Ethiopian Journal of Environmental Studies & Management 19(3): 326 – 342, 2026
ISSN:1998-0507 doi: https://ejesm.org/doi/v19i3.6
Submitted: March 27, 2026 Accepted: May 30, 2026

GEO-ASSESSMENT AND ECOLOGICAL RISK OF HEAVY METALS IN BOTTOM SEDIMENTS OF OKPARE OLOMU RIVER, SOUTHERN NIGERIA

***BIOSE, E.[1] AND NWODO, G.O.[2]**
[1]Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City, Edo State, Nigeria
[2]Department of Geomatics, Faculty of Environmental Sciences, University of Benin, Benin City, Edo State, Nigeria
*Corresponding author: ekene.biose@uniben.edu

Abstract
This study looked at the geo-assessment and ecological risk of heavy metals in the bottom sediments of the Okpare Olomu River in Southern Nigeria. An Ekman grab sampler was used to gather bottom sediment samples every three months for a year from four points along the river. We used standard analytical methods and Atomic Absorption Spectroscopy (Solaar 969 Unicam Series Model) to look for certain physicochemical features and heavy metals in the samples. The sediment texture was predominantly sandy, while several physicochemical properties varied significantly across the sampled stations. Mean concentrations of heavy metals and THC in sediment samples were 64.653±40.52 (Fe), 0.699±1.02 (Cr), 0.098±0.13 (Cd), 0.902±0.82 (Cu), 4.179±1.06 (Zn), 2.87±1.68 (Mn), 0.022±0.03 (Pb), and 681.146±967.36 (THC), respectively. The order of heavy metal concentrations was Fe > Zn > Mn > Cu > Cd > Cr > Pb. Geo-assessment indices indicated that the sediments were influenced by varied levels of human contamination. The enrichment factor showed that some metals, especially chromium and copper at the stations that were most severely impacted, were moderately to very highly enriched. The geo-accumulation index showed that chromium levels varied from very polluted to extremely polluted. Cadmium and copper levels were also high at several locations. The pollution load index, contamination factor, and degree of contamination showed that all of the stations that were analysed were polluted. Stations 2 and 4 had the highest levels of pollution. The prospective ecological risk index showed that Station 1 had a low ecological risk, Station 3 had a moderate risk, Station 4 had a high risk, and Station 2 had a very high ecological risk. These findings underscore the importance of remediation and continuous sediment quality monitoring.

Keywords: *Geo-assessment, Bottom sediments, Heavy metals, Ecological risk, Okpare Olomu River*

Introduction

Surface waters are indispensable to ecological stability, biodiversity conservation, and human well-being. They sustain fisheries, agriculture, domestic water supply, transportation, and a wide range of ecosystem functions. Despite their importance, the quality of many freshwater systems is increasingly threatened by human activities and climate-related pressures, making regular monitoring essential for environmental protection and sustainable resource management (Uddin *et al.,* 2021; Idehen and Ezenwa, 2019). Across the world, declining water and sediment quality has become a major environmental concern, largely driven by industrial effluents, agricultural runoff, urban expansion, and other land-based sources of pollution that impair aquatic ecosystems and endanger public health (Rahman *et al*., 2021; Achieng *et al*., 2014).

In tropical river systems, these pressures are often intensified by indiscriminate waste disposal, catchment disturbance, and petroleum-related activities. This situation is especially evident in the Niger Delta, where prolonged oil exploration, gas flaring, industrial emissions, and spill events have contributed substantially to environmental degradation (Odukoya *et al*., 2002; Ololade *et al*., 2009; Agbalagba *et al*., 2013; Iwuoha *et al*., 2013; Sowunmi, 2019). The Okpare Olomu River in Delta State represents an important freshwater resource for surrounding communities, supporting fishing, irrigation, transportation, and domestic needs. However, increasing exposure to oil-related operations, dredging, sand mining, and other anthropogenic disturbances has heightened concern over the quality of its sediments and the possible ecological consequences.

Heavy metals are one of the most important pollutants in water since they last a long time, are hazardous, and don't break down naturally. Some metals, like iron, zinc, and copper, are needed in small amounts, but others, like cadmium, lead, and nickel, can be potentially hazardous even in little amounts. Their tendency to persist in the environment, accumulate in sediments, and biomagnify through food webs makes them especially hazardous to aquatic organisms and humans (Tam and Wong, 2000). Bottom sediments are widely recognized as both repositories and secondary sources of contaminants. They integrate pollutant inputs over time and often contain metal concentrations that exceed those of the overlying water column, thereby providing valuable information on the cumulative impact of anthropogenic activities (Begum et al., 2009). Elevated metal concentrations in sediments frequently reflect pollution inputs rather than purely natural geochemical sources (Uaboi-Egbenni *et al*., 2010). Under changing environmental conditions such as resuspension, oxidation-reduction shifts, or physical disturbance, these accumulated contaminants may be released back into the aquatic system, posing renewed risks to aquatic life and ecosystem functioning (USEPA, 2001).

