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Assessing Anthropogenic Pressure through Biomonitoring: Aquatic Biota as Indicators of Water Quality in an Urban Lake

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Abstract

Urban areas in Jakarta face significant pressure on clean water resources due to increasing population and anthropogenic activities. This research aims to conduct biomonitoring of the Situ Bambon Ciracas lake ecosystem, East Jakarta, by analyzing water quality and the community structure of macrozoobenthos, phytoplankton, and zooplankton as bioindicators. A descriptive quantitative method was used, involving measurements of water physical-chemical parameters (TDS, TSS, pH, BOD, COD, Total-P) and identification of aquatic biota. The results indicate that the water quality of Situ Bambon Ciracas lake is lightly to moderately polluted, dominated by organic compounds. BOD (5–34.67 mg/L) and COD (17.05–193.56 mg/L) values consistently exceeded the Class 3 water quality standards, and TDS showed an increasing trend. The biota community structure reflects these conditions: macrozoobenthos showed moderate diversity (H′=1.2, E=0.6). Phytoplankton (H′=3.12–3.2, E=0.74–0.76) and zooplankton (H′=2.11–2.16, E=0.76–1.95) showed high diversity and evenness, but were dominated by bioindicator species tolerant to organic pollution (e.g., *Oscillatoria* sp., *Nitzschia* sp., *Colpoda* sp., *Closterium* sp.). The positive correlation between the abundance of these bioindicator species and high BOD and COD confirms organic waste as the main driver of ecological change. In conclusion, the Situ Bambon Ciracas lake ecosystem is under significant anthropogenic pressure. The dominance of pollution-tolerant species, despite existing diversity, highlights the urgency of comprehensive management and restoration efforts to maintain the sustainability of this urban lake.

Keywords: biomonitoring; aquatic bioindicators; urban lake pollution; anthropogenic pressure; water quality assessment

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INTRODUCTION

Urban areas such as the Special Capital Region of Jakarta face mounting challenges in maintaining clean water availability and mitigating environmental pollution (Alao et al., 2024). Rapid population growth and expansive infrastructure development have escalated water demand beyond the capacity of existing resources. According to the Central Statistics Agency of DKI Jakarta Province (2022), the population reached 10,644,776 in 2021, marking a 0.45% increase from the previous year. This demographic trend intensifies pressure on natural resources, particularly water, which is increasingly scarce and vulnerable to quality degradation. The emphasized that urbanization and industrialization in Indonesia are strongly associated with declining groundwater quality, reflecting heightened ecological stress that surpasses current environmental mitigation efforts (Haerudin et al., 2019; Mulyasari et al., 2019; Whiteley et al., 2021).

Excessive groundwater extraction in urban settings has triggered complex environmental issues, including severe land subsidence and restricted access to potable water. Simultaneously, surface water pollution remains a critical concern. Untreated domestic, industrial, and agricultural waste is frequently discharged into water bodies, deteriorating water quality and diminishing their viability as raw water sources (Jha et al., 2020; Yu et al., 2018; Zhao et al., 2020). In their study of urban rivers in Yogyakarta, found that population density and slum settlement ratios were positively correlated with elevated levels of organic pollutants such as BOD, COD, and TSS highlighting the role of anthropogenic activities in driving water quality degradation (Calligaris et al., 2018; Duan et al., 1999).

Urban lakes, reservoirs, ponds (situ), and embankments serve essential hydrological functions, acting as surface water sources, groundwater recharge zones, and flood control systems. These roles are particularly vital during the rainy season to prevent inundation and during dry periods to sustain water availability (Blanchette et al., 2010; Huang & Korai, 2025). Beyond ecological services, these water bodies support recreational and economic activities such as fishing and aquaculture, underscoring their social and economic significance. Freshwater ecosystems are among the most biodiverse biomes, hosting over 10,000 fish species and one-third of all vertebrate species . Yet, they are also among the most threatened globally, with widespread declines reported (Sugianti & Hafiludin, 2022).

Situ Bambon Ciracas lake, located in East Jakarta near the PKP Foundation Campus, exemplifies such a multifunctional urban lake. It currently serves as a rainwater retention basin and supports local fishing activities. However, its potential as a clean water source remains underutilized. Routine monitoring by the East Jakarta Environmental Agency indicates that the lake is lightly to moderately polluted (Luo et al., 2018; Nigro et al., 2017; Xia et al., 2025). Previous research reported that many urban lakes in Jakarta fail to meet national recreational water standards due to elevated pollutant levels, with Water Quality Index (WQI) values fluctuating seasonally and categorized as moderate to poor. These findings suggest that while urban lakes hold promise for water resource development, they require comprehensive management to improve their ecological condition (Ibrahim, 2019).

