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Assessment of Heavy Metal Levels, Pollution Indices and Ecological Risks of Floodplain Sediments in Urban Areas in Delta State, Nigeria

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ABSTRACT: The aim of this study is to assess heavy metals levels, pollution indices and ecological risks of floodplain sediments in urban areas in Delta State, Nigeria. The levels of nine heavy metals (Cd, Pb, Cr, Ni, Cu, Co, Mn, Zn and Fe) were measured in floodplain sediments of urban areas in Delta State, Nigeria. Sediment samples from the nine urban areas were collected for three months (July-September) covering the wet season. The sediment samples were digested with aqua regia, and the heavy metal levels in the digests were quantified by means of atomic absorption spectrometry. The levels of heavy metals in the sediments were: Cd 1.13-7.38, Pb 5.05-8.05, Cr 4.16-9.17, Ni 3.48-4.48, Cu 7.49-12.9, Co 6.27-14.2, Mn 310-744, Zn 71.3-133 and Fe 1036-1692 mg kg^{-1}. The results showed significant spatial variation in the metal distribution patterns. The pollution indices suggested that Cd is the main heavy metal contaminant in the floodplain sediments. The ecological risk indices indicate that very high ecological risks are associated with exposure to these heavy metals but with significant impact from Cd.

Keywords: CPI, Geoaccumulation index, Enrichment factor, Flooding, Urbanization Industrialization

Introduction

Industrialization and urbanization unquestionably contribute significantly to human and economic development, but they have also had negative effects on pollution, which greatly contribute to the degradation of the environment (Adewoye *et al*., 2021). The water environment has remained extremely important to man; it contains living organisms that are food for man, and man continually takes care of its non-living resources and other aesthetic values. These ecosystems are at risk by a variety of human actions (Olagunju *et al*., 2015). Primary causes of contamination in surface streams and floodplain sediment, include run-off, agriculture, industries, mining etc (Omotoso and Tijani, 2011).
According to Ajala *et al*. (2024), floodplain lands are vital ecological and hydrological systems that support a variety of plant and animal species and are essential to the management of water resources. Additionally, they can be used to pinpoint contamination events that are naturally occurring or caused by humans in a certain location (Smith *et al*., 2011). Waste is frequently haphazardly released on open spaces due to the closeness of factories and other human-related activities; urban runoff carries waste and deposits it in floodplains during rainy seasons, which may act as sink for the deposition and buildup of heavy metals (Iwegbue *et al*., 2017; Tesi *et al*., 2016; Iwegbue *et al*., 2020; Aziza *et al*., 2021). Since heavy metals are naturally occurring elements of the earth's crust, they can be found in rocks and soils in a variety of natural concentrations in sediments, waterways, and living things (Osakwe and Okolie, 2015). In comparison to geogenic or lithological sources, human activities such as mining, domestic, industrial, agricultural, transportation, and other anthropogenic processes have led to higher and more hazardous concentrations of heavy metals (Obasi *et al*., 2024). Due to their biological buildup after being released into the environment, heavy metals are a significant determinant of the

health of both humans and living things (Adewoye *et al*., 2021). Because of its possible effects on the environment and related hazards, heavy metal pollution is a serious environmental problem. Heavy metals can present serious threats to human health and the environment when emitted in excess (Moulton and Westcott 2015).

Numerous pollution and ecological risk indices can be used to assess the degree of heavy metal pollution in sediments. The most thorough approach to assessing sediment pollution is thought to be the use of ecological and pollution indices. According to Emoyan *et al*. (2021), Iwegbue *et al*. (2018), Tesi *et al*. (2020), Iwegbue *et al*. (2023), Ajala *et al*. (2024) and Obasi *et al*. (2024), the most popular indices are the contamination/pollution index, enrichment factor (EF), index of geoaccumulation (Igeo), contamination factor (C_f), ecological risk factor (E_r^i), degree of contamination (C_d), pollution load index (PLI), and potential ecological risk index (PERI). For example, the C_f is used to evaluate the degree of contamination of particular heavy metals relative to the background level (Ajala *et al*., 2024). The C_d is used to quantify the overall level of contamination at a specific sampling site. The Igeo is used to evaluate the possibility of heavy metal pollution in sediments by comparing the current sediment contents to pre-industrialization levels. The PERI evaluates the cumulative ecological risk of several heavy metals at a given location, whereas the E_r^i characterizes the possible risk of a particular heavy metal in sediments. Therefore, this study's objective is to assess the ecological risks, pollution indices, and heavy metal levels of sediments from a few flooded metropolitan areas in Delta State, Nigeria. The present level of heavy metal contamination and related hazards in the flooded sediments of the studied sites will be better understood as a result of this investigation.

