

Integrated Assessment of Heavy Metal Contamination Spatial Distribution Ecological Risk and Human Health Implications in Soils of Osubi and Surrounding Areas Delta State Nigeria

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Abstract

Soil pollution by heavy metals is a major environmental and human health problem worldwide. This paper evaluated the levels, location distribution, ecological hazards, and human health consequences of heavy metals in the Osubi and surrounding soils of the Okpe Local Government Area, Delta State, Nigeria. Standard analytical procedures were used to test 15 (15) soil samples (Fe, Mn, Zn, Cr, Cd, Ni, and Pb). Concentrations were between 201.5 and 377.1mg/kg (Fe), 6.28 and 160.7mg/kg (Mn), 52.98-240.4mg/kg (Zn), 20.23-144.4mg/kg (Cr), 0.68-24.85mg/kg (Cd), 7.53-44.5mg/kg (Ni), and 2.16-91.7mg/kg. Pollution indices, which included Metal Pollution Index (MPI), Pollution Load Index (PLI), Modified Degree of Contamination (mCd), Nemerow Pollution Index (PNI), and Potential Ecological Risk Index (PERI), showed low and moderate contamination, with the MPI implying significant pollution. Principal Component Analysis (PCA) and correlation outcomes had blamed the accumulation of heavy metals majorly to anthropogenic sources which included automobile emissions, industrial effluents, waste disposal and agricultural practices. Spatial analysis allowed defining hotspots, especially in the area of PTI Skills, WOJ 30, and Government Land, which reflects effects of human activities concentration. There was an assessment of health risk Hazard Index (HI) with high Hazard Index (HI) values (HI child = 5.50; HI adult = 1.89) which showed high non-carcinogenic risks, particularly in children. The toxicant was dominated by Cr, Cd and Pb and there may be potential neurological and renal consequences. The research suggests policy intervention measures such as tightening environmental standards, physical surveillance, population-based surveillance of health and remediation

solutions that are environmentally friendly like phytoremediation. Altogether, the research results present essential information about the dynamics of soil contamination and prove the necessity of combined management strategies to protect the environment and human well-being in the region under investigation.

Keywords: *Heavy metals, soil contamination, ecological risk, health risk assessment, Osubi.*

Introduction:

According to Eyankware et al., (2024), soil contamination by heavy metals poses a serious environmental issue, arising from both natural processes and anthropogenic activities. Metals such as cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn) can be harmful to flora, fauna, and humans, even in minimal amounts. It is essential to comprehend the origins, effects, and possible remediation techniques to effectively tackle this challenge (Ulakpa et al., 2021). According to Osisyana et al., (2025), the presence of heavy metals in soil due to geogenic processes may stem from the weathering of parent rocks and metallic minerals. In contrast, the heavy metals associated with anthropogenic activities are primarily attributed to industrial operations such as mining, metallurgy, and energy production, as well as agricultural practices involving fertilizers, pesticides, and animal wastes, along with waste disposal methods, all of which significantly contribute to heavy metal contamination.

According to Patience et al., (2026), this approach enhances scientific understanding of how heavy metal contamination spreads across agricultural landscapes and offers a replicable framework for environmental monitoring.

