

This article is published in Open Access and distributed under the terms of the Creative Commons Attribution-NoDerivatives 4.0 International licence (CC BY-ND 4.0): <https://creativecommons.org/licenses/by-nd/4.0/>

p-ISSN 1733-1218; e-ISSN 2719-826X

<https://doi.org/10.21697/seb.5901>

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 Alex²

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

Received: 2025-03-27; Revised: 2025-07-16; Accepted: 2025-07-26; Published Online First: 2025-07-29

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 the spatial abundance of benthic macroinvertebrates (BMs) at five stations in the reservoir. Physico-chemical parameters were determined, while BMs were collected using a 0.6 m² Van Veen grab and identified using standard taxonomic guides. Data were analyzed using descriptive statistics and ANOVA; the Shannon–Wiener index was used to assess BMs diversity, and Principal Component Analysis (PCA) was applied to examine relationships among the variables. The highest levels of several physico-chemical parameters, including nitrate, phosphate, and heavy metals, were recorded at Station 4 (mining pit). Spatial variations were significant for most parameters except temperature and phosphate. The Shannon–Wiener diversity index was 1.63 at the reservoir inlet, indicating moderate pollution. PCA revealed that Gastropoda showed the strongest associations with total hardness, iron, sulphate, and dissolved oxygen (DO). The study indicated metal-related toxicity at the mining pit station, where concentrations of several metals exceeded USEPA and NESREA limits and were associated with reduced 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 wydobywaniem 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 (BM) 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 (wzrost górniczy). 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 wzroście 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. 2017, 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). A broader investigation of the physico-chemical characteristics, plankton, benthic macroinvertebrates, and fish fauna of Lokpanta Reservoir was presented in Oyediran (2023). 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 $7^{\circ}29'13.65''$ / $7^{\circ}29'48.01''$ E and longitude $5^{\circ}58'25.02''$ / $5^{\circ}58'37.49''$ 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.

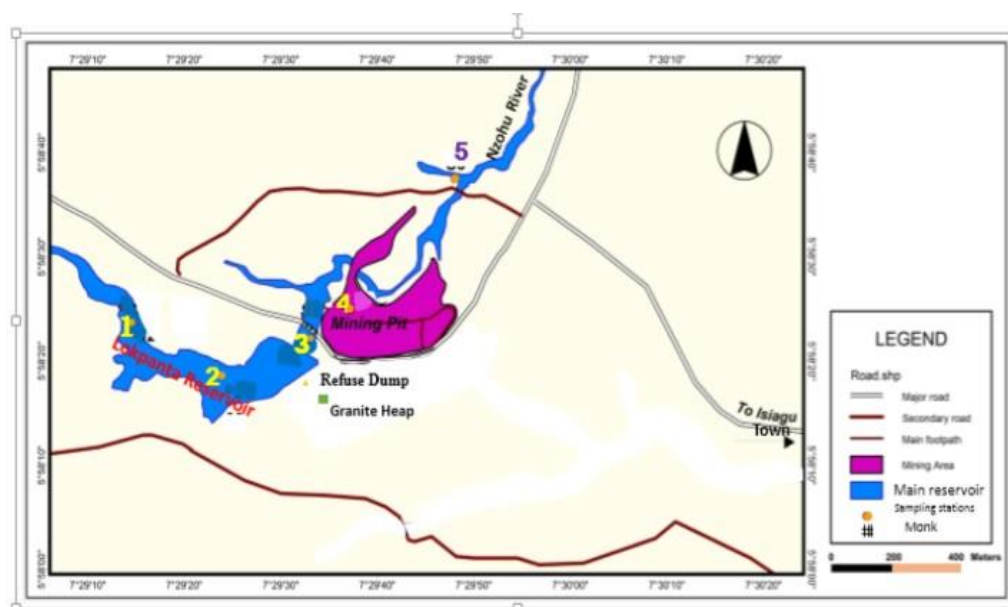


Figure 1. Map of Lokpanta Reservoir.

Number of individuals/m² = (N x 1m²)/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 A1, Appendix) 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/m² with relatively higher taxa richness, including annelids, arthropods, and molluscs, while Station 2 (middle of the reservoir) showed extremely low abundance (1.7 ind/m²), suggesting ecological stress. Station 3 (outlet of the reservoir) recorded the highest abundance of 2299.9 ind/m², 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/m²), 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.

