

Limnological Sampling Techniques and Monitoring Strategies for Ecological Health Assessment

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Abstract: Freshwater ecosystem integrity is facing a growing threat from human interventions such as agricultural effluent, industrial and domestic effluent, and climatic variations. An accurate evaluation of the ecological status of an aquatic ecosystem is dependent on the proper incorporation of well-designed limnological sampling methods. This paper describes a rigorous assessment of the use of multi-level sampling approaches conducted at five different locations in a tropical freshwater reservoir and inflowing stream system. The assessment includes physicochemical parameters, biological communities, habitat features, and environmental DNA (eDNA) sequencing analysis to develop the Ecological Health Index (EHI). Seasonal sampling during the pre-monsoon, monsoon, and post-monsoon periods was done. Physicochemical variables such as pH, dissolved oxygen, electrical conductivity, total dissolved solids, nitrate, and total phosphorus were determined in situ and later validated via lab work. Indices that include the Shannon diversity index and Pielou's evenness index were calculated based on phytoplankton, zooplankton, and macroinvertebrates. The findings suggest significant spatial variation with respect to ecological status; wherein upstream sites are oligotrophic to mesotrophic (EHI: 70.3-82.9) while downstream agricultural impacted sites are eutrophic to hypertrophic (EHI: 35.5-48.2). The correlation between the composite index and individual biological/physicochemical measurements is highly significant ($r^2 = 0.87$, $p < 0.01$). These results emphasize the importance of using the multi-proxy approach in the ecological regulation process and reservoir management. In this study, an efficient and inexpensive methodology has been proposed for use in freshwater quality monitoring programs in tropical/subtropical conditions.

Keywords: Limnological Monitoring; Freshwater Health Assessment; Ecological Health Index; Phytoplankton Diversity; Edna Metabarcoding; Trophic Status; Water Quality Indices.

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I. Introduction

Freshwater ecosystems, which include lakes, reservoirs, rivers, and wetlands, represent some of the most biologically diverse and productive ecosystems on earth; however, they are also highly susceptible to various forms of anthropogenic disturbance (Stefanidis & Papastergiadou, 2024; Contieri et al., 2024). Urbanization, overpopulation, agriculture, and industry have all contributed to degradation of aquatic ecosystems in the tropics and subtropics, resulting in water quality and environmental degradation. Ecological evaluation in aquatic ecosystems is thus essential for ensuring sustainable management and developing sound policies and strategies aimed at preserving aquatic ecosystems. Limnology, a science dealing with the study and measurement of physicochemical and biological properties of inland water, serves as a basis for ecological evaluations (Lee et al., 2011; da Silva et al., 2022). Despite its significance, the use of standard and integrative sampling schemes continues to be inconsistent among various geographical areas, especially for developing countries where the shortage of resources constrains the capabilities to carry out monitoring activities.

In essence, the central challenge facing water resources management professionals is the disjointed structure of current monitoring systems. Most of the literature tends to only consider physicochemical parameters, ignoring the biological metrics which are more indicative and informative indicators of changes within the ecosystem (Rocha et al., 2020; Chen et al., 2019). Alternatively, biological assessment alone can also be informative but will not reveal the root cause of any changes observed without accompanying information regarding physicochemical properties. In addition, monitoring during wintertime or monsoons becomes difficult due to logistics issues, while low frequency sampling may also be challenging for proper determination of ecological changes (Sampaio et al., 2021). The increasing trend in the utilization of

technologies like eDNA metabarcoding and automated monitoring devices presents revolutionary possibilities, although the combination of traditional sampling procedures still lags behind (Sakata et al., 2021; Euclide et al., 2021).

The three main contributions made by this study to the discipline of applied limnology and water ecosystem assessment include: development of an integrated sampling approach involving the use of physico-chemical, biological, habitat and environmental DNA parameters collected in multiple locations within a tropical dam ecosystem; development and validation of a single composite Ecological Health Index (EHI) based on the monitoring parameters; and evaluation of concordance between the individual monitoring proxies and EHI to establish the diagnostic parameters used in water resource assessment.

The structure of the remaining sections of this paper includes: Section 2 scientific review of limnological assessment techniques and ecological health indices; Section 3 description of the study site, sampling and analysis techniques used, and index calculation; Section 4 presentation of spatial and temporal trends in ecosystem assessment; Section 5 interpretation of findings in ecological terms and implications for water resource management; and Section 6 conclusions and recommendations for further research.