Materials and methods

Study area description: The map of the study area showing the sampling locations is shown in Figure 1. The detailed description of the study area has been reported elsewhere (Ohwo *et al*., 2023).

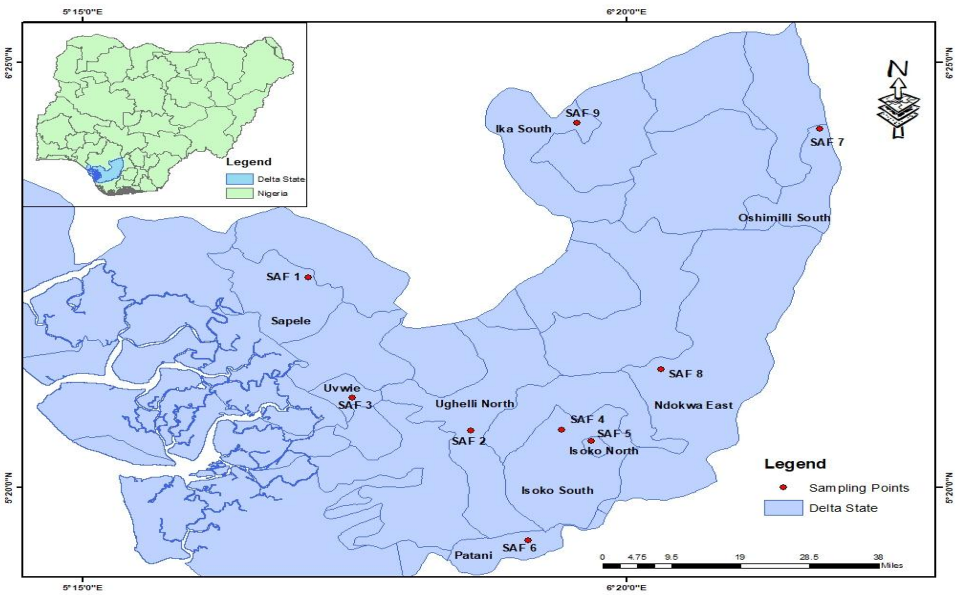

Figure 1: Map of the study area

Samples collection: Surface sediments were collected from nine flooded areas with a plastic mud grab sampler to avoid metal contamination and to maintain the integrity of the samples. The composite sampling technique was adopted to obtain a representative sample at each flooded area. Sediment samples were collected for three months (July-September) covering the wet season. The sediment samples were packed in plastic containers and transported to the laboratory in ice chests. The samples were stored at 4 °C prior to pretreatment. The sediment samples were air-dried, ground in an agate mortar and sieved to pass through a 2-mm sieve.

Reagents: The reagents used were hydrofluoric acid (HF) (48-50 % v/v), nitric acid (HNO_3) (70 % v/v) and hydrochloric acid (HCl) (36 % v/v) obtained from BDH, Poole, UK. The calibration standards were prepared by diluting 1000 mg L^{-1} commercial stock solutions of the heavy metals with 0.25 mol L^{-1} nitric acid.

Chemical analysis: A mass of 0.5 g of sediment sample was placed in a 100-mL Teflon beaker and HNO_3 (5 mL), HCl (15 mL) and HF (5 mL) were added, covered and allowed to stand overnight. The next day, the mixture was heated to 110 °C on a hot plate for 1 h, cooled to room temperature, filtered through a Whatman No. 1 filter paper and made up to 25 mL with 0.25 mol L^{-1} HNO_3. The Cd, Pb, Cr, Ni, Cu, Co, Mn, Zn and Fe levels in the sample solutions were determined by atomic absorption spectrometry (AAS).

