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RESEARCH ARTICLE

EVALUATION OF HEAVY METAL POLLUTION IN SOILS OF OIL EXPLORATION HOST COMMUNITIES UTILISING INDIGENOUS EARTHWORMS AS BIOINDICATORS

Biose E[a*]., and Agbate A.E[b].

[a] *Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City, Nigeria.*
[b] *Hydrobiology and Fisheries Unit, Department of Animal and Environmental Biology, Faculty of Life Sciences, University of Benin, Benin City, Nigeria.*
**Corresponding author email: ekene.biose@uniben.edu*

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ABSTRACT

This study assessed the risk of heavy metal pollution in soils of oil extraction host communities by utilising indigenous earthworms as bioindicators. Soil and earthworm samples at a depth of 0-20 cm were obtained from the same quadrant across five coastal wetlands in Delta State. Fifty samples were gathered from the research region. Concentrations of specific heavy metals were assessed via Atomic Absorption Spectroscopy (Solaar 969 Unicam Series Model). The average concentrations of heavy metals and total hydrocarbon content in soils were 217.741±130.42 (Fe), 5.997±6.33 (Cr), 0.275±0.13 (Cd), 4.732±3.00 (Cu), 34.729±33.37 (Zn), 23.298±19.19 (Mn), 10.856±2.90 (Pb), and 17694.98±47114.37 (THC). The enrichment factor (EF) indicates substantial enrichment of Fe, Cr, and Mn, considerable enrichment of Cd, Cu, and Zn, and exceedingly high enrichment of Pb. The geoaccumulation index (Igeo) reveals that Fe is moderately contaminated, Cr is moderately to heavily polluted, Cd and Cu are heavily to extremely polluted, while Pb demonstrates extreme pollution. The contamination factor (CF) indicates a significantly elevated presence of Fe, Cr, Zn, and Mn, while Cd, Cu, and Pb also demonstrate substantial contamination. All sample locations exhibit a significantly elevated level of contamination (CD > 24 = very high degree of contamination). According to Tomlinson et al. (1980), the PLI value for the studied soils demonstrates PLI > 1. The indexes of potential ecological danger were arranged in the following order: EiRCd, EiRPb, EiRCu, EiRZn, EiRCr, EiRMn. Cadmium was the primary factor contributing to the potential ecological danger, as all sampling locations exhibit significant ecological risk to the environment. The bioaccumulation factor (BAF) indicated that the earthworm samples accumulated chromium (Cr), cadmium (Cd), copper (Cu), and zinc (Zn), as BAF values exceeding 1 signify metal bioaccumulation. It is necessary to evaluate the heavy metal concentrations of Cd, Cu, Zn, and Pb in the adjacent vegetation. It is essential to implement suitable engineering and ecological strategies to regulate soil heavy metal concentrations, alongside conducting ecological restoration in contaminated areas. This underscores the necessity of adhering to the recommendations outlined in the United Nations Environment Program's 2011 environmental assessment report and the 2030 Agenda for Sustainable Development Goals (SDGs) regarding the remediation of oil spills in Delta State, as the survival of human life and other biotic elements in this region is at risk.

KEYWORDS

coastal wetlands, Heavy metals, Enrichment factor, contamination factor, total hydrocarbon content

1. INTRODUCTION

Nigeria has been a prominent participant in crude oil exploration and extraction for decades. This has led to considerable environmental difficulties, especially in oil-producing and processing areas (Adewuyi and Olowu, 2012). Onshore and offshore oil installations significantly contribute to pollution by discharging waste from exploration and refining activities. These encompass greasy substances, exhausted catalysts, and residues, which frequently infiltrate the environment; (Uzoekwe and Oghosanine, 2011). This pollution results in severe repercussions, demonstrated by extensive soil and water contamination (Adeniyi and Afolabi, 2002; Adeniyi et al., 2008). Crude oil and its refined derivatives, containing hazardous substances such hydrocarbons, heavy metals, and polycyclic aromatic hydrocarbons (PAHs), present significant threats to ecosystems and human health (Albers, 1995; Akporido, 2008; Commendatore and Esteves, 2004).

Soils can become contaminated by the accumulation of heavy metals and metalloids due to emissions from expanding industrial zones, mine tailings, disposal of high-metal waste, leaded petrol and paints, land application of fertilisers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, petrochemical spills, atmospheric deposition and vehicular emissions (Khan et al., 2008; Zhang et al., 2010). Heavy metals represent a poorly delineated category of inorganic chemical hazards, with the most prevalent at contaminated sites being lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), iron (Fe), and manganese (Mn) (Tam and Wong, 2000; Karen, 2005; Aloysius et al., 2013; Nwachukwu et al., 2013).

Soils serve as primary repositories for heavy metals introduced into the environment by the aforementioned anthropogenic activities. Unlike organic contaminants, which are oxidised to carbon dioxide through microbial processes, most metals resist microbial or chemical degradation, resulting in their total concentration in soils remaining for an extended period following their introduction (Kirpichtchikova et al., 2006;

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Adriano, 2003). Alterations in their chemical forms (speciation) and bioavailability are, nonetheless, feasible. Toxic metals in soil can significantly impede the biodegradation of organic pollutants (Maslin and Maier, 2000). Soil heavy metal contamination may present risks and hazards to humans and ecosystems through: direct ingestion or contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal-human), consumption of contaminated groundwater, diminished food quality (safety and marketability) due to phytotoxicity, decreased land usability for agricultural production leading to food insecurity, and land tenure issues (Ling et al., 2007; McLaughlin et al., 2000). The proper conservation and rehabilitation of soil ecosystems tainted by heavy metals necessitate their characterisation and remediation (Asaolu and Olaofe, 2004; Abii and Nwosu, 2009).

