

Original Article

Heavy Metal Contamination and Sediment Quality in the Niger River: A Multi-Index Approach

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Abstract

Sediment quality serves as a critical indicator for evaluating pollution levels in aquatic environments. This study assessed the concentrations of heavy metals (Cu, Cd, Fe, Mn, Pb, Zn) and sediment quality in the Niger River at two locations: Agenebode and Illushi. Results indicated that the concentrations of Cu, Fe, Mn, and Zn were generally higher in sediments from Agenebode compared to Illushi and followed the order: Fe > Zn > Cu > Mn > Cd > Pb, with mean concentrations exceeding sediment quality guidelines established by USEPA for most metals, except Zn at Illushi and Mn/Pb at both sites. The contamination factor (CF) revealed moderate contamination for Cd at Agenebode and Illushi, Pb at Agenebode, and Mn at Illushi ($1 \leq CF < 3$), while other metals showed CF values below 1, indicating low contamination. Pollution Load Index (PLI) values were below 1 across both sites, signifying no overall metal pollution, while geo-accumulation index (Igeo) for Cd, Cu, Fe, Mn, Pb, and Zn ranged between 0 and 1, indicating no contamination, with specific Igeo values of -3.6910 at Agenebode and -3.6288 at Illushi. The mean Igeo ranking of heavy metal pollution was Pb > Cd > Fe > Cu > Mn > Zn at Agenebode and Mn > Cd > Zn > Fe > Cu > Pb at Illushi, while the individual ecological risk (Er) and the potential ecological risk index (PERI) suggested low ecological risk for heavy metals at both study sites. The river plays a vital role as a livelihood source for surrounding communities, ensuring the quality of its water and sediments is essential. Continuous monitoring and assessment of heavy metal contamination is recommended to effectively evaluate ecological risks and guide pollution management strategies for the Niger River.

Keywords: Bioaccumulation, Catchment, Ecosystem, Ecological risk (Er), Quality guidelines.

INTRODUCTION

In developing nations such as Nigeria, the increase in industrial/agricultural production and urban development to meet the ever-growing population needs and demands has resulted in the continuous release of pollutants into its inland water bodies, particularly along its rivers, their basins and watersheds. These pollutants typically persist both in soluble or suspended forms and eventually settle down to the bottom or taken up by aquatic organisms (Jenyo-Oni and Oladele, 2016). Heavy metals are common environmental pollutants and their presence in the aquatic ecosystem specifies the existence of natural or anthropogenic sources, such as geologic

weathering, mining practices, industrial activities, urban development, as well as deposition from the atmosphere and biological systems (Nangbes *et al.*, 2018; 2019). Heavy metals such as lead, copper, chromium, and zinc are often associated with mining and urbanization within river and lake catchments (McDonald *et al.*, 2010; Jasiak *et al.*, 2021; Zilkey *et al.*, 2025). Increased levels of heavy metals in bottom sediments of the water column could be an indicator of anthropogenic pollution rather than natural enrichment by geological weathering (Wakida *et al.*, 2008). They occur either in dissolved or particulate form in water bodies (Farsani *et al.*, 2019), and their concentration is chiefly influenced by some physicochemical parameters such as redox potential, pH,

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in a parallel increase in industrial/agricultural practices, including the use of inorganic fertilizers, and heightened organic waste discharge into its catchment. These underscore the urgency to evaluate ecological and potential risks of heavy metals in its sediments. This study evaluates the level of heavy metal in sediments and sediment quality of the River by utilizing indices such as; Contamination Factor (CF), Pollution Load Index (PLI), Geo-accumulation Index (Igeo) and Potential Ecological Risk Index (PERI). This will provide current sediment quality data, which would be useful in predicting changes in sediments and in the development/implementation of effective control measures by government and policymakers to conserve the quality of water and sediment of the Niger River, due to its importance to the livelihood and health of Nigerians.

MATERIALS AND METHODS

Description of study location

The lower Niger River in Edo State, South-South Nigeria, flows through Agenebode and Illushi communities in Etsako East Local Government Area and Esan South East Local Government Area respectively (Oseji *et al.*, 2019). The lower Niger River is highly turbid particularly during the rainy season and receives runoff from industrial mining sites in Kogi state, and also from agricultural lands, effluent discharges from rice mills, and domestic waste from its immediate catchment. Inhabitants of Agenebode and Illushi are predominantly farmers and anglers and engage in activities such as bathing, local rice processing and religious worship (Oseji *et al.*, 2019). These suburbs are located within the tropical rainforest belt of Nigeria. It's characterized by two distinct seasons; the wet season, which spans from April and November with a break in August and the dry season from December to March with a cold harmattan spell between December and January, with temperature averages of about 24 °C in the rainy season and 28 °C in the dry season (UNOCHA, 2018).

