Original Research Article

EXPLORING THE LEVELS OF HEAVY METALS IN SOIL: A CASE STUDY OF AHOADA WEST LOCAL GOVERNMENT AREA IN RIVERS STATE

Abstract

Background: Heavy metal-polluted soils are becoming more widespread around the world, as geologic and anthropogenic activity grow. The risk of soil contamination by metals increases drastically with increasing industrialization, urbanization, and oil spillage. Thus, it is necessary to monitor heavy metals concentration in agricultural areas because they can pose serious risks to human health and the environment.

Hypothesis: The hypothesis speculates that heavy metals in Ahoada West Local Government Area are affected by geological and anthropogenic factors, exhibiting differences based on soil depth and location. The basis for hypothesis include: geologic and anthropogenic factors. It also involves soil depth variability where metal concentrations are expected to fluctuate with soil depth due to variables such as leaching, sedimentation, and organic matter decomposition, which can all influence metal mobility and availability. And lastly, it is based on location specific factors where different locations may have distinct sources of pollution or soil compositions that influence heavy metal concentrations.

Objectives: the objective of the study was to investigate heavy metals concentration (lead, cadmium, chromium and iron) in soils of Ahoada West Local Government Area, specifically Akinima, Oruama, and Joinkrama 4.

Methods: Soil samples were collected from three places at varying depths (0-5, 0-10, and 0-15 cm). Concentrations of heavy metals were quantified using a Flame Atomic Absorption Spectrophotometer. ANOVA was employed to ascertain significant differences in heavy metal concentrations at $p<0.05$ (IBM SPSS, 21 version).

Results: Results indicated that the concentrations (ppm) of lead (1.44-13.99), chromium (5.23-23.57), cadmium (0.22-2.28), and iron (3.92-13.36) were below the WHO limits. Also, it was observed that heavy metal concentrations increased with increasing soil depths, in the following order 0-15 > 0-10 > 0-5 cm. In terms of spatial distribution, Oruama had significantly higher heavy metal concentrations, followed by Joinkrama 4, and Akinima, with the exception of chromium, which was significantly higher in Joinkrama 4 (8.00; 17.29) in comparison with Oruama (7.30; 15.34), and Akinima (5.23; 12.43) for 0-5 and 0-10 cm respectively.

Conclusion: The study concludes that Oruama community generally had significantly higher levels of heavy metals, although the analyzed soil samples were below WHO permissible limits. This study, advances the understanding of heavy metal dynamics in soil health and agricultural sustainability in Ahoada West, by providing localized information on concentrations relative to depth of soil and locations. It emphasizes the need for regular monitoring to avoid possible pollution and bioaccumulation.

Key words: heavy metals, Akinima, Oruama, Joinkrama 4, environmental monitoring, soil

1.0 Introduction

Exposure to heavy metals is becoming a serious problem, particularly in emerging nations of the world[1]. Although heavy metal is naturally present in the earth's crust, geogenic and human activities have caused it to contaminate the soil[2]. Heavy metal contamination has resulted from industrialization and technological advancement, severely reducing human and animal health[3]. The accumulation of heavy metals in agricultural soil can lead to soil pollution and enhanced absorption by food crops, thereby jeopardizing food quality and safety[1]. Thus, if accumulated in increased concentration exceeding safe thresholds, it may pose a major health risk to people and other living things[4]. Heavy metals and metalloids, including cadmium, lead, arsenic, mercury, and chromium, are environmental pollutants that can accumulate to dangerous amounts in agricultural soils, reducing crop health and productivity[5]. Lead exposure, for instance, can harm the human body's skeletal, circulating, neurological, endocrine, and immune system. Similarly, cadmium exposure can cause cancer[6]. Heavy metals can adversely affect several biological components and organelles. Metal ions can harm human DNA via interactions with both DNA and nuclear proteins. This, in turn, can induce cell cycle regulation, apoptosis, and even cancer. Heavy metals have been shown to induce site-specific damage to human DNA and nuclear proteins upon interaction. The metal causes direct damage by inducing conformational changes in the biomolecules. The generation of reactive oxygen and nitrogen species, along with other endogenous oxidants, is accountable for the indirect harm resulting from heavy metal exposure[7].

