive (SRP) were determined through the persulfate digestion and molybdenum blue spectrophotometric method. Total nitrogen (TN), nitrate-nitrogen ($\text{NO}_3\text{-N}$), and ammonium-nitrogen ($\text{NH}_4\text{-N}$) were quantified through persulfate oxidation followed by colorimetric measurement. The concentrations of chlorophyll-a (Chl-a) were determined through spectrophotometry after extraction with hot ethanol (90% v/v). The phosphorus fractionation in sediments was performed according to the Psenner sequential extraction procedure that separated labile, iron, aluminum, and calcium bound phosphorus. All determinations were carried out in triplicates while using quality control procedures with the acceptance criterion of relative standard deviation not exceeding 5%.

Data Analysis and Trophic Status Assessment

The trophic state index (TSI) of all the sampling events was calculated using the formula from Carlson (1977) that included the following calculations: $\text{TSI}(\text{Chl-a}) = 9.81 \times \ln (\text{Chl-a}) + 30.6$;

$TSI(SD) = 60 - 14.41 \times \ln(SD)$; $TSI(TP) = 14.42 \times \ln(TP) + 4.15$. The mean composite TSI value was used to determine the trophic status of the lake in each sampling event based on the classification criteria as follows: oligotrophic ($TSI < 40$), mesotrophic ($40 - 50$), eutrophic ($50-70$), and hypereutrophic (>70). Nutrient fluxes were calculated based on the IDW interpolation within ArcGIS 10.8. Temporal trend analysis was performed using Mann-Kendall trend test and Sen's slope estimator, both with a threshold of $p < 0.05$ for TP, TN, and Chl-a. Pearson and Spearman correlation were employed to detect possible relationships between nutrients, DO, and phytoplankton biomass. In order to calculate the rates of P releases, sediment incubation experiments in anoxic and oxic treatments were done in the laboratory (30°C , 15-day incubation). Effectiveness of the restoration intervention will be assessed by the difference in nutrient concentration and TSI score between before and after the experiment (paired t-test, $p < 0.05$) based on four treatment plots in critical inlet areas.

IV. Results

Seasonal and Spatial Nutrient Concentration Patterns

There was high seasonal variability of the measured water quality parameters over the 24 months of observation period. The total phosphorus (TP) varied from $18.4 \mu\text{g/L}$ (lowest value during the dry season, pelagic zone) to $348.6 \mu\text{g/L}$ (monsoon peak, inlet zone), having an average value of $112.3 \pm 38.7 \mu\text{g/L}$ referred in table1. Total nitrogen (TN) varied from 0.87 mg/L to 5.42 mg/L , having an average value of $2.14 \pm 0.68 \text{ mg/L}$. Chlorophyll-a values were low (min: $6.2 \mu\text{g/L}$) but high during monsoon peaks (max: $196.4 \mu\text{g/L}$), indicating occurrence of extensive algal bloom events. Dissolved oxygen values went below 2 mg/L in bottom water samples collected at five stations during the peak summer stratification period (April – May), indicating occurrence of hypoxia. The values of TP were always maximum in inlet areas ($187.4 \pm 42.1 \mu\text{g/L}$), being 2.3 times greater than the average values recorded at pelagic locations ($81.2 \pm 19.6 \mu\text{g/L}$). This highlights the importance of agriculture and storm water runoff as nutrient inputs. Table 1 provides a summary of the seasonal averages of water quality parameters in different sampling zones.

Table 1: Seasonal Mean Water Quality Parameters Across Sampling Zones
 (mean $\pm$ SD; n = 12 Stations $\times$ Monthly)