II. Literature Review

There have been significant advances in the theory and methodology of limnological monitoring over the past two decades due to increased awareness of the multidimensional characteristics of aquatic ecosystem health. Traditional methods for assessing the quality of water involved physicochemical indices like pH, DO, nutrients concentration, among others, to evaluate the condition of the ecosystem. While all these indices have remained important over the years, it has become much more effective in diagnosing ecosystem health when they are used in conjunction with biological communities. Implementation of national aquatic ecological monitoring programs, such as the National Aquatic Ecological Monitoring Program (NAEMP) in Korea (Lee et al., 2011) has been instrumental in bringing a new era of integrated monitoring systems. It was shown by these studies that biological measures, such as community structure of macroinvertebrates and algal indices, are very sensitive to sub-lethal conditions of pollution and indicate integrated effects of cumulative environmental stresses that instant analyses of chemicals cannot detect (Raj & Philip, 2024a). The conclusion reached on the basis of this set of researches is obvious: one-parameter assessment of ecosystem's condition is inadequate for its comprehensive evaluation (Khanaa et al., 2013).

Use of indices and ecological metrics to characterize communities and ecosystems within freshwater systems has been gaining ground as an effective way of summarizing otherwise complicated biological data into useful information for management purposes. Some of these indices include the Shannon diversity index, the Evenness index by Pielou, and the index of limnological conditions for urban wetlands (Pinilla, 2010). Fuzzy comprehensive assessment involving numerous biotic and abiotic parameters has been used to classify the ecosystem status of sub-basin areas characterized by land use gradients, while indices were reviewed for application in assessing Argentina's freshwater systems (Rocha et al., 2020; Chen et al., 2019). The above-mentioned studies clearly show that indices composed of physical/chemical and biological sub-indexes perform better than individual indices in classification and ecological assessment of systems. From these investigations, one can clearly see that index calculation approaches, including the weight allocation for the components and the establishment of reference conditions, play a crucial role in ecological effectiveness of an index.

Indeed, some of the key innovations in freshwater ecology methodology have been fueled by progress in molecular biology, remote sensing, and automation in sensors. In particular, environmental DNA metabarcoding represents an innovative tool capable of reconstructing fish community assemblies in rivers and lakes, outperforming traditional sampling techniques in terms of detection and taxonomic precision (Euclide et al., 2021; Raj & Philip, 2024b). In addition, automated monitoring tools that rely on flow cytometry, computer vision, and machine learning have opened up new horizons for high-frequency minimally invasive monitoring of phytoplankton communities in lakes, overcoming the limitations of

traditional periodic manual sampling campaigns with regard to temporal resolution (Sampaio et al., 2021; Pomati et al., 2011). Specific adaptations of methodologies to difficult field conditions, such as winter ice-covered lakes, or turbid coastal zones using solid phase adsorption toxin tracking methodology, have expanded the application spectrum of limnology assessments to poorly accessible environments (Block et al., 2019; Lane et al., 2010). In other words, the combined use of classical and novel methodologies greatly extends the geographic and time spans of ecological studies.

In addition to the biotic and physicochemical indicators, increasing consideration is being paid to the limnology of alternative water bodies, such as abandoned coal mine pit lakes, aquaculture facilities, and groundwater ecosystems subjected to ferrochrome contamination threat (Boutros et al., 2015; Marin et al., 2021). The genetic diversity of fish stocks and assessment of wetlands conservation represent examples of the linkage between the limnological monitoring practices and sustainable development principles (Kaboré et al., 2022). An overview of current environmental monitoring technologies incorporating approaches based on remote sensing, sensor networks, and data analytics for ecological monitoring (Sadulla, 2024). In addition, the application of landscape-level analysis combined with basic quality techniques was suggested as a promising tool in the management of fresh water reservoirs, linking the results of local monitoring to catchment-wide ecology (da Silva et al., 2022). The main conclusion is that the future of limnological monitoring is associated with the merging of conventional limnological approaches with digital, genetic, and spatial tools employed through the adaptive management strategy.

III. Materials and Methods

Study Area Description

This research was carried out within and around Ghunghutta Reservoir, which is a permanent, tropical freshwater lake situated in central India, with an approximate latitude and longitude of 22°30'N and 82°45'E, respectively. The lake functions as a multifunctional aquatic body that provides irrigation, fisheries, drinking water, and some biodiversity conservation services. The catchment area extends over approximately 312 km² and consists of a mixture of agricultural land, mainly rice and wheat, scrubland, and semi-urban localities. Five fixed sampling locations (sites S1-S5) were set up following a gradient pattern starting from the upstream inflow (site S5, reference point) to mid-reservoir zone (sites S3, S1) and down towards agriculture-influenced zones (sites S2, S4). The sites S2 and S4 were impacted by runoff due to fertilized agriculture, which provided enhanced nutrient input to the sites. Agricultural and peri-urban land cover types mapped with the help of satellite data (Sentinel-2, 10 m resolution) showed that their combined share is over 68%. All sampling locations were recorded using a GPS locator (Garmin GPSMAP 64, ±3 m) and site-specific bathymetry maps prepared using an echosounder. Climatic conditions in the study area were characterized as tropical monsoon climate, which is defined by three hydrological seasons including pre-monsoon season (March-May), monsoon season (June-September) and post-monsoon season (October-February).