Soil is an essential natural resource for a country's economic and agricultural growth. Its significance, which is undeniable, is evidenced by the existence of microbiological organisms as well as humans, plants, and animals. Unfortunately, a number of man-made and natural elements can cause the soil to deteriorate, which would consequently reduce its production[8].

Soil-related issues have become a significant danger to human society[9]. Heavy metal contamination induces alterations in the size, composition, and activity of microbial populations, adversely affecting various factors associated with plant quality and production. Heavy metals interfere with important microbial processes and reduces the quantity and activity of soil microorganisms, thus having harmful impacts on the soil biota[10,11]. Soil microorganisms are essential to soil ecosystems because they regulate nutrient cycling, sustain soil fertility, and enhance plant quality, with their activity potentially affected by heavy metal presence[11].

High levels of heavy metal build up are proven to considerably have detrimental effects on the ecosystem and endanger the lives of those living in it. When these heavy metals are discharged into the geoenvironment, the soil acts as a significant sink and repository[12]. Wuana and Okieimen[13] assert that the accumulation of heavy metals and metalloids in soils can occur from a variety of sources such as emissions from burgeoning industrial zones, disposal of high metal wastes, leaded gasoline and paints, fertilizers application on land, sewage sludge, pesticides, wastewater irrigation, residues from coal combustion, petrochemical spills, and atmospheric deposition. The use of soil for agricultural production and other human activities is limited by contamination[14].

The physical and chemical properties of soil from the Niger Delta region of Nigeria have been compromised by petroleum hydrocarbons and heavy metals. Nigerian petroleum gotten from the Niger Delta contains various concentrations of heavy metals[15]. Oil spills result to heavy metal pollution of terrestrial and aquatic habitat, particularly in areas that produce oil. Crude oil extraction, processing, transportation, and storage are among the operations that contribute to oil spills; which are defined as the discharge of oil into the environment. Spills can also be caused by intentional actions (such as sabotage and oil bunkering) and accident, as well as improper maintenance of engineering equipment[16].

Oil spills and illegal refining could result in unpredictable fire outbreaks that burn vegetation and leave a crust on the soil, necessitating remediation or revegetation[15]. Since Nigeria's crude oil activities is centered on the Niger Delta, the region frequently experience oil spills[16]. Consequently, the worldwide issue of heavy metal contamination necessitates cooperation across communities, governments, and scientific entities. Because governmental laws are crucial for both pollution cleanup and source management[17]. Hence, this study's objective was to investigate heavy metals concentration (lead, cadmium, chromium, and iron) in soils of Ahoada West Local Government Area; specifically, Akinima, Oruama, and Joinkrama 4.

2.0 Materials and Methods

Study area

The study's focus is on the communities of Joinkrama 4, Oruama, and Akinima in the Ahoada West Local Government Area of Rivers State, Nigeria. These communities are situated on the Eastern bank of the Orashi River, a prominent Niger Delta River. Akinima is situated at roughly 5.1046° N, 6.4529° E, while Joinkrama 4 is situated at roughly 4.8265° N, 6.0665° E. The Nigeria Agip Oil Company (NAOC) and Shell Petroleum Development Company (SPDC) run several hydrocarbon flow stations in the area[18]. The region is situated in an area where fishermen and farmers make up the majority of the population. Important operations like oil exploration, illicit bunkering, and transportation are major contaminations in that area[19]. Soil contamination has been an issue in the Niger Delta due to oil production and exploration. The environment has been widely contaminated by oil spills and gas flaring, adversely affecting agricultural output and jeopardizing public health[20-22].