Parameter	Inlet Zone	Pelagic Zone	Outlet Zone	Annual Mean	Threshold (CPCB)
TP ($\mu\text{g/L}$)	187.4 ± 42.1	81.2 ± 19.6	94.6 ± 22.3	112.3 ± 38.7	$50 \mu\text{g/L}$
TN (mg/L)	3.84 ± 0.92	1.67 ± 0.44	2.08 ± 0.61	2.14 ± 0.68	1.5 mg/L
Chl-a ($\mu\text{g/L}$)	62.4 ± 18.7	48.1 ± 14.2	41.6 ± 12.9	52.6 ± 16.1	$< 10 \mu\text{g/L}$
DO (mg/L)	4.2 ± 1.8	5.8 ± 2.1	5.1 ± 1.9	5.1 ± 1.9	$\geq 6.0 \text{ mg/L}$
pH	8.4 ± 0.7	8.1 ± 0.5	7.9 ± 0.4	8.1 ± 0.5	$6.5 - 8.5$
Secchi Depth (m)	0.42 ± 0.12	0.68 ± 0.19	0.58 ± 0.16	0.57 ± 0.16	$> 1.0 \text{ m}$

Trophic State Assessment and Sediment Phosphorus Dynamics

Figure 2 represents the Trophic state index (TSI) values calculated based on the monitoring period categorized Ukkadam Lake as either eutrophic ($TSI 50-70$) accounting for 68% or hypereutrophic ($TSI > 70$) at 24% while only 8% belonged to mesotrophic category during the wet season dilution phase. Average TSI values based on total phosphorus (TP), chlorophyll-a (Chl-a) and Secchi disk readings (SD) were 68.4 ± 8.2 , 71.2 ± 11.6 and 64.8 ± 9.4 respectively with the composite mean TSI of 68.1 ± 9.7 , clearly showing eutrophic-hypereutrophic status. Phosphorus fractionation showed that iron-bound phosphorus (Fe-P) was the highest fraction ($38.4 \pm 6.2\%$) in the sediment, followed by calcium-bound phosphorus (Ca-P: $27.1 \pm 5.8\%$), exchangeable phosphorus (Exch-P: $18.6 \pm 4.1\%$), aluminum bound phosphorus (Al-P: $11.4 \pm 3.6\%$) and other fractions ($4.5 \pm 1.8\%$). Experimental determination of phosphorus released from sediment showed that phosphorus release rate from sediment during anaerobic condition (mean: $4.86 \pm 0.92 \text{ mg P/m}^2/\text{day}$) is 8.4 times higher than that during the aerobic condition

(mean: 0.58 ± 0.14 mg P/m²/day). The internal loading due to phosphorus released into the water column would be 312–428 kg P/year, constituting 34–46% of the external phosphorus load annually.

