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*Research Article*

**Mining Pollution and Environmental Responsibility in Freshwater Ecosystems: Benthic Macroinvertebrates in Lokpanta Reservoir, Nigeria**

**Zanieczyszczenia górnicze i odpowiedzialność środowiskowa w ekosystemach słodkowodnych: makrobezkręgowce bentoniczne w zbiorniku Lokpanta w Nigerii**

**Oyediran Ajiboye Gabriel[1*] and Ugwumba Adiaha Alda Alex[2]**
[1] Federal College of Agriculture, Ishiagu, Nigeria
[2] University of Ibadan, Ibadan, Nigeria
ORCID: OAG https://orcid.org/0000-0002-4071-488X; UAAA https://orcid.org/0000-0002-8612-616X
• oyediranajiboye@fcaishiagu.edu.ng
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## Abstract

Lokpanta Reservoir, located in Ishiagu, Ebonyi State, Nigeria, represents an example of a freshwater ecosystem affected by increasing anthropogenic pressure. Crop farming and stone mining activities influence water quality, aquatic biodiversity, and the relationship between local communities and their natural environment. Therefore, we investigated the relationship between physico-chemical parameters of the surface water and spatial abundance of benthic macroinvertebrates (BMs) of the reservoir at five stations. Physico-chemical parameters were determined while BMs were collected using $0.6m^2$ Van veen grab and their identification was done using standard guides. Data were analyzed using descriptive statistics, ANOVA while Shannon-Wiener index was applied for BMs and Principal Component Analysis (PCA) for relationships between the variables. The levels of physico-chemical parameters including nitrate, phosphate and heavy metals were more in Station 4 (mining pit). Spatial variations were significant for most parameters except temperature and phosphate. Shannon-Wiener diversity index showed 1.63 at inlet of the reservoir to be moderately polluted. PCA revealed that gastropoda was most sensitive with total hardness, iron, sulphate and DO. The study affirmed metal toxicity in the mining pit station with elevated concentrations of most metals beyond USEPA and NESREA limits which adversely impacted on the BMs diversity and abundance. The findings indicate that Lokpanta Reservoir is significantly affected by anthropogenic pollution. Beyond ecological degradation, these results emphasize the need for responsible management of human activities, protection of aquatic biodiversity, and sustainable approaches that recognize the interdependence between local communities and freshwater ecosystems.

**Keywords**

environmental responsibility, human–nature relations, freshwater ecosystems, mining pollution, water quality, benthic macroinvertebrates, aquatic biodiversity, sustainable water management, SDG 6 – Clean Water and Sanitation

**Streszczenie**

Zbiornik wodny Lokpanta, położony w Ishiagu w stanie Ebonyi (Nigeria), stanowi przykład ekosystemu słodkowodnego poddanego narastającej presji antropogenicznej. Uprawa roślin oraz działalność związana z wydobyciem kamienia wpływają na jakość wody, bioróżnorodność organizmów wodnych oraz relacje między lokalnymi społecznościami a ich środowiskiem naturalnym. Celem badań było określenie zależności między parametrami fizykochemicznymi wód powierzchniowych a przestrzennym rozmieszczeniem i liczebnością makrobezkręgowców bentosowych (BMs) w pięciu stanowiskach badawczych zbiornika. Oznaczono parametry fizykochemiczne wody, natomiast makrobezkręgowce bentosowe pobierano przy użyciu chwytacza Van Veena o powierzchni 0,6 m² i identyfikowano na podstawie standardowych kluczy. Dane analizowano z wykorzystaniem statystyki opisowej oraz analizy wariancji (ANOVA), natomiast do oceny różnorodności makrobezkręgowców zastosowano wskaźnik Shannona-Wienera, a do określenia zależności między badanymi zmiennymi – analizę głównych składowych (PCA). Najwyższe wartości parametrów fizykochemicznych, w tym stężeń azotanów, fosforanów oraz metali ciężkich, odnotowano na stanowisku 4 (wyrobisko górnicze). Dla większości parametrów stwierdzono istotne zróżnicowanie przestrzenne, z wyjątkiem temperatury i fosforanów. Wartość wskaźnika różnorodności Shannona-Wienera wynosząca 1,63 przy dopływie do zbiornika wskazywała na umiarkowany stopień zanieczyszczenia. Analiza PCA wykazała, że ślimaki (Gastropoda) były najbardziej wrażliwe na twardość ogólną wody, stężenie żelaza, siarczanów oraz zawartość tlenu rozpuszczonego (DO). Badanie potwierdziło toksyczny wpływ metali w obrębie stanowiska zlokalizowanego przy wyrobisku górniczym, gdzie stężenia większości metali przekraczały dopuszczalne wartości określone przez USEPA i NESREA, co negatywnie oddziaływało na różnorodność i liczebność makrobezkręgowców bentosowych. Uzyskane wyniki wskazują, że zbiornik Lokpanta pozostaje pod istotnym wpływem zanieczyszczeń pochodzenia antropogenicznego. Oprócz degradacji ekologicznej podkreślają one potrzebę odpowiedzialnego zarządzania działalnością człowieka, ochrony bioróżnorodności ekosystemów wodnych oraz wdrażania zrównoważonych rozwiązań uwzględniających współzależność między lokalnymi społecznościami a ekosystemami słodkowodnymi.