In sustainable lake management, monitoring must encompass both abiotic parameters (e.g., pH, BOD, COD, Total-P) and biotic indicators (Al-Khashman et al., 2017; Mutri et al., 2024; Pasika & Gandla, 2020). Biomonitoring using living organisms to assess environmental quality has proven effective in detecting ecological changes that may not be captured by physicochemical measurements alone highlighted that bioindicators offer a cost-effective and integrative approach to assess pollution, serving as early warning systems that reflect cumulative stressor impacts over time (Chen et al., 2025; Mousavi Mashhadi et al., 2016). Aquatic macroinvertebrates, or macrobenthos, are widely used bioindicators due to their sensitivity to environmental changes, diverse taxonomy, and rapid response to pollutants (Al-Ghamdi et al., 2014; Bodrud-Doza et al., 2016; Jan et al., 2021; Nigro et al., 2017; Zhao et al., 2020).

This group includes Mollusca, Annelida, and aquatic insects such as Ephemeroptera, Diptera, Trichoptera, and Plecoptera. Phytoplankton, as primary producers, also play a crucial role in aquatic ecosystems by generating oxygen and sequestering carbon through photosynthesis (Pore et al., 2020). Their species diversity is a key indicator of ecosystem health, with high diversity typically reflecting low contamination levels. This study applies biomonitoring to assess the community structure of macrozoobenthos and phytoplankton in Situ Bambon Ciracas lake, aiming to evaluate water quality and ecological integrity under anthropogenic pressure. The findings are expected to provide essential baseline data to inform sustainable urban lake management strategies and support the potential utilization of the lake as a clean water source.

METHOD

The methodology describes in detail the steps taken in this research. The explanation of these steps starts from the preparation stage, field activities, to field data analysis, and then ends with the results following the research objectives. The research location is Situ Klapadua/Situ Bambon Ciracas lake at Jalan Raya PKP 6°20'19.99"LS 106°53'8.57"BT as shown in **Figure 1**. The research was conducted from January to March 2023.

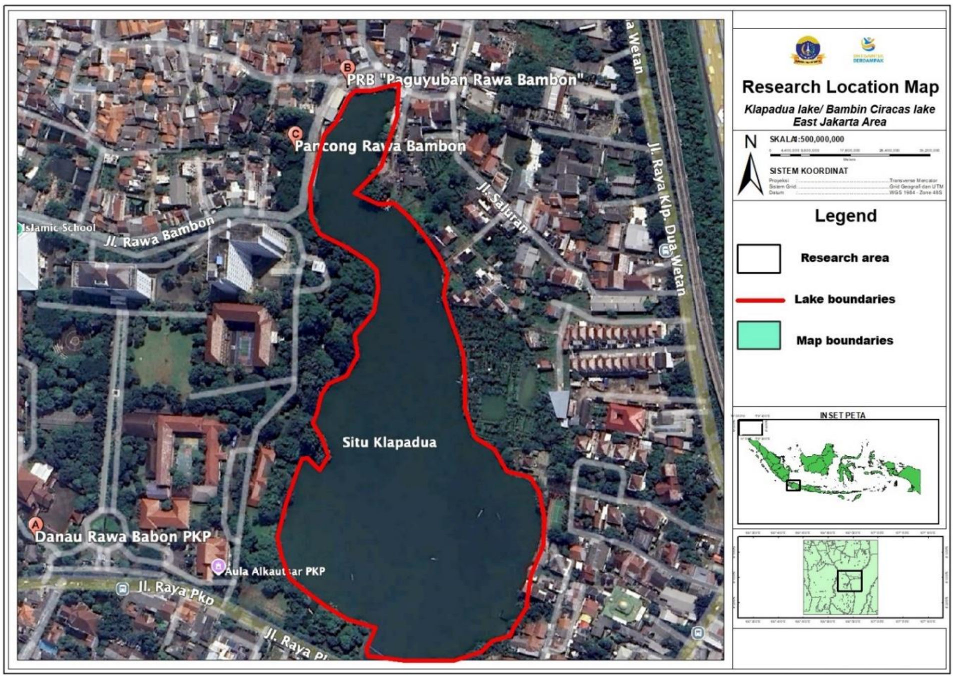


Figure 1. Research site map of Situ Klapadua/Situ Bambon Ciracas lake

Research Equipment

The equipment used in this research includes instruments for measuring physical and chemical water parameters in the field and laboratory, such as GPS, thermometers, pH meters, DO meters, turbidimeters, UV-Vis spectrophotometers, and BOD incubators. Additionally, equipment for biological sample collection and analysis was used, including plankton nets, Ekman grabs, sample bottles, binocular and compound microscopes, counting chambers, Petri dishes, forceps, and preservatives for fixing macrozoobenthos, phytoplankton, and zooplankton samples.

