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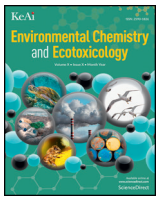

Ecotoxicological risk assessment of heavy metals from remediated oil spill site in Niger Delta region, Nigeria

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ABSTRACT

Ecotoxicological risk assessment studies provide information about environmental risk and the magnitude of such risk for further action when necessary. The study assessed the ecotoxicological risk of heavy metals (HMs)- Lead (Pb), Cadmium (Cd), Chromium (Cr), Nickel (Ni), Iron (Fe), and Copper (Cu)) from remediated oil spill site in Niger Delta region to establish the site contamination and ecological risk status of environmental mediums (soil and sediment) based on contamination factor (CF), enrichment factor (EF), Geo-Accumulation Index (I_{geo}), Pollution Load Index (PLI), Degree of Contamination Index (DCI), Risk Index (RI), and Principal Component Analysis (PCA). The mean concentration of HMs such as Pb (0.234 mg/kg), Ni (0.307 mg/kg), Fe (1.552 mg/kg), Cr (0.299 mg/kg) and Cd (0.004 mg/kg) exceeded the allowable limit of World Health Organization while Cu (0.527 mg/kg) was within the WHO limit. The contamination status indicated a low CF, zero EF, no pollution of heavy metals, and very low DCI. The ecological risk estimation of soil and sediment indicated low RI for both soil and sediment and trend as RI_{soil}: Cd (0.72) > Fe (0.1) > Ni (0.075) > Pb (0.06) > Cu (0.02) > Cr (0.018) and RI_{Bs}: Cd (2.01) > Ni (0.085) > Pb (0.075) > Fe (0.041) > Cu (0.01) > Cr (0.0018). The PCA revealed a strong correlation among many of the HMs suggested common sources and distribution patterns, while the negative and weak correlation of Cd and Fe with other HMs suggested other sources of the metals other than the anthropogenic sources. Therefore, the HMs in the environmental mediums were deemed contaminated and can be fit for human use in the coming years.

1. Introduction

Environmental harmful agents due to anthropogenic activities are numerous and remain among the major issue faced by various governments, communities, individuals, scientists, and regulators across the globe. As a result of development in both technology and industrial actions, many of the world resources are not put into sustainable use, while many of the processing activities of these resources lead to the discharge of products and by-products into the environment leading to the degradation of the environment [1–3]. The resulting impact of this product and by-products as pollutants in the environment can range from local to regional as well as transboundary as pollutants capable of being transferred, dispersed, and stored in several environmental components [4].

Globally, oil spill holds significant interest due to their potential human health risk impact and long-term effect on environmental quality. In Europe, there are 340,000 potentially contaminated sites forecasted to increase even more by 2025 [5,6]. In Nigeria, according to UNEP [7] oil exploitation and exploration activities in the Niger Delta have led to various levels of contamination of over 2000 sites in the region, while environmental impact due to remediation activities have also increased along the line [6,8]. Oil spill in Nigeria occurs due to sabotage, pipe corrosion, and natural factors [9]; however, there is a lack of reliable information about the number of oil spills in the Niger Delta [10]. According to Amnesty International [11], the oil spilt in the region has run to over 546millions gallons in many decades, with many communities living in a highly polluted environment.

Aside from hydrocarbons, heavy metals (HMs) are other active elements found in crude oil, and they pose serious environmental and health risks to the surrounding organisms [12]. Understanding the fate of these elements when realised in the environment is critical in their management and clean-up [13], considering their potential toxicity, persistence, non-

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degradability, and bioaccumulation [14–16]. When HMs are released into the environment components such as soil, their physicochemical properties influence their environmental fate in which they move through the soil into the groundwater through infiltration and away from the point source to other components such as surface water and sediment [13]. Remediation activities are carried out for oil spill sites, and the environment is then monitored over some time to improve its quality and safety for human engagement. Environmental monitoring can be done through ecotoxicological risk assessment, based on assessing the hazard potential of existing or new environmental chemicals in an ecosystem. Ecotoxicology is a tool that serves for the evaluation of environmental quality [17].

Several ecotoxicological studies have been carried out on various environmental components, including surface water and freshwater sediment [12,18–24], wastewater, landfill solid waste, and leachate [17,25–27] and anthropogenic sites [28–31]. All these studies are significant to environmental quality improvement considering the widespread of many chemicals that can impact the economy, environment, public health, and social system at large [3,32]. Also, ecotoxicological studies have been combined with other analytical methods to improve their viability for environmental health studies. Such includes ecotoxicological indexes combined with health risk assessment [33,34], bioindicator species [35] and geographical information systems (GIS), and multivariate statistical analysis [36] as means of providing enhanced environmental decisions based on scientific approaches.

The novelty of this present study is the possibility of predicting the environmental quality of an oil spill site after remediation action. Such prediction is significant considering the impact of the oil spill and specifically HMs in the environment [37]. However, there are limited related environmental toxicology studies of post-remediated site assessment in Nigeria, and the present study tends to adopt various contamination status tools, ecological risk estimation, and statistically identify the sources of the HMs.

