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ORIGINAL RESEARCH ARTICLE

Metals contamination and its ecological risk assessment in the coastal sediments of Badagry Creek, Nigeria

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ABSTRACT

This study was carried out to assess heavy metals contamination and potential ecological risk in Badagry Creek, Nigeria. Concentrations of six heavy metals associated with environmental pollution were determined in the sediments using atomic absorption spectrophotometry. The evaluation of heavy metals pollution was determined using the geo-accumulation index (I_{geo}), modified degree of contamination and potential ecological risk index. Results showed the ranking order of heavy metals in the sediment was iron (Fe) > chromium (Cr) > lead (Pb) > zinc (Zn) > copper (Cu) > cadmium (Cd). Among sampling stations, Fe, Cu, and Zn concentrations was found to be significantly ($p<0.05$) varied, whereas the concentration of Pb, Cr, and Cd was found insignificantly ($p>0.05$) different. The I_{geo} results suggested that the sediment pollution level was found in the category of unpolluted to moderately polluted. Based on the modified degree of contamination, sediments categorized from non-contamination to slight contamination with heavy metals. The potential ecological risk to the biological community was recorded from low to moderate risk of heavy metals pollution. Among different heavy metals, Cd posed the most substantial risk across the sampling stations. Consequently, there is urgent requirement of appropriate regulation and management by the relevant regulatory bodies in order to stop the indiscriminate dumping of sewage and untreated waste into the creek.

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INTRODUCTION

As areas of transition between the marine and terrestrial habitats, creeks and lagoons are essential to the health of coastal ecosystems. In addition to providing essential functions like fish spawning grounds, habitat for aquatic species, and community recreational possibilities, they are frequently abundant in biodiversity. However, human activity is endangering these ecosystems more and more, which causes pollutants, most notably heavy metals, to build up in sediment. Because they are long-lasting and difficult to oxidise, degrade, eliminate, or transform into less hazardous components through biological or chemical processes, heavy metals are poisonous and pose major environmental hazards. There are several different sources of heavy metals, such as air deposition, urban garbage, agricultural runoff, and industrial effluents. Heavy metals are non-biodegradable, can accumulate in aquatic environments, and are mostly transported by natural waters as part of the global biological cycle (Siddiquee *et al.*, 2009). Sediments are a great way to monitor metal pollution in coastal environments because heavy metal inputs eventually end up in the estuarine zone and on the continental shelf (Satpathy *et al.*, 2012). As a result, concentrations in sediments are frequently much higher than those in ambient solution (Clark, 1999). The potential for toxic effects on aquatic life forms, the destruction of natural ecosystems, and the potential for major health risks to humans through

the consumption of contaminated seafood have all been caused by anthropogenic metal contamination in coastal and marine habitats (Hu *et al.*, 2013; Naser, 2013; Pan & Wang, 2012).

In order to detect and comprehend human-induced metal input into the marine environment, it is crucial to monitor sediment quality for metal spatial distribution, accumulation, and seasonal fluctuation. Numerous studies have indicated that the amount of metals in coastal sediment is higher than their background quantity in nature. Nevertheless, it is necessary to assess both the hazards posed by the metals in the sediments and their concentrations. Calculating the enrichment factor, pollution load index, geo-accumulation index, and contamination factor is typically how heavy metal contamination and pollution are evaluated (Hu *et al.*, 2013; Mashiatullah *et al.*, 2013; Satpathy *et al.*, 2012). Given the growing concentration of heavy metals in sediments and their subsequent discharge into the water, which may endanger ecological health, the evaluation of the possible ecological risk of heavy metal contamination was suggested as a diagnostic tool for water pollution control purposes (Hu *et al.*, 2019). The biological community's sensitivity to the total level of contamination at a location is gauged by the potential ecological RI (Hakanson, 1980). It considers elements' possible ecological risk factors (ERi), sedimentological toxic reaction factors, and contamination factors. Earlier studies on the coastal sediments of southwest Nigeria showed that the content and distribution of heavy metals varied (Olowu *et al.*, 2010; Don Pedro *et al.*, 2004). However, we carried out an ecological risk assessment on the sediment of Badagry Creek in Nigeria to comprehend the complete extent of heavy metal pollution in the sediment of tropical coastal water. This study aimed to ascertain the concentration and spatial distribution of metals (Fe, Pb, Cr, Cu, Zn, and Cd) in the sediment of Badagry Creek and used the geo-accumulation index (I_{geo}), enrichment factor (EF), contamination factor (CF), modified degree of contamination (mC_{deg}), and ecological risk index (ERI) to assess the possible ecological risk of heavy metal contamination.

