Water quality analysis of Serantangan Lake using macrozoobenthos as indicators

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Abstract. Illegal gold mining in West Kalimantan has led to the formation of Serantangan Lake, a post-mining void with potential for freshwater resources, tourism, and agriculture. However, mercury contamination and degraded water quality pose significant ecological and public health risks. This study evaluated the lake's water quality using macrozoobenthos as bioindicators across three stations representing varied environmental conditions. The research was conducted from December 2024 to February 2025. A total of 1,078 macrozoobenthos individuals were collected, representing 14 genera, 14 families, and 9 orders. Diversity indices revealed the highest biodiversity at Station I (H′ = 1.13, E = 0.98) and the lowest at Station III (H′ = 0.42, E = 0.37), which was adjacent to active mining. Dominance index (D) and Family Biotic Index (FBI) further confirmed poor ecological conditions at Station III (D = 0.41, FBI = 8.6), indicating very poor water quality. Physicochemical measurements showed elevated mercury levels (up to 0.0027 mg/L) and BOD (up to 12.6 mg/L), with transparency, mercury contamination, and hardness significantly correlated with macrozoobenthos abundance and diversity. Canonical Correspondence Analysis (CCA) and Principal Component Analysis (PCA) revealed distinct macrozoobenthos assemblages influenced by environmental parameters.

1 Introduction

The primary environmental impact of illegal gold mining, particularly through open-pit methods is the creation of large excavation sites known as "voids". Over time, these voids accumulate water and transform into artificial bodies of water, commonly referred to as pit lakes. In West Kalimantan, especially in the Sagatani area of South Singkawang District, such mining practices have been widespread, a prominent example of this transformation is exemplified by the formation of Serantangan Lake.

Serantangan Lake is located in Sagatani Subdistrict, South Singkawang District, approximately 22 kilometers from the center of Singkawang City, West Kalimantan. The lake has significant potential in freshwater resources, fisheries, and ecotourism.

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Recognizing these potentials, the Singkawang City Government has proposed several utilization initiatives, including designating the lake as a raw water source for South Singkawang, promoting it as a freshwater tourism destination, and integrating it into the irrigation system for agriculture and aquaculture [1]. However, the continued practice of illegal gold mining has severely degraded the lake's water quality. Mercury (Hg) contamination has been documented across the lake's 400 hectare expanse [2], raising not only ecological concerns but also public health risks, particularly for communities relying on the lake for water, food, and recreation. These threats underscore the urgent need for environmental assessment, including a comprehensive water quality assessment.

Given the limitations of physicochemical monitoring alone, biological indicators offer a more integrative and responsive measure of ecological health. To evaluate the water quality of Serantangan Lake, biological assessment using aquatic organisms, particularly macrozoobenthos offers a sensitive and informative approach. Macrozoobenthos are benthic invertebrates that live in close contact with sediments, making them especially susceptible to pollutants such as organic matter and heavy metals, including mercury [3]. Their wide distribution, ecological significance, and rapid response to environmental stressors make them reliable indicators of water quality and ecosystem health [4].

While macrozoobenthos based assessments have been conducted in various Indonesian freshwater systems, this study represents a significant advancement by applying these methods to a tropical post mining lake a context that remains largely unexplored in Indonesia. Similar assessments in countries on Southeast Asia have highlighted the challenges of mercury contamination and biodiversity loss in post mining aquatic ecosystems [5]. Furthermore, by situating Serantangan Lake within the broader context of tropical post-mining lakes in Southeast Asia, this study provides comparative insights into regional patterns of ecological status of pit lake.

Serantangan Lake remains understudied in terms of biological water quality assessment, particularly using macrozoobenthos as indicators of mining-related contamination. This study aims to assess the ecological condition of Serantangan Lake by analyzing the abundance and diversity of macrozoobenthos communities, examining their correlation with key physicochemical water parameters, and applying biotic indices to evaluate overall water quality.

