SSR Journal of Multidisciplinary (SSRJM)
Volume 2, Issue 12, 2025 Homepage: https://ssrpublisher.com/ssrjm/ ISSN: 3049-1304
Email: office.ssrpublisher@gmail.com

Seasonal Variations and Correlation of Heavy Metal Concentrations in Oil-Polluted Soils of the Niger Delta, Nigeria

Kotingo, Ebizimo Kelly & Ambah Binaebi

Institute of Biodiversity, Climate Change, and Watershed, Niger Delta University, Bayelsa State, Nigeria

Received: *01.12.2025* | ***Accepted:*** *26.12.2025* | ***Published:*** *29.12.2025*

***Corresponding Author:** Kotingo, Ebizimo Kelly

DOI: *10.5281/zenodo.18081811*

Abstract **Original Research Article**

This study investigated the concentrations and interrelationships of selected heavy metals—iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), cadmium (Cd), chromium (Cr), lead (Pb), and nickel (Ni) in soils collected from three oil-impacted communities (Ayamasa, Ibelebiri, Ikarama) and a control site (Okumbiri) in the three senatorial districts of Bayelsa State, Niger Delta region of Nigeria. Composite oil samples were collected along four line transects measuring 10 by 50 m with allowance of 20 m at two depths (0–15 cm and 15–30 cm) during dry and wet seasons and analyzed using an atomic absorption spectrophotometer following standard digestion protocols. ANOVA in SPSS was used to compare mean values for soil data, and Duncan's multiple range test was used to differentiate the generated mean values. Results revealed significantly elevated heavy metal concentrations in the oil-impacted sites compared to the control, particularly in surface soils. Across all sites and seasons, Fe ranged from 212.26 to 1,248.96 mg/kg, Mn from 29.16 to 250.18 mg/kg, Cu from 0.18 to 7.05 mg/kg, Zn from 1.53 to 105.03 mg/kg, Cd from 0.32 to 8.43 mg/kg, Cr from 0.44 to 14.02 mg/kg, Pb from 1.55 to 28.06 mg/kg, and Ni from 1.23 to 15.20 mg/kg. The dry season generally exhibited higher concentrations, indicating reduced leaching compared to the wet season. Correlation analyses showed strong positive associations among most metals, particularly in the dry season, suggesting common anthropogenic sources likely linked to oil exploration and related activities. These findings highlight the environmental risks posed by oil pollution in the region and the need for proactive soil remediation and regulatory monitoring.

Keywords: Heavy metal contamination, Niger Delta, oil-polluted soils, seasonal variation, soil depth, correlation analysis, environmental monitoring.

Introduction

The Niger Delta region of Nigeria, endowed with vast petroleum reserves, has experienced extensive environmental degradation due to decades of crude oil exploration, production, and spillages (Mmon & Chukwuokea, 2011; Agbonifo, 2016). While petroleum-derived hydrocarbons are economically valuable, their components ranging from volatile organic compounds to persistent polycyclic aromatic hydrocarbons (PAHs) pose significant risks to both ecological and human health (CCME, 2008; USEPA, 2011). One of the most concerning consequences of oil contamination is the enrichment of soil with heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and zinc (Zn), which are often introduced via drilling fluids, brine discharge, and hydrocarbon breakdown processes (Cunha et al., 2018; Daneshhfar & Ardjmand, 2021).

These heavy metals, being non-biodegradable and capable of bioaccumulation, negatively impact microbial activity, soil structure, crop yield, and ultimately human well-being (Ikechukwu & Oseze, 2018; Angon et al., 2022). While some metals occur naturally in trace amounts, oil exploitation dramatically alters their concentrations in the soil, making them hazardous to agricultural sustainability and public health (Vidali, 2001; Abioye, 2011; Malolo et al., 2024). Moreover, the contamination reduces soil porosity and aeration, further limiting nutrient cycling and productivity (Koyode et al., 2009; Adekunle, 2011).

Although prior research has examined heavy metal levels in oil-polluted areas of the Niger Delta, there remains a significant gap in understanding how these concentrations fluctuate seasonally and across soil depths (Fatoba et al., 2015; Obasi et al., 2019). Most studies focus on single-time-point assessments or surface-layer samples, often neglecting subsurface dynamics and seasonal variations that influence metal mobility and retention. Consequently, this leaves critical questions unanswered regarding the long-term geochemical behavior of metals under varying hydrological and climatic regimes.

This study seeks to bridge this gap by conducting a comparative analysis of heavy metal concentrations across both dry and wet seasons, and at two soil depths (0–15 cm and 15–30 cm), within crude oil-impacted and uncontaminated sites in Bayelsa State. By integrating seasonal data, vertical stratification, and statistical correlation analysis, the research aims to generate robust insights to inform environmental remediation and sustainable land-use policy.

Materials and Method

Study Design

This study adopted seasonal stratified ecological sampling to investigate the seasonal variations of heavy metal concentrations in crude oil impacted communities in Bayelsa State, Nigeria. The design enabled both spatial and temporal comparisons between oil-impacted communities (Ayamasa, Ibelebiri, and Ikarama) and a control community (Okumbiri), which has no documented history of oil spills. The environmental sampling of the study was conducted in Febuary 2024 (to represent dry season) and September 2024 (to represent wet season), allowing for the assessment of temporal variations in environmental parameters.