MATERIALS AND METHODS

Study area

The study was conducted in Badagry Creek, which is situated in south-west Nigeria between latitudes 6°23¹ and 6°28¹N and longitudes 2°42¹ and 3°23¹E (Figure 1). In addition to connecting Ologe Lagoon, the creek is primarily fed by the Yewa River in Nigeria and the River Ajara in the Republic of Benin. The Egbado plateau forms its northern boundary, while the River Yewa, which flows through Ologe lagoon, forms its western boundary. The Atlantic Ocean forms the southern border, while the mangrove swamps expanse forms the eastern limit. Through Lake Nokue and Lake Porto-Novo, the Badagry Creek spans the Lagos Harbour and is impacted by floods and tides from both the Lagos and Cotonou harbours. Nine stations were randomly selected and fixed with the aid of the Global Positioning System (GPS) kit (Magellan, SporTrak PRO MARINE [IEC – 529 IPX7 Model]), along the transect of the creek for the study. The sampling stations in Badagry Creek lie between Longitude 2° 49'44.7''E and 3°12'30.6''E and Latitude 6°26'21.0''N and 6° 2702.9''N (Figure 1).

Sample collection and chemical analysis

The sediment samples were taken from a motorised boat at each sampling station using a stainless steel Van-Veen grab between November 2021 and September 2023. The grab was carefully cleaned before being redeployed in a different station. Sediment samples were shipped to the Nigerian Institute for Oceanography and Marine Research in Lagos in a cooler box after being tagged and kept in metal-free polyethylene bags. In the preparatory lab, materials were homogenised, air-dried at room temperature, and sub-sampled for metal analysis prior to analysis. In order to achieve a uniform bulk, the air-dried sediment samples were sieved after being ground into a powder using a mortar and pestle. Each powder sediment sample weighed 2 g, and the normal protocol was followed for digestion (APHA, 2005). Ten millilitres of concentrated nitric acid (HNO_3) were added to a 50 millilitre crucible containing 2 grams of each sediment sample. To allow for oxidation, the mixture was put in a fume hood on a hot plate for 30 to 45 minutes. The combination was cooled and then reheated on a hot plate until the digest turned clear, adding 2.5 ml of concentrated (70%) hydrochloric acid ($HClO_4$). After cooling, the samples were filtered using Whatman filter paper number 42 into a 25 ml volumetric flask, and deionized water was added to make up the difference. In the same way, a blank solution was made. Following that, each filtrate was placed into a polyethylene bottle and kept in a refrigerator at 4°C prior to metal analysis. Lastly, atomic absorption spectrometry (Model PG-990) was employed to analyse the filtrates for heavy metals at the Central Laboratory of NIOMR, Lagos. The selected metals' standard solutions (1000 mg/L) of Fe, Pb, Cr, Cu, Zn, and Cd were obtained from Agilent and diluted to create solutions of different standard concentrations. Three replicates were used for every analysis. For a 95% accuracy rate, the standards were reused after every five sample readings (US EPA, 1996). Every analytical technique was conducted in perfect compliance with national regulations.

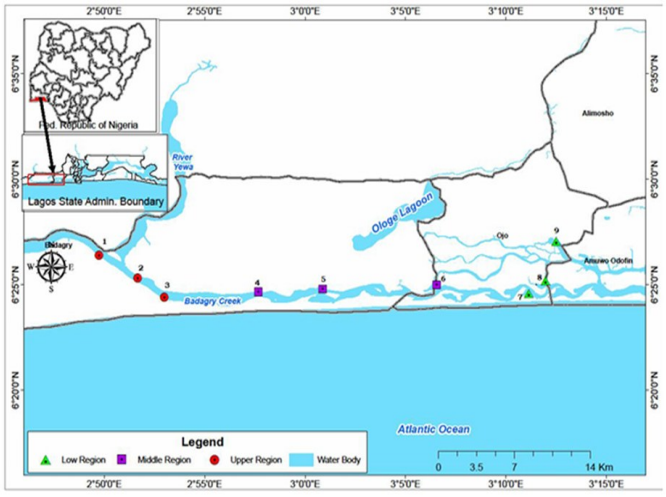

Figure 1. *Map of Badagry Creek in Southwest, Nigeria, showing the sampling stations. Station 1: Apa; 2: Gbaji; 3: Yovoyan Jetty; 4: Akarakumo; 5: Ajido; 6: Irewe; 7: Igbolobi; 8: Iyagbe; 9: Ojo.*

Statistical analysis

The Minitab 16 version was used for statistical analysis. Values for the concentrations of heavy metals are expressed in mg/kg dry mass. The tests for equal variance and normality were applied to all data. Using descriptive statistics, the quantities of heavy metals in the sediment were described. These included the mean and standard deviation (mean ± SD). Significant differences in the heavy metal concentrations between the various stations were identified using one-way analysis of variance (ANOVA) and multiple comparisons (Tukey's test) accepted at $p < 0.05$ following Zar (2001).