**Słowa kluczowe**

odpowiedzialność środowiskowa, relacje człowiek–natura, ekosystemy słodkowodne, zanieczyszczenie górnicze, jakość wody, makrobezkręgowce bentoniczne, bioróżnorodność wodna, zrównoważone zarządzanie wodą, SDG 6 – Czysta woda i warunki sanitarne

## Introduction

Over the last century, fossil fuel combustion, agrochemical application, metallurgical industrial activities, and industrial waste have globally increased the release of various heavy metals and other pollutants into the environment, thereby stressing terrestrial, atmospheric, and aquatic ecosystems beyond their natural recycling capability (Okeke et al. 2014, 58). The water bodies in Nigeria are not left out of these ongoing ecological disturbances. The waste from these activities has, over the years, predisposed the environment to danger, especially the aquatic ecosystem, which is at the receiving end of most of these wastes. Benthic macroinvertebrates differ in sensitivity to organic disturbance; hence, their relative diversity and abundance have been used to interpret the pollution levels in water bodies.

Benthic macroinvertebrates are those organisms that live on or inside the sediments at the bottom of a water body (Idowu and Ugwumba 2005, 15). The molluscs among them have restricted mobility, making them good biomonitoring species in aquatic environments (Albutra et al. 2020, 103) for assessing the site-specific impacts of certain environmental stressors. Benthic macroinvertebrates play an important role in aquatic communities, including mineralization, mixing of sediments and flux of oxygen into sediments, cycling of organic matter, and the assessment of the quality of inland water (George et al. 2009, 59). The distribution of benthic macroinvertebrate fauna is determined by several factors, such as the physical nature of the substratum, depth and nutritive content, degree of stability, and oxygen content of the water body. Benthic macroinvertebrates are threatened by changes in their habitat associated with pollution, erosion, and siltation (Lydeard et al. 2004, 324).

The assessment of the water quality status of a water body is more reliable when the diversity and abundance of benthic macroinvertebrates are complemented by its physico-chemical properties (Ogbeibu and Oribhabor 2002, 2427–2428; Patang et al. 2018, 7–10). Lokpanta Reservoir is of major importance to the people living in the immediate environment and surrounding communities of Ishiagu and Lokpanta for drinking, fishing, and other farming activities.

Beyond ecological monitoring, the degradation of freshwater ecosystems caused by anthropogenic activities also raises broader questions concerning environmental responsibility, sustainable management of natural resources, and the ethical dimensions of human interactions with aquatic environments. Reservoirs used by local communities are not only biological systems but also socio-ecological spaces in which environmental quality directly affects human well-being, aquatic biodiversity, and the long-term relationship between people and nature. From this perspective, assessing pollution and biodiversity loss in Lokpanta Reservoir contributes not only to environmental monitoring but also to a reflection on responsible human conduct toward shared natural resources.

However, the proximity of the reservoir to granite, dolomite, and pyrite mines exposes it to the associated threat of pollution (Oyediran et al. 2023, 109). Due to these various activities in its catchment, the reservoir is highly vulnerable to pollution (Asiegbu et al. 2021, 3). Many of the water bodies in the ecoregion are reported to be contaminated with metals such as iron, calcium, and sodium from mining discharge (Ezekwe et al. 2013, 101, Oyediran et al. 2023, 648).

The current work focused on assessing the impact of human activities on water quality and on the distribution of macroinvertebrates in Lokpanta Reservoir. The water quality parameters were further related to the diversity and abundance of benthic macroinvertebrates in the reservoir at different purposely selected stations. The general environmental impacts of mining in Ishiagu were investigated by Nwaugo et al. (2008, 78) and Ezekwe et al. (2013, 99). Recently, the neighbouring reservoirs of Umuchieze and Lekwensi have been studied only with an emphasis on microbial flora and physico-chemical parameters (Ugbogu et al. 2013, 1), while Oyediran et al. (2017, 44) documented only the distribution of macrobenthos in the Ivo River, Ishiagu, Ebonyi State. There is a dearth of information on the use of benthic macroinvertebrates as bioindicator organisms in the ecoregion of southeast Nigeria, with reference to water bodies in Ishiagu, Ebonyi State. The technique used in the study is relatively inexpensive and provides a reliable water quality classification that is extensively used globally (Azrina et al. 2006, 338). Therefore, the study investigates the impact of anthropogenic activities, especially mining, on water quality and the spatial abundance of benthic macroinvertebrates (BMs) as bioindicators in Lokpanta Reservoir.

## 1. Materials and Methods

### 1.1. Description of the Study Area

Lokpanta Reservoir is located in Ishiagu, Ivo Local Government Area of Ebonyi State, Nigeria and lies between latitude 7029’ 13 .65” and 7029’ 48. 01” E and longitude 5058’25. 02” and 5058’37.49” N with an elevation of 86.3 m above sea level. The reservoir has a total estimated area of 97,000 m2.

The sampling stations were divided into five stations.

**Station 1:** Inlet of the reservoir**.**

**Station 2:** Middle of the reservoir

**Station 3:** Outlet of the reservoir

**Station 4:** Mining pit.

**Station 5:** Nzohu River

### 1.2. Determination of physico-chemical Parameters of Surface Water

Monthly sampling was conducted between April 2014 and March 2016. Physico-chemical parameters, including temperature, transparency, pH, nitrate, phosphate, alkalinity, total hardness, chloride, dissolved oxygen, biological oxygen demand, total dissolved solids (TDS), total suspended solids (TSS) and metal concentrations, were determined using the methods as described by APHA (2005, 1104).

### 1.3. Collection and Identification of Macrobenthos

Sediments were collected using a 0.6 m² Van Veen grab. The collected samples were labelled and washed through a sieve with a 0.5 mm mesh size. The retained material was preserved in 4% formalin solution in the laboratory. Samples were sorted under a magnifying lens, and BMs were separated from the sediment using forceps. As far as possible, species were identified using the guides of Pennak (1978, 82–97) and Brown (1994, 33–42), and the specimens were then counted.