Monitoring for Integrated Freshwater is illustrated in figure 1, showing methods of monitoring such as physical-chemical analysis, water column sampling, and sediment sampling. Monitoring provides information related to health of the ecology using factors like biodiversity, water quality, functioning of ecosystems, and early warning indicators.

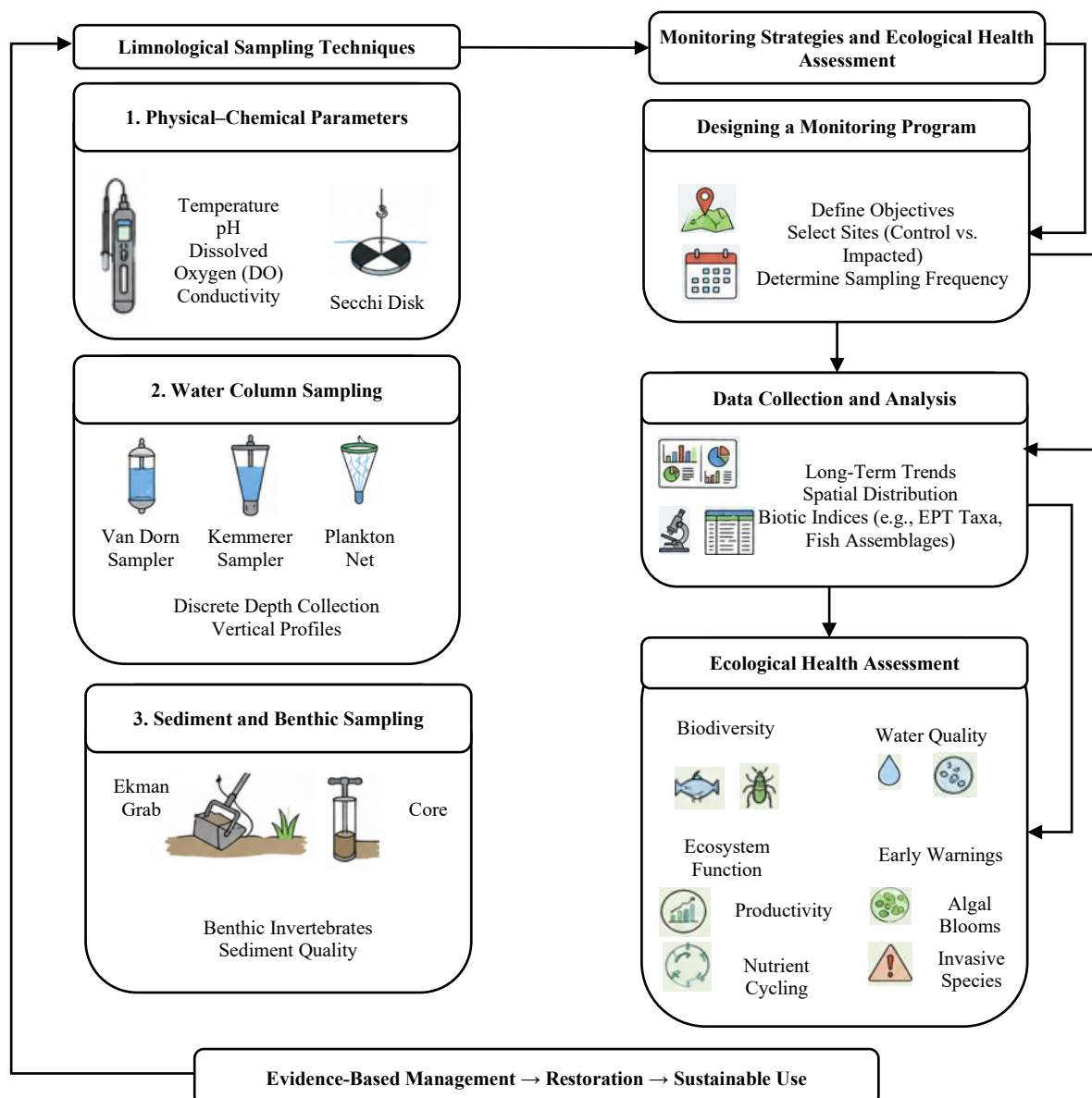


Figure 1: Limnological Sampling Techniques and Ecological Health Assessment Framework