2. Materials and methods

2.1. Study area

The study was undertaken within Ogale, Eleme Local Government Area, Rivers State of Nigeria. Eleme is located between latitude 4° 44'0"N and 4°50'0"N and longitude 7°6'0"E and 7°12'0"E (Fig. 1). Eleme is part of the metropolitan city of Port Harcourt, and it covers an area of 138km^2 and, as of the 2006 census, had a population of 190,884. The spill/remediated site is known as Okuluebu, an area of farmland, forest, and swamp, about 4km^2 Northeast of Ogale town in Ogoniland [10]. The area's climate condition is endowed with abundant sunshine and rainfall due to its location near the equator, which can also influence the rate of dispersing and environmental fate of the pollutants.

2.2. Data collection and procedure

The point of collection (stations) for the soil and sediment samples were selected based on the area of high risk to the environment, representing the boundary of the remediated area and closer to human activities such as farmlands and fishing spots.

Soil samples (3-composite samples) were collected at 200 m, 400 m, and 600 m from the identified area of the remediated activities. At each point, a radius of about 5-10 m was made, and ten random soil samples were collected around the radius into a collection pan at a depth of about 0-15 cm and mixed to form a composite sample for the designated point. The process was repeated at every point, and three (3) composite soil was collected.

Sediment: A sediment sample (surface) was collected underneath the waters of the adjoining stream away from the spill site. The sediment sample was collected at about 1 km from the identified remediated site and 3-5 m into the stream from the dyke. Ten (10) samples were randomly collected

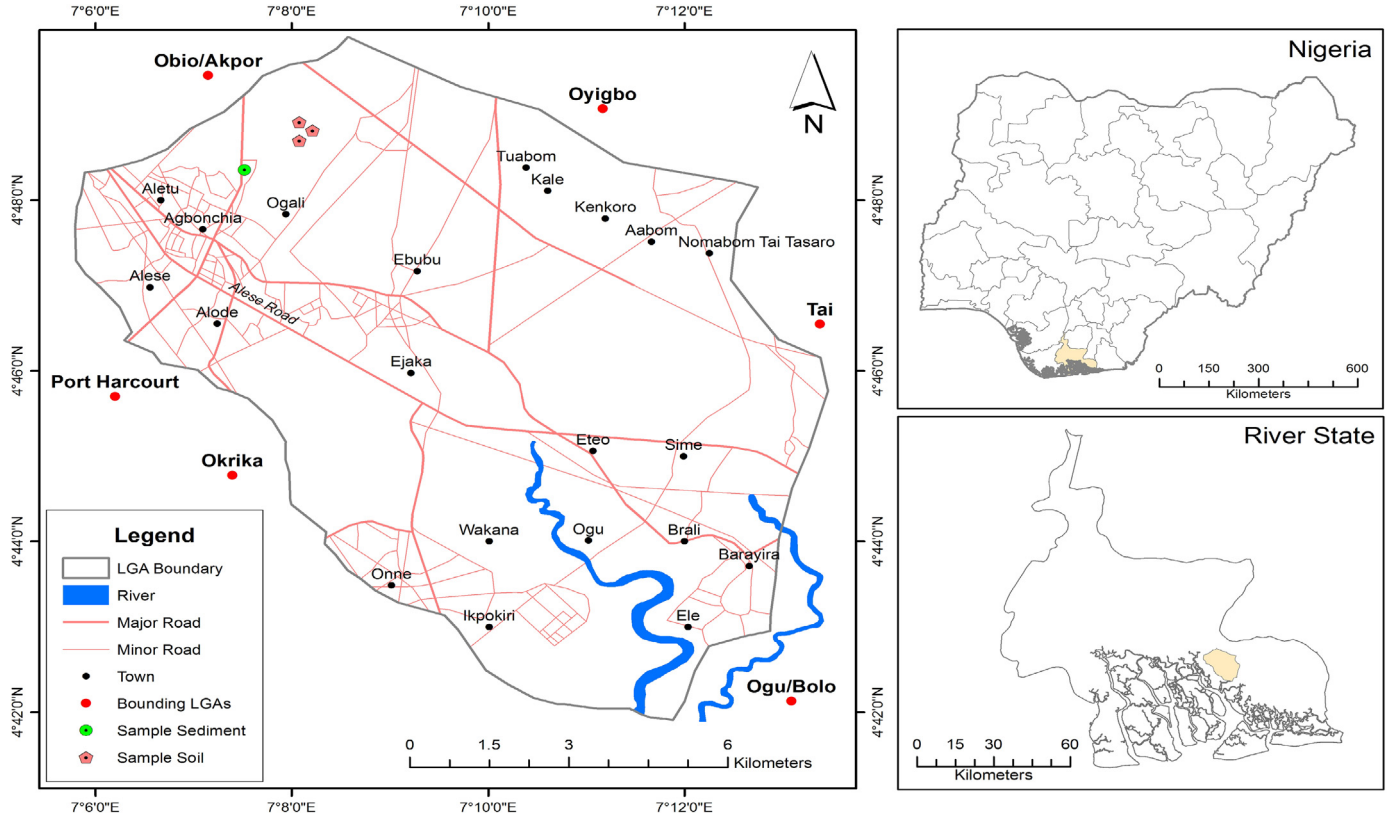

Fig. 1. Overview of Study Area and Samples Collection Points.

from about 300 m into the stream (frontward (150 m) and backward (150) and rigorously mixed to form the sediment soil sample.

