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Original Research Paper

Ecological Risk Assessment of Trace Metals in Bottom Sediments of Damba Dam Gusau, Zamfara State, Nigeria

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Abstract

Pollution and ecological risk indices give qualitative and quantitative information on an ecosystem's status. This study assessed the pollution level and environmental risk of Cd, Cr, Pb, and Zn in Damba Dam sediments using Atomic Absorption Spectroscopy (AAS) and pollution indices (geo-accumulation index, contamination factor, pollution load index, Nemerow pollution index, and potential ecological risk index). The results showed the concentration of the metals as follows: Zn (0.04±19.45 mg/kg upstream, 0.03±21.78 mg/kg middle stream, 0.04±6.52 mg/kg downstream), Pb (0.04±4.88 mg/kg upstream, 0.01±18.09 mg/kg middle stream, 0.01±11.10 mg/kg downstream), and Cd (0.00±15.03 mg/kg upstream, 0.01±39.70 mg/kg middle stream, 0.01±55.38 mg/kg downstream), with geo-accumulation index values of 0.00 (Zn), 0.00 (Pb), 0.00 (Cd) upstream, 0.00 (Zn), 0.02 (Pb), 0.00 (Cd) middle stream, and 0.00 (Zn), 0.02 (Pb), 0.00 (Cd) downstream, pollution load index values of 0.03, 0.01, and 0.01, and Nemerow pollution index values of 0.00, 0.03, and 0.03 showing a decrease in pollution from upstream to downstream, with no ecological risk posed by the metals (potential ecological risk index < 150, Er < 40). No significant ecological risk is associated with trace metal contamination in Damba Dam sediments. The study therefore, recommends that trace metals in the dam's sediments should be monitored for effective management, and conservation of Damba Dam's ecosystem in order to prevent possible ecological and human health risks.

Keywords: Trace metals, Ecological risk, Pollution, Damba dam

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1. Introduction

Trace metals (TMs) are known for their high toxicity, resistance to degradation, and ability to accumulate in biological systems. They are significant global concern, particularly regarding the increasing levels found in seafood and the associated threats to human health. Additionally, certain trace metals act as environmental endocrine disruptors and pose serious threat to aquatic organisms, making them a top priority for marine pollution control efforts (Wang et al., 2020). Once trace metal enters the dam, seawater, river, and ocean, it bio-accumulates and bio-amplifies in food webs, resulting in harm to ecosystems and human health (Wang et al., 2018). Trace metals can enter the environment through various sources, including industrial and agricultural activities, transportation, and waste disposal methods (Reddy and Sunitha, 2023).

Trace metals are more predominant in sediments than in the water column as they are generally saved in the least layers of water bodies (Bhuyan et al., 2023). The benthic environment of aquatic ecosystems absorbs these trace metals, which originate mainly from natural weathering, erosion, industrial wastes, and atmospheric deposition (Jaishankar et al., 2014). Anthropogenic activities including the discharge of agricultural waste, improper disposal of Industrial wastes, and inadequate drainage system design, have been identified as significant contributors to the existence of trace metals in various aquatic backgrounds (Islam et al., 2015).

The mobility of metals, their bioavailability and toxicity to organisms emphatically depend on their chemical form (Klink et al., 2019). The pervasive problem of trace metal pollution resulting from industrial wastewater is a significant concern globally. Specifically, the presence of Cu (II) ions originating from sources such as metal plating, mining, tanneries, painting, car radiator manufacturing, and intensive use of fertilizers and fungicidal sprays in agriculture, poses serious threat to both human health and aquatic life (El-Sharkawy et al., 2025; Liu et al., 2018). Moreover, these harmful substances cannot be naturally decomposed. Potentially toxic metals drift into the silt through regular or anthropogenic sources and influence different natural parts in aquatic biological systems (Jean-Lavenir et al., 2024). In understanding their impact on aquatic ecosystems, and ultimately, on human health, wastewaters are significant anthropogenic source of metals in aquatic ecosystems when discharged untreated or with impurities. They can cause significant changes to water bodies. Trace metals which are not subject to decomposition, are processed through biogeochemical processes with different retention times in different parts of the atmosphere (Vithanage, 2022). Trace metals that are retained in plants, animals, and nature in general, they can bio accumulate. Consequently, it is essential to conduct chemical analysis and speciation of trace metals, such as lead, cadmium, zinc, and copper, to understand their impact on aquatic ecosystems and, ultimately, human health (Amra, 2014). The main anthropogenic sources of cadmium appear to be mining, and metal smelting industries involved in the manufacture of alloys and batteries (Alloway, 2012). Transport of cadmium to sediments occurs mainly through sorption to organic matter and co-precipitation with iron, aluminium, and manganese oxides. Aquatic organisms exhibit a wide range of sensitivities to lead (Pb), which may be accumulated at relatively high levels by aquatic biota (Tolkou et al., 2023). Lead and Nickel in aquatic environment may be from leaded gasoline, while zinc and cadmium are from vehicle tires, galvanized parts, and other chemicals in lubricant oil and grease may be washed into water bodies (Cuput et al., 2024).