2 Materials and Methods

2.1 Study area and sampling design

The research was conducted over a three-month period, from December 2024 to February 2025, at Serantangan Lake, located in Singkawang District, Singkawang City, West Kalimantan Province. Macrozoobenthos samples were taxonomically identified at the Laboratory of the Aquatic Resources Management, while physicochemical water parameters were analyzed at the Soil Quality and Health Laboratory, Faculty of Agriculture, Universitas Tanjungpura, and at the Standardization and Industrial Services Center (BARISTAND) in Pontianak City. Sampling stations were selected using a purposive sampling method to represent distinct environmental conditions across the lake. Station 1 was situated on the left side of the lake, an area designated for raw water source by the regional water company (PDAM). Station 2 represented the central outflow, which is utilized for rice field irrigation. Station 3 was positioned on the right edge, adjacent to ongoing gold mining activities. The research stations and their geographic coordinates are presented in Figure 1 and Table 1

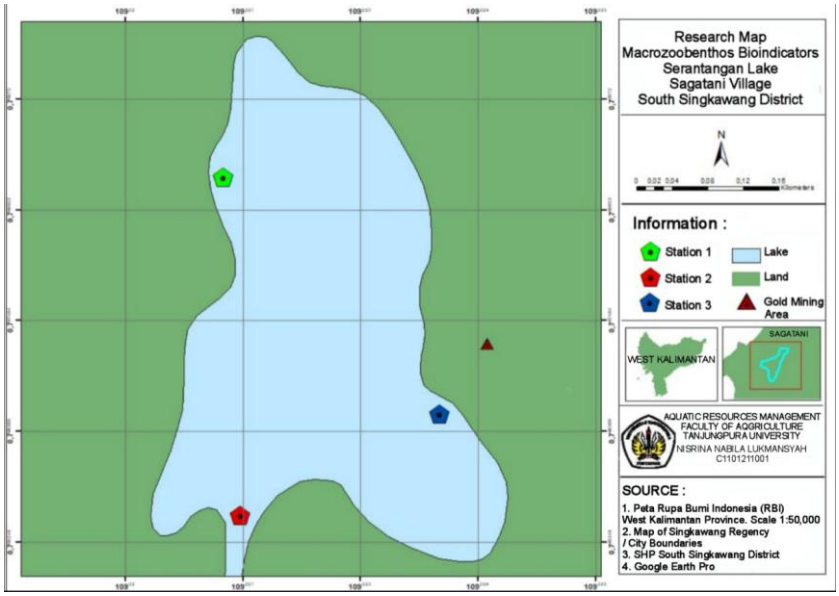

Fig. 1. Map of Sampling Sites and Adjacent Gold Mining Area in Serantangan Lake

Table 1. GPS Coordinates of Sampling Stations in Serantangan Lake

Observation stations	Coordinates
Station 1	0°45'28.5552"N, 109°0'58.7304"E
Station 2	0°45'25.974"N, 109°0'59.4612"E
Station 3	0°45'31.8204"N, 109°1'9.4728"E

2.2 Macrozoobenthos sampling and water quality analysis

Macrozoobenthos sampling was conducted using an Ekman grab sampler, which was deployed to collect sediment from the lake bottom. The collected sediment was subsequently filtered through a 1 mm mesh sieve to separate macrozoobenthic organisms. The retained specimens were preserved in 70% ethyl alcohol and stored in labelled sample bottles. Sampling was performed at eight replicate points within each station to ensure spatial representation and data reliability. Following collection, samples were examined and identified under microscope using standard taxonomic keys. Identification was carried out to the lowest possible taxonomic level to assess community composition and diversity.

Water quality parameters assessed in this study included both in-situ and ex-situ measurements. In-situ parameters comprising transparency, depth, temperature, pH, and dissolved oxygen (DO) were measured directly at each of the three sampling stations during four field sampling events using calibrated field instruments. In contrast, ex-situ parameters such as Biological Oxygen Demand (BOD), mercury (Hg) concentration, and water hardness were analyzed from water samples collected in sterile bottles and transported under controlled conditions. All samples were stored in cool boxes and processed within 24 hours and analytical procedures followed Indonesian National Standards (SNI).

2.3 Data analysis

The data analysis focused on evaluating the structure and ecological quality of macrozoobenthos community using several indices. These included the Shannon-Wiener diversity index (H′) to assess species richness, the evenness index (E) to measure the uniformity of individual distribution across taxa, the Simpson dominance index (D) to identify dominant species, and the Family Biotic Index (FBI) to infer water quality based on the tolerance levels of macrozoobenthos families. Relative abundance was also calculated and defined as the number of benthic individuals per unit area (m^2), following Brower et al. (1990). The grab sampler used had an opening area of 30 x 15 cm^2.