Both soil and sediment samples were collected with an auger, dipped down into each medium, and turned 360° before being withdrawn, and samples were taken. Collected samples were instantly wrapped in foil papers, appropriately labelled, and taken to the University of Port Harcourt laboratory for analysis. The details of the sample collection points and the label (adopted henceforth) are presented in Table 1.

2.3. Data analysis

2.3.1. Laboratory analysis procedure

The collected samples were analysed for heavy metals (HM) such as Lead (Pb), Cadmium (Cd), Chromium (Cr), Nickel (Ni), Iron (Fe), and Copper (Cu). Heavy metals were determined under ASTMD 4691 method by Atomic Absorption Spectrophotometry (Perkin Elmer Analyst 400). Calibration of the AAS was significant to the outcome of the analysis, which was consistently done on the instrument before analysing the samples. For digestion of samples into a solution for analysis, 1 g of oven-dried sample was weighed using a top-loading weighing scale and transferred into a 250 ml beaker. In order to prevent contamination or impurities, the beaker was washed with nitric acid and distilled water before it was made available for the transfer of the weighed 1 g sample. With the aid of a dropping pipette, the samples in a 250 ml beaker were mixed with 5 ml of HNO_3 followed by 15 ml of concentrated H_2SO_4 and 0.3 ml of $HClO_4$. The mixed concentration/sample was digested in a fume cupboard, and heating was allowed till a dense white fume appeared; the samples were indigested for 15mins and allowed to cool off before being diluted with distilled water. The diluted sample was then filtered using acid-washed Whatman No. 44 filter paper into a 50 ml volumetric flask and diluted to mark. The sample was then aspirated into an AAS machine at the interval for readings of heavy metals concentration in each sample.

Quality Assurance/Control: All samples were analysed in triplicates, and the mean was estimated for accuracy and precision. The ASS machine used for heavy metals concentration determination has a high accuracy level of 99.776% and can achieve higher sensitivity of >0.9 absorbance and precision that is <0.5% relative to the standard deviation (RSD).

2.3.2. Contamination status and ecological risk estimation

2.3.2.1. Contamination Factor (CF). CF was adopted to ascertain the extent of soil contamination with heavy metals. CF is expressed;

$$CF = {}^{C_n}/_{B_n} \tag{1}$$

Where; C_n = Concentration of heavy metals in soil samples and B_n = Background value of heavy metals in a natural state. The heavy metals are classified based on the CF as CF < 1: Low, 1 ≤ CF < 3: Moderate, 3 ≤ CF < 6: Considerable High, and CF ≥ 6: Very High [38,39].

2.3.2.2. Enrichment Factor (EF). EF can differentiate between metals from anthropogenic activities and natural sources [40]. The enrichment factor of the metals was calculated as the ratio of elemental concentration of sediment normalised to a reference Fe. EF is expressed as;

$$EF = \frac{C_x/C_{ref}}{B_x/B_{ref}} \tag{2}$$

Where; C_x = Concentration of HM content in the anthropogenic impacted soil, C_{ref} = concentration of referenced metal in the anthropogenic impacted soil, Bx = Concentration of HM content in the undisturbed soil, and B_{ref} = concentration of referenced metal in the undisturbed soil. The heavy metals are classified as EF <1: Zero Enrichment, 1 ≤ EF < 3: Less Enrichment, 3 ≤ EF < 5: Moderate Enrichment, 5 ≤ EF < 10: Moderately Enrichment, 10 ≤ EF < 25: High Enrichment, 25 ≤ EF < 50: Very High Enrichment and EF > 50: Exceptionally High Enrichment [41].

2.3.2.3. Geo-Accumulation Index (I_{geo}). I_{geo} estimated the contamination magnitude of the heavy metals in the anthropogenic impacted soil/sediment. I_{geo} is expressed thus;

$$I_{geo} = \log_2 \frac{HM_s}{1.5 \times HM_c} \tag{3}$$

Where; HM_s = Samples heavy metal concentration, HMs = Reference heavy metal concentration and 1.5 = Constant. The heavy metals are classified as $I_{geo} \leq 0$: No Pollution, I_{geo} (0–1): Moderate Pollution, I_{geo} (1–2): Strong Pollution. I_{geo} (2–3): High Pollution, I_{geo} (3–4): Very High Pollution, I_{geo} (4–5): Severe Pollution, and $I_{geo} \leq 5$: Extreme Pollution [41,42].

