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Toxic Metals in Farmland Soils of Three Communities in Yenagoa Local Government Area: Concentrations and Impacts Assessment

Augustine Avwerosuo Chokor
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Abstract: *Sustainable agriculture is closely associated with farmland soils quality which is necessary for crops growth, and adequate supply of healthy foods. In this study, some toxic metals (Zn, Cu, Pb, Cd, Ni, & Cr) contents of soils in farmlands of three communities in Yenagoa LGA were evaluated. Analyses of soils samples were performed with Atomic Absorption Spectroscopy (AAS) after digestions with (5:1) mixtures of nitric and perchloric acids. The result reveals large variations in concentrations of metals in soils within and among the communities. However, the mean concentrations (mg/kg) of metals in the communities' farm soils were: Zn (126.19±55.87), Cu (61.73±29.37), Pb (11.09±6.9), Cd (1.85±0.86), Ni (11.24±4.83), and Cr (2.56±1.53). The average sum of the six determined metals (∑6Metals) in the three communities in decreasing order was: Kpansia (244.71±54.05), Ikarama (205.61±48.28), Amarata (193.37±46.48). The overall average ∑6Metals for the communities was 214.66±50.21mg/kg. Evaluations using various indices reveals overall slight pollution by these metals with cadmium been the major driver of the pollution as reflected by its very high contamination factor. Zinc (Zn) and Cu showed moderate contamination factors, and their contributions to the overall pollutions were secondary. The other trio (Pb, Ni, & Cr) exhibited negligible impact on the overall pollutions due to their low contamination factors. The sequence of metals pollutions in the soils was: Cd > Cu ~ Zn > Pb > Ni > Cr. While the order of pollution in the communities was: Kpansia (KP) > Ikarama (IK) > Amarata (AM). The potential ecological risk index for individual metal (ER) were all low in all communities except for cadmium (Cd) which was very high in AM, extremely high in both KP and IK and thus impacting high risks values on the comprehensive potential ecological risk index (RI). These high levels of cadmium and the tendency of the metals to geo-accumulate in these soils overtime calls for measures to be put in place that will maintain levels that pose negligible human and ecological health risk.*

Keywords: *contamination factor, pollution load, degree of contamination, geo-accumulation, potential ecological risk.*

Augustine Avwerosuo Chokor
Department of Chemistry, Faculty of Science, Federal University Otuoke, P.M.B 126, Yenagoa,
Bayelsa State, Nigeria
Email: chokoraa@fuotuoke.edu.ng
https://orcid.org/0000-0001-5090-7071

1.0 Introduction

Agriculture plays a major role in global food security and economic development. It supports the livelihoods of millions of people and contributes substantially to socioeconomic development. However, sustainable agriculture is fundamentally dependent on healthy and productive soils, which are essential for crop growth and development and the production of safe and nutritious food. Thus, elevated concentrations of potentially toxic metals in agricultural soils pose significant threats to crop productivity, food safety and human health. Heavy metals are generally described as metallic elements and metalloids with relatively high atomic mass and density, although there is no universally accepted definition of the term. These elements occur naturally in the environment and, unlike organic contaminants, cannot be degraded into harmless substances, although they can undergo transformations into different chemical species as soil conditions change or metal-binding organic matter decomposes (Ndema Mbongué *et al*., 2024; Drall *et al*., 2025). Heavy metals occur naturally in rock formations and ore minerals; consequently, natural background concentrations of these elements exist in environmental media such as soils, sediments, water and biological tissues. Their generally low background concentrations in environmental media, together with their biological roles, have led to their classification as trace or micronutrient elements (Chokor, 2019; Ramasimong *et al*., 2025).

Soil contamination by heavy metals occurs when their concentrations increase to levels capable of causing harmful effects on vegetation and other components of the environment (Chokor & Ekanem, 2016). Metal-containing leachates may contaminate groundwater, while humans may be exposed to toxic metals through direct contact with or ingestion of contaminated soil. Human exposure may also occur through the consumption of contaminated groundwater and food products through the food chain (Igwe and Abia, 2006; Chokor, 2019; 2021a). Some metals, including Cu and Zn, are essential micronutrients required for normal physiological and biological functions in living organisms. However, at elevated concentrations, these metals may accumulate in biological tissues and pose adverse health and ecological effects (Al-Anbari *et al*., 2015; Chokor, 2016; Kowalska *et al*., 2018). Other metals, such as Pb, Hg and Cd have no known essential biological functions in humans and may produce toxic effects even at relatively low concentrations (Chokor, 2017a; 2019; 2020).

Metal contamination of farmland soils originates from both natural and anthropogenic sources. Natural sources include the weathering of parent rocks, volcanic emissions and atmospheric deposition of mineral particles. Anthropogenic activities are major contributors to heavy-metal contamination and include industrial effluents from mining operations, oil exploration and refining, metal smelting and manufacturing processes (Zhou and Haynes, 2010; He *et al.*, 2015; Chokor, 2020). Other sources include the application of agrochemicals, including phosphate fertilizers contaminated with cadmium and arsenic, copper-based fungicides and zinc-containing pesticides (Zhang *et al*., 2025). The use of sewage sludge as biosolids, application of animal manure containing elevated metal concentrations from supplemented feeds, and irrigation with untreated industrial wastewater also represent important anthropogenic sources of metal contamination in soils (Wuana & Okieimen, 2011; Kumar *et al*., 2017). Unlike organic contaminants, microbial and chemical processes in the soil environment generally do not degrade metals. Consequently, metals and their associated ecotoxicological effects may persist in soils for extended periods after their introduction (Zhou & Haynes, 2010).

