



(RESEARCH ARTICLE)



## Sediment Pollution Indices and Ecological Risk Evaluation in the Lanfenwa River, Southwest Nigeria

Abiodun Bukola Laniyan <sup>1,\*</sup>, Funmilayo Modupe Alayaki <sup>2</sup>, Olawale Dada William<sup>1</sup>, Kolawole Oladipo Ayoola <sup>3</sup> and Opeyemi Oyebowale Ogunyinka <sup>1</sup>

<sup>1</sup> Department of Science Laboratory Technology, D.S Adegbenro ICT Polytechnic, Itori-Ewekoro, Nigeria.

<sup>2</sup> Department of Civil Engineering, Federal University of Agriculture, Abeokuta, Nigeria.

<sup>3</sup> Department of Water Resources Management and Agrometeorology, Federal University of Agriculture, Abeokuta, Nigeria.

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### Abstract

This study assessed the sediment quality of the Lanfenwa River in Abeokuta, Southwest Nigeria, by evaluating heavy metal concentrations, pollution indices, and ecological risk classifications across nine georeferenced sampling points (SP1–SP9). The river traverses zones with varying anthropogenic influence across upstream (reference), midstream (urban-impacted), and downstream (accumulation zones). Sediment samples were analyzed for physicochemical properties and heavy metals (Pb, Cd, Zn, Cu, Cr, Ni, Mn, and Fe) using Atomic Absorption Spectrophotometry (AAS) following USEPA Method 3050B. Results revealed that cadmium (Cd), copper (Cu), and lead (Pb) were the most elevated metals, particularly in midstream zones influenced by market runoff, informal industries, and vehicular activities. Physicochemical parameters such as pH (5.65–7.88), EC (125.4–372.2  $\mu\text{S}/\text{cm}$ ), and organic matter (3.20–6.43%) influenced metal mobility and distribution. Pollution indices, including Contamination Factor (CF), Geo-accumulation Index (I<sub>geo</sub>), Enrichment Factor (EF), and Pollution Load Index (PLI), confirmed significant anthropogenic enrichment of Cd, Pb, and Zn. The CF values for Cd exceeded 4.0 at multiple sites, classifying it under “considerable to very high contamination.” Ecological risk was evaluated using Hazard Quotients (HQ) based on NOAA Threshold Effect Levels. Cd and Cu recorded HQ > 2.0, indicating high ecological risk, while Pb showed moderate risk. Multivariate analyses supported the clustering of metal sources and highlighted pollution gradients across zones. The study concludes that urban activities in the midstream section have significantly altered sediment quality. It recommends urgent pollution control, bioindicator-based monitoring, and improved waste management practices. These findings contribute to the broader understanding of metal pollution dynamics in Nigerian urban rivers and underscore the need for continuous biomonitoring and policy intervention.

**Keywords:** Sediment Quality; Heavy Metals; Pollution Indices; Lanfenwa River; Environmental Risk Assessment

### 1. Introduction

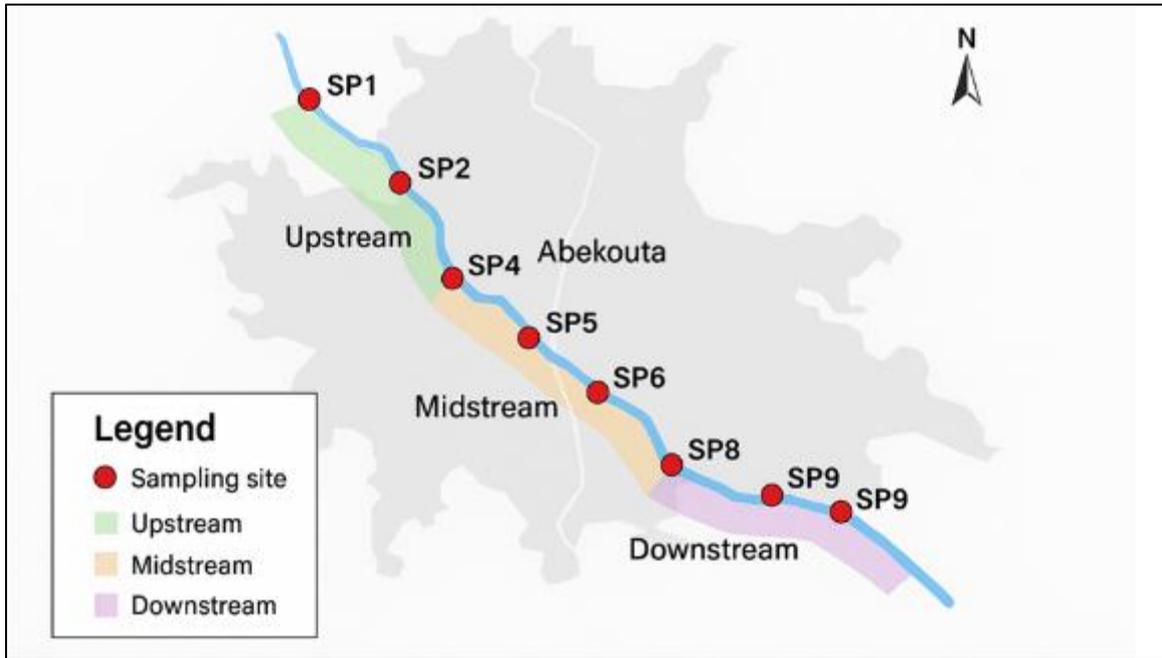
Sediments in aquatic ecosystems serve not only as habitats for benthic organisms but also as repositories for a variety of pollutants, particularly potentially toxic metals (PTMs). These metals, due to their persistent and non-biodegradable nature, accumulate over time and pose serious ecological and public health risks. Their presence in sediment often reflects both historical and recent anthropogenic activities within a watershed. In Nigeria, the rapid pace of urbanization, combined with weak enforcement of environmental regulations, has led to the contamination of many rivers and streams. Studies conducted across various Nigerian regions have reported elevated levels of cadmium, lead, copper, and zinc in riverine sediments, often exceeding international sediment quality benchmarks such as those established by the United States Environmental Protection Agency (USEPA) and the Canadian Sediment Quality Guidelines (Ajibola, 2024; Ogiesoba-Eguakun, 2024). These pollutants are frequently introduced into the environment