2.3.2.4. Pollution Load Index (PLI). PLI was adopted to estimate the extent of pollution among the sampled soil/sediment from different locations based on the time factor. PLI is expressed as:

$$PLI = \sqrt[n]{CF_1 * CF_2 * CF_3 * \ldots\ldots\ldots CF_n} \tag{4}$$

Where PLI = Pollution Load Index, CF = Contamination factor, and n = number of elements. The PLI >1 indicates pollution, while PLI < 1 indicates no pollution [39].

2.3.2.5. Degree of Contamination Index (DCI). DCI was utilised to estimate the sum of CF of the studied metals. DC is expressed as;

$$DCI = \sum_{i=1}^{n} CF \tag{5}$$

The DC of the heavy metals are classified as DCI < 1: Low: 1 ≤ DCI < 3: Moderate: 3 ≤ DCI < 6: Considerable and DCI ≥ 6: Very High [38,39].

2.3.2.6. Modified Degree of Contamination (MDC). As the name implies, it is the modification of the DCI equation, which is expressed as;

$$MDC = \frac{\sum_{i=1}^{n} CF}{n} \tag{6}$$

Where n = number of heavy metals. MDC is classified as MDC < 1: Nil to Very Low Degree of Contamination, 1.5 ≤ MDC < 2A: Low Degree of Contamination, 2 ≤ MDC < 4: Moderate Degree of Contamination, 4 ≤ MDC < 8: High Degree of Contamination, 8 ≤ MDC < 16: Very High Degree of Contamination, 16 ≤ MDC < 32: Extremely High Degree of Contamination and MDC ≥ 32: Ultra-High Degree of Contamination [39,43].

2.3.2.7. Risk Index (RI). RI is expressed as the given product of the contamination factor (CF) of the heavy metals and toxicological response factor (Tr) of each heavy metal [34,44], and its expressed as thus;

$$RI = CF_n \times T_r \tag{7}$$

Table 1
Sample and Sampling Location Details.

Sample (s)	Sampling Distance (m)	Latitude	Longitude	Label
Soil	200	04.811637	07.134643	Composite Soil I- **CSI**
	400	04.813582	07.136865	Composite Soil II- **CSII**
	600	04.815248	07.134643	Composite Soil III- **CSIII**
Sediment	≥300	04.805921	07.125312	Sediment Soil- **SS**

Heavy metals' RI was classified as RI < 30: Low Risk, RI: 30–60: Moderate Risk, RI: 60–120: Considerable Risk, RI: 120–240: High Risk, and RI >240: Significantly High Risk [34].

2.3.2.8. Modified Ecological Risk Index (MRI). \MRI is expressed as the given product of the enrichment factor (EF) of the heavy metals and toxicological response factor (Tr) of each heavy metal [41], and its expressed;

$$MRI = EF_n \times T_r \quad (8)$$

The heavy metal MRI was classified as MRI < 40: Low Risk, MRI 40–80: Moderate Risk, MRI 80–160: Considerable Risk, MRI 160–320: High Risk, and MRI >320: Very High Risk [42].

2.3.3. Statistical analysis

The source and distribution of HM across the environmental medium were analysed through statistical tools such as Pearson's Correlation Coefficient (PCC) analysis and Principal Component Analysis (PCA) using the Statistical Package for the Social Sciences (SPSS) version 21 platform.

3. Result and discussion

3.1. Heavy metal concentrations in soil and sediment

The HMs concentration in the composite soil and sediment are summarised in Table 2.

The pH of the soil and sediment samples showed a concentration trend in descending order of SS (5.13) > CSI (5.01) > CSII (4.80) > CSIII (3.35). The outcome indicated that the soil pH is acidic, which can be attributed to the spillage's impact on the soil's characteristics. The study corroborated with that of [46], where the pH of the soil studied became acidic (5.6) due to the oil spill's impact. Chukwujindu [47] reported a similar outcome of pH-acidity (5.41) in the study conducted on crude oil-impacted soil. The Pb of the soil and sediment samples showed a concentration trend in descending order of CSI (0.374) > CSII (0.322) > BS (0.290) > CSIII (0.006) and exceeded the allowable limit (0.1 mg/kg); hence, the soil was impacted with Pb. The finding showed similarity to the report of Udon and Chukwu [46] and Udoetok et al. [48], where the Pb at the spilt site exceeded the allowable limit. The Pb can find its way into the human system through bioaccumulation in plants and animals, and Pb poisoning in humans damages the kidneys, liver, heart, brain, skeleton, and nervous system [45,49], which chronic exposure to low levels of Pb capable of limiting the intelligence capacity in children [45].