Elevated metal concentrations in soil may inhibit plant growth, reduce biomass accumulation and decrease crop yield (Scoccianti *et al*., 2006; Sutapa and Bhattacharyya, 2008). Significant negative correlations between crop yield and concentrations of Cd, Cu, Pb, Zn and Cr in plant roots and shoots have also been reported (Sutapa and Bhattacharyya, 2008). Nickel (Ni) is an essential micronutrient and a component of the urease enzyme required for nitrogen metabolism in higher plants. However, at toxic concentrations, Ni can inhibit plant growth, photosynthesis, seed germination and sugar transport and induce chlorosis, necrosis and wilting (Sreekanth *et al*., 2013; Bhalerao *et al*., 2015). Metals in soils can enter food chains, resulting in contamination of forage and food products and potentially causing adverse effects on human health (Bazzi *et al.*, 2020). Exposure to elevated concentrations of toxic metals can cause a range of adverse effects, including gastrointestinal, neurological, renal, hepatic and reproductive disorders (Chokor, 2020; 2021b). Lead, a systemic toxicant, can adversely affect several organs and physiological systems, including the kidneys, liver, hematopoietic system, central nervous system, endocrine system and reproductive system (Ibrahim *et al.*, 2006; Sharma *et al.*, 2014; Singh *et al.*, 2018; Chokor, 2018). Long-term accumulation of cadmium in body tissues and organs can result in kidney dysfunction, hepatic damage and hypertension (Klassen, 2001; Manahan, 2003). Although zinc is essential for normal physiological functions, excessive exposure can cause systemic dysfunction and impair growth and development (Chokor, 2020; 2021a). Similarly, although copper is an essential element, excessive exposure can cause anaemia, hepatic and renal damage and gastrointestinal irritation (Spee *et al.*, 2005). Chromium contamination is of particular concern because certain chromium species, especially hexavalent chromium [Cr(VI)], exhibit toxic, mutagenic and carcinogenic properties (Zhitkovich, 2011; Remy *et al.*, 2017). Exposure to soluble nickel compounds has been associated with respiratory, reproductive and developmental effects (ATSDR, 2000; IARC, 2017; Buxton *et al.*, 2019).

Several indices have been developed to assess the extent of heavy-metal contamination and its potential environmental implications (Akpakpan *et* al., 2024; Kowalska *et al.*, 2018; Chokor, 2019). The contamination/pollution index (C/P) is used to assess the degree of contamination or pollution associated with metal concentrations, while the geoaccumulation index (Igeo) compares current metal concentrations with background or pre-industrial concentrations to determine the severity of metal accumulation and pollution. The contamination factor (CF) evaluates the contamination level of an individual metal relative to its background concentration. Additionally, the potential ecological risk index (PERI) integrates the contamination levels and toxicological responses of individual metals to estimate their potential ecological risks (Abrahim and Parker, 2008; Likuku *et al.*, 2013; Kowalska *et al.*, 2018; Chokor, 2019). The combined application of these indices provides a more comprehensive assessment of the contamination status and potential ecological implications of metals in agricultural soils than concentration data alone.

Bayelsa State, located in Nigeria's Niger Delta region, has experienced prolonged environmental contamination associated with crude-oil exploration and production, gas flaring, pipeline leakages, illegal refining, bunkering activities and industrial waste discharge. Crude oil and petroleum-related wastes may contain trace metals such as vanadium, nickel, lead and chromium. Consequently, oil spills may pose risks not only from hydrocarbon contamination but also from associated metal contaminants. Oil spills, together with other anthropogenic activities, may therefore contribute to the contamination of farmland soils by potentially toxic metals in the region. The occurrence of petroleum-related environmental pollution in the Niger Delta has consequently generated concerns about the quality of agricultural soils and the safety of crops cultivated in affected areas.

Although heavy-metal contamination has been investigated in different environmental compartments of the Niger Delta, information on the current concentrations and contamination status of multiple potentially toxic metals in farmland soils across communities in Yenagoa Local Government Area remains limited. In particular, comparative information on Zn, Cu, Pb, Cd, Ni and Cr in agricultural soils of the selected communities and their potential ecological implications is insufficient. Addressing this gap is important for understanding the present quality of agricultural soils and for supporting appropriate environmental monitoring and soil-management strategies in the study area.

The assessment of toxic metals in farmland soils is therefore important for identifying metals that may constitute particular environmental concerns, establishing the degree of soil contamination, and determining the potential ecological implications of metal accumulation. The findings can provide useful baseline information for environmental monitoring, agricultural soil management, food-safety assessment and the development of appropriate pollution-control strategies in Yenagoa Local Government Area.

Therefore, this study aimed to determine the concentrations of Zn, Cu, Pb, Cd, Ni and Cr in farmland soils from three selected communities in Yenagoa Local Government Area of Bayelsa State, Nigeria, and to assess their contamination and potential ecological risks using relevant pollution and ecological-risk indices.

2.0 Methodology

2.1 Study Area and Site Locations

Farmland soils in Yenagoa Local Government Area (LGA), Bayelsa State, in the Niger Delta region of Nigeria, were investigated in this study. Three communities—Ikarama (IK; 05°09′17.45″ N, 06°27′08.13″ E), Amarata (AM; 04°55′43.91″ N, 06°17′11.90″ E), and Kpansia (KP; 04°55′47.47″ N, 06°18′49.86″ E)—were selected for the study. The communities were selected based on their extensive farming activities, proximity to oil-related infrastructure, and reported history of pollution events. Ikarama is a rural community that has experienced several incidents of crude-oil spills, whereas Amarata and Kpansia are peri-urban communities subject to potential pollution pressures from urban and industrial waste disposal, automobile workshop activities and domestic wastewater.

