Malaysian Journal Of Civil Engineering

Full Paper

ANALYSIS OF HEAVY METAL CONTAMINANT BY CRUDE OIL SPILLAGE IN IBELEBIRI OF OGBIA, BAYELSA STATE, NIGERIA.

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Article history
Received
05 November 2024
Received in revised form
20 February 2025
Accepted
24 February 2025

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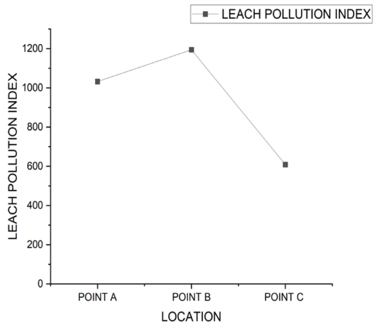
Graphical abstract



Abstract

Crude oil spillage in the Niger Delta region has led to significant environmental degradation and health concerns. This study investigated the levels of heavy metal contaminants (lead, cadmium, chromium, Iron, and Cobalt) in top-soil, sub-soil, and groundwater at Ibelebiri, Ogbia, Bayelsa State, where there are indices of crude oil spillage. Samples were collected from three locations A, B, and C with C as the control. Collected samples from these locations at the topsoil, sub-soil, and water were analyzed using Atomic Absorption Spectroscopy (AAS) and results were then compared using WHO standards. To further verify the contaminate level and pathway into groundwater, pollution indices such as the metal contaminate index (MI), heavy metal pollution index (HPI), and leach pollution index (LPI) were used. The results showed elevated concentrations of heavy metals, exceeding WHO guidelines. Lead (Pb) and cadmium (Cd) levels ranged from 0.24 mg/L to 0.01 mg/L, across all locations and sampled media. Chromium (Cr) and Cobalt (Co) levels ranged from 1.5 mg/L to 0.01 mg/L, across all locations and sampled media. Iron (Fe) consistently shows elevated concentrations across all locations, particularly in Location B, which reaches 69.52 mg/L. Calculated values of MI and HPI revealed that water and soil samples are in pure conditions for all locations since MI values < 1, and HPI <100 at 0.077-0.027 and 0.154-5.27, suggesting minimal metal contaminations. The LPI is seen to be higher than the leach standard with higher values ranging from 1194.65-1032.245, indicating severe contamination in both areas. In contrast, the control point shows a much lower LPI value 608.665 when compared with the standard. The findings indicate the potential for serious health risks and environmental degradation in the contaminated areas in Ibelebiri. It also emphasizes the need for monitoring and remediation efforts to prevent further contamination.

Keywords: heavy metal contaminants, groundwater, top-soil, sub-soil, crude oil spillage

1.0 INTRODUCTION

Due to oil production and exploration activities that cause extensive environmental degradation, crude oil spills have become a recurrent environmental problem in the Nigerian Niger Delta, especially in Bayelsa State (Osuji *et al*., 2015; Nwankwoala *et al*., 2017; Doe and Amadi, 2019).

According to the Nigerian Department of Petroleum Resources (DPR), over 3,000 crude oil leaks occurred in the Niger Delta region between 2015 and 2020, this, alarming rate of frequent crude oil spills poses serious harm to the environment (DPR, 2020). Ibelebiri, a town in the Ogbia Local Government Area of the Niger Delta, has frequently seen crude oil spills, which have seriously degraded the environment and raised health issues. Groundwater, a vital source of drinking water for the community, is susceptible to contamination from crude oil spills, posing serious risks to human health and the ecosystem (WHO, 2018). Similarly, a study by (Osuji *et al*.,2015) found that crude oil spills in the Niger Delta region have contaminated groundwater sources, posing health risks to nearby communities (National Research Council, 2015). The groundwater sources serve as the primary water source for; drinking, agriculture, industry, and ecosystems, thus supporting human health and economic development (National Research Council, 2015, Ijaola and Sakwe, 2024). However, the quality of groundwater is increasingly compromised by contaminants that stem from anthropogenic activities on surface water and soil (Ogunlowo, 2024), weighty metals which pose significant risks to both human health and the environment also confirmed by the Agency for Toxic Substances and Disease Registry, 2019. Among the pronounced sources of groundwater contamination, Crude oil spills are a known source of heavy metals introduction into the aquifer (Amadi and Smith, 2017) which alters the quality of the water, as the development of crude oil exploration increases the tendency of oil spill incident which released heavy metals contamination (Ahmad Dasuki *et al,* 2015). Moreover, Sajad *et al*., (1998) stated that the quality of groundwater is a function of natural processes as well as anthropogenic activities and that the type, extent, and duration of anthropogenic activities on groundwater quality are controlled by the geochemical, and physical processes and the hydrological condition present in the hydrological setting of that area (Ijaola and Sakwe, 2024).