Sampling Design and Physicochemical Analysis

Sampling was done in three seasons (May 2023-pre-monsoon; August 2023-monsoon; December 2023-post monsoon) for all five sites, which gave rise to 15 site season combinations for each parameter. Water samples were taken from sub-surface level (0-0.5 m) by using Van Dorn horizontal water sampler (2.2L capacity) and from bottom level (1.0m above sediment) to represent vertical variability in stratified sites. Water temperature, pH, dissolved oxygen (DO), Electrical Conductivity (EC), and turbidity values were measured in-situ through a water quality sonde (YSI Pro Plus; accuracy $\pm 0.1^{\circ}\text{C}$, $\pm 0.01\text{pH}$ unit, $\pm 0.1\text{ mg/l DO}$). Composite grab samples were kept in acid washed polyethylene bottles (1L amber) at cold temperatures up to 24 hours after sampling. Laboratory analysis of parameters such as TDS, BOD, nitrate ion (NO_3^-), total phosphorus (TP) and chlorophyll-a was performed according to APHA standard analytical methods (APHA, 2017). The measurement of chlorophyll-a concentration was performed by spectrophotometric measurement after the chlorophyll extraction using acetone (90% v/v) from the water sample. This was performed through the determination of chlorophyll-a absorbance at wavelengths 664 nm

and 750 nm using UV-vis spectrophotometer (Shimadzu UV-1800). Glassware was previously precombusted at 550 °C for 4 hours. A total number of 270 data readings associated with water quality analysis were collected. Quality control measures included field blanks, replicates, and validation of reference materials for all laboratory tests.

Biological Assessment, eDNA Sampling, and Ecological Health Index Construction

Samples of phytoplankton and zooplankton were collected by plankton nets (mesh sizes of 55 µm and 200 µm, respectively) through vertical hauls covering a depth of 2 m at each location, which were subsequently fixed in Lugol's iodine (2% v/v). Sampling of macroinvertebrates was done through kick samples of a standard D-frame net with 500 µm mesh size in an area of 0.25 m² at each location. The samples were fixed in 70% ethanol and the macroinvertebrates identified up to family level using taxonomic keys. Diversity was measured using Shannon-Wiener diversity index (H') and Pielou's evenness index (J'), while trophic levels were measured by the ratio of cyanobacteria to diatoms biovolumes and chlorophyll-a content based on OECD trophic state classification criteria. For the eDNA, 1 liter of water sample was filtered through 0.2 µm polycarbonate membrane filters (Nuclepore, 47 mm) within 4 hours after sampling, followed by DNA extraction with DNeasy Power Water Kit (Qiagen). For metabarcoding analysis of the water sample, sequencing of PCR amplicons from mitochondrial DNA (targeting 12S rRNA gene) for fish identification and chloroplast DNA (targeting 18S rRNA gene) for identifying phytoplankton, was done using Illumina MiSeq platform (2×300bp paired-end reads). Bioinformatics analyses were conducted using DADA2 and SILVA databases. The Ecological Health Index (EHI) was formulated using a composite weighted score comprising of Physicochemical sub-index (Weight: 0.35), Biological sub-index (Weight: 0.40), and Habitat Assessment sub-index (Weight: 0.25), based on the entropy-weighted scoring scheme similar to the fuzzy comprehensive assessment approach. The Ecological Health Index Scores were interpreted into five categories: Very Good (>80), Good (65-80), Moderate (50-65), Poor (35-50), and Very Poor (<35).

IV. Results

Physicochemical Water Quality Characteristics

The distribution pattern of physicochemical properties in the five sampling stations has been presented in table 1. The water temperature was in the range of 18.4°C (post-monsoon period, Site S5) to 32.1°C (pre-monsoon period, Site S4). The mean pH levels were well within the limit of acceptability (6.8-8.6), but the values beyond 8.5 at Site S4 in the pre-monsoon period indicated that the region experienced vigorous photosynthesis of algae due to hypereutrophication.

Table 1: Seasonal mean Physicochemical Water Quality Parameters Across Five Sampling Sites (n = 3 seasons per site). BIS = Bureau of Indian Standards

Parameter	Unit	Min	Max	Mean ± SD
Water Temperature	°C	18.4	32.1	24.7 ± 4.2
pH	—	6.8	8.6	7.6 ± 0.5
Dissolved Oxygen	mg/L	4.2	9.8	7.1 ± 1.4
Electrical Conductivity	µS/cm	212	684	438 ± 92
Turbidity	NTU	3.6	48.2	18.4 ± 9.7
Total Dissolved Solids	mg/L	148	442	282 ± 66
BOD	mg/L	1.2	6.8	3.5 ± 1.6
Nitrate (NO ₃ ⁻)	mg/L	0.4	4.8	2.3 ± 1.1
Total Phosphorus	mg/L	0.02	0.34	0.16 ± 0.08
Chlorophyll-a	µg/L	2.1	28.6	12.4 ± 7.8