The study area is characterized by agricultural activities that provide an important source of livelihood for local communities. The environmental setting, including the prevailing vegetation, soil characteristics, drainage conditions and anthropogenic activities, provides an appropriate context for assessing the occurrence and distribution of potentially toxic metals in farmland soils. A map showing the location of Yenagoa LGA and the three selected communities, together with the sampling locations, should be provided as Fig**.** 1. The assessment of toxic metals in farmland soils is therefore important for identifying metals that may constitute particular environmental concerns, establishing the degree of soil contamination, and determining the potential ecological implications of metal accumulation. The findings can provide useful baseline information for environmental monitoring, agricultural soil management, food-safety assessment and the development of appropriate pollution-control strategies in Yenagoa Local Government Area.

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Fig. 1: Map of the study area

2.2 Sample Collection

A standard hand auger was used to collect soil samples from the 0–20 cm surface layer of farmland soils in the three communities. At each sampling location, surface litter was removed before soil collection, and the sampling equipment was cleaned between sampling points to minimize cross-contamination. A total of 135 individual soil samples were collected and combined to obtain 27 composite samples, comprising nine composite samples from each community. Five individual soil samples were combined and thoroughly homogenized to form each composite sample. The composite samples were collected from geographically separated farmlands to improve spatial representation of the study area. The geographical coordinates of the sampling locations were recorded using a handheld GPS device.

The composite soil samples were placed in clean, labeled polyethylene bags and transported to the laboratory for preparation and analysis (Chokor and Ekanem, 2016). The sampling was conducted during rainy and dry seasons of 2025.

2.3 Sample Preparation and Analysis

The soil samples were air-dried in a clean, well-ventilated laboratory environment for approximately two weeks (Chokor, 2017b). Representative portions of the dried samples were obtained using the quartering method. The dried representative soil samples were gently disaggregated using a porcelain mortar and pestle and passed through a 2-mm stainless-steel sieve. A known mass of the sieved soil sample was digested using a 5:1 (v/v) mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$), following the procedure of Tessier *et al.* (1979).

The resulting digest was cooled and diluted to a known volume with deionized water before instrumental analysis.

The total concentrations of Zn, Cu, Pb, Cd, Ni and Cr in the digested soil samples were determined using an atomic absorption spectrophotometer (Buck Scientific Model 210 VGP). Report the analytical wavelengths, calibration ranges, and instrumental detection limits for each metal. Where applicable, the analytical conditions used for flame operation and instrumental calibration should also be provided to ensure reproducibility of the measurements.

2.4 Quality Control and Quality Assurance

Analytical-grade reagents obtained from BDH and Sigma were used throughout the analysis. Buck Scientific certified standard solutions were used to prepare calibration standards for the atomic absorption spectrophotometer. Calibration curves were prepared for each metal before sample analysis, and instrument response was checked throughout the analytical procedure.

Reagent blanks were subjected to the same digestion procedure using the same quantities of reagents as the samples to account for potential contamination arising from the analytical procedure. Matrix-spike analyses were performed to assess analytical recovery, precision and potential matrix effects. All analytical determinations were performed in triplicate, and the results were expressed as mean ± standard deviation (SD).

The method detection limit (MDL), limit of detection (LOD), limit of quantification (LOQ), percentage recovery and calibration correlation coefficient (R^2) should be reported where these parameters were determined. Where a certified reference material was used, its recovery results should also be reported. These quality-control measures were used to verify the reliability and reproducibility of the analytical results.

2.5 Contamination and Ecological Risk Assessment

The contamination status and potential ecological risks associated with the measured metal concentrations were evaluated using the contamination/pollution index (C/P), geoaccumulation index (Igeo), contamination factor (CF), modified degree of contamination (mCd), pollution load index (PLI), potential ecological risk factor (ER) and comprehensive potential ecological risk index (RI). The indices were selected to provide complementary information on the contamination status of individual metals, the overall degree of metal accumulation and the potential ecological risks associated with the combined metal concentrations (Abrahim and Parker, 2008; Likuku *et al*., 2013; Kowalska *et al*., 2018; Chokor, 2019).

2.5.1 Contamination/Pollution Index (C/P)

The contamination/pollution index (C/P) was used to assess the degree of contamination or pollution associated with the concentration of each investigated metal. The index was calculated according to the equation and classification scheme according to equation 1

$$C/P = \frac{C_{metal}}{C_{target}} \qquad (1)$$

where C_{metal} is the measured concentration of the heavy metal in the soil or sample and C_{target} is the target reference/standard limit (e.g., maximum permissible standard, target value, or baseline background concentration). The resulting values were interpreted according to the classification criteria adopted from Lacatusu (1998).

2.5.2 Geoaccumulation Index (Igeo)

The geoaccumulation index (I_{geo}) was used to evaluate the degree of metal accumulation in the farmland soils relative to the selected background concentrations. The index was calculated using equation 2

$$I_{geo} = log_2\left[\frac{C_n}{1.5 \times B_n}\right] \quad (2)$$

where $\boldsymbol{C_n}$ is the measured concentration of the metal in the soil and $\boldsymbol{B_n}$ is its corresponding geochemical background concentration. The factor 1.5 accounts for possible variations in the background concentration caused by lithogenic processes. The Igeo values were classified according to the established categories ranging from unpolluted to extremely polluted.

2.5.3 Contamination Factor (CF)

The contamination factor (CF) was used to evaluate the contamination level of an individual metal relative to its background concentration and was calculated using equation 3

$$CF = \frac{C_n}{B_n} \quad (3)$$

.The CF values were interpreted using the standard classification criteria.