Metals are naturally occurring environmental elements that can pose a risk to humans and animals. Heavy metal contamination is one of the primary causes of declining water quality, which has a significant influence on seafood variety. Heavy metal ingestion from contaminated locations offers a higher health risk for humans (Nur Afifah *et al,* 2017). According to the National Research Council (2015), heavy metals are defined as metallic elements with a density of at least five times that of water and exhibit various toxic effects in humans, correlated with their mass. Increasing ecological and global health concerns have arisen regarding the contamination of the environment by heavy metals such as lead, cadmium, chromium, iron, cobalt, mercury, and copper, to name a few can enter the human body through inhalation and ingestion, leading to harmful accumulation in body tissues. Heavy metals are toxic and carcinogenic, leading to severe health issues and significant risks such as cancer, reproductive disorders, and developmental problems (World Health Organization, 2018).

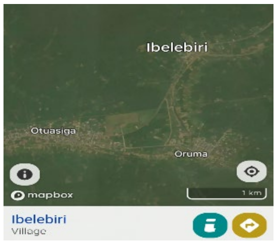
Crude oil, which contains these metals, exacerbates the contamination of both soil and water sources, especially in oil-producing regions like the Niger Delta. Oyewole, 2022, further affirms that crude oil spills introduce heavy metals into groundwater and terrestrial ecosystems. Crude oil, comprising a complex mixture of hydrocarbon and non-hydrocarbon compounds (including heavy metals), can spill into the environment due to extraction, refining, transportation, storage, and various accidents.

Despite previous research on heavy metal contamination in surface and groundwater, data on groundwater contamination in many Bayelsa communities remain scarce, complicating effective management and risk assessment. This study aims to assess the migration and concentration of heavy metals in groundwater over time, providing valuable insights for long-term monitoring and remediation efforts; as the pathways, presence, and concentration of leached heavy metals like lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), and cobalt (Co) from the oil spills into groundwater. The findings also assess their environmental and health impacts, through identifying and quantifying heavy metals (contaminants from oil spills) along leach pathways (topsoil, subsoil, and aquifer); evaluating the environmental and health risks associated with heavy metal-contaminated groundwater by comparing it to WHO standards, as well as FEPA and USEPA standards, with view of polluted sites and a control site.

2.0 METHODOLOGY

2.1 Description of Collection Site

Ibelebiri is a village in Ogbia Local Government Area, Bayelsa State. Ibelebiri is located at a latitude of 4°38’59.99"N and a longitude of 6°15'60.00"E near the Uruama and Oruma villages, in Bayelsa State (Figure 1), where there is heavy crude oil exploration which is known for its significant history of crude oil spills and groundwater contamination. The community contains fishermen who are mostly indigenes and civil servants, traders, students, and artisans by profession who are mostly non-indigenes. The Spill site is located across the community river between latitude 4°55’51.457"N and longitude 6°24’54.80352" (Figure 2); where samples were collected, the site was selected based on proximity to the crude oil spill source and groundwater flow direction (Figure 3) The area is known for heavy oil deposits and has experienced environmental degradation, especially through oil spills from pipelines, oil theft, and operational leaks.



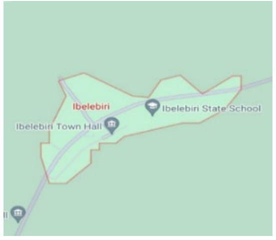


Figure 1 GPS Coordinate of Ibelebiri**. Figure 2** Locations of Sampling Site.