The minimum and maximum levels of dissolved oxygen content were observed as 4.2 mg/L at the site having eutrophic conditions i.e., S2 (monsoon, bottom layer) and 9.8 mg/L at Site S5, respectively. The

average value of DO among different sites and different seasons was found to be 7.1 ± 1.4 mg/L. Levels of DO below the critical level of 5 mg/L (the level at which fish gets stressed) occurred only at the Sites S2 and S4 during monsoon season due to higher organic loadings. Turbidity levels were much higher at sites downstream, up to 48.2 NTU at Site S4 during monsoon. The level of total phosphorus recorded in Site S4 (mean: 0.31 mg/L) was more than 12 times above the eutrophication threshold value of 0.025 mg/L, while the BOD concentrations recorded in Sites S2 and S4 were higher than the BIS standards of 3 mg/L. One-way ANOVA revealed that there were significantly different DO levels ($F_{4, 10} = 18.7$, $p < 0.001$), TP levels ($F_{4, 10} = 24.3$, $p < 0.001$), and turbidity levels ($F_{4, 10} = 15.6$, $p < 0.001$).

Biological Community Structure and Diversity Indices

The biological community structure and the diversity indices for each site are shown in table 2. A total of 47 species of phytoplankton, 23 species of zooplankton, and 19 families of macroinvertebrates were documented among all study sites during all seasons. The reference site (S5) exhibited dominance of diatoms (*Cyclotella*, *Navicula*) and copepods (*Diaptomus*), resulting in highest Shannon diversity ($H' = 3.05$) and Pielou's evenness ($J' = 0.89$). On the other hand, the highly nutrient-enriched Site S4 was mainly composed of cyanobacterial bloom-forming organisms (*Anabaena*, *Eudorina*) as well as pollutant-adapted oligochaetes (*Tubifex*), thus showing lower diversity ($H' = 1.28$; $J' = 0.46$). The appearance of *Tubifex* and *Chironomus* larvae as dominating macroinvertebrates at Sites S2 and S4 is a good indicator of organic enrichment and the scarcity of oxygen available in the benthic layer. eDNA metabarcoding revealed that Site S5 had 12 fish ASVs that were related to Cyprinidae, Channidae, and Notopteridae families while Site S4 only recorded 4 fish ASVs, which include catfish species (*Cleridae*). There were significant variations among sites concerning the H' ($H = 16.8$, $p = 0.002$) and J' ($H = 14.3$, $p = 0.006$).

Table 2: Biological Community Structure, Diversity Indices, and Trophic Status Classification at Each Sampling Site

Sampling Site	Dominant Taxa	Shannon Index (H')	Pielou's Evenness (J')	Trophic Status
Site S1	<i>Cyclotella</i> , <i>Navicula</i> , <i>Diaptomus</i>	2.84	0.81	Mesotrophic
Site S2	<i>Microcystis</i> , <i>Oscillatoria</i> , <i>Chironomus</i>	1.62	0.54	Eutrophic
Site S3	<i>Spirogyra</i> , <i>Hydra</i> , <i>Daphnia</i>	2.41	0.74	Mesotrophic
Site S4	<i>Anabaena</i> , <i>Eudorina</i> , <i>Tubifex</i>	1.28	0.46	Hypertrophic
Site S5	<i>Pediastrum</i> , <i>Bosminidae</i> , <i>Cyprinidae</i> spp.	3.05	0.89	Oligotrophic

Ecological Health Index and Integrated Assessment

The composite EHI scores along with the sub-index values for each sampling location are shown in figure 2. Sampling location S5 had the highest composite EHI score at 82.9, and belonged to the 'Good' level of ecological health because it was oligotrophic, rich in biodiversity, and least affected by anthropogenic activities. Sampling locations S1 and S3 were rated as 'Moderate', with composite EHI scores of 70.3 and 65.0, respectively, due to their relatively moderate physicochemical and biological conditions and seasonal nutrient input, though protected from extreme environmental degradation through flushing and riparian vegetation. Location S2 was rated as 'Poor' at 48.2 mainly because of high BOD, turbidity levels, and pollution tolerant biota, while location S4 had the poorest rating at 35.5 because of hyper-eutrophication, hypoxia, and reduced biological diversity. Pearson correlation analysis indicated highly significant positive correlations between EHI composite index and Shannon Diversity Index ($r = 0.94$, $p < 0.01$) while there were highly significant inverse relationships between the composite EHI and Total Phosphorus ($r = -0.92$, $p < 0.01$) and BOD ($r = -0.88$, $p < 0.01$). The biological sub-index was always most correlated with the composite EHI index as compared to the physicochemical ($r^2 = 0.87$) and habitat

sub-indices ($r^2 = 0.82$), emphasizing the dominance of biological indices in estimating the ecological status of a waterbody. Stratification of EHI scores on seasonal basis revealed that the scores obtained during monsoon period were the lowest for all sites, with an average EHI score depression of 11.4 ± 3.2 points as compared to the post monsoon EHI scores, owing to higher turbidity levels and lower Dissolved Oxygen levels during peak rainfall.