Analysis of heavy metal contamination

To evaluate the contamination based on the concentration of heavy metals in sediment samples, indicators such as the geo-accumulation index (I_{geo}), enrichment factor (EF), contamination factor (CF), and modified degree of contamination (mC_{deg}) were used.

Geo-accumulation index (I_{geo})

Heavy metal pollution levels in sediments can be evaluated using the geo-accumulation index. According to Liu *et al.* (2022), I_{geo} is a crucial metric for differentiating between the concentrations of heavy metals caused by nature and human influence. The initial proposal was made by Müller (1981). I_{geo} was expressed as:

$$\mathrm{Igeo} = \log_2\left(\frac{C_n}{1.5\,B_n}\right) \quad (1)$$

Where C_n is the measured value of an examined metal (n) and B_n denotes the background concentration of the given metal (n). In the equation, 1.5 is the background matrix correction factor due to lithological effects. Bn = Fe 41000; Cu 50 mg/kg; Pb 19 mg/kg; Zn 95 mg/kg; Cr 90 mg/kg; Cd 0.15 mg/kg (Hakanson, 1980; GESAMP, 1982; Salomons & Froster, 1984). The levels of sediment pollution (Muller, 1981): Unpolluted ($I_{geo} < 0$); Unpolluted to moderately polluted ($0 < I_{geo} < 1$); Moderately polluted ($1 < I_{geo} < 2$); Moderately to strongly polluted ($2 < I_{geo} < 3$); Strongly polluted ($3 < I_{geo} < 4$); Strongly to extremely polluted ($4 < I_{geo} < 5$); and Extremely polluted ($I_{geo} > 5$).

Enrichment factor (EF)

Enrichment factor is a popular normalisation technique used to distinguish metals with natural variability from those with anthropogenic variability. The EF for each heavy metal was determined as follows:

$$\mathrm{EF} = \frac{\left(\frac{\mathrm{Xc}}{\mathrm{Xr}}\right)\mathrm{sample}}{\left(\frac{\mathrm{Xc}}{\mathrm{Xr}}\right)\mathrm{background}} \quad (2)$$

Where (Xc / Xr) s is the heavy metal to immobile element ratio in the samples of interest, and (Xc / Xr) b is the heavy metal to immobile element ratio in the selected reference (pre-industrial values) sample (Zhang *et al.*, 2007). Iron (Fe) was selected as the normalising element because it is a major sorbent phase for trace metals (Turner & Millward, 2000). EF is categorised as background concentration / no enrichment (< 1); minor enrichment (1 – 3); moderate enrichment (3 – 5); moderately severe enrichment (5 – 10); severe enrichment (10 – 25); very severe enrichment (25 – 50); extremely severe enrichment (> 50) (Bam *et al.*, 2011).

Contamination factor (CF) and modified degree of contamination (mC_{deg})

CF can be used to determine whether a particular metal in an ecosystem is contaminated. Qingjie *et al.* (2008) describe it as a single index indication that shows the ratio of an element at a study site to the same element at a reference value, background site, or national criteria for an element. The CF equation is as follows:

$$\mathrm{CF} = \frac{C_{hm}}{B_{hm}} \quad (3)$$

Where C_{hm} is the concentration of heavy metal in sediment, B_{hm} is the geo-chemical pre-industrial concentration or reference value of heavy metal.

Cf < 1 represents low contamination; 1 < Cf < 3 suggests moderate contamination; 3 < Cf < 5 denotes considerable contamination, and Cf > 6 refers to very high contamination (Hakanson, 1980). The modified degree of contamination (mC_{deg}) is a multi-element pollution indicator that is used to evaluate the quality of sediments (Brady *et al.*, 2015). The non-conservative behaviour and background metal concentrations in the sediments are taken into account by this updated index. Additionally, it changed the standards to precisely determine the sediments' level of contamination. Brady *et al.* (2015) used the following mathematical expression to represent the modified degree of contamination:

$$mCdeg = \frac{\sum_{i=1}^{n} CF}{n} \quad (4)$$

Where: CF = contamination factor for the individual element, n = number of metals tested.