The Shannon-Wiener diversity index, as described by [6], was employed to quantify the diversity of macrozoobenthos. This index integrates both the number of species and the relative abundance of individuals. The formula used to calculate H′ is as follows:

$$p_i = \frac{n_i}{N} \quad (1)$$

$$H' = -\sum p_i \, Log \, p_i \quad (2)$$

Where H′ is Shannon-Wiener diversity index, n_i is the number of individuals belonging to species-i, and N is total number of individuals recorded across all species. The evenness index (E) was used to assess the uniformity of individual distribution among species. It was calculated by comparing the observed diversity index to its theoretical maximum.

$$H' \max = Log \, S \quad (3)$$

$$E = \frac{H'}{H'max} \quad (4)$$

Where E represent evenness index and S is total number of observed species. The Simpson's dominance index (D) was applied to quantify the extent to which one or few taxa numerically dominate the assemblage. The calculation follows the method described by [7]:

$$D = \sum(pi^2) \quad (5)$$

The Family Biotic Index is a widely recognized metric for evaluating the degree of organic pollution in aquatic ecosystems. It is based on the tolerance values assigned to macrozoobenthic families, which reflect their sensitivity to environmental stressors. The FBI was calculated following the methodologies outlined by [8]:

$$FBI = \frac{\sum(n_i \times t_i)}{N} \quad (6)$$

Where FBI is Family Biotic Index, n_i is the number of individuals in family-i, and t_i denotes the tolerance score assigned to family-i. The FBI value reflects the cumulative response of the benthic community to organic pollution and is interpreted based on the classification criteria presented in Table 2.

Table 2. Classification of Water Quality Based on FBI Values

FBI Value	Water Quality Classification	Level of Organic Pollution
0.00 – 3.75	Excellent	No apparent organic pollution

FBI Value	Water Quality Classification	Level of Organic Pollution
3.76 – 4.25	Very Good	Slight organic pollution
4.26 – 5.00	Good	Moderate organic pollution
5.01 – 5.75	Fair	Fairly polluted
5.76 – 6.50	Fairly Poor	Rather heavily polluted
6.51 – 7.25	Poor	Heavily polluted
7.26 – 10.00	Very Poor	Severely polluted

To assess the relationship between macrozoobenthos abundance and diversity and selected environmental parameters, a non-parametric Spearman's rank correlation analysis was performed using IBM SPSS Statistics version 29.0. Prior to the analysis, each variable was ranked according to its magnitude, from highest to lowest. The correlation coefficient was then calculated using the following formula:

$$r_{rho} = 1 - \frac{n\sum d^2}{n(n^2-1)}$$

Where r_{rho} is Spearman's rank correlation coefficient, d is difference between the ranks of each paired observation, and n is total number of paired observations. The strength of the correlation is presented in Table 3.

Table 3. Classification of Correlation Strength Based on Spearman's Rank

Spearman's Rank	Category
0.00 – 0.199	Very weak
0.20 – 0.399	Weak
0.40 – 0.599	Moderate
0.60 – 0.799	Strong
0.80 – 1.00	Very Strong

To further investigate the multivariate relationships between environmental parameters and macrozoobenthos community structure, a Principal Component Analysis (PCA) was conducted using PAST software version 4.03. PCA is a robust ordination technique that reduces data dimensionality while retaining the maximum variance, thereby facilitating the identification of dominant environmental gradients influencing community patterns.

In addition, a Canonical Correspondence Analysis (CCA) was employed to examine the association between macrozoobenthos community composition and physicochemical variables across sampling sites. CCA is a direct gradient analysis that simultaneously incorporates dependent (biological) and independent (environmental) variables, enabling the detection of underlying ecological relationships. This analysis was also performed using PAST version 4.03.

3 Results and Discussion

A total of 1,078 macrozoobenthos individuals from 14 genera, 14 families, and 9 orders were collected from Serantangan Lake during four sampling periods at three stations. Ordo yang ditemukan yaitu Mesogastropoda, Architaenioglossa, Decapoda, Haplotaxida, Diptera, Coleoptera, Ephemeroptera, Odonata, and Hemiptera.