Soil Sample Collection

Soil sampling was conducted within each delineated 50 × 10 m plot using a soil screw auger measuring 30 cm in length and 3.5 cm in diameter. Composite samples were systematically collected along each line transect at two depth intervals: 0–15 cm (surface layer) and 15–30 cm (subsurface layer). This stratified sampling approach aligned with established environmental protocols for assessing vertical distribution of soil contaminants (International Atomic Energy Agency, 2004).

Following collection, all samples were properly labeled and securely packaged to prevent contamination. The samples were then transported to the Chemical Science Laboratory at Ahmadu Bello University, Zaria, for elemental analysis. Heavy metals analyzed included cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), manganese (Mn), and iron (Fe), selected due to their environmental relevance and potential ecological impact (Pan et al., 2020).

Laboratory Analysis of Soil Samples

The analytical procedure for assessing heavy metal concentrations in soil samples was conducted in accordance with the methodology outlined by Bates (2006). Initially, collected soil samples were subjected to air-drying, followed by mechanical pulverization to achieve a fine powder. The powdered samples were subsequently sieved through a 2 mm mesh to ensure uniform particle size suitable for spectrometric analysis.

To account for vertical heterogeneity in soil composition, samples were stratified by depth into two categories: surface layer (0–15 cm) and subsurface layer (15–30 cm). This stratification enabled comparative analysis of heavy metal distribution across soil horizons.

Quantitative determination of heavy metals—specifically cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), manganese (Mn), and iron (Fe)—was performed using atomic absorption spectrophotometry (AAS), employing a Perkin-Elmer Model 403 instrument. Calibration of the spectrophotometer was verified using certified standard solutions for each target metal. Concentration values were extrapolated from calibration curves plotting absorbance against known concentrations, with results expressed in milligrams per kilogram (mg/kg).

Methods of Data Analysis

To evaluate the heavy metal concentration of soil samples, laboratory results were subjected to statistical analysis using the Analysis of Variance (ANOVA) method. This approach enabled the identification of significant differences among sample groups. To further distinguish the means, the Duncan Multiple Range Test was applied within the Statistical Package for the Social Sciences (SPSS). Alphabetical groupings (a, b, c, d) were used to indicate statistically significant variations between categories, providing clarity in the interpretation of results. Using paleontological software, correlation matrices were systematically generated for the dry and wet seasons in order to compute the Pearson's correlation coefficient (r). Values close to +1 or -1 indicate strong linear correlations, whereas values close to zero show weak or no association. The degree of connection provides insight into the seasonality, routes, and sources of contaminants. For the charts, Microsoft Excel version 2019 was utilized.

Results

Table 1 shows Fe concentrations exhibited extraordinary spatial variability, with Ayamasa and Ibelebiri demonstrating significantly elevated accumulation levels (1248.96±62.35 mg/kg and 1235.39±96.54 mg/kg respectively at 0-15cm depth) when contrasted with Ikarama's intermediate concentrations (621.06±18.79 mg/kg) and the control site's baseline measurements (346.15±33.14 mg/kg). Mn demonstrated comparable spatial accumulation characteristics across contaminated locations, with severely affected sites (Ayamasa: 250.18±17.46 mg/kg; Ibelebiri: 236.43±14.13 mg/kg) showing approximately threefold enrichment compared to moderately impacted areas (Ikarama: 169.84±5.74 mg/kg) and uncontaminated reference conditions (70.09±6.72 mg/kg).

Cu, Zn, Cd, Cr, Pb, and Ni concentrations revealed statistically significant inter-site disparities that directly correlate with petroleum contamination intensity gradients across the sampling network. Zn accumulation proved exceptionally concerning at Ayamasa (105.03±3.37 mg/kg) and Ibelebiri (101.72±8.14 mg/kg), representing approximately 45-fold enrichment factors relative to background concentrations (2.33±0.17 mg/kg). Cd and Pb concentrations presented particularly alarming elevation characteristics, with maximally contaminated locations exhibiting Cd levels reaching 7.71±0.89 mg/kg and 8.43±0.83 mg/kg respectively. Pb accumulation displayed comparable contamination signatures, achieving maximum concentrations of 28.06±3.76 mg/kg at Ibelebiri, representing approximately tenfold enrichment above natural background concentrations. Cr and Ni demonstrated distinct site-specific accumulation patterns, with Ibelebiri consistently recording the highest concentrations across both depth intervals. Cr reached peak levels of 13.66±2.03 mg/kg and 14.02±1.41 mg/kg at surface and subsurface depths respectively, whilst Ni achieved maximum concentrations of 15.20±0.79 mg/kg and 14.57±1.05 mg/kg.