The thresholds for sediment quality classification for multi-element indices, as adapted from Brady *et al.* (2015), indicate that sediment is uncontaminated if $mC_{deg} < 1.5$; slightly contaminated if $1.5 < mC_{deg} < 2$; moderately contaminated if $2 \leq mC_{deg} < 4$; moderately – heavily contaminated if $4 \leq mC_{deg} < 8$; severely contaminated if $8 \leq mC_{deg} < 16$; heavily contaminated if $16 \leq mC_{deg} < 32$ and extremely contaminated if $mC_{deg} > 32$.

Ecological risk index (ERI)

Hakanson (1980) developed the potential ecological risk index to evaluate the possible effects of heavy metals on ecosystems. According to Zhang *et al.* (2018), it is related to the amounts of heavy metals in sediments, the kind of pollutant, its degree of toxicity, and how sensitive water bodies are to heavy metal pollution. The following formulas were used to calculate the

ecological risk factor (ER^i) of a single element and the potential ecological risk index (ERI) of a multi-element:

$$ER^i = Tr^i * CF^i \quad (5)$$

$$ERI = \sum_{i=1}^{n} ER^i \quad (6)$$

Where ER^i is the ecological risk index of an individual element, ERI is the potential ecological risk index (ERI) of multi-element. CF^i is the contamination factor of heavy metal "i"; Tr^i is the toxic response factor for the given heavy metal of "i", which accounts for the toxic requirement and the sensitivity requirement. The toxicity coefficients of Pb, Cr, Cu, Zn and Cd were 5, 2, 5, 1 and 30 mg/kg, respectively (Hakanson, 1980; Zhang *et al.*, 2013). The grading standards for both ER^i and ERI are ER^i < 40 (low risk); 40 ≤ ER^i < 80 (moderate risk); 80 ≤ ER^i < 160 (considerate risk); 160 ≤ ER^i < 320 (high risk); 320 ≤ ER^i (very high risk) and ERI < 150 (low risk); 150 ≤ ERI < 300 (moderate risk); 300 ≤ ERI < 600 (considerate risk); 600 ≤ ERI (very high risk), respectively (Guo *et al.*, 2010).

RESULTS AND DISCUSSION

Heavy metals concentration in sediment of Badagry Creek

The findings regarding the heavy metals content across all samples are presented graphically in Figure 2. The results of heavy metal concentrations in the sediment samples ranged from 463.02 to 7519.95, 4.68 to 92.10, 2.36 to 303.52, 1.07 to 27.03, 1.06 to 98.58 and 0.00 to 1.43 for Fe, Pb, Cr, Cu, Zn and Cd, respectively. The concentrations of heavy metals (Fe, Cu and Zn) significantly varied among stations ($p < 0.05$), whereas Pb, Cr, and Cd showed no significant difference among stations ($p > 0.05$). The ranking order of concentration of heavy metals in the sediments from Badagry Creek were Fe > Cr > Pb > Zn > Cu > Cd, with average concentrations of 4585.96 mg/kg, 100.82 mg/kg, 38.68 mg/kg, 13.62 mg/kg, 8.28 mg/kg and 0.48 mg/kg, respectively. The greatest average quantities of Fe, Pb, Cr, Cu, and Zn were detected at station 1 (Apa). A variety of human activities, including sand mining and boat transportation, may be attributed for the elevated levels of heavy metals in station 1 (Apa). Additionally, this station receives a significant amount of sewage and household wastewater from neighbouring communities in addition to input from the River Yewa. The average concentration of Pb and Cd in the study exceeded the standard guidelines of safety limits for metal concentrations in marine sediment as set by the United States Environmental Protection Agency (US EPA). High concentrations of Pb and Cd were detected in station 1 (Apa) and station 9 (Ojo), respectively. The study's Pb and Cd values were greater than those found in the top continental crust (Wedepohl, 1995). The detected Pb concentrations exceeded the Pb concentrations reported from the sediments of Ologe Lagoon (Adeyemi *et al.*, 2019). Anthropogenic activities such as increased vehicle traffic emissions from lead tetraethyl in petroleum and generator emissions in the Badagry Creek catchment may be the cause of the high Pb content in the study area. The sediments' Cd concentration range was marginally less than the range of Cd contents documented for the South-western Boughrara Lagoon's sediments (Tlig *et al.*, 2023). Metal plating, electroplating, galvanised pipe zinc, nickel-cadmium batteries, and waste materials made of scrap metal and plastic are possible sources of cadmium in the study areas. More specifically, one of the possible causes of the elevated Cd is industrial wastewater in the Badagry Creek catchment. The sediments of Badagry Creek had greater levels of chromium than those of Ologe Lagoon (Adeyemi *et al.*, 2019) and Lagos Lagoon (Bawa-Allah *et al.*, 2017). The human inputs of industrial wastewater discharge, urban runoff, and household sewage may be the cause of the chromium pollution in the sediment of Badagry Creek. Textile industries, electroplating, leather tanning, metal polishing, chromate preparation, magnetic tapes, paints, cement, paper, rubber, composition floor coverings, and more all require chromium. Iron is one of the most prevalent metals in the environment, so the high concentrations of Fe found in the study could be explained by the creek's abundance of Fe. Bawa-Allah *et al.* (2017) reported higher concentrations of Fe in the sediments of Lagos Lagoon than the values obtained in this study. The concentrations of Cu and Zn found in this investigation were lower than those found in other reports (Tlig *et al.*, 2023; Singh *et al.*, 2020).