To better characterize sediment contamination, several index-based approaches have been developed and widely applied. These include the enrichment factor, geoaccumulation index, contamination factor, pollution load index, and potential ecological risk index, all of which help to distinguish between natural and anthropogenic sources, assess contamination intensity, and evaluate ecological implications (Kiymaz *et al*., 2014; Ofomola *et al*., 2017; Ogwueleka and Christopher, 2020).

When combined with appropriate statistical tools, these indices provide a robust framework for interpreting the distribution, origin, and ecological significance of heavy metals in aquatic sediments.

The extent and dispersion of heavy metal contamination in the bottom sediments of the Okpare Olomu River remain inadequately comprehended, notwithstanding the river's ecological and economic importance. Establishing this knowledge is necessary for identifying contamination hotspots, understanding likely sources, and evaluating ecological risk within this intensively used river system. Therefore, this study assesses contaminants in the bottom sediments of the Okpare Olomu River, Southern Nigeria, with emphasis on their distribution, degree of contamination, and potential ecological risk

Study Area

This study was conducted in the Ughelli South Local Government Area, along the Okpare Olomu River in Delta State, South-South Nigeria. The investigation was conducted in the range of 5°30′N to 6°00′E. The degree of human activity and proximity to areas that had previously been impacted by oil spills were taken into consideration while selecting sampling locations. Delta State, which spans about 16,842 km², is located in the tropical rainforest region of Nigeria. Numerous aquatic and terrestrial plants and animals can be found there, making it one of the nation's ecologically vulnerable regions (NDES, 1997; Uyigue and Agho, 2007; Ekpo *et al*., 2018). Additionally, the region offers vital ecosystem services like farming, fishing, and water supply for nearby residences (Ebewore, 2020). Despite these biological resources, the area has been under constant pressure from oil production and exploration operations, which has had a negative impact on population health and environmental quality.

Climate

Delta State has an equatorial climate with alternating rainy and dry seasons and is located in the tropical rainforest zone (UNDP, 2006). The wet season runs from April to October, whereas the dry season is from November to March. Rainfall is highest from April through September. Every year, the state receives about 3000 mm of rain, the most of which is heavy. The relative humidity is typically high during the rainy months. The temperature is often higher, the humidity is lower, and there is less rain during the dry season (Agbaire and Emoyan, 2012). According to Okumagba and Ozabor (2014), the average monthly temperature ranges from 22°C to 26°C in the cooler months and from 28°C to 33°C in the warmer months. The average annual temperature is approximately 30°C. The movement of water, sediment, and contaminants in the study region are all impacted by these meteorological factors.

Vegetation and Land Use

Delta State's vegetation ranges from savannah in the northeast to evergreen forest in the heart of the state to mangrove swamps along the coast. The secondary rainforest that makes up the majority of the research region has been severely disrupted by deforestation, population expansion, industrialisation, and the construction of new roads and other infrastructure. Along the river are floating macrophytes such as water hyacinth (*Eichhornia crassipes*), oil palm (*Elaeis guineensis*), and bamboo (*Bambusa* sp.) (Ibe, 1988; Nnaji, 2008). Farming, logging, and fishing are the main sources of income for the locals. The state produces a variety of goods, including fruits, vegetables, rice, yam, and cassava.

This demonstrates how farming is practiced there (Nnaji, 2008). In recent years, ecological circumstances have gotten worse due to oil exploration and gas flaring. This has resulted in reduced soil production, diminished surface water quality, and the demise of aquatic plants and animals (Nnaji, 2008; Okumagba and Ozabor, 2014).

Materials and Methods

Sampling and Sample Collection

For physicochemical and heavy metal analyses, we took sediment samples directly from the Okpare Olomu River's bottom at each sampling location using an Ekman grab sampler. The grab was used to collect bottom materials from soft, fine-grained sediments by being lowered from a boat into the river. The retrieved silt samples were placed in sterile plastic bags, appropriately labelled, and transported to the laboratory for examination. Samples were collected in four locations along the river.Sampling covered a period of twelve months. Maps of the region where the investigation was conducted are shown in Figure 1.