In various regions of the world, particularly in developing countries, the challenges posed by unregulated waste production and careless dumping are exacerbated by the growing global population and swift urban expansion. Heavy metals (HMs) in soil have the characteristics of biotoxicity, accumulation and non-degradability, which make it easy to accumulate in soil (Li et al. 2019; Zwolak et al. 2019). The lack of rigorous compliance with waste management regulations, coupled with inadequate urban planning and limited intervention from governmental bodies, has led to improper waste disposal practices prevalent in urban centers across Nigeria (Backsion et al., 2006; Omene et al., 2015; Eyankware et al., 2016). Human activities lead to the creation of waste, which consists of unwanted materials deemed valueless by their original users. According to Obasi et al. (2015) and Igwe et al. (2020, 2021), the rampant and careless disposal of such waste is a significant contributor to heavy metal contamination and poses a serious threat to human health. The amount and composition of waste produced in any specific area are influenced by various social characteristics, economic status, population density, consumption habits, and the types of services offered to the public (Eyankware, 2019; Odesa, et al., 2024a). Research indicates that soil acts as the main recipient of heavy metal (HM) components from municipal waste, and elevated concentrations of these heavy metals can result in soil contamination (Benedicta et al., 2017; Eyankware & Ephraim, 2021; Eyankware & Obasi, 2021; Islam et al., 2015; Obasi et al., 2015; Turhan et al., 2020; Ulakpa & Eyankware, 2021). Significant contributors to the presence of HMs in soil include mine tailings and municipal waste, which encompasses refuse from human activities, small-scale industries, and commercial operations (Ezemokwe et al., 2016; Igwe et al., 2020). In a similar vein, sources of heavy metals include hazardous waste such as paint, varnishes, batteries, expired medications, insecticides, as well as ashes from heating systems and the organic fraction known for its significant accumulation capacity (Akakuru et al., 2021, b; Onyeonwuna et al., 2024; Opara et al. 2023a, b). Heavy metals (HMs) pose a prolonged threat to soil ecosystems,

adversely affecting soil enzymes (Akakuru et al., 2023a, b). Their toxicity and enduring presence in the soil render heavy metals a significant concern (Yako vlev et al., 2020). Unlike organic pollutants, HMs are non-biodegradable (Eyankware and Obasi, 2021). They can accumulate in the soil, posing risks to the food chain through the consumption of vegetables grown in contaminated areas (Abdusalam, 2009; Igwe et al., 2020). The contamination of soil by heavy metals (HMs) can result in detrimental effects such as the degradation of soil biota, alterations in physicochemical properties of the soil, various risks, and other adverse impacts on the soil ecosystem. Research conducted by Ogunbanjo et al. (2016), Riyad et al. (2015), and Papa et al. (2010) has confirmed that HM contamination negatively influences human health, animal life, soil productivity, as well as the diversity and abundance of vegetation. Over the past few decades, several traditional methodologies, including the enrichment factor (EF), contamination factor (Cf), degree of contamination, index of geoaccumulation (Igeo), and pollution load index (PLI), have been developed and utilized to evaluate the pollution levels of heavy metals in soil (Islam et al., 2014; Islam et al., 2015). Each approach employs a distinct methodology for estimating and interpreting results. Risk assessment serves as a crucial tool in the realm of environmental health, playing an essential role in the evaluation, control, and management of hazards. Consequently, ecological risk assessment is integral to the ongoing research concerning soil pollution (Fairbrother et al., 2007; Igwe et al., 2020; Kumar et al., 2018; Sahito et al., 2016). Evidence indicates that heavy metals adversely impact the environment (Ogunbanjo et al., 2016). The presence of heavy metals in proximity to urban and rural waste poses a threat to both ecosystems and human health, emerging as a significant concern for public and environmental well-being, especially in regions adjacent to waste disposal sites. Heavy metals (HMs) can significantly infiltrate the food chain through the uptake by plants, including vegetables and other arable crops, as noted by Zhao et al. (2010). Consequently, the consumption of vegetables cultivated in soils contaminated with high levels of metals poses a serious health risk due to heavy metal exposure. To our knowledge, there has been no prior research investigating the characteristics of these pollutants and their potential ecological repercussions on soil in the designated study area. Therefore, this study was conducted to evaluate the effects of heavy metals on soil health by employing various assessment indices, including

Materials and Methods

Location, accessibility, Climate and topography

The study area is located in the city of Osubi and its environs, depicted in Fig. 1, which falls under the jurisdiction of the Okpe local government area in Delta State. The study area lies within latitude 5°35' -5°36'N and a longitude 5°48'E-5°50'E. This town is undergoing a transformation into a vibrant modern community, distinguished by its accelerated development and the introduction of architectural projects focused on modern living. Notably, it hosts the internationally recognized Nigeria-Petroleum Training Institute (PTI). Additionally, the area is home to Warri Airport, alongside significant infrastructural advancements. Such developments have prompted a considerable influx of residents, resulting in rampant and unregulated disposal of both domestic and industrial waste, which poses a direct threat to the environment, particularly affecting soil quality within the study area.