Considering the Cd, the concentration trend of the samples indicated CSI (0.006) > CSIII (0.003), CSII (0.002) > BS (0.010), and within the allowable limit except for the soil sample that is 200 m away from the edge of the remediated area. The value reported for CSI was higher than that reported by [50]. According to Pinto et al. [51] and Lichtfouse [52], Cd can impede a plant's growth and development and is a vital contaminant due to its high toxicity level. The Cr of the soil and sediment samples showed a concentration trend in descending order of CSI (0.596) > CSII (0.298) > BS (0.032) > CSIII (0.003) and exceeded the allowable limit (0.01 mg/kg) except for the soil sample at CSIII which is about 600 m away from the remediated site; however, the soil (between 200 and 400 m) and sediment was impacted with Cr. The outcome showed similarity to other related studies with exceeded Cr from spilt sited [46,48,50]. Cr has no biological function linking human physiological activities; hence, regarded as non-essential to humans/mammals. Cr in its compounded forms, such as chromates of Ca, Zn, Sr, and Pb, are highly soluble in water, toxic and carcinogenic [50].

Table 2
Physiochemical and heavy metal concentrations of composite soil and sediment.

Parameters	Soil Samples (Mg/Kg)				Sediment (Mg/Kg)		
	CSI	CSII	CSIII	Mean	SD	SS	WHO*
pH	5.01	4.80	3.35	4.38	0.904	5.13	–
Pb (mg/kg)	0.374	0.322	0.006	0.234	0.199	0.290	0.1
Cd (mg/kg)	0.006	0.002	0.003	0.004	0.002	0.010	0.003
Cr (mg/kg)	0.596	0.298	0.003	0.299	0.297	0.032	0.01
Ni (mg/kg)	0.488	0.419	0.015	0.307	0.256	0.344	0.05
Fe(mg/kg)	1.829	1.599	1.228	1.552	0.303	1.911	0.005
Cu(mg/kg)	0.098	0.058	0.002	0.527	0.048	0.035	2.0

* World Health Organization Allowable Limit [45].

The Ni of the soil and sediment samples showed a concentration trend in descending order of CSI (0.488) > CSII (0.419) > BS (0.0344) > CSIII (0.015) and exceeded the allowable limit (0.05 mg/kg) except for the soil sample at CSIII which is about 600 m away from the remediated site; however, the soil (between 200 and 400 m) and sediment was impacted with Ni. The outcome showed similarity to other related studies with exceeded Ni from spilt sited [53]. Human exposure to Ni can result in health impacts such as allergies, cardiovascular and kidney diseases, lung fibrosis, and lung and nasal cancer. The Fe of the soil and sediment samples showed a concentration trend in descending order of BS (1.911) > CSI (1.829) > CSII (1.599) > CSIII (0.006) and exceeded the allowable limit (0.005 mg/kg); hence, the soil was impacted with Fe. The finding showed similarity to the report of [46], which also reported a high concentration of Fe. According to Adiele et al. [54], the amount of Fe in the soil can be influenced by the soil texture, pH, organic matter, calcium carbonate ($CaCO_3$), and other soil attributes. Considering the Cu, the concentration trend of the samples indicated CSI (0.098) > CSII (0.058) BS (0.035) > CSIII (0.002) and within and lower than the allowable limit (2.0 mg/kg). There was a similarity with the study conducted by [50], where the Cu was lesser than the WHO allowable limit. The proper daily intake for humans is 2.5 mg·kg^{-1} [50,55]; however, intake above this is capable of causing anaemia, liver and kidney damage, and irritation of both stomach and intestine [50,56]. Based on the mean concentration, the soil HMs trended in descending order as Fe > Cu > Ni > Cr > Pb > Cd.

3.2. Contamination status of heavy metal concentrations of soil and sediment

The contamination status and ecological risk estimation composite soil and sediment are summarised in Table 3 and shown in the plot box in Fig. 2. The contamination status of the remediated spilt site based on CF for both soil and sediment samples indicated that all the heavy metals CF estimated below 1 (that is <1); hence HM are classed as CF < 1 (low contamination). The outcome confirmed that human-related activities on the soil had been contaminated with heavy metals. The EF of the sample showed that all HM showed EF < 1, indicating zero enrichment except for Cd in the CSI and BS samples, with 1 ≤ EF < 3 indicating less enrichment. According to Mohammed and Abdu [57] and Ustaoglu [35], soil enrichment with Cd can be linked to various human actions. Based on the mean value of the EF, the descending trend order of the HM based on their EF values showed that Cd (0.667) > Ni (0.423) > Pb (0.322) > Cr (0.230) > (0.095) for soil samples while EF values of BS indicated Cd (1.667) > Pb (0.357) > Ni (0.141) > Cu (0.056) > Cr (0.023). The estimated I_{geo} for the HM both in soils and sediment samples have values lower than zero ($I_{geo} < 0$), indicating no pollution. The descending trending order based on the mean value of soil samples showed that Fe (−1.66) > Cd (−1.82) > Ni (−2.32) > Pb (−2.52) > Cr (−2.81) > Cu (−3.0) while the I_{geo} of sediment sample descended as Cd (−1.35) > Fe (−1.57) > Pb (−2.02) > Ni (−2.31) > Cu (−2.81) > Cr (−3.22). The outcome showed similarity to the study conducted by [12], where all HM analysed indicated $I_{geo} < 0$, although Chai et al. [58] reported otherwise about their study. Also, Cüce et al. [33] reported higher values for I_{geo} in their study due to the great influence of human actions.