Heavy metal contamination is particularly alarming, as metals such as cadmium (Cd), lead (Pb), and copper (Cu) are frequently released into the environment during oil extraction processes. These metals are prone to accumulation in soils, negatively impacting soil biota, vegetation, and microorganisms (Chen and Hu, 2019; Schneider et al., 2017; Wu et al., 2017). Moreover, earthworms, acknowledged as ecosystem engineers, are integral to soil processes such as nutrient cycling and organic matter decomposition (Edwards, 2004; Frouz et al., 2014). Notwithstanding the deleterious effects of heavy metals, earthworms sequester these pollutants in their tissues via organometallic compound production within chloragogenous cells (Morgan and Morris, 1982; Anitha Kunhikrishnan et al., 2013).

Soil invertebrates, including earthworms, are terrestrial annelids characterised by bilateral symmetry (Schaefer and Juliane, 2007). They are crucial elements in the formation of soil structure, decomposition of organic matter, and nutrient cycling. The actions of earthworms are seen as beneficial for soil health and may hypothetically enhance bioremediation (Hickman and Reid, 2008). Despite the myriad ways in which earthworm activities enhance soil health, less research has been conducted to examine the impact of earthworms on the remediation of petroleum hydrocarbon contamination in soil (Hickman and Reid, 2008). In some study stated that earthworms may initiate the degradation process and might thus be utilised in the repair of oil-contaminated soil with moderate total petroleum hydrocarbon (TPH) concentrations (Schaefer and Juliane, 2007). Soil invertebrates, such as earthworms, may serve as effective sentinel organisms for soil chemical pollution due to their direct interaction with soil pore water, unlike many vertebrates that are indirectly exposed via the food chain (Kammenga et al., 2000; Dedeke et al., 2015). Metal buildup in earthworm species generally proceeds via two pathways: absorption through cutaneous contact or ingestion of organic debris, followed by adsorption through gut tissues.

Earthworms are progressively utilised in ecological risk assessments owing to their capacity for bioaccumulation and their susceptibility to pollutants. Their gut flora, which markedly differs from the adjacent soil, is likewise influenced by heavy metal exposure. Research indicates that metal contamination impairs the variety and resilience of gut and soil microbiota, resulting in diminished ecosystem functionality (Pass et al., 2015; Munees and Saghir, 2012; Gans et al., 2005). This study seeks to evaluate the risk associated with heavy metal pollution in soils of oil exploration host communities by utilising indigenous earthworms as bioindicators.

2. Materials And Methods

2.1 Site Location

This study was conducted in Delta State, South-South Nigeria, at a latitude of 5° 30' 0.00''N and a longitude of 6° 00' 0.00''E. Sample regions were selected based on parameters like population activity, traffic density, road segments, and post-oil spill events. Soil and earthworm samples were collected from five accessible locations in Delta State: Control (Sapele), Kwale, Emevor, Effurun, and Olomoro. Soil and earthworm samples were collected from multiple locations, and their geographic coordinates were documented using a global positioning system (GPS). A control environment inside the study site was designated, and samples were collected. Delta State encompasses a total land area of 16,842 square kilometres and is classified as a tropical rainforest, featuring ecosystems rich in diverse species of flora and fauna, both aquatic and terrestrial, and is recognised as one of the most ecologically sensitive regions in Nigeria. Soil and earthworm samples were collected from the following locations based on accessibility:

Site 1: Control (Sapele)	N 05o 48. 502’ E 005o 44. 041’
Site 2: Kwale	N 05o 41. 989’E 006o 27. 832’
Site 3: Emevor	N 05o 29. 411’ E 006o 05. 680’
Site 4: Effurun	N 05o 34. 795’E 005o 46. 964’
Site 5: Olomoro	N 05o 27. 461’E 006o 10. 413’

Figure 1 illustrates a map of the study region.

2.2 Microclimate of the Research Area

As per UNDP, Delta State is situated in the tropical regions of the world, exhibiting alternating wet and dry seasons, and possessing characteristics of the rainforest zone, with an average rainfall of 3000mm distributed from April to October, succeeded by a pronounced dry season lasting up to four months, from November to February (UNDP, 2006; Agbaire and Emoyan, 2012). The site is situated inside the global equatorial climate zone and Nigeria's tropical rainforest region, exhibiting an average temperature of 30 degrees Celsius. The mean monthly temperature for the warmest months varied between 28°C and 33°C, whilst the mean monthly temperature for the coolest month ranged from 22°C to 26°C (Okumagba and Ozabor, 2014).

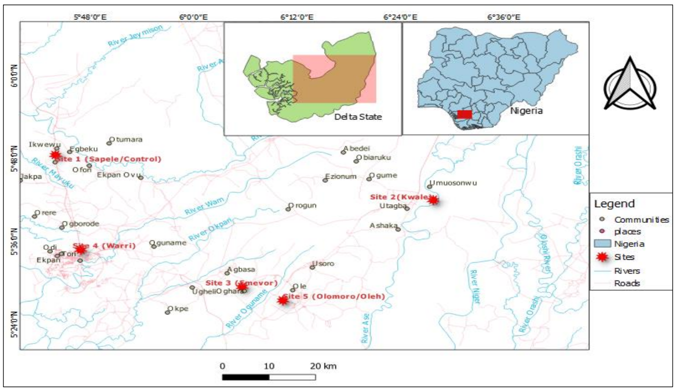

Figure 1: Map of Delta State showing soil and earthworm sampling collection.