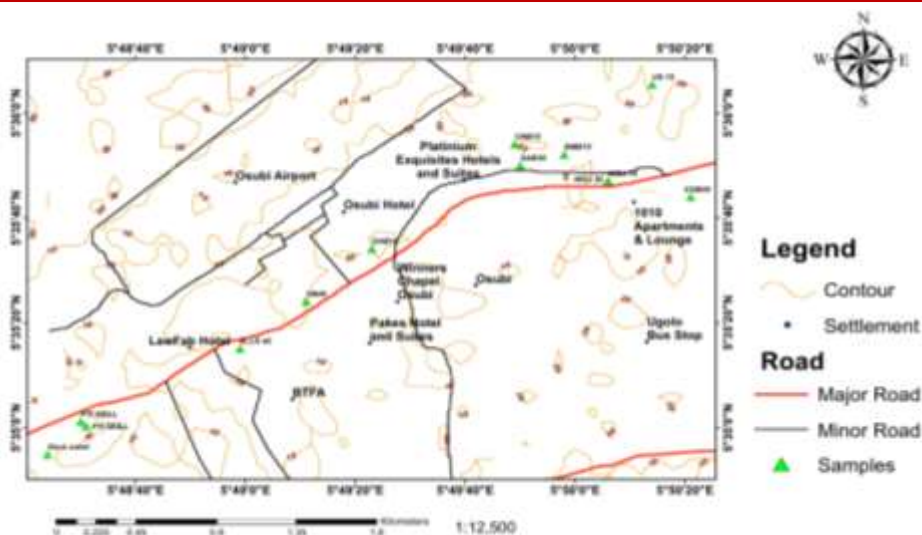


Fig.1: Topographic map of the study area.

Geology of the study area

The geology of the Odebi area, situated near Warri in the Niger Delta, has been the subject of investigation by several researchers (Ofomola 2015, Orji and Eze 2018, Uwadiogwu, et al., 2018, Okumoko and Izeze 2020). This region is characterized by an upper layer predominantly composed of sand interspersed with a limited amount of shale, while the lower section primarily consists of shale. The geological profile reaches a thickness exceeding 3700 meters. In various locations, the upper layer of Benin is overlain by thin layers of laterite with differing thicknesses, although these layers are more prominently exposed closer to the coastline. The principal aquifer units within this region are found in the upper delta lithofacies (Akuijeze & Ohaji, 1989). Furthermore, the water table, defined as the first occurrence of groundwater beneath the surface, is estimated to lie between 4 and 5 meters deep (Uchegbulam & Ayolabi, 2014).