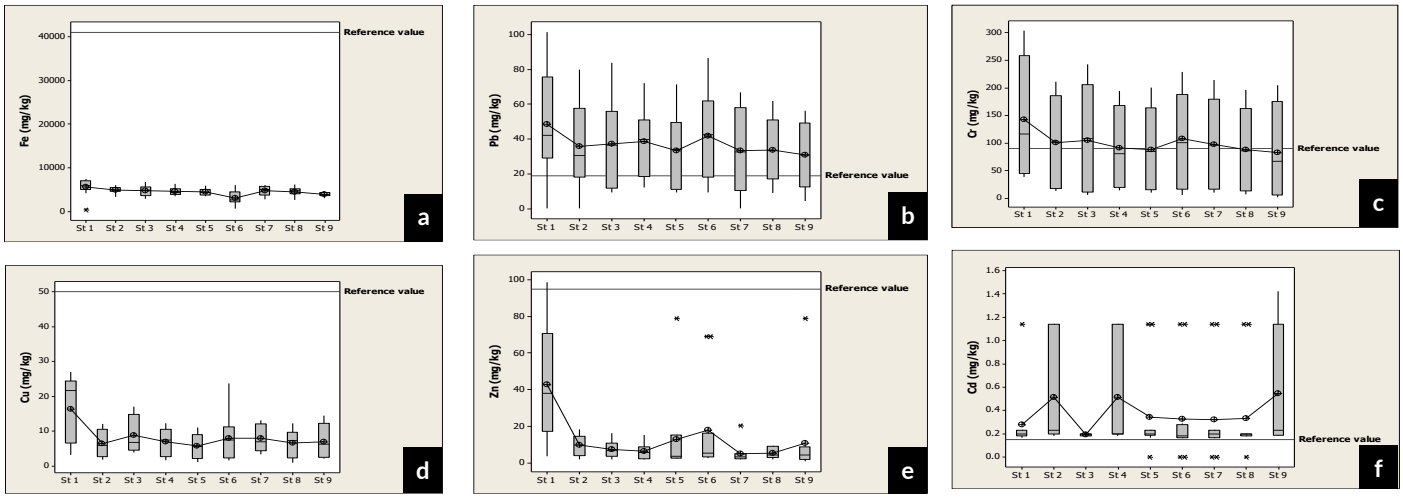

Figure 2. *Concentration (mg/kg) of (a) Fe, (b) Pb, (c) Cr, (d) Cu, (e) Zn and (f) Cd in sediments samples in comparison with the Standard Reference value (Hakanson, 1980; GESAMP, 1982; Salomons & Froster, 1984). St 1: Apa; St 2: Gbaji; St 3: Yovoyan Jetty; St 4: Akarakumo; St 5: Ajido; St 6: Irewe; St 7: Igbolobi; St 8: Iyagbe; St 9: Ojo.*