Table 1: Mean ± standard error of heavy metal mean concentration (mg/kg) in soil (dry season)

Heavy Metals Mg/Kg		Ayamasa	Ibelebiri	Ikarama	Okumbiri (Control)
Fe	015cm	1248.96^{a}±62.35	1235.39^{a}±96.54	621.06^{b}±18.79	346.15^{c}±33.14

	15-30cm	1235.77^{a}±46.75	1141.73^{a}±138.90	609.68^{b}±34.45	312.80^{c}±31.95
Mn	0-15cm	250.18^{a}±17.46	236.43^{a}±14.13	169.84^{b}±5.74	70.09^{c}±6.72
	15-30cm	231.41^{a}±18.16	206.40^{a}±4.10	152.38^{b}±7.98	57.91^{c}±8.91
Cu	0-15cm	6.77^{a}±0.73	7.05^{a}±0.78	3.00^{b}±0.18	0.29^{c}±0.06
	15-30cm	5.51^{a}±0.83	5.48^{a}±0.70	2.52^{a}±0.31	0.18^{a}±0.06
Zn	0-15cm	105.03^{a}±3.37	101.72^{a}±8.14	18.11^{b}±3.26	2.33^{c}±0.17
	15-30cm	69.19^{b}±0.73	83.90^{a}±6.06	14.22^{c}±2.92	1.56^{d}±0.09
Cd	0-15cm	7.71^{a}±0.89	8.43^{a}±0.83	1.65^{b}±0.31	0.49^{b}±0.06
	15-30cm	6.91^{a}±0.63	7.14^{a}±0.71	1.34^{b}±0.16	0.34^{b}±0.05
Cr	0-15cm	5.59^{b}±0.56	13.66^{a}±2.03	1.76^{c}±0.20	0.75^{c}±0.21
	15-30cm	5.46^{b}±0.74	14.02^{a}±1.41	1.24^{c}±0.08	0.67^{c}±0.26
Pb	0-15cm	24.35^{a}±1.06	28.06^{a}±3.76	9.81^{b}±1.09	2.93^{c}±0.29
	15-30cm	22.47^{a}±0.94	23.57^{a}±1.66	9.21^{b}±1.07	2.50^{c}±0.37
Ni	0-15cm	9.74^{b}±0.40	15.20^{a}±0.79	5.72^{c}±0.46	1.94^{d}±0.34
	15-30cm	9.24^{b}±0.17	14.57^{a}±1.05	4.89^{c}±0.20	1.41^{d}±0.17

Source: Analysis by Author (2024). Means followed by different letters in a row are significantly different from one another

Heavy Metal Concentration in Soil Wet Season

Table 2: Fe concentrations demonstrated remarkable spatial heterogeneity, with Ayamasa and Ibelebiri recording dramatically elevated accumulation levels (1248.96±62.35 mg/kg and 1235.39±96.54 mg/kg respectively within 0-15cm stratum) contrasted against Ikarama's moderate levels (621.06±18.79 mg/kg) and the control location's baseline concentrations (346.15±33.14 mg/kg). Mn exhibited parallel accumulation trends across contaminated locations, with severely impacted sites (Ayamasa: 250.18±17.46 mg/kg; Ibelebiri: 236.43±14.13 mg/kg) demonstrating threefold elevation compared to moderately affected areas (Ikarama: 169.84±5.74 mg/kg) and pristine conditions (70.09±6.72 mg/kg). Cu, Zn, Cd, Cr, Pb, and Ni concentrations exhibited statistically significant spatial disparities that directly correlate with petroleum contamination severity gradients across the investigation sites. Zn accumulation proved particularly concerning at Ayamasa (105.03±3.37 mg/kg) and Ibelebiri (101.72±8.14 mg/kg), representing approximately 45-fold enrichment factors when compared against background concentrations (2.33±0.17 mg/kg).

Cd and Pb concentrations presented alarming elevation characteristics, with maximally contaminated locations exhibiting Cd levels reaching 7.71±0.89 mg/kg and 8.43±0.83 mg/kg respectively, considerably surpassing established regulatory limits for agricultural soil matrices. Pb accumulation displayed similar contamination signatures, achieving peak concentrations of 28.06±3.76 mg/kg at Ibelebiri, representing approximately tenfold enrichment above natural background levels.

Table 2: Mean ± standard error of heavy metal mean concentration (mg/kg) in soil (Wet season)

