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RESEARCH ARTICLE

EVALUATION OF HEAVY METAL CONTAMINATION PATTERNS IN SOILS SURROUNDING IWOFE AND ADJACENT AREAS IN SOUTHERN NIGERIA

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ABSTRACT

The research was carried out in the Iwofe Rumuolumeni region of Port Harcourt, Rivers State, Nigeria, to evaluate the presence and concentrations of heavy metal pollutants in the soil. Seven soil samples were gathered and subjected to analysis for various heavy metals, namely lead, cadmium, zinc, chromium, nickel, iron, and copper, utilizing an AAS machine. The objective was to examine the extent of contamination in soils near Iwofe Rumuolumeni in Port Harcourt, Rivers State, Nigeria. The outcomes revealed the presence of cadmium, zinc, nickel, iron, and copper, with respective range values of 0.05–5.94 mg/kg, 0.26–1.10 mg/kg, 0.74–2.23 mg/kg, 15.17–129.56 mg/kg, and 0–5.09 mg/kg. Notably, soil samples IWF 3 and 5 exhibited elevated cadmium concentrations at 1.10 mg/kg and 5.94 mg/kg, respectively. The proximity of IWF 3 to an oil terminal and IWF 5 to an abandoned cement factory likely contributed to the high cadmium levels. The study suggests a potential cadmium pollution issue, as the mean concentration exceeds the World Health Organization's target values, indicating significant pollution originating from local industrial activities. The predominant distribution pattern of heavy metals found in the study is iron > cadmium > nickel > copper > zinc. The findings emphasize the necessity for a more comprehensive trace element analysis in the area. The Contamination Factor (CF) and Geoaccumulation Index (Igeo) indicate moderate to heavy contamination, particularly for cadmium and zinc. These results highlight potential adverse effects on agricultural productivity and local livelihoods, underscoring the importance of implementing mitigation measures and conducting detailed trace element analyses.

KEYWORDS

Heavy metals, Soil analysis, Contamination, Target values, Pollution

1. INTRODUCTION

Soil, encompassing the loose surface material that blankets a significant portion of the Earth's land, comprises both inorganic particles and organic matter. It plays a crucial role in agriculture by offering structural support to plants and serving as their primary source of water and nutrients. Soils exhibit significant diversity in their chemical and physical attributes. Various processes, including leaching, weathering, and microbial activity, contribute to the formation of a wide array of soil types. Heavy metals are found in soils either naturally or as a consequence of human activities. Natural sources of heavy metals encompass atmospheric volcanic emissions, continental dust transport, metal-rich rock weathering, and volcanic eruptions. Anthropogenic activities, such as mining operations, smelting processes, the use of metal-containing chemicals, industrial disposal of waste sludge, combustion of fossil fuels, military training, and the production and disposal of electronics, constitute significant sources of heavy metals in soils.

Industrial wastewater is also known to contain elevated concentrations of various heavy metals, including chromium (Cr), zinc (Zn), nickel (Ni), cobalt (Co), and cadmium (Cd), copper (Cu), and lead (Pb), as reported by (Khan et al., 2017). According to a study, the pollution of the environment with toxic metals has notably increased since the onset of the industrial revolution (Voegelan et al., 2003). It is a problem to be concerned about when heavy metals including cadmium, lead, chromium, copper, and zinc pollute the soil. While heavy metals are naturally present in contaminated soil, they are also primarily a product of local industry (mostly the non-ferrous sector, but also power plants, the iron, steel, and chemical sectors).

The progression of society and the rapid pace of industrialization contribute significantly to the introduction of various heavy metals, such as copper (Cu), lead (Pb), zinc (Zn), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni), and mercury (Hg), into sediment and soil. These heavy metals pose a potential threat to human health as they easily enter the human body through the food chain. Their rapid accumulation in the environment, resistance to biodegradation, and strong bioavailability make them prone to entering the human system. While some heavy metals, like zinc (Zn) and copper (Cu), are essential minerals crucial for body organs and human health, excessive consumption can be toxic and lead to mental health issues. Other heavy metals predominantly exhibit harmful effects on human well-being (Luo and Jia, 2021).

Heavy Metals in Contaminated Soil: Source, Accumulation, Health Risk and Remediation Process" by it is emphasized that soil contamination by heavy metals and metalloids can occur through emissions from various sources (Abdullahi et al., 2021). The toxic nature of heavy metals poses risks to both human health and the environment. Given their potential for bioaccumulation and toxicity, these compounds should undergo mandatory monitoring. A comprehensive understanding of the sources, chemistry, and potential risks associated with toxic heavy metals in contaminated soils is essential for making informed decisions about suitable remediation strategies. In their 2021 study, Onwuka et al. conducted soil analysis in oil-bearing areas of Rivers State and observed

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that the soils exhibited acidity and low organic matter content.

The majority of measured values fell significantly below the suggested DPR Standard, indicating that oil pollution had altered nearly all physicochemical parameters. This alteration implies a potential decline in agricultural productivity and a reduction in means of subsistence for the affected regions. Despite the low heavy metal levels in the soils, staying below DPR permitted levels, the impact on soil quality was considered minimal. The ANOVA results highlighted a significant difference in chromium concentrations between the study soils and control soils. The findings suggest that, as of the study period, the assessed areas in Rivers State had not experienced negative impacts from oil extraction and exploration activities. However, the study strongly recommends regular monitoring of these areas to prevent the accumulation of contaminants beyond the maximum tolerance levels.