Assessment of heavy metals contamination/pollution in sediments

Geo-accumulation index

The geo-accumulation index values of heavy metals in the sediment of each sampling station are presented in Table 1. The study's I_{geo} values for Pb, Cr, Cu, and Zn are less than those found in Ologe Lagoon sediments (Adeyemi *et al.*, 2019). Positive and greater than zero (> 0) Pb I_{geo} in sampling stations indicated that the sediments of Badagry Creek were unpolluted to moderate pollution by Pb. The highest I_{geo} value (2.50) obtained in Ojo (station 9) for Cd indicated moderate to strong pollution by Cd. This greatest level of Cd pollution (class 3) suggests that anthropogenic loadings from the surrounding environment were the primary source of the metal. Ojo is a municipal town that is home to several noteworthy locations, including the Alaba International Market and Lagos State University. The average I_{geo} values of Pb and Cd were 0.43 and 0.16, indicating that the study area was unpolluted to moderately polluted by these heavy metals. Other heavy metals, such as Fe, Cr, Cu, and Zn, had -3.76, -3.25, -3.84, and -0.44 I_{geo} mean values, respectively. These values are indicative of unpolluted environment.

Enrichment factor (EF)

The enrichment factors of heavy metals in sediments of the study areas in Badagry Creek are shown in Table 2. Anthropogenic metal contributions to the sediments were evaluated using the enrichment factor. The order of EF average values of heavy metals was Cd > Pb > Cr > Cu > Zn (Table 2). The enrichment factor values for Cr, Pb, and Cd sediments of study areas exhibit moderately severe to severe enrichment. This might be ascribed to a variety of human-impact causes in Badagry Creek. The increase in lead tetraethyl emissions from vehicle traffic, generator emissions, e-waste discharges, and electroplating and metal industries near the Badagry Creek watershed may be the cause of the significant enrichment of Cd and Pb in the creek. Cd was shown to have a comparable significant EF value in southwest Iranian coastal soils (Hamid *et al.*, 2022). According to the station's EF rating, Ojo (station 9) had a very high Cd enrichment. Copper and zinc with enrichment factor less than 3 (EF < 3) in all the study stations, suggesting minor enrichment of the metals in the sediments.

Contamination factor (CF) and modified degree of contamination ($mC_{deg.}$)

The spatial distribution of contamination factors for heavy metals (Fe, Pb, Cr, Cu, Zn and Cd) in sampling stations are presented in Table 3. An individual metal's level of contamination in an environment can be determined using the contamination factor value. With regard to the contamination factor, low contamination (CF < 1) was observed for Fe, Cu and Zn in the sediment of all the stations. Pb and Cd had the contamination factor of between one and three (CF: 1 – 3) in all the sampling stations, indicating moderate contamination of Pb and Cd in sediments investigated. The study showed moderate contamination of Cr in all the sampling stations except station 5 (Ajido), 8 (Iyagbe) and 9 (Ojo) with low contamination of Cr in the sediments. Generally, sampling stations had low to moderate levels of metal contamination, according to the CF values for heavy metals, with the exception of Cd at the Ojo (station 9). The Cd contamination at Ojo (station 9) was very high. Naik *et al.* (2023) found the greatest CF value for Cd in the coastal sediment in the southwest Bay of Bengal, and the study's highest CF average value for Cd supports their findings. The chemical industry, mineral processing, battery manufacture, and inappropriate waste disposal are among the anthropogenic activities frequently linked to elevated Cd concentrations (Chen *et al.*, 2024). Nevertheless, the drawbacks of enrichment and contamination factors are

Table 1. Geo- accumulation Index of Fe, Cu, Pb, Zn, Cr and Cd in sediments of the Badagry Creek.

Metals (mg/kg)	Sampling station									Mean
	St 1	St 2	St 3	St 4	St 5	St 6	St 7	St 8	St 9	
Fe	-3.43	-3.62	-3.66	-3.74	-3.77	-4.27	-3.67	-3.74	-3.95	-3.76
Cu	-2.19	-3.51	-3.07	-3.43	-3.67	-3.23	-3.22	-3.47	-3.43	-3.25
Pb	0.89	0.33	0.50	0.38	0.38	0.55	0.35	0.32	0.13	0.43
Zn	-1.89	-3.46	-4.04	-3.73	-5.66	-2.24	-4.43	-4.77	-4.35	-3.84
Cr	0.08	-0.42	-0.36	-0.56	-0.61	-0.31	-0.47	-0.61	-0.69	-0.44
Cd	-0.32	-0.10	-0.17	0.03	-0.40	0.09	-0.03	-0.17	2.50	0.16

Fe: Iron; Cu: Copper; Pb: Lead; Zn: Zinc; Cr: Chromium; Cd: Cadmium. St 1: Apa; St 2: Gbaji; St 3: Yovoyan Jetty; St 4: Akarakumo; St 5: Ajido; St 6: Irewe; St 7: Igbolobi; St 8: Iyagbe; St 9: Ojo.