Sample Collection

Using a clean soil auger[23], soil samples were taken from four sites in three chosen communities (Akinima, Oruama, and Joinkrama 4) in Ahoada West Local Government Area, Rivers State at surface depth of 0-5, 0-10, and 0-15 cm. Four soil samples were taken from each site and subsequently combined to create a representative sample of that location. The samples collected were stored in an airtight container and kept in a cool, dark place until analysis.

Quantification of heavy metals using atomic absorption spectrophotometer

Sample preparation process followed the method described by Gong et al.[24], although slightly modified. A mixture containing 100 mL of HNO_3, H_2SO_4, and $HClO_4$ in the proportion of 40%:40%:20% were placed in a conical flask. Ten milliliter (10 mL) of the sample was placed into a conical flask. Two milliliter (2 mL) of the combined acid mixture was added to each of conical flask containing the sample. This was digested in a fume cupboard with hot plate until white vapors emerged. Subsequently, it was cooled and filtered into a 100 mL volumetric flask and then diluted to the 100 mL mark with distilled water. The heavy metals content was determined using flame atomic absorption spectrophotometer (mode: S4=71096) as cited by Duru *et al*.[25]

Statistical analysis

All acquired data were statistically analysed, and the mean ± standard deviation was used to represent the findings. One-way Analysis of Variance (ANOVA) (homogeneity of variance), followed by a post-hoc Tukey Test, was employed to ascertain whether a significant difference existed between the experimental groups. *A p-value < 0.05* was considered statistically significant. All statistical analysis was performed using IBM SPSS software version 21.

3.0 Results

Table 1. Heavy metal concentrations in soil from Akinima

Heavy metals	ppm			
	0 – 5 cm	0 – 10 cm	0 – 15 cm	FAO/ WHO[26,27]

Pb	1.44±0.13[a]	5.03±0.10[b]	9.04±0.06[c]	100-300
Cr	5.23±0.09[a]	12.43±0.07[b]	19.22±0.16[c]	350
Cd	0.22±0.02[a]	0.52±0.01[b]	0.83±0.02[c]	3-8
Fe	3.92±0.08[a]	5.51±0.17[b]	9.51±0.10[c]	50000

Values are expressed as Mean ± Standard Deviation (SD). Values in a row with different alphabetical superscripts do differ significantly (*p*< *0.05*). (a) means 0-5 cm is significantly different from other groups. (b) means 0-10 cm is significantly different from other groups, and (c) means 0-15 cm is significantly different from other groups.

Table 1 shows the heavy metal concentrations (ppm) in soil from Akinima, 0-15 cm was significantly higher for Pb (9.04), Cr (19.22), Cd (0.83), and Fe (9.51) in comparison with 0-10 cm (5.03,12.43,0.52, and 5.51), and 0-5 cm (1.44, 5.23, 0.22, and 3.92) respectively.

Table 2. Heavy metal concentrations in soil from Oruama

		ppm		
Heavy metals	0 – 5 cm	0 – 10 cm	0 – 15 cm	FAO/ WHO[26,27]
Pb	5.04±0.08[a]	9.28±0.18[b]	13.99±0.01[c]	100-300
Cr	7.30±0.18[a]	15.34±0.24[b]	23.57±0.11[c]	350
Cd	1.77±0.08[a]	1.82±0.08[b]	2.28±0.11[c]	3-8
Fe	8.24±0.11[a]	11.03±0.09[b]	13.36±0.14[c]	50000

Values are expressed as Mean ± Standard Deviation (SD). Values in a row with different alphabetical superscript do differ significantly (*p*< *0.05*). (a) means 0-5 cm is significantly different from other groups. (b) means 0-10 cm is significantly different from other groups, and (c) means 0-15 cm is significantly different from other groups.