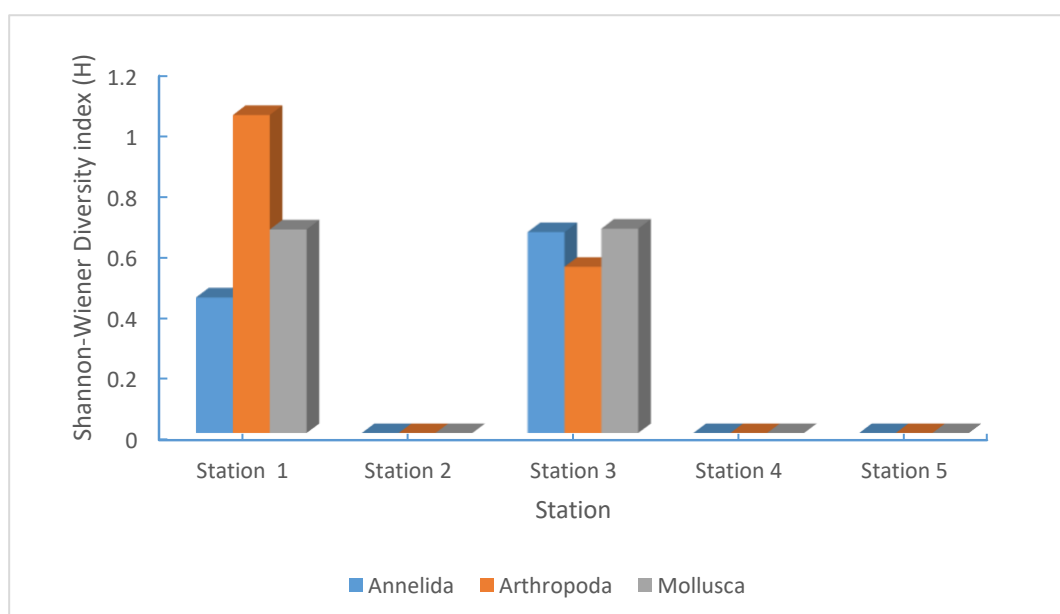
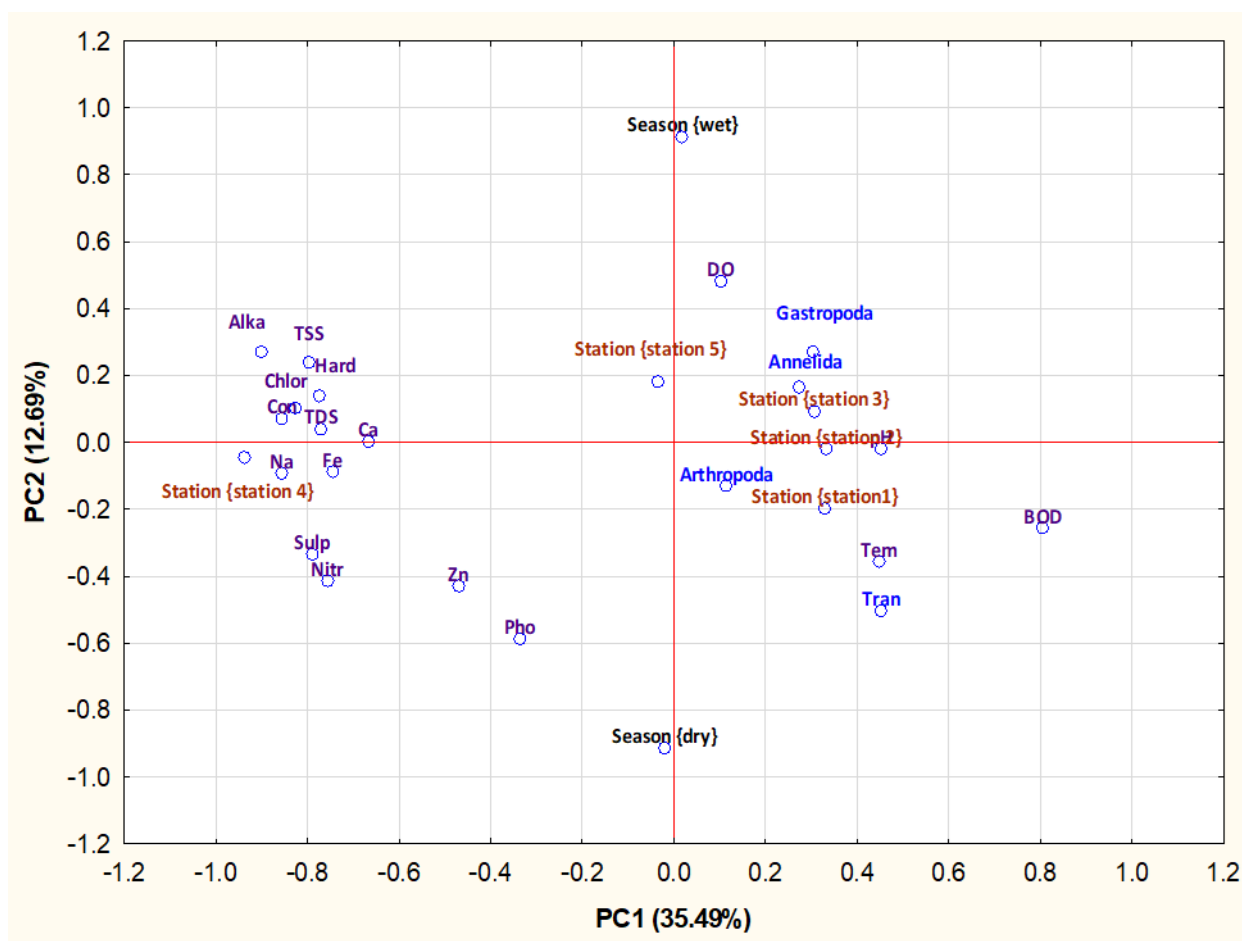