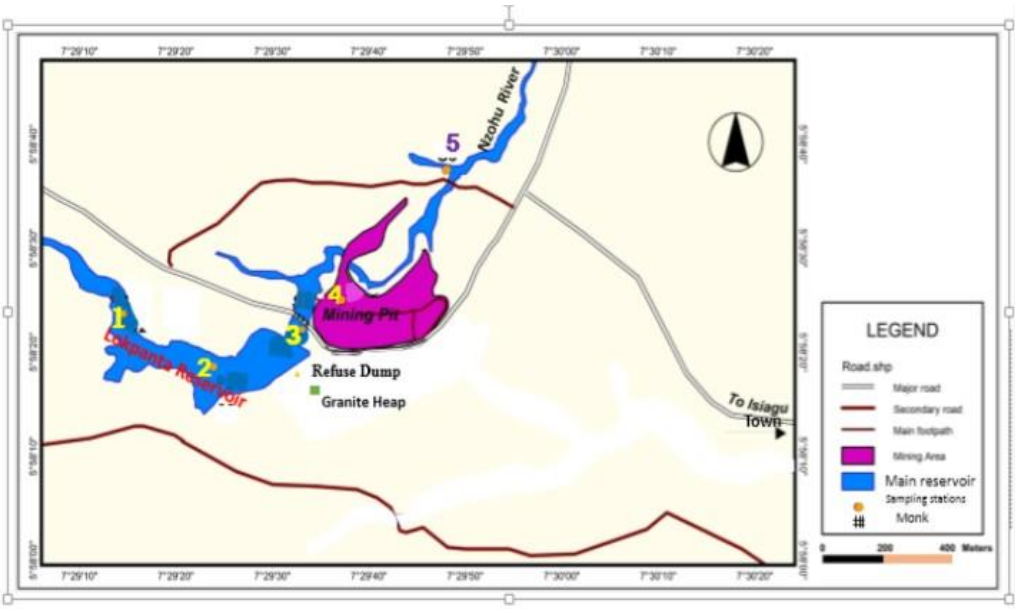


**Figure 1.** Map of Lokpanta Reservoir.

Number of individuals/m$^2$ = (N x 1m$^2$)/A (Azrina et al. 2006, 340)

Where N is the number of individuals in the Van Veen grab and A is the sampling surface area of the Van Veen grab

### 1.4. Data analysis

Data were analysed using descriptive statistics, with mean values of parameters presented in tables and graphs. One-way ANOVA and an analysis of the homogeneity of the abundance of benthic macroinvertebrates among the five sampling stations were performed using IBM SPSS Statistics 20 software. Principal Component Analysis (PCA) was conducted using Statistica Version 12 to analyse the relationship between the physico-chemical parameters and benthic macroinvertebrate abundance. Benthic macroinvertebrate diversity was assessed using the Shannon–Wiener diversity index in the Paleontological Statistics software package (PAST 4.03).

## 2. Results

### 2.1. Differences in Physico-chemical Parameters

Spatial variations in the physico-chemical properties and comparisons of mean values between the stations are given in Table A1 (Appendix). Most parameters showed significant spatial variation across stations. A relatively better water quality was observed at Station 1 (inlet) and Station 3 (outlet). Severely degraded water quality occurred at Station 4 (mining pit) and Station 5 (Nzohu River). These stations recorded very high levels of TDS, TSS, chloride, hardness, calcium, iron, and sodium. The temperature at all the sampling stations showed no significant difference ($p > 0.05$), while the other variables differed significantly ($p < 0.05$) between stations. The TSS levels recorded at all five stations were above the NESREA limit. According to NESREA (2011, 23–24) and USEPA (2006, 45), the levels of chloride, hardness, calcium, and sodium in the mining pit and Nzohu River (Table 1) were considered harmful to aquatic life and human consumption.

### 2.2. Diversity and abundance of macroinvertebrates

Benthic macroinvertebrates showed marked spatial differences in both diversity and abundance across the stations. Station 1 (inlet of the reservoir) had a moderate abundance of 171.6 ind/m$^2$ with relatively higher taxa richness, including annelids, arthropods, and molluscs, while Station 2 (middle of the reservoir) showed extremely low abundance (1.7 ind/m$^2$), suggesting ecological stress. Station 3 (outlet of the reservoir) recorded the highest abundance of 2299.9 ind/m$^2$, dominated largely by pollution-tolerant taxa such as Chironomus larvae and the gastropods *Melanoides tuberculata* and *Lymnaea natalensis*. Station 4 (mining pit) recorded a complete absence of benthic macroinvertebrates. In the same vein, Station 5 (Nzohu River) had negligible abundance (3.3 ind/m$^2$), reflecting harsh environmental conditions and instability.

### 2.3. Spatial Distribution of Benthic Macroinvertebrate Groups

Benthic macroinvertebrates encountered at the sampling stations of Lokpanta Reservoir are shown in Table A2 (Appendix). There was a total of three phyla and eight taxa across all five sampling stations. Chironomus larvae had the highest relative density. Associations of the diversity index between stations are presented in Figure 2. The biodiversity indices provided information about the environmental conditions under which the benthic macroinvertebrates lived (Azrina et al. 2006, 338).

The Shannon–Wiener index (H') was also significantly higher ($p < 0.05$) at the reservoir's inlet and outlet. It is evident that the Shannon–Wiener diversity index at the inlet and outlet of the reservoir indicated a moderately polluted status, while the other stations were severely polluted.