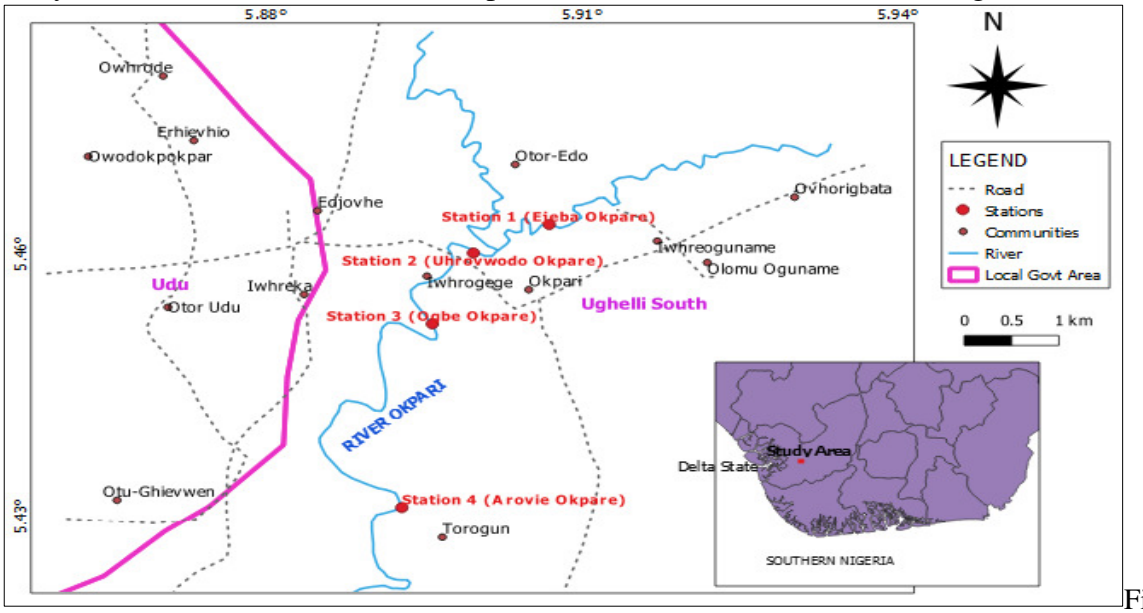

Fig. 1: Map showing surface water sampling stations

Sampling Periodicity

The four sampling stations were visited quarterly between January and December 2020. A total of five field trips were undertaken within the twelve-month study period, and samples were collected from each station during each visit. Sampling was carried out between 7:00 a.m. and 11:00 a.m. Nigerian time, beginning from Station 1 upstream and proceeding successively to Station 4 downstream. Field equipment was inspected and calibrated in accordance with the manufacturers' specifications before use.

Laboratory Analysis

Sediment assessment followed the method described by Davey and Conyers (1988). Electrical conductivity was determined using the APHA (1992) method. Organic matter content was determined by the Walkley and Black (1934) procedure, while moisture content was measured according to Page *et al.* (1982). Available phosphorus and exchangeable cations were analysed

following Onyeonwu (2000), and total nitrogen was determined by the Kjeldahl method as described by Bremner (1965). Particle size distribution of the sediment was determined using the modified hydrometer method of Ibitoye (2006). Total hydrocarbon content (THC) was measured with a HACH DR spectrophotometer in accordance with APHA (1998). Sample digestion and heavy metal determination followed the method of AOAC (2000) using an atomic absorption spectrophotometer (Solaar 969 Unicam Series Model).

Geo-Assessment of Heavy Metals – Risk Evaluation

Enrichment Factor (EF)

Duce (1975) presented EF as an effective instrument for this objective. Iron (Fe) was chosen as the normalising element since it is often employed as a reference element in studies of sediment contamination (Nweke and Ukpai, 2016). Levy *et al*. (1992) figured out the enrichment factor by using the following formula:

EF = (X/Fe)sample / (X/Fe)background

Contamination Factor, Degree of Contamination, and Pollution Load Index

According to Hakanson (1980), the contamination factor was found by dividing the measured concentration of each metal by the background concentration of that element.

CF = Cmetal / Cbackground

Nonetheless, the PLI may be articulated as

$$PLI\ of\ a\ study\ area\ = n\sqrt{C_f^i\ 1 \times C_f^i\ 2 \times C_f^i\ \ 3 \times C_f^i\ \ldots \times C_f^i\ n} \quad - - -$$

The pollution load index was determined by taking the nth root of the product of the contamination factors for the metals being studied (Tomlinson et al., 1980; Nweke and Ukpai, 2016).

Index of Geo-Accumulation (Igeo)

It was first proposed by Muller (1969) and then discussed by Boszke et al. (2004). The index was determined by:

Igeo = log2 (Cn / 1.5Bn)

where Cn represents the quantified concentration of the metal in the sediment, and Bn denotes the geochemical background concentration of the identical metal (Wedepohl, 1995; Chakravarty and Patgiri, 2009).

Potential Ecological Risk Index

The ecological risk index created by Hakanson (1980) was utilised to assess the ecological consequences of heavy metal pollution in the sediments.