Table 2 shows the heavy metal concentrations in soil from Oruama, 0-15 cm was significantly higher for Pb (13.99), Cr (23.57), Cd (2.28) and Fe (13.36) in comparison with 0-10 cm (9.28, 15.34,1.82, and 11.03), and 0-5 cm (5.04, 7.30, 1.77, and 8.24) respectively.

Table 3. Heavy metal concentrations in soil from Joinkrama 4(JK 4)

	ppm			
Heavy metals	0 – 5 cm	0 – 10 cm	0 – 15 cm	FAO/ WHO[26,27]
Pb	3.07±0.08^{a}	8.74±0.10^{b}	11.57±0.14^{c}	100-300
Cr	8.00±0.02^{a}	17.29±0.12^{b}	21.71±0.11^{c}	350
Cd	0.45±0.02^{a}	0.73±0.01^{b}	1.29±0.09^{c}	3-8
Fe	5.32±0.16^{a}	7.54±0.11^{b}	13.16±0.11^{c}	50000

Values are expressed as Mean ± Standard Deviation (SD). Values in a row with different alphabetical superscripts do differ significantly (*p< 0.05*). (a) means 0-5 cm is significantly different from other groups. (b) means 0-10 cm is significantly different from other groups, and (c) means 0-15 cm is significantly different from other groups.

Table 3 shows the heavy metal concentrations (ppm) in soil from Joinkrama 4, 0-15 cm was significantly higher for Pb (11.57), Cr (21.71), Cd (1.29) and Fe (13.16) in comparison with 0-10 cm (8.74,17.29,0.73, and 7.54), and 0-5 cm (3.07, 8.00, 0.45, and 5.32) respectively.

Table 4: Heavy metal concentrations in soil from depth 0-5 cm

	ppm			
Heavy metals	Akinima	Oruama	Joinkrama 4 (JK 4)	FAO/ WHO[26,27]
Pb	1.44±0.13^{a}	5.04±0.08^{b}	3.07±0.08^{c}	100-300
Cr	5.23±0.09^{a}	7.30±0.18^{b}	8.00±0.02^{c}	350
Cd	0.22±0.02^{a}	1.77±0.08^{c}	0.45±0.02^{c}	3-8
Fe	3.92±0.08^{a}	8.24±0.11^{b}	5.32±0.16^{c}	50000

Values are expressed as Mean ± Standard Deviation (SD). Values in a row with different alphabetical superscripts do differ significantly (*p< 0.05*). (a) means Akinima is significantly different from other groups, (b) means Oruama is significantly different from other groups, and (c) means JK4 is significantly different from other groups.

Table 4 shows the heavy metal concentrations (ppm) in soil from depth 0-5cm, Oruama was significantly higher for Pb (5.04), Cd (1.77), and Fe (8.24) in comparison with JK 4 (3.07,0.45, and 5.32), and Akinima (1.44, 0.22, and 3.92) respectively. While for Cr concentration, JK 4 (8.00) was significantly higher than Oruama (7.30), and Akinima (5.23).

Table 5. Heavy metal concentrations in soil from depth 0-10 cm

	ppm			
Heavy metals	Akinima	Oruama	Joinkrama 4 (JK 4)	FAO/ WHO[26,27]
Pb	5.03±0.10^{a}	9.28±0.18^{b}	8.74±0.10^{c}	100-300
Cr	12.43±0.07^{a}	15.34±0.24^{b}	17.29±0.12^{c}	350
Cd	0.52±0.01^{a}	1.82±0.08^{b}	0.73±0.01^{c}	3-8
Fe	5.51±0.17^{a}	11.03±0.09^{b}	7.54±0.11^{c}	50000

Values are expressed as Mean ± Standard Deviation (SD). Values in a row with different alphabetical superscripts do differ significantly (*p<0.05*). (a) means Akinima is significantly different from other groups, (b) means Oruama is significantly different from other groups, and (c) means JK4 is significantly different from other groups.