### 2.4. Multivariate analysis

Based on the principal component analysis biplot in Figure 3, the three groups of benthic macroinvertebrates, Annelida, Arthropoda, and Mollusca (Gastropoda) encountered showed strong positive associations with the less disturbed inlet and outlet of the reservoir, which were characterized by acceptable levels of temperature, pH, and BOD. In contrast, a negative relationship between benthic macroinvertebrates and the elevated concentrations of chloride, sodium, and calcium in the mining pit indicated pollution stress.

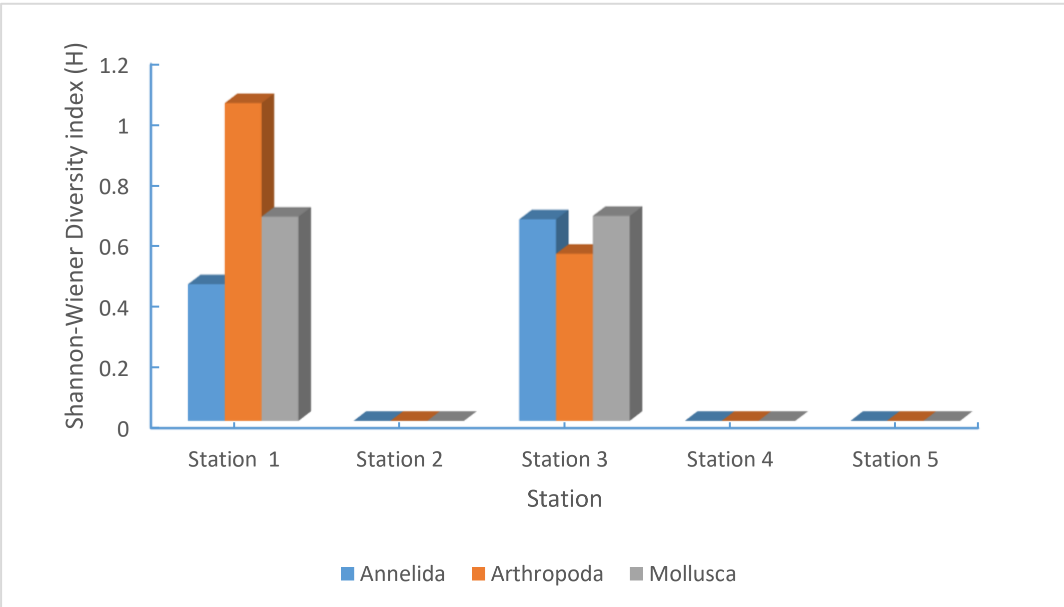


**Figure 2.** The Shannon-Wiener indices of BMI in Lokpanta Reservoir

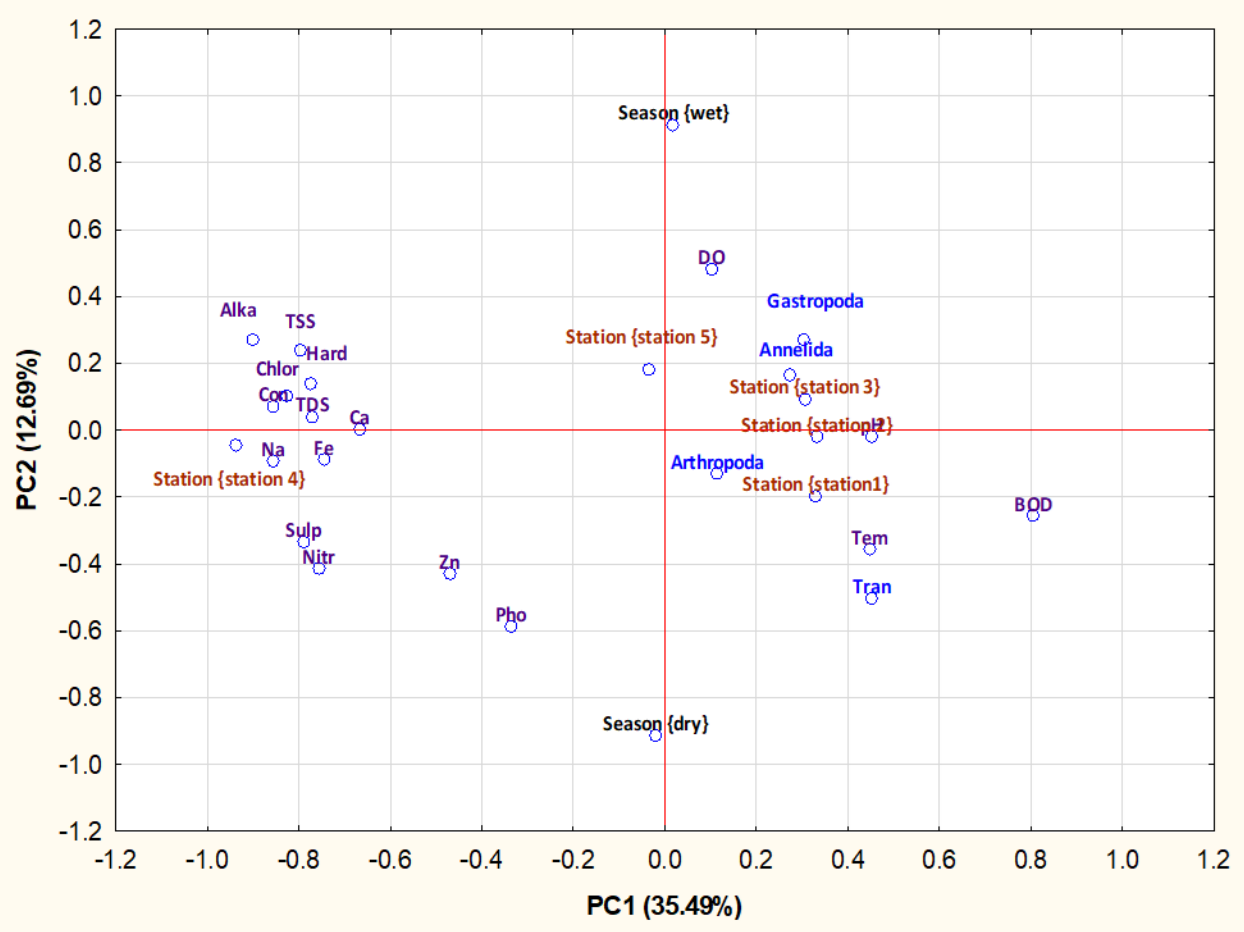


**Figure 3.** Principal Component Analysis (PCA) biplot of physico-chemical parameters, benthic macroinvertebrates, and sampling stations.

## 3. Discussion

## 3. Physico-chemical Parameters

The observed spatial variability in physico-chemical parameters across the five stations reflects the influence of anthropogenic activities, particularly mining and agriculture, within the reservoir catchment. Similar patterns of spatial heterogeneity linked to human activities have been widely reported in tropical aquatic systems (Akindele and Olutona 2014; Ezekwe et al. 2013). Temperature remained relatively uniform across stations, indicating limited thermal variation and suggesting that it was not a major driver of ecological differences in the reservoir. This observation agrees with findings from similar tropical systems where temperature tends to show limited spatial fluctuation (Ezekwe et al. 2013, 105). In contrast, most other parameters varied significantly, indicating localized pollution inputs.

The inlet (Station 1) and outlet (Station 3) exhibited relatively stable water quality conditions, characterized by near-neutral pH and moderate dissolved oxygen (DO). These conditions are within the acceptable limits recommended by USEPA and NESREA (2011) for aquatic life, suggesting relatively lower pollution pressure. The relatively higher DO observed at the outlet may be associated with increased water movement and aeration, as reported by Ebere et al. (2019, 196). Conversely, the mining pit (Station 4) and Nzohu River (Station 5) recorded markedly elevated levels of TDS, TSS, chloride, total hardness, calcium, sodium, and iron. These values exceeded permissible limits and are indicative of intense anthropogenic disturbance. Elevated TDS and ionic concentrations in mining-impacted waters have been attributed to mineral weathering, leaching, and hydrogeochemical processes associated with mining activities (Eze & Uko 2003, 82; Fernandes 2015, 260).