Table 1: presents the modified grading criteria for assessing the possible ecological danger of heavy metals in soil

E^i_R	Pollution degree	RI	Risk level	Risk degree
EiR< 30	Slight	RI< 40	A	Slight
30≤EiR< 60	Medium	40 ≤ Ri< 80	B	Medium
60≤EiR<120	Strong	80≤Ri< 160	C	Strong
120≤EiR< 240	Very Strong	160≤RI 320	D	Very strong
EiR≥ 240	Extremely strong	RI≥ 320	-	-

Source: Jiang *et al.* (2014)

Data Analysis

All data analyses were conducted utilising Microsoft Excel and Statistical Package for the Social Sciences (SPSS) version 20.00. The enrichment factor, contamination factor, degree of contamination, pollutant load index, geo-accumulation index, and possible ecological risk index were calculated utilising Microsoft Excel.

Results and Discussion

Physicochemical Characteristics of Bottom Sediments

The physicochemical characteristics and heavy metal concentrations of bottom sediment samples collected from the four stations along the Okpare Olomu River are presented in Tables 2 and 3. Among the measured sediment properties, electrical conductivity (EC), magnesium (Mg), sand, and silt showed highly significant spatial variation ($p < 0.01$), while organic carbon (OC), sodium (Na), cation exchange capacity (CEC), and clay varied significantly among stations ($p < 0.05$). In contrast, pH, total nitrogen (N), calcium (Ca), and potassium (K) did not differ significantly across the sampling stations ($p > 0.05$).

The pH of the sediment was relatively uniform across the study area, with mean values of 6.24, 5.94, 5.92, and 5.94 at Stations 1, 2, 3, and 4, respectively. These values indicate moderately acidic to slightly acidic sediment conditions, with Station 1 being slightly less acidic than the other locations. The acidic nature of the sediments is consistent with earlier reports by Akani *et al*. (2008) and Etim and Adie (2012), and suggests the presence of exchangeable hydrogen ions that may enhance metal mobility within the sediment matrix.

Electrical conductivity values were highest at Station 4, followed closely by Station 1, with mean values of 20.65 and 18.98 µS/cm, respectively, whereas lower values were observed at Stations 2 and 3. The marked variation in EC across stations may reflect differences in dissolved ionic constituents and localized anthropogenic inputs along the river stretch. Organic carbon was highest at Station 2 and also relatively elevated at Station 4, while the lowest value occurred at Station 3. The elevated organic carbon at Station 2 may be associated with runoff-borne particulate matter, agricultural residues, and decomposing organic debris entering the river at that location. The comparatively low value at Station 3 may be attributed to continuous sediment disturbance arising from dredging activities. Since organic carbon serves as an index of organic matter accumulation in sediments, its distribution is important in understanding contaminant binding and nutrient dynamics (Davies and Tawari, 2010).

Table 2: Physicochemical characteristics of sediments from Okpare Olomu River

Parameters	**Station 1** $\bar{X}$±SD (Min-Max)	**Station 2** $\bar{X}$±SD (Min-Max)	**Station 3** $\bar{X}$±SD (Min-Max)	**Station 4** $\bar{X}$±SD (Min-Max)	p-Value
pH	6.24±0.35 (5.70-6.55)	5.94±0.51 (5.03-6.25)	5.92±0.52 (5.00-6.29)	5.94±0.30 (5.43-6.20)	p>0.05
EC (us/cm)	18.98 [a] ±4.66 (15.58-26.90)	8.71 [c] ±1.29 (8.00-11.01)	11.03 [b] ±3.16 (5.63-13.26)	20.65 [a] ±12.20 (10.94-42.00)	P<0.01
Organic carbon (%)	2.33 [b] ±3.29 (0.46-8.07)	3.25 [a] ±1.38 (1.09-4.40)	0.47 [b] ±0.52 (0.06-1.28)	2.75 [a] ±1.64 (0.58-4.40)	P<0.05
Total nitrogen (%)	0.21±0.24 (0.06-0.64)	0.16±0.04 (0.10-0.18)	0.23±0.44 (0.03-1.01)	0.36±0.59 (0.06-1.41)	P>0.05
Na (meq/100g)	1.51 [a] ±0.28 (1.24-1.80)	1.01 [b] ±0.47 (0.35-1.40)	0.77 [b] ±0.20 (0.55-0.98)	1.14 [a] ±0.27 (0.78-1.40)	P<0.05
Ca (meq/100g)	0.35±0.27 (0.10-0.64)	0.21±0.24 (0.00-0.48)	0.36±0.22 (0.07-0.64)	0.72±0.57 (0.10-1.22)	P>0.05
Mg (meq/100g)	0.93 [a] ±0.09 (0.77-0.97)	0.47 [d] ±0.04 (0.39-0.49)	0.63 [c] ±0.04 (0.55-0.65)	0.81 [b] ±0.00 (0.81-0.81)	P<0.01
K (meq/100g)	0.45±0.35 (0.10-0.86)	1.58±1.51 (0.14-3.20)	0.48±0.39 (0.20-1.14)	1.25±0.78 (0.62-2.10)	P>0.05
CEC (meq/100g)	3.24 [a] ±0.40 (2.97-3.91)	3.26 [a] ±1.67 (1.93-5.09)	2.25 [b] ±0.12 (2.13-2.41)	3.92 [a] ±0.47 (3.40-4.41)	P<0.05
Sand (%)	93.32 [b] ±0.53 (92.41-93.74)	92.97 [b] ±1.20 (90.84-93.64)	94.59 [a] ±0.19 (94.44-94.89)	91.04 [c] ±1.13 (89.45-92.64)	P<0.01
Silt (%)	1.06 [b] ±0.58 (0.16-1.78)	0.79 [b] ±0.13 (0.61-0.99)	0.77 [b] ±0.30 (0.26-0.98)	2.53 [a] ±0.44 (2.11-3.14)	P<0.01
Clay (%)	5.62 [b] ±0.71 (4.58-6.45)	6.24 [a] ±1.31 (5.38-8.55)	4.63 [b] ±0.12 (4.58-4.85)	6.43 [a] ±1.09 (4.58-7.41)	P<0.05