Table 2. Enrichment factor of Cu, Pb, Zn, Cr and Cd in sediments of the Badagry Creek.

Metals (mg/kg)	Sampling station									Mean
	St 1	St 2	St 3	St 4	St 5	St 6	St 7	St 8	St 9	
Fe	-	-	-	-	-	-	-	-	-	-
Cu	2.37	1.08	1.51	1.23	1.07	2.06	1.36	1.20	1.43	1.48
Pb	20.06	15.41	17.93	17.39	17.82	28.35	16.22	16.63	16.84	18.52
Zn	2.91	1.12	0.77	1.00	0.27	4.10	0.59	0.49	0.76	1.33
Cr	11.42	9.20	9.88	9.06	8.99	15.53	9.17	8.75	9.55	10.17
Cd	8.65	11.45	11.26	13.64	10.33	20.61	12.43	11.88	87.06	20.81

Fe: Iron; Cu: Copper; Pb: Lead; Zn: Zinc; Cr: Chromium; Cd: Cadmium. St 1: Apa; St 2: Gbaji; St 3: Yovoyan Jetty; St 4: Akarakumo; St 5: Ajido; St 6: Irewe; St 7: Igbolobi; St 8: Iyagbe; St 9: Ojo.

Table 3. Contamination factors and modified degree of contamination of Fe, Cu, Pb, Zn Cr and Cd in sediments of the Badagry Creek.

Metals (mg/kg)	Sampling stations								
	St 1	St 2	St 3	St 4	St 5	St 6	St 7	St 8	St 9
Fe	0.14	0.12	0.12	0.11	0.11	0.08	0.12	0.11	0.10
Cu	0.33	0.13	0.18	0.14	0.12	0.16	0.16	0.14	0.14
Pb	2.78	1.88	2.12	1.96	1.95	2.20	1.91	1.87	1.64
Zn	0.40	0.14	0.09	0.11	0.03	0.32	0.07	0.05	0.07
Cr	1.58	1.12	1.17	1.02	0.99	1.21	1.08	0.98	0.93
Cd	1.20	1.40	1.33	1.53	1.13	1.60	1.47	1.33	8.47
mC_{deg}	1.1	0.8	0.8	0.8	0.7	0.9	0.8	0.7	1.9
Class	0	0	0	0	0	0	0	0	1
Squal	Uncont.	Uncont.	Uncont.	Uncont.	Uncont.	Uncont.	Uncont.	Uncont.	Slightly cont.

Fe: Iron; Cu: Copper; Pb: Lead; Zn: Zinc; Cr: Chromium; Cd: Cadmium. St 1: Apa; St 2: Gbaji; St 3: Yovoyan Jetty; St 4: Akarakumo; St 5: Ajido; St 6: Irewe; St 7: Igbolobi; St 8: Iyagbe; St 9: Ojo. mC_{deg} : Modified degree of Contamination, Squal : Sediment qualification, Uncont.: Uncontaminated, cont.: contaminated.

Table 4. Potential ecological risk of individual (ER^i) and multi (ERI) elements in sediments across sampling stations of Badagry Creek.

	ER^i					ERI	Ecological Grade
	Cu	Pb	Zn	Cr	Cd		
St 1	1.6	13.9	0.4	3.2	36.0	55.1	Low risk
St 2	0.7	9.4	0.1	2.2	42.0	54.5	Low risk
St 3	0.9	10.6	0.1	2.3	40.0	53.9	Low risk
St 4	0.7	9.8	0.1	2.0	46.0	58.6	Low risk
St 5	0.6	9.8	0.03	2.0	34.0	46.4	Low risk
St 6	0.8	11.0	0.3	2.4	48.0	62.5	Low risk
St 7	0.8	9.6	0.1	2.2	44.0	56.6	Low risk
St 8	0.7	9.3	0.1	2.0	40.0	52.0	Low risk
St 9	0.7	8.2	0.1	1.9	254.0	264.8	Moderate risk

Cu: Copper; Pb: Lead; Zn: Zinc; Cr: Chromium; Cd: Cadmium. St 1: Apa; St 2: Gbaji; St 3: Yovoyan Jetty; St 4: Akarakumo; St 5: Ajido; St 6: Irewe; St 7: Igbolobi; St 8: Iyagbe; St 9: Ojo.