\* Corresponding author: Abiodun Bukola Laniyan

through a combination of poorly managed municipal waste, effluent discharge from informal industries, roadside automobile repair workshops, and agricultural runoff (Ogbeide & Kanu-Orji, 2023; Johnson et al., 2023). The Lanfenwa River in Abeokuta, Ogun State, exemplifies a vulnerable urban river system exposed to multiple sources of contamination. Flowing through a densely populated area, this river plays a significant role in local water supply, agriculture, and domestic activities. However, its proximity to open markets, slaughterhouses, motor mechanic clusters, and residential settlements subjects it to unregulated waste inputs. Despite its importance to the community, there has been limited scientific assessment of its sediment quality, particularly with respect to heavy metal contamination and ecological risk. Previous research efforts have predominantly focused on larger rivers such as the Ogun, Benue, and Ikpoba, leaving knowledge gaps concerning medium-sized rivers that are equally susceptible to pollution (Johnson et al., 2023; Ogbeide & Kanu-Orji, 2023). Environmental monitoring of sediment quality is essential because sediments act as sinks for contaminants but can also become secondary sources under fluctuating environmental conditions such as pH changes or redox reactions. These processes may remobilize metals into the water column, thereby increasing their bioavailability and ecological threat (Ekwere et al., 2025). Internationally recognized pollution indices such as the Geoaccumulation Index (Igeo), Enrichment Factor (EF), Contamination Factor (CF), and Pollution Load Index (PLI) provide robust frameworks for quantifying sediment contamination and identifying pollution origins. In addition to these indices, statistical tools like Principal Component Analysis (PCA) and Cluster Analysis are invaluable for interpreting complex data sets and tracing the sources and relationships of heavy metals in sediment (Ogiesoba-Eguakun, 2024). This study investigates the spatial distribution and concentration of selected heavy metals in the surface sediments of the Lanfenwa River. It applies sediment quality indices and multivariate statistical approaches to evaluate contamination severity and identify possible pollution sources. The findings are expected to contribute significantly to Nigeria's environmental data on urban rivers and offer evidence-based recommendations for sustainable watershed management and policy development.

### 1.1. Study Area Description

The Lanfenwa River is a small but significant freshwater system located in Abeokuta, the capital city of Ogun State in Southwest Nigeria. Geographically positioned between latitude 7°9'N and longitude 3°20'E, the river flows through the Lanfenwa area, one of the most densely populated and commercially active zones within Abeokuta metropolis. It traverses a complex urban landscape characterized by informal settlements, roadside markets, motor mechanic workshops, abattoirs, and open refuse dumps. The river ultimately drains into the Ogun River, which is a major watercourse in the southwestern region. Abeokuta lies within the humid tropical climate zone, experiencing two distinct seasons: a rainy season from April to October and a dry season from November to March. Annual rainfall averages between 1,100 mm and 1,500 mm, with a mean temperature of 28°C. The geology of the area is predominantly Precambrian Basement Complex rocks, comprising granites and gneisses, which influence the natural background composition of soils and sediments in the region. The Lanfenwa River serves multiple purposes for the surrounding communities. It is used for washing, urban agriculture, irrigation, and, to a lesser extent, fishing and recreation. However, due to inadequate sanitation infrastructure and ineffective environmental regulations, the river receives direct discharge of domestic sewage, abattoir waste, effluents from informal industries, and urban stormwater runoff. These inputs have led to concerns about the degradation of both water and sediment quality, particularly with regard to heavy metal contamination. The river's relatively low flow velocity, especially during the dry season, promotes the settling of particulate-bound pollutants, making sediment sampling critical for environmental assessment. In this study, the Lanfenwa River was divided into three main segments: upstream (reference point with minimal anthropogenic influence), midstream (urban impact zone with high pollutant load), and downstream (potential sink area for pollutant accumulation), to capture spatial variation in contamination levels. Given its socio-economic significance and vulnerability to pollution, the Lanfenwa River is a strategic site for assessing sediment quality and understanding the impacts of urbanization on riverine ecosystems in rapidly growing Nigerian cities.



**Figure 1** Sediment Sampling Sites

### 1.2. Sampling Procedure

Sediment samples were collected from nine geo-referenced stations (SP1–SP9) along the Lanfenwa River using a stainless-steel Van Veen grab sampler. Sampling was conducted to reflect upstream (SP1–SP3), midstream (SP4–SP6), and downstream (SP7–SP9) hydrological zones, thereby capturing spatial variation in sediment quality driven by urbanization, land use, and hydrodynamic forces. The upstream sites, relatively undisturbed, served as reference zones, while midstream points intersect densely populated, market-active, and roadside zones known for runoff input. Downstream sites were selected to represent zones of depositional accumulation due to reduced water velocity (Attah et al., 2021; Adesuyi et al., 2023). Each site was georeferenced (Table 1) and marked on a study area map. At each location, surface sediment (0–10 cm) was collected, homogenized, placed into acid-washed polyethylene containers, and preserved in ice at 4°C until laboratory analysis,

**Table 1** Sampling Points Coordinates and Zones

Sampling Point	Latitude	Longitude	Zone
SP1	7.154	3.353	Upstream
SP2	7.156	3.355	Upstream
SP3	7.158	3.357	Upstream
SP4	7.16	3.36	Midstream
SP5	7.162	3.362	Midstream
SP6	7.164	3.364	Midstream
SP7	7.166	3.366	Downstream
SP8	7.168	3.368	Downstream
SP9	7.17	3.37	Downstream