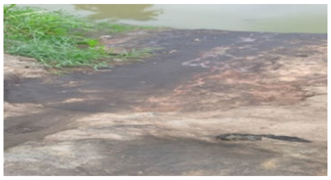


Figure 3 Crude Oil Spill Site.

All the figures are part of researched conducted. Hence source from the present work 2024.

2.2 Sampling

Soil samples were collected from three locations A, B, and, C within the research area. Using a hand trowel, auger, sample bottles, polythene bags, and coolers, samples were obtained from these selected sites to investigate the impact of contamination as shown in Table 1. The control, soil samples were taken from location C within the community's residential area at latitude and longitude as indicated in Table 1. To understand the vertical distribution of contaminants, soil samples were collected at three different depths at each location, namely; topsoil and samples were collected using a hand trowel.0.3 m depth; Subsoil samples were collected at the intermediate depth of 0.9m: while aquifer samples were taken from 1.5m depth with the help of an auger. This multi-depth sampling approach ensures a comprehensive analysis of contaminant distribution across the vertical profile of the soil.

These are then represented as L1S1 – Location A sample 1, L1S2 – Location A sample 2, L1S3 - Location A sample 3, L2S1 – Location B sample 1, L2S2 – Location B sample 2, L2S3- Location B sample 3, L3S1 – Location C sample 1, L3S2 – Location C sample 2, L3S3- Location C sample 3.

Table 1 Samples Location using GPS

S/N	Sampling Site	Type of system	Latitude (N	Longitude
	Location A	Soil and water	4°55’51.457"N	6°24’54.80352"E
	Location B	Soil and water	4°56’19.97556"N	6°25’49.74924"E
	Location C	Soil and water	4°56’18.0852"N	6°25’47.56836"E

2.3 Laboratory Analysis

Heavy metal analysis was carried out using hydrochloric acid digestion and an Atomic Absorption Spectrometer (AAS), metal ion concentration was determined (model Philips PU 9100) with a hollow cathode lamp and the Fuel flame (air acetylene) the chromium, cobalt, cadmium, iron, and lead at the parameters analyzed.

For soil samples, 1-5g of air-dry soil (0.15 mm) was weighed into a 300 ml-calibrated digestion tube. 3ml of sample was added to concentrated HNO_3 (in the fume hood) and swirled carefully, and then tubes were placed in the rack. After that, the tube rack was placed in the block digester, and then a glass funnel was inserted at the neck of the tubes. Slowly, the temperature was increased to about 145^{O}C for 1 hour, and then 4 ml of concentrated $HClO_4$ was added and heated to 240^{O}C for another hour. The tubes were lifted out of the block digester and carefully placed on a rack holder to cool at room temperature. The solutions were then filtered through Whatman No. 42 filter paper and brought into a 50ml tube. Each batch contained at least one reagent blank (no soil). After this, heavy metals such as Pb, Cd, Cr, Fe, and Co were determined using an Atomic Absorption Spectrophotometer (AAS).

2.4 Data Processing

2.4.1 Metal Contaminate Index (MI)

Metal contaminate Index is a numerical value indicating the level of metal contamination in water bodies, it is a useful tool for assessing water quality and environmental health. It is expressed mathematically as:

$$\sum_{i=1}^{n}\frac{C_i}{M_AC_i} \rightarrow \equiv \sum_{i=1}^{n}\frac{C_i}{S_i}$$

Where:

C_i is the concentration (mean values of the ith heavy metals in the samples analyzed.

M_AC_i or S_i is the maximum allowed concentration of the ith heavy metals

2.4.2 Heavy Metal Pollution Index (HPI)

The Heavy Metal Pollution Index is a statistical tool used to assess the overall quality of groundwater and surface water concerning heavy metal contamination. It provides a collective rating of the impact of individual heavy metals on water quality, helping to identify areas with severe pollution. HPI is calculated by quantifying the concentration of heavy metal in water samples and then compared the results with standard or threshold value, such as those set by WHO or EPA (Mohan *et al.,* 1996; Prasad and Kumari, 2008; Prasad and Mondal, 2008).