that they are single-element indices that fail to include the influence that many contaminating elements can have on the health of the sediment (Hakanson, 1980). To get around restrictions in contamination and enrichment factors, the Hakanson-modified contamination index was employed. It takes into account the background metal concentration in the sediments as well as the non-conservative behaviour. The results of the modified degree of contamination revealed that stations 1, 2, 3, 4, 5, 6, 7 & 8 with $mC_{deg} < 1.5$ were un-contaminated, while station 9 ($1.5 < mC_{deg} < 2$) is slightly contaminated (Table 3). Hence, heavy metal levels in the study region were found to be uncontaminated to mildly contaminated, according to the results of the modified degree of contamination index. Ojo (station 9) was slightly contaminated with Cd, suggesting that Cd constituted a concern in this station. Multi-metal indices, such as the modified degree of contamination index, have limitations because they only evaluate the degree of contamination rather than pollution (Brady *et al.*, 2015). This constraint was addressed by evaluating the overall potential influence on the biological community and estimating the possible danger of pollution from specific metals in the stations using the prospective ecological risk index.

Ecological risk

The ecological risk factor (ERi) of individual heavy metals across sampling stations in Badagry Creek is presented in Table 4. The results revealed that the ecological risk factor values of heavy metals (Pb, Cr, Cu, Zn and Cd) across sampling stations were less than 40 (ERi < 40), except Cd in stations 2, 3, 4, 6, 7, 8 & 9. By implication, Pb, Cr, Cu, and Zn content in all the stations and Cd in stations 1 & 5 posed a low ecological risk. Cadmium in station 9 had an ecological risk factor (ERi) of 254.0, indicating high risk. Cd in stations 2, 3, 4, 6, 7 & 8 posed moderate risk (Table 4). Across all sampling stations, Zn presents a relatively low danger, but Cd, with its relatively high ecological risk levels, poses the most significant risk. The potential ecological risk of collective heavy metals across sampling stations in Badagry Creek, Nigeria, is shown in Table 4. The results showed that the ecological risk of heavy metals to the biological community in stations 1, 2, 3, 4, 5, 6, 7 & 8 were low (ERI < 150), and moderate (ERI value of 264.8) in station 9 (Ojo). In a related finding, the majority of the sampling locations in China's Xingkai Lake and Xiaoxingkai Lake were found to have low to modest ecological risks (Jiang *et al.*, 2022).

Conclusion

The findings demonstrated the variability of Fe, Pb, Cr, Cu, Zn, and Cd in the sediments of Badagry Creek. The sediments included the highest quantity of iron (Fe) and the least amount of deposited Cd. While Pb, Cr, and Cd concentrations were not significantly different between stations ($p > 0.05$), the concentrations of heavy metals (Fe, Cu, and Zn) were. The heavy metal concentrations in the sediments from Badagry Creek were ranked as Fe > Cr > Pb > Zn > Cu > Cd. The research area's sediment level of pollution was unpolluted to moderately polluted, according to $I_{geo's}$ findings. Cu and Zn values were found to be

slightly enriched in the sediments, whereas Cd, Pb, and Cr were found to be significantly enriched in the study stations, according to the enrichment factor. Low levels of Fe, Cu, and Zn contamination and moderate levels of Cd and Pb contamination were found in the sediments under investigation. The study stations' moderate levels of Cd, Pb, and Cr contamination in their sediments may be caused by localised human environmental inputs. The main source of contaminants in Badagry Creek is its close vicinity to dispersed sources, including ports, highways, and urban and industrialised regions. With the exception of station 9 (Ojo), which was marginally contaminated, all stations were found to be uncontaminated by the modified degree of contamination results. Across all sampling stations, Zn poses a relatively low danger, but Cd, with its comparatively high ecological risk levels, poses the most significant risk. The biological community were at low and moderate risk, respectively, to heavy metal pollution in the research areas, according to the ecological risk assessment results. Further research should be undertaken to understand sources, chemistry and potential toxicity of heavy metals in the creek.

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DECLARATIONS

Authors contribution

Conceptualization, methology: K.J.B. and A.F.; Software, validation: K.J.B. and E.K.A.; Investigation: K.J.B. and A.F.; Data curation: K.J.B.; Writing -original draft preparation: K.J.B.; Writing-review and editing: K.J.B. and A.F.; Supervision: K.J.B. and E.K.A. All authors have read and agreed to the published version of the manuscript.

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