Some group scientist in their study, "Physiochemical Characteristics and Heavy Metals Contents in Soils from Abraka Cassava Plants and Farmlands along a Major Highway in Delta State, Nigeria," observed that soils along the expressway were enriched with heavy metals, primarily due to automobile exhaust emissions (Osakwe et al., 2015). The residual percentage was predominantly associated with nickel, chromium, and iron. Cadmium and manganese were mainly found in fractions bound to exchangeable and Fe-Mn oxide, respectively, while copper and lead were largely associated with the organic phase. The metal speciation pattern revealed in the study suggests that iron, nickel, and chromium are geogenic metals that are not easily mobilized and made available to biota.

In contrast, the remaining four trace metals—copper, lead, manganese, and cadmium—originate from human-made sources. In the study conducted by Ekpete and Festus, which assessed the impact of automobile emissions on soil along Iwofe Rumuolumeni in Port-Harcourt, River State, the results indicated significantly higher concentrations of heavy metals in the soil samples compared to the control site (Ekpete and Festus, 2013). This suggests an enrichment of heavy metals in the soil attributed to automobile emissions along the busy roads. On the other hand, Nde and Edori investigated the levels of various heavy metals, including Cd, Cr, Zn, Cu, As, Pb, Mn, Co, Fe, and Ni, in the soil of the vehicle spare parts market in Mile II, Port Harcourt, Rivers State, Nigeria (Nde and Edori, 2023). The results showed that all the analyzed metals, except for Cu and Fe, were below the recommended World Health Organization (WHO) standards.

The concentrations of Cu and Fe exceeded the WHO standard limits, indicating a potential environmental concern. The study recommends the adoption of a proper waste management system in the vehicle spare parts market for the adequate disposal of waste to address the situation. In a study on environmental pollution in selected areas of Port Harcourt using index models, the results showed that Iron (Fe) was the most abundant metal, with a range of values from 10.44 to 19.54 mg/kg (Verla et al., 2017). Following Fe, Nickel (Ni) ranged from 8.03 to 13.6 mg/kg, Cadmium (Cd) from 3.96 to 5.41 mg/kg, Lead (Pb) from 1.36 to 7.64 mg/kg, Zinc (Zn) from 0.09 to 7.24 mg/kg, Copper (Cu) from 0.16 to 0.32 mg/kg, and Arsenic (As) from 0.07 to 0.11 mg/kg. All metal concentrations were reported to be below the permissible limits set by NESRA. The aim of this research is to assess the extent of heavy metal contamination distribution in soils around the study areas and proposes potential solutions to address the issue.

1.2 Review of The Study Area

Iwofe, Rumuoulumeni area is located at Obio Akpor Local Government Area of Rivers State as shown in Figure 1. It runs between longitude 6° 55′ 30″ and 6° 59′ 15″ E and latitudes 4° 46′ 3″ and 4° 50′15″ N. The study area lies on the recent Coastal Plain of the eastern Niger Delta. Its surface geology consists of fluvial sediments which includes the recent sediments transported by Niger River distributaries and other rivers, such as Andoni, Bonny and New Calabar. These materials deposited as regolith overburden of 30m thickness are clays, peat, silts, sands and gravels. The depositional sequence exhibits massive continental sand stones overlying an alternation of sandstones and clays of marginally marine origin, but eventually grading downwards into marine clays. Sands, by far, form the largest group of rock types in the study area followed by clays then mangrove swamps of Pliocene Age. (NDEBUNOG, 2023). Figure 1 shows the location map of the study area.

1.3 General Geology of The Study Area

The study area, situated within Obio Akpor Local Government Area of Rivers State (Figure 1), spans between longitude 6° 55′ 30″ and 6° 59′ 15″ E and latitudes 4° 46′ 3″ and 4° 50′ 15″ N on Port Harcourt Sheet 329 with a scale of 1:100,000. It lies along the failing arm of the triple junction system (aulacogen), formed during the late Jurassic when the American and African plates split, leading to the creation of the Niger Delta wedge (Burke et al., 1972). The southeastern and southwestern arms evolved into the passive continental margin of Africa, while the third arm formed the Benue Trough. Throughout the middle Cretaceous Period, the Niger Delta clastic wedge continued to prograde into a depocentre situated above the collapsed continental margin, receiving sediments from the Benue and Bida Basins. Sediments from the Niger, Benue, and Cross River were present during the Tertiary Period, contributing to the morphological evolution of the Niger Delta from the Paleocene to early Eocene, as noted (Dust and Omatsola, 1989).

According to Short and Stauble, the tertiary Niger Delta deposits exhibit three distinct depositional cycles, with the first two starting in the middle Cretaceous and concluding during the Paleocene Marine Transgression (Short and Stauble, 1967). The second of these cycles occurred in late Paleocene to Eocene Time (Doust and Omatsola, 1990). The present Niger Delta is categorized into three formations—Benin Formation, Agbada Formation, and Akata Formation—based on sedimentological and faunal configurations, as illustrated in Figure 2 (Short and Stauble, 1967). The Paleocene marks the initiation of Delta expansion, characterized by marine clays, later covered by paralic sediments, and followed by continental gravels and sands in subsequent sequences. The geological map of the study area is depicted in Figure 2.