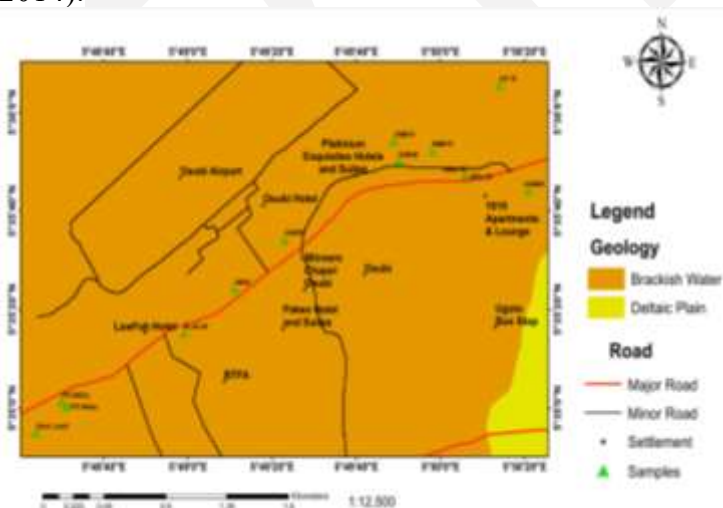


Fig.2: Geology map of the study area

Sample and sampling techniques

A total, fifteen (15) soil samples were obtained from the study area see Fig. 1. To extract the soil, a steel auger was employed, reaching a depth of 0–15 cm, and the samples were stored in transparent plastic bags. Once in the laboratory, the samples were air-dried for three days by laying them out on sheets of transparent plastic placed on a bench. Following this, the samples were sieved through a 2 mm mesh and then repackaged in clear plastic bags for future analysis. Subsequently, 20 g of the sieved, air-dried soil samples were transferred into conical flasks of 250 cm³ capacity, which had been thoroughly cleaned, and 100 cm³ of a 0.5 M nitric acid solution was introduced. A mechanical shaker was employed to agitate the flasks for a minimum duration of 30 minutes. Following this, the materials were filtered using ashless Whatman filter paper 40 and transferred into 100 cm³ plastic bottles. Control samples were analyzed for background concentrations of target analytes prior to being spiked with known quantities of As, Co, Cr, Cd, Copper (Cu), Lead (Pb), Nickel (Ni), and Zinc (Zn). These samples then underwent the complete extraction procedure to evaluate the recovery rates of the method. The percentage recoveries were calculated based on the variations between the baseline concentrations and the concentrations of the spiked samples. For the formulation of solutions aimed at spiking samples with cadmium, a general-purpose reagent, specifically cadmium nitrate with at least 99 percent purity, was employed. When preparing solutions for the spiking of samples containing lead, copper, and zinc, analytical-grade lead nitrate, as well as analytical-grade granules of copper and zinc, were utilized. Additionally, a reagent blank for each respective metal was produced and processed in its entirety prior to its application in sample analysis. Calibration curves were constructed using metals and metal salts of analytical grade. The concentrations of cadmium, copper, lead, and zinc were assessed utilizing a Varian Techtron AA6 atomic absorption spectrophotometer coupled with metallic hollow cathode lamps. Acetylene gas served as the fuel, while air functioned as the support. An oxidizing flame was consistently applied throughout the analysis. The determination of the four metal concentrations was achieved through the use of calibration curves. A reagent blank was utilized to calibrate the instrument to zero.

Heavy metal Index

The Nemerow pollution index (NPI)

The NPI method for assessing heavy metal contamination in soil enables the calculation of a comprehensive pollution level by integrating both the average and maximum values of individual pollution indices for various heavy metals found in the soil. This methodology emphasizes the most significant pollutant while also considering the overall average pollution, thereby offering a more thorough understanding of soil contamination and its environmental consequences. Subsequently, the derived index value is classified to ascertain the extent of soil pollution, which can range from unpolluted to severely polluted.

$$NP = \sqrt{(p_{ave}^1 + p_{max}^2)/2} \quad (1)$$

As proposed by Ogundele, et al., (2020)

Pave and Pmax are the average and maximum values of single pollution index (SPI) for all heavy metals. The NP indices of each metal was calculated and classified into 5 grades: NPs < .7, 0.7 ≤ NP ≤ 1.0, 1.0 ≤ NPs ≤ 2.0, 2.0 ≤ NPs ≤ 3.0 and NPs > 3.0 indicating safety, precaution, slightly

polluted, moderate polluted and serious polluted domain, respectively (Cheng & Zhu 2007; Ogunkunle and Fatoba 2013).

Pollution Load Index (PLI)

Hakanson's (1980) formula was used to calculate the PLI.

$$P = \sqrt{(P_{max} + P)/2} \quad (2)$$

Where: P is the Nemerow pollution index, P_{max} is the maximum single pollution index, $\bar{P}$ is the average of all single pollution indices.