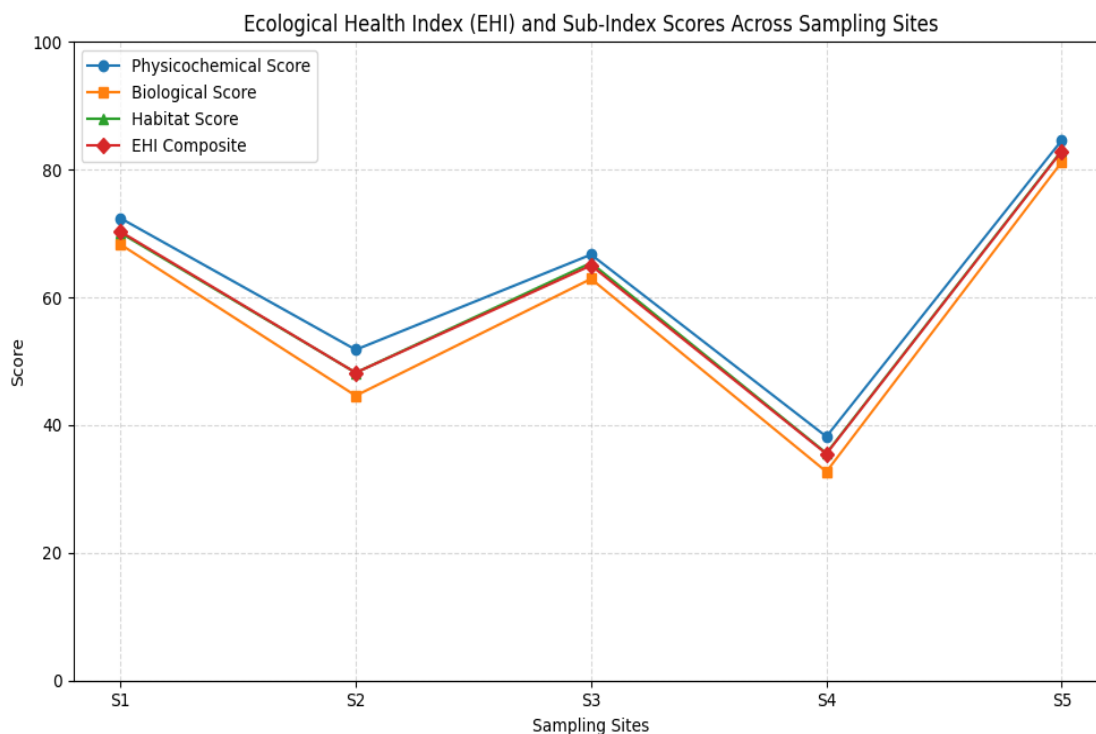


Figure 2: Composite Ecological Health Index (EHI) Scores and Sub-Index Components Across Sampling Sites

V. Discussion

Conclusion: The findings from this study illustrate that an integrated approach of multi-proxy limnological monitoring is far superior when attempting to assess freshwater system health than any method that relies on a single-parameter assessment. In particular, the distinct spatial trend of EHI from 'Good' to 'Very Poor' at reference locations located upstream and agricultural-influenced sites located downstream, respectively, mirrors the same trend seen for other comparable tropic lakes using similar limnological assessment tools and is indicative of the effect of agricultural pollution, nutrient input, and organics loading on the physical chemical characteristics of the system. This strong relationship between the overall EHI and biological diversity indices ($r^2 = 0.91$) is significant in validating the construction of the EHI and illustrating that biological assemblages are reliable indicators of the environment.

Cyanobacterial domination (*Anabaena*, *Microcystis*, *Oscillatoria*) and oligochaete-dominant bottom communities at Sites S2 and S4 confirm the presence of eutrophication and organic pollution based on total phosphorus and BOD measurements that far exceed the limits set for trophic state. The total phosphorus level measured at Site S4 (0.31 mg/L) was more than 12 times higher than the threshold for eutrophication according to the OECD standard, while the cyanobacteria bloom that occurred at the site in the pre-monsoon period creates serious threats of cyanotoxins formation, water supply disruption, and fish kill incidents. The seasonal drop in EHI values during the monsoon season (average drop of 11.4 ± 3.2 points) indicates the importance of hydrological connections in transferring catchment-sourced pollutants to the reservoirs during intense rainfall events, in line with the technical difficulties associated with high-frequency

monitoring studies in both aquaculture farms and reservoir systems. The statistical trends are important from the managerial perspective because interventions aimed at reducing nutrients through agricultural pathways into the sub-catchments of Site S2 and Site S4 will result in the most significant improvement in the composite EHI values, while the monsoon season is the key period for such studies.