Data Acquisition

In order to obtain a comprehensive picture of the conditions in Situ Bambon Ciracas lake, the data collection phase was meticulously designed, integrating direct field observations with the utilization of established sources. This approach was divided into two main pillars: primary data acquisition and secondary data exploration.

The collection of primary data forms the core of the field investigation, where essential information is recorded directly. A vital aspect of this data includes the measurement of biotic factors, namely the inventory and characterization of macrozoobenthos and phytoplankton communities, which serve as crucial biological indicators for the health of aquatic ecosystems. Equally important, abiotic factors are also measured in the field, specifically the identification and description of the basic substrate type of the waters.

On the other hand, secondary data complements the research with rich contextual information from existing databases. This category includes data on physical and chemical water quality, such as concentrations of Total Coliform and Fecal Coliform, providing background on pollution conditions. Furthermore, field guides and scientific literature from books and journals serve as crucial references, enriching the analysis and interpretation of field findings. This comprehensive approach ensures the completeness of data for a holistic ecological assessment of Situ Bambon Ciracas lake.

Data Processing and Data Interpretation

The collected data from measurements of physical-chemical water parameters and identification of aquatic biota will be processed and analyzed quantitatively. For physical-chemical parameters (TDS, TSS, pH, BOD, COD, Total-P), data will be processed to observe trends and fluctuations, and then compared with applicable water quality standards (PP No. 22 Tahun 2021) to determine water quality status (Ibrahim, 2019; Jalili et al., 2019; Jha et al., 2020). Analysis of macrozoobenthos, phytoplankton, and zooplankton community structure will be performed by calculating the Shannon-Wiener diversity index (H') (Nayanathara Thathsarani Pilapitiya & Ratnayake, 2024) using Equation (1) as follows:

$$H' = -\sum \frac{ni}{N} log_2(\frac{ni}{N}) \quad ...(1)$$

where *ni* is the number of individuals of the i-th species and N is the total number of individuals of all species. Additionally, the Evenness index (E) will also be calculated to assess the evenness of individual distribution among species, using Equation (2).

$$E = \frac{H'}{log_2(S)} \quad ...(2)$$

where S is the total number of species. To understand the relationship between the distribution of plankton and benthos with environmental parameters, multivariate analysis will be applied, which can help identify the dominant environmental factors influencing the community structure of aquatic biota in Situ Bambon Ciracas lake.

RESULTS AND DISCUSSION

The water quality of Situ Bambon Ciracas lake indicates light to moderate pollution, primarily driven by organic compounds. This condition reflects the broader challenges faced by urban lakes in Jakarta, which are under pressure from land use change, sedimentation, eutrophication, and untreated waste discharge (Luo et al., 2018). The following subsections detail the physicochemical characteristics of the lake and their implications for ecosystem health.

Physical Parameters

Additional physical parameters include thermal stratification and mixing processes, evaporation rates, and wind-driven surface dynamics. Thermal stratification governs the vertical distribution of heat, nutrients, and oxygen, while wind forcing contributes to surface mixing, wave generation, and sediment resuspension (Umar et al., 2020). Evaporation constitutes a major component of the lake water balance, particularly in tropical and arid regions, and is strongly influenced by surface temperature, solar radiation, and atmospheric conditions. Collectively, these physical parameters provide essential insights into the hydrological behavior and environmental status of lakes and form a critical basis for integrated lake monitoring using both in situ measurements and Earth observation data.

Total Dissolved Solids (TDS) in Situ Bambon Ciracas lake show an increasing trend over time, suggesting accumulation of dissolved minerals and organic residues from biomass decomposition, surface runoff, and anthropogenic waste. Although current TDS levels remain below the EPA drinking water threshold (500 mg/L), the upward trajectory warrants attention due to potential impacts on aquatic biota and water usability (Siebert et al., 2010; Yu et al., 2018). Total Suspended Solids (TSS) exhibit a decreasing trend, possibly due to natural sedimentation and flocculation. However, residual suspended solids can still impair light penetration and photosynthetic activity. Similar fluctuations have been observed in anthropogenically influenced wetlands such as Baraila, India, where TSS ranged from 16.5 to 457.5 mg/L, highlighting the dynamic nature of sediment input in urban watersheds **(Figure 2)**.