Heavy Metals Mg/Kg		**Ayamasa**	**Ibelebiri**	**Ikarama**	**Okumbiri (Control)**
Fe	0-15cm	755.10^{a}±37.92	756.87^{a}±31.29	616.52^{b}±7.74	212.26^{c}±36.96
	15-30cm	792.64^{a}±9.46	724.58^{ab}±28.27	636.75^{b}±54.15	265.11^{c}±28.83
Mn	0-15cm	153.55^{b}±20.76	223.71^{a}±8.25	112.41^{b}±15.30	29.16^{c}±5.56
	15-30cm	160.28^{a}±21.45	246.56^{a} ±11.51	199.97^{b}±14.95	31.79^{c}±6.21
Cu	0-15cm	2.69^{a}±0.35	2.95^{a}±0.07	2.36^{a}±0.21	0.27^{b}±0.08
	15-30cm	3.29^{a}±0.33	3.31^{a}±0.27	2.92^{a}±0.20	0.33^{b}±0.22
Zn	0-15cm	72.47^{a}±7.51	67.58^{a}±8.32	14.42^{b}±3.16	1.53^{b}±0.17
	15-30cm	80.68^{a}±6.67	82.04^{a}±7.34	18.10^{b} ±5.32	1.90^{b}±0.26
Cd	0-15cm	6.23^{a}±0.24	6.91^{a}±0.55	1.95^{b}±0.08	0.32^{c}±0.06
	15-30cm	6.95^{a}±0.33	7.18^{a}±0.46	2.02^{b}±0.08	0.40^{c}±0.06
Cr	0-15cm	3.81^{b}±0.29	5.13^{a}±0.38	1.33^{c}±0.13	0.44^{d}±0.15
	15-30cm	4.07^{b}±0.35	5.78^{a}±0.30	1.66^{c}±0.11	0.79^{d}±0.12
Pb	0-15cm	22.44^{a}±0.99	20.33^{a}±0.86	8.20^{b}±0.82	1.55^{c}±0.21
	15-30cm	25.01^{a}±0.29	21.08^{b}±0.85	9.53^{c}±0.75	1.61^{d}±0.21
Ni	0-15cm	8.25^{b}±0.46	13.14^{a}±1.74	4.07^{c}±0.08	1.23^{d}±0.08
	15-30cm	9.23^{b}±0.20	14.17^{a}±1.35	4.39^{c}±0.10	1.41^{d}±0.12

Source: Analysis by Author (2024). Means followed by different letters in a row are significantly different from one another.

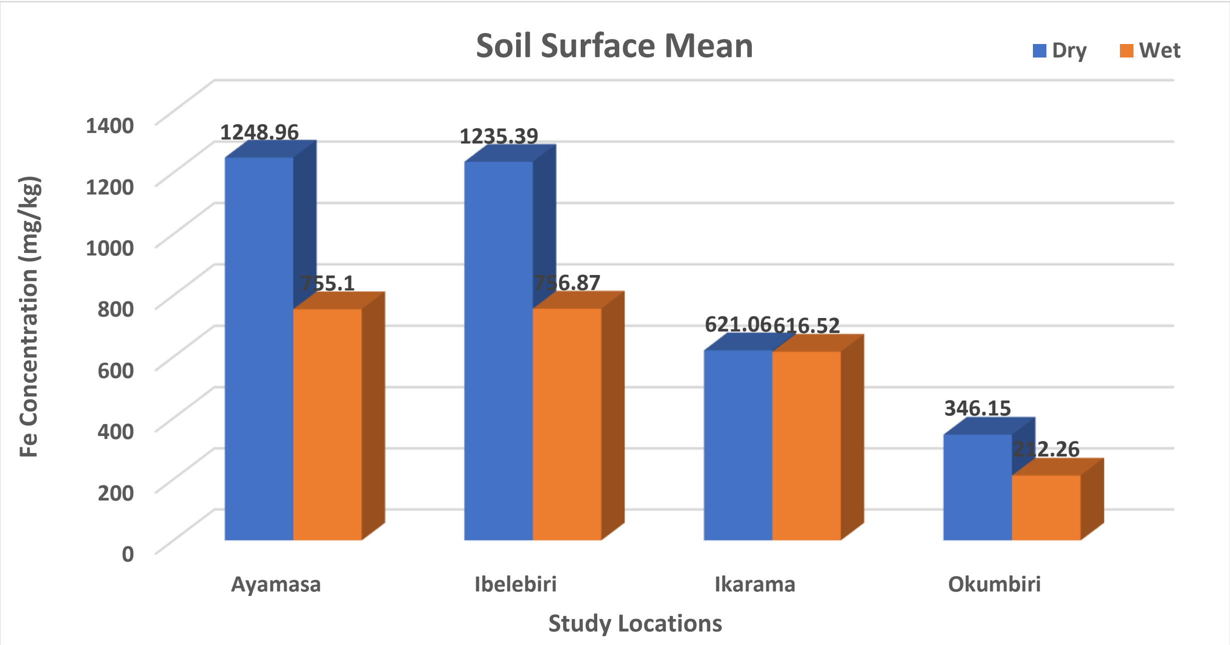

Figure 1: Seasonal Variations of the distribution of Iron (Fe) Concentration in Surface Soil.