Sampling periodicity and sample collection

Sediment samples were taken quarterly over a 24-month period, encompassing both wet and dry seasons. Eight (8) sampling events were carried out, four (4) during the wet season (June 2021 to October 2022) and four (4) in the dry season (November 2021 to April 2023). Four sampling locations with two locations at Illushi and Agenebode communities respectively picked for this study. In each community, the first sampling point was the reference site, characterized by little to no human disturbance and situated upstream, while the second

sampling point characterized by constant human activities and disturbance was located downstream (Figure 1). Sampling was conducted between 7:30 and 9:00 hours to maintain consistency. Using an Ekman grab sampler, sediment samples were collected from the riverbed, transferred into labeled polythene bags. After which it was transported to the Benin-Owena River Basin Development Authority/University of Benin Joint Analytical Research Laboratory in Benin City, Edo State.

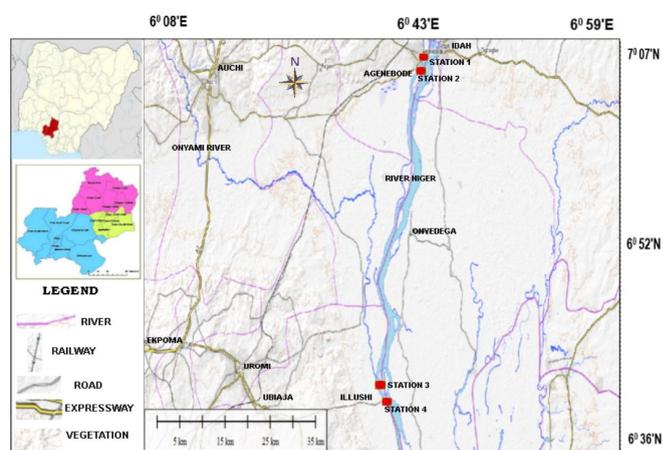


Figure 1. Study locations (Agenebode and Illushi) in the Lower Niger River, Edo State.

Digestion of sediment samples

Sediment samples were dried, grounded and sieved with the use of a mortar/pistol and a 2-mm mesh size sieve until a homogeneous fine powder was achieved. Heavy metals in the sediment samples were obtained by the Perchloric-Nitric Acid-Sulphuric Acid digestion method (USEPA, 2007). Sediment samples were digested by taking 100g of the dried sediment sample and adding 4ml Perchloric acid, 20ml concentrated Nitric acid and 2ml Concentrated Tetraoxosulphate (VI) Acid. The mixture was digested using aluminum block digester 120V (HACH Digesdahl Digestion Apparatus 18299-01). Complete digestion occurred, when a white crystalline mixture was obtained, after the disappearance of the white chlorate forms. The final content was allowed to cool and the mixture filtered using a Whitman filter paper No. 541, to determine the heavy metals (iron, zinc, copper, cadmium and lead). The filtrate was analyzed using Unican 929 Atomic Absorption Spectrophotometer (Anani and Olomukoro, 2018).

Data analysis

Evaluation of Data

Statistical Assumption is based on Chi-square Test Analysis to ascertain the relationship or differences between means for Agenebode and Illushi, between sites

were in the order of Fe > Zn > Cu > Mn > Cd > Pb at Agenebode and Illushi. Mean concentrations exceeded the

sediment guidelines by USEPA (2018), except for Zn at Illushi and Mn/Pb for both communities.

Table 2: Concentration of Heavy Metals in Sediments

Heavy Metals	Agenebode		Illushi		USEPA (2018) Sediment Quality Guidelines
	Reference	Impacted	Reference	Illushi Impacted	
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Fe (mg/kg)	433.00±41.99	424.74±50.64	328.22±21.95	319.79±29.36	30
Mn (mg/kg)	16.42±2.87	15.55±3.84	14.08±1.13	14.94±2.07	30
Cu (mg/kg)	86.27±8.42	81.85±7.86	47.53±5.25	45.07±8.27	16
Zn (mg/kg)	130.70±23.44	118.23±31.30	81.04±12.65	80.85±15.08	110
Cd (mg/kg)	8.06±1.91	8.44±1.77	7.23±1.88	7.38±1.45	0.6
Pb (mg/kg)	2.85±0.91	3.01±1.067	2.19±0.45	2.02±0.53	40