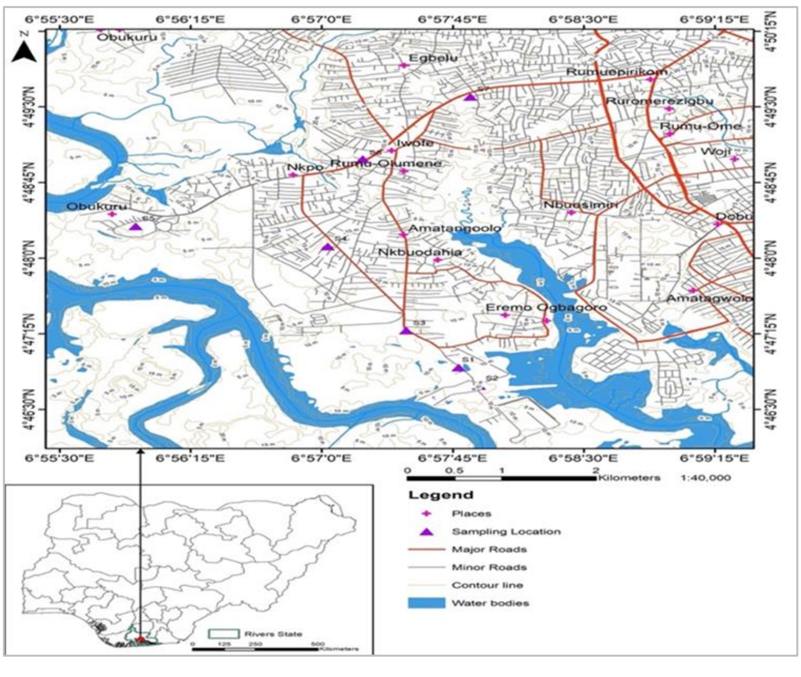

Figure 1: Location Map of Iwofe, Rumolumeni Area and its Environs, Port Harcourt, Rivers State.

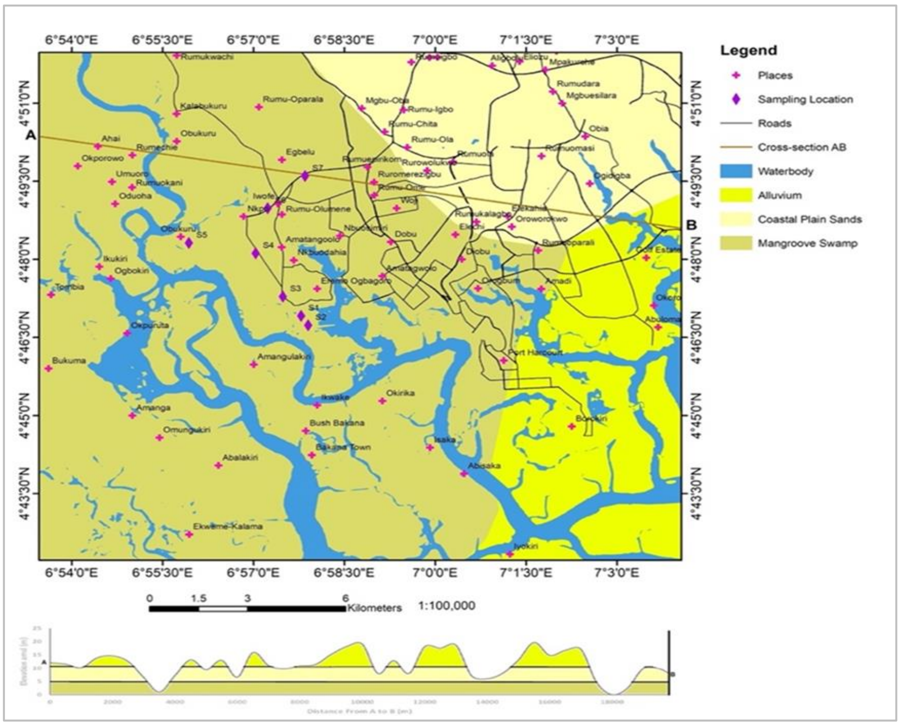

Figure 2: Geologic Map of Iwofe, Rumolumeni Area and its Environs, Port Harcourt

2. Materials and Methods

Seven (7) soil samples were collected from depths ranging from 0 to 30 cm. Composite sampling method was used to collect the soil samples from the study area. Each of the soil samples were stored in sterilized plastic containers and transferred to **Scopex Nigeria Limited Environmental Laboratory**, situated at Aker Road, off Iwofe road for geochemical analysis. The analysis was carried out using an Atomic Absorption Spectrometry technique, utilizing an Atomic Absorption Spectrometer (AAS) machine model GBC XplorrAA. This technique uses the absorption of optical radiation by free atoms in the gaseous state as a quantitative spectro analytical method for identifying chemical elements (Welz and Sperling, 2008).

2.1 Contamination Factor (CF)

The assessment of soil contamination is also carried out using the contamination factor. CF is a quantification of the degree of contamination relative to either average crustal composition of respective metal or to the measured background values from geologically similar and uncontaminated area (Tijani, 2004). It is computed using the equation as:

$$C_f = C_o/C_n \quad (1)$$

The C_f is the single element index. C_o is the mean content of metals from at least five sampling sites and C_n is the metal concentration of the control samples.

Table 1: Location of Sampling Points and their Co-ordinates.

Sampling locations	Coordinate	Samples collected
IWF 1 Along Nkpor Road	4° 46′ 53″N 6° 57′ 50″E	Soil
IWF 2 Along Nkpor Road	4° 46′ 44″N 6° 57′ 54″E	Soil
IWF 3 Along Nkpor Road	4° 47′ 17″N 6° 57′ 29″E	Soil
IWF 4 Jesus Ave off Aker Road	4° 48′ 7″N 6° 57′ 2″E	Soil
IWF 5 Ignatius Ajuru University	4° 48′ 19″N 6° 55′ 56″E	Soil
IWF 6 Along Epirikom Road	4° 48′ 59″N 6° 57′ 15″E	Soil
Control Glorious Covenant Church	4° 49′ 36″N 6° 57′ 50″E	Soil

2.2 Degree of Contamination

A significant number of indicators have been designed to approximate the quality of soils (Caeiro et al., 2005).