Total nitrogen levels were predominantly low at all locations, with the highest mean value seen at Station 4, succeeded by Station 3. Nitrogen, a critical nutrient for the growth and survival of aquatic species, may be present at low concentrations in this study due to inadequate nutrient retention in sediments or potential disturbances associated with petroleum contamination. Across all stations, sediment texture followed the order sand > clay > silt, indicating a predominantly sandy substratum. This sandy composition indicates elevated permeability and diminished adsorption capacity, potentially facilitating the downward migration of pollutants and decreasing the retention of heavy metals in the sediment. Sheoran *et al*. (2009) observed that sandy and acidic sediments exhibit a weak capacity to store heavy metals, therefore promoting their migration into adjacent groundwater and surface water systems.

Heavy Metals in Bottom Sediments

The findings indicated that Fe, Cr, and Cd exhibited substantial variability among stations ($p < 0.05$), but Cu, Zn, Mn, and total hydrocarbon content (THC) demonstrated highly significant regional disparities ($p < 0.01$). Lead (Pb), on the other hand, did not demonstrate a big variation between the four locations ($p > 0.05$). The concentration pattern of heavy metals in the sediment was Fe > Zn > Mn > Cu > Cd > Cr > Pb. This basic pattern is

similar to what Ashiru and Ogundare (2019) found for sediments from the Ugbo Water Way in Ondo State.

The mean concentrations of iron at Stations 1, 2, 3, and 4 were 58.24, 81.61, 29.14, and 89.62 mg/kg, respectively. Stations 2 and 4 had much higher values. At Stations 2 and 4, the levels of chromium were also high, with Station 4 having the highest average level. The Cr values in this study were lower than those reported for Ekpan Creek by Ogamba *et al*. (2017). However, the spatial pattern suggests that these values came from humans, possibly because of industrial and petroleum-related activities. This is because chromium often enters water systems through industrial discharges and waste disposal (Ogbeibu *et al*., 2014). The highest levels of cadmium were found at Station 2, followed by Station 3. Stations 1 and 4 had lower levels. This pattern is significant due to cadmium's high toxicity, which is linked to severe health consequences, including renal dysfunction, anaemia, bone marrow disorders, cancer, bronchitis, and damage to the liver and brain (Dara, 2000; Koji *et al*., 2004). Station 4 had the most copper, and Station 3 had the least. The elevated Cu at Station 4 may reflect petroleum-related activities in the area, whereas the low value at Station 3 may again be influenced by sediment removal and constant physical disturbance due to dredging. Elevated copper levels have been associated with anaemia, kidney and liver damage, and gastrointestinal irritation (Puyate *et al*., 2007).