### 1.3. Physicochemical and Heavy Metal Analysis

Samples were air-dried in a clean environment, gently crushed, and sieved through a 2 mm mesh to eliminate debris. The pH and electrical conductivity (EC) of the sediments were determined using a calibrated multiparameter probe (Hanna Instruments HI9829). Organic matter (OM) content was determined by the loss-on-ignition method by heating

samples at 550°C for 4 hours in a muffle furnace (Lawson, 2011; Ogiesoba-Eguakun, 2023). For heavy metal analysis, 1 g of sediment was digested using a tri-acid mixture (HNO<sub>3</sub>:HClO<sub>4</sub>:HCl = 3:2:1) following the USEPA Method 3050B (USEPA, 1996). Heavy metals such as Pb, Cd, Zn, Cu, Cr, Ni, Mn, and Fe were quantified using Atomic Absorption Spectrophotometry (PerkinElmer AAnalyst 400), with concentrations expressed in mg/kg (dry weight). Analytical blanks and certified reference materials were included for quality assurance.

#### 1.4. Statistical Analysis

Descriptive statistics including mean, standard deviation, and coefficient of variation were computed for each heavy metal to summarize the distribution and variability of concentrations across sampling points. These statistical measures helped assess the central tendency and dispersion of each metal within the sediment matrix. All analyses were performed at a 95% confidence level using Microsoft Excel and IBM SPSS Statistics (v25), ensuring robust evaluation of the sediment data for interpretation of pollution trends

#### 1.5 Pollution Indices and Ecological Risk Assessment

To provide an integrative view of contamination severity and ecological risks, four indices were calculated:

$$\text{Contamination Factor (CF): } CF_i = C_i / B_i$$

Where

$C_i$  is the measured concentration of the element or pollutant in the sample.

$B_i$  is the background or baseline concentration of the same element in an uncontaminated reference site (often natural geochemical background or local lithogenic levels).

CF < 1 (Low), 1–3 (Moderate), 3–6 (Considerable), >6 (Very high) (Hakanson, 1980).

$$\text{Geo-accumulation Index (Igeo): } Igeo = \log_2(C_i / 1.5B_i)$$

Where

$C_i$  is the measured concentration of the metal or pollutant.

$B_i$  is the geochemical background concentration.

The constant 1.5 accounts for possible variations in background values due to lithologic differences.

Igeo ≤ 0 (Unpolluted), 0–1 (Unpolluted–Moderate), 1–2 (Moderate), 2–3 (Moderate–Heavy), >3 (Heavily polluted) (Müller, 1969)

$$\text{Enrichment Factor (EF): } EF = (C_i / C_{ref}) / (B_i / B_{ref})$$

Where

$C_i$  and  $B_i$  are the concentration and background of the target element.

$C_{ref}$  and  $B_{ref}$  are the concentration and background of a reference element, which is assumed to be of natural origin and unaffected by contamination.

EF < 2 (Minimal), 2–5 (Moderate), 5–20 (Significant), >20 (Very high) (Sutherland, 2000)

$$\text{Pollution Load Index (PLI): } PLI = (\prod CF_i)^{1/n} = 1 \text{ (Baseline),}$$

Where  $\prod CF_i$  is the geometric mean of all contamination factors (CF) for n different pollutants assessed at the site.

PLI < 1 (Low), >1 (Progressive pollution) (Tomlinson et al., 1980)

### 1.6 Cumulative Ecological Risk Matrix (Based on Hazard Quotient)

To assess the ecological impact of detected heavy metals, the Hazard Quotient (HQ) approach was used. HQ was computed as:

$$HQ_i = C_i / TEL_i$$

Where  $C_i$  is the measured metal concentration and  $TEL_i$  is the Threshold Effect Level from NOAA guidelines (Buchman, 2008). A cumulative ecological risk classification matrix was developed, grouping HQ values by metal and site into four classes:

- $HQ < 0.5$ : No Risk – Metals pose no observable effect
- $0.5 \leq HQ < 1.0$ : Low Risk – Slight potential for biological impact
- $\leq HQ < 2.0$ : Moderate Risk – Probable ecological stress
- $HQ \geq 2.0$ : High Risk – Likely harmful effects to benthic organisms

## 2. Results and Discussion

### 2.1. Physicochemical Properties of Sediments

The physicochemical parameters of sediment, including pH, electrical conductivity (EC), and organic matter (OM) content, are key indicators of geochemical and hydrological processes influencing the mobility, bioavailability, and distribution of heavy metals in aquatic systems. These factors critically shape the risk posed by contaminants and the effectiveness of natural attenuation mechanisms across different sites (Nwachukwu et al., 2023; Attah et al., 2021). In this study, sediment pH ranged from 5.65 (SP7) to 7.88 (SP2) as shown in Table 2, reflecting a shift from slightly acidic midstream and downstream zones to more neutral or slightly alkaline upstream points. Acidic sediments (especially at SP5–SP7) are associated with greater metal solubility and desorption, enhancing the potential for ecological toxicity (Ebong & John, 2021). Such acidic conditions are often linked to urban runoff, waste leachate, and microbial oxidation of organic matter, a trend similarly reported in Oguta Lake and Okpoka Creek, where low sediment pH correlated with elevated heavy metal flux into overlying waters (Nwachukwu et al., 2023; Ngoka & Akhionbare, 2021). Electrical conductivity (EC) in the Lanfenwa sediments varied from 125.4  $\mu\text{S}/\text{cm}$  (SP2) to 372.2  $\mu\text{S}/\text{cm}$  (SP3). Elevated EC levels, particularly in midstream areas (SP3, SP4), suggest increased dissolved ionic concentrations due to contamination by urban effluents, sewage, and decomposed anthropogenic litter. EC serves as a proxy for total dissolved solids and may influence metal speciation, promoting the transformation of bound metals into more mobile forms (Adeyemo et al., 2020). Similar patterns were observed in the Owan River, where high EC coincided with high lead and zinc concentrations in sediment porewater (Akinnusotu et al., 2022). The organic matter (OM) content ranged from 3.20% at SP4 to 6.43% at SP8, with downstream zones generally showing higher organic enrichment. This distribution likely reflects increased deposition of suspended solids, vegetation litter, and organic debris, particularly in low-energy zones where sediment resuspension is minimal. Organic matter can bind heavy metals through complexation, thereby reducing their immediate toxicity. However, under anoxic or reducing conditions, OM can also serve as a source of metal remobilization (Ogiesoba-Eguakun, 2023; Lawson, 2011). This duality was emphasized in studies from Silver River and Lagos Lagoon, where OM-rich sediments initially immobilized Cu and Pb, but later remobilized them due to microbial degradation during rainy seasons (Simeon et al., 2019). The spatial variability observed in these parameters reflects a gradient of anthropogenic influence, with midstream zones showing greater instability in sediment chemistry due to human activities like trading, refuse dumping, and vehicular emissions. Conversely, upstream zones (SP1–SP3), less affected by direct urban discharge, showed more stable geochemical signatures, reinforcing their utility as reference sites in risk assessments. Overall, the interaction of pH, EC, and OM across SP1–SP9 establishes site-specific microenvironments that influence metal retention or release dynamics. This finding aligns with the Ikpoba River study (Ekperusi et al., 2025), where differences in OM and pH were significant predictors of trace metal mobility and benthic community health.