Table 5 shows the heavy metal concentrations(ppm) in soil from depth 0-10 cm, Oruama was significantly higher for Pb (9.28), Cd (1.88) and Fe (11.03) in comparison with JK 4 (8.74, 0.73, and 7.54), and Akinima (5.03, 0.52, and 5.51) respectively. While for Cr concentration, JK 4 (17.29) was significantly higher than Oruama (15.34), and Akinima (12.43).

Table 6. Heavy metal concentrations in soil from depth 0-15 cm

	ppm			
Heavy metals	Akinima	Oruama	Joinkrama 4 (JK 4)	FAO/ WHO[26,27]
Pb	9.04±0.06[a]	13.99±0.01[b]	11.57±0.14[c]	100-300
Cr	19.22±0.16[a]	23.57±0.11[b]	21.71±0.11[c]	350
Cd	0.83±0.02[a]	2.28±0.11[b]	1.29±0.09[c]	3-8
Fe	9.51±0.10[a]	13.36±0.14[b]	13.16±0.11[b]	50000

Values are expressed as Mean ± Standard Deviation (SD). Values in a column with different alphabetical superscripts do differ significantly ($p< 0.05$). (a) means Akinima is significantly different from other groups, (b) means Oruama is significantly different from other groups, and (c) means JK4 is significantly different from other groups.

Table 6 shows the heavy metal concentrations (ppm) in soil from depth 0-15 cm, Oruama was significantly higher for Pb (13.99), Cr (23.57), and Cd (2.28) in comparison with JK 4 (11.57, 21.71 and 1.29), and Akinima (9.04, 19.22 and 0.83 0.52) respectively. While for Fe concentration, there was no significant different between Oruama, and JK 4, although Akinima was significantly lower.

4.0 Discussion of Findings

Soil is the most valuable constituent of the farming ecosystem, and agricultural production depends on using agricultural soil sustainably so that plants can flourish. Pollutants such as heavy metals can contaminate soil, making it less suitable for use in agricultural production and other human activities[2,28] and thus puts human health at risk. The accumulation of heavy metals in soil can degrade soil quality, diminish fertility and crop yields, hence posing risks to human and animal health[29]. Heavy metals such as mercury (Hg), cadmium (Cd), nickel (Ni), lead (Pb), arsenic (As), and chromium (Cr) frequently serve as contaminants in soil environments. This form of contamination is extensive in the soil environment, broadly distributed, and poses significant biological risks[2]. This study considered the concentration of heavy metals in soil samples obtained from selected communities (Akinima, Oruama, and Joinkrama 4) in Ahoada West, Rivers State. Heavy metals such as lead (Pb), chromium (Cr), cadmium (Cd), and iron (Fe) were analysed and detected for their different concentrations.

The heavy metal analysis from soils in Akinima, Oruama, and JK4 communities revealed significant increases in lead (Pb), chromium (Cr), cadmium (Cd), and iron (Fe) concentrations with increasing depth ($p < 0.05$). Additionally, it revealed that lead, chromium, iron, and cadmium were below the FAO/WHO[26,27] permissible limit for all the locations. The concentrations of Pb and Cd from this study was within the range of Akande and Ajayi[1] (Pb; 0.70-36.75, Cd 0.18 -0.63 mg/kg). Omeka and Igwe[12] had a similar Pb (1.15-5.6 mg/kg) value but higher Cd (1.15-3.95 mg/kg) and Fe (129.5-1304.16 mg/kg) levels when compared with this study. Additionally, there was a trend in increasing heavy metals concentration as the depth increases[30]. This is because leaching, organic matter content, soil composition/texture and microbial activity can influence the mobility and retention of metals in soil[25].

The heavy metal concentration at different depths is shown on Table 4-6. For depths 0-5cm and 0-10cm, the concentration of heavy metals analyzed for the different communities was significantly in the order Oruama>Jk 4> Akinima except for Cr which had a different order of Jk4 > Oruama > Akinima respectively. Whereas for 0-15cm depth (Table 6), the concentration of all the heavy metals analysed was significantly in the order Oruama> Jk4> Akinima.