The Contamination Degree (Cd) is calculated by (Hakånson, 1980):

$$Cd = \sum C f \quad (2)$$

2.3 Index of Geoaccumulation

The index of geoaccumulation (Igeo) actually enables the assessment of contamination by comparing the current and pre-industrial concentrations originally used with bottom sediments; it can also be applied to the assessment of soil contamination. It is computed using the equation as:

$$I_{geo} = \log_2 (Cn/1.5Bn) \quad (3)$$

Where, Cn is the measured concentration of a given element in the soil tested and Bn is the background value the concentration of elements in the earth's crust. The constant 1.5 allows us to analyze natural fluctuations in the content of a given substance in the environment as well as very small anthropogenic influences.

Table 2: Contamination factor (CF) and degree of contamination (Cd values) (Håkanson, 1980)

S/N	CF Value	Level of Contamination	Cd Value	Degree of Contamination
1	CF < 1	Low contamination factor	Cd<7	Low degree of contamination
2	1 < CF < 3	Moderate contamination factor	7≤Cd<14	Moderate degree of contamination
3	3< CF < 6	Considerable contamination factor	14≤Cd<21	High degree of contamination
4	CF ≥ 6	Very high contamination factor	Cd≥21	Very high degree of contamination

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Table 3: Index of Geoaccumulation (Igeo) for Contamination Level in Soil (Muller, 1969)		
Igeo Class	**Igeo Value**	**Contamination Level**
0	Igeo ≤ 0	Uncontaminated
1	0 < Igeo < 1	Uncontaminated to moderately contaminated
2	1 < Igeo < 2	Moderately contaminated
3	2 < Igeo < 3	Moderately to strongly contaminated
4	3 < Igeo < 4	Strongly contaminated
5	4 < Igeo < 5	Strongly to extremely contaminated
6	5 < Igeo	Extremely contaminated

3. Results and Discussion

The soil samples were analyzed for the presence of various heavy metals, including copper (Cu), cadmium (Cd), chromium (Cr), nickel (Ni), cobalt (Co), iron (Fe), zinc (Zn), and lead (Pb) as shown in Table 4. The heavy metal concentration values of Cadmium (Cd) ranges from 0.05 – 5.94 mg/kg with mean value of 1.4mg/kg, Copper (Cu) 0.90 – 5.09 mg/kg with mean value of 1.22mg/kg, Iron (Fe) 15.17 – 129.56 mg/kg with 62.24mg/kg, Nickel (Ni) 0.74 – 2.23 mg/kg with mean value 1.26mg/kg and Zinc (Zn) 0.26 – 1.10 mg/kg with mean value 0.58mg/kg, no concentrations for lead and chromium were recorded as shown in Table 4. The concentration values of heavy metals analyzed from the control area are Cadmium (Cd) 0.04mg/kg, Copper (Cu) 0.001mg/kg, Iron (Fe) 60.84mg/kg, Nickel (Ni) 0.41mg/kg as shown in Table 4. Figure 3 and 4 illustrate that Iron (Fe) has the highest concentration, followed by Cadmium (Cd) and Nickel (Ni), while Zinc (Zn) shows the lowest concentration.

The average Cadmium (Cd) content is 1.20 mg/kg, influenced by high concentrations in certain areas (IWF 5 and IWF 3) and lower amounts in others (IWF 1, IWF 2, IWF 4, and IWF 5). This can be attributed to the high concentrations from IWF 5 and IWF 3 with 5.94 mg/kg and 1.20 mg/kg respectively and low amounts from IWF 1, IWF 2, IWF 4 and IWF 5 with 0.39 mg/kg, 0.05 mg/kg, 0.58 mg/kg and 0.32 mg/kg respectively. The elevated Cadmium concentrations in IWF 3 may be linked to its proximity to an oil terminal and emissions from petrol tankers passing through. In IWF 5, high Cadmium concentrations could be attributed to atmospheric conditions, fossil fuel combustion, burning of garbage, and proximity to a former cement factory in the area as shown in Table 4 and Figure 3 and 4.

The mean and standard deviation values of Cadmium (Cd) ranges from 1.40± 2.25 with variance value of 5.08, Copper (Cu) 1.22±1.98 with variance value of 3.91, Iron (Fe) 62.24±39.60 with variance value of 1568.03, Nickel (Ni) 0.74±0.57 with variance value 0.33 and Zinc (Zn) 0.58±0.33 with variance value 0.11 as shown in Table 5. High standard deviation and variance values for Iron and Cadmium suggest significant variability in their concentrations across the study area. The concentration of Iron is notably high in IWF 1 compared to other study areas, indicating a localized or specific source of Iron in that particular area. Nickel and Zinc have relatively lower standard deviation and variance values, suggesting more consistent concentrations across the study area. It's essential to consider these variations in metal concentrations for environmental and health assessments, as high concentrations of certain metals, such as Cadmium and Iron, may have environmental implications or potential health risks.