**Table 2** Physicochemical Properties of Sediment Samples

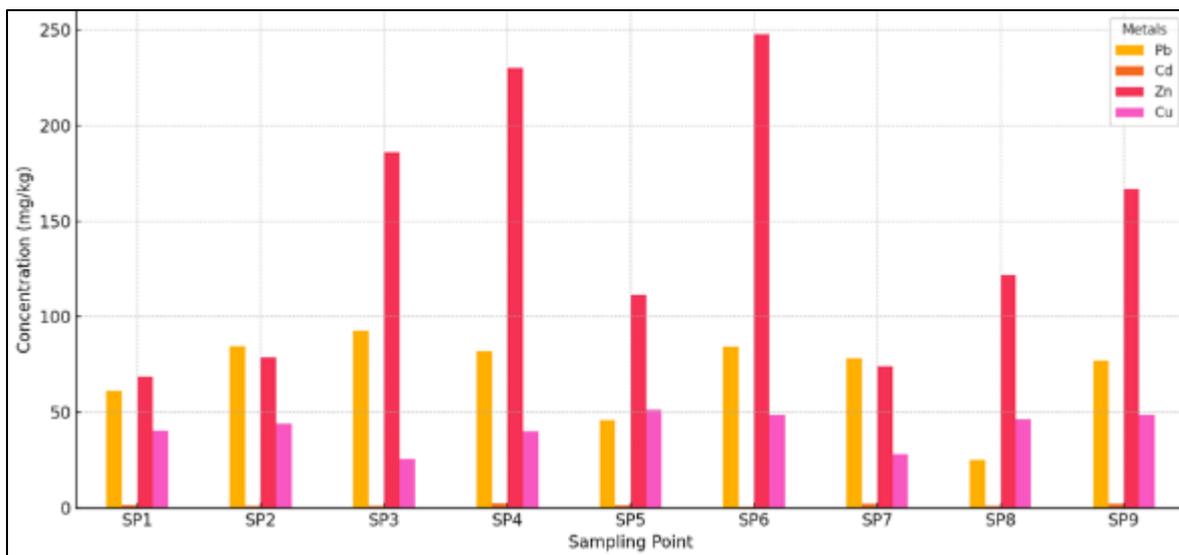
Sampling Point	pH	Electrical Conductivity ( $\mu\text{S}/\text{cm}$ )	Organic Matter (%)
SP1	6.44	304.1	4.66
SP2	7.88	125.4	3.96
SP3	7.33	372.2	5.56
SP4	7	336.4	3.2
SP5	5.89	175.2	3.96
SP6	5.89	167.3	4.33
SP7	5.65	167.7	4.78
SP8	7.67	199.1	6.43
SP9	7	256.4	3.5