Sediments are normally occurring material that are separated by cycles of enduring and disintegration, and are then distributed by the activity of wind, water, or ice or by the force of gravity acting on the particles that settle at the bottom of a body of water. Moreover, sediments play an important role in dispersing pollution because they can carry, mobilize, and redistribute harmful substances into the water column (Miranda et al., 2021). Although trace metals can be deposited in sediments after being absorbed by suspended materials and accumulating to high concentrations, this retention is not permanent, and the metals may be on the loose if the adjoining environment changes (Custodio et al., 2020). Trace metal sorption is affected by a few circumstances, including pH, alkalinity, and parts of clay silicate and exchangeable carbonate (Li et al., 2023). Distinct metal input sources may be indicated by varying metal levels along the watershed. Soil and sediments have been evaluated using a variety of methods to determine the extent of trace metal contamination. Geochemical calibration strategies, such as ecological risk index, sediment quality guidelines, geo-accumulation index, pollution load index, contamination factor, and enrichment factor are a few examples of these procedures (Algül and Beyhan, 2020; Astatkie et al., 2021; Onoyima, 2021); multivariate statistical methods (Okibe et al., 2020); Monte Carlo simulation method (Chen et al., 2019; Kuang et al., 2021).

The Damba Dam is an important water supply source for households and local farmers in Damba Area of Gusau, Zamfara State. It is used for both irrigating crops and providing recreating activities to the communities living upstream and downstream of the dam. Though a Study has been carried out on the trace metals concentration in aquatic organisms of this Dam (Mshelizah et al., 2016), however, no research has been done on the trace metals in the sediments of this dam.

Trace metal analyses in sediment from various regions of the world have been studied and reported in multiple research papers (Kieri et al. 2021; Onoyima et al., 2021). Damba dam being one of the water sources in Damba, requires the evaluation trace metals in its water so as to reduce the risk of taking up the toxicity produced by the trace metals. It is against this background that the study aimed to assess the presence and concentration of trace metals as well as determine the ecological risks of trace metals in the bottom sediments of Damba Dam.

2. Materials and Methods

2.1 Study Area

Damba Dam is one of the major Dams in Zamfara State, Nigeria. The dam is located eastward of Gusau Local Government Area of the State on latitude 12°09' 46.7"N and longitude 6°15' 32.6"E. The reservoir is strategic to the people of Zamfara State especially the residents of Damba. It is the source of local fishing, irrigation for the community and local farmers living downstream and upstream of the study area (Mshelizah, 2021).