Lead (Pb) has no known biological role, and has been found to cause toxicity at quantities as low as 10 μg/kg in drinking water[31]. Lead has adverse effect on both children and adults. Lead (Pb) impairs both physical and cognitive development in children. Pregnant woman exposed to lead might result in anemia, renal impairment, cephalalgia, fatigue or irritable mood[32]. The lead concentration of the present study, was within the range of Adekiya *et* al[33] who had 0.7-6.7 mg/kg. The Pb contents of the soil samples were lower than the FAO[26,27] permissible limit.

The observed Lead levels likely originated from petrochemical activities or petroleum-based products, as suggested by previous studies[13].

Common forms of chromium in soils include Cr (III) and Cr (VI), which have different level of toxicity. Contrary to Cr (VII), which is a potent oxidizer and extremely poisonous, Cr (III) is a micronutrient and a non-toxic entity, exhibiting toxicity levels that are 10-100 times lower than those of Cr (VI). Cr (VI) is known to negatively impact microbial cell metabolism at high concentrations and alters the composition of soil microbial populations[34,35].

In humans, chromate compounds can induce DNA damage, and allergic dermatitis[32]. The chromium concentration of this study was comparable to Rani *et al*. [36] (9.65-127.21 mg/kg) but higher than Gogoi *et al*.[37] (Cr value of 0.56-0.84 mg/kg). The level of chromium in the soil from all the locations was below the FAO/WHO[26,27] permissible limit of 300-350 ppm.

Cadmium is a non-essential metal, highly hazardous metal that impacts multiple organs and can, in certain instances cause death[38]. Cadmium, present in fertilizers, pesticides, and industrial wastes, elevates the overall concentration of Cd in soils[13], putting people at risk for cancer, anemia and kidney impairment. The level of cadmium in this study was below FAO/WHO[26,27] limit of 5-8 ppm. This study aligns with the claims of Onwugbuta *et al.*[39] who had cadmium range of 1.91-15.04 mg/kg. Although the range, was wider than what this study had. Although, the concentration of all assessed heavy metals were below WHO standards, constant monitoring is necessary due to the disastrous impacts heavy metals have on terrestrial and aquatic life[34].

The research contributes greatly to the knowledge of soil health of soil health and agricultural sustainability in Ahoada West, Rivers State by emphasizing the role of soil as a resource for agriculture and drawing attention to the risks associated by heavy metal contamination, which can hinder plant growth and pose health threats, to humans.

5.0 Conclusion

Heavy metals concentration obtained from soils of selected communities in Ahoada West, Rivers State disclosed that the concentrations of lead (Pb), cadmium (Cd), iron (Fe), and chromium (Cr) were below WHO standard. Despite the amounts of heavy metals being below WHO guidelines, regular monitoring and mitigation measures should be implemented to prevent potential future contamination. The limitations of the study include the examination of only three soil depths, which might have limited insights into changes at additional depths. The study focused on only three communities, which may distort the depiction of heavy metal poisoning in the region. Furthermore, the study focused on a single season, which might overlook seasonal variations in heavy metal concentrations. From the study, it is therefore recommended to develop a consistent program for tracking heavy metals level over time. It is necessary to encourage practices such as phytoremediation and organic amendments to improve soil health. And lastly, farmers and the communities should be educated about pollution hazards and sustainable practices.

Ethics Committee Approval: Ethical approval was granted by the Research and Ethics Committee of Rivers State University, Port Harcourt, Nigeria, with the reference number RSU-REC/2024/FS/0001.

Informed Consent: Not necessary

Use of Ai: Chatgpt 4.0 was used to get insight on the hypothesis, topic, limitations, and recommendation of the study.

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