Table 4: Concentration of Heavy Metals of soil samples collected from the sampling area					
Location of Sampling points	**Cadmium (Cd)**	**Copper (Cu)**	**Iron (Fe)**	**Nickel (Ni)**	**Zinc (Zn)**
IWF 1 (mg/kg)	0.39	0.001	129.56	1.54	0.58
IWF 2 (mg/kg)	0.05	0.9	58.49	0.87	0.27
IWF 3 (mg/kg)	1.1	5.09	64.22	1.36	0.85
IWF 4 (mg/kg)	0.58	0.001	74.28	0.74	0.26
IWF 5 (mg/kg)	5.94	0.001	15.17	0.83	1.1
IWF 6 (mg/kg)	0.32	1.36	31.75	2.23	0.44
Mean concentration	1.4	1.22	62.24	1.26	0.58
Control (mg/kg)	0.04	0.001	60.84	0.67	0.41

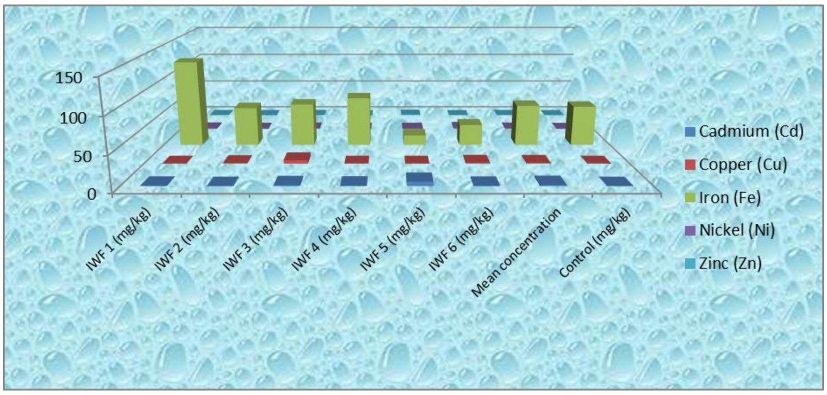

Figure 3: Concentration of heavy metals against heavy metal sampling points

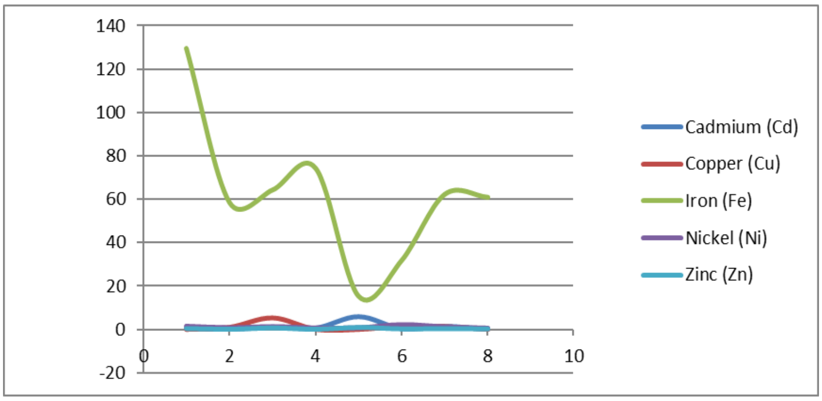

Figure 4: Scatter diagram showing the concentration of heavy metals of soil samples

Table 5: Heavy Metals concentration values of soil samples with statistical parameters

Location Sampling points	Cadmium (Cd) mg/kg	Copper (Cu) mg/kg	Iron (Fe) mg/kg	Nickel (Ni) mg/kg	Zinc (Zn) mg/kg
IWF 1	0.39	0.001	129.56	1.54	0.58
IWF 2	0.05	0.9	58.49	0.87	0.27
IWF 3	1.1	5.09	64.22	1.36	0.85
IWF 4	0.58	0.001	74.28	0.74	0.26
IWF 5	5.94	0.001	15.17	0.83	1.1
IWF 6	0.32	1.36	31.75	2.23	0.44
Mean	1.40	1.22	62.24	1.26	0.58
Min	0.05	0.001	15.17	0.74	0.26
Max	5.94	5.09	129.56	2.23	1.1
Std. Dev.	2.25	1.98	39.60	0.57	0.33
Variance	5.08	3.91	1568.03	0.33	0.11

Comparison of heavy metal concentration values of soil samples with ACV and WHO target value of soil (1996) mg/kg (Puyate et al., 2007; Ekpete and Festus, 2013; Nde and Edori, 2023; Velar et al., 2017). The mean concentration values of the following heavy metals in the soil samples Cadmium (Cd), Copper (Cu), Nickel (Ni), Zinc (Zn) are 1.4mg/kg, 1.22mg/kg, 1.26mg/kg, 0.58mg/kg respectively, which are below the ACV expect Iron (62.24mg/kg) which is above the ACV standard values of 40mg/kg as shown in Table 6 (Puyate et al.,2007).

The mean concentration value of cadmium (1.40mg/kg) is above ACV standard values and higher than mean concentrations but below mean concentrations (Ekpete and Festus, 2013; WHO, 1996; Puyate et al., 2007; Nde and Edori, 2023; Velar et al., 2017). The mean concentration value of Copper (1.22mg/kg) is below the mean concentration value of copper and WHO target value (Nde and Edori, 2023; Ekpete and Festus, 2013; Velar et al., 2017; WHO, 1996). The mean concentration value of Iron (62.24mg/kg) is higher than the mean concentration value of Iron and below the mean concentration value of Iron (Velar et al., 2017; Nde and Edori, 2023; WHO, 1996).

The mean concentration value of Nickel (1.26) is below the mean concentration value of Iron in (Nde and Edori, 2023; Velar et al., 2017; WHO target value (1996). The mean concentration value of Zinc (0.58mg/kg) is below the mean concentration value of zinc as shown in Table 6 (Nde and Edori, 2023; Ekpete, 2013; Velar et al., 2017; WHO target value 1996). Cadmium and Iron concentrations are above the ACV standard values, indicating a potential environmental concern. Copper, Nickel, and Zinc concentrations are generally below the ACV and other reference standard values, suggesting lower environmental risk.

Table 6: Comparison of Heavy Metals concentration values of soil samples of the study with Control values and ACV (Puyate et al., 2007).