Modified degree of contamination (mCd)

mCd is calculated using the following formula:

$$mCd = \sum (Cf/n) \quad (3)$$

Where Cf is the contamination factor for each individual heavy metal
n: is the total number of heavy metals evaluated.

The Metal Pollution Index (MPI), which estimated the aggregate impact of individual heavy metals on soil quality (Horton, 1965; Mohan et al., 1996), was evaluated using Caeiro et al., (2005) Equation 4:

$$MPI = \sqrt[n]{M_1 \times M_2 \times M_3 \times \dots \times M_n} \quad (4)$$

where M_n = concentration of the metal.

The Potential Ecological Risk Index (PERI)

The PERI is calculated in two main steps as shown in equation 5 and 6 respectively:

- i. Calculate the Ecological Risk for each metal (Er):

$$Er = Tr \times \frac{cm}{cb} \quad (5)$$

Where **Tr**: is the biological toxicity factor for each heavy metal (e.g., higher values for Cd and Hg, lower for Cr), **Cm**: is the measured average concentration of the metal in the soil sample, **Cb**: is the background value for that metal in a less contaminated soil of the region.

- ii. Sum the individual risks (PERI):

$$PERI = \sum Er \quad (6)$$

Note: $\sum Er$: (for all heavy metals being assessed).

Statistical analyses

The evaluation of the studied parameters was conducted using principal component analysis (PCA), Pearson correlation analysis, contamination metrics, and metal pollution indices. Within the framework of PCA, the process of component loading involved condensing a vast dataset encompassing numerous variables into a limited set of linear combinations that represented a significant portion of the overall data variance. This method facilitated a straightforward association of the variables with their respective sources or processes, as illustrated in Equation (7).

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^N (X_{N-} - N)^2 \quad (7)$$

When $\bar{X}_i$ represents the statistical mean, I represent the intervals between variables, and N represents the number of outcomes.

2

The modeling of concentration distribution and dispersion patterns in the area was conducted utilizing Microsoft Excel and Surfer 12 software. The results obtained were compared against the guidelines set forth by the World Health Organization (WHO). Additionally, Pearson's correlation coefficient was computed with the aid of version 23 of the Statistical Package for Social Sciences (SPSS).

Non-carcinogenic and carcinogenic risk assessment

The hazard index (HI) is a measure of the non-carcinogenic risk and is defined as the sum of the hazard quotients related to the human interface with soils and dust from Port Harcourt through accidental oral ingestion, contact with exposed skin surfaces, and nasal inhalation of soil or dust particles. The Chronic Daily Intake (CDI) values for the three exposure routes were calculated by making use of the following equations (USEPA, 2001; Durant, 1996; USEPA, 1989):

$$HQ_{ing} = \left[\frac{C \times IngR \times EF \times ED \times CF}{BW \times AT_{nc}} \right] / RfD \quad (8)$$

$$RQ_{inh} = \left[\frac{C \times InhR \times EF \times ET \times ED}{PEF \times 24 \times AT_{nc}} \right] / RfDi \quad (9)$$

$$RQ_{derm} = \left[\frac{C \times SA \times AF \times ABS_d \times EF \times ED \times CF}{BW \times AT_{nc}} \right] / (RfD \times GIABS) \quad (27)$$

$$\text{Hazard index (HI)} = \sum HQ = HQ_{ing} + HQ_{inh} + HQ_{dermal} \quad (10)$$

HI is the sum of the hazard quotients for the three exposure pathways.