2.3 Vegetation and Land Use

The flora varies from coastal mangrove swamps to central evergreen forests and northeastern savannahs. Delta State possesses three distinct soil types. This encompasses alluvial soil on marine deposits along the coastline, alluvial and hydromorphic soils on marine and lacustrine deposits in the Niger and Benin rivers, and ferral soils on loose sandy sediments in the northern and northeastern regions. Ferral soils typically have a golden hue (Nnaji, 2008; Okoh et al., 2010). The soils are tropical ferruginous, comprising loamy, clayey, and sandy types that facilitate cultivation, since agriculture and fishing are the predominant activities in the study region. Their colouration ranges from greyish-brown to reddish-brown to brown (Okoh et al., 2010). The watershed of the research region predominantly consists of a secondary rainforest zone that has been significantly deforested and impacted by human activities due to rapid population growth, industrialisation, and infrastructure expansion. The flora comprises palm trees (Elaeis guineensis), bamboo (Bambusa sp.), water hyacinth (Eichhornia crassipes), and several macrophytes present in the river (Ibe, 1988; Nnaji, 2008). Agriculture, Forestry, and Aquaculture: The state comprises two primary agricultural sectors: food crop cultivation and industrial crop cultivation.

2.4 Sample Collection and Preparation

2.4.1 Collection of Soil Samples

A manually operated stainless steel soil auger was employed to collect soil samples from depths of 0 to 20 cm. Prior to transportation to the laboratory, approximately 100 g of soil samples from each locati0n were put in polyethylene bags and labelled (Owa, 1992; Olukanni and Adebiyi, 2012). Composite samples were collected from all sampling regions and partitioned into three quadrants to produce a singular composite sample. The soil samples were air-dried at ambient temperature (25°C - 27°C) for a duration of two to three days. The materials were pulverised, subjected to sieving with a 2mm mesh, and stored in appropriately labelled sample containers for laboratory analysis. Soil samples were analysed for the subsequent physical and chemical properties utilising the techniques outlined below. To prevent sample contamination, essential quality assurance protocols were implemented.

2.4.2 Collection and Identification of Earthworm Samples

Earthworm specimens were obtained by excavating and sorting the soil inside the designated quadrant at each sampling location, thereafter placed in marked plastic containers (Owa, 1992). Earthworm specimens were collected in duplicate at each sampling locati0n. The earthworm specimens were transported to the laboratory in plastic containers, each containing 3-5 earthworms and an ice pack. The earthworms were positioned in petri dishes and subsequently refrigerated for 24 hours to expel the soil from their intestines. They were then removed, gently rinsed with deionised water, and frozen for future analysis (Bamgbose et al., 2000; Agbaire and Emoyan, 2012). The earthworm specimens were classified by the Department of Animal and Environmental Biology at the University of Benin, Benin City, following the methodologies of Sims and Gerrard (1985) and Nature Watch (2003).

2.5 Earthworm Identification

The species of earthworm identified was Aporrectodea longa. Aporrectodea is a genus of earthworms from the Lumbricidae family of the Animalia kingdom, comprising species categorised as Clitellata. The genus comprises several prevalent earthworm species within the Palearctic ecozone, predominantly located in global agricultural soils (Perez-Losada et al., 2009). Aporrectodea longa measures 8 to 12 cm in length when stationary. The organism is elongated and slender, featuring a dark purplish head, whilst the posterior section of the body is typically significantly lighter with discernible pores (Perez-Losada et al., 2009).

Plate 1: Earthworm samples in petri dishes after been rinsed with deionized water

2.6 Analytical Examination of Soil Samples

The soil pH was assessed using the methodology established (Davey and Conyers, 1988). The method of APHA (1992) was employed to ascertain electrical conductivity. The soil's organic matter percentage was ascertained using the method outlined (Walkey and Black, 1934). The moisture content was assessed following the methodology outlined (Page et al., 1982). Available phosphorus and exchangeable cations were assessed using the approach outlined (Onyeonwu, 2000). The total soil nitrogen was quantified using the Kjeldahl method as per (Bremmer, 1965). The soil particle size distribution was ascertained utilising the enhanced Hydrometer Method outlined (Ibitoye, 2006). The total hydrocarbon content (THC) was measured using a HACH DR spectrophotometer in accordance with the APHA method (APHA, 1998).

2.7 Digestion of Soil and Earthworm Samples

Soil samples (0.5g) were subjected to treatment with strong nitric acid (10 cm^3, specific gravity 1.42). The mixture was refluxed in a Kjeldahl flask for 45 minutes and subsequently evaporated to dryness. Aqua regia (5 cm^3) was introduced and evaporated to near dryness, after which 10 cm^3 of distilled water was added, and the suspension was filtered through Whiteman no. 42 filter paper into a 25 ml volumetric flask. The filtrate was quantitatively transferred to a 50 cm^3 volumetric flask and diluted to the calibration mark (Agbeni, 1995).

Earthworm samples were subjected to ashing at 600°C for 24 hours, after which the ash from each sample would be weighed. Three (3) grammes of dried earthworm samples were measured, individually digested with 10 cm^3 of strong nitric acid (specific gravity 1.42), and dried in a Kjeldahl flask on a heating mantle. The digest was re-dissolved in 5 cm^3 of strong nitric acid, quantitatively transferred to a volumetric flask, and diluted to 50 cm^3 with distilled water (Awofolu, 2005). The sample was digested using the wet oxidation technique. A reagent blank was made using the same process, except the sample. To extract metals, 2 ml of sulphuric acid, 4 ml of perchloric acid, and 20 ml of nitric acid were combined with 0.2 g of the ashed sample. The mixture was heated on a mantle until it turned colorless. Subsequent to chilling, the liquid was diluted with distilled water to a final volume of 100 ml prior to analysis. After the digestion of earthworm tissues and soil samples, an atomic absorption spectrophotometer (AAS Bulk Scientific Model 210, VGP) was employed to ascertain the amounts of iron (Fe), chromium (Cr), cadmium (Cd), copper (Cu), zinc (Zn), manganese (Mn), and lead (Pb). All samples were analysed in duplicate to ensure consistency, accuracy, and precision.The concentration of heavy metals in the digested samples was determined using the method established by the Association of Analytical Chemists (AOAC, 2000).

2.8 Assessment of Data – Risk Evaluation

Quantitative indicators were employed to evaluate heavy metal contamination, facilitating straightforward comparison of the obtained values.