Heavy Metals	IWF 1 (mg/kg)	IWF 2 (mg/kg)	IWF 3 (mg/kg)	IWF 4 (mg/kg)	IWF 5 (mg/kg)	IWF 6 (mg/kg)	Mean concentratio n	Control (mg/kg)	ACV (Puyate et al.,2007)
Cadmium (Cd)	0.39	0.05	1.1	0.58	5.94	0.32	1.4	0.04	10
Copper (Cu)	0.001	0.9	5.09	0.001	0.001	1.36	1.22	0.001	20
Iron (Fe)	129.56	58.49	64.22	74.28	15.17	31.75	62.24	60.84	40
Nickel (Ni)	1.54	0.87	1.36	0.74	0.83	2.23	1.26	0.67	38
Zinc (Zn)	0.58	0.27	0.85	0.26	1.1	0.44	0.58	0.41	70

Table 7: Comparison of Heavy Metal concentration value results from the study area with Ekpete and Festus (2013), Nde and Edori (2023), velar et al., (2017) and WHO standard values for soil (1996)

Heavy Metals	This Study	Ekpete & Festus (2013)	Nde & Edori (2023)	Velar et al., (2017)	WHO Target Value of Soil (1996) mg/kg
Cadmium (Cd)	1.4	0.06	2.16	3.7	0.8
Zinc (Zn)	0.58	3.99	10.74	3.19	50
Copper (Cu)	1.22	1.43	6.12	0.18	36
Nickel (Ni)	1.26	-	4.83	8.53	35
Iron (Fe)	62.24	-	131.48	13.09	50,000

3.1 Assessment of Source of Contamination

3.1.1 Classification of Contamination Factor (CF) (Hakanson, 1980) and Degree of Contamination (Hakanson, 1980)

The contamination factor value of cadmium ranges from 0.005mg/kg to 0.11mg/kg with degree of contamination value of 0.838mg/kg, Copper 0.0001mg/kg to 0.254mg/kg with degree of contamination value of 0.368, Iron 0.379mg/kg to 3.239mg/kg with degree of contamination value of 9.337, Nickel 0.0195mg/kg to 0.0587mg/kg with degree of contamination value of 0.199 and Zinc 0.0037mg/kg to 0.0121mg/kg with degree of contamination value of 0.5 as shown in Table 8. According to Hakanson, soil contamination factor values range from 0.0083 to 1.556 and the degree of contamination value of ranges from 0.05 to 9.337 and their contamination level ranges from low to moderate contamination as shown in Table 8 and 9 (Hakanson, 1980).

Cadmium falls within the range specified by Hakanson indicating low to moderate contamination (Hakanson, 1980). Copper falls within the range specified by Hakanson indicating low to moderate contamination (Hakanson, 1980). Iron (Fe): falls within the range specified by Hakanson indicating low to moderate contamination (Hakanson, 1980). Nickel falls within the range specified by Hakanson indicating low contamination (Hakanson, 1980). Zinc (Zn): falls within the range specified by Hakanson indicating low to moderate contamination (Hakanson, 1980). The contamination factor values for Cadmium, Copper, Iron, Nickel, and Zinc suggest varying degrees of contamination, with Iron having the highest degree of contamination (9.337), indicating a higher level of concern. According to Hakanson suggests that the contamination levels for these heavy metals fall within the low to moderate range (Hakanson, 1980).

Table 8: Degree of Contamination (Cd) of soil samples (Hakanson, 1980)							
Heavy Metals	**IWF 1 (mg/kg)**	**IWF 2 (mg/kg)**	**IWF 3 (mg/kg)**	**IWF 4 (mg/kg)**	**IWF 5 (mg/kg)**	**IWF 6 (mg/kg)**	**ΣCF**
Cadmium (Cd)	0.039	0.005	0.11	0.058	0.594	0.032	0.838
Copper (Cu)	0.0001	0.045	0.2545	0.0001	0.0001	0.068	0.3676
Iron (Fe)	3.239	1.4622	1.6055	1.857	0.3792	0.7937	9.3367
Nickel (Ni)	0.0405	0.0229	0.0358	0.0195	0.0218	0.0587	0.1992
Zinc (Zn)	0.0083	0.0038	0.0121	0.0037	0.0157	0.0063	0.05

Table 9: Classification of Contamination Factor (CF) and Degree of Contamination (Hakanson, 1980)						
Heavy Metals	**Mean Concentration**	**ACV (Puyate et al.,2007)**	**Contamination Factor values (CF)**	**Contamination level**	**ΣCF**	**Degree of Contaminatio n**
Cadmium (Cd)	1.4	10	0.14<1	Low	0.838<7	Low
Copper (Cu)	1.22	20	0.061<1	Low	0.368<7	Low
Iron (Fe)	62.24	40	1.556>1<3	Moderate	9.337>1 4	Moderate
Nickel (Ni)	1.26	38	0.0331<1	Low	0.199<7	Low
Zinc (Zn)	0.58	70	0.0083<1	Low	0.05<7	Low

3.1.2 Igeo values (Muller, 1969)

The Igeo values range from 3.219 to 10.70 and their contamination level ranges from strong to extreme contamination. This indicates that the soil samples collected from the study area are highly contaminated with heavy metals as shown in Table 10.