2.5.4 Modified Degree of Contamination (mCd)

The modified degree of contamination (mCd) was used to describe the overall degree of contamination resulting from the investigated metals. It was calculated from the contamination factors of the individual metals according to equation 4

$$mC_d = \sum \frac{CF}{n} \quad (4)$$

where ΣCF represents the sum of the contamination factors for all investigated metals and n is the number of metals evaluated.

2.5.5 Pollution Load Index (PLI)

The pollution load index (PLI) was used to provide an integrated assessment of the overall metal pollution status of the investigated soils. It was calculated as:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{1/n} \quad (5)$$ _

where CF represents the contamination factor for each metal and n is the number of metals considered. A PLI value of 1 represents baseline levels, whereas values greater than 1 indicate progressive deterioration or pollution relative to the selected background condition.

2.5.6 Potential Ecological Risk Factor (ER)

The potential ecological risk factor (ER) was used to estimate the ecological risk associated with each individual metal by incorporating its contamination level and toxicological response. It was calculated as:

$$ER = Tr \times CF \quad (6)$$

where Tr is the toxic-response coefficient of the metal and CF is its contamination factor. The ER values were interpreted according to the ecological-risk classification.

2.5.7 Comprehensive Potential Ecological Risk Index (RI)

The comprehensive potential ecological risk index (RI) was used to estimate the overall potential ecological risk posed by all investigated metals and was calculated according to equation 7

$$RI = \sum ER \quad (7)$$

where ER represents the potential ecological risk factor for each individual metal. The RI values were interpreted according to the classification scheme adopted from

2.6 Statistical Analysis

Descriptive statistics were used to summarize the concentrations of the investigated metals in the soil samples from the three communities. Results were expressed as mean ± standard deviation. Where appropriate, differences in metal concentrations among communities were evaluated. Statistical analyses were performed using Origin.

3.0 Results and Discussion

3.1 Concentrations of metals in farmland soils

Table 1 presents the mean ± standard deviation and concentration ranges of Zn, Cu, Pb, Cd, Ni and Cr in farmland soils collected from

Amarata (AM), Kpansia (KP) and Ikarama (IK). Considerable spatial variability was observed both within and among the three communities. The overall mean concentrations followed the order Zn > Cu > Ni > Pb > Cd > Cr, with mean concentrations of 126.19 ± 55.87, 61.73 ± 29.37, 11.24 ± 4.83, 11.09 ± 6.90, 1.85 ± 0.86 and 2.56 ± 1.53 mg/kg, respectively. Thus, Zn was the most abundant of the six investigated metals, whereas Cd had a relatively low absolute concentration but was subsequently found to be the most important contaminant when evaluated against background and critical values.

The mean total concentration of the six metals (∑6Metals) was highest in Kpansia (244.71 ± 54.05 mg/kg), followed by Ikarama (205.61 ± 48.28 mg/kg) and Amarata (193.37 ± 46.48 mg/kg). The overall mean ∑6Metals for the three communities was 214.66 ± 50.21 mg/kg. The relatively higher total metal concentration observed in Kpansia may reflect its greater exposure to urban, domestic and other anthropogenic inputs, whereas the elevated concentrations observed in Ikarama may be associated with its documented history of petroleum-related pollution. However, these proposed sources should be regarded as possible contributors rather than definitive sources because concentration data alone cannot establish contaminant provenance.

Table 1: The mean± standard deviation and ranges of metals' concentrations in Farmlands' soils of the different communities

Metals	**Mean and range of concentrations (mg/kg)**			
	AM	**KP**	**IK**	**Ave**
Zn	118.87±52.40	137.46±60.25	122.26±54.80	126.19±55.87
	(93.91 - 172.96)	(107.38 - 190.70)	(95.30 - 180.17)	(118.- 137.46)
Cu	53.08±22.32	72.54±37.88	59.58±29.92	61.73±29.37
	(41.50 - 77.98)	(56.02 - 105.45)	(42.63 - 84.56)	(53.08 – 72.54)
Pb	8.85±6.10	15.12±7.10	9.29±7.50	11.09±6.9
	(2.06 - 15.76)	(2.80 - 26.02)	(2.21 - 16.30)	(8.85 – 15.17)
Cd	1.66±0.75	2.02±1.10	1.88±0.73	1.85±0.86
	(0.41 - 2.15)	(0.76 - 2.53)	(0.59 - 2.23)	(1.66 – 2.02)
Ni	9.81±4.73	13.29±5.15	10.62±4.70	11.24±4.83
	(7.30 - 15.08)	(10.15 - 19.53)	(7.90 - 16.33)	(9.81 – 13.29)
Cr	1.43±1.00	4.28±2.50	1.98±1.20	2.56±1.53
	(0.80 - 2.66)	(3.10 - 6.57)	(1.31 - 3.37)	(1.43 – 4.28)
∑6Metals	193.37±46.48	244.71±54.05	205.61±48.28	214.66±50.21
	(168.80 – 281.53)	(187.23 – 345,80)	(157.93 – 293.95)	(193.37 – 244.76)

Zinc concentrations ranged from 93.91–172.96 mg/kg in AM, 107.38–190.70 mg/kg in KP, and 95.30–180.17 mg/kg in IK. The corresponding mean concentrations were 118.87 ± 52.40, 137.46 ± 60.25 and 122.26 ± 54.80 mg/kg, respectively. The highest mean Zn concentration occurred in Kpansia. The mean concentrations exceeded the Canadian and Finnish critical values of 50 and 90 mg/kg, respectively, and were also above the 100 mg/kg values reported for Denmark and Eastern Europe. These comparisons indicate that Zn enrichment warrants attention, although the interpretation should acknowledge that guideline values are jurisdiction-specific and may differ in their derivation, land-use assumptions and ecological endpoints.