2.9 Enrichment Factor (EF)

Duce introduced the use of the enrichment factor (EF) to evaluate contamination levels and to analyse the distribution of anthropogenic components in soil from the research region (Duce, 1975). Iron (Fe) was selected as the normalising element for the determination of EF values, as it is a commonly utilised reference element (Nweke and Ukpai, 2016). The equation for the enrichment factor is presented below:

Enrichment Factor = (X/Fe) soil / (X/Fe) background (Levy et al., 1992)

The equation (X /Fe) soil denotes the heavy metal (X) to iron (Fe) ratio in soil samples from the research locations, while (X /Fe) background signifies the natural background value of the metal-Fe ratio. The normalising element, Fe, with a natural background concentration of 26.304 mg/kg was utilized in this study.

Sutherland identifies five groups based on the enrichment factor (EF) (Sutherland, 2000). When EF is less than 2, there is either a decline of mineral enrichment or no enrichment at all. 2≤EF<5 indicates moderate enrichment, 5≤EF<20 signifies significant enrichment, 20≤EF<40 denotes very high enrichment, and EF>40 represents extremely high enrichment.

2.10 Contamination Factor, Contamination Degree and Pollution Load Index

The severity of pollution and its variation were assessed using the pollution load index. The pollutant load index is determined as a concentration factor. The concentration factor is the ratio derived from dividing the concentration of each metal. The pollution load indices of the locati0n are determined as the n-th root of the product of the n-CFs derived for the investigated metals (Tomlinson et al., 1980; Nweke and Ukpai, 2016). The CF and PLI are articulated as follows:

CF = Cmetal concentration / Cbackground concentration of the same metal and

Hakanson delineates the interpretation of CF values as follows (Hakanson, 1980):

If CF < 1, it indicates minimal contamination. If 1 < CF < 3, it indicates the presence of moderate contamination. If 3 < CF < 6, considerable contamination is present; if CF > 6, very high contamination is present.

The pollution degree quantifies the overall level of contamination at a locati0n. The total of the contamination factors is represented by the equation:

$CD = \sum_{i=1}^{n} CF$

Hakanson classifies the degree of contamination as follows: CD < 6 indicates low contamination, 6 ≤ CD < 12 signifies moderate contamination, 12 ≤ CD < 24 denotes considerable contamination, and CD > 24 represents very high contamination (Hakanson, 1980). Nonetheless, the PLI may be articulated as

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

This empirical index offers a straightforward, comparable method for evaluating the extent of heavy metal pollution. If the Pollution Load Index (PLI) exceeds 1, it indicates the presence of pollution; conversely, if PLI is less than 1, it signifies the absence of metal contamination.

2.11 Geo-accumulation index (Igeo)

Ihenyen proposed that the geo-accumulation index (Igeo) is extensively utilised to assess the degree of heavy metal pollution in soil articulate it as (Ihenyen, 1998; Muller, 1969; Boszke et al., 2004):

Igeo = Log2 (C_n / 1.5 B_n) or $\quad I_{geo} = Log_2 \frac{C_n}{1.5 \times B_n}$

Where Cn represents the concentration of metals in soil and Bn denotes the geochemical background concentration of the metal (n) (Wedepohl, 1995). Factor 1.5 serves as the adjustment coefficient for lithospheric background matrix effects.

The geoaccumulation index comprises seven classes (0 to 6), representing different levels of enrichment relative to background values, from unpolluted to extremely polluted (Chakravarty and Patgiri, 2009). Class 0 (practically unpolluted): Igeo ≤ 0; Class 1 (unpolluted to moderately polluted): 0 < Igeo < 1; Class 2 (moderately polluted): 1 < Igeo < 2; Class 3 (moderately to heavily polluted): 2 < Igeo < 3; Class 4 (heavily polluted): 3 < Igeo < 4; Class 5 (heavily to extremely polluted): 4 < Igeo < 5; Class 6 (extremely polluted): Igeo ≥ 5.

2.12 Potential Ecological Risk Index (RERI)

The potential ecological risk index method proposed by Hakanson was employed to assess heavy metal contamination through sedimentological analysis, as illustrated in the equation below (Hakanson, 1980). This method was utilised to evaluate heavy metal pollution in soil and to correlate ecological and environmental impacts with their toxicological effects, specifically the toxic-response factor Tri for Fe, Cr, Cd, Cu, Zn, Mn, and Pb. The ecological risk factor (Er), quantitatively representing the potential ecological risk of a specific contaminant, is delineated by Hakanson in the equation below (Hakanson, 1980).

$Er = Tr \cdot Cf$

Tr represents the toxic-response factor for a certain substance, whereas Cf denotes the contamination factor. The subsequent phrases were employed to delineate the ecological risk factor. Eri <40 signifies minor ecological threat, 40≤Eri <80 denotes moderate risk, 80≤Eri <160 reflects considerable risk, 160≤Eri <320 represents severe risk, and Eri ≥320 indicates extremely high risk. Environmental hazard. The potential ecological risk index (RI) was defined similarly to the degree of pollution, as the aggregate of the risk components.

$RI = \Sigma\, Er$
$i=1$

Where Er i represents the singular index of ecological risk factors, and m denotes the quantity of heavy metals. The subsequent terminologies will be employed for the possible ecological risk index as delineated by Hakanson: RI<150 indicates low ecological risk; 150≤RI<300 signifies moderate ecological risk; and RI>600 denotes very high ecological risk. Refer to Table 1 (Hakanson, 1980).

Table 1: shows the adjusted grading standard of potential ecological risk 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	-	-

E^i_R is the potential ecological risk index of a single element; RI is a comprehensive potential ecological risk index. (Jiang et al., 2014).