The cancer risk values associated with exposure to PAHs in soils/dust through ingestion, inhalation and dermal contact pathways were estimated by using equations 30-33.

$$Risk_{ing} = \frac{C \times IngR \times EF \times ED \times CF \times SFO}{BW \times AT_{ca}} \quad (11)$$

$$Risk_{inh} = \frac{C \times InhR \times EF \times ED \times IUR}{PEF \times AT_{ca}} \quad (12)$$

$$Risk_{dermal} = \frac{C \times SA \times AF \times ABS_d \times EF \times ED \times CF \times SFO \times GIABS}{BW \times AT_{ca}} \quad (13)$$

$$ILCR = \sum Risk = Risk_{ing} + Risk_{inh} + Risk_{dermal} \quad (14)$$

where the CDI for ingestion, inhalation and dermal contact pathways were designated as CDI_{ing} , CDI_{inh} and CDI_{dermal} respectively, while the cancer risk for ingestion, inhalation and dermal contact were designated as $Risk_{ing}$, $Risk_{inh}$ and $Risk_{dermal}$ respectively. The definition of terms and values of parameters are given in Tables 3.8, 3.9 and 3.10. The qualitative classifications of the incremental

lifetime cancer risk (ILCR) values are given as follows: very low when the estimated value is $\leq 10^{-6}$; low when the value is between 10^{-6} and 10^{-4} ; moderate when the value is between 10^{-4} and 10^{-3} ; high when the value is between 10^{-3} and 10^{-1} and very high when the value $\geq 10^{-1}$ (Man *et al.*, 2013).

Results

Table 1: Show results of heavy metal within the study area, the values are in mk/kg.

	SOIL SAMPLE								
	Latitude	Easting	Fe	Mn	Zn	Cr	Cd	Ni	Pb
BMB15	05° 35' 52.7"	05° 49'	229.67	6.28	54.68	21.57	0.829	7.526	2.896
CNB15	05° 35' 54.38"	05° 49' 49.29"	237.53	9.73	59.42	20.75	0.954	9.63	3.388
OAB15	05° 35' 34.33"	05° 49' 23.49"	298.16	7.22	75.28	28.64	0.786	8.54	3.574
SAB30	05° 35' 50.4	05° 49' 50.6"	374.25	10.93	94.67	31.38	0.683	14.69	4.163
CGB45	05° 35' 44.7"	05° 50' 21.8"	243.58	6.43	63.15	24.25	0.927	8.12	3.695
VB45	05° 35' 24.1"	05° 49' 11.1"	234.84	7.95	52.98	20.23	0.874	9.73	2.163
Govt. Land	05° 34' 55.0"	05° 48' 24.0"	311.2	121.3	202.1	93.3	44.7	28.4	73.4
B.J.K 45			201.5	78.7	91.2	55.6	20.3	11.2	36.6
US 15	05° 36' 5.36"	05° 50' 14.12"	223.6	95.4	102.4	77.8	22.7	15.5	41
PTI SKILL	05° 35' 1.1"	05° 48' 30.6"	331	145.7	215.4	102.4	50	30.2	77.8
PTI SKILL	05° 35' 0.3"	05° 48' 31.8"	354.1	151	220.3	122.3	66.1	39.1	89.3
PTI JUNCTION	05° 34' 25.27"	05° 48' 1.34"	256.8	98.3	115.7	80.4	28.6	16.1	55.5
WOJ 15	05° 35' 47.9"	05° 50' 61.1"	303.3	115.5	191	91.4	40.1	22.5	70.7
WOJ 30	05° 35' 47.9"	05° 50' 61.1"	377.1	160.7	240.4	144.4	70.4	44.5	91.7
Min.			201.5	6.28	52.98	20.23	0.683	7.526	2.163
Max.			377.1	160.7	240.4	144.4	70.4	44.5	91.7
Avgr.			284.045	72.51	127.0486	65.31571	24.85379	18.98114	39.70564
CONTROL POINT									
FUPRE 15			181.4	66.6	87.4	41.1	17.4	9	28.4
FUPRE 30			271	110.1	184.2	88.6	31.3	19.7	61.6
Avgr.			226.2	88.4	135.8	64.85	24.35	14.35	45

Table 2: Results of Contamination Factor, Degree of Concentration, Pollution Load Index and Metal Pollution Index.