The high TSS levels observed across all stations may be linked to surface runoff, dredging, and land clearing activities, which introduce suspended particles into the water column (Ebere et al. 2019, 97). Elevated TSS is known to reduce light penetration and impair primary productivity, thereby affecting overall ecosystem functioning (Azrina et al. 2006, 344). The slightly acidic conditions observed in the mining pit and Nzohu River stations may be associated with acid-forming reactions from sulphate compounds derived from mining residues and explosives (Karlsson and Kauppila 2015, 7). Increased nitrate levels in these stations further support this assertion, as nitrate enrichment is often linked to the oxidation of nitrogenous compounds in explosives used during quarrying.

Globally, mining-impacted water bodies in agricultural catchments consistently exhibit DO depression concurrent with elevated conductivity and metal loads, a combination that produces synergistic toxic effects on benthic communities exceeding what either stressor alone would generate (Mwedzi et al. 2020, 584–587). The elevated concentrations of calcium, sodium, and total hardness recorded in the mining-impacted stations can be attributed to rock weathering, dissolution of carbonate minerals, and leaching processes (Umeham & Elekwa 2005, 33). Similarly, high iron concentrations exceeding USEPA and NESREA limits are consistent with the geology of the area, particularly the presence of iron-rich dolomite and associated minerals (Fernandes 2015, 256). Overall, the physico-chemical profile of Lokpanta Reservoir thus confirms a well-established global pattern: mining activities create extreme hydrogeochemical gradients that radically degrade water quality in adjacent water bodies, with downstream ecosystems receiving attenuated but still significantly polluted waters. This highlights the need for effective environmental management strategies.

### 3.2. Benthic Macroinvertebrates

The low overall abundance and limited taxonomic richness of benthos recorded reflect the severely degraded water quality at most stations. Only three phyla and eight taxa were identified across all five stations, a figure markedly lower than the 20–40 taxa typically encountered in relatively undisturbed tropical freshwater systems (Chang et al. 2014, 2140). The low abundance of benthic macroinvertebrates observed could be attributed to the elevated levels of TSS, total hardness, iron, calcium, and sodium. Benthic macroinvertebrates are considered to be sensitive to these parameters; thus, their abundance and distribution are largely controlled by them (Azrina et al. 2006, 343). The relatively cleaner water quality recorded at the inlet and outlet of the reservoir is confirmed by the presence of *Ephemerella dorothea*. Species of the order Ephemeroptera are sensitive to environmental disturbance, which makes them good indicator species in tropical aquatic ecosystems (Bonada et al. 2006, 506).