Figure 2. Shannon–Wiener diversity indices of benthic macroinvertebrates in Lokpanta Reservoir.**Figure 3.** Principal Component Analysis (PCA) biplot of physico-chemical parameters, benthic macroinvertebrates, and sampling stations.

3. Discussion

3.1. 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 (2006) 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 and 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 and 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-Lopez et al. 2019, 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 (WHO 2004; NESREA 2011; USEPA 2006). 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 (Albutra et al. 2017, 101–102). 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 (Ayoola and Ajani 2009). 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.

Funding:

This research received no external funding.

Institutional Review Board Statement:

Not applicable.

Conflicts of Interest:

The authors declare no conflict of interest.

Data Availability Statement:

The data supporting the findings of this study are available within the article and its Appendix.

AI Tools Declaration:

AI Tools Declaration: During the preparation of this manuscript, the authors used Claude Sonnet (Anthropic) to support language refinement and the presentation of data interpretation. The AI tool was not used to replace the authors' scholarly analysis, interpretation, or conclusions. All AI-assisted content was reviewed, verified, and approved by the authors, who take full responsibility for the final manuscript.

References

- Akindele, Emmanuel O., and Godwin O. Olutona. 2014. "Water Physicochemistry and Zooplankton Fauna of Aiba Reservoir Headwater Streams, Iwo, Nigeria." *Journal of Ecosystems*: 1–12. <https://doi.org/10.1155/2014/105405>.
- Albutra, B. Queenilyn, Cordulo P. Ascaño, and Cesar G. Demayo. 2017. "Water Quality Assessment Using Macroinvertebrates along the Mining Area of Brgy." *International Journal of Advanced and Applied Sciences* 4 (11): 99–103. <https://doi.org/10.21833/ijaas.2017.011.015>.
- American Public Health Association (APHA). 2005. *Standard Methods for the Examination of Water & Wastewater Analysis*. 21st ed. American Water Works Association/Water Environment Federation.
- Asiegbu, Victoria Onyebuchi, Ajiboye Gabriel Oyediran, and Ifeanyichukwu Clinton Ezekwe. 2021. "Conservation Status of Fish Fauna in the Ivo River Basin Southeast, Nigeria." *Acta Scientific Microbiology* 4 (7): 3–7.
- Ayoola, S. O., and E. K. Ajani. 2009. "Seasonal Variations in Fish Distribution and Physico-chemical Parameters of Wetland Areas in Oyo State, Nigeria." *International Journal of Biological and Chemical Sciences* 3 (1): 107–116. <https://doi.org/10.4314/ijbcs.v3i1.42741>.
- Azrina, M. Z., Chee Kong Yap, Ismail A. Rahim, A. Ismail, and S. G. Tan. 2006. "Anthropogenic Impacts on the Distribution and Biodiversity of Benthic Macroinvertebrates and Water Quality of the Langat River, Peninsular Malaysia." *Ecotoxicology and Environmental Safety* 64 (3): 337–347. <https://doi.org/10.1016/j.ecoenv.2005.04.003>.
- Bonada, Nuria, Narcís Prat, Vincent H. Resh, and Bernhard Statzner. 2006. "Developments in Aquatic Insect Biomonitoring: A Comparative Analysis of Recent Approaches." *Annual Review of Entomology* 51: 495–523. <https://doi.org/10.1146/annurev.ento.51.110104.151124>.
- Brown, David S. 1994. *Freshwater Snails of Africa and Their Medical Importance*. Taylor and Francis.
- Chang, Feng Hsun, Justin E. Lawrence, Blanca Rios-Touma, and Vincent H. Resh. 2014. "Tolerance Values of Benthic Macroinvertebrate for Stream Biomonitoring: Assessment of Assumptions Underlying Scoring Systems Worldwide." *Environmental Monitoring and Assessment* 186: 2135–2149.
- Ebere, Enyoh Christian, Verla Andrew Wirnkor, Verla Evelyn Ngozi, Peter Ndu Okeke, and Shirish S. Pingale. 2019. "Chemometric Assessment of Orashi River after Confluence with Oguta Lake." *Indonesian Journal of Fundamental and Applied Chemistry* 4 (3): 91–103.
- Eze, C. L., and E. D. Uko. 2003. "Preliminary Investigations of Acid Mine Drainage (AMD) Problems in the Ishiagu Lead/Zinc Open-pit Mine, Southeast, Nigeria." *African Journal of Environmental Pollution Health* 1 (2): 77–83.
- Ezekwe, Ifeanyichukwu Clinton, Ahamefula Sunday Ezekwe, and George Nwabuko Chima. 2013. "Metal Loadings and Alkaline Mine Drainage from Active and Abandoned Mines in the Ivo River Basin