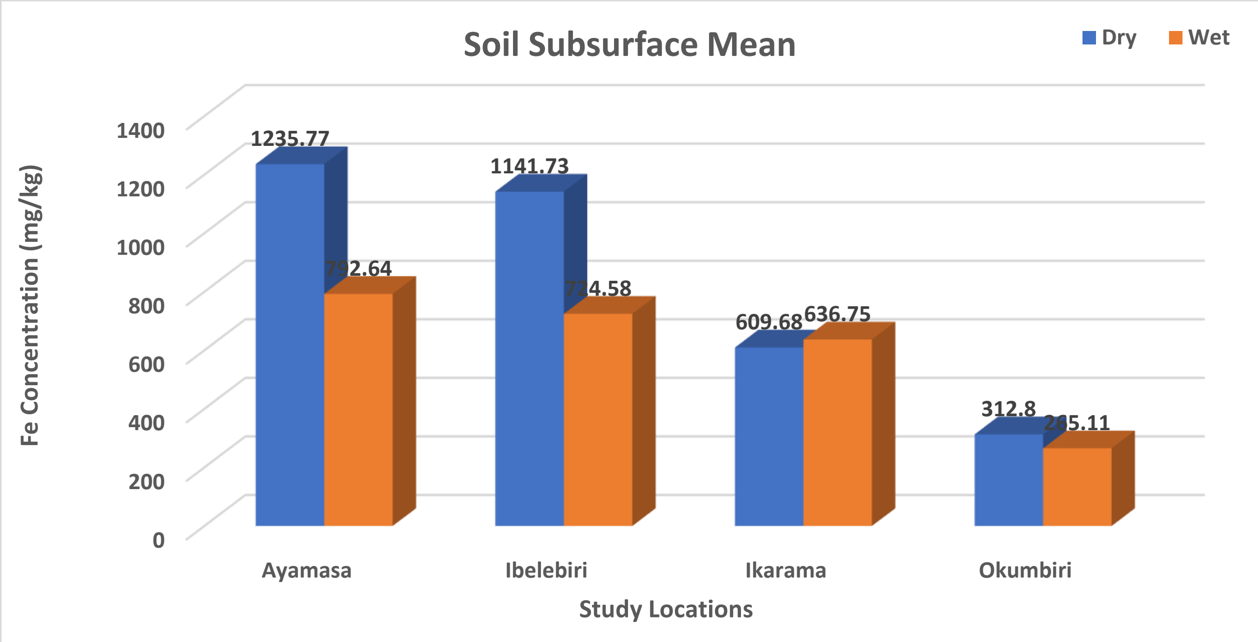

Figure 2: Seasonal Variations of the Distribution of Iron (Fe) Concentration in Subsurface Soil.

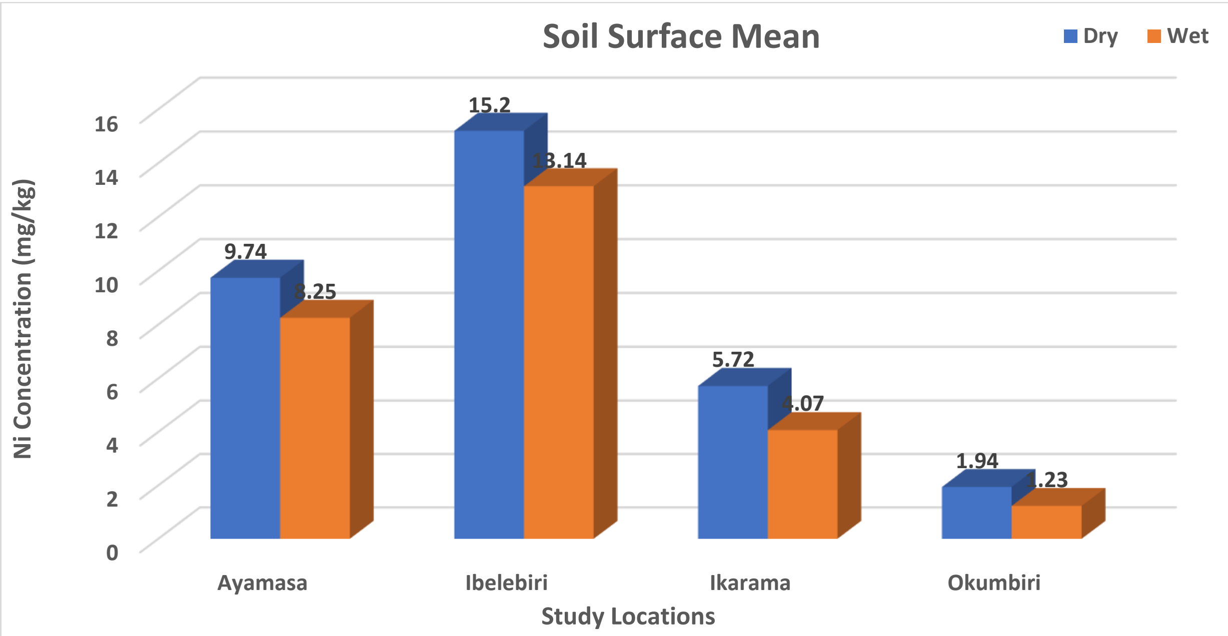

Figure 3: Seasonal Variations of the Distribution of Nickel (Ni) Concentration in Surface Soil.