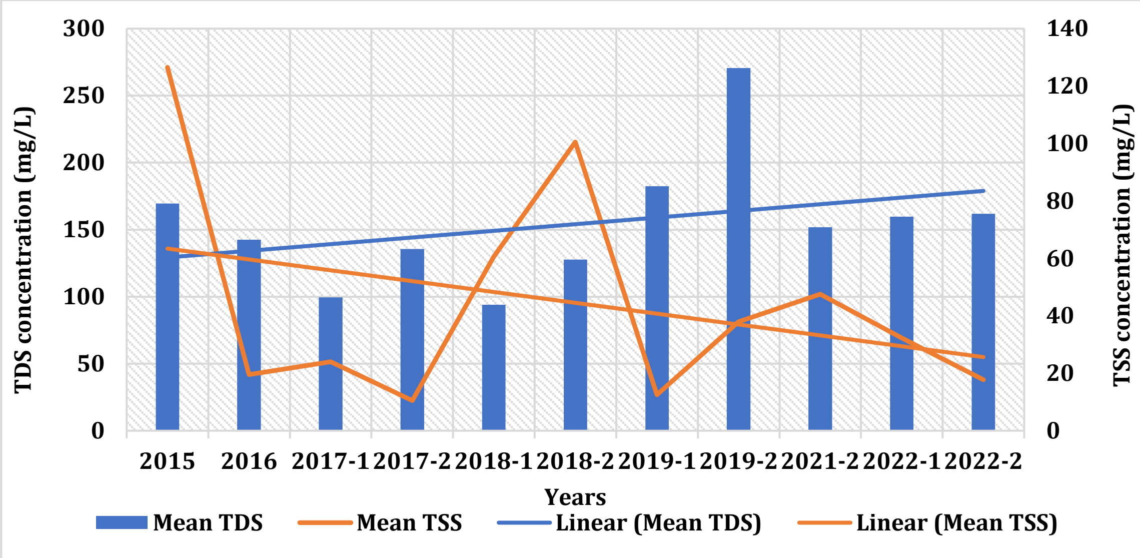


Figure 2. Trends in total dissolved solids (TDS) and total suspended solids (TSS) concentrations

Chemical Parameters

pH levels range from 7.0 to 8.9, indicating neutral to slightly alkaline conditions **(Figure 3)**. These fluctuations may result from phytoplankton photosynthesis or alkaline domestic waste inputs. Alkaline pH can influence nutrient solubility and pollutant toxicity, affecting aquatic life resilience. Biochemical Oxygen Demand (BOD) values range from 5 to 34.67 mg/L, consistently exceeding the Class 3 water quality standard (6 mg/L) set by Government Regulation No. 22 of 2021 **(Figure 4)**. Elevated BOD reflects intense microbial decomposition of organic matter, which can deplete dissolved oxygen and threaten aerobic organisms. Chemical Oxygen Demand (COD) values fluctuate between 17.05 and 193.56 mg/L, also surpassing the Class 3 threshold (40 mg/L). The strong correlation between BOD and COD supports the conclusion that organic pollutants likely from domestic and agricultural sources are the primary contaminants (Jan et al., 2021; Luo et al., 2018; Yu et al., 2018).