- Area of Southeastern Nigeria.” *Mine Water Environment* 32 (2): 97–107.
<https://doi.org/10.1007/s10230-013-0220-1>.
- Fernandes, Nandini Vaz. 2015. “Impact of Iron Ore Mining: Comparison of Physicochemical Parameters and Heavy Metals in Upstream and Downstream Sites of a River.” *International Journal of Scientific Research* 4 (7): 254–257.
- George, A. D. I., J. F. N. Abowei, and E. R. Daka. 2009. “Benthic Macro Invertebrate Fauna and Physicochemical Parameters in Okpoka Creek Sediments, Niger Delta, Nigeria.” *International Journal of Animal and Veterinary Advances* 1 (2): 59–65.
- Idowu, E. O., and A. A. A. Ugwumba. 2005. “Physical, Chemical and Benthic Faunal Characteristics of a Southern Nigeria Reservoir.” *The Zoologist* 3: 15–25.
- Karlsson, Teemu, and Tommi Kauppila. 2015. “Release of Explosives Originated Nitrogen from the Waste Rocks of a Dimension Stone Quarry.” In *10th International Conference on Acid Rock Drainage and IMWA Annual Conference*. Accessed March 13, 2025.
https://www.imwa.info/docs/imwa_2015/IMWA2015_Karlsson_182.pdf.
- Kohlmann, Bert, Danny Vasquez, Alejandro Arroyo, and Monika Springer. 2021. “Taxonomic and Functional Diversity of Aquatic Macroinvertebrate Assemblages and Water Quality in River of the Dry Tropics of Costa Rica.” *Frontiers in Environmental Science* 9: 1–17.
<https://doi.org/10.3389/fenvs.2021.660260>.
- Lopez-Lopez, Eugenia, Jacinto E. Sedeno-Diaz, Erick Mendoza-Martinez, Andrea Gomez-Ruiz, and Emilio Martínez Ramírez. 2019. “Water Quality and Macroinvertebrate Community in Dry Land Streams: The Case of the Tehuacan-Cuicatlan Biosphere Reserve (Mexico).” *Water (Switzerland)* 11 (7): 1376. <https://doi.org/10.3390/w11071376>.
- Lydeard, Charles, Robert H. Cowie, Winston F. Ponder, et al. 2004. “The Global Decline of Non-marine Mollusks.” *BioScience* 54 (4): 321–330. [https://doi.org/10.1641/0006-3568\(2004\)054\[0321:TGDONM\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2004)054[0321:TGDONM]2.0.CO;2).
- Mitchell, Andrew J., Melissa S. Hobbs, and Thomas M. Brandt. 2007. “The Effect of Chemical Treatments on Red-rim Melania, *Melanoides tuberculata*, an Exotic Aquatic Snail That Serves as a Vector of Trematodes to Fish and Other Species in the USA.” *North American Journal of Fisheries Management* 27 (4): 1287–1293. <https://doi.org/10.1577/M06-252.1>.
- Mwedzi, Tongayi, Nqobizitha Siziba, Oghenekaro N. Odume, Eisen Nyamazana, and Innocent Mabika. 2020. “Response of Macroinvertebrates Community Metrics to Urban Pollution in Semi-arid Catchments around the City Bulawayo, Zimbabwe.” *Water SA* 46 (4): 583–592.
<https://doi.org/10.17159/wsa/2020.v46.i4.9071>.
- NESREA (National Environmental Standards and Regulations Enforcement Agency). 2011. “National Environmental Surface and Groundwater Quality Control Regulations.” *Federal Republic of Nigeria Official Gazette* no. 49, vol. 98, Government Notice no. 136. The Federal Government Printer.