The PLI of the soil sampled indicated that the PLI values of the HM are <1, indicating no pollution. The outcome indicated that the concentration values of the HM cannot be taken to have polluted the soil, and the presence of HM can be linked to natural occurrences from weathering rocks and soils [23]. The trend of HM descended as Fe (0.181) > Cd (0.148) > Ni (0.089) > Pb (0.067) > Cr (0.049) > Cu (0.04). The DCI of the soil sampled indicated that the DCI values of the HM are <1, indicating a low degree of

Table 3
Contamination status and ecological risk estimation for composite soil and sediment.

	Contamination Factor (CF)				Enrichment Factor (EF)				Geo-Accumulation Index (I_{geo})			
HM	CFI	CFII	CFIII	CFSS	EFI	EFII	EFIII	EFSS	$I_{geo}I$	$I_{geo}II$	$I_{geo}III$	$I_{geo}SS$
Pb	0.019	0.016	0.0003	0.015	0.481	0.472	0.012	0.357	−1.90	−1.97	−3.70	−2.02
Cd	0.04	0.013	0.02	0.067	1.026	0.333	0.667	1.667	−1.57	−2.05	−1.88	−1.35
Cr	0.017	0.009	0.00008	0.0009	0.438	0.250	0.003	0.023	−1.95	−2.25	−4.24	−3.22
Ni	0.024	0.021	0.001	0.017	0.627	0.615	0.028	0.141	−1.79	−1.86	−3.30	−2.31
Fe	0.040	0.034	0.026	0.041	1	1	1	1	−1.59	−1.64	−1.76	−1.57
Cu	0.007	0.004	0.0001	0.002	0.168	0.112	0.006	0.056	−2.36	−2.59	−4.05	−2.81
				Risk Index (RI)		MRI						
HM	PLI	DCI	MDC	RI_{soil}	RI_{Ss}	MRISoil	MRISS			Tr*	BGV*	
Pb	0.067	0.035	0.012	0.06	0.075	1.61	1.785			5	20	
Cd	0.148	0.073	0.024	0.72	2.01	20.01	50.01			30	0.15	
Cr	0.049	0.026	0.009	0.018	0.0018	0.46	0.046			2	35	
Ni	0.089	0.015	0.005	0.075	0.085	2.115	0.705			5	20	
Fe	0.181	0.1	0.033	0.1	0.041	1	1			1	47	
Cu	0.04	0.011	0.004	0.02	0.01	0.475	0.28			5	15.1	

T_r = Toxic Response Factor and BGV = Background Value [60–62].