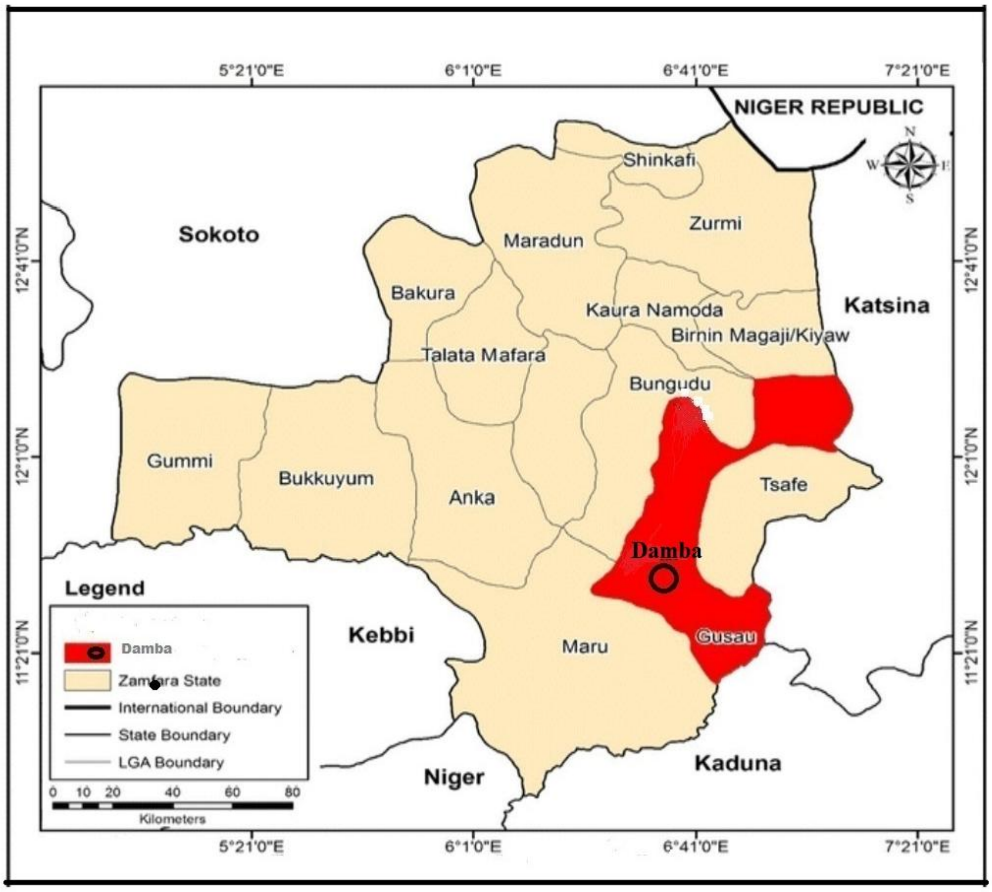

Figure 1. Map of Zamfara State Showing the study area

2.2 Sediment Sampling and Preservation

Three (3) composite samples were collected at the banks of the dam from upstream, middle stream, and downstream in March 2024 using a clean sampling grab and were immediately put in a pre-cleaned polythene bag. The samples were transported to the laboratory where they were spread in a tray and allowed to dry at room temperature. After drying, lump samples were gently crushed using a crucible, mortar and pestle, sieved with a 2 mm mesh size sieve and transferred into sample containers that were sealed and properly labelled.

2.3 Sediment Digestion and Trace Metals Analysis

Digestion of the sediment samples was carried out using the method described by Onoyima et al. (2021). This was achieved by dissolving 2.00 g of the dried powdered sediment sample in a clean beaker, followed by the addition of 2.00 ml of concentrated HCl, 5.00 ml of concentrated HNO_3, and 2.00 ml of concentrated HF. The mixture was then heated to boil for one hour and allowed to cool. The sample was filtered with Whatmans' filter paper no 1, and then the filtrate was transferred into a 100 mL volumetric flask and made up with distilled water.

The prepared sample solution was transferred into pre-cleaned, labeled sample bottles in readiness for analysis using Atomic Absorption Spectrometer (AAS) model AA-6300 (Shimadzu, Uk). Finally, four trace metals (Cd, Cr, Pb, and Zn) were analyzed using AAS machine. The analysis was done in triplicate. Six pollution indices were utilized for assessing the degree of contamination in the sediments, and data were analyzed using descriptive statistical analysis to determine the mean and percentage relative standard deviation.

3. Results and Discussion

Table 1. Mean concentration of trace metals in sediment samples

	Mean concentration (mg/kg) ± % RSD			
Metals (mg/kg)	**Upstream**	**Middle stream**	**Downstream**	**WHO**
Zn	0.04±19.45	0.03±21.78	0.04±6.52	300
Cd	BDL	0.01±39.70	0.01±55.38	3.0
Pb	0.04±4.88	0.01±18.09	0.01±11.10	100
Cr	BDL	BDL	BDL	100