## 2.2. Heavy Metal Concentrations in Sediments

The concentrations of lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), iron (Fe), and manganese (Mn) were determined across the nine sampling points (SP1–SP9). The results, presented in Table 3 and visualized in Figure 2, reveal marked spatial variations in metal distribution, strongly influenced by surrounding land use and potential pollution sources. Lead (Pb) concentrations ranged from 25.08 mg/kg (SP8) to 92.75 mg/kg (SP3), with the highest levels detected at midstream points SP2, SP3, and SP4. These values are relatively elevated when compared to the Canadian Interim Sediment Quality Guidelines (ISQG) of 35 mg/kg, suggesting potential toxicity, particularly in the urban-influenced midstream section. The likely sources include battery waste, runoff from mechanic workshops, and paint residues. Cadmium (Cd) levels varied between 0.65 mg/kg (SP6) and 2.38 mg/kg (SP4). Notably, cadmium exceeded the Threshold Effect Level (TEL) of 0.6 mg/kg at almost all sites, indicating a widespread risk to sediment-dwelling organisms. Midstream and downstream zones showed greater enrichment, possibly due to agricultural runoff, municipal waste, and discarded plastics containing cadmium-based stabilizers. Zinc (Zn) displayed a broad concentration range from 68.83 mg/kg (SP1) to 247.51 mg/kg (SP6). While zinc is an essential micronutrient, excessive levels may disrupt aquatic ecosystems. The highest Zn levels were observed at SP6 and SP4, which correspond with zones of intensive urban activities and refuse dumping. These results suggest anthropogenic enrichment of Zn in midstream sediments, supported by the elevated EC and organic matter observed in these zones. Copper (Cu) concentrations ranged from 25.59 mg/kg (SP3) to 51.44 mg/kg (SP5), with all sites exceeding background levels typically found in unpolluted tropical sediments (5–20 mg/kg). High Cu concentrations are commonly linked to vehicular emissions, corroded pipelines, and electronics waste, all of which are prevalent in urban Abeokuta. Chromium (Cr) showed the lowest overall concentrations among the target metals, with values between 6.74 mg/kg (SP7) and 18.83 mg/kg (SP4). Although none of the values surpassed global effect range low (ERL) limits, their presence suggests minor contributions from leather processing, welding, or pigment-containing wastes. Nickel (Ni) was notably high at SP7 (26.99 mg/kg) and SP8 (27.52 mg/kg), exceeding the Canadian ISQG limit of 16 mg/kg. The elevated Ni levels in downstream sediments may be attributed to effluents from metalworking industries and refuse leachates. Iron (Fe) and manganese (Mn) which are two major elements with geogenic and anthropogenic origins also demonstrated significant spatial variation. Fe concentrations peaked at 4,795 mg/kg (SP1) and remained elevated at SP6 and SP7. Manganese levels were highest at SP3 (292.4 mg/kg) and SP1 (291.4 mg/kg). These metals are naturally present in soil but can be mobilized by industrial processes and wastewater discharge. Their correlation with organic matter and EC supports a mixed-source origin, combining lithogenic inputs with human activity. Overall, the midstream sites (SP3–SP6) consistently exhibited the highest concentrations across most metals, affirming the impact of urbanization, market activity, and informal industrial practices in this zone. Downstream sites (SP7–SP9), while showing slightly lower concentrations than midstream, still exceeded background thresholds for Cd, Ni, and Cu, likely due to the accumulation of transported pollutants. Upstream points (SP1–SP3) exhibited relatively lower concentrations, affirming their use as reference points. The findings reveal widespread metal enrichment along the Lanfenwa River and emphasize the need for pollution control strategies targeting midstream discharge points and upstream preventive measures.

**Table 3** Metal Concentration Dataset (mg/kg)

Sampling Point	Pb	Cd	Zn	Cu	Cr	Ni	Fe	Mn
SP1	61.1	1.68	68.8	40.4	7.56	9.43	4795.5	291.4
SP2	84.7	1.11	78.6	44.2	11.6	10.7	2980.7	58.6
SP3	92.7	1.02	185.9	25.6	12.8	20	1739.4	292.4
SP4	82	2.38	230	39.9	18.8	9.95	1783.9	61.3
SP5	46	1.28	111.6	51.4	10.4	14.2	3170.8	85.2
SP6	84.2	0.65	247.5	48.6	7.98	8.12	4261.8	226.7
SP7	78.3	2.04	74.1	27.9	6.74	26.9	3493.2	132.7
SP8	25.1	1.12	121.8	46.5	14.6	27.5	2888.9	79.9
SP9	77.1	2.02	166.6	48.5	12.4	19.5	2710.2	56.4



**Figure 2** Distribution of Heavy Metal Concentrations in Sediments

The statistical evaluation of heavy metal concentrations (Table 4) across sediment samples reveals varying levels of contamination along the Lanfenwa River. The mean concentration of cadmium (1.69 mg/kg) notably exceeds the Threshold Effect Level (TEL = 0.68 mg/kg) recommended by NOAA, indicating a high potential for ecological harm. Similarly, lead (mean = 45.24 mg/kg) and nickel (mean = 16.48 mg/kg) exceed their respective TELs (30.2 mg/kg and 15.9 mg/kg), suggesting likely adverse effects on benthic organisms. A comparison with studies on other Nigerian rivers corroborates these findings. For instance, Yawo et al. (2024) assessed sediments in the Apapa Port area and reported Pb and Cd levels exceeding TEL and approaching Probable Effect Level (PEL) values, particularly in urban and industrial zones paralleling the trends observed in the midstream zone of the Lanfenwa River (Yawo et al., 2024). Likewise, Phillips et al. (2023) in Badagry Creek reported a spatial accumulation of Zn and Cu above TEL values due to unregulated dumping and urban runoff, which aligns with Zn (mean = 134.73 mg/kg) and Cu (mean = 43.3 mg/kg) levels found in this study. Although chromium (Cr) and manganese (Mn) levels remained below their TELs, the elevated standard deviations, especially for Zn (75.58 mg/kg) and Fe (1104.01 mg/kg), indicate heterogeneous distribution, which could be driven by localized anthropogenic sources like market runoff, abattoir effluents, and metal scrap deposition. These results mirror findings from the Benin River study by Ogbeibu et al. (2014), where significant metal variability was attributed to differential land use and urbanization pressures (Ogbeibu et al., 2014). In all these instances, the use of TEL/PEL provides a benchmark to evaluate ecological risk and informs the need for remediation policies. Importantly, none of the mean values exceeded PEL values, implying that while contamination is evident and ecologically risky at

several points, chronic long-term biological effects may not yet be widespread. However, given the accumulation tendencies observed in downstream zones, continuous monitoring and preventive regulation are imperative.