Table 3: Spatial Variation of Chemical Parameters of Sediment Samples

Parameters	Agenebode		Illushi		P- Value
	Ref	Imp	Ref	Imp	
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Iron (mg/kg)	433.00±41.99 ^C	424.75±50.64 ^C	328.22±21.95 ^{AB}	319.79±29.36 ^A	$p < 0.01$
Manganese (mg/kg)	16.42±2.87 ^C	15.55±3.84 ^C	14.08±1.13 ^A	14.94±2.07 ^{AB}	$p < 0.01$
Copper (mg/kg)	86.27±8.42 ^C	81.85±7.86 ^C	47.53±5.25 ^{AB}	45.07±8.27 ^A	$p < 0.01$
Zinc (mg/kg)	130.70±23.44 ^B	118.23±31.30 ^B	81.04±12.65 ^A	80.85±15.08 ^A	$p < 0.01$
Cadmium (mg/kg)	8.06±1.91	8.44±1.76	7.46±2.45	7.83±2.49	$p > 0.05$
Lead (mg/kg)	2.85±0.91	3.01±1.07	2.19±0.45	2.02±0.53	$p > 0.05$

Note: Where: $p < 0.01$ indicates highly significant difference; $p > 0.05$ indicates no significant difference.

Table 4: Temporal Variation of Chemical Parameters for Sediment Samples

Parameter	Wet Season			Dry Season			Sig.
	Mean ± SD	Min	Max	Mean ± SD	Min	Max	
Iron (mg/kg)	356.72±50.93	274.48	538.84	362.17±47.61	287.53	401.42	$p > 0.05$
Manganese (mg/kg)	14.04±2.63	8.95	21.89	14.95±3.07	7.53	19.77	$p > 0.05$
Copper (mg/kg)	56.47±16.27	32.77	98.56	58.60±14.77	39.32	68.31	$p > 0.05$
Zinc (mg/kg)	95.37±26.08	56.73	130.70	91.46±19.61	63.79	118.23	$p > 0.05$
Cadmium (mg/kg)	7.86±183	3.88	11.78	7.94±1.72	4.31	13.24	$p > 0.05$
Lead (mg/kg)	2.46±0.81	1.28	4.86	2.35±0.94	0.83	4.65	$p > 0.05$

Note: Where: $p < 0.05$ indicates significant difference; $p > 0.05$ indicates no significant difference.

Contamination Factor (CF) & Pollution Load Index (PLI)

The Contamination Factor (CF) indicates the level of heavy metal pollution (Yustiawati *et al.*, 2024). Table 5 summarizes the Contamination factors

accumulated to the PLI value. It reveals that Cd at Agenebode/Illushi, Pb at Agenebode and Mn at Illushi were above 1 ($1 \leq CF < 3$), and classified as moderate degree, while others were classified as low degree ($CF < 1$), according to the grading system of Ali *et al.*, (2016). Pollution Load Index for Agenebode and Illushi is

than was observed in this study. The high iron content in the sediments at Agenebode and Illushi could be due to its high composition in the soil surrounding its catchment in Edo State often washed into the river as runoffs. The soil is predominantly reddish in colour and geological analysis has revealed it contains high concentrations of iron. Also, anthropogenic activities may have profound influence on it within its catchment, due to increase in human population. Iron is a key constituent of internal fertilization in the water column, where it combines with phosphorus, and when low dissolved oxygen (DO) levels results, there is an alteration of redox conditions, which releases phosphorus, sulfur, and iron from sediments into the water column (Conley *et al.*, 2009; Han *et al.*, 2015; Beutel *et al.*, 2020; Zhao *et al.*, 2022).

Copper (Cu) and Cadmium (Cd) at Agenebode/Illushi and Zinc (Zn) at Illushi revealed mean concentration above international guidelines set by USEPA (2018), suggesting natural/anthropogenic origins (Aradpour *et al.*, 2020) and possible contamination at these sites. Mean copper values (45.07 – 86.27) were significantly lower than that reported by Akoteyon and Kodja (2022) for River Ogun. Asibor *et al.* (2015), Omoko *et al.* (2019) in stream sediments within Onne, Jire and Imeokparia (2018), Makanjuola and Makanjuola (2018), Yawo *et al.* (2022), Ozdemir *et al.* (2024) and Douglas *et al.* (2025) recorded lower values than was observed in this study for other rivers from southern Nigeria. Makanjuola and Makanjuola (2018) reports that aquatic plants absorb three (3) times more copper than plants on dry lands, exposing aquatic organisms that feed on them to accumulated levels of Cu.