Data are mean ± % RSD of three replicate results, BDL: Below detection limit

The mean concentrations of the trace metals in the sediments of Damba Dam are presented in **Table 1**. The result indicates that while the concentrations of Cr in all the samples were below the detection limit (BDL), the levels of other trace metals at each sampling point are decreasing in the following order: Zn >Pb> Cd. Zn has the lowest mean concentration of 0.03±21.78 mg/kg in the middle stream, 0.04±6.52 mg/kg downstream, and the highest value of 0.04±19.45 mg/kg upstream. Several researches on zinc revealed that it was present in sediments at higher concentrations than other metals (Hamuna and Wanimbo, 2021; Kuang et al., 2021, Onoyima et al., 2021). This may be as a result of its release into the environment from both natural and anthropogenic sources. The release from anthropogenic sources are however, greater than those from natural sources. (Obasi and Akudinobi, 2020). According to American Galvanizers Association, approximately 0.004% of the Earth's crust is projected to comprise of zinc and is rated 24th in order of abundance (Kleen, 2010). It can naturally enrich sediments containing a variety of minerals, including Sphalerite (ZnS), Smithsonite ($ZnCO_3$), and Hemimorphite [$Zn_4(Si_2O_7(OH)_2.H_2O$] (Al-Edresy et al., 2019). Fabricating metals, battery and printing material production, agriculture, and other human activities are examples of anthropogenic Zn input (Al-Edresy et al., 2019; Yunus et al., 2020). In spite of its low toxicity, zinc can be detected in sediment in high concentrations and in an easily mobilizable form (Tamás and Farsang, 2016). Among the trace metals analyzed, Pb was the second most abundant. The mean concentration was at its maximum upstream at 0.04±4.88 mg/kg, 0.01±18.09 mg/kg, and 0.01±11.10 mg/kg in the middle and downstream respectively. Lead accumulates in the human body via absorption, bioavailability, bio-concentration, and biomagnification disrupts the neurological, skeletal, reproductive, hematopoietic, renal, and cardiovascular systems (Collins et al., 2022). Cd was not detected upstream and has the lowest mean concentration of 0.01±39.70 mg/kg at middle stream. The concentration was highest downstream with a mean concentration of 0.01±55.38 mg/kg. The concentrations of all the TMs were below the permissible limit set by the World Health Organization (WHO). There is however, a sharp contrast with the concentration of TMs recorded by Mshelizah et al 2016 on aquatic organisms in Damba dam. The variations may be due to the season and points of sample collection.

Table 2. Results of Contamination Factor (CF)

Sampling locations	Contamination factor (CF)			
	Zn	Cd	Pb	Cr
Upstream	0.00	0.00	0.00	0.00
Middle stream	0.00	0.05	0.00	0.00
Downstream	0.00	0.05	0.00	0.00

Results of Contamination Factor (CF) shown in **Table 2** placed the trace metal in the sediments under three categories; low contamination, moderate contamination, and considerable contamination. All the metals (Cr, Cd, Pb, and Zn) were in the low contamination class at all the studied locations. The PLI values for the downstream, middle stream, and upstream, respectively, varied from 0.01 to 0.03. The highest value (0.03) occurred at the upstream while the least value (0.01) occurred at the middle stream (**Table 3**). The PLI values are less than 1 (< 1), indicating that the site is not polluted. The NPI values for the upstream, middle stream, and downstream ranged from 0.03 to 0.00, respectively. The study sites has a Nemerow Pollution Index (NIP) value of less than 0.7 (< 0.7) indicating the absence of trace metal pollution (**Table 3**).

Table 3. Results of Pollution Load Index (PLI), and Nemerow Pollution Index (NPI)

Sampling location	PLI	NPI
Upstream	0.03	0.00
Middle stream	0.01	0.03
Downstream	0.01	0.03

Keys: PLI>1 is Polluted $PI_{nemerow}$<0.7 is Safety Domain
PLI<1 is Not polluted 0.7≤ $PI_{nemerow}$<1.0 is Precaution domain