On the contrary, the high abundance of *Chironomus sp* larvae, *Lymnaea natalensis*, and *Melanoides tuberculata* at the reservoir outlet, all pollution-tolerant species, does not necessarily indicate that the station is the most polluted. Their high dominance could be connected to other factors, including the presence of a food source at the station and the facultative nature of these organisms, despite the fact that the station was not oligotrophic. The near-total dominance of pollution-tolerant taxa, particularly *Chironomus sp* larvae, *Melanoides tuberculata*, and *Lymnaea natalensis*, and the corresponding absence or scarcity of pollution-sensitive groups such as Ephemeroptera, Plecoptera, and Trichoptera (EPT) is a globally recognised signature of anthropogenic degradation in freshwater ecosystems (Lopez et al. 2022, 1376).

Studies in Malaysia confirmed that *Chironomus kiiensis* and *C. javanus* thrived in rivers with high total organic matter (TOM), ammonium nitrogen, and the trace metals zinc, copper, and manganese—conditions broadly analogous to those at Station 3 (Wang et al. 2021, 22). Furthermore, the burrowing ability of these organisms enabled them to inhabit less impacted sediments at the station (Shadrin et al. 2017, 67–68). However, the scant diversity of benthic macroinvertebrates in the study area could be connected to the low conductivity and phosphate levels observed (Nkwoji et al. 2020, 7–8). The total absence of benthic macroinvertebrates in the mining pit and at the station on Nzohu River may be due to metal toxicity in the mining pit and the regular pumping of water into the Nzohu River, which washes away the nutrients needed for their survival. The number of benthic macroinvertebrate species encountered at each of the stations was not uniform because of different anthropogenic disturbances in the reservoir. According to Padmanabha (2011, 69), a Shannon-Wiener diversity index of >3 signifies clean water, <1.0 reflects severe pollution, while values between these thresholds indicate moderate pollution. Following this classification, the Shannon-Wiener diversity indices at all the stations were below three, indicating that three out of the five stations of the reservoir were severely polluted, while the inlet and outlet of the reservoir showed moderate pollution.

### 3.3. Spatial Relationships Between Physico-chemical Parameters and Benthic Macroinvertebrates

Alkalinity, iron, nitrate, chloride, TSS, TDS, sodium, total hardness, calcium, and iron had high component loadings in the PCA biplot, indicating that these were the primary factors driving changes in Lokpanta Reservoir's physico-chemical properties. The observed close positive associations between the mining pit and Nzohu River stations with respect to nitrate, sulphate, and TSS indicate that there was nutrient enrichment at these two stations. The negative relationship between nitrate and sulphate and all the benthic macroinvertebrate groups contributed to the reduction in their abundance, possibly because most of the nitrate and sulphate were inorganic in origin, as they are likely products of the breakdown of mining explosives used during mining activities.

In the same vein, the high concentrations of sodium, calcium, and iron in the mining pit and Nzohu River stations contributed to suspected metal toxicity, which hindered benthic macroinvertebrate abundance. These metals were probably products of hydrogeochemical reactions during the mining operations, which caused their concentrations to exceed the recommended limits for drinking water as well as for aquatic life, particularly in the mining pit. Hence, little or no life was observed at this station. *Lymnaea natalensis*, *Ephemerella dorothea*, and *Hirudo* sp. were among the most sensitive groups of benthic macroinvertebrates in this study, considering their absence from Stations 2, 4, and 5. This could be attributed to poor water quality, which disrupts their feeding behaviour and their ability to regulate osmotic balance.

The discernible positive association between molluscs and BOD reflects their adaptation to low-oxygen habitats, which is characteristic of this group of benthic macroinvertebrates. Most benthic macroinvertebrates cannot survive in water with low DO concentrations and high levels of metals (Obiyor et al. 2017, 207). Water hardness, on the other hand, has the capacity to modify the toxicity of heavy metals to aquatic organisms (Khan and Ghosh 2001). This was probably the reason for the total absence of benthic macroinvertebrates in the mining pit, which was the most severely polluted station. The suspected use of agricultural chemicals such as fertilizers, herbicides, and pesticides could have had strong effects on the benthic macroinvertebrates at the inlet, in the middle of the reservoir, and in the Nzohu River, causing severe changes in their composition. Each of the benthic macroinvertebrates has a different level of tolerance to pollution in a water body (Rosenberg and Resh 1993, 283–288).

In a mining-affected river in Costa Rica, the spatial distribution of arsenic and lead in sediments was the single strongest predictor of macroinvertebrate family richness and abundance, with hotspots of metal contamination corresponding precisely to zones of near-zero benthic diversity (Kohlmann et al. 2021, 15). The present findings are therefore consistent with this global pattern: mining discharges introduce multi-element contamination that exceeds the physiological tolerance thresholds of most benthic invertebrates, producing community collapse at heavily impacted stations.

There was a high diversity of annelids and molluscs at the inlet and outlet of the reservoir, as they had surfaces for attachment that these organisms use as habitat. Most of the physico-chemical parameters were within the permissible limits at these stations. The mining pit had the lowest diversity of all the benthic macroinvertebrates; this indicates that the station was under severe pollution stress. The presence of *M. tuberculata* as the only benthos in Station 5 (Nzohu River) could be connected to its adaptation to poor water conditions, which is supported by an efficient operculum that can withstand extreme water quality conditions (Mitchell et al. 2007, 1287–1288). In the same vein, the possession of a hard shell is a protective adaptation that enables it to tolerate environmental stress. The pumping of impacted water to other parts of the reservoir impairs water quality by causing perturbation that cannot support the survival of resident benthos. It is evident that the mining discharge into Lokpanta Reservoir constitutes a high level of stress for benthic macroinvertebrates.