Copper concentrations were 53.08 ± 22.32 mg/kg in AM, 72.54 ± 37.88 mg/kg in KP and 59.58 ± 29.92 mg/kg in IK. Kpansia therefore recorded the highest mean Cu concentration, whereas Amarata had the lowest. The mean concentrations were above several of the international critical values presented in Table 2. The elevated Cu concentrations may be associated with a combination of agricultural and urban inputs, including copper-containing agrochemicals and wastes; however, additional source-specific evidence would be required to establish the dominant contribution.

Lead concentrations ranged from 2.06–15.76 mg/kg in AM, 2.80–26.02 mg/kg in KP and 2.21–16.30 mg/kg in IK, with mean concentrations of 8.85 ± 6.10, 15.12 ± 7.10 and 9.29 ± 7.50 mg/kg, respectively. Kpansia recorded the highest mean Pb concentration. Although the observed Pb concentrations were generally below most of the critical values presented in Table 2, the considerable spatial variability suggests heterogeneous inputs within the study area. Possible contributors include vehicular activities, waste disposal and petroleum-related activities, but these sources cannot be conclusively established from concentration data alone.

Cadmium recorded mean concentrations of 1.66 ± 0.75, 2.02 ± 1.10 and 1.88 ± 0.73 mg/kg in AM, KP and IK, respectively. These concentrations were above all of the critical values presented in Table 2. In particular, the mean Cd concentrations substantially exceeded the values reported for Canada, Denmark, Finland, the Czech Republic, Ireland, Eastern Europe, Switzerland and the Netherlands. This finding is important because Cd is a non-essential toxic metal and can pose environmental concerns even when its absolute concentration is relatively low. Agricultural inputs, particularly phosphate fertilizers, are recognized potential sources of Cd in cultivated soils. Nevertheless, direct attribution to phosphate fertilizer application requires information on fertilizer type, application rate and historical land-use practices.

Nickel concentrations ranged from 7.30–15.08 mg/kg in AM, 10.15–19.53 mg/kg in KP and 7.90–16.33 mg/kg in IK, with corresponding means of 9.81 ± 4.73, 13.29 ± 5.15 and 10.62 ± 4.70 mg/kg. Kpansia again recorded the highest mean Ni concentration. Except for the comparison with the Canadian critical value, the mean concentrations were generally below the critical limits reported for the countries listed in Table 2. The relatively low Ni concentrations indicate limited enrichment relative to most of the cited guideline values.

Chromium concentrations were 0.80–2.66 mg/kg in AM, 3.10–6.57 mg/kg in KP and 1.31–3.37 mg/kg in IK, with an overall mean concentration of 2.56 ± 1.53 mg/kg. Kpansia had the highest Cr concentration range. The observed concentrations were considerably lower than the critical values presented in Table 2, indicating relatively low Cr enrichment based on the selected guideline comparisons. Nevertheless, the spatial differences in Cr concentration indicate that local variability exists and should be considered when evaluating possible sources.

3.2 Comparison with international critical values

The comparison presented in Table 2 shows that the degree of concern differs considerably among the investigated metals. Zn and Cu showed concentrations exceeding several of the listed critical values, while Pb, Ni and Cr were generally below most of the corresponding limits. Cd showed the most consistent exceedance of the listed critical values. This distinction is important because absolute concentration alone does not adequately describe contamination severity; the interpretation also depends on the selected reference or regulatory value.

Table 2: Critical limits of metals in soil for several countries

Countries	Critical limits (mg/kg)					
	Zn	**Cu**	**Pb**	**Cd**	**Ni**	**Cr**
Canada	50	30	25	0.5	20	20
Denmark	100	30	40	0.3	10	50
Finland	90	32	38	0.3	40	80
Czech Republic	150	70	70	0.4	60	130
Netherland	140	36	85	0.8	35	100
Switzerland	200	50	50	0.8	50	75
Ireland	150	50	50	1.0	30	100
Eastern Europe	100	55	32	0.2	85	90

Sources: De Vries and Bakker, 1998; Eastern Europe includes Russia, Ukraine, Moldova and Belarus)

3.3 Contamination/pollution index

The contamination/pollution (C/P) indices calculated using the Canadian critical values are presented in Table 3, while their classification criteria are presented in Table 4. The C/P index represents the ratio between the measured concentration of a metal and its selected critical/reference value. Values greater than one indicate that the measured concentration exceeds the selected reference value.

The mean C/P values for the six metals were 2.53 for Zn, 2.06 for Cu, 0.44 for Pb, 3.71 for Cd, 0.56 for Ni and 0.13 for Cr. Based on the classification presented in Table 4, Zn, Cu and Cd were within the pollution category, whereas Pb, Ni and Cr fell within the contamination category. Cd recorded the highest mean C/P value and was therefore the principal contributor to the overall pollution status.

The mean C/P values for the three communities were 1.40 for AM, 1.78 for KP and 1.53 for IK, with an overall mean of 1.57. These values fall within the slight-pollution category according to the classification adopted in this study. Kpansia had the highest overall C/P value, followed by Ikarama and Amarata. This pattern is broadly consistent with the concentration data and suggests greater overall enrichment in Kpansia. The ranking of the metals based on their mean C/P values was Cd > Zn > Cu > Ni > Pb > Cr. The dominance of Cd is particularly noteworthy because it combines relatively elevated concentrations with a comparatively low critical/reference value. Thus, Cd represents the most important metal requiring attention in the study area.