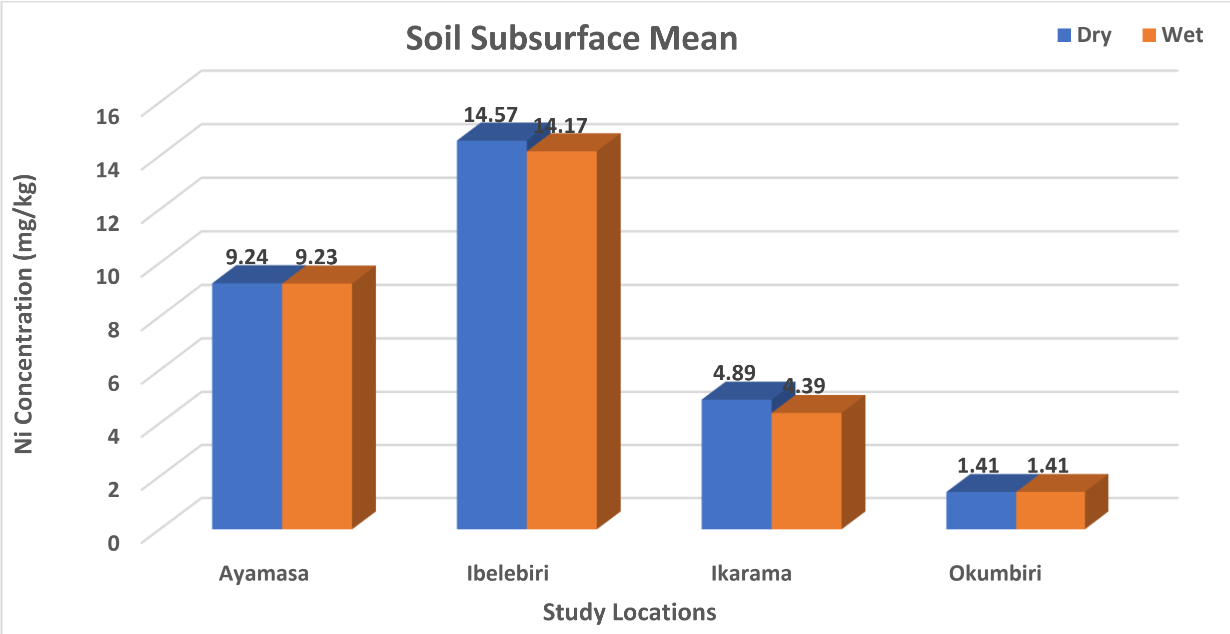

Figure 4: Seasonal Variations of the Distribution of Nickel (Ni) Concentration in Subsurface Soil.

Table 3: In the dry season, the soil exhibits a high degree of inter-metal correlation, suggesting a common origin or mutual influencing factors. Cadmium (Cd), in particular, demonstrates very strong positive relationships with other metals including: Cd–Mn (0.9483), Cd–Pb (0.9446), Cd–Zn (0.9175). Similarly, Zn, Pb, and Ni also show robust linkages, such as: Zn–Mn (0.9076), Cu–Zn (0.9318) and Cr–Ni (0.9356). These high coefficients indicate that during dry periods—when there is little rainfall to cause dilution or dispersion—metals likely accumulate in the soil due to shared anthropogenic sources such as industrial discharges, vehicular emissions, or atmospheric deposition. The soil remains relatively undisturbed, allowing for greater chemical bonding or similar absorption behaviors.

Table 3: Correlation of Heavy Metal Concentrations in Dry Season Soil

	Fe	**Mn**	**Cu**	**Zn**	**Cd**	**Cr**	**Pb**	**Ni**
Fe	1							
Mn	0.8915	1						
Cu	0.81907	0.83831	1					
Zn	0.88306	0.90762	0.93181	1				
Cd	0.92595	0.94831	0.80788	0.91752	1			
Cr	0.81485	0.78882	0.85634	0.86489	0.85518	1		
Pb	0.88278	0.91541	0.83802	0.91431	0.94455	0.84701	1	
Ni	0.82768	0.81137	0.87404	0.86654	0.85353	0.93555	0.85425	1

Table 4: During the wet season, the correlation values slightly decline, although many remain significant. Notably strong associations include: Cr–Ni (0.9483), Cd–Ni (0.8986), Cr–Mn (0.9102) and Cd–Zn (0.8730). The wet season introduces variables such as increased leaching, surface runoff, and changes in soil pH and redox potential, all of which can influence metal mobility and distribution. The overall softer correlation values might reflect how metals disperse or are selectively retained under saturated conditions. Nonetheless, the persistence of strong associations—especially involving Cr, Cd, and Ni—suggests enduring shared pathways or chemical affinities.

Table 4: Correlation of Heavy Metal Concentrations in Wet Season Soil

	Fe	Mn	Cu	Zn	Cd	Cr	Pb	Ni
Fe	1							
Mn	0.78482	1						
Cu	0.55889	0.5928	1					
Zn	0.74377	0.76283	0.73357	1				
Cd	0.79633	0.85426	0.75314	0.87296	1			
Cr	0.7599	0.91019	0.67583	0.8937	0.86544	1		
Pb	0.84007	0.74695	0.66288	0.85327	0.87359	0.79773	1	
Ni	0.7599	0.90982	0.68885	0.83981	0.89863	0.94831	0.81789	1

Discussions

Ayamasa soils had varying levels of heavy metals concentration depending on the season and depth. For example, iron (Fe) mean values for surface samples during the dry season were 1248.96 mg/kg, whereas subsurface layer samples had mean values of 1235.77 mg/kg (Figures 1 and 2). Compared to the values obtained in the control location, these values are significantly higher. The control location, Okumbiri, has mean values of 346.15 mg/kg for surface samples and 312.80 mg/kg for subsurface samples. Adesina and Kasali (2014) conducted a similar study in the western region of Nigeria and found that the presence of crude oil in farmland soil used for maize production had a greater concentration of iron (1041 ppm) than unpolluted soil samples (647 ppm). They also noted that, with values of 1553 and 807 ppm, respectively, they saw a similar pattern in both polluted and unpolluted soil samples.