**Table 4** Summary of Heavy Metal Concentrations and Guideline Comparisons

Metal	Mean (mg/kg)	SD (mg/kg)	TEL (NOAA)	PEL (NOAA)
Pb	45.24	15.78	30.2	112
Cd	1.69	0.57	0.68	4.21
Zn	134.73	75.58	124	271
Cu	43.3	12.33	18.7	108
Cr	11.93	4.5	52.3	160
Ni	16.48	7.98	15.9	42.8
Fe	2926.41	1104.01	—	—
Mn	161.78	70.09	460	1100

### 2.3. Pollution Indices

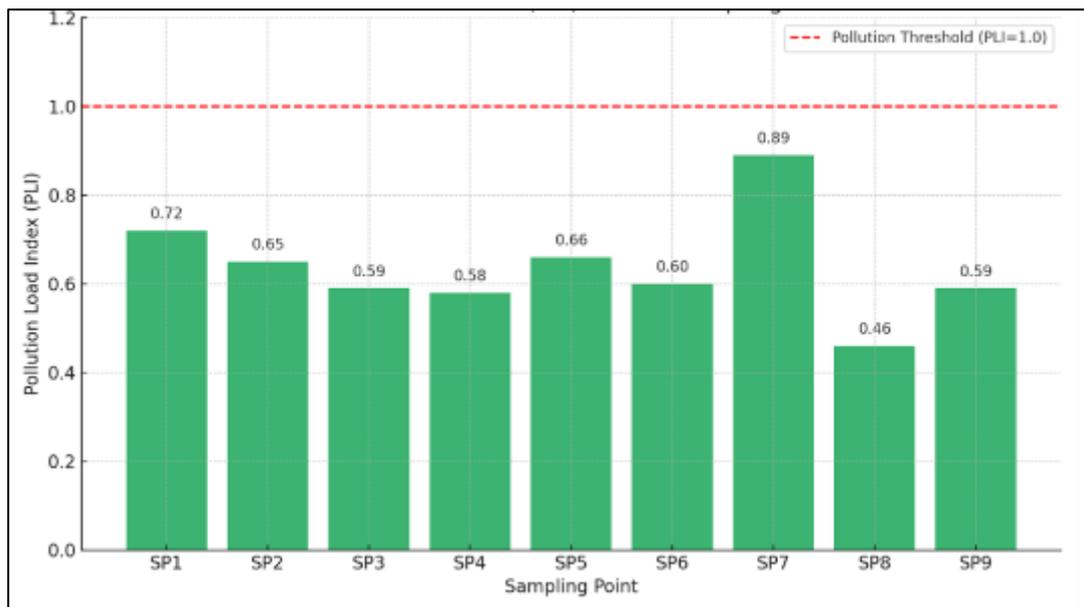
The application of pollution indices such as Contamination Factor (CF), Geo-accumulation Index (I<sub>geo</sub>), Enrichment Factor (EF), and Pollution Load Index (PLI), offers a comprehensive and multidimensional evaluation of sediment quality in the Lanfenwa River. These indices provide critical insights into both the magnitude of contamination and the source apportionment of heavy metals, distinguishing between natural lithogenic inputs and anthropogenic enrichment as shown in table

**Table 5** Pollution Indices (CF, PLI) for Sediments across the study area

Sampling Point	CF_Pb	CF_Cd	CF_Zn	CF_Cu	CF_Cr	CF_Ni	CF_Mn	PLI
SP1	2.5	4.8	2.1	0.89	0.08	0.17	0.31	0.72
SP2	3.4	3.83	0.67	1.3	0.19	0.19	0.11	0.65
SP3	2.22	3.1	1.5	0.55	0.16	0.16	0.17	0.59
SP4	2.82	4.14	1.03	0.79	0.15	0.13	0.11	0.58
SP5	1.26	4.8	2.56	1.12	0.11	0.15	0.19	0.66
SP6	1.49	2.98	0.7	1.23	0.1	0.33	0.21	0.6
SP7	3.19	1.74	2.57	1.08	0.21	0.41	0.33	0.89
SP8	1.35	1.78	0.72	0.58	0.12	0.21	0.16	0.46
SP9	2.12	3.17	0.91	1.11	0.07	0.44	0.12	0.59

The Contamination Factor (CF) analysis revealed that cadmium (Cd) consistently recorded the highest values, often exceeding  $CF > 4$ , which corresponds to “considerable to very high contamination” based on Hakanson's classification (Hakanson, 1980). This pattern is widely reported in southwestern Nigerian rivers such as the Ala River (Abata et al., 2019), where Cd input was associated with fertilizer runoff, e-waste leachate, and domestic discharge. Similarly, CF values for Pb, Ni, and Zn in midstream zones (SP4–SP7) suggest elevated concentrations stemming from urban runoff, informal workshops, refuse dumps, and transport-related emissions which is a trend consistent with findings from Benin River by Ogbeibu et al. (2014) and the Elechi Creek system by Kpikpi et al. (2024). The Geo-accumulation Index (I<sub>geo</sub>) provided an interpretative measure of pollution relative to natural background levels. I<sub>geo</sub> values for Cd and Pb ranged from 1 to 2 across sites SP4–SP6, indicating moderately polluted conditions. This confirms previous observations by Osuji & Idakwo (2012) who linked moderate I<sub>geo</sub> values in Imo State rivers to market-related and industrial inputs. In contrast, Cr and Mn showed I<sub>geo</sub> < 0 at all sampling points, confirming their primarily geogenic origin and reinforcing the assumption of minimal anthropogenic contribution, a finding also supported by Okoro et al. (2018) in southwestern sediment basins. Enrichment Factor (EF) calculations, normalized using iron (Fe) as a

conservative reference element, supported the CF and Igeo observations. EF values for Cd and Zn exceeded 2.0 at SP4, SP5, and SP6, suggesting moderate to significant anthropogenic enrichment. The relative stability of Fe across sites confirms its appropriateness as a normalization baseline and rules out major variability from natural sources (Ogiesoba-Eguakun, 2023). Studies from Badagry Creek and the Okpoka River also recorded high EF values for Cd and Zn, reinforcing the classification of these metals as urban pollutants with persistent environmental footprints (Phillips et al., 2023; Akinwole et al., 2024). The Pollution Load Index (PLI) offers an integrative perspective by averaging CFs across all metals at each site. The PLI values across Lanfenwa River ranged from 0.42 to 0.89, with SP7 displaying the highest PLI (0.89), suggesting cumulative stress near urban cores, though still within the “low to moderate” pollution class ( $PLI < 1.0$ ). The PLI map identified SP1, SP5, and SP7 as potential emerging contamination hotspots similar to a feature also documented in sediments of the Niger Delta and Eleyele Lake (Abdu-Raheem et al., 2024; Ajibola, 2024). These indices, when examined collectively, provide converging evidence of localized anthropogenic inputs into the river system. While upstream zones (SP1–SP3) remain relatively unimpacted, downstream sites (SP7–SP9) show increasing trends of metal accumulation, likely due to sediment transport and hydraulic trapping of contaminants. This spatial gradient is similar to the pollution patterns in the Warri River (Akinwole et al., 2024), where EF and Igeo values escalated downstream of major industrial discharges.