The metabarcoding eDNA survey provided crucial data on biodiversity that would not be collected by traditional fish survey using nets; notably, the prevalence of the pollution-resistant Claridae family in site S4 and the presence of the diversified Cyprinidae family in Site S5. This supports the body of evidence being built regarding the use of eDNA surveys as supplementary methods in freshwater assessment. The habitat assessment sub-index, although the poorest predictor of composite EHI with $r^2 = 0.82$, was still able to provide useful contextual data on vegetation condition, substrate composition, and hydro-morphological changes, which cannot be observed via any form of chemical or biological monitoring alone. Future refinements of the system should see increased use of high-frequency sensing technology and a comprehensive eDNA database which includes amphibian and aquatic macrophyte samples, which were not part of this investigation. Linking up with remotely-sensed water quality maps, such as those from Sentinel-3 OLCI, is recommended to decrease per sample costs of monitoring.

VI. Conclusion

In this research, an integrative approach using various proxies within limnological sampling was assessed in terms of suitability for assessing ecosystem health at five sites in a tropical freshwater reservoir complex. These results show that significant heterogeneity exists in ecosystem health, which is attributed to diffuse agriculture, whereby the reference upstream sites were assessed as Good (EHI = 82.9) and the downstream nutrient-enriched sites as Very Poor (EHI = 35.5) in their ecological health status. The composite Ecological Health Index was significantly correlated with individual measures of ecosystem health, especially Shannon Diversity ($r = 0.94$, $p < 0.01$) and total phosphorous ($r = -0.92$, $p < 0.01$). The seasonal study highlighted the importance of monsoon sampling because sampling during the monsoons is vital to record the occurrence of major stress events that cause a decrease in EHI scores by as much as 11.4 ± 3.2 . The biological aspects indicated the presence of high organic loading due to the prevalence of cyanobacteria and pollution-tolerant macroinvertebrates. The results clearly show that the EHI is an effective and economical test tool for decision-making regarding reservoir management in tropical regions. These recommendations to the managers involve nutrient management in agricultural practices of the sub-watersheds for Site S2 and S4, the implementation of riparian buffers, and the adoption of real-time monitoring using sensors to augment sampling at different periods. Further studies can be directed toward the assessment of EHI score changes through time under different land-use scenarios, the incorporation of amphibians and macrophytes into the eDNA technique, and the development of remote sensing-based proxies for water quality parameters to facilitate ecological health monitoring throughout the whole reservoir watershed.

Declaration Statements

Conflict of Interest: The authors declare no conflict of interest.

Funding: This research received no specific funding.

Dataset Description: All physicochemical, biological, and eDNA datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

References

- [1] Stefanidis, K., & Papastergiadou, E. (2024). Ecological monitoring and assessment of freshwater ecosystems: new trends and future challenges. *Water*, 16(11), 1460. <https://doi.org/10.3390/w16111460>