Quality assurance: The European Commission (2019) guidelines for quality assurance was followed in this study. Blanks determination was carried out in addition to recovery study. Heavy metals levels in blank samples were below their limit of quantifications. The per cent of heavy metals recovered ranged between 91.2 % and 99.5 %. Triplicate analysis was done and the relative standard deviations for the replicate analyses were less than 9 % while the R^2 values obtained from the calibration curves were > 0.9995.

Statistical analysis: The analysis of variance (ANOVA) was used to determine if the observed differences in heavy metals levels in sediments of these flooded areas were significant after the Shapiro-Wilk test was used to test for normality of the data. All statistical analyses were performed at p = 0.05 with SPSS version 23.0 software (SPSS Inc., USA).

Contamination/Pollution Index (CPI): Assessment of sediments for heavy metals pollution based on absolute metal levels provide inadequate information on the significance of the value obtained with the intrinsic sediment feature and how the values are related to the maximum allowable limits for the metals (Iwegbue, 2014). The CPI highlights the degree of contamination/pollution of a study site. The CPI was computed as the ratio between metal effectively measured by chemical analysis to reference value. The CPI was derived by employing the equation 1 below and the computed CPI values were interpreted according to the scheme provided in Table 1.

$$\text{CPI} = \frac{\text{Concentration of metal in sediment}}{\text{DPR target value}} \qquad (1)$$

Quantification of Enrichment Factor (EF): The EF is a relatively simple and straightforward tool for measuring the extent of enrichment and for comparing the contamination levels of different environmental media (Agca and Ozdel 2014). Heavy metals EF is used to distinguish between metal originating from human activities and those of natural processes. The EF of heavy metals in the sediments were calculated following the equation of Reimann and De Caritat (2000).

$$\text{EF} = \frac{(\text{Level of test heavy metal})}{(\text{Level of reference heavy metal})} \div \frac{(\text{Background level of test heavy metal})}{(\text{Background level ofreference heavy metal})} \qquad (2)$$

Fe being the most abundant among the heavy metals studied was used as the reference heavy metal. The crustal abundance values (CAV) of the heavy metals were used as their background levels. The interpretation of EF values is provided in Table 1.

Geo-accumulation Index (I_{geo}): The Igeo was assessed with the equation of Muller (1969) and interpreted according to the scheme in Table 1.

$$\text{Igeo} = \text{Log } 2\, \frac{\text{Measured levels of the heavy metals in the sediment}}{1.5 \times \text{Background level of the heavy metals}} \qquad (3)$$

Table 1: Significance of the contamination/pollution index, Geo-accumulation index and enrichment factor (Iwegbue *et al*., 2018)

Metals	NUPRC (2018)	CAV	CPI values	Significance	Igeo Values	Significance	EF Values	Significance
Cd	0.8	0.3	<0.1	Very slight contamination	<0	Practically unpolluted (Class 1)	<2	Deficiency to minimal enrichment
Pb	85	20	0.10-0.25	Slight contamination	0-1	Unpolluted to moderately polluted (Class 2)	2-5	Moderate enrichment
Cr	100	90	0.26-0.50	Moderate contamination	1-2	Moderately polluted (Class 3)	5-20	Significant enrichment
Ni	35	68	0.51-0.75	Severe contamination	2-3	Moderately to strongly polluted (Class 4)	20-40	Very high enrichment
Cu	36	45	0.76-1.00	Very severe contamination	3-4	Strongly polluted (Class 5)	>40	Extremely high enrichment
Co	20	19	1.10-2.00	Slight pollution	4-5	Strongly polluted to very polluted (Class 6)		
Mn	-	850	2.10-4.00	Moderate pollution	>5	Extremely polluted (Class 7)		
Zn	140	95	4.10-8.00	Severe pollution				
Fe	-	47000	8.10-16.0	Very severe pollution				
			>16.0	Excessive pollution				

Ecological risk assessment

Ecological risk assessment of heavy metals in the sediments: The potential ecological risk index (PERI) of the heavy metals was determined using the equation given by Hakanson (1980).

$$PERI = \sum_{i=1}^{n} E_r^i \quad (4)$$

where; $$E_r^i = T_f^i \times C_f^i \quad (5)$$

and $$C_f^i = \frac{C_s^i}{C_r^i} \quad (6)$$

$$C_d = \sum_{i=1}^{n} C_f^i \quad (7)$$

where; C_r^i the level of heavy metals in sample,
C_s^i the background levels,
E_r^i the ecological risk factor,
C_f^i the contamination factor for a particular metal,
T_f^i the toxic response factor for each metal, and
RI the potential ecological risk factor for all the metals.