Sensitive taxa such as Ephemeroptera (Baetidae) were found exclusively at Station 1, and were absent from Stations 2 and 3. Similarly, Diptera (Tipulidae) and Odonata (Gomphidae) were only recorded at Station 1. These groups are widely recognized as indicators of relatively good water quality due to their moderate to high sensitivity to pollution and low oxygen levels [9]. In contrast, Station 3 was dominated by more tolerant taxa, including Gastropoda (Ampullariidae and Viviparidae), Crustacea (Palaemonidae), Annelida (Tubificidae), and Diptera (Chironomidae), which are commonly associated with degraded conditions [9]. Table 4 presents the distribution of macrozoobenthos taxa across stations.

Table 4. Distribution of Macrozoobenthos Taxa in Serantangan Lake

Ordo	Family	Station 1	Station 2	Station 3
Mesogastropoda	Ampullariidae	v	v	v
Architaenioglossa	Viviaridae	v	v	v
Decapoda	Palaemonidae	v	v	v
Haplotaxida	Tubificidae	v	v	v
Diptera	Tipulidae	v	-	-
	Chironomidae	v	v	v
Coleoptera	Dystiscidae	v	v	-
Ephemeroptera	Baetidae	v	-	-
Odonata	Corduliidae	v	v	-
	Gomphidae	v	-	-
Hemiptera	Corixidae	v	v	-
	Gerridae	v	v	-
	Naucoridae	v	v	-
	Nepidae	v	v	-

Figure 2 illustrates the relative abundance of macrozoobenthos across stations, with Station 1 recording the highest density (12976 individuals/m²), followed by Station 2 (7978 individuals/m²), and Station 3 (3000 individuals/m²). The elevated abundance at Station 1 likely reflects favorable physicochemical conditions, including greater depth and water transparency (Table 7), which support diverse macrozoobenthic communities. Station 2's moderate abundance may result from agricultural runoff at the central outflow, creating transitional habitats for moderately tolerant taxa [10]. Station 3 exhibited the lowest abundance, likely due to reduced transparency, elevated BOD, and increased mercury levels (Table 7), which can suppress sensitive species and favor tolerant groups. These patterns are consistent with previous findings linking macrozoobenthos decline to organic enrichment and pollutant exposure.

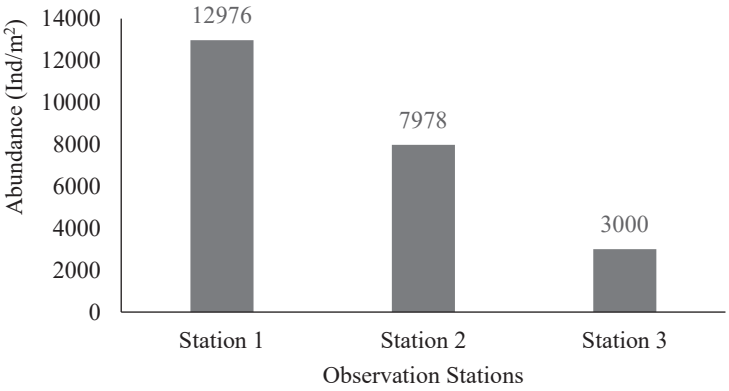

Fig. 2. The Abundance of Macrozoobenthos in Serantangan Lake

These abundance trends are further supported by ecological indices presented in Table 5. The Shannon-Wiener diversity index (H′) ranged from 0.42 to 1.13, with the highest value at Station 1 (1.13), followed by Station 2 (1.03), and the lowest at Station 3 (0.42). Evenness index (E) values similar with this pattern, ranging from 0.37 to 0.98, with Station 1 showing high evenness values (0.98), Station 2 moderately even (0.90), and Station 3 the least (0.37). Conversely, the dominance index (D) revealed an inverse trend, with the highest dominance at Station 3 (0.41), indicating community skewness toward a few tolerant taxa. Station 1 exhibited the lowest dominance (0.08), while Station 2 was intermediate (0.10). Together, these indices reinforce the interpretation that Station 1 supports a more diverse and evenly distributed macrozoobenthos assemblage, while Station 3 is characterized by ecological stress, low biodiversity, and dominance by tolerant taxa.