Table 3: Heavy metal contents of sediment

Parameters	**Station 1** $\bar{x}$±SD (Min-Max)	**Station 2** $\bar{x}$±SD (Min-Max)	**Station 3** $\bar{x}$±SD (Min-Max)	**Station 4** $\bar{x}$±SD (Min-Max)	p-Value
Fe (mg/kg)	58.24^{ab} ±35.18 (30.00-99.30)	81.61^{a} ±44.28 (40.00-143.90)	29.14^{b} ±20.79 (14.20-56.80)	89.62^{a} ±37.44 (62.40-135.45)	P<0.05
Cr (mg/kg)	0.13^{b} ±0.12 (0.03-0.32)	0.96^{a} ±1.21 (0.04-2.32)	0.16^{b} ±0.17 (0.01-0.44)	1.54^{a} ±1.31 (0.11-2.51)	P<0.05
Cd (mg/kg)	0.04^{c} ±0.04 (0.00-0.10)	0.367^{a} ±0.20 (0.00-0.40)	0.11^{b} ±0.09 (0.03-0.25)	0.06^{c} ±0.04 (0.00-0.10)	P<0.05
Cu (mg/kg)	0.29^{c} ±0.33 (0.06-0.80)	1.05^{b} ±0.52 (0.14-1.40)	0.27^{c} ±0.23 (0.08-0.60)	2.00^{a} ±0.48 (1.21-2.50)	P<0.01
Zn (mg/kg)	5.24^{a} ±1.34 (3.12-6.40)	5.46^{a} ±0.95 (4.13-6.38	2.24^{c} ±0.98 (1.19-3.23)	3.77^{b} ±0.40 (3.34-4.19)	P<0.01
Mn (mg/kg)	2.74^{b} ±1.41 (1.05-4.20)	2.04^{b} ±0.14 (1.90-2.20)	1.53^{b} ±0.76 (0.70-2.20)	5.17^{a} ±1.03 (3.53-6.30)	P<0.01
Pb (mg/kg)	0.02±0.03 (0.00-0.08)	0.04±0.04 (0.00-0.08)	0.00±0.00 (0.00-0.00)	0.03±0.04 (0.00-0.07)	P>0.05
THC (mg/kg)	282.57^{b} ±288.39 (120.56-793.76)	6229.83^{a} ±9091.75 (1266.40-22464.26)	56.67^{c} ±43.48 (8.12-91.30)	155.51^{b} ±121.39 (35.88-283.12)	P<0.01

x ± SD represents the mean calculated from monthly values at each station, with ± indicating the standard deviation; min–max denotes the minimum and maximum values for each parameter at each station; post hoc indicates that values with differing superscripts (a > b > c > d) are statistically significant ($p < 0.05$ or 0.01), whereas values sharing the same superscript are not significantly different ($p > 0.05$). *$p < 0.05$ (significant difference), **$p < 0.01$ (very significant difference)

Zinc concentrations were highest at Stations 1 and 2 and lowest at Station 3, with highly significant spatial variation. Although the Zn concentrations reported here were lower than values from some other Nigerian aquatic systems, the distribution pattern may still indicate localized contamination sources. High zinc concentrations in sediments have previously been linked with sewage and anthropogenic discharges (Ihenyen, 1998; Ogbeibu *et al*., 2014). Manganese was highest at Station 4 and lowest at Station 3, while lead was generally low across all stations and was not detected at Station 3. Notwithstanding the low absolute Pb values, the presence of lead in sediment remains environmentally relevant because of its recognized toxicity and common association with petroleum products, urban runoff, sewage sludge, and other waste inputs (Ideriah *et al*., 2006). The weakly acidic character of the river environment may further favour the release of these metals into solution, thereby increasing their potential bioavailability to aquatic organisms (Ashiru and Ogundare, 2019; Olatunji and Ajayi, 2016).

Total hydrocarbon content showed the clearest evidence of spatial contamination, with Station 2 recording an exceptionally high mean value compared with the other stations. This strongly suggests substantial hydrocarbon loading at that location and supports field observations of oil and grease around the river margins.

Enrichment Factor (EF)

Sediments serve as natural repositories of environmental change and contamination history, and their composition often reflects both natural inputs and anthropogenic disturbances (Fagbote and Olanipekun, 2010). The enrichment factor results indicate varying levels of metal enrichment across the four stations. Iron showed moderate enrichment at Stations 1 and 3 and significant enrichment at Stations 2 and 4. Chromium was significantly enriched at Stations 1 and 3, but showed extremely high enrichment at Stations 2 and 4. Cadmium showed depletion at Station 1, moderate enrichment at Stations 3 and 4, and significant enrichment at Station 2. Copper exhibited moderate enrichment at Stations 1 and 3, significant enrichment at Station 2, and very high enrichment at Station 4. Zinc displayed moderate enrichment at Stations 3 and 4, but significant enrichment at Stations 1 and 2.

Manganese showed moderate enrichment at Stations 1, 2, and 3, and significant enrichment at Station 4. Lead was depleted at Station 3, but showed enrichment at the remaining stations.

Overall, the enrichment pattern indicates that Stations 2 and 4 are the major hotspots of anthropogenic metal input in the river system. Particularly noteworthy are the extremely high enrichment values for chromium at Stations 2 and 4, the very high enrichment of copper at Station 4, and the significant enrichment of cadmium and copper at Station 2. These results suggest that metal loading at these stations is unlikely to be derived solely from natural background conditions and is more plausibly related to oil-related activities, waste discharge, and other human disturbances along the river corridor.