2.13 Bioaccumulation Factor (BAF)

The Bioaccumulation Factor (BAF) quantifies metal accumulation in earthworms as the ratio of metal concentrations in earthworms to those in the soil substrate (Mountouris et al., 2002). When the metal content in earthworms exceeds that of the soil substrate, the bioaccumulation factor (BAF) surpasses 1, signifying bioaccumulation (Dedeke et al., 2015).

The BAF will be calculated via the formula:

BAF = Cbiota/Csubstrate

Cbiota and Csubstrate represent the total concentrations of heavy metals in earthworms and soil substrate, respectively.

2.14 Statistical Analysis

All statistical analyses were performed utilising Microsoft Excel and the Statistical Package for the Social Sciences (SPSS) version 20.00 software. Information All assessments for the enrichment factor, contamination factor (CF), degree of contamination, pollutant load index (PLI), and geo-accumulation index (Igeo)The Potential Ecological Risk Index (RERI) and Bioaccumulation Factor (BAF) were computed utilising Microsoft Excel (2016).

3. Result And Discussion

3.1 Concentration of Heavy Metals and Total Hydrocarbon Content in Soil

The concentrations of heavy metals in soil samples collected from five sites are summarised in Table 2. Heavy metals, including iron (Fe), cadmium (Cd), copper (Cu), zinc (Zn), manganese (Mn), and lead (Pb), exhibited a highly significant difference (p < 0.01), although chromium (Cr) shown no significant difference (p > 0.05) in comparison to the control environment. The effects of crude oil spillage on soil qualities include elevated petroleum hydrocarbon levels, acidic pH values, and heightened concentrations of heavy metals such as lead, zinc, cadmium, and chromium (UNEP, 2011; Ogboi, 2012). The divergence of these soil indicators from their provisional or guideline values may lead to detrimental environmental and health issues, as well as restrict the utilisation of the affected soil. (Nwankwo et al., 2015).

The concentration of heavy metals in the soils of coastal wetlands in Delta State is as follows: Fe > Zn > Mn > Pb > Cr > Cu > Cd. The mean concentration of Fe across the study locations, including Kwale, Emevor, Effurun, and Olomoro, was 299.51, 243.44, 196.40, and 131.62 mg/kg, respectively, while the control environment had a lower concentration of 26.30 mg/kg. Statistical analysis revealed a significantly significant difference (p<0.01) in comparison to the control setting. The elevated levels of Fe in the soil samples may originate from natural lithogenic and pedogenic processes, in addition to anthropogenic factors contributing to environmental contamination (Knezevic et al., 2009; Olukanni and Adeoye, 2012; Chinedu and Chukwuemeka, 2018). The mean concentrations of Cr at Kwale, Emevor, Effurun, and Olomoro were 7.52, 2.87, 4.35, and 9.25 mg/kg, respectively. Olomoro exhibited the highest concentrations, followed by Kwale, whereas the control environment recorded the lowest concentration at 0.95 mg/kg. a group researcher reported a higher concentration of chromium (7.663 mg/kg) in their study, which evaluated the variation of certain soil contamination indicators resulting from oil spillage in Akinima, Rivers State (Nwankwo et al., 2015). The value recorded in this study was below the maximum allowable limits (MAL) of 100 mg/kg in soil as established (EGASPIN, 2002). Chromium (Cr) toxicity in the environment is uncommon; however, it poses certain risks to human health due to its accumulation in skin, lungs, muscle fat, liver, dorsal spine, hair, nails, and placenta. This accumulation is linked to various health conditions (Reyes-Gutiérrez et al., 2007; Nwankwo et al., 2015).

Table 2: Heavy metal content of soil at different locations

Parameters	Site 1 Control (Sapele)	Site 2 Kwale	Site 3 Emevor	Site 4 Effurun (Warri)	Site 5 Olomoro	
	X̄±SD (Min-Max)	X̄±SD (Min-Max)	X̄±SD (Min-Max)	X̄±SD (Min-Max)	X̄±SD (Min-Max)	p-Value
Fe (mg/kg)	26.30 ^{c} ±14.14 (9.60-45.96)	299.51 ^{a} ±191.66 (111.80-552.87)	243.44 ^{a} ±107.17 (160.00-403.43)	196.40 ^{a} ±131.84 (100.00-385.45)	131.62 ^{b} ±20.57 (100.10-153.99)	p<0.01
Cr (mg/kg)	0.95±1.25 (0.03-2.32)	7.52±7.87 (0.07-16.21)	2.87±2.61 (0.05-5.20)	4.35±3.91 (0.07-7.41)	9.25±9.20 (0.09-18.72)	p>0.05
Cd (mg/kg)	0.00 ^{c} ±0.00 (0.00-0.00)	0.36 ^{a} ±0.05 (0.30-0.40)	0.36 ^{a} ±0.13 (0.20-0.50)	0.24 ^{a} ±0.05 (0.20-0.30)	0.14 ^{b} ±0.13 (0.00-0.30)	p<0.01

Table 2 (cont): Heavy metal content of soil at different locations

Cu (mg/kg)	0.19 [c] ±0.19 (0.01-0.40)	7.74 [a] ±3.03 (5.11-11.00)	2.29 [b] ±0.19 (2.13-2.50)	6.60 [a] ±2.33 (4.24-8.90)	2.30 [b] ±0.20 (2.10-2.50)	p<0.01
Zn (mg/kg)	3.70 [c] ±0.46 (3.20-4.10)	29.12 [b] ±8.00 (20.46-35.90)	7.68 [c] ±4.25 (5.20-15.20)	88.04 [a] ±21.06 (65.01-104.40)	14.07 [c] ±0.84 (12.60-14.60)	p<0.01
Mn (mg/kg)	4.23 [b] ±0.66 (3.26-5.10)	36.73 [a] ±36.47 (10.21-81.50)	13.50 [a] ±3.14 (10.24-16.50)	28.42 [a] ±3.67 (22.70-32.70)	14.54 [a] ±3.64 (8.03-16.30)	p<0.01
Pb (mg/kg)	0.00 [c] ±0.00 (0.00-0.00)	11.78 [a] ±3.41 (5.87-14.50)	7.22 [b] ±0.41 (6.50-7.50)	12.11 [a] ±2.03 (10.03-14.50)	12.31 [a] ±2.01 (10.50-14.50)	p<0.01
THC (mg/kg)	65.01 [c] ±61.72 (6.91-164.68)	4289.33 [b] ±4934.50 (493.50-9688.38)	63830.73 [a] ±86690.15 (228.90-158794.22)	1539.19 [b] ±1658.86 (87.85-3348.94)	1120.66 [b] ±1269.94 (42.30-2507.99)	p<0.05