- Nkwoji, Joseph Ahamefula, S. I. Ugbana, and M. Y. Ina-Salwany. 2020. "Impacts of Land-based Pollutants on Water Chemistry and Benthic Macroinvertebrates Community in a Coastal Lagoon, Lagos, Nigeria." *Scientific African* 7: e00220. <https://doi.org/10.1016/j.sciaf.2019.e00220>.
- Nwaugo, Victor Oluoha, Reginald A. Onyeagba, Emmanuel I. Akubugwo, and Osita Ugbogu. 2008. "Soil Bacterial Flora and Enzymatic Activities in Heavy Metal Pb and Zn Contaminated Soil of Ishiagu, Ebonyi State." *Biokemistri* 20 (2): 77–84.
- Obiyor, Ikenna Kelvin, Christopher Didigwu Nwani, Gregory Ejikeme Odo, Josephine Chinenye Madu, Doris Ulumma Ndudim, and Ifeanyi Oscar Ndimkaoha Aguzie. 2017. "Benthic Fish Fauna and Physicochemical Parameters of Otamiri River, Imo State, Nigeria." *Fisheries and Aquaculture Journal* 8 (2): 199–208. <https://doi.org/10.4172/2150-3508.1000199>.
- Ogbeibu, Anthony Ekata, and Blessing Julius Oribhabor. 2002. "Ecological Impact of River Impoundment Using Benthic Macro-invertebrates as Indicators." *Water Research* 36 (10): 2427–2436. [https://doi.org/10.1016/S0043-1354\(01\)00489-4](https://doi.org/10.1016/S0043-1354(01)00489-4).
- Okeke, Chloma Udoka, Okon Ekanem Eno, and Harami Malgwi Adamu. 2014. "Bioaccumulation of Heavy Metals in Mechanic Workshops." *International Journal of Mathematics and Physical Sciences Research* 2 (1): 58–65.
- Oyediran, Ajiboye Gabriel. 2023. "Physico-Chemical Parameters, Plankton, Benthic Macroinvertebrates and Fish Fauna of Lokpanta Reservoir, Ishiagu, Ebonyi State, Nigeria." PhD diss., University of Ibadan.
- Oyediran, Ajiboye Gabriel, Lawreance Azubuike Ebeniro, Omotade Paul Ayodele, Khalid Sayfullah Olaoti, and Peter Tochukwu Nwoga. 2017. "Seasonality, Abundance and Distribution of Macro-benthic Invertebrates as Bio-indicators of Water Quality in Ikwo River, Ishiagu, South-Eastern Nigeria." *Journal of Faunal & Biological Sciences* 4 (2): 43–46. <https://www.faunajournal.com/archives/2017/vol4issue2/PartA/3-4-11-397.pdf>.
- Oyediran, Ajiboye Gabriel, K. S. Olaoti, U. A. Azuine, O. Falana, and E. P. Emerue. 2023. "Diversity and Abundance of Benthic Molluscs in Ivo River, Ishiagu, Ebonyi State Nigeria." In *38th Annual Conference of Fisheries Society of Nigeria (FISON), Yenogoa, Bayelsa State, Nigeria*.
- Padmanabha, B. 2011. "Diversity of Macroinvertebrates as a Tool to Assess Aquatic Pollution in Lentic Ecosystems." *Nature Environment and Pollution Technology* 10 (1): 69–71.
- Patang, Fatmawati, Agoes Soegianto, and Sucipto Hariyanto. 2018. "Benthic Macroinvertebrates Diversity as Bioindicator of Water Quality of Some Rivers in East Kalimantan, Indonesia." *International Journal of Ecology* 2018: 1–11. <https://doi.org/10.1155/2018/5129421>.
- Pennak, Robert W. 1978. *Freshwater Invertebrates of the United States*. John Wiley & Sons.
- Rosenberg, David M., and Vincent H. Resh. 1993. *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman and Hall.