It is expressed mathematically as;

$$HPI = \frac{[\sum\frac{W_i}{Q_i}]}{[\sum W_i]}$$

$where:$

$Wi \ = \ Unit\ Weight$

$Which\ is\ interpreted\ as\ W_i = \frac{K}{S_i}$

$K = 1\ Constant$

$Si = Standard\ permissible\ limit\ values\ which\ is\ the\ highest\ recommended\ standard\ by\ WHO$

$And\ Q = \ Sub - Index\ Value$

$Which\ is\ interpreted\ as\ Q = \frac{[/Mi(-)Ii/]}{[Si-Ii]} \times 100$

Ii = the ideal value permissible limit values which is the lowest recommended

$Mi \ = \ Monitored\ values\ of\ the\ heavy\ metals$

2.4.3 Leach Pollution Index (LPI)

The LPI measures the possibility of leachate contamination in a specific area. It is a single number ranging from 5 to 100 (Simeon and Ayotamuno,2019) that provides critical insight into the contamination potential of the soil to leach hazardous substances into groundwater (Churchill E. and Ogunlowo 2022). It is an increasing scale index; the higher value means a poor environmental condition, with a standard LPI value of 7.37 (Kumar and Alappat, 2003).

To calculate the LPI (leach pollution index) using WHO's Standard values for groundwater quality.

$$\text{LPI} = \frac{\sum(wi \times pi)}{\sum wi}$$

Where:

Wi *is the weight assigned to the parameter*

Pi *is the sub − index for the parameter, calculated as*:

$$\text{Pi} = \frac{observed\ value}{standard\ Value} \times 100$$

The Wi *should be Sum to* 1

3.0 RESULTS AND DISCUSSION

3.1 Comparative Quantitative Analysis Of Heavy Metals Pollutants With The Soil Horizon Of Selected Polluted Site And Control

Figure 4, presents the concentration of heavy metals across different locations of soil layers, including top-soil, sub-soil, and aquifers. Lead (Pb) concentrations in most areas are below the detection limit, except for locations in L2, where values of 0.087 mg/l and 0.075 mg/l are observed, indicating some degree of contamination in the subsoil and aquifer.

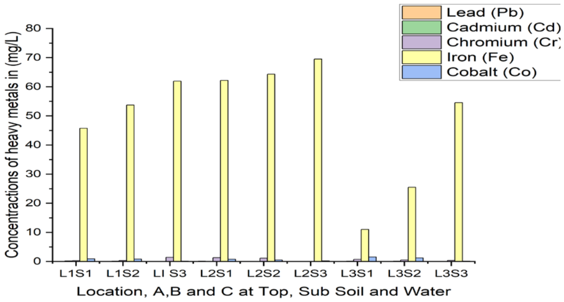


Figure 4 Comparison of concentrations for sampled heavy metal at each location

Figure 4, presents the concentration of heavy metals across different locations of soil layers, including top-soil, sub-soil, and aquifers. Lead (Pb) concentrations in most areas are below the detection limit, except for locations in L2, where values of 0.087 mg/l and 0.075 mg/l are observed, indicating some degree of contamination in the subsoil and aquifer. Cadmium (Cd) shows a more varied distribution, with higher concentrations observed in L1 (0.214 mg/g) at the topsoil, indicating contamination from surface exposure, and decreasing concentrations with depth. Chromium (Cr) exhibits significant variability, particularly in Location 1, where it reaches a peak of 1.450 mg/L, indicating substantial contamination at this location, likely due to the spill. Iron (Fe) consistently shows elevated concentrations across all locations, particularly in Location 2, where it reaches 69.52 mg/L, signifying widespread pollution. Cobalt (Co) concentrations are also elevated, peaking at 1.536 mg/g in L3, indicating its mobility and persistence in the environment.

3.2 Comparative analysis of the heavy metal concentration of polluted site and control with Standards

The comparison of heavy metal concentrations between the two polluted areas (Locations A and B) and the control point (Location C) was further explained in Table 2 and Figure (5-6). Table 2 also revealed the comparison of heavy metals within the polluted locations, control locations, and standards.