Table 10: Classification of Igeo values (Muller, 1969)			
Heavy Metals	**Mean concentration (mg/kg)**	**Igeo values**	**Contamination level**
Cadmium Cd)	1.40	3.219<5	Strongly
Copper (Cu)	1.225	4.030<5	Strongly
Iron (Fe)	62.245	10.70>5	Extremely
Nickel (Ni)	1.262	4.998<5	Strongly
Zinc (Zn)	0.583	4.767<5	strongly

3.1.2 Assessment of source of contamination relationship of Heavy metals in soil samples using Correlation, Hierarchical Cluster Analysis and Principal Component Analysis

The significance of the observed correlation coefficient results is presented in Table 11. Out of the 15 correlation values found between two parameters, one (1) were found to have a strong positive correlation at the 1% level ($P < 0.05$), one (1) were found to be between Cd and Zn (0.8244). A strong positive correlation between Cadmium (Cd) and Zinc (Zn) at a 1% significance level suggests that there is a high degree of simultaneous release or a common source of contamination for these two metals in the study area. Cadmium (Cd) and Iron (Fe) have strong negative correlation as shown in Table 11. The strong negative correlation between the two pairs of heavy metals suggests that they originated from different sources of contamination. In other words, changes in the concentration of one metal are associated with a decrease in the concentration of the other. Common sources of contamination for the correlated metals, and consideration of local factors, industrial activities, or natural processes that may contribute to these correlations.

The dendrogram divides the source of contamination of the sampling location and heavy metals into 2 clusters and 3 clusters based on their similarity in contamination sources, as shown in Figures 5 and 6. For heavy metals, Cluster 1 (Nickel, Zinc, Copper and Cadmium) has the same source of contamination, Cluster 2 (Iron), has different source of contamination compared to the metals in Cluster 1, as shown in Figure 5. Similarly, for sampling location, Cluster 1 (IWF 2, IWF 3, and IWF 4) has the same source of contamination, Cluster 2 (IWF 5 and IWF 6) has the same source of contamination, but it's different from Cluster 1 as shown in Figure 6. Cluster 3 (IWF 1) has difference source of contamination compare to Cluster 1 and 2. The distinction in sources for Iron (Fe) and the separation of sampling locations into different clusters indicate variability in contamination sources within the study area. The presence of distinct clusters may point to different contamination sources within the study area.

The heavy metal values obtained from the water samples were analyzed using the Principal Component Analysis (PCA): Extraction and Rotation method, which revealed two components related elements and their communalities from the PCA, as shown in Table 12 (Kaiser 1960). There are two components of the following heavy elements (Cd-Cu-Fe-Ni-Zn). Form extraction method, component 1 and 2 with eigenvalues of 2.193 and 1.425 accounted for 72% of variances (43.861 and 28.498) of the heavy metals component of the study area. While component 3, 4 and 5 with eigenvalues of 0.712, 0.641 and 0.03 respectively accounted for 38% of variances (14.236, 12.812 and 0.592) of the heavy metals component of the study area. Component 1 and 2 are the most significant component and their source of contamination may likely associated with the oil terminal in the study area and emissions from petrol tankers passing through the study area as shown Table 13 and Figure 7. Components 3, 4, and 5 contribute to the overall variance but to a lesser extent. They may represent additional sources of contamination.

From rotation method (Varimax with Kaiser Normalization), there are two component. Component 1 shows a strong correlation between Cadmium (0.947) and Zinc (0.882) with communality values of 0.943 and 0.834. This indicates that they share the same source of contamination while component 2 reveals a strong correlation between Copper (0.836) and Nickel (0.759) with communality values of 0.719 and 0.643 which suggest that they have same source of contamination. The communality value of Cadmium indicates that the study area is highly contaminated with Cadmium. High cadmium concentrations in specific areas may have adverse effects on soil quality, agricultural productivity, and livelihoods. Iron (Fe) is identified as having its own source of contamination based on the PCA rotation method with communality value of (0.479) as shown in Table 13. From the PCA, the result revealed that Cd, Cu, Zn and Ni are dominant metals with the highest variance and eigenvalues, as shown in Table 13 and Figure 8. Cadmium (Cd) has a high communality value (0.943), indicating that the study area is highly contaminated with Cadmium. Pollution from heavy metals, especially cadmium, can lead to environmental degradation and negatively impact the health of ecosystems and communities. The results from PCA provide valuable insights into the structure of the heavy metal data and their potential sources in the study area.

Table 12: Correlation Heavy metals of soil samples					
	Cadmium (Cd)	*Copper (Cu)*	*Iron (Fe)*	*Nickel (Ni)*	*Zinc (Zn)*
Cadmium (Cd)	1				
Copper (Cu)	-0.18777	1			
Iron (Fe)	-0.56975	-0.08879	1		
Nickel (Ni)	-0.3661	0.258817	0.043381	1	
Zinc (Zn)	0.82443	0.265777	-0.33711	-0.04709	1

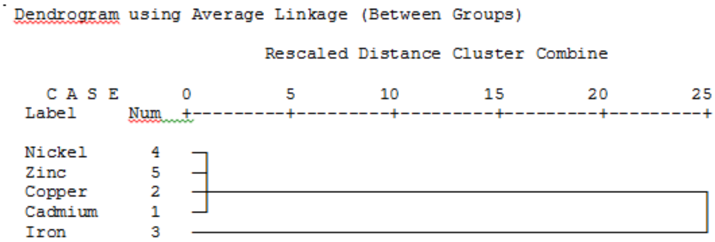

Figure 5: Dendrogram using average linkage between groups of soil showing contamination relationship between heavy metals

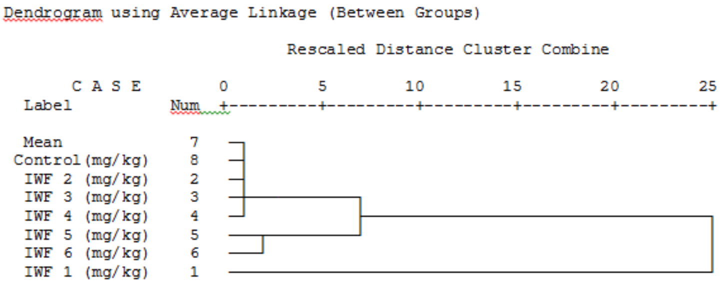

Figure 6: Dendrogram using average linkage between groups of soil showing contamination relationship between sampling points.