The T_f^i values used were 30, 5, 2, 5, 5, 1 and 1 for Cd, Pb, Cr, Ni, Cu, Mn and Zn respectively.

The interpretation of the ecological risk is presented in Table 2.

Table 2: Indices for interpretation of potential ecological risk for heavy metals pollution (Håkanson, 1980)

Contamination factor (C_f)	Contamination factor for an individual metal	Degree of contamination (C_d)	Degree of contamination of the environment	E_r	Ecological risk factor for an individual metal	Potential Ecological Risk Index (PERI)	Pollution Degree
$C_f < 1$	Low	$C_d < 5$	Low contamination	$E_r < 40$	Low risk	$RI < 65$	Low risk
$1 \le C_f < 3$	Moderate	$5 \le C_d < 10$	Moderate contamination	$40 \le E_r < 80$	Moderate risk	$65 \le RI < 130$	Moderate risk
$3 \le C_f < 6$	Considerable	$10 \le C_d < 20$	Considerable contamination	$80 \le E_r < 160$	Considerable risk	$130 \le RI < 260$	Considerable risk
$C_f \ge 6$	High	$C_d \ge 20$	High contamination	$160 \le E_r < 320$	High risk	$RI \ge 260$	Very high risk
				$E_r \ge 320$	Very high risk		

Results

The results obtained for the heavy metal levels are shown in Table 3. The computed CPI, Igeo and EF of heavy metals in the floodplain sediments are displayed in Tables 4, 5 and 6 respectively. Contamination factor, degree of contamination and contamination level due to heavy metals in the floodplain sediments are shown in Table 7 while ecological risk factor, potential ecological risk index and pollution degree due to heavy metals in the floodplain sediments are shown in Table 8.

Table 3: Heavy metals levels (mg kg^{-1}) in the flooded sediments

	Cd	Pb	Cr	Ni	Cu	Co	Mn	Zn	Fe
SAF1	1.67	7.41	9.09	3.90	12.9	7.10	469	133	1692
SAF2	2.58	6.73	9.17	3.48	7.49	13.8	744	100	1036
SAF3	7.38	5.89	4.16	4.46	12.2	12.1	310	71.3	1495
SAF4	1.22	7.40	6.77	3.92	12.4	6.27	556	129	1499
SAF5	2.88	7.59	7.66	3.61	7.64	13.8	681	95.3	1148
SAF6	7.32	5.13	6.19	4.48	12.5	12.9	331	91.1	1587
SAF7	1.13	7.08	6.31	3.78	11.9	6.68	573	115	1410
SAF8	4.35	8.05	6.85	3.77	8.99	14.2	635	91.4	1212
SAF9	5.81	5.05	6.59	4.47	12.4	11.9	365	107	1627

Table 4: Contamination/pollution index of heavy metals in the flooded sediments

	Cd	Pb	Cr	Ni	Cu	Co	Zn	Mn	Fe
SAF1	2.09	0.09	0.09	0.11	0.36	0.36	0.95	0.55	0.04
SAF2	3.23	0.08	0.09	0.10	0.21	0.69	0.71	0.88	0.02
SAF3	9.23	0.07	0.04	0.13	0.34	0.61	0.51	0.36	0.03
SAF4	1.53	0.09	0.07	0.11	0.34	0.31	0.92	0.65	0.03
SAF5	3.60	0.09	0.08	0.10	0.21	0.69	0.68	0.80	0.02
SAF6	9.15	0.06	0.06	0.13	0.35	0.65	0.65	0.39	0.03
SAF7	1.41	0.08	0.06	0.11	0.33	0.33	0.82	0.67	0.03
SAF8	5.44	0.09	0.07	0.11	0.25	0.71	0.65	0.75	0.03
SAF9	7.26	0.06	0.07	0.13	0.34	0.60	0.76	0.43	0.03