### 3.4. Environmental Responsibility and Sustainable Management Implications

The results of this study highlight that the degradation of aquatic ecosystems should not be interpreted only as a biological or physico-chemical problem but also as a challenge concerning the quality of human relationships with the natural environment. The observed changes in the abundance and diversity of benthic macroinvertebrates reflect the consequences of human activities and demonstrate the need for more responsible interactions between local communities, economic activities, and freshwater ecosystems.

Mining activities, agriculture, and other forms of anthropogenic pressure around reservoirs create conflicts between short-term human benefits and the long-term preservation of ecological integrity. Addressing such challenges requires not only technical solutions and pollution control measures but also a broader recognition of environmental responsibility, including obligations toward ecosystems that sustain both biodiversity and human well-being.

In this context, aquatic organisms such as benthic macroinvertebrates should not be viewed exclusively as indicators of water quality but also as components of complex ecological communities affected by human decisions. Their decline reflects broader disruptions in human–nature relationships and emphasizes the importance of sustainable resource management based on respect for ecological processes.

Therefore, protecting reservoirs such as Lokpanta requires an integrated socio-ecological approach that combines scientific monitoring with responsible environmental governance. Such an approach supports the protection of aquatic biodiversity while also safeguarding the needs of present and future generations who depend on freshwater resources.

## Conclusions

The water quality and the biota of Lokpanta Reservoir were negatively impacted by its proximity to the discharge point of a mining pit. Marked spatial variation in physico-chemical parameters was recorded across the five stations, with Station 4 (mining pit) and Station 5 (Nzohu River) consistently recording the most degraded water quality. Specifically, concentrations of chloride, TDS, TSS, total hardness, calcium, sodium, and iron at these two stations substantially exceeded the permissible limits prescribed by NESREA and USEPA. Lokpanta Reservoir is polluted. The dominance of the pollution-tolerant insect Chironomus larvae and the abundance of another pollution-tolerant macroinvertebrate, the gastropod *Melanoides tuberculata*, indicate this pollution. The poor water quality of the reservoir possibly did not support the plankton populations, which are major food sources for benthic macroinvertebrates.

Elevated levels of TSS, chloride, sodium, calcium, and water hardness hindered benthic macroinvertebrate abundance in the mining pit and Nzohu River stations. These parameters, identified by PCA, were responsible for the spatial variations observed, together with nutrient enrichment factors (nitrate, sulphate, and TSS) and indicators of metal toxicity (calcium and iron) in the mining pit and Nzohu River stations. Thus, Lokpanta Reservoir is disturbed, and there is an urgent need to control the release of mining waste into surface waters in order to safeguard aquatic biodiversity and the well-being of the people in Ishiagu, Lokpanta, and their neighbouring communities who depend on this water for daily domestic use.

Beyond technical measures aimed at pollution control, the findings of this study emphasize the need for a broader understanding of environmental responsibility in human interactions with freshwater ecosystems.

The degradation of aquatic biodiversity caused by anthropogenic activities highlights the ethical obligation to manage natural resources in a way that respects ecological integrity and supports the well-being of both human communities and non-human life forms.

Sustainable management of reservoirs such as Lokpanta should therefore be based not only on ecological assessment but also on responsible decision-making that recognizes the interdependence between human activities and natural systems. Such an approach strengthens the foundation for a more balanced and sustainable relationship between society and freshwater environments.

## Statements

**Author Contributions**: Conceptualization: A.G.O., A.A.A.U.; Methodology, A.G.O.; Validation, A.G.O., A.A.A.U.; Formal Analysis, A.G.O.; Investigation, A.G.O.; Writing – Original Draft Preparation, A.G.O.; Writing – Review & Editing, A.G.O., A.A.A.U.; Visualization, A.G.O.; Supervision: A.A.A.U. All authors have read and agreed to the published version of the manuscript.

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**Appendix**

**Table A1.** Spatial variation of Physico-chemical Parameters in Lokpanta Reservoir

This table presents the spatial variation in physico-chemical water parameters and heavy metal concentrations recorded across the sampling stations in Lokpanta Reservoir. It includes measurements related to water quality characteristics and pollutant levels, allowing a comparison of environmental conditions among different areas of the reservoir affected by anthropogenic activities.