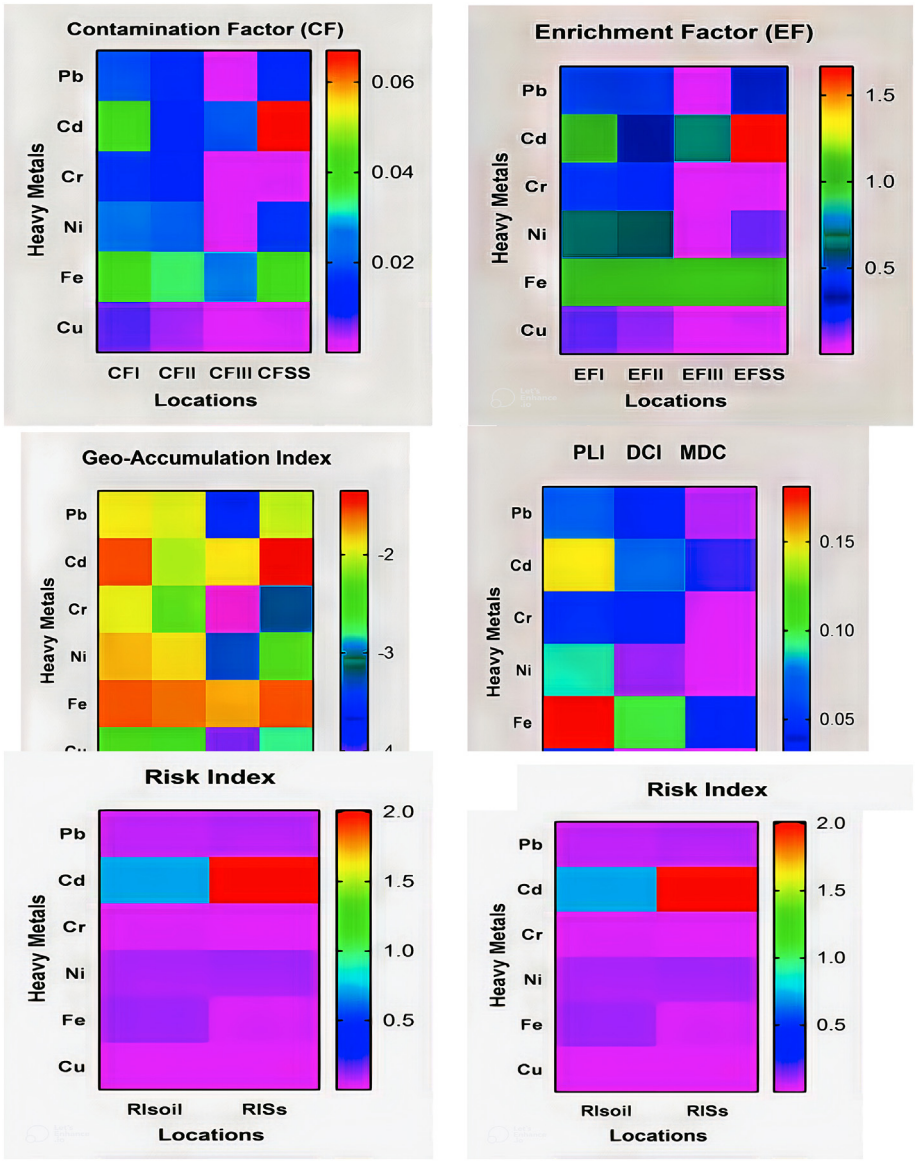

Fig. 2. Heat Map of various Contamination Status and Ecological Risk Estimation for Composite Soil and Sediment.

Table 4
Pearson's Correlation Coefficient (PCC) Analysis.

	Pb	Cd	Cr	Ni	Fe
Pb	1.000				
Cd	0.336	1.000			
Cr	0.714	−0.126	1.000		
Ni	0.997	0.268	0.764	1.000	
Fe	0.871	0.755	0.419	0.832	
Cu	0.882	0.107	0.956	0.912	1.000

Table 5
Rotation component matrix of HM across the Environmental Mediums.

	PC1	PC2
Pb	0.981	
Cd	0.953	
Cr	0.910	0.367
Ni	0.873	0.440
Fe		0.973
Cu	0.575	0.817
Eigenvalues	3.795	1.978
% of Variance	63.255	32.971
Cumulative %	63.255	96.225

contamination index. The DCI value indicated that HM descended trend order are Fe (0.1) > Cd (0.073) > Pb (0.035) > Cr (0.026) > Ni (0.015) > Cu (0.011). The MDC of the soil sampled indicated that the MDC values of the HM are <1, indicating nil to a very low degree of contamination. The MDC value indicated that HM descended trend order are Fe (0.033) > Cd (0.024) > Pb (0.012) > Cr (0.009) > Ni (0.005) > Cu (0.004). The DCI and MDC values further established the natural occurrence of the HMs in the environmental medium; however, Li et al. [59] noted that the concentration of HM, such as Cd, increases in the environment due to industrial activities.

3.3. Ecotoxicology risk estimation (ERE) of soil and sediment

Based on the RI estimation, the ERE of the studied area indicated that HM of the soil and sediments from the remediated spilled site has an RI value <30, indicating a low risk. The descending trending order based on the RI_{soil} value of soil samples showed that Cd (0.72) > Fe (0.1) > Ni (0.075) > Pb (0.06) > Cu (0.02) > Cr (0.018) while the RI_s of sediment sample descended as Cd (2.01) > Ni (0.085) > Pb (0.075) > Fe (0.041) > Cu (0.01) > Cr (0.0018). The ERE of the studied area based on the MRI estimation indicated that HM of the soil and sediments from the remediated spilled site has MRI value <30, indicating low risk except for the Cd in the sediment, which showed MRI 50 indicating moderate risk. The descending trending order based on the MRIsoil value of soil samples showed that Cd (20.01) > Ni (2.115) > Pb (1.61) > Fe (1.00) > Cu (0.475) > Cr (0.46) while the MRIBS of sediment sample descended as Cd (50.01) > Pb (1.785) > Fe (1.00) > Ni (0.075) > Cu (0.28) > Cr (0.046).

3.4. Source and distribution of HM across the environmental mediums

The PCA analysis, including Pearson's correlation coefficient (PCC), rotation component matrix of HM, and screen plot, are summarised and presented in Tables 4–5 and Fig. 3. The analysis indicated no significant relationship among the HM ($p > .0500$; however, there was a strong positive correlation (>0.7) between Pb (1.00), Cr (0.714), Ni (0.997), Fe (0.871), and Cu (0.882) while Cd (0.336) showed weak correlation. Also, there was a significant positive correlation between HM such as Cd—Fe (r: 0.755), Cr—Ni (r: 7.64), Cr—Cu (r: 9.56), and Ni—Fe (r: 0.832) and Ni—Cu (0.912). On the other hand, a negative correlation was noticed between Cd—Cr (r:-0.126) and a weak correlation between Cd—Ni (r: 0.268), Cd—Cu (r: 0.107), and Cr—Fe (r: 0.419).