Table 5: Geoaccumulation index of heavy metals in the flooded sediments

	Cd	Pb	Cr	Ni	Cu	Co	Mn	Zn	Fe
SAF1	1.89	-4.27	-3.89	-4.71	-2.39	-2.01	-1.44	-0.10	-5.38
SAF2	2.52	-4.40	-3.88	-4.87	-3.17	-1.05	-0.78	-0.51	-6.09
SAF3	4.04	-4.60	-5.02	-4.52	-2.47	-1.24	-2.04	-1.00	-5.56
SAF4	1.44	-4.27	-4.32	-4.70	-2.44	-2.18	-1.20	-0.14	-5.56
SAF5	2.68	-4.23	-4.14	-4.82	-3.14	-1.05	-0.90	-0.58	-5.94
SAF6	4.02	-4.80	-4.45	-4.51	-2.43	-1.14	-1.95	-0.65	-5.47
SAF7	1.33	-4.33	-4.42	-4.75	-2.50	-2.09	-1.15	-0.31	-5.64
SAF8	3.27	-4.15	-4.30	-4.76	-2.91	-1.01	-1.01	-0.64	-5.86
SAF9	3.69	-4.82	-4.36	-4.51	-2.44	-1.26	-1.80	-0.41	-5.44

Table 6: Enrichment factor of heavy metals in the flooded sediments

	Cd	Pb	Cr	Ni	Cu	Co	Mn	Zn
SAF1	155	10.3	2.81	1.59	7.96	10.4	15.3	38.9
SAF2	390	15.3	4.62	2.32	7.55	33.0	39.7	47.8
SAF3	773	9.26	1.45	2.06	8.52	20.0	11.5	23.6
SAF4	128	11.6	2.36	1.81	8.64	10.3	20.5	42.6
SAF5	393	15.5	3.48	2.17	6.95	29.7	32.8	41.1
SAF6	723	7.60	2.04	1.95	8.23	20.1	11.5	28.4
SAF7	126	11.8	2.34	1.85	8.81	11.7	22.5	40.4
SAF8	562	15.6	2.95	2.15	7.75	29.0	29.0	37.3
SAF9	559	7.29	2.12	1.90	7.96	18.1	12.4	32.5

Table 7: Contamination factor, degree of contamination and contamination level due to heavy metals in the sediments of the flooded areas

	Contamination factor (C_f)								Degree of contamination (C_d)	Contamination level
	Cd	Pb	Cr	Ni	Cu	Co	Mn	Zn		
SAF1	5.57	0.37	0.10	0.06	0.29	0.37	0.55	1.40	8.71	Low contamination
SAF2	8.60	0.34	0.10	0.05	0.17	0.73	0.88	1.05	11.9	Considerable contamination
SAF3	24.6	0.29	0.05	0.07	0.27	0.64	0.36	0.75	27.0	High contamination
SAF4	4.07	0.37	0.08	0.06	0.28	0.33	0.65	1.36	7.19	Low contamination
SAF5	9.60	0.38	0.09	0.05	0.17	0.73	0.80	1.00	12.8	Considerable contamination
SAF6	24.4	0.26	0.07	0.07	0.28	0.68	0.39	0.96	27.1	High contamination
SAF7	3.77	0.35	0.07	0.06	0.26	0.35	0.67	1.21	6.75	Low contamination
SAF8	14.5	0.40	0.08	0.06	0.20	0.75	0.75	0.96	17.7	Considerable contamination
SAF9	19.4	0.25	0.07	0.07	0.28	0.63	0.43	1.13	22.2	High contamination

Table 8: Ecological risk factor, potential ecological risk index and pollution degree due to heavy metals in the sediments of the flooded areas

	Ecological risk factor (E^i_r)								**Potential ecological risk index**	**Pollution degree**
	Cd	Pb	Cr	Ni	Cu	Co	Mn	Zn		
SAF1	167	1.85	0.20	0.29	1.43	0.75	0.55	1.40	173	Considerable risk
SAF2	258	1.68	0.20	0.26	0.83	1.45	0.88	1.05	264	Very high risk
SAF3	738	1.47	0.09	0.33	1.36	1.27	0.36	0.75	744	Very high risk
SAF4	122	1.85	0.15	0.29	1.38	0.66	0.65	1.36	128	Moderate risk
SAF5	288	1.90	0.17	0.27	0.85	1.45	0.80	1.00	294	Very high risk
SAF6	732	1.28	0.14	0.33	1.39	1.36	0.39	0.96	738	Very high risk
SAF7	113	1.77	0.14	0.28	1.32	0.70	0.67	1.21	119	Moderate risk
SAF8	435	2.01	0.15	0.28	1.00	1.49	0.75	0.96	442	Very high risk
SAF9	581	1.26	0.15	0.33	1.38	1.25	0.43	1.13	587	Very high risk