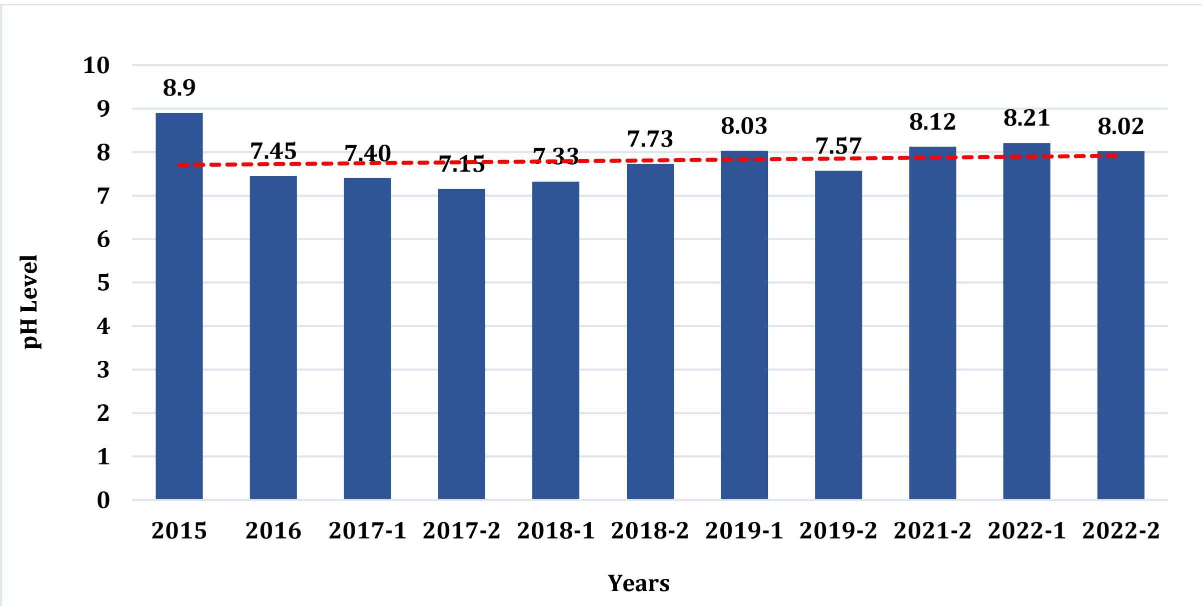


Figure 3. The pH levels of the waters from 2015-2022

Total Phosphorus (Total-P) concentrations have declined from 2015 to 2022, with a peak value of 0.26 mg/L, remaining within the safe limit (1.0 mg/L) **(Figure 5)**. However, phosphorus remains a critical nutrient that can trigger eutrophication even at low concentrations. Seasonal variation in Total-P, as reported in Baraila wetland, underscores the need for continuous monitoring.

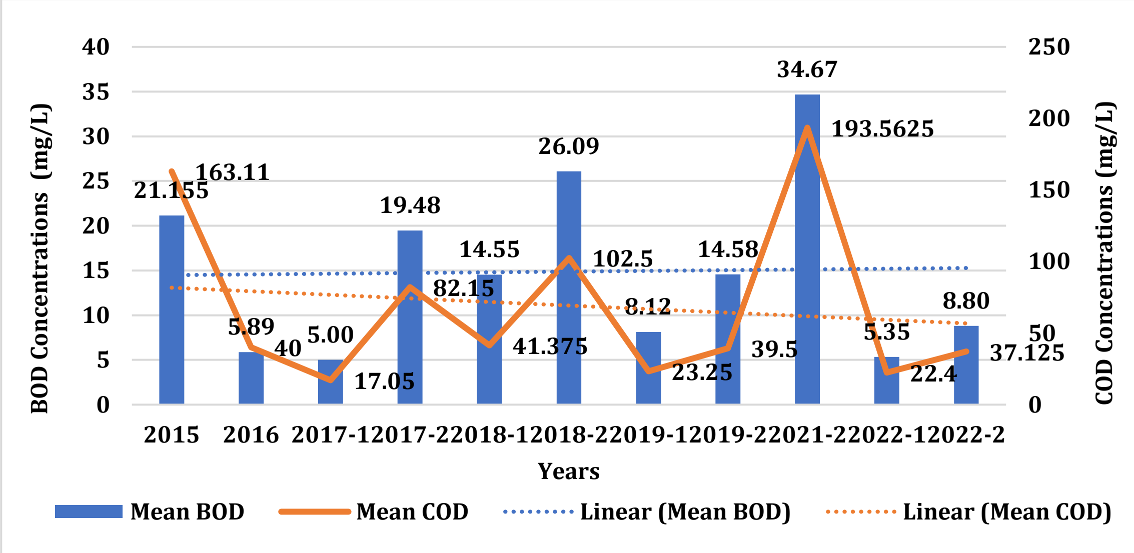


Figure 4. Concentrations of BOD and COD

This study reveals several important new findings that enhance the understanding of ecological stress in urban lake environments. Despite high diversity and evenness indices in phytoplankton and zooplankton communities, the dominance of pollution-tolerant species such as *Oscillatoria sp., Nitzschia sp.*, and *Colpoda sp*. indicates that species composition is a more reliable indicator of water quality than diversity metrics alone. Ordination analysis further confirms a strong positive correlation between elevated BOD and COD levels and the abundance of these tolerant taxa, validating their role as bioindicators of organic pollution. Notably, the frequent presence of *Oscillatoria* and *Scenedesmus genera* known to produce cytotoxins under nutrient-rich conditions raises concerns about potential health risks for aquatic organisms and humans, emphasizing the need for toxin-specific monitoring.