SOIL SAMPLE												
STREET	CF1	CF2	CF3	CF4	CF5	CF6	CF7	NEMEROW	PLI	MPI	mCd	PERI
BMB15	1.266097	0.094294	0.625629	0.524818	0.047644	0.836222	0.101972	1.032707	0.286351	11.73991	0.499525	7.889839
CNB15	1.309427	0.146096	0.679863	0.504866	0.054828	1.07	0.119296	1.088827	0.333206	13.65882	0.554911	9.426998
OAB15	1.64366	0.108408	0.861327	0.696837	0.045172	0.948889	0.125845	1.332095	0.344221	14.10989	0.632877	9.092252
SAB30	2.06312	0.164114	1.083181	0.763504	0.039253	1.632222	0.146585	1.695336	0.427611	17.52432	0.841711	12.84592
CGB45	1.342778	0.096547	0.72254	0.590024	0.053276	0.902222	0.130106	1.105055	0.319905	13.11415	0.548213	8.75905
VB45	1.294598	0.119369	0.606178	0.492214	0.05023	1.081111	0.076162	1.066323	0.293826	12.04608	0.531409	9.003238
Govt. Land	1.715546	1.821321	2.312357	2.270073	2.568966	3.155556	2.584507	26.87763	2.304951	94.30231	2.346904	114.4431
B.J.K 45	1.110805	1.181682	1.043478	1.352798	1.166667	1.244444	1.288732	1.792516	1.194569	48.90548	1.198372	52.59664
US 15	1.232635	1.432432	1.171625	1.892944	1.304598	1.722222	1.443662	2.785104	1.438311	58.8733	1.45716	61.3573
P.T.I Skill 30	1.824697	2.187688	2.464531	2.491484	2.873563	3.355556	2.739437	48.55566	2.523502	103.2346	2.562422	126.317
P.T.I Skill 45	1.95204	2.267267	2.520595	2.975669	3.798851	4.344444	3.144366	125.0235	2.902528	118.7236	3.000462	162.1488
P.T.I Junction 30	1.415656	1.475976	1.323799	1.956204	1.643678	1.788889	1.954225	4.184002	1.63474	66.905	1.651204	74.7381
WOJ 15	1.671996	1.734234	2.185355	2.223844	2.304598	2.5	2.489437	16.67376	2.136493	87.41687	2.158495	102.4524
WOJ 30	2.078831	2.412913	2.750572	3.513382	4.045977	4.944444	3.228873	224.9043	3.161442	129.303	3.282142	174.4361

Discussion

Statistical Analysis

Pearson Correlation Matrix

In environmental science, Pearson correlation matrix is utilized to examine the interconnections between various heavy metals and soil characteristics, where each cell represents the Pearson correlation coefficient (r) between two variables, with a scale from -1 to +1. Coefficients approaching +1 imply a robust positive linear relationship, signifying that either two metals or a metal in conjunction with a soil property tend to rise or fall in tandem, potentially indicating shared origins or influences. Conversely, a coefficient near -1 reflects a strong negative correlation, while values close to 0 denote a weak or nonexistent linear relationship.

Table 3: Pearson correlation matrix

	<i>Fe</i>	<i>Mn</i>	<i>Zn</i>	<i>Cr</i>	<i>Cd</i>	<i>Ni</i>	<i>Pb</i>
Fe	1						
Mn	0.474712	1					
Zn	0.719204	0.930256	1				
Cr	0.579592	0.979743	0.946865	1			
Cd	0.587583	0.972363	0.963742	0.986091	1		
Ni	0.747586	0.888921	0.95718	0.941076	0.960775	1	
Pb	0.527039	0.991033	0.956284	0.980691	0.984231	0.910717	1

Warnings

Only one component was extracted. Component plots cannot be produced.

Correlation matrix

In sciences, correlation matrix pertaining to heavy metals in soil examines the linear associations among various heavy metals, as well as between these metals and soil characteristics such as pH, organic matter, and clay content. Through the computation of Pearson's correlation coefficient (r), these matrices reveal the strength and direction (whether positive or negative) of the relationships among variables, thereby facilitating the identification of the origins and dynamics of heavy metals in contaminated soil. (Eyankware et al., 2024; Omoko et al., 2023; Onyeonwuna et al., 2024). From Table 4, it is quite clear that most of the parameters were significantly correlated with Mn, which may be due to deposition of dumpsites which may leach into the soil within the study area.