For manganese (Mn) concentration, Ibelebiri had higher mean values during the dry and wet seasons (236.43 and 223.71 mg/kg) for surface layers than Okumbiri (70.09 and 29.16 mg/kg), and subsurface samples showed higher concentrations in Ibelebiri (206.40 and 246.56 mg/kg) than Okumbiri (57.91 and 31.79 mg/kg). The high levels of anthropogenic activities associated with crude oil exploration and exploitation in Ibelebiri, as opposed to Okumbiri, which has little to no crude oil activities, may be the cause of the high manganese readings in Ibelebiri. According to Orisakwe's (2021) metal study, the wanton devastation of the region's ecological resources, as well as the wanton destruction of the residents' economic resources, has made crude oil a curse.

Another heavy metal whose concentration in soils can significantly impact soil quality and productivity is copper. In this investigation, the average Cu levels in soil samples taken during the Ikarama dry season at the surface layer (3.00 mg/kg) are significantly greater than those taken at the control (0.29 mg/kg), (Table 1). Wet season samples at the subsurface layer showed a similar pattern (Table 2). This finding supports that of a previous study by Nwadiogbu et al. (2024), which found that copper values ranged from 1.84 to 9.78 mg/kg in areas contaminated by crude oil in Rivers State, Nigeria.

In Ayamasa, the average zinc values for surface and subsurface samples during the dry season were 105.03 and 69.19 mg/kg, respectively, whereas the average values for samples taken at depths of 0–15 cm and 15–30 cm during the rainy season were 72.47 and 80.68 mg/kg, respectively. Table 1 showed mean values of 2.33 and 1.56 mg/kg (0-15 cm depth) for dry season samples and 1.53 and 1.90 mg/kg (15-30 cm depth) for wet season samples when compared to the control (Okumbiri) (Table 2). In contrast to Okumbiri, which has no history of crude oil activity, reported lower results, this demonstrated that Ayamasa's high zinc concentration is triggered by crude oil activities. Ayamasa's dry and wet season zinc distribution samples differed from Okumbiri's (control) dry and wet season samples.

In addition, the cadmium levels were higher in the area affected by crude oil (Ibelebiri) than in the area where there had never been any crude oil activity (control). While subsurface samples showed mean values of 7.320 and 7.460 and 0.320 and 0.370 for the two locations, respectively, the details in Tables 1 and 2 showed that the mean values of cadmium for surface samples of dry and wet season soils were 8.390 and 7.050 in Ibelebiri compared to 0.500 and 0.320 in Okumbiri. This outcome supports a previous finding from a study conducted by Nwadiogbu et al. (2024).

Ikarama's surface and subsurface samples have higher mean levels of chromium for both dry and wet seasons (Tables 1 and 2), compared to Okumbiri's results. Previous research revealed a similar trend. According to a study by Nwadiogbu et al. (2024), all soil samples contaminated by petroleum hydrocarbons had greater concentrations of heavy metals than the values of the control soil samples taken some distance away from areas contaminated by crude oil.

Significant differences in lead concentrations between studied locations and seasons are also evident in lead levels. The mean lead levels in Ayamasa are depicted in Tables 1 and 2. The dry season samples obtained at soil depths of 0–15 cm had mean values of 24.35, while the subsurface samples had mean values of 22.47. The control location's dry season samples collected at soil depths of 0–15 cm had mean values of 2.93, and 15–30 cm had mean values of 2.50. Wet season samples in Ayamasa have surface and subsurface mean values of 22.44 and 25.01, while in Okumbiri, the mean surface values are 1.55 and the subsurface mean values are 1.61. These values demonstrated that lead levels were higher in areas affected by crude oil than in areas where there has never been any history of crude oil activity. According to a related study by Bankole et al. (2024), lead concentrations in areas contaminated by crude oil frequently increase in comparison to areas where no crude oil activity occurs. Lead levels in the aforementioned study ranged from 148 to 9078 mg/kg. Compared to the results of this study, these high mean value ranges are significantly higher. This may be related to the fact that, Okpare-Olumu has higher amounts of illicit crude oil bunkering activities.

When compared to control locations that have no history of crude oil activity, the mean Ni values in Ibelebiri varied according to depth and season. In comparing the distribution, it was found that the mean values of Ni in the dry and wet season surface samples were 15.20 and 13.14 mg/kg, respectively, whereas the mean values in the control dry and wet season samples were 1.94 and 1.23 mg/kg (Figure 3). In a similar vein, samples taken at a depth of 15 to 30 cm had mean values of 14.57 and 14.17 mg/kg in Ibelebiri and 1.41 and 1.41 mg/kg in Okumbiri (Figure 4). The average Ni values found in this investigation were slightly lower than the findings of a previous study conducted in the region by Iwegbue (2011), which reported a Ni range of 7.0 - 42.3 mg/kg.