Table 4: Enrichment Factor of bottom Sediments

	Enrichment factor across the sampled stations			
HM	Station 1	Station 2	Station 3	Station 4
Fe	4.10	5.75	2.05	6.31
Cr	13.20	96.20	16.00	154.00
Cd	1.33	12.22	3.73	2.00
Cu	4.87	17.47	4.43	33.33
Zn	5.19	5.40	2.22	3.74
Mn	3.91	2.92	2.19	7.39
Pb	2.40	3.60	0.00	2.80

When EF < 2 depletion of mineral enrichment or no enrichment; 2≤EF<5 moderate enrichment; 5≤EF<20 significant enrichment; 20≤EF<40 very high enrichment; EF>40 extremely high enrichment (Sutherland, 2000)

Geo-accumulation Index (Igeo)

The geo-accumulation index further substantiates the degree of sediment pollution. At Station 3, iron levels varied from unpolluted to moderately polluted; Stations 1 and 2 exhibited moderate pollution, while Station 4 had moderate to heavy pollution. Chromium exhibited the most pronounced contamination pattern, with Stations 1 and 3 designated as very polluted and Stations 2 and 4 categorised as extremely polluted. Cadmium levels were virtually unpolluted at Station 1, unpolluted to moderately contaminated at Station 4, moderately polluted at Station 3, and strongly polluted at Station 2.

Table 5: Geo-accumulation Index (*I-geo*) of Bottom Sediments from Okpare Olomu River

	Geoaccumulation Index (I*geo*) of sediment samples			
	Stationn1	Station 2	Station 3	Station 4
Fe	1.45	1.94	0.45	2.07
Cr	3.14	6.00	3.42	6.68
Cd	-0.17	3.03	1.32	0.42
Cu	1.70	3.54	1.56	4.47
Zn	1.79	1.85	0.57	1.32
Mn	1.38	0.96	0.55	2.30
Pb	0.68	1.26	0.00	0.90

Class 0 (virtually unpolluted): Igeo ≤ 0; Class 1 (unpolluted to moderately polluted): 0 < Igeo < 1; Class 2 (moderately polluted): 1 < Igeo < 2; Class 3 (moderately to highly polluted): 2 < Igeo < 3; Class 4 (severely contaminated): 3 < Igeo < 4; Class 5 (heavily to highly polluted): 4 < Igeo < 5; Class 6 (severely contaminated): 5>Igeo (Chakravarty and Patgiri, 2009)

Copper exhibited moderate pollution levels at Stations 1 and 3, severe pollution at Station 2, and severe to extreme pollution at Station 4. Zinc levels were unpolluted to moderately polluted at Station 3, while Stations 1, 2, and 4 exhibited moderate pollution. Manganese levels were classified as unpolluted to moderately contaminated at Stations 2 and 3, moderately polluted at Station 1, and moderately to badly polluted at Station 4. Lead remained within the unpolluted to moderately polluted range at most stations, except Station 2 where it was moderately polluted. These Igeo results reinforce the conclusion that chromium and copper are major contaminants of concern in the sediments of Okpare Olomu River, particularly at Stations 2 and 4. The results also indicate that

although some metals occur at relatively low absolute concentrations, their accumulation relative to background levels is sufficient to classify several locations as polluted.

Contamination Factor, Degree of Contamination, and Pollution Load Index

The contamination factor analysis showed that iron was moderately contaminating at Station 3, considerably contaminating at Stations 1 and 2, and very highly contaminating at Station 4. Chromium recorded very high contamination at all sampled stations. Cadmium showed moderate contamination at Stations 1 and 4, considerable contamination at Station 3, and very high contamination at Station 2.

Table 6: Concentration Factor (CF), Contamination Degree and Pollution Load Index

Locations	Concentration Factor of Four Sampled Stations								PLI
	Fe	Cr	Cd	Cu	Zn	Mn	Pb	CD	
Station 1	4.10	13.20	1.33	4.87	5.19	3.91	2.40	35.00	4.02
Station 2	5.75	96.20	12.22	17.47	5,40	2.92	3.60	143.56	9.44
Station 3	2.05	16.00	3.73	4.43	2.22	2.19	0.01	30.64	1.59
Station 4	6.31	154.00	2.00	33.33	3.74	7.39	2.80	209.57	9.06

Copper exhibited significant contamination at Stations 1 and 3, whereas it demonstrated extreme contamination at Stations 2 and 4. Zinc exhibited moderate contamination at Station 3 and significant contamination at Stations 1, 2, and 4. Manganese exhibited moderate pollution at Stations 2 and 3, significant contamination at Station 1, and severe contamination at Station 4. Lead pollution varied from little at Station 3 to high at Stations 1 and 4, and significant at Station 2. The level of pollution was significantly elevated at all four sites, with the highest values seen at sites 4 and 2. Correspondingly, pollutant load index values surpassed 1 at all sites, signifying that the entire research region is contaminated concerning the evaluated metals. The elevated PLI values at Stations 2 and 4 indicate that these sites are the most contaminated areas of the river. This widespread contamination likely reflects cumulative impacts of petroleum-related activities, indiscriminate waste inputs, and sediment disturbance in the coastal wetland environment of Delta State.