- Shadrin, Nickolai V., Elena Anufriieva, V. P. Belyakov, and A. I. Bazhora. 2017. "Chironomidae Larvae in Hypersaline Waters of the Crimea: Diversity, Distribution, Abundance and Production." *The European Zoological Journal* 84 (1): 61–72. <https://doi.org/10.1080/11250003.2016.1273974>.
- Ugbogu, Ositadinma, R. A. Onyeagba, and C. E. Ogbonna. 2013. "Microbial Quality of Two Man-made Lakes in Lokpa Abia State, Nigeria." In *Delivering Water, Sanitation and Hygiene Services in an Uncertain Environment: 36th WEDC International Conference, Nakuru, Kenya*. <https://hdl.handle.net/2134/30977>.
- Umeham, S. N., and I. Elekwa. 2005. "The Hydrobiological Status of Ngwui, Ikwu and Eme Streams in Umuahia North L.G.A., Abia State, Nigeria." *Journal of Environment* 1: 31–36.
- USEPA (United States Environmental Protection Agency). 2006. *National Recommended Water Quality Criteria*. Office of Water, US Environmental Protection Agency.
- Wang, Zhan, Wenke Wang, Zaiyong Zhang, Xinyue Hou, Zhitong Ma, and Baohui Chen. 2021. "River-Groundwater Interaction Affected Species Composition and Diversities Perpendicular to a Regulated River in an Arid Riparian Zone." *Global Ecology and Conservation* 27: e01595. <https://doi.org/10.1016/j.gecco.2021.e01595>.
- WHO (World Health Organisation). 2004. *Guideline for Drinking Water Quality*. 3rd ed. Vol. 1.

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±0.15 ^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±0.18 ^a	3.09±0.16 ^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	0.01±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

Note: Values are expressed as mean ± SEM. Values with different superscripts within the same row are significantly different at $p < 0.05$. Trans = transparency; Temp = water temperature; DO = dissolved oxygen; BOD = biochemical oxygen demand; TDS = total dissolved solids; TSS = total suspended solids; Cond = conductivity; Alk = alkalinity; Nit = nitrate; Pho = phosphate; Sul = sulphate; Cl = chloride; Hard = hardness; Ca = calcium; Na = sodium; Fe = iron; Zn = zinc. 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.

Table A2. Benthic Macroinvertebrates Densities (individual/m²) 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	<i>Hirudo sp</i>	3.3	-	45.0	-	-	48.3
	<i>Lumbricus rubellus</i>	16.7	-	73.3	-	-	90.0

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