3.4 Geoaccumulation index

The geoaccumulation index (Igeo) values calculated using upper continental crust (UCC) background concentrations are presented in Table 5. The Igeo provides an estimate of the degree to which measured metal concentrations are enriched relative to a selected geochemical background. The index should be interpreted cautiously because UCC values represent generalized background conditions and may not adequately capture the natural geochemical characteristics of the local soils.

The mean Igeo values for Zn were 0.242, 0.452 and 0.283 in AM, KP and IK, respectively, indicating unpolluted to moderately polluted conditions. Copper recorded mean Igeo values of 0.338, 0.788 and 0.504, also corresponding to unpolluted to moderately polluted conditions. The mean Igeo values for Pb, Ni and Cr were negative in all three communities, indicating unpolluted conditions relative to the adopted UCC background values.

Table 3: Heavy metal pollution profiles calculate from the range and mean concentrations individual metal C/P index

Samples	Mean and range of C/P values			
	AM	KP	IK	Ave
Zn	2.38 (1.88 – 3.46)	2.75 (2.15 – 3.81)	2.45 (1.91 – 3.60)	2.53 (2.38 – 2.75)
Cu	1.77 (1.38 – 2.60)	2.42 (1.87 – 3.52)	1.99 (1.42 – 2.82)	2.06 (1.77 – 2.42)
Pb	0.35 (0.08 – 0.63)	0.60 (0.11 – 1.04)	0.37 (0.09 – 0.65)	0.44 (0.35 – 0.60)
Cd	3.32 (0.82 – 4.30)	4.04 (1.52 – 5.06)	3.76 (1.18 – 4.46)	3.71 (3.32 – 4.04)
Ni	0.49 (0.37 – 0.75)	0.66 (0.51 – 0.98)	0.53 (0.40 – 0.82)	0.56 0.49 – 0.66)
Cr	0.07 (0.04 – 0.13)	0.21 (0.16 – 0.33)	0.10 (0.07 – 0.17)	0.13 (0.07 – 0.21)
Ave	1.40 (0.07 – 3,32)	1.78 (0.21 – 4.04)	1.53 (0.10 – 3.76)	1.57 (1.40 – 1.78)

*range in brackets; AM = Amarata; KP = Kpansia; IK = Ikarama

Table 4: Significance of intervals of contamination/pollution (C/P) index

C/P	Significance
<0.1	Very slight contamination
0.10 – 0.25	Slight contamination
0.26 – 0.50	Moderate contamination
0.51 – 0.75	Severe contamination
0.76 – 1.0	Very severe contamination
1.1 – 2.0	Slight pollution
2.1 – 4.0	Moderate pollution
4.1 – 8.0	Severe pollution
8.1 – 16.0	Very severe pollution
>16	Excessive pollution

Source: Lacatusu, 1998

Cadmium exhibited a markedly different pattern, with mean Igeo values of 2.883 in AM, 3.166 in KP and 3.063 in IK. These values correspond to moderately to strongly polluted conditions for AM and strongly polluted conditions for KP and IK, according to the adopted Igeo classification. Cd was therefore the dominant metal responsible for geochemical enrichment in the study soils.

The high Cd Igeo values suggest substantial enrichment relative to the adopted UCC background. Possible sources include phosphate fertilizers, petroleum-related materials, domestic wastes and other anthropogenic inputs. However, because Igeo is dependent on the selected background concentration, the observed enrichment should be interpreted as evidence of relative accumulation rather than definitive proof of a particular source.

3.4 Geoaccumulation index

The geoaccumulation index (Igeo) values calculated using upper continental crust (UCC) background concentrations are presented in Table 5. The Igeo provides an estimate of the degree to which measured metal concentrations are enriched relative to a selected geochemical background. The index should be interpreted cautiously because UCC values represent generalized background conditions and may not adequately capture the natural geochemical characteristics of the local soils.

The mean Igeo values for Zn were 0.242, 0.452 and 0.283 in AM, KP and IK, respectively, indicating unpolluted to moderately polluted conditions. Copper recorded mean Igeo values of 0.338, 0.788 and 0.504, also corresponding to unpolluted to moderately polluted conditions. The mean Igeo values for Pb, Ni and Cr were negative in all three communities, indicating unpolluted conditions relative to the adopted UCC background values.

Table 5: Ranges and mean Igeo values calculated from Upper continental crust (UCC) background values

Metal	Igeo		
	AM	**KP**	**IK**
Zn	0.242 (-0.098 – 0.783)	0.452 (0.096 – 0.924)	0.283 (-0.077 – 0.842)
Cu	0.338 (-0.017 – 0.893)	0.788 (0.416 – 1.328)	0.504 (0.021 – 1.00)
Pb	-1.2447 (-3.350 - -0.414)	-0.474 (-2.907 – 0.309)	-1.177 (-3.248 - -0.366)
Cd	2.883 (0.866 – 3.256)	3.166 (1.756 – 3.491)	3.063 (1.391 – 3.309)
Ni	-2.845 (-3.272 - -2.225)	-2.407 (-2.796 - -1.852)	-2.731 (-3.158 - -2.110)
Cr	-6.593 (-7.430 - -5.697)	-5.011 (-5.476 - -4.393)	-6.123 (-6.719 - -5.3560)

*range in brackets; UCC values were abstracted from Rudnick and Gao, 2003

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3.5 Contamination factor and modified degree of contamination

The contamination factors (CF) and ecological risk factors (ER) presented in Table 6 provide further evidence of differences in metal enrichment among the communities. The mean CF values for Cd were 11.07, 13.47 and 12.53 in AM, KP and IK, respectively. Based on the classification of Hakanson (1980), these values represent very high contamination by Cd in all three communities.