| Physico-chemical Parameters | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 | Standard NESREA | USEPA |
|---|---|---|---|---|---|---|---|
| Temp(°C) | 28.46±0.26$^{a}$ | 27.47±0.24$^{a}$ | 27.65±0.30$^{a}$ | 26.42±0.24$^{a}$ | 27.22±0.27$^{a}$ | | 25-30 |
| Trans(m) | 0.29±0.04$^{b}$ | 0.23±0.02$^{b}$ | 0.11±0.03$^{ab}$ | 0.065±0.005$^{a}$ | 0.10±0.007$^{ab}$ | - | 25-30 |
| pH | 7.1±0.12$^{b}$ | 7.24±0.07$^{b}$ | 7.30±0.09$^{b}$ | 6.56±0.14$^{a}$ | 7.18±0.12$^{b}$ | 6.5-8.5 | 6.5-8.5 |
| DO(mg/L) | 4.70±0.12$^{a}$ | 4.88±0.06$^{a}$ | 4.72±0.11$^{a}$ | 4.46±0.10$^{a}$ | 6.31±0.12$^{b}$ | Not<6 | 7.5 |
| BOD (mg/L) | 2.54±0.10$^{b}$ | 2.58±0.06$^{b}$ | 2.68±015$^{b}$ | 1.00±0.035$^{a}$ | 1.83±0.05$^{a}$ | - | 2.0-6.0 |
| TDS (mg/L) | 3.87±0.89$^{a}$ | 10.88±2.52$^{a}$ | 29.55±4.03$^{a}$ | 5739.55±830.96$^{c}$ | 2288.05±410.68$^{b}$ | - | 250-500 |
| TSS (mg/L) | 6.02±2.48$^{a}$ | 6.94±0.51$^{a}$ | 74.31±7.74$^{b}$ | 313.13±36.86$^{d}$ | 151.56±16.10$^{c}$ | 0.25 | - |
| Cond(μ/cm) | 0.03±0.004$^{a}$ | 0.01±0.001$^{a}$ | 0.03±0.001 | 11.38±1.31$^{c}$ | 1.55±0.18$^{b}$ | - | 250 |
| Alk (mg/L) | 3.49±018$^{a}$ | 3.09±016$^{a}$ | 7.92±0.54$^{a}$ | 32.61±1.71$^{c}$ | 17.74±0.78$^{b}$ | 600 | 600 |
| Nit(mg/L) | 2.41±0.47$^{a}$ | 0.50±0.07$^{a}$ | 1.30±0.13$^{a}$ | 8.97±1.07$^{c}$ | 3.71±0.41$^{b}$ | 9.1 | 10 |
| Pho(mg/L) | 0.02±0.003$^{a}$ | 0.01±0.002$^{a}$ | 0.02±0.003$^{a}$ | 0.04±0.002$^{a}$ | 0.03±0.004$^{a}$ | 3.5 | 5.0 |
| Sul(mg/L) | 0.09±0.03$^{a}$ | ND | 0.24±0.06$^{a}$ | 4.09±0.46$^{c}$ | 1.27±0.23$^{b}$ | 100 | 500 |
| Cl(mg/L) | 44.62±4.30$^{a}$ | 21.08±0.86$^{a}$ | 42.87±2.13$^{a}$ | 6590.22±852.11$^{c}$ | 647.75±82.64$^{b}$ | 300 | 250 |

| Physico-chemical Parameters | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 | Standard NESREA | USEPA |
|---|---|---|---|---|---|---|---|
| Hard(mg/L) | 10.48±0.97[a] | 8.58±0.94[a] | 19.14±1.09[a] | 53926.80±7894.56 [c] | 2549.78±217.55[b] | - | 150-500 |
| Ca(mg/L) | 0.97±0.11[a] | 0.42±0.08[a] | 1.98±0.20[a] | 1664.60±397.68[c] | 171.21±10.82[b] | 180 | - |
| Na(mg/L) | 1.19±0.15[a] | 0.70±0.07[a] | 1.38±0.18[a] | 1638.34±188.71[c] | 217.2±15.68[b] | 120 | 200 |
| Fe(mg/L) | 0.01±0.00[a] | 001±0.00[a] | 0.05±0.01[b] | 4.68±0.82[c] | 0.92±0.15[ab] | 0.05 | 0.3 |
| Zn | ND | ND | 0.002±0.001[a] | 0.02±0.006[b] | 0.007±0.004[a] | 0.01 | 3.0 |
| Cd | ND | ND | ND | ND | ND | - | 0.003 |
| Cu | ND | ND | ND | ND | ND | 0.001 | 2.0 |
| Pb | ND | ND | ND | ND | ND | 0.01 | 0.01 |

N.B: The values were expressed as mean ±SEM. Values with different superscripts within the same row are significantly different at $p<0.05$.Tranp =Transparency, Temp=Water Temperature, DO=Dissolve Oxygen, BOD = Biochemical Oxygen Demand, TDS=Total Dissolved Solids, TSS=Total suspended solid, Cond=Conductivity, Alka=Alkalinity, Nit= Nitrate, Pho=Phosphate, Sul=Sulphate, Cl=chloride, Hard=Hardness, Ca= Calcium, Na= Sodium, Fe= Iron, Zn= Zinc Station 1: Entrance of the reservoir, Station 2: Middle of the reservoir, Station 3: Outlet of the reservoir, Station 4: Mining pit, Station 5: Nzohu River.

**Table A2.** Benthic Macroinvertebrates Densities (individual/$m^2$) in Lokpanta Reservoir

This table summarizes the distribution, abundance, and diversity of benthic macroinvertebrate communities identified across the sampling stations in Lokpanta Reservoir. It provides information on their taxonomic composition and ecological indicators used to assess the biological condition of the freshwater ecosystem under anthropogenic pressure.

| | | **Stations** | | | | | **Total** |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| **Phylum** | **Species** | | | | | | |
| **Annelida** | *Hirudo sp* | 3.3 | - | 45.0 | - | - | 48.3 |
| | *Lumbricus rubellus* | 16.7 | - | 73.3 | - | - | 90.0 |

| | | **Stations** | | | | | **Total** |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | |
| **Arthropoda** | *Chironomus sp larvae* | - | | 1625 | - | | 1625.0 |
| | *Ephemerella dorothea* | 16.7 | - | 113.3 | - | - | 130.0 |
| | *Hydrocanthus sp* | 18.3 | 1.7 | 130.0 | - | - | 150.0 |
| | *Sympertrum flaveolum* larvae | 8.3 | - | 30.0 | - | - | 38.3 |
| **Mollusca** | (Class Gastropoda) *Lymnaea natalensis* | 43.3 | - | 115.0 | - | - | 158.3 |
| | *Melanoides tuberculata* | 65.0 | - | 168.3 | - | 3.3 | 236.6 |
| | **Grand Total** | **171.6** | **1.7** | **2299.9** | **-** | **3.3** | **2476.5** |