Table 5. Mean Diversity, Evenness, and Dominance Index of Macrozoobenthos in Serantangan lake

Observation Stations	Diversity (H′)	Evenness (E)	Dominance (D)
Station 1	1.13	0.98	0.08
Station 2	1.03	0.90	0.10
Station 3	0.42	0.37	0.41

Table 6. FBI Scores and Water Quality Classification by Station

Observation Stations	FBI	Water Quality Category
Station 1	3.8	Excellent
Station 2	3.9	Very good
Station 3	8.6	Very poor

Family Biotic Index (FBI) values across stations ranged from 3.8 to 8.6 (Table 6). Station 1 recorded the lowest score (3.8), indicating excellent water quality, followed by Station 2 (3.9), classified as very good. In contrast, Station 3 exhibited the highest FBI value (8.6), reflecting very poor water quality. Lower FBI scores denote communities dominated by sensitive taxa, whereas higher scores suggest a prevalence of tolerant groups.

Water quality characteristics of Serantangan Lake are summarized in Table 7, based on average values recorded at three sampling stations. Temperature ranged from 28.6°C at Station 1 to 29.2°C at Station 3, all within the acceptable deviation of ±3°C. Transparency was highest at Station 1 (75.9 cm) and lowest at Station 3 (70.3 cm), suggesting increased turbidity near Station 3, potentially due to sediment disturbance or anthropogenic inputs.

DO concentrations ranged from 6.1 to 7.6 mg/L, with all stations meeting the standars with minimum requirement of >6 mg/L (Class 1) and >4mg/L (Class 2). pH values ranged from 6.1 to 6.5, comfortably within the acceptable range of 6–9. Depth varied across stations, with Station 1 being the deepest (247.5 cm) and Station 2 the shallowest (204.8 cm). Water hardness ranged from 168 to 180 mg/L, well below the regulatory limit of 500 mg/L.

However, two parameters at Station 3 exceeded regulatory thresholds. BOD averaged 12.6 mg/L, surpassing the Class 1 (<2 mg/L) and Class 2 (<3 mg/L) limits. Mercury levels at Station 3 reached 0.0027 mg/L, exceeding the Class 1 (<0.001 mg/L) and Class 2 (<0.002 mg/L) standards, likely due to contamination from nearby illegal gold mining activities. These exceedances pose risks to aquatic life, particularly intolerant macrozoobenthos taxa, and are consistent with biological findings showing reduced diversity and increased dominance of tolerant species at Station 3.

Table 7. Average Physicochemical Parameters and Standard Thresholds in Serantangan Lake

Parameters	Unit	Station 1	Station 2	Station 3	Water quality standards*	
					Class 1	Class 2
Temperature	°C	28.6	28.8	29.2	Dev 3	
Transparency	cm	75.9	73	70.3	-	
DO	mg/L	7.6	6.9	6.1	> 6	> 4
pH	-	6.5	6.1	6.1	6 – 9	
Depth	cm	247.5	204.8	222.8	-	
BOD	mg/L	5.06	4.75	12.6	< 2	< 3
Mercury	mg/L	0.0002	0.0002	0.0027	< 0.001	< 0.002
Hardness	mg/L	168	180	180	< 500	

*[11]

Spearman's rank correlation analysis was conducted to examine the relationship between physicochemical parameters and macrozoobenthos abundance and diversity (Table 8), using a sample size of $n = 12$ and a significance level of $\alpha = 0.05$. The results revealed that water transparency, mercury contamination, and hardness were significantly correlated with both macrozoobenthos abundance and diversity ($p < 0.05$).

Transparency showed a strong positive correlation with macrozoobenthos abundance (r = 0.728, p = 0.008) and diversity (r = 0.690, p = 0.016), implying that clearer water conditions enhance macrozoobenthos community structure. Increased transparency may promote light penetration, stimulate primary productivity, and improve visual feeding efficiency, thereby supporting a more diverse and abundant macroinvertebrate assemblage [10].

Table 8. Correlation of Psychochemical Characters with Macrozoobenthos Abundance and Diversity

Parameters	Abundance			Diversity		
	Spearman's correlation values (r)	Level	p-value	Spearman's correlation values (r)	Level	p-value
Temperature	0.1810	Very Weak	0.574	0.08	Very Weak	0.791
Transparency	0.728	Strong	0.008*	0.690	Strong	0.016*
DO	0.381	Fair	0.241	0.381	Fair	0.216
pH	0.494	Fair	0.130	0.495	Fair	0.106
Depth	0.049	Very Weak	0.882	0.126	Very Weak	0.694
Mercury	-0.646	Strong	0.027*	-0.620	Strong	0.036*
BOD	-0.448	Fair	0.146	-0.406	Fair	0.191
Hardness	-0.660	Strong	0.024*	-0.615	Strong	0.035*

Mercury showed a strong negative correlation both with abundance (r = -0.646, p = 0.027) and diversity (r = -0.620, p = 0.036), indicating that elevated mercury levels may suppress both organism abundance and species richness. This pattern reflects the toxic effects of mercury on sensitive taxa, leading to reduced population density and simplified community composition. [12] reported that mercury contamination from small-scale mining in Bukidnon, Philippines, led to reduced abundance and diversity, along with altered species composition, particularly the absence of sensitive taxa in polluted downstream sites.