x ± SD = average mean generated from values across the months per station, ± standard deviation; min–max = minimum and maximum values for each parameter per station; post hoc = values with different superscripts (a > b > c > d) are significantly different ($p < 0.05$ or 0.01) while values with same superscript are not significantly different ($p > 0.05$). $p < 0.05$ (significant difference) $p < 0.01$ (highly significant difference)

3.2 Assessment of Contamination in Wetland Soils

3.2.1 Enrichment Factor (EF)

This research identifies significant enrichment of Fe, Cr, and Mn, alongside very high levels of Cd, Cu, and Zn, and extremely high Pb contamination in the soils of the coastal wetlands of Delta State. The escalation of oil activities has led to significant environmental pollution due to oil spills, which include blowouts, leakages from tanks or tanker trucks, and the disposal of waste petroleum products into the environment. The findings suggest that both lithogenic and anthropogenic sources significantly contribute to the enrichment of Fe, Cr, Mn, Cd, Cu, Zn, and Pb, with urbanisation, industrialisation, oil spill pollution, and runoff identified as key factors in this study.

Table 3: Enrichment factor (EF) in the Study area

Enrichment factor across the Locations				
H/M	**Site 2 Kwale**	**Site 3 Emevor**	**Site 4 Effurun**	**Site 5 Olomoro**
Fe	11.39	9.25	7.47	5.00
Cr	7.89	3.01	4.56	9.69
Cd	36.00	36.00	24.00	14.00
Cu	40.72	12.06	34.72	12.11
Zn	7.87	2.08	23.80	3.80
Mn	8.68	3.19	6.71	3.44
Pb	117.82	72.20	121.12	123.08

H/M – Heavy Metal

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).

EF values below 1.5 indicate that heavy metals primarily originate from natural (crustal) sources, such as weathering processes, whereas EF values exceeding 1.5 imply a higher likelihood of anthropogenic sources (Zhang and Liu, 2002). In this study, EF values exceeded 1.5 at all sampled sites, indicating anthropogenic influx due to oil spill pollution. This unselective action may elevate the concentration of heavy metals in these soils. It is necessary to evaluate the concentration of heavy metals, specifically Cd, Cu, Zn, and Pb, in the surrounding vegetation at these sites.

3.2.2 Geoaccumulation Index (I-geo)

In table 4, the soil sample from Olomoro exhibited moderate pollution levels for Fe (1<I-geo<2), while the soil samples obtained from Kwale, Emevor and Effurun were moderately to heavily polluted (2<I-geo <3). In relation to Cr, the soil samples obtained from Emevor and Effurun were moderately polluted (1<I-geo<2), while the soil samples obtained from Kwale and Olomoro were moderately to heavily polluted (2<I-geo<3). In relation to Cd, the soil samples obtained from Olomoro was heavily polluted (3< I-geo<4), while the soil samples obtained from Kwale, Emevor and Effurun were heavily to extremely polluted (4<I-geo<5). In relation to Cu, the soil samples obtained from Emevor and Olomoro were heavily polluted (3<I-geo<4), while the soil samples obtained from Kwale and Effurun were heavily to extremely polluted (4<I-geo<5). In relation to Zn, the soil samples obtained from Emevor was unpolluted to moderately polluted (0<I-geo<1), Olomoro was moderately polluted (1<I-geo<2), Kwale was moderately to heavily polluted (2<I-geo<3) while Effurun was heavily polluted (3<I-geo<4). In relation to Mn, the soil samples obtained from Emevor and Olomoro were moderately polluted (1<I-geo<2) while Kwale and Effurun were moderately to heavily polluted (2<I-geo<3). In relation to Pb, the soil samples obtained from all the study areas were extremely polluted (5>I-geo). The findings from this research reveals that Fe was moderately polluted, Cr was moderately to heavily polluted in Kwale and Olomoro, Cd and Cu were heavily to extremely polluted in Kwale, Emevor and Effurun while Pb exhibits an extremely pollution in soils of the study area. A group researcher showed that the geo accumulation index of five different communities in Ogoni land exhibited a very strongly pollution (Igeo > 5) degree with heavy metals in selected communities (Ogwugwa et al., 2018).

3.2.3 Concentration Factor (CF), Contamination Degree (CD) and Pollution Load Index

This research indicates significant contamination levels of Fe, Cr, Zn, and Mn in the soils of Kwale, Effurun, and Olomoro, while Cd, Cu, and Pb also show considerable contamination in these areas. A group researcher reported comparable findings and attributed the contamination levels in soils to anthropogenic sources that typically enter the soil through human activities (Sripathy et al., 2015). Removing heavy metals from soils is challenging due to their irreversible immobilisation within various soil components (Sripathy et al., 2015). The contamination degree in the soils of coastal wetlands in Delta State, as interpreted using Hakanson's framework, reveals a very high degree of contamination (CD ≥ 24) across all communities, indicating significant contamination levels in table 5 (Hakanson's, 1980). A group researcher reported significant levels of contamination, including elevated concentrations of heavy metals, in specific communities within Ogoni land (Ogwugwa et al., 2018).