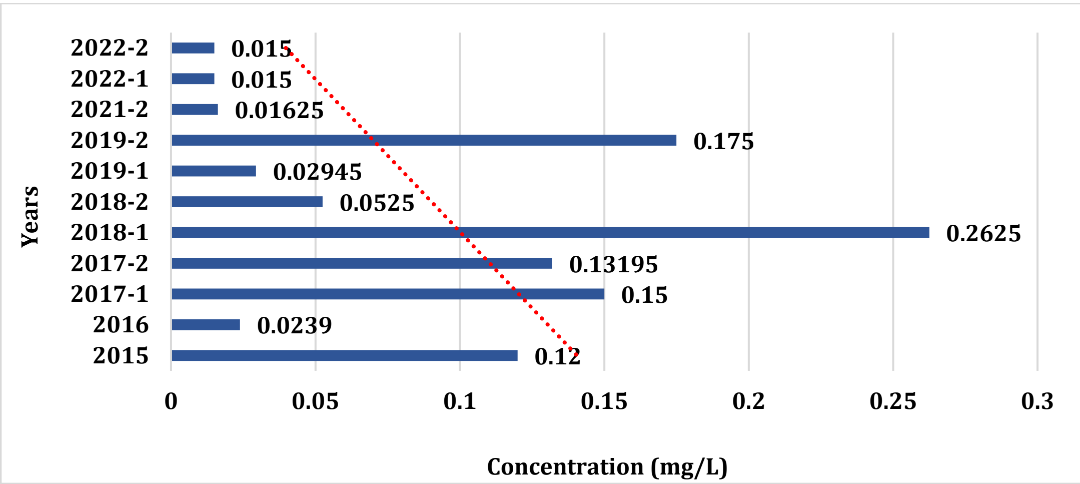


Figure 5. Total phosphorus concentration from 2015 to 2022

Another significant observation is the unusually high evenness value (E = 1.95) in the zooplankton community, which may reflect either a computational anomaly or a unique ecological condition where species abundances are nearly uniform; this warrants further investigation. Although Total Phosphorus concentrations have declined over time, the continued dominance of eutrophic indicator species suggests that internal nutrient cycling or sediment release may sustain eutrophic conditions, even when chemical parameters appear within safe limits. Additionally, spatial variation in species composition across the inlet, middle, and outlet zones of the lake reflects a pollution gradient, offering practical insight for targeted remediation strategies such as sediment dredging or buffer zone establishment. Collectively, these findings underscore the value of integrated biomonitoring in diagnosing ecological stress and guiding sustainable urban lake management.

Community Structure of Benthos, Phytoplankton, and Zooplankton

The analysis of aquatic biota community structure, including benthos, phytoplankton, and zooplankton, is crucial in biomonitoring for assessing the health of aquatic ecosystems. These organisms act as bioindicators that are sensitive to changes in water quality due to their rapid response to environmental conditions and relatively short life cycles.

The benthic community in Situ Bambon Ciracas lake shows moderate diversity, with a Shannon-Wiener Diversity Index (H′) of 1.2 and an Evenness Index (E) of 0.6. Based on general criteria, an H′ value between 1 and 3 indicates moderate species diversity, and an E value between 0.6 and 1 indicates high evenness, suggesting a stable community that may, however, be under stress. Identified species include Diptera (pupa), Coleoptera (pupa), and Penaeus monodon. The presence of specific species in the benthic community can provide an overview of the sediment conditions and the level of pollution at the bottom of the waters, as benthos have limited mobility and tend to accumulate pollutants. Benthic macroinvertebrates are sensitive to short-term and long-term environmental variations and respond quickly to pollutants such as excess nutrients, sediments, and metals. These results are consistent with research in the Namu Sira-sira River, North Sumatra, which also found the macrozoobenthos diversity index to be in the moderate category (H′ 1.42–1.60) in waters ranging from fairly good to lightly polluted. Another study on urban lakes in Karelia, Russia, also classified the waters as moderately polluted based on zoobenthos, with a dominance of groups tolerant to environmental conditions, such as Chironomidae larvae, which indicates the community's adaptation to anthropogenic pressure.

Phytoplankton act as primary producers and form the base of the food web in aquatic ecosystems. The species diversity of phytoplankton in Situ Bambon Ciracas lake is generally high, with H′ values ranging from 3.12 to 3.2 at the inlet, middle, and outlet of the lake. The evenness (E) values are also high, ranging from 0.74 to 0.76, indicating a stable community. Despite high diversity, the dominance of several phytoplankton species is a concern. Species such as Nitzschia palea, Oscillatoria curviceps, Cyclotella meninghiana, and Gomphonema parvulum show dominance. Specifically, the genera Oscillatoria and Scenedesmus were observed in the highest and most common numbers. These genera are known to be pollution-tolerant and are frequently found in organically polluted water. The presence of *Oscillatoria sp.* also shows a direct relationship with agricultural wastewater pollution. The dominance of Cyanophyta (such as Oscillatoria) in nutrient-rich environments has also been reported in studies in Thai lentic ecosystems, where phytoplankton density peaked in hypereutrophic waters. This indicates that high diversity does not always mean healthy water conditions if dominated by pollution indicator species. Research in Lake Maybalyk, Kazakhstan, also classified water quality as moderately polluted based on the phytoplankton saprobic index, emphasizing the role of microalgae as water quality indicators.