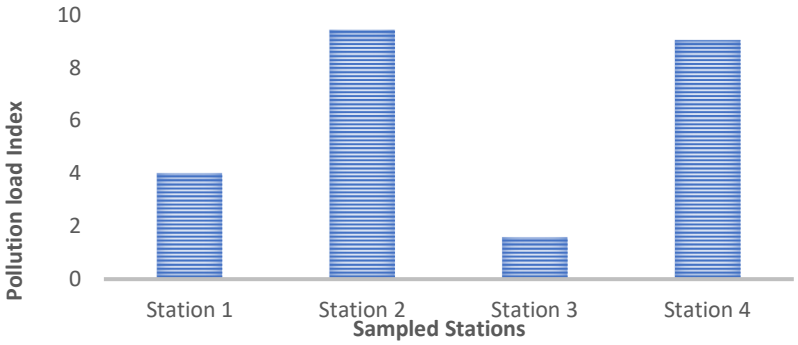

Fig. 2: Pollution load index of bottom sediments from Okpare Olomu River

Potential Ecological Risk Index (PERI)

Zn, Mn, and Pb posed very little ecological risk at all sites, according to the prospective ecological risk assessment. At Stations 1 and 3, copper posed a slight ecological risk; at Station 2, it posed a strong ecological risk; and at Station 4, it posed a very strong ecological risk. At Station 1, chromium posed a small ecological risk; at Station 3, it posed a strong ecological risk; at Station 2, it posed a very strong ecological risk; and at Station 4, it posed an extremely strong ecological risk. At Station 1, cadmium showed a moderate ecological risk, at Stations 3 and 4, it showed a significant ecological risk; and at Station 2, it showed an exceptionally strong ecological risk.

Table 7: Potential Ecological Risk Index (PERI) of Bottom Sediment from Okpare Olomu River

		Zn	Cu	Cr	Mn	Pb	Cd	RI
T^i_R		1.00	5.00	2.00	1.00	5.00	30.00	-
Station 1		5.19	24.33	26.40	3.91	12.00	40.00	111.83
Station 2	E^i_R	5.40	87.33	192.40	2.92	18.00	366.67	672.72
Station 3		2.22	22.17	32.00	2.19	0.00	112.00	170.58
Station 4		3.74	166.67	308.00	7.39	14.00	60.00	559.79

Eri <40 indicates low potential ecological danger; 40≤Eri <80 signifies moderate potential ecological risk; 80≤Eri <160 denotes considerable potential ecological risk; 160≤Eri <320 reflects high potential ecological risk; and Eri ≥320 represents very high ecological risk. RI<150 indicates minimal ecological risk; 150≤RI<300 signifies moderate ecological risk; and RI>600 denotes very high ecological risk (Hakanson, 1980; Jiang *et al*., 2014).

According to the integrated ecological risk assessment, Station 1 was classified as low ecological risk, Station 3 as moderate ecological risk, Station 4 as considerable ecological danger, and Station 2 as extremely high ecological risk. The results indicate that cadmium and chromium are the primary contributors to ecological risk in the sediments of the Okpare Olomu River, especially at Stations 2 and 4. The ecological consequences are significant as these metals can become accessible under varying redox and pH conditions, potentially entering the aquatic food chain.

Overall, the results show that bottom sediments from the Okpare Olomu River are impacted by substantial anthropogenic contamination, with Stations 2 and 4 emerging consistently as the most polluted and ecologically threatened locations within the study area.

Conclusion

This study shows that the bottom sediments of the Okpare Olomu River are polluted with heavy metals. The pollution and ecological risk indices show that humans have had significant impact on the whole study region. The most afflicted locations were Stations 2 and 4, where cadmium and chromium were the main causes of ecological concern. The high levels of enrichment factors, geo-accumulation indices, contamination factors, pollution load indices, and probable ecological risk values all point to petroleum-related activities, effluent discharges, and sediment disruption as the main causes of contamination in the river system. These conditions pose a substantial risk to the ecological integrity

of the river and may also affect the health and livelihoods of those dependent on it.

In view of these findings, priority should be given to remediation and pollution control measures, especially at Stations 2 and 4, where the levels of contamination and ecological risk were most pronounced. Regular monitoring of sediment quality and heavy metal concentrations should also be established to track changes over time and support early intervention. In addition, stricter enforcement of environmental regulations is necessary to reduce indiscriminate discharges, uncontrolled petroleum-related inputs, and unregulated dredging or sand mining activities.

Community involvement in environmental stewardship should be encouraged, while future investigations should incorporate biological monitoring in order to complement chemical assessments and provide a more comprehensive understanding of ecological and public health implications. Such measures are essential for protecting biodiversity, sustaining fisheries resources, and preserving the long-term environmental quality of the Okpare Olomu River.

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