Hardness, was also strongly correlated with abundance (r = -0.660, p = 0.024) and diversity (r = -0.615, p = 0.035), indicating that elevated mineral content may adversely affect both population density and diversity. This pattern suggests that increased hardness can alter benthic habitat conditions such as substrate composition making them less suitable for sensitive taxa and reducing macroinvertebrate abundance. The negative correlation with diversity implies a narrowing of ecological niches and dominance by a few resilient taxa. Other parameters such as temperature, DO, pH, depth, and BOD showed very weak to fair correlations with macrozoobenthos metrics, but none were statistically significant (p > 0.05).

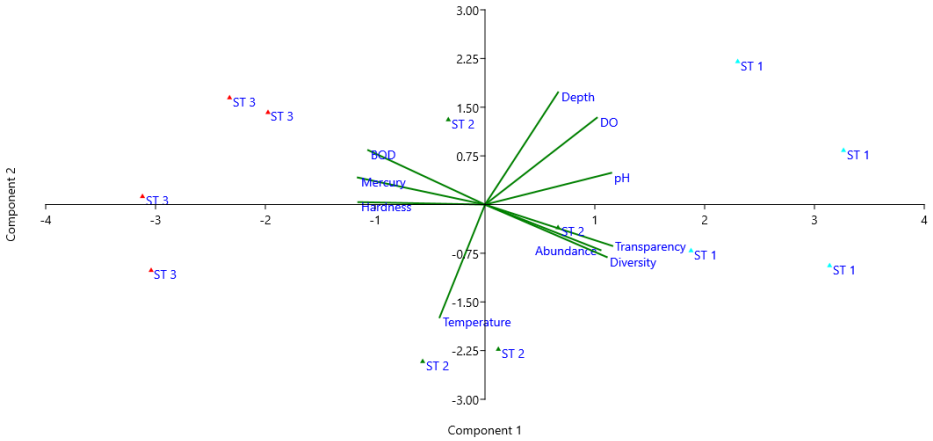

Fig. 3. PCA Plot between Physicochemical Factors and Macrozoobenthos

To further explore the ecological dynamics of macrozoobenthos in Serantangan Lake, Principal Component Analysis (PCA) was employed to identify multivariate patterns between physicochemical parameters and macrozoobenthos community structure (Figure 3). The PCA plot revealed that transparency was positively associated with both abundance and diversity, suggesting that clearer water conditions support a richer and more populated macrozoobenthos assemblage. These variables were positioned opposite BOD, mercury, and hardness, suggesting that elevated pollutant levels are linked to reduced macrozoobenthos metrics. Additionally, depth, DO, and pH were inversely related to temperature, implying that cooler, deeper, and more oxygenated conditions favor sensitive taxa. Spatially, Station 1 clustered near vectors for depth, DO, pH, and transparency. Station 2, associated with temperature, BOD, mercury, and hardness. Station 3, aligned with BOD, mercury, and hardness.