Discussion

Heavy metals levels in the floodplain sediments: The individual results obtained for the heavy metals are shown in Table 3. Analysis of variance showed that the levels of the heavy metals varied significantly ($p < 0.05$) from one flooded area to the other. The levels of cadmium varied from 1.13 to 7.38 mg kg^{-1}. The maximum level of Cd was found at SAF3 and the minimum level was found at SAF7. The levels of Cd found in this study were higher than the target value of 0.8 mg kg^{-1} stipulated by the Nigerian Upstream Petroleum Regulatory Commission (NUPRC) (NUPRC, 2018). The levels of Cd obtained in this study were lower than the range of 7.68 to 20 mg kg^{-1} reported in sediments of flooded areas in southeast, Nigeria (Ajala *et al*., 2024), 8.1 to 29.5 mg kg^{-1} reported in sediments of flooded areas in Eschweiler, Germany (Weber *et al*., 2015) and not detected to 23.3mg kg^{-1} reported for sediments of flooded areas in Cracow, Poland (Strzebonska *et al*., 2015) but higher than the range of 0.1 to 0.79 mg kg^{-1} reported for flooded sediments in Slupsk, Poland (Obolewski and Glinska-lewczuk, 2013).

The levels of Pb varied from 5.05 to 8.05 mg kg^{-1}. The maximum level of Pb was found at SAF8 and the minimum level was found at SAF9. The levels of Pb found in this study were below the target value of 85 mg kg^{-1} stipulated by NUPRC (NUPRC, 2018). The levels of Pb obtained in this study were lower than the range of 31.7 to 160 mg kg^{-1} reported in sediments of flooded areas in southeast, Nigeria (Ajala *et al*., 2024) and the range of 8.0 to 165 mg kg^{-1} reported for flooded sediments in Slupsk, Poland (Obolewski and Glinska-lewczuk, 2013), 772 to 1683 mg kg^{-1} reported in sediments of flooded areas in Eschweiler, Germany (Weber *et al*., 2015) and not detected to 263 mg kg^{-1} reported in sediments of flooded areas in Cracow, Poland (Strzebonska *et al*., 2015) but were higher than the range of 1.7 to 2.36 mg kg^{-1} reported for sediments of flooded areas in southwestern Nigeria (Adewoye *et al*., 2020).

The levels of Cr varied from 4.16 to 9.17 mg kg^{-1}. The maximum level of Cr was found at SAF2 and the minimum level was found at SAF3. The levels of Cr found in this study were below the target value of 100 mg kg^{-1} stipulated by NUPRC (NUPRC, 2018). The levels of Cr obtained in this study were similar to the range of 3.81 to 16.8 mg kg^{-1} reported for in sediments of flooded areas in southeast, Nigeria (Ajala *et al*., 2024) and the range of 3.9 to 7.9 mg kg^{-1} reported for flooded sediments in Slupsk, Poland (Obolewski and Glinska-lewczuk, 2013).

The levels of Ni varied from 3.48 to 4.48 mg kg^{-1}. The maximum level of Ni was found at SAF6 and the minimum level was found at SAF2. The levels of Ni found in this study were below the target value of 35 mg kg^{-1} stipulated by NUPRC (NUPRC, 2018). The levels of Ni obtained in this study were lower than the range of 5.46 to 12.6 mg kg^{-1} reported in sediments of flooded areas in southeast, Nigeria (Ajala *et al*., 2024) and the range of 4.7 to 10.6 mg kg^{-1} reported for flooded sediments in Slupsk, Poland (Obolewski and Glinska-lewczuk, 2013) but were higher than the range of 1.27 to 2.20 mg kg^{-1} reported for sediments of flooded areas in southwestern Nigeria (Adewoye *et al*., 2020).