Table 4: I-geo of heavy metal contamination in the study areas

Geoaccumulation Index (I*geo*)				
H/M	**Site 2 Kwale**	**Site 3 Emevor**	**Site 4 Effurun**	**Site 5 Olomoro**
Fe	2.92	2.63	2.32	1.74
Cr	2.39	1.00	1.60	2.69
Cd	4.58	4.58	4.00	3.22
Cu	4.76	3.01	4.53	3.01
Zn	2.39	0.47	3.99	1.34
Mn	2.53	1.09	2.16	1.20
Pb	6.30	5.59	6.34	6.36

Table 5: The concentration factor, contamination degree and the pollution load index of the Study area

Concentration Factor									
Locations	Fe	Cr	Cd	Cu	Zn	Mn	Pb	**CD**	**Pollution Load Index**
Kwale	11.39	7.89	36.00	40.72	7.87	8.68	117.82	230.36	19.47
Emevor	9.25	3.01	36.00	12.06	2.08	3.19	72.20	137.79	9.25
Effurun	7.47	4.56	24.00	34.72	23.80	6.71	121.12	222.37	17.72
Olomoro	5.00	9.69	14.00	12.11	3.80	3.44	123.08	171.12	10.41

If CF < 1: it means that low contamination exists; If 1 < CF > 3: it means that moderate contamination exists; If 3 < CF < 6: it means that considerable contamination exists; If CF > 6: it means that very high contamination exists. CD < 6 = low degree of contamination; 6 ≤ CD < 12 = moderate degree of contamination; 12 ≤ CD < 24 = considerable degree of contamination; CD ≥ 24 = very high degree of contamination. When PLI > 1, it means that a pollution exists; If PLI < 1, there is no metal pollution (Hakanson, 1980).

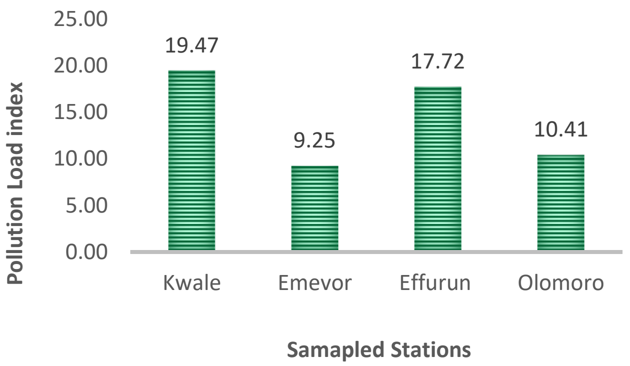

Figure 2: Shows the pollution load index of the study area

According to a study, the Pollution Load Index (PLI) values for soils from selected communities demonstrate that all sampled areas are contaminated (PLI > 1) by the analysed heavy metals, as illustrated in Figure 2 (Tomlinson et al., 1980). The sampling demonstrates that oil spill pollution has substantially contributed to environmental contamination by heavy metals, with soil variations in this region dependent on land use type in comparison to the control environment. A group researcher demonstrated that the pollution load index derived from the five communities indicates a decline in soil quality, as the PLI exceeds 1 (Ogwugwa et al., 2018). The primary occupations of residents in Sapele, Kwale, Emevor, Effurun, and Olomoro are agriculture and fishing. The heavy metal contamination of wetland ecosystems identified in this study presents a significant health risk and economic challenge for the residents of the coastal wetlands in Delta State.

3.2.4 Potential Ecological Risk Index (PERI)

The potential ecological risk indices of the soils in the study areas are presented in Table 6. The analysed metals present potential ecological risks ranked as follows: EiRCd > EiRPb > EiRCu > EiRZn > EiRCr > EiRMn. All sampling sites exhibited a significant potential ecological risk associated with Cd, Pb, Cu, Zn, Cr, and Mn. Cadmium was the primary factor contributing to the potential ecological risk, as all sampling points exhibited significant ecological risk to the environment. Consequently, Cd emerged as the critical element warranting further investigation, even at low concentrations.

Table 6: Potential Ecological Risk Index (PERI)

		Zn	**Cu**	**Cr**	**Mn**	**Pb**	**Cd**	**RI**
T^i_R		1.00	5.00	2.00	1.00	5.00	30.00	-
Site 2 (Kwale)	E^i_R	7.87	203.58	15.77	8.68	589.10	1080.00	1905.00
Site 3 (Emevor)		2.08	60.32	6.01	3.19	361.00	1080.00	1512.59
Site 4 (Effurun)		23.80	173.58	9.12	6.71	605.60	720.00	1538.80
Site 5 (Olomoro)		12.11	70.00	10.01	3.80	17.18	290.82	403.90

Eri <40, low potential ecological risk; 40≤Eri <80, moderate potential ecological risk; 80≤Eri <160, considerable potential ecological risk; 160≤Eri <320, high potential ecological risk; and Eri ≥320, very high ecological risk. RI<150, low ecological risk; 150≤RI<300, moderate ecological risk; and RI>600, very high ecological risk. (Hakanson, 1980).

The scope RI indicates that the soil's potential ecological risk levels in the sampling areas were classified as levels B and C, reflecting moderate and very strong degrees of ecological damage, respectively. According to a study, the risk level across the soils of the study area in the coastal wetlands of Delta State is classified as extremely strong, designated as level D (Jiang et al., 2014). Hakanson's framework for assessing ecological risk reveals that Kwale, Emevor, and Effurun exhibit a very high ecological risk (RI>600), whereas Olomoro presents a considerable ecological risk (300 < RI ≤ 600) (Hakanson's, 1980). It is essential to implement suitable engineering and ecological measures to regulate soil heavy metal concentrations, alongside conducting ecological restoration in contaminated areas.