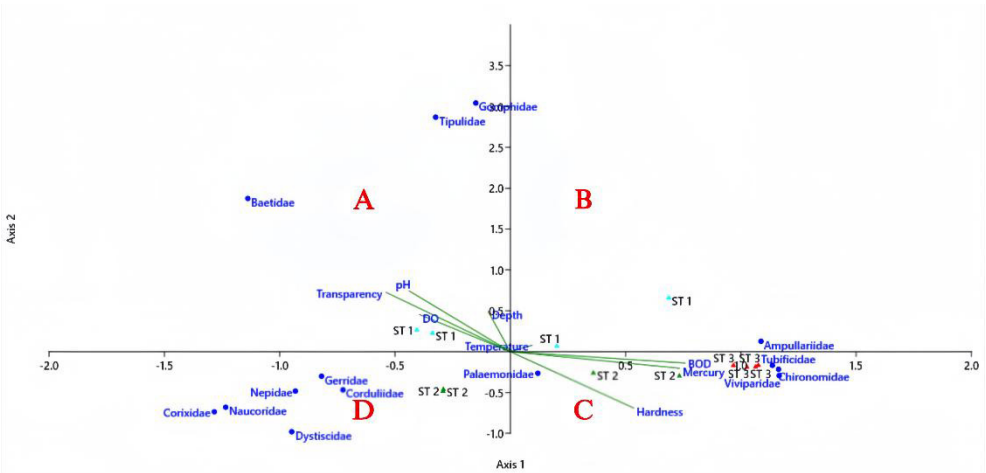

Fig. 4. CCA of Macrozoobenthos Families Distribution in Relation to Environmental Parameters

The Canonical Correspondence Analysis (CCA) triplot was used to visualize the distribution of macrozoobenthos families in response to measured physicochemical

parameters. Figure 4 revealed distinct groupings of macrozoobenthos families in response to measured environmental parameters, forming four clusters, i.e. A, B, C, and D.

Group A (Baetidae, Gomphidae, Tipulidae) correlated with transparency, pH, dissolved oxygen, and depth, indicating a preference for well-oxygenated, clear, and chemically stable habitats. These taxa were concentrated at Station 1, which exhibited the highest diversity and excellent water quality. Baetidae and Gomphidae are sensitive bioindicators of low organic pollution and high oxygen levels [9], while Tipulidae show moderate tolerance, favoring less enriched waters. Group B (Ampullariidae) showed an association with temperature, indicating thermal tolerance and adaptation to warmer waters. This aligns with findings from tropical systems, where *Pomacea* spp. exhibit increased metabolic activity, growth, and survival under elevated temperatures [13].

Group C (Tubificidae, Chironomidae, Viviparidae, Palaemonidae) showed strong associations with BOD, mercury, and hardness, suggesting resilience to pollution and organic enrichment. Tubificidae and Chironomidae are dominant in eutrophic systems and serve as indicators of ecological stress [4]. Viviparidae and Palaemonidae tolerate metal contamination and variable water chemistry, making them valuable indicators in disturbed freshwater ecosystems. Viviparidae gastropods exhibit high metal (Cd, Pb, and Hg) bioaccumulation capacity [14], while Macrobrachium spp. demonstrate adaptability across diverse freshwater habitats [15].

Group D (Gerridae, Nepidae, Corixidae, Naucoridae, Corduliidae, Dytiscidae) showed no clear association with measured parameters, suggesting influence from unmeasured environmental factors. These assemblage patterns reflect the ecological gradient across stations, with Station 1 favoring sensitive taxa and Station 3 dominated by tolerant species under degraded conditions.

The spatial heterogeneity in ecological condition observed across Serantangan Lake emphasizes the critical necessity for site specific management strategies. The marked disparity between Station I (excellent condition) and Station III (very poor condition) highlights the influence of localized physicochemical stressors on macrozoobenthos communities. These observations yield important implications for the rehabilitation and sustainable management of post mining lake, including the implementation of targeted restoration efforts in ecologically compromised zones, the development of bioindicator based monitoring framework, and the adoption of adaptive management approaches.

4 Conclusion

The ecological condition of Serantangan Lake varied markedly across sampling stations, with Station 1 exhibiting the highest macrozoobenthos abundance and diversity, supported by favorable physicochemical conditions such as high transparency, high dissolved oxygen, and low pollutant levels. In contrast, Station III showed signs of ecological degradation, characterized by elevated BOD and mercury concentrations, reduced diversity and evenness, and a high dominance index, indicating a community dominated by tolerant taxa. The Family Biotic Index (FBI) classified Station I as excellent, Station II as very good, and Station III as very poor, reflecting a clear gradient of water quality. Spearman's correlation analysis identified strong positive correlations between water transparency and both macrozoobenthos abundance and diversity, while mercury and hardness showed negatively correlated. Multivariate analyses (PCA and CCA) further revealed distinct associations between macrozoobenthos families and environmental parameters, distinguishing taxa based on their tolerance levels and habitat preferences, highlighting their potential as bioindicators for monitoring ecological status of Serantangan Lakes.

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The habitat types of freshwater prawns (Palaemonidae: *Macrobrachium*) with abbreviated larval development in Mesoamerica (Mexico, Guatemala, and Belize), (IntechOpen Limited, London, 2019)