The levels of Cu varied from 7.49 to 12.9 mg kg^{-1}. The maximum level of Cu was found at SAF1 and the minimum level was found at SAF2. The levels of Co varied from 6.27 to 14.2 mg kg^{-1}. The maximum level of Co was found at SAF8 and the minimum level was found at SAF4. The levels of Cu and Co found in this study were below their target value of 36 mg kg^{-1} and 20 mg kg^{-1} respectively stipulated by NUPRC (NUPRC, 2018). The levels of Cu obtained in this study were lower than the range of 7.28 to 106 mg kg^{-1} reported in sediments of flooded areas in southeast, Nigeria (Ajala *et al*., 2024), 241 to 568 mg kg^{-1} reported in sediments of flooded areas in Eschweiler, Germany (Weber *et al*., 2015) and not detected to 115 mg kg^{-1} reported in sediments of flooded areas in Cracow, Poland (Strzebonska *et al*., 2015) but were comparable to the range of 2.8 to 30.9 mg

kg^{-1} reported for flooded sediments in Slupsk, Poland (Obolewski and Glinska-lewczuk, 2013) and higher than the range of 4.17 to 5.93 mg kg^{-1} reported for sediments of flooded areas in southwestern Nigeria (Adewoye *et al*., 2020).

The levels of Mn varied from 310 to 744 mg kg^{-1}. The maximum level of Mn was found at SAF2 and the minimum level was found at SAF3. The levels of Mn found in this study were below the crustal abundance value (CAV) of 850 mg kg^{-1} for Mn (Turiekan and Wedepohl, 1960). The levels of Mn obtained in this study were higher than the range of 15.2 to 42.4 mg kg^{-1} reported for sediments of flooded areas in southeast, Nigeria (Ajala *et al*., 2024) but comparable to the range of 111 to 1190 mg kg^{-1} reported for flooded sediments in Slupsk, Poland (Obolewski and Glinska-lewczuk, 2013) and 17 to 979 mg kg^{-1} reported for sediments of flooded areas in Cracow, Poland (Strzebonska *et al*., 2015).

The levels of Zn varied from 71.3 to 133 mg kg^{-1}. The maximum level of Zn was found at SAF1 and the minimum level was found at SAF3. The levels of Zn found in this were below the target value of 140 mg kg^{-1} stipulated by NUPRC (NUPRC, 2018). The levels of Zn obtained in this study were higher than the range of 14.4 to 76.7 mg kg^{-1} reported for sediments of flooded areas in southeast, Nigeria (Ajala *et al*., 2024), 18.8 to 67.4 mg kg^{-1} reported for flooded sediments in Slupsk, Poland (Obolewski and Glinska-lewczuk, 2013) and 7.44 to 13.9 mg kg^{-1} reported for sediments of flooded areas in southwestern Nigeria (Adewoye *et al*., 2020). However, the Zn levels obtained in this study was lower than the range of 1797 to 8760 mg kg^{-1} reported for sediments of flooded areas in Eschweiler, Germany (Weber *et al*., 2015) and 12 to 1013 mg kg^{-1} reported for sediments of flooded areas in Cracow, Poland (Strzebonska *et al*., 2015).

The levels of Fe varied from 1036 to 1692 mg kg^{-1}. The maximum level of Fe was found at SAF1 and the minimum level was found at SAF2. The levels of Fe found in this study were below the crustal abundance value (CAV) of 47000 mg kg^{-1} (Turiekan and Wedepohl, 1960). The levels of Fe obtained in this study were lower than the range of 1685 to 3562 mg kg^{-1} reported for sediments of flooded areas in southeast, Nigeria (Ajala *et al*., 2024) but higher than the range of 330 to 597 mg kg^{-1} reported for sediments of flooded areas in southwestern Nigeria (Adewoye *et al*., 2020) and 15 to 359 mg kg^{-1} reported for sediments of flooded areas in Cracow, Poland (Strzebonska *et al*., 2015).