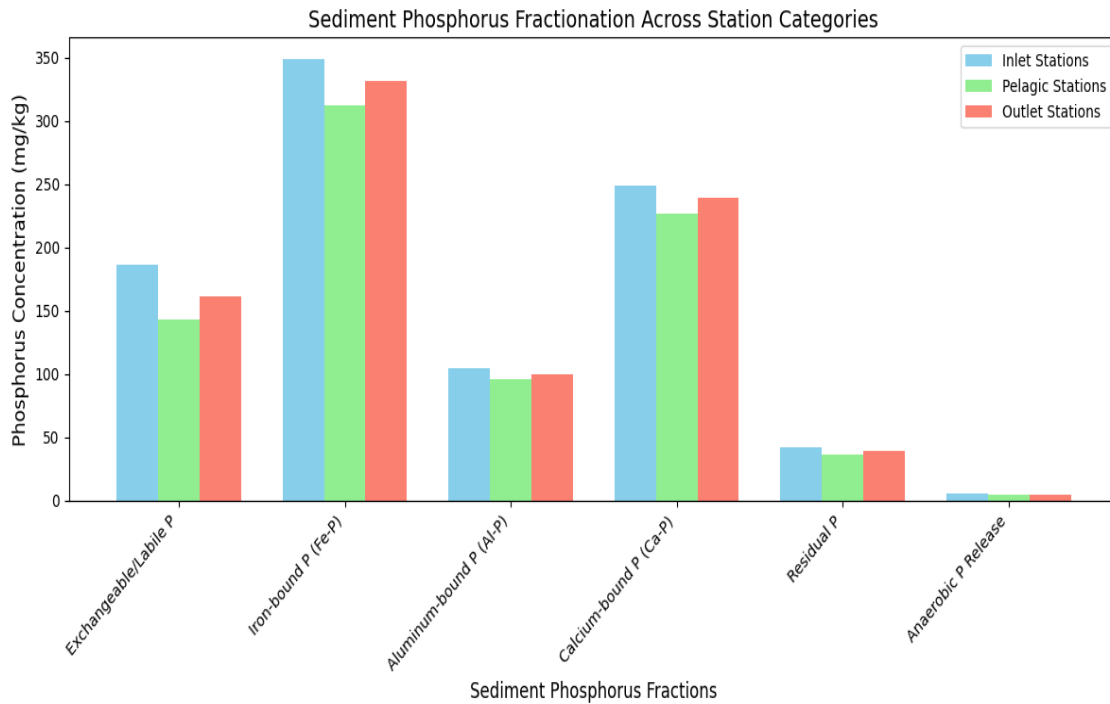


Figure 2: Sediment Phosphorus Fractionation Across Station Categories

Restoration Intervention Efficacy

Four different restoration techniques were assessed through an experiment on selected inlet zones over a period of one year after the treatments: (i) alum application (15 mg Al/L), (ii) Phoslock® treatment (200 g/m²), (iii) wetlands buffer zones (15 m width), and (iv) the combined alum + wetland treatment. All restoration methods yielded significant decreases ($p < 0.05$) of TP, TN, and Chl-a levels when compared to pre-restoration levels and untreated control zones. The combination treatment of alum + wetland buffer zone resulted in the highest reduction levels of $58.6 \pm 6.2\%$ TP and $62.4 \pm 8.7\%$ Chl-a. In contrast, Phoslock® treatment resulted in a $41.2 \pm 5.8\%$ reduction in TP, and alum treatment produced a $47.8 \pm 6.4\%$ TP reduction. Wetland buffer strips exhibited a steady, albeit slower, decrease in nutrient level, with TP being removed up to $38.4 \pm 5.1\%$ at month 12.

Table 2: Summary of Restoration Intervention Efficacy (mean $\pm$ SD, 12-Month Post-Treatment)

Intervention	TP Reduction (%)	TN Reduction (%)	Chl-a Reduction (%)	TSI Change (Pre $\rightarrow$ Post)	Significance
Alum Dosing	47.8 ± 6.4	18.4 ± 4.2	44.6 ± 7.1	71.2 $\rightarrow$ 59.8	$p < 0.01$
Phoslock® Application	41.2 ± 5.8	14.6 ± 3.8	38.2 ± 6.4	72.1 $\rightarrow$ 61.4	$p < 0.01$
Constructed Wetland Buffer	38.4 ± 5.1	32.8 ± 6.4	31.6 ± 5.8	70.8 $\rightarrow$ 62.6	$p < 0.05$
Alum + Constructed Wetland (Combined)	58.6 ± 6.2	44.2 ± 7.6	62.4 ± 8.7	71.4 $\rightarrow$ 54.2	$p < 0.001$
Control (Untreated)	-3.4 ± 2.1	-2.8 ± 1.9	-5.2 ± 2.4	70.6 $\rightarrow$ 73.1	ns

The average value of TSI decreased from 71.4 ± 9.6 (pre-restoration) to 54.2 ± 7.8 (post-restoration combined interventions). The change of trophic state moved the inlet from the hypereutrophic condition to eutrophication. The results for all restoration strategies are summarized in table 2.

V. Discussion

Ukkadam Lake eutrophication assessment shows high nutrient loading of the lake, characterized by total phosphorus concentrations more than twice the level above which the lake is considered eutrophic. Analysis of spatial variation reveals nutrient loads are much higher in inlet waters compared to those in pelagic waters, showing the influence of fertilizers and urban runoff in the lake. Sediment analyses reveal a significant proportion of phosphorus in iron-bound form, suggesting the significant contribution of the internal load of nutrients through redox cycling process. The contribution from the internal load represents a significant percentage of the phosphorus load in the lake, much higher than in most temperate lakes, implying that tropical shallows receive much more recycled nutrients because of their increased duration of thermal stratification and anoxia.