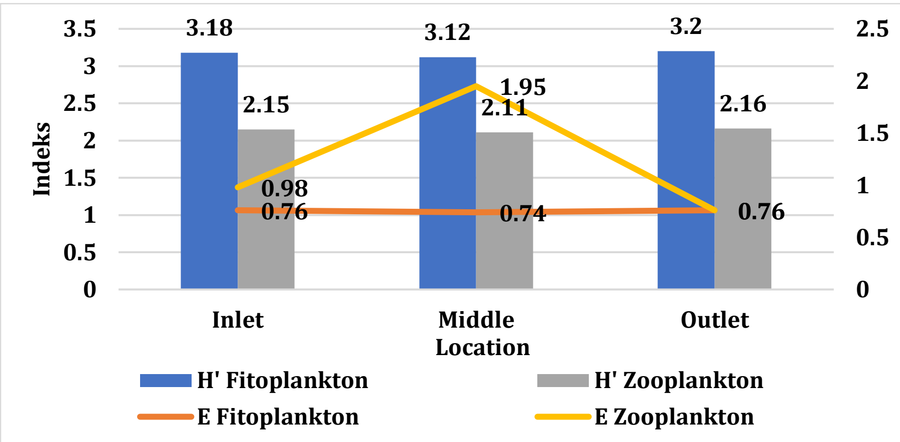


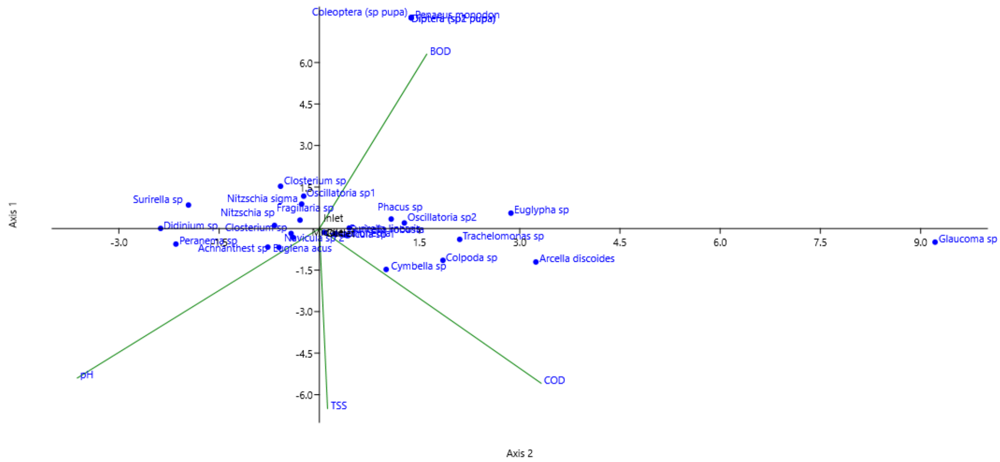
Figure 6. The diversity index and evenness index of plankton species in Situ Bambon Ciracas lake

The zooplankton community in Situ Bambon Ciracas lake shows moderate diversity, with H' values between 2.11 and 2.16, and remarkably high evenness (E values ranging from 0.76 to 1.95), indicating a very stable community **(Figure 6)**. Key identified species, such as *Colpoda sp., Didinium sp., Glaucoma sp., Arcella discoides, and Closterium sp.*, offer crucial insights into the water's condition.

For instance, Colpoda sp. is polysaprobic, thriving in highly polluted environments, while *Glaucoma sp*. and *Arcella sp.* discoides are found in eutrophic waters. *Closterium sp*. is generally associated with polluted waters, and the presence of ciliates like Didinium sp. also points to polysaprobic conditions in rivers. This evidence strongly suggests the presence of organic pollution in the lake. Furthermore, a study in Brazil's Almada River revealed that urban pollution impacts zooplankton diversity, leading to lower species richness in active decomposition zones. However, the overall zooplankton abundance was higher in these zones, implying that even as diversity declines, tolerant species can flourish in polluted conditions by utilizing abundant nutrients.

The Interrelationship between Water Quality and Biotic Community Structure

The ordination of the relationship between plankton and benthos distribution based on environmental parameters in Situ Bambon Ciracas lake **(Figure 7)** provides a strong visualization of the interactions between the physical-chemical conditions of the waters and the biotic community. The ordination diagram illustrates how specific species correlate with measured environmental parameters, offering visual evidence of the impact of pollution.