Contamination/pollution index (CPI): The CPI of the heavy metals in the floodplain sediments are shown in Table 4. The CPI of the heavy metals ranged from 1.41-9.23, 0.06-0.09, 0.04-0.09, 0.10-0.13, 0.21-0.36, 0.31-0.71, 0.51-0.95, 0.36-0.88, and 0.02-0.04 for Cd, Pb, Cr, Ni, Cu, Co, Zn, Mn and Fe respectively. The CPI of Cd falls into the slight to very severe pollution categories. The CPI of Pb, Cr and Fe fall into the very slight contamination category. The CPI of Ni falls into the slight contamination and CPI of Cu fall into the moderate contamination. The CPI of Co falls into the severe contamination while the CPI of Zn and Mn fall into the severe to very severe contamination.

Geoaccumulaton index (Igeo): The Igeo of the heavy metals in the floodplain sediments are shown in Table 5. The Igeo of the heavy metals ranged from 1.33 to 4.04, -4.82 to -4.15, -5.02 to -3.88, -4.87 to -4.51, -3.17 to -2.44, -2.18 to -1.01, -2.04 to -0.78, -1.0 to -0.10 and -6.09 to -5.38 for Cd, Pb, Cr, Ni, Cu, Co, Zn, Mn and Fe respectively. Based on the Muller (1969) classification, the Igeo of all the heavy metals except Cd fall into the practically unpolluted category (Class 1). However, the Igeo of Cd falls into the moderately to strongly polluted (Class 1 to 4).

Enrichment factor (EF): The EF of the heavy metals in the floodplain sediments are shown in Table 6. The EF of the heavy metals ranged from 126-773, 7.29-15.6, 1.45-4.62, 1.59-2.32, 6.95-8.81, 10.3-33.0, 11.5-39.7 and 23.6-47.8 for Cd, Pb, Cr, Ni, Cu, Co, Zn, Mn and Fe respectively. Based on Loska and Wiechula (2003), the EF of Cd fall into the extremely high enrichment, Pb and Cu fall into the significant enrichment, Cr and Ni fall into the minimal to moderate enrichment, Co and Mn fall into the significant to very high enrichment while Zn fall into the very high to extremely high enrichment.

Contamination factor and degree of contamination of heavy metals: The computed contamination factors (C_f) of the heavy metals in the floodplain sediments are shown in Table 7. The contamination factor of Cd ranged from considerable to high contamination while that of Zn ranged from low to moderate. Whereas the contamination factor for Pb, Cr, Ni, Cu, Co and Mn fall into the low contamination. On the average, the contamination factor of the heavy metals followed the order: Cd > Zn > Mn > Co > Pb > Cu > Cr > Ni. The heavy metals degree of contamination (C_d) in these floodplain sediments ranged from 6.75 to 27.0 with an average of 15.7. On the average, the contamination level of the heavy metals in the floodplain sediments was considerable contamination with significant contribution from Cd.

Ecological risk factor and potential ecological risk index of heavy metals: The computed ecological risk factors (E_r^i) of heavy metals in the floodplain sediments are shown in Table 8. The E_r^i of Cd ranged from considerable to very high risk whereas that of the other heavy metals was low. On the average, the E_r^i of the metals followed the order: Cd > Pb > Cu > Co > Zn > Mn > Ni > Cr. The potential ecological risk index of heavy metals in these floodplain sediments ranged from 119 to 744 with an average of 388. On average, the risk level of heavy metals in the floodplain sediments very high risk with Cd also contributing significantly to the risk level.

Conclusion

The results from this study revealed that with the exception of Cd, the heavy metal levels in the floodplain sediments were below their respective NUPRC limits. The results showed significant spatial variation in the metal distribution patterns. The pollution indices suggested that Cd is the main heavy metal contaminant in the floodplain sediments. The ecological risk indices indicate that very high ecological risks are associated with exposure to these metals but with significant impact from Cd.

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Author Contributions

This study was conceptualization and design by Onoriode O. Emoyan. The collection, preparation, and analysis of samples for the determination of metals were by Onoriode O. Emoyan, Charles Otobrise and Beatrice O. Peretiemo-Clarke. The compilation and statistical analysis of metals results was by Otobrise and Beatrice O. Peretiemo-Clarke. The first draft of the manuscript was written by Onoriode O. Emoyan and Otobrise. All authors commented on previous versions of the manuscript, and review and editing of the final manuscript was by Onoriode O. Emoyan and Otobrise. All authors read and approved the final manuscript.

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