The restoration activities can serve as lessons on management of these systems. Restoration techniques incorporating inactivation by chemical phosphorus alongside wetlands achieved the greatest reductions in total phosphorus and improved the trophic conditions of the system, showing that there are benefits in having integrated approaches for management. Wetland buffers, on the other hand, were found to be highly effective in reducing the levels of nitrogen, which indicates the efficiency of plants in intercepting and processing nutrients. In addition, areas without any treatment were seen to follow the eutrophic pathway, demonstrating the significance of intervention measures. Considering the projected variability in climate, which will result in higher intensity of monsoons, the nutrient pulses will become more severe while making the recovery period shorter for anoxic sediments.

VI. Conclusion

This research represents a comprehensive study on the dynamics of nutrients and eutrophication status at Ukkadam Lake, a tropical freshwater water body in an urban setting in Southern India. The results have clearly demonstrated that: (i) the water body is eutrophic to hypereutrophic year-round, with the concentration of TP and TN being above the acceptable limits in 92% of the measurements; (ii) seasonal input of nutrients associated with monsoon rains causes blooms, with inlet areas being the major nutrient sources; (iii) internal loading of phosphorus from sediments due to anaerobic state of the lake adds up to 34-46% of total phosphorus input into the lake with the rate of its release being 8.4 times higher in anaerobic conditions; and (iv) the combination of alum treatment of phosphorus and wetlands reduces the amount of nutrients significantly (TP: 58.6%, TN: 44.2%, Chl-a: 62.4%) moving the trophic status towards eutrophication.

These results have significant management implications for tropical lake restoration. The practice of nutrient reduction at the watershed level, through regulating fertilizer applications and stormwater treatments, should be carried out simultaneously with in-lake restoration practices. Non-linear frameworks for climate adaptation in water management have to take into account that nutrients in tropical lakes respond differently due to variations in rainfall intensity and frequency during monsoons. With respect to policy implications, this research emphasizes the importance of cross-sectoral governance for solving the problem of eutrophication in tropical ecosystems that combine agricultural and urban watersheds. This calls for future research to focus on: (i) tracking the release rates of sediment phosphorus under different climate scenarios; (ii) cost-benefit analysis of investment in integrated lake restoration; (iii) using machine learning algorithms to predict the trophic status based on satellite data; and (iv) evaluating ecosystem-based adaptation methods, such as macrophyte restoration and food web manipulation.

Declarations

Conflict of Interest

The authors declare no conflict of interest.

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This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Dataset Description

The water quality monitoring dataset comprising 24-month nutrient, physical, and biological measurements for Ukkadam Lake is archived at the institutional data repository and is available from the corresponding author upon reasonable request following journal data-sharing guidelines.