Table 13: Principal Component Analysis (PCA)			
Extraction Method			
Component	Eigenvalues	% of Variance	Cumulative %
1	2.193	43.861	43.861
2	1.425	28.498	72.359
3	0.712	14.236	86.596
4	0.641	12.812	99.408
5	0.03	0.592	100
Rotation Method: Varimax with Kaiser Normalization			
Heavy metals	Component 1	Component 2	Communalities
Cadmium	0.947	-0.214	0.943
Copper	0.142	0.836	0.719
Iron	-0.692	0.02	0.479
Nickel	-0.139	0.789	0.643
zinc	0.882	0.238	0.834

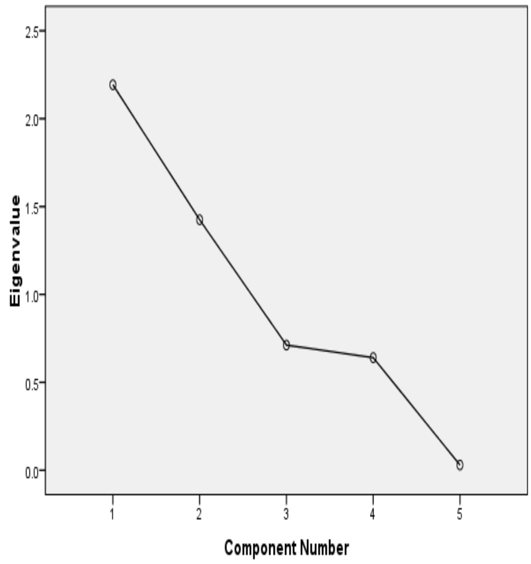

Figure 7: Scree plot of Eigenvalue against component number

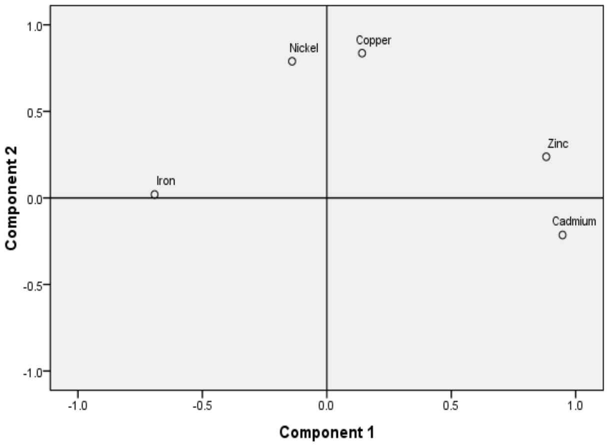

Figure 8: Component plot in Rotated space

4. Conclusion

The in-depth examination of soil samples in the Iwofe Rumuolumeni area of Port Harcourt, Rivers State, Nigeria, has brought to light noteworthy levels of heavy metal contamination, particularly in relation to cadmium and zinc. The concentrations of cadmium observed in samples IWF 3 and IWF 5 exceed the permissible limits set by the World Health Organization (WHO), indicating severe pollution in these specific locations. The likely sources of this contamination are attributed to the proximity of an oil terminal and an abandoned cement factory. The predominant distribution pattern of heavy metals in the study area follows the sequence of iron > cadmium > nickel > copper > zinc. Additionally, the Contamination Factor and Geoaccumulation Index findings point towards a state of moderate to heavy contamination, heightening environmental concerns. On the other hand, the levels of chromium, lead, nickel, and copper in the soil samples fall below W.H.O limits, suggesting minimal contamination from these metals. However, the heightened cadmium levels pose a significant threat to agricultural productivity and the well-being of the local communities. A thorough trace element analysis is imperative to fully grasp the extent of contamination and develop effective mitigation strategies. Taking proactive measures to address pollution sources, such as the oil terminal and industrial activities, is essential for preserving both environmental integrity and human health in the region.

Recommendation

Based on the findings of the study, the following recommendations are proposed:

1. **Further Investigation**: Conduct more detailed trace element analysis to comprehensively assess the extent and sources of heavy metal contamination in the study area. This will provide a clearer understanding of the pollutants' distribution and aid in devising targeted mitigation strategies.

2. **Pollution Control Measures**: Implement measures to control and mitigate the sources of heavy metal pollution, particularly cadmium, such as regulating industrial activities near the affected areas. Efforts should be made to monitor and reduce emissions from nearby facilities, such as oil terminals and abandoned factories, to prevent further contamination of the soil.

3. **Environmental Monitoring**: Establish a continuous environmental monitoring program to track changes in heavy metal concentrations over time. Regular monitoring will help gauge the effectiveness of pollution control measures and identify emerging environmental threats promptly.

4. **Community Awareness and Education**: Raise awareness among local communities about the risks associated with heavy metal contamination and its impact on human health and the environment. Education initiatives should emphasize the importance of sustainable practices and encourage community participation in environmental conservation efforts.

5. **Agricultural Best Practices**: Provide guidance and support to farmers in the affected areas to adopt best practices for soil management and remediation. Techniques such as phytoremediation and soil amendment can help reduce heavy metal concentrations in agricultural soils and improve crop productivity.

6. **Policy Development**: Advocate for the implementation of stringent environmental regulations and policies aimed at controlling industrial emissions and protecting soil quality. Collaborate with relevant government agencies and stakeholders to develop and enforce regulations that promote sustainable development and safeguard environmental health.

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