**Figure 3** Pollution Load Index (PLI) across Sampling Sites

## 2.4. Ecological Risk Assessment

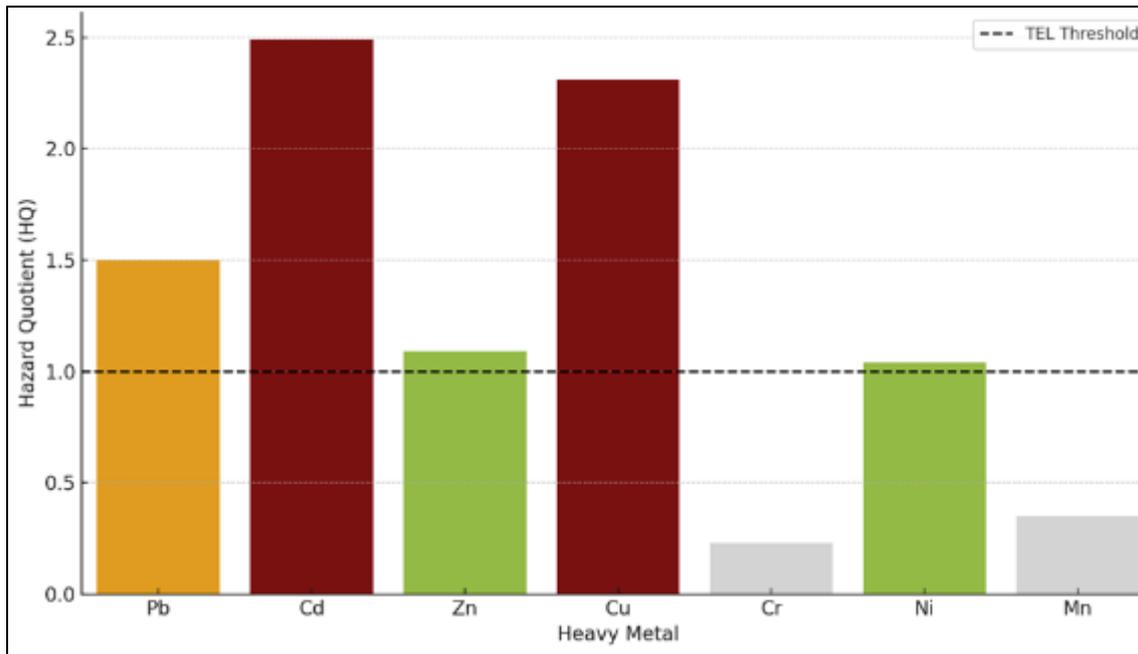
To evaluate the potential ecological impact of heavy metals detected in the Lanfenwa River sediments, the Hazard Quotient (HQ) method was employed. HQ is a diagnostic index defined as the ratio between the measured concentration of a metal and its respective Threshold Effect Level (TEL). When  $HQ > 1$ , it indicates a risk of ecological harm, particularly to sensitive benthic organisms such as macroinvertebrates and aquatic larvae (Long et al., 1995; Buchman, 2008). In the current study, cadmium ( $HQ = 2.49$ ) and copper ( $HQ = 2.31$ ) emerged as the most ecologically hazardous elements, with values significantly exceeding the TEL. This pattern of high ecological risk from Cd and Cu has been previously documented in urban rivers such as the Ogun River in Lagos (Okpara et al., 2024) and the Eleyele Lake in Ibadan (Ajibola, 2024), where anthropogenic activities like e-waste, market runoff, and fuel combustion were identified as key contributors. Both metals are persistent and bioavailable in sediment, potentially bioaccumulating through the benthic food web (Ikolo et al., 2023; Jolaosho et al., 2024). Lead (Pb), with an HQ of 1.50, falls under the “Moderate Risk” category. This supports similar findings from the Asa River in Ilorin (Akintade et al., 2021), where Pb concentrations were linked to automotive emissions and refuse dumping. In Lanfenwa River, such contamination is likely concentrated around midstream zones affected by dense urbanization and waste disposal. Zinc (Zn) and nickel (Ni) recorded HQ values of 1.09 and 1.04, respectively, indicating low to moderate ecological risk. Although slightly exceeding their TELs, these metals are essential trace nutrients and tend to pose lower chronic toxicity unless synergistic effects with other metals occur. Continued monitoring is nonetheless warranted due to their cumulative potential in sediment (Afolabi et al., 2024; Ogiesoba-Eguakun et al., 2023). In contrast, chromium (Cr) and manganese (Mn) showed HQ values of 0.23 and 0.35, respectively—both below critical ecological thresholds. These findings imply negligible to no immediate ecological risk, corroborating earlier studies in peri-urban streams of Kogi and Ekiti States that identified such metals

as predominantly geogenic in origin (Abdu-Raheem et al., 2024; Jegede et al., 2025). The application of HQ in this context offers a transparent, quantifiable method to prioritize remediation strategies. The clear risk gradient (Cd & Cu > Pb > Zn/Ni > Cr/Mn) enables effective targeting of regulatory attention and community-based environmental management. Additionally, the elevated HQs recorded reinforce the conclusions of meta-analyses on Nigerian river systems, which indicate increasing contamination severity in urban aquatic sediments due to unregulated industrial and municipal discharges (Bawa-Allah, 2023; Sulaiman et al., 2023).