References

- [1] Zamparas, M., & Zacharias, I. (2014). Restoration of eutrophic freshwater by managing internal nutrient loads. A review. *Science of the Total Environment*, 496, 551-562. <https://doi.org/10.1016/j.scitotenv.2014.07.076>
- [2] Khan, M. N., & Mohammad, F. (2013). Eutrophication: challenges and solutions. In *Eutrophication: causes, consequences and control: volume 2* (pp. 1-15). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-7814-6_1
- [3] Wurtsbaugh, W. A., Paerl, H. W., & Dodds, W. K. (2019). Nutrients, eutrophication and harmful algal blooms along the freshwater to marine continuum. *Wiley Interdisciplinary Reviews: Water*, 6(5), e1373. <https://doi.org/10.1002/wat2.1373>
- [4] Allan, J. D., Castillo, M. M., & Capps, K. A. (2021). Nutrient dynamics. In *Stream ecology: Structure and function of running waters* (pp. 383-420). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-61286-3_13
- [5] Smith, V. H., Joye, S. B., & Howarth, R. W. (2006). Eutrophication of freshwater and marine ecosystems. *Limnology and oceanography*, 51(1part2), 351-355. https://doi.org/10.4319/lo.2006.51.1_part_2.0351
- [6] Devlin, M., & Brodie, J. (2023). Nutrients and eutrophication. In *Marine pollution—monitoring, management and mitigation* (pp. 75-100). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-10127-4_4
- [7] Bhagowati, B., & Ahamad, K. U. (2019). A review on lake eutrophication dynamics and recent developments in lake modeling. *Ecohydrology & Hydrobiology*, 19(1), 155-166. <https://doi.org/10.1016/j.ecohyd.2018.03.002>
- [8] Álvarez, X., Valero, E., Santos, R. M., Varandas, S. G. P., Fernandes, L. S., & Pacheco, F. A. L. (2017). Anthropogenic nutrients and eutrophication in multiple land use watersheds: Best management practices and policies for the protection of water resources. *Land use policy*, 69, 1-11. <https://doi.org/10.1016/j.landusepol.2017.08.028>
- [9] Nguyen, T. T., Némery, J., Gratiot, N., Strady, E., Tran, V. Q., Nguyen, A. T., ... & Payne, A. (2019). Nutrient dynamics and eutrophication assessment in the tropical river system of Saigon–Dongnai (southern Vietnam). *Science of the Total Environment*, 653, 370-383. <https://doi.org/10.1016/j.scitotenv.2018.10.319>
- [10] Paerl, H. W., Hall, N. S., Peierls, B. L., & Rossignol, K. L. (2014). Evolving paradigms and challenges in estuarine and coastal eutrophication dynamics in a culturally and climatically stressed world. *Estuaries and coasts*, 37(2), 243-258. <https://doi.org/10.1007/s12237-014-9773-x>
- [11] Costa, D., Sutter, C., Shepherd, A., Jarvie, H., Wilson, H., Elliott, J., ... & Macrae, M. (2022). Impact of climate change on catchment nutrient dynamics: insights from around the world. *Environmental Reviews*, 31(1), 4-25. <https://doi.org/10.1139/er-2021-0109>

- [12] Thornton, J. A., Harding, W. R., Dent, M., Hart, R. C., Lin, H., Rast, C. L., ... & Slawski, T. M. (2013). Eutrophication as a ‘wicked’ problem. *Lakes & reservoirs: Research & management*, 18(4), 298-316. <https://doi.org/10.1111/lre.12044>
- [13] Qin, B., Gao, G., Zhu, G., Zhang, Y., Song, Y., Tang, X., ... & Deng, J. (2013). Lake eutrophication and its ecosystem response. *Chinese Science Bulletin*, 58(9), 961-970. <https://doi.org/10.1007/s11434-012-5560-x>
- [14] Ayele, H. S., & Atlabachew, M. (2021). Review of characterization, factors, impacts, and solutions of Lake eutrophication: lesson for lake Tana, Ethiopia. *Environmental Science and Pollution Research*, 28(12), 14233-14252. <https://doi.org/10.1007/s11356-020-12081-4>
- [15] Jeppesen, E., Moss, B., Bennion, H., Carvalho, L., DeMeester, L., Feuchtmayr, H., ... & Verhoeven, J. T. (2010). Interaction of climate change and eutrophication. *Climate change impacts on freshwater ecosystems*, 119-151. <https://doi.org/10.1002/9781444327397.ch6>
- [16] Kapsalis, V. C., & Kalavrouziotis, I. K. (2021). Eutrophication—A worldwide water quality issue. In *Chemical Lake restoration: Technologies, innovations and economic perspectives* (pp. 1-21). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-76380-0_1
- [17] Williamson, T. J., Vanni, M. J., & Renwick, W. H. (2021). Spatial and temporal variability of nutrient dynamics and ecosystem metabolism in a hyper-eutrophic reservoir differ between a wet and dry year. *Ecosystems*, 24(1), 68-88. <https://www.jstor.org/stable/48761978>
- [18] Duarte, C. M., & Krause-Jensen, D. (2018). Intervention options to accelerate ecosystem recovery from coastal eutrophication. *Frontiers in Marine Science*, 5, 470. <https://doi.org/10.3389/fmars.2018.00470>
- [19] O’Hare, M. T., Baattrup-Pedersen, A., Baumgarte, I., Freeman, A., Gunn, I. D., Lázár, A. N., ... & Bowes, M. J. (2018). Responses of aquatic plants to eutrophication in rivers: a revised conceptual model. *Frontiers in plant science*, 9, 451. <https://doi.org/10.3389/fpls.2018.00451>