Table 2 Comparison of heavy metals concentration within the Polluted locations, Control locations and Standards

Locatns/ Pollutants	L1S1	L1S2	LI S3	L2S1	L2S2	L2S3	L3S1	L3S2	L3S3	WHO	EPA
Lead (Pb)	<0.001	<0.001	<0.001	0.087	0.075	0.059	<0.001	<0.001	<0.001	0.01	0.015
Cadmium (Cd)	0.214	0.124	0.076	0.053	0.023	<0.001	0.106	0.100	0.055	0.003	0.005
Chromium (Cr)	0.281	0.323	1.450	1.338	1.123	<0.001	0.716	0.528	0.387	0.05	NA
Iron (Fe)	45.78	53.72	61.89	62.18	64.32	69.52	11.02	25.48	54.55	NA	0.3
Cobalt (Co)	0.911	0.8.21	0.097	0.784	0.523	0.232	1.536	1.235	0.117	0.00	0.00

N/B: All pollutant Parameter are in mg/L, NA= Not Applicable.

Location A marked increase in heavy metal levels is observed in the polluted areas. lead (Pb) levels, though low in the control point (0.001 mg/L), show a drastic increase in Location B (0.075 mg/L), reflecting a high degree of contamination, likely due to the crude oil spill. Similarly, cadmium (Cd) and chromium (Cr) levels are significantly elevated in the polluted areas compared to the control point. iron (Fe) concentrations are notably high in both polluted areas, exceeding 60 mg/L in Location B, which is more than twice the value found at the control point (11.02 mg/L). This indicates severe contamination in the affected regions. cobalt (Co) concentrations, while higher in the control point at top-soil (1.536mg/L), remain elevated across the polluted locations, with slight variations. This suggests that although cobalt may naturally occur in the region, its levels are aggravated by the spill.

The comparison of heavy metal concentrations with WHO and EPA standards reveal that most pollutant levels exceed the permissible limits as shown in Table 3. For Lead (Pb), the mean concentrations at Location B (0.074 mg/L) are significantly higher than the WHO and EPA standard of 0.01 and 0.015 mg/L, indicating unsafe levels for human and environmental health. cadmium (Cd), which is highly toxic even at low concentrations, exceeds the WHO standard of 0.003mg/L at all points, particularly in Location A (0.138 mg/L), where it is more than 13 times the recommended limit. chromium (Cr) and iron (Fe) concentrations in all polluted areas are far above the WHO standards of 0.05 mg/L respectively. chromium levels reach as high as 0.821 mg/g in Location B, while iron levels are also high, with the highest value recorded at 69.52 mg/L in Location B. These findings indicate the potential of serious health risks and environmental degradation in the contaminated areas in Ibelebiri.

3.3 Metal Contaminates Index

Metal contaminates index is widely used in confirmations of heavy metal within the environmental media, according to Caeiro *et al.,* 2005 it can be categorized or classified as:

Table 4 Classification of Metal Contaminated Index in environmental medial

Class	Property/characterization	Calculated MI Values
I	Very Pure	< 0.3
Ii	Pure	0.3-1
Iii	Slightly Affected	1-2
Iv	Moderately Affected	2-4
V	Strongly Affected	4-6
Vi	Seriously Affected	>6

Source: Caeiro et al 2005.

Table 4 presents the calculated Metal Contaminate Index (MI) values for three locations (A, B, and C) across three sampling points (Top-Soil, Sub-Soil, and Water). The MI classification indicates the level of metal contamination in each sample. All samples analyzed indicate a very pure condition for all locations since MI values < 1, suggesting minimal metal contamination. The analysis further implies that the consumption of water in these locations appears to be safe as well as the soil environment since low metal contamination levels are suggested. In contrast, Singh *et al*. (2017) findings in the evaluation of soil contamination within industrial areas, reported that MI values range from 0.23 to 1.42 implying that soil in those areas is pure and slightly affected. Zhang *et al*. (2019) came out with a similar report of MI values ranging from 0.12 to 2.56, but similar to this study, MacDonald *et al*. (2014) have MI value ranging from 0.05-0.35 when applied to river water.