Conclusion

The results of this study revealed a clear pattern of elevated heavy metal concentrations in soils from oil-impacted areas, particularly Ayamasa, Ibelebiri, and Ikarama, when compared to the control site, Okumbiri. These differences were consistently observed across both dry and wet seasons, with surface soils (0–15 cm) exhibiting notably higher contamination levels than subsurface layers (15–30 cm). Metals such as iron (Fe), manganese (Mn), zinc (Zn), cadmium (Cd), lead (Pb), and nickel (Ni) showed significant enrichment in affected sites—often exceeding control values by several multiples. The correlation analyses further suggest strong positive relationships among most heavy metals, especially in the dry season, indicating potential common sources of contamination—likely linked to anthropogenic activities such as oil exploration and spillage. These findings highlighted the persistent nature of heavy metal pollution in the region and underscore the urgent need for environmental monitoring, pollution source identification, and sustainable remediation efforts.

References

Abioye, O. P. (2011). Bioremediation of hydrocarbon-polluted sites. *Biotechnology and Molecular Biology Review*, *6*(3), 60–65.

Adekunle, I. M. (2011). Impacts of petroleum activities on soil properties of a spill site in a typical tropical rainforest zone of Nigeria. *Environmental Monitoring and Assessment*, *178*(1–4), 517–526.

Agbonifo, J. (2016). *Corporate Social Responsibility and Petroleum Pollution in the Niger Delta*. Routledge.

Angon, P. B., Nwinyi, O. C., & Afolayan, A. F. (2022). Environmental risk assessment of heavy metals from petroleum-polluted soils in Nigeria. *Environmental Pollution and Management*, *45*(2), 87–95.

Bankole, A. O., Ogunkeyede, A. O., Adedosu, T. A., Udeochu, U., Agboro, H., & Isukuru, E. J. (2024). Assessment of Heavy Metal Exposure in Soils of Ihwrekreka Communities, Delta State, Nigeria. Journal of Geoscience and Environment Protection, 12, 279-303.

Bates, R. G. (2006). *Preparation and Measurement of pH Solutions: A Laboratory Manual*. Wiley-Interscience.

CCME. (2008). *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health*. Canadian Council of Ministers of the Environment.

Cunha, J. P., Lima, M. D., & Costa, S. C. (2018). Drilling fluid discharge and its environmental impact: A case study from Brazil. *Journal of Petroleum Science and Engineering*, *165*, 133–142.

Daneshhfar, A., & Ardjmand, M. (2021). Characterization and disposal of petroleum-based drilling fluids: Global perspectives. *Petroleum Research*, *6*(3), 287–296.

Ebiye, P. N., Eregha, P. B., & Essien, A. (2021). Oil spillage and economic viability of the Niger Delta region: A socio-ecological critique. *International Journal of Environmental Studies*, *78*(4), 562–578.

Fatoba, P. O., Adeleke, R. A., & Oke, A. O. (2015). Assessment of trace metal contamination in soils and plants from a major industrial area in South-Western Nigeria. *Environmental Nanotechnology, Monitoring & Management*, *3*, 24–30.

Ikechukwu, O., & Oseze, P. (2018). Heavy metal contamination and its impact on soil fertility in the Niger Delta region. *Journal of Environmental Chemistry and Ecotoxicology*, *10*(4), 30–36.

Iwegbue, C. M. A. (2011). Distribution of heavy metals in soil profiles of automobile mechanic waste dumps in urban areas of southern Nigeria. *Environmental Research Journal*, *5*(2), 67–71.

Koyode, A. A., Ogunlaja, A. O., & Adekunle, A. S. (2009). Effects of petroleum on soil physical properties and root development of crops. *Journal of Applied Sciences Research*, *5*(9), 1233–1240.

Malolo, R., Ajayi, J. O., & Umeh, C. (2024). Exposure pathways of heavy metals in oil-polluted soils of the Niger Delta. *Environmental Health Reports*, *41*(2), 102–115.

Mmon, P., & Chukwuokea, B. (2011). Petroleum exploration and poverty in the Niger Delta region of Nigeria. *International Journal of Business and Social Science*, *2*(21), 123–131.

Nwadiogbu, J. O., Ikelle, I. I., Onwuka, J. C., Ikeh, O. A., Nwankwo, N. V. & Anarado, I. L. (2024). Assessment of Heavy Metals in a Soil Contaminated by Petroleum Hydrocarbons at Ebudu, Rivers State, *Nigeria. Greener Journal of Environmental Management and Public Safety*, 12(1): 10-15.

Obasi, S. N., C.M. Ahukaemere, C. M., G.D. Aloni, G.D. and Obasi, C. C. (2019). Effect of Oil Spillage on Selected Heavy Metals Concentration in the Soils of Ihugbogo in Ahoada East, Niger-Delta, Nigeria. *Bulgarian Journal of Soil Science*, Vol 4, Issue 2, Pp 140-149.

Orisakwe, O. E. (2021). Crude oil pollution and toxic metal exposure in the Niger Delta:

Implications for public health. *Toxicology Communications*, *5*(2), 80–90.

USEPA. (2011). *Introduction to Petroleum Hydrocarbons*. United States Environmental Protection Agency.

Vidali, M. (2001). Bioremediation: An overview. *Pure and Applied Chemistry*, *73*(7), 1163–1172.