Based on dimensionality decomposition, Kaiser-Meyer-Olkin (KMO) and Bartlett's test was conducted to determine the data suitability for PCA, and the outcome indicates (>0.5) and (<0.001) for KMO and Bartlett's analysis, respectively. The principal component (PC1) indicated 63.255% of the variance while all the HM as strong positive correlations (Pb: 0.981, Cd: 0.953, Cr:0.910, Ni:0.873) while Fe showed no correlation and Cu indicated a correlation r:5.575. The eigenvalues indicated that the PC1 has >1 and constitutes 63.255% of the total variance. The principal component (PC2) indicated 32.971% of the variance, while the HM with strong positive correlations includes Fe (r: 0.973) and Cu (r: 0.817), while Pb and Cd show no correlation, and Cr (r:0.367) and Ni (r:0.440) indicated a week correlation. The eigenvalues indicated that the PC2 has >1 and constitutes 96.255% of the total variance. PCC analysis which showed a significant positive correlation among HMs illustrated similarities in their sources and distributions. The finding was supported by [12,63], which asserted that the correlation of HM in environmental mediums indicated

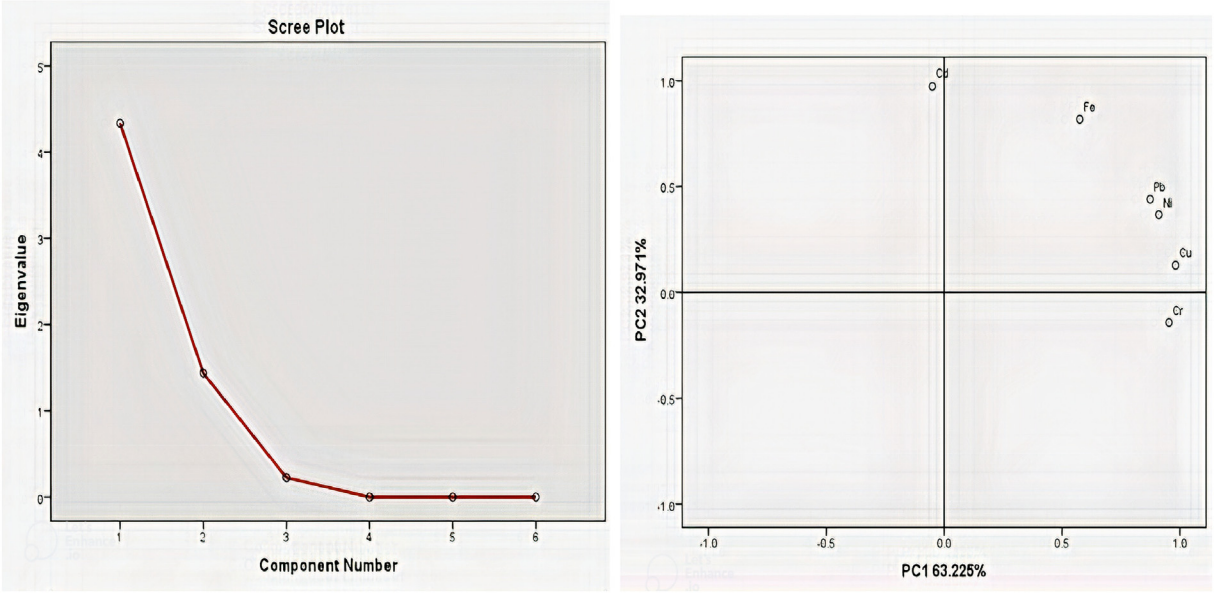

Fig. 3. Scree plot of eigenvalues after PCA and rotated component matrix of HMs in the Environment.

differences in their origin and transformation. According to Ustaoglu et al. [64], HM that indicated strong correlation could have the same form of source and distribution pattern with the changing in the physical and chemical composition of their medium, while the absence of such correlation between and among HM implies a lack of mutual forms form of source and distribution pattern. Considering this in the present study, a large extent of solid correlation among many HMs suggested familiar sources and distribution patterns. The negative and weak correlation of Cd and Fe with other HMs can suggest other sources of the metals other than the anthropogenic impacted sources. Such a source could be attributed to the parent materials dominated in the area. Accordingly, Fe has been reported to be surplus material in many Nigerian soils [28,65,66].

4. Conclusion

The focus of ecotoxicological risk assessment is to establish the potential risk associated with an environment due to anthropogenic impact. Various indicators (CF, EF, I_{geo}, PLI, DCI, MDC, RI, and MRI) were used to predict the environmental quality of the remediated oil spill site. The HMs concentration values of the environmental medium exceeded the allowable limit except for Cu and Cr; hence, the environment is termed contaminated. Although a contaminated environment indicated no potential ecological risk, HMs in the environment share a common source and distribution pattern, which suggest an anthropogenic impacted source. Conclusively, HM in the environmental medium (soil and sediment) are not at their natural states due to human activities (oil spill/remediated action), and the environment is still contaminated but can be fit for human use again in the coming years. Therefore, environmental sustainability practices are encouraged to improve the quality of the various mediums.

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CRediT authorship contribution statement

Omobolaji O. Afolabi: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Olufemi M. Adesope:** Supervision, Validation, Formal analysis, Data curation, Visualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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