The mean zinc values (80.85 – 130.70) recorded in this study were lower than those reported by Adebayo (2017) and Udiba *et al.* (2018). Asibor *et al.* (2015), Jire and Imeokparia (2018), Makanjuola and Makanjuola (2018), Omoko *et al.* (2019), Kieri *et al.* (2021), Akoteyon and Kodja (2022), Yawo *et al.* (2022), Ozdemir *et al.* (2024), Araújo *et al.* (2025) and Douglas *et al.* (2025) documented higher values than was recorded for this study. Yustiawati *et al.* (2024) surmises that living materials such as algae and shells along with industrial waste are potential sources of Zn. The mean Cadmium values (7.23 – 8.44) were higher than those reported by Makanjuola and Makanjuola (2018), Omoko *et al.* (2019), Kieri *et al.* (2021), Ottong and Ekanem (2021) from Udo Awankwo River, Akoteyon and Kodja (2022), Ozdemir *et al.* (2024), Araújo *et al.* (2025) and Douglas *et al.* (2025). Nwajei *et al.* (2014) and Nwankwoala and Angaya (2017) recorded values comparable to those from this study in Nigerian rivers. While, Jire and Imeokparia (2018) and Udiba *et al.* (2018) recorded higher values than was observed in this study. Cadmium is a by-product of lead and zinc mining/smelting, more mobile in the aquatic

environment and akin in toxicity to lead and chromium (Moore and Ramamoorthy, 1984; Makanjuola and Makanjuola, 2018). Cadmium contamination in the aquatic environment is regularly associated with fertilizers in agricultural areas (Mico *et al.*, 2006; N'guessan *et al.*, 2009), from paints usage/disposal and deposited on road surfaces from studded tires (Makanjuola and Makanjuola, 2018). According to Saria (2016), cadmium content may vary due to anthropogenic activities specifically through aquaculture practices as algacide used in fish ponds for the control of growth of phytoplanktons and filamentous algae and certain fish disease results in increased cadmium content in river sediments, when waste water from these ponds are released in natural water bodies. The practice of aquaculture in the lower Niger River catchment occurs at different scales; however, the absence of regulatory standards among local fish farmers poses a potential risk of cadmium release into the environment.

Manganese (Mn) and Lead (Pb) concentrations were within acceptable guideline limits by USEPA (2018), designating lesser risk of pollution by these metals (Zahra *et al.*, 2014) and suggesting that these metals via natural means maintain their concentrations in the sediments with minimal anthropogenic influence (Olomukoro and Enabulele, 2024). Manganese is an essential micronutrient that plays an important role as a constituent and co-activator of several enzymes responsible for biological processes in fish and shows relatively low toxicity to aquatic biota (Maage *et al.*, 2000). Early signs of manganese toxicity include; headache, muscle cramps, fatigue and aggressiveness, progressing into Parkinson's disease-like symptoms such as tremors and manganism (Makanjuola and Makanjuola, 2018). Mean values for Mn (14.08 – 16.42) in this study was higher than that of Asibor *et al.* (2015) and Adebayo (2017), but lower than that reported by Makanjuola and Makanjuola (2018) and Akoteyon and Kodja (2022). Lead is a by-product of ore processing such as sulphide ores of copper and zinc and gets into rivers from building materials such as lead pipes (Makanjuola and Makanjuola, 2018). The mean values of Pb (2.02 – 3.01) recorded in this study was higher than those reported by Adebayo (2017), Moslen *et al.* (2018), Omoko *et al.* (2019), Udiba *et al.* (2018), Ottong and Ekanem (2021), Kieri *et al.* (2021), Yawo *et al.* (2022) and Douglas *et al.* (2025). However, Asibor *et al.* (2015), Makanjuola and Makanjuola (2018) and Akoteyon and Kodja (2022) recorded higher values than was observed in this study.

Contamination Factor (CF) & Pollution Load Index (PLI)

Analysis of Contamination Factor (CF) gives an insight to the state of metal contamination in sediments

Agenebode and Mn at Illushi in the sediments even at Illushi in the sediments even with the high iron, zinc and copper content recorded. Pollution Load Index (PLI), Geo-accumulation Index (Igeo) and Potential Ecological Risk (PERI) suggest elevated metal concentration due primarily to natural geochemical processes and not pollution. However, this does not diminish the potential risks associated with these naturally high concentrations. Higher metal values do not necessarily translate to contamination; it depends on the contamination indices used and whether the values fall within acceptable ranges. As contamination indices factors in the absolute metal concentrations, reference background levels, toxicity and ecological risk thresholds. There is need for continuous assessments of the potential ecological impacts of heavy metal contamination in the Niger River, with the tenacity to effectively measure, monitor and manage pollution, as well as their risk to living organisms due to increased anthropogenic activities within its catchment.

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CREDIT AUTHOR STATEMENT

UC and **CU**: Conceptualization and Methodology. **UC** and **CU**: Data curation and Investigation. **UC**: Writing- Original draft preparation. **AV**, **BS** and **FO**: Supervision. All authors reviewed the manuscript.

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