Copper and Zn followed Cd in terms of contamination factor, whereas Pb, Ni and Cr generally exhibited lower CF values. The overall order of contamination based on mean CF was Cd > Cu > Zn > Pb > Ni > Cr. This ranking agrees broadly with the C/P and Igeo results and identifies Cd as the principal contaminant of concern.

The modified degree of contamination (mCd) considers the combined contribution of the investigated metals. Mean mCd values were 2.60 for AM, 3.25 for KP and 2.90 for IK, indicating moderate degrees of overall contamination according to the classification adopted in this study. The highest mean mCd occurred in Kpansia, consistent with its higher total metal concentration and C/P value.

However, mCd represents an averaged measure and may obscure the contribution of individual metals. In this study, such masking is particularly important because Cd exhibited very high contamination while several other metals showed comparatively low CF values. Consequently, mCd should be interpreted together with the individual CF values rather than as an independent indication that all six metals pose comparable environmental concerns.

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The pollution load index (PLI) provides an integrated measure of the combined contamination factors of the investigated metals. The mean PLI values were **0**.65 for AM, 1.00 for KP and 0.73 for IK. These values indicate that the overall pollution burden was greatest in Kpansia. The PLI values for Amarata and Ikarama were below one, while Kpansia was approximately one, suggesting the need for continued monitoring and more detailed investigation of metal accumulation in the agricultural soils.

3.6 Pollution load index and ecological risk

The ecological risk factor (ER) showed that Cd was the dominant contributor to potential ecological risk. While the ER values for Zn, Cu, Pb, Ni and Cr were generally low, Cd recorded very high to extremely high ecological risk across the communities. The dominance of Cd in the ecological risk assessment is consistent with the results obtained from the C/P, Igeo and CF indices.

The comprehensive potential ecological risk index (RI), which integrates the ecological risk contributions of the investigated metals, ranged from moderate to high depending on the community and concentration range.

Table 6: lower range (LR), upper range (UR), and mean (M) values for contamination factors (CF), modified degree of contaminations (mCd), Pollution load index (PLI), ecological risk indices (ER), and the comprehensive ecological risk indices (RI) for the different communities

Metal	Amarata (AM)						
	CF				ER		
	LR	UR	M		LR	UR	M
Zn	1.40	2.58	1.77		1.40	2.58	1.77
Cu	1.48	2.79	1.90		7.41	13.93	9.48
Pb	0.15	1.13	0.63		0.74	5.63	3.16
Cd	2.73	14.33	11.07		82.00	430.00	332.00
Ni	0.16	0.32	0.21		0.78	1.60	1.04
Cr	0.012	0.03	0.02		0.02	0.06	0.03
Cd*	5.93	21.18	15.59	RI= ∑ER	92.34	453.80	347.49
mCd	0.99	3.53	2.60				
PLI	0.32	1.01	0.65				
Kpansia (KP)							
Zn	1.60	2.85	2.05		1.60	2.85	2.05
Cu	2.00	3.77	2.59		10.00	18.83	12.95
Pb	0.20	1.86	1.08		1.00	9.29	5.40
Cd	5.07	16.87	13.47		152.00	506.00	404.00
Ni	0.22	0.42	0.28		1.08	2.08	1.41
Cr	0.03	0.07	0.05		0.07	0.14	0.09
Cd*	9.12	25.82	19.52	RI= ∑ER	165.75	539.19	425.91
mCd	1.52	4.30	3.25				
PLI	0.54	1.47	1.00				
Ikarama (IK)							
Zn	1.42	2.69	1.82		1.42	2.69	1.82
Cu	1.52	3.02	2.13		7.61	15.10	10.64
Pb	0.16	1.16	0.66		0.79	5.82	3.32
Cd	3.93	14.87	12.53		118.00	446.00	376.00

Ni	0.17	0.35	0.23		0.84	1.74	1.13
Cr	0.01	0.04	0.02		0.03	0.07	0.04
Cd*	7.22	22.12	14.40	RI= ∑ER	128.69	471.42	392.95
mCd	1.20	3.69	2.90				
PLI	0.54	1.10	0.73				

**C_d* refers to degree of contamination

The mean RI values were 347.49 for AM, 425.91 for KP and 392.95 for IK. According to the classification presented in Table 7, these mean values fall within the high ecological risk category. Cd was the principal contributor to the elevated RI values. Therefore, although several of the investigated metals occurred at relatively low concentrations, the high toxicity weighting and enrichment of Cd substantially increased the overall ecological risk.

These findings emphasize the importance of considering both concentration and toxicity when evaluating contaminated soils. A metal with a relatively low absolute concentration can contribute substantially to ecological risk if its toxic-response coefficient is high.

3.7 Correlation analysis and possible sources of metals

The Pearson correlation coefficients among the six metals are presented in Table 8. A very strong positive correlation was observed between Pb and Ni ($r = 0.889$, $p < 0.01$), suggesting that their concentrations varied in a similar manner across the sampled soils. Strong positive relationships were also observed between Zn and Cd ($r = 0.817$) and between Cu and Cd ($r = 0.776$), while Zn and Cu were positively correlated ($r = 0.753$, $p < 0.05$). These relationships may indicate common or partially overlapping sources, similar environmental behaviour or co-transport processes.

In contrast, weak or very weak relationships were observed among several metal pairs, particularly those involving Cr. The relatively weak correlations between Cr and the other metals suggest that its spatial distribution may be influenced by factors different from those controlling the distributions of Zn, Cu and Cd. However, correlation alone cannot establish contaminant sources because similar concentrations can arise from different processes and different metals can behave similarly under common soil conditions.