Table 4 Calculated and Classification of Metal Contaminate Index within each sampled location

Locations	MI	Class	Properties
Location A			
Sample 1, Top-Soil	0.077969	1	very pure
Sample 2 Sub-Soil	0.048968	1	very pure
Sample 3 Water	0.055671	1	very pure
Location B			
Sample Top-Soil	0.054370267	1	very pure
Sample 2 Sub-soil	0.038913067	1	very pure
Sample 3 Water	0.007643733	1	very pure
Location C			
Sample 1 Top-Soil	0.049973733	1	very pure
Sample 2 Sub-Soil	0.044502933	1	very pure
Sample 3 Water	0.027264333	1	very pure

3.4 Heavy Metal Pollution Index (HPI)

Table 5 presents the calculated Total Heavy Metal Pollutant Index (HPI) values for three locations (A, B, and C) across three sampling points (Top-Soil, Sub-Soil, and Water).

Table 5 Calculation of the Total Heavy Metal Pollutant Index within each sampled location

Locations	HPI	Class	Interpretations
Location A			
Sample 1, Top-Soil	5.271866	<100	Safe
Sample 2 Sub-Soil	3.069786	<100	Safe
Sample 3 Water	1.992805	<100	Safe
Location B			
Sample Top-Soil	1.60892	<100	Safe
Sample 2 Sub-soil	0.82822	<100	Safe
Sample 3 Water	0.15474	<100	Safe
Location C			
Sample 1 Top-Soil	2.66330751	<100	Safe
Sample 2 Sub-Soil	2.4996664	<100	Safe
Sample 3 Water	1.38433149	<100	Safe

The HPI classification, in Table 5 indicates the level of heavy metal pollution. The findings presented HPI values < 100, for all sampled locations at a range of 0.15-5.27 indicating a safe condition compared to Adeleke, (2020), where HPI values range from 12.45 to 45.67, indicating safe to moderate pollution levels. From Figure 5, the top-soil samples have higher HPI values than the Sub-Soil and Water samples. Similar to what is obtainable in Table 5, Location A has the highest HPI values, while Location B has the lowest. Liu et al. (2019) evaluated HPI in soil and water around mining areas in China, finding values between 20.5 and 65.2 in contrast to this study.

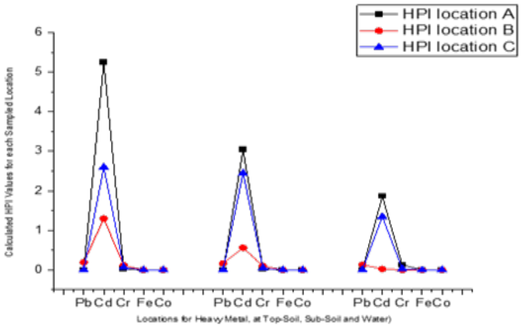


Figure 5 Comparison of Calculated Values of HIP for sampled heavy metal at each location

3.5 Leach Pollution Index (LPI)

Figure 6 (a & b) shows representative calculated values of the Leach Pollution Index (LPI) which provides a quantitative assessment of the pollution levels at each location.

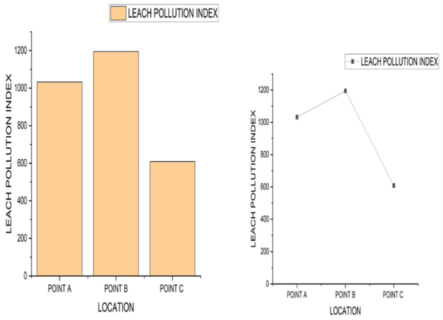


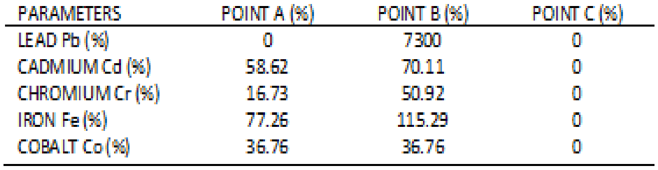
Figure 6 (a & b) Comparison of Calculated Values of LPI for sampled heavy metal at each location

The highest LPI is observed in Location B (1194.65), followed by Location A (1032.245), indicating severe contamination in both areas. In contrast, the control point shows a much lower LPI value (608.665), emphasizing the significant impact of crude oil spills in the polluted zones. This implies that pollutants, especially those from industrial or agricultural sources are seeping into groundwater and causing an increase in some heavy metals. Though Point C (Control) has less contamination, it still has some pollution indicators, which may be the result of slow infiltration from surrounding sources.