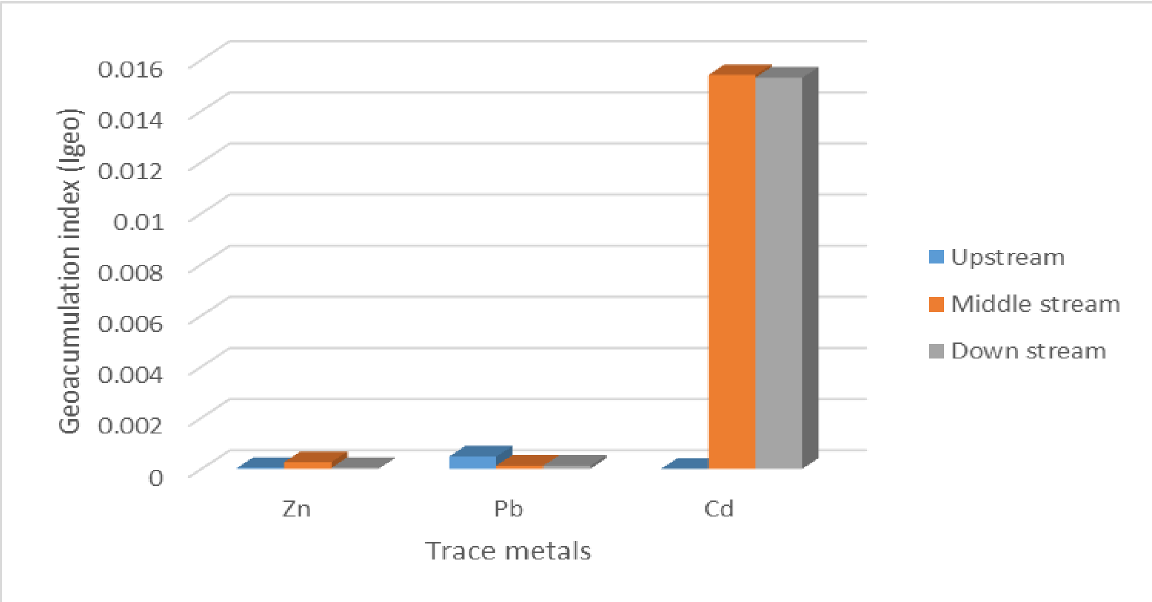

Figure 2. Geo-accumulation index of trace metals in bottom sediment of Damba Dam.

The geo accumulation index (Igeo), contamination factor (CF), pollution load index (PLI), and Nemerow pollution index (NPI) were jointly used in assessing the level of trace metal pollution in this study. Igeo and CF assessed the degree of individual trace metal contamination. The studied trace metals in the sediments can be classified as unpolluted to moderately polluted (Igeo < 1). The metal pollution can be classified in decreasing order by geo-accumulation index, as Cd >Pb> Zn > Cr.

PERI value ranged between 0.01 – 1.50 for Upstream, Middle stream and Downstream respectively (**Table 4**). All the metals had decreasing mean ERF values: Cd >Pb> Zn > Cr. The maximum value for CD (1.50) was detected in both the middle stream and downstream whereas all ERF values were below 40. Naturally, Cd is destructive, very toxic to the environment, health of humans and other organisms. It is therefore, necessary to caution any activity that can lead to the upsurge of Cd in this study area. All PERI values were also below 150, indicating that these areas have low ecological risk.

Table 4. Contributions of each metal to total ecological risk factor (ERF) and evaluation of potential ecological risk index (PERI) of trace metal pollution in sediments

Sampling location	ERF				PERI	Risk Grade
	Zn	Cd	Pb	Cr		
Upstream	0.00	NP	0.01	NP	0.01	Low ecological risk
Middle stream	0.00	1.50	0.00	NP	1.50	Low ecological risk
Downstream	0.00	1.50	0.00	NP	1.50	Low ecological risk

NP: Not polluted.

4. Conclusion

The results from this study confirm the presence of Zn, Cd, and Pb in sediments of Damba dam. The levels of Zn, Cd, and Pb in all the sampling points were below the permissible limits set by WHO. The use of collective indices in this study gave a clear status of trace metals concentration, pollution, and ecological risk in the bottom sediments of Damba Dam. This work has provided vital information on the variability of concentrations of the metals in the sediment. Due to factors such as a change in water level, change in temperature, geomorphological setup, and other physicochemical processes, the metals showed variations with levels that did not pose a threat to the aquatic environment under study. However, there is need for regular monitoring to ensure trace metals do not accumulate on sediments of the dam.

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Conflict of Interest

The authors declared no conflict of interest.

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