3.2.5 Average Bioaccumulation of Heavy Metals in Earthworm Samples

Table 7 presents the mean bioaccumulation of Fe in Kwale, Emevor, Effurun, and Olomoro, recorded at 30.00, 14.35, 15.69, and 11.50 (mg/kg), respectively. Following the same methodology as applied to Fe within the study area, the mean bioaccumulation values for Cr, Cd, Cu, Zn, Mg, and Pb are recorded as 2.11, 2.06, 4.17, and 3.78 (mg/kg), 0.23, 0.30, 0.20, and 0.11 (mg/kg), 4.16, 5.06, 5.81, and 5.18 (mg/kg), 10.63, 10.56, 15.32, and 11.23 (mg/kg), 5.61, 6.36, 6.27, and 6.72 (mg/kg), and 3.72, 2.35, 2.6, and 2.87 (mg/kg), respectively. The average bioaccumulation of Fe, Cr, Cd, Cu, Zn, Mn, and Pb in earthworm samples collected from the control environment was 8.30, 0.03, 0.00, 0.07, 0.70, 0.09, and 0.00 (mg/kg), respectively.

Table 7: Mean Bioaccumulation of heavy metals in earthworm

Parameters	Site 1 Control (Sapele)	Site 2 Kwale	Site 3 Emevor	Site 4 Effurun	Site 5 Olomoro
Fe (mg/kg)	8.30	30.00	14.35	15.69	11.50
Cr (mg/kg)	0.03	2.11	2.06	4.17	3.78
Cd (mg/kg)	0.00	0.23	0.30	0.20	0.11
Cu (mg/kg)	0.07	4.16	5.06	5.81	5.18
Zn (mg/kg)	0.70	10.63	10.56	15.32	11.23
Mn (mg/kg)	0.09	5.61	6.36	6.27	6.72
Pb (mg/kg)	0.00	3.72	2.35	2.26	2.87

3.2.6 Bioaccumulation Factor of Heavy Metals in Earthworm

Table 8 presents a summary of the bioaccumulation factor (BAF) for heavy metals in earthworm samples collected from soils in selected coastal wetlands of Delta State. The mean bioaccumulation of Fe, Cr, Cd, Cu, Zn, Mn, and Pb concentrations was higher in earthworms from the study area compared to those from the control environment. The bioaccumulation factors (BAFs) for all tested metals were below unity, with the exceptions of chromium at Kwale, Emevor, Effurun, and Olomoro; cadmium at Emevor; copper at the control environment, Emevor, Effurun, and Olomoro; and zinc at Emevor, which exhibited BAF values greater than one (Table 8). This study's results indicate that earthworm samples collected from Kwale, Emevor, Effurun, and Olomoro exhibited bioaccumulation of Cr, Cd, Cu, and Zn, as evidenced by BAF values greater than 1 for these metals. The findings of this study indicated that earthworm samples exhibited bioaccumulation of copper, as evidenced by BAF values exceeding 1, which signifies the accumulation of the metal in the environment under control conditions.

Table 8: Bioaccumulation factor (BAF) of heavy metals in earthworm

Parameters	Site 1 Control (Sapele)	Site 2 Kwale	Site 3 Emevor	Site 4 Effurun	Site 5 Olomoro
Fe	0.28	0.16	0.09	0.16	0.08
Cr	0.60	30.14	41.20	59.57	42.00
Cd	0.00	0.58	1.00	0.67	0.55
Cu	1.00	0.81	2.38	1.37	2.47
Zn	0.22	0.52	1.65	0.24	0.79
Mn	0.02	0.55	0.62	0.22	0.42
Pb	0.00	0.30	0.32	0.23	0.26

A. longa exhibited higher metal concentrations due to individual variations in their habits (Dedeke et al., 2015). This observation aligns with the findings of which indicated that the accumulation of heavy metals in earthworms differs among species (Hobbelen et al., 2006). The concentrations of heavy metals in earthworms were directly correlated with their concentrations in the corresponding soil. In this study, A. longa exhibited higher concentrations of heavy metals at the study locations compared to the control environment, with the exception of copper, which was elevated in the control environment. This aligns with the findings of who indicated that metal concentrations in earthworm tissue correlate directly with their levels in the surrounding soil (Gupta et al., 2005). Similar bioaccumulation patterns were noted by as referenced in (Suthar et al., 2008; Dedeke et al., 2015). This study demonstrated a correlation between the accumulation of heavy metals in soil samples and the metal concentrations in earthworm tissues. A. longa exhibits contamination with heavy metals, a condition likely applicable to other fauna in the same environment (Eliagwu et al., 2007). This study demonstrated that earthworms accumulated heavy metals from the soils of the study areas, indicating their potential use as bio-indicators for heavy metal pollution. Immediate measures are necessary to reduce activities that lead to the accumulation of heavy metals in the environment. Ongoing assessment of contamination levels is essential to evaluate the effects of heavy metals on terrestrial ecosystems.

4. Conclusion

This study demonstrated the significant environmental impact of oil exploration activities on the soils of host communities in Delta State. High concentrations of heavy metals, including iron (Fe), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn), were identified, prompting significant concerns regarding their effects on environmental and human health. These contaminants degrade soil quality and accumulate in native earthworms, indicating broader ecological risks. The recorded pollution levels underscore the impacts of oil spills, industrial emissions, and inadequate waste management practices in the region. Regulatory agencies should enhance enforcement measures to mitigate additional contamination and uphold accountability for oil-related pollution. Community-oriented solutions, such as increasing awareness of sustainable practices and applying soil remediation techniques, are crucial for reversing environmental damage. Bioremediation and phytoremediation are effective techniques for restoring soil health and safeguarding the livelihoods of local communities. These measures can safeguard both the environment and the health of individuals residing in impacted communities. This study reinforces the necessity for implementing the recommendations outlined in the United Nations Environment Program (2011) environmental assessment report and the 2030 Agenda for Sustainable Development Goals (SDGs) regarding the cleanup of oil spills in the Niger Delta region, as the survival of human lives and other living entities in this area is at risk.

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