Axis	Eigenvalue	% of constr. in.	% of total inertia
1	0.032947	80.88	80.88
2	0.0077881	19.12	19.12

Axis	Eigenval	p
1	0.03295	0.822
2	0.007788	0.338

Figure 7. Ordination of the relationship between the distribution of plankton and benthos based on environmental parameters in Situ Bambon Ciracas lake

A positive correlation between pollution-tolerant phytoplankton and zooplankton species (e.g., *Oscillatoria sp., Scenedesmus sp., Achnanthes sp., Gomphonema sp., Nitzschia sp*. among phytoplankton, and *Colpoda sp., Didinium sp., Glaucoma sp., Arcella discoides, Closterium sp.* among zooplankton) and high BOD and COD values confirms that organic pollution is the primary driver of community structure changes in Situ Bambon Ciracas lake. The increase in decomposed organic matter leads to heightened microorganism activity, which in turn reduces dissolved oxygen availability and creates favorable conditions for pollution-tolerant species. This observation is consistent with studies elsewhere; for example, a study in Lake Taihu, China, found a significant positive relationship between phytoplankton biomass and COD and BOD, alongside the influence of temperature and total phosphorus on phytoplankton dynamics.

Similarly, research in Lake Geriyo, Nigeria, identified positive correlations between specific phytoplankton and zooplankton groups with parameters such as BOD, COD, and ammonia, reinforcing the pattern of biotic response to organic pollutant loads. While phytoplankton diversity and zooplankton evenness are relatively high, the dominance of pollution bioindicator species points to significant environmental stress. Diversity indices, though useful, have limitations as they do not always reveal whether a community comprises tolerant or intolerant species, and community responses to increased pollution are not always linear.

These findings are consistent with the literature asserting that biomonitoring using benthic macroinvertebrates and plankton is an effective approach for assessing the quality of aquatic ecosystems. Changes in community structure, such as reduced diversity of sensitive species and dominance by tolerant species, form the basis for evaluating anthropogenic impacts in urban environments like Situ Bambon Ciracas lake, providing crucial information for future management and restoration strategies.

CONCLUSION

Biomonitoring conducted at Situ Bambon Ciracas lake reveals that the lake is experiencing light to moderate pollution, predominantly driven by organic compounds. This is evidenced by consistently elevated Biochemical Oxygen Demand (BOD) values, ranging from 5 to 34.67 mg/L, which exceed the Class 3 water quality standard of 6 mg/L. Similarly, Chemical Oxygen Demand (COD) values fluctuate between 17.05 and 193.56 mg/L, frequently surpassing the regulatory limit of 40 mg/L. An increasing trend in Total Dissolved Solids (TDS) further indicates the accumulation of dissolved minerals and organic substances, reflecting ongoing anthropogenic input from domestic, agricultural, and industrial sources. The structure of the aquatic biota community mirrors these pollution conditions. Macrozoobenthos exhibit moderate diversity ($H' = 1.2$), suggesting a community under ecological stress but still functionally present. Phytoplankton and zooplankton communities show high diversity ($H' = 3.12–3.2$ and $H' = 2.11–2.16$, respectively) and high evenness, yet are dominated by pollution-tolerant species such as *Oscillatoria sp*., *Nitzschia sp*., *Colpoda sp*., and *Closterium sp*.. These taxa are known bioindicators of organic pollution and eutrophic conditions. Ordination analysis confirms a strong positive correlation between the abundance of these species and elevated BOD and COD levels, reinforcing the conclusion that organic waste is the primary driver of ecological change in the lake. Importantly, the dominance of tolerant species despite the presence of overall diversity suggests that the ecosystem is undergoing a shift toward a pollution-adapted state. This condition reflects significant anthropogenic pressure and highlights the limitations of relying solely on diversity indices to assess ecological health. The emergence of cytotoxin-producing genera such as Oscillatoria and Scenedesmus also raises concerns about potential health risks for aquatic organisms and humans, especially under nutrient-rich conditions. Spatial variation in species composition across the inlet, middle, and outlet zones of the lake indicates a pollution gradient, offering practical insights for targeted management interventions. Although Total Phosphorus levels have declined over time, the persistent dominance of eutrophic indicator species suggests that internal nutrient cycling or sediment release may continue to sustain ecological stress.

AUTHOR CONTRIBUTIONS

Conceptualization, NC and HA; methodology, H; software, RI; validation, FMJ, NC, and ARN; formal analysis, HA; investigation, H; resources, RI; data curation, FMJ; writing—original draft preparation, ARN; writing—review and editing, NC; visualization, HA; supervision, H; project administration, RI; funding acquisition NC.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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