To evaluate the significance of these LPI values, it is essential to compare them to standard threshold values established for soil contamination assessments. According to environmental standards, the acceptable LPI threshold for hazardous leachates is 7,500. Any value above this indicates a potential risk for contaminant migration into groundwater sources (Osokpor and Omo-Irabor *2020*)). In this study, all recorded LPI values significantly exceed the standard threshold, with the lowest being 1032.25 and the highest reaching 1194.65 These values are greater than the standard, indicating a severe contamination risk across all locations. However, the control had a value that was a bit lower than the standard threshold of 608.665. The high LPI values suggest that the soil in the studied locations, particularly the topsoil and subsoil, has a high potential for contaminant migration, primarily driven by the presence of heavy metals. This poses a significant risk of groundwater pollution, especially in areas where crude oil spills have heavily impacted the environment. The highest LPI value at Location B (1194.65) suggests that this area has the greatest leaching potential, likely due to higher concentrations of heavy metals in the topsoil and subsoil that may be a result of closer proximity to the spill site or other factors such as soil type and permeability. Conversely, Location 3 has the lowest LPI (608.67) suggesting that the area still has pollutants of considerable measure which if not controlled could pose a feature risk as the value remains almost as the standard threshold.

Table 6, shows the percentage increase in heavy metal concentrations at Locations A and B compared to the Control point at location C. Point B has the highest leaching percentages for most heavy metals, indicating potential environmental and health concerns. The most striking increase is seen in Lead (Pb), with Location B showing a leaching rate of 7300% increase compared to point A and the control (C), underscoring the severity of contamination from the crude oil spill. Cadmium (Cd) levels also exhibit substantial increases, particularly at Location B, 70.11% higher than at the control point. Chromium (Cr) and Iron (Fe) levels significantly increase in both polluted locations. Iron, in particular, exhibits an increase of 115.29% at Location B compared to the control point, reflecting extensive contamination in the region. Cobalt (Co) also shows a notable increase, though less pronounced compared to the other metals. The environmental health risk impact from elevated Pb leaching into water can result in neurological damage, especially in children. Cd and Cr are carcinogens and excessive exposure through the usage of water can lead to cancer. Fe and Co leaching can affect water quality.

Table 6 Percentage comparative impact of leaching heavy metals from Topsoil into water.



PARAMETERS	POINT A (%)	POINT B (%)	POINT C (%)
LEAD Pb (%)	0	7300	0
CADMIUM Cd (%)	58.62	70.11	0
CHROMIUM Cr (%)	16.73	50.92	0
IRON Fe (%)	77.26	115.29	0
COBALT Co (%)	36.76	36.76	0

4.0 CONCLUSION

The study highlights the devastating impact of oil spills on the environment and public health. The significant contamination of soil and groundwater with lead, cadmium, chromium, iron, and cobalt exceeds WHO standards, posing severe health risks to residents. Soil Contamination was discovered as Lead, Cadmium, and Chromium levels in soil samples from affected areas were significantly higher than in control sites also groundwater contamination, is possible because Cobalt concentrations varied significantly across soil layers, indicating potential leaching into groundwater. However, the calculated values of MI and HPI are in contract with the analyzed result which shows that water and soil samples are in pure conditions for all locations since MI values < 1, and HPI <100 suggesting minimal metal contaminations. The LPI is seen to be higher as higher values range from (1194.65-1032.245), indicating severe contamination in both areas. In contrast, the control point shows a much lower LPI value (608.665). Therefore, exposure to these heavy metals can lead to health risks characterized by neurological damage, kidney problems, and cancer. Then, regular monitoring of soil and groundwater quality, implementation of effective remediation strategies, and enforcement of stricter regulations on oil companies operating in the area are recommended. The understanding of the severity of heavy metal contamination on the environmental and human health status through crude oil spillage in Bayelsa State, urgent action to mitigate and prevent further pollution, and ensure a safer environment for communities is required.

Acknowledgments

The author wishes to thank Itoya Ofure Favour who collected the samples from Ibelebril, articulated the results, and presented them for laboratory analysis at Al Barr Laboratories Services, Analytical Research and Reference Laboratory 24. NIIT Road Etegwe, Yenagoa, Bayelsa State. Also, Ogunlowo Olusanjo proofread the manuscript.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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