- [2] Lee, S. W., Hwang, S. J., Lee, J. K., Jung, D. I., Park, Y. J., & Kim, J. T. (2011, January). Overview and application of the national aquatic ecological monitoring program (NAEMP) in Korea. In *Annales de Limnologie-International Journal of Limnology* (Vol. 47, No. S1, pp. S3-S14). EDP Sciences. <https://doi.org/10.1051/limn/2011016>
- [3] Contieri, B. B., Rosa, J., Scoarize, M. M. R., Urbano, V. D. A., & Benedito, E. (2024). Anthropogenic land uses lead to changes in limnological variables in Neotropical streams. *Environmental Monitoring and Assessment*, 196(8), 702. <https://doi.org/10.1007/s10661-024-12825-6>
- [4] Block, B. D., Denfeld, B. A., Stockwell, J. D., Flaim, G., Grossart, H. P. F., Knoll, L. B., ... & Hampton, S. E. (2019). The unique methodological challenges of winter limnology. *Limnology and Oceanography: Methods*, 17(1), 42-57. <https://doi.org/10.1002/lom3.10295>
- [5] Sampaio, F. G., Araújo, C. A., Dallago, B. S. L., Stech, J. L., Lorenzetti, J. A., Alcântara, E., ... & Bueno, G. W. (2021). Unveiling low-to-high-frequency data sampling caveats for aquaculture environmental monitoring and management. *Aquaculture Reports*, 20, 100764. <https://doi.org/10.1016/j.aqrep.2021.100764>
- [6] da Silva, F. L., Fushita, Â. T., da Cunha-Santino, M. B., & Bianchini Jr, I. (2022). Adopting basic quality tools and landscape analysis for applied limnology: An approach for freshwater reservoir management. *Sustainable water resources management*, 8(3), 65. <https://doi.org/10.1007/s40899-022-00655-8>
- [7] Rocha, L., Hegoburu, C., Torremorell, A., Feijoó, C., Navarro, E., & Fernández, H. R. (2020). Use of ecosystem health indicators for assessing anthropogenic impacts on freshwaters in Argentina: a review. *Environmental Monitoring and Assessment*, 192(9), 611. <https://doi.org/10.1007/s10661-020-08559-w>
- [8] Sakata, M. K., Watanabe, T., Maki, N., Ikeda, K., Kosuge, T., Okada, H., ... & Minamoto, T. (2021). Determining an effective sampling method for eDNA metabarcoding: a case study for fish biodiversity monitoring in a small, natural river. *Limnology*, 22(2), 221-235. <https://doi.org/10.1007/s10201-020-00645-9>
- [9] Pomati, F., Jokela, J., Simona, M., Veronesi, M., & Ibelings, B. W. (2011). An automated platform for phytoplankton ecology and aquatic ecosystem monitoring. *Environmental science & technology*, 45(22), 9658-9665. <https://doi.org/10.1021/es201934n>
- [10] Pinilla, G. (2010). An index of limnological conditions for urban wetlands of Bogotá city, Colombia. *Ecological Indicators*, 10(4), 848-856. <https://doi.org/10.1016/j.ecolind.2010.01.006>
- [11] Raj, M. P., & Philip, R. S. (2024). Unravelling the seasonal dynamics of limnological parameters and assessment of ecological health: A case study of Lingadheeranahalli Lake in Bangalore North, Karnataka, India. *Biosciences Biotechnology Research Asia*, 21(3), 1087. <http://dx.doi.org/10.13005/bbra/3288>
- [12] Lane, J. Q., Roddam, C. M., Langlois, G. W., & Kudela, R. M. (2010). Application of Solid Phase Adsorption Toxin Tracking (SPATT) for field detection of the hydrophilic phycotoxins domoic acid and saxitoxin in coastal California. *Limnology and Oceanography: Methods*, 8(11), 645-660. <https://doi.org/10.4319/lom.2010.8.0645>
- [13] Chen, J., Wang, Y., Li, F., & Liu, Z. (2019). Aquatic ecosystem health assessment of a typical sub-basin of the Liao River based on entropy weights and a fuzzy comprehensive evaluation method. *Scientific Reports*, 9(1), 14045. <https://doi.org/10.1038/s41598-019-50499-0>
- [14] Kaboré, I., Tampo, L., Bancé, V., Daboné, C., Mano, K., Ayoro, H. J., & Ouéda, A. (2022). Preliminary biological data of Sahel wetland ecosystems in Burkina Faso: Implications for ecological health assessment. *Frontiers in Conservation Science*, 3, 913333. <https://doi.org/10.3389/fcosc.2022.913333>
- [15] Euclide, P. T., Lor, Y., Spear, M. J., Tajjioui, T., Vander Zanden, J., Larson, W. A., & Amberg, J. J. (2021). Environmental DNA metabarcoding as a tool for biodiversity assessment and monitoring: Reconstructing established fish communities of north-temperate lakes and rivers. *Diversity and Distributions*, 27(10), 1966-1980. <https://doi.org/10.1111/ddi.13253>

- [16] Khanaa, V., Thooyamani, K. P., & Udayakumar, R. (2013). Categorization and forecast of critical cardiac arrhythmias using filter bank and fuzzy classification approach. *Middle-East Journal of Scientific Research*, 18(12), 1798-1802.
- [17] Boutros, N., Shortis, M. R., & Harvey, E. S. (2015). A comparison of calibration methods and system configurations of underwater stereo-video systems for applications in marine ecology. *Limnology and Oceanography: Methods*, 13(5), 224-236. <https://doi.org/10.1002/lom3.10020>
- [18] Raj, M. P., & Philip, R. S. (2024). Seasonal Dynamics and Ecological Health of Ullal Lake in Bengaluru North, Karnataka, India Introspected through Limnological Perspective and Physiological Response Assessment on Zebrafish (*Danio rerio*). *Asian Journal of Biological and Life Sciences*, 13, 297-307. <https://doi.org/10.5530/ajbls.2024.13.38>
- [19] Sadulla, S. (2024). State-of-the-art techniques in environmental monitoring and assessment. *Innovative Reviews in Engineering and Science*, 1(1), 25-29.