Principal component analysis (PCA) was therefore used as an additional multivariate approach to investigate patterns of association among the metals. As shown in Table 9, two principal components accounted for approximately 87.0% of the total variance, with PC1 explaining 54.3% and PC2 explaining 32.7%.

PC1 was associated primarily with the group of metals linked broadly with Zn, Cu and Cd. The association of these metals may reflect common contributions from agricultural, urban and industrial activities. PC2 was principally associated with Pb and Ni, which may be consistent with petroleum-related or other anthropogenic inputs in the study area. However, these interpretations should be considered indicative rather than definitive source assignments, because PCA identifies statistical associations rather than proving specific sources.

Table 7: Grading standard for single and comprehensive potential ecological risk index

Monomial potential ecological risk factor (ER)	Comprehensive potential ecological risk factor (RI)	Pollution level (ecological hazard)
≤40	≤150	Low
40 – 80	150 – 300	Moderate
80 – 160	300 – 600	High

160 – 320	>600	Very high
>320		Extremely high

Hakanson, 1980

The combined correlation and PCA results therefore suggest that the observed metal concentrations may arise from multiple overlapping sources rather than from a single contamination pathway. Agricultural inputs, urban activities, waste disposal and petroleum-related activities may all contribute to the observed metal distribution. Confirmation of these sources would require additional evidence, such as detailed land-use information, source-specific sampling, soil physicochemical properties, petroleum hydrocarbon measurements and, where appropriate, source-apportionment techniques.

Table 8: Correlation matrix showing the relationship between concentrations levels of metals in the soils

	Zn	Cu	Pb	Cd	Ni	Cr
Zn	1.000					
Cu	0.753*	1.000				
Pb	0.431	0.322	1.000			
Cd	0.817**	0.776*	-0.433	1.000		
Ni	-0.217	-0.457	0.889**	-0.314	1.000	
Cr	-0.183	0.305	0.379	0.0953	0.141	1.000

****significant at the 1% level, significant at the 5% level**

Table 9: Summary of Principal component analysis of metals' concentrations in the soils

Test Component	Variable compared	Result	Significance
PCA Component 1	Industrial, Urban & Agricultural activities	54.3%	Dominant
PCA Component 2	Petroleum related activities	32.7%	Secondary

The results demonstrate that Cd represents the principal metal of environmental concern in the investigated farmland soils, despite Zn having the highest absolute concentration. The distinction arises because Cd showed the greatest enrichment relative to its reference values and contributed disproportionately to the ecological risk indices. Kpansia consistently exhibited the highest overall metal burden based on ∑6Metals, C/P, mCd and PLI, while Ikarama also showed substantial enrichment and ecological risk. These findings support the need for continued monitoring of farmland soils, particularly with respect to Cd accumulation and potential transfer into agricultural crops.

4. 0 Conclusion

The study assessed the contamination status, ecological risk, and potential environmental implications of six metals (Zn, Cu, Pb, Cd, Ni, and Cr) in farmland soils from Amarata, Kpansia, and Ikarama communities in Yenagoa Local Government Area, Bayelsa State, Nigeria. The overall degree of metal pollution followed the order Kpansia > Ikarama > Amarata, with the comparatively higher contamination at Kpansia plausibly associated with its more urbanized setting and greater exposure to domestic, municipal, industrial, and other anthropogenic wastes. The relatively elevated contamination observed at Ikarama, despite its rural character, is consistent with the documented influence of petroleum-related activities and recurrent oil-pollution events in the area. Statistical analyses further demonstrated substantial variability in metal concentrations among the soils, indicating heterogeneous anthropogenic inputs rather than a uniformly distributed geogenic source.

The mean concentrations of Cd, Zn, and Cu exceeded several international soil critical limits, whereas Pb, Ni, and Cr generally remained below the critical limits reported for most of the countries considered. The C/P index similarly identified Zn, Cu, and Cd as being within the pollution category, while Pb, Ni, and Cr were predominantly within the contamination category. The geoaccumulation index provided further evidence of differential enrichment: Ni, Pb, and Cr were generally classified as unpolluted (Igeo < 0), Zn and Cu as unpolluted to moderately polluted (0 ≤ Igeo < 1), while Cd exhibited moderate to strong pollution, with mean Igeo values of 2.883, 3.166, and 3.063 in Amarata, Kpansia, and Ikarama, respectively.

The contamination factor followed the order Cd > Cu > Zn > Pb > Ni > Cr, demonstrating that Cd was the principal contaminant across the studied farmlands. This finding was reinforced by the ecological risk assessment, in which Cd contributed disproportionately to the potential ecological risk, while the other metals generally presented low individual ecological risk. The mean RI values indicated high potential ecological risk across the three communities, with Cd identified as the dominant contributor to this risk. Principal component analysis further suggested that urban, industrial, and agricultural activities constituted the dominant source group, while petroleum-related activities represented an additional important source, indicating that the observed metal burden is associated with multiple anthropogenic inputs.

Overall, the findings demonstrate that cadmium constitutes the most critical environmental concern in the studied farmland soils, despite the generally lower concentrations of Pb, Ni, and Cr. The PLI values, which ranged from 0.65 in Amarata to 1.00 in Kpansia and 0.73 in Ikarama, indicate that the soils require continued monitoring and more detailed investigation rather than immediate classification as uniformly polluted. The study therefore recommends sustained monitoring of farmland soils, particularly for Cd, Zn, and Cu, together with improved management of agricultural inputs, domestic and industrial wastes, and petroleum-related pollution sources to minimize further accumulation and potential transfer of toxic metals through the agricultural food chain.

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