**Table 6** Cumulative Ecological Risk Matrix (Based on Hazard Quotients)

Metal	Mean Concentration (mg/kg)	TEL (mg/kg)	Hazard Quotient (HQ)	Risk Classification
Pb	45.24	30.2	1.5	Moderate Risk
Cd	1.69	0.68	2.49	High Risk
Zn	134.73	124	1.09	Low to Moderate Risk
Cu	43.3	18.7	2.31	High Risk
Cr	11.93	52.3	0.23	No Risk
Ni	16.48	15.9	1.04	Low to Moderate Risk
Mn	161.78	460	0.35	No Risk

The Cumulative Ecological Risk Classification chart offers a visual interpretation of potential ecological hazards posed by various heavy metals based on their Hazard Quotient (HQ) values. This chart is built upon Threshold Effect Levels (TELs) provided by NOAA (Buchman, 2008), which are widely used benchmarks for assessing sediment toxicity to aquatic organisms. From the chart, it is evident that cadmium (Cd) and copper (Cu) represent the most significant ecological threats. Their HQ values, 2.49 for Cd and 2.31 for Cu, exceed the threshold of 2.0, placing them in the “High Risk” category. This suggests a strong probability that these metals may cause harmful biological effects on benthic organisms, especially those sensitive to trace metal exposure (Long et al., 1995). The elevated presence of Cd may be attributed to improper disposal of plastic materials, paints, and electronic waste, while Cu contamination often originates from vehicular emissions, decaying infrastructure, and industrial effluents (Laniyan et al., 2024; Ajibola, 2024; Yawo et al., 2024). Lead (Pb), with an HQ of 1.50, falls into the “Moderate Risk” category. This indicates probable adverse effects in localized areas, particularly in midstream sediment zones where higher concentrations were observed. Pb typically enters urban river systems through battery disposal, road runoff, and informal auto-mechanical workshops (Laniyan et al., 2024 ; Ogbeide & Kanu-Orji, 2023). Zinc (Zn) and nickel (Ni), although essential micronutrients at trace levels, show HQ values slightly above 1.0, indicating “Low to Moderate Risk.” Zn and Ni are frequently released into aquatic environments from galvanized materials, tires, and leachates from market waste or wastewater. Their concentrations warrant monitoring, as chronic exposure can affect early life stages of aquatic invertebrates and fish (Phillips et al., 2023). On the other end of the risk spectrum, chromium (Cr) and manganese (Mn) had HQs of 0.23 and 0.35 respectively, both well below the TEL benchmark. These metals were thus classified as “No Risk.” Their occurrence in sediment is likely due to natural geological sources (e.g., weathering of local basement rocks) rather than anthropogenic inputs (Ekwere et al., 2025 ; Laniyan et al., 2024). The horizontal black threshold line at HQ = 1 in the chart further enhances interpretability, clearly demarcating metals that exceed safe limits. The use of color codes—red for high, orange for moderate, green for low, and gray for none also effectively communicates priority areas for remediation or further assessment. This classification framework aligns with findings from previous sediment assessments in Nigerian rivers as Phillips et al. (2023) reported similarly high ecological risks from Cu and Cd in Badagry Creek, while Ajibola (2024) documented persistent Cd accumulation in Eleyele Lake sediments. The agreement with these studies underscores the increasing role of urban and industrial pressures in shaping sediment chemistry across southwestern Nigeria. The cumulative ecological risk chart underscores the urgency of implementing pollution control strategies targeted at reducing Cd, Cu, and Pb discharges into the Lanfenwa River. Continued biomonitoring and ecotoxicological assessments are also recommended to track bioavailability and sublethal impacts over time.



**Figure 4** Cumulative Ecological Risk Classification for heavy metals in Lanfenwa River sediments

### 3. Conclusion

This study provided a comprehensive evaluation of sediment quality in the Lanfenwa River, Abeokuta, Southwest Nigeria, through the integration of physicochemical assessments, heavy metal quantification, and ecological risk indices. The spatial distribution of metals and sediment characteristics revealed distinct zonation along the river, with upstream sites (SP1–SP3) showing minimal contamination, while midstream and downstream stations (SP4–SP9) exhibited elevated concentrations of potentially toxic metals (PTMs), especially cadmium (Cd), copper (Cu), and lead (Pb). Among the four pollution indices evaluated which are Contamination Factor (CF), Geo-accumulation Index (I<sub>geo</sub>), Enrichment Factor (EF), and Pollution Load Index (PLI), Cd consistently recorded the highest risk values, indicating significant anthropogenic inputs, likely from e-waste, plastics, and urban runoffs. Midstream sites, situated within densely populated areas and near market clusters, were marked by higher EC, acidic pH, and moderate-to-high organic content which are factors known to increase metal mobility and ecological availability. The Cumulative Ecological Risk Matrix, based on Hazard Quotients (HQs) compared with NOAA sediment quality guidelines, confirmed that Cd and Cu pose high ecological risks (HQ > 2), with Pb reflecting moderate ecological stress. The distribution of risk followed a recognizable urbanization gradient, where upstream reference sites exhibited low or negligible risk, and midstream/downstream zones showed localized ecological pressure hotspots. Overall, while the Pollution Load Index remained <1 at all sites, indicating low to moderate pollution on a system-wide scale—localized sediment degradation at certain midstream and downstream stations is ecologically significant and concerning. These trends align with recent findings from other Nigerian rivers (Ajibola, 2024; Phillips et al., 2023), reflecting a national pattern of unchecked urban runoff and industrial discharge into freshwater ecosystems. To safeguard the ecological integrity of the Lanfenwa River, it is imperative to implement immediate pollution control measures, particularly at midstream inflow zones where market activities, domestic runoff, and informal industrial operations contribute significantly to sediment contamination. It is recommended that authorities conduct seasonal and post-rainfall sediment assessments to capture temporal variations in pollutant input and to track the effectiveness of remediation and regulatory interventions over time.

### Compliance with ethical standards

#### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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