Table 4: Correlation Matrix

Correlation Matrix ^a								
		Fe	Mn	Zn	Cr	Cd	Ni	Pb
Correlation	Fe	1.000	.441	.708	.584	.564	.753	.512
	Mn	.441	1.000	.923	.972	.971	.873	.989
	Zn	.708	.923	1.000	.948	.962	.956	.955
	Cr	.584	.972	.948	1.000	.983	.941	.979
	Cd	.564	.971	.962	.983	1.000	.952	.984

Sig. (1-tailed)	Ni	.753	.873	.956	.941	.952	1.000	.904
	Pb	.512	.989	.955	.979	.984	.904	1.000
	Fe		.050	.002	.011	.014	.001	.026
	Mn	.050		.000	.000	.000	.000	.000
	Zn	.002	.000		.000	.000	.000	.000
	Cr	.011	.000	.000		.000	.000	.000
	Cd	.014	.000	.000	.000		.000	.000
	Ni	.001	.000	.000	.000	.000		.000
	Pb	.026	.000	.000	.000	.000	.000	
a. Determinant = 1.00E-009								

Inverse of a correlation matrix

There are two main ways to understand the phrase "inverse of a correlation matrix" in connection to heavy metals in soil, rather than referring to a single mathematical procedure. In the first interpretation, the relationships between heavy metals and soil properties are shown by computing the inverse of the mathematical correlation matrix, also known as partial correlation. The second interpretation concerns spatial inversion models that use statistical analysis and remote sensing methods to predict heavy metal concentrations. Understanding and predicting the complex spatial distribution and environmental factors that influence heavy metal pollution in soil is the main goal in both cases. Deduction from Table 5, suggested that an inverse relationship has been identified in the study area, indicating that an increase in the available Cr and Fe concentrations in the soil corresponds with a decrease in the pH levels of the dumpsite soil. These inverse correlations identified in the current study align with the findings presented in (Eze, et al., 2020).

Table 5: Inverse correlation Matrix

Inverse of Correlation Matrix							
	Fe	Mn	Zn	Cr	Cd	Ni	Pb
Fe	13.722	13.063	-18.602	-14.264	30.028	-16.640	-2.737
Mn	13.063	90.741	-15.967	-43.278	-1.750	11.925	-47.925
Zn	-18.602	-15.967	67.514	42.127	-2.486	-18.877	-60.852
Cr	-14.264	-43.278	42.127	79.195	-2.481	-27.449	-40.339
Cd	30.028	-1.750	-2.486	-2.481	213.806	-118.756	-111.895
Ni	-16.640	11.925	-18.877	-27.449	-118.756	91.900	75.389
Pb	-2.737	-47.925	-60.852	-40.339	-111.895	75.389	189.358

Principal Component Analysis (PCA)

PC applied to heavy metals in soil is a statistical technique employed to simplify the analysis of intricate data concerning soil heavy metals, which often involves numerous elements. This method achieves a reduction in dimensionality by converting the data into a more manageable collection of uncorrelated variables known as principal components. Consequently, PCA facilitates the detection of contamination patterns, enhances the comprehension of the interrelationships among various heavy metals, and aids in pinpointing potential sources of pollution. Findings from Table 6, showed that PCA not only validate earlier outcomes but also indicate that ongoing anthropogenic activities in the region have significantly impacted the soil quality in the area (Akpoveta et al., 2010; Osakwe, 2014; Osakwe et al., 2012).

Table 6:

Communalities		
	Initial	Extraction
Fe	1.000	.453
Mn	1.000	.910
Zn	1.000	.972
Cr	1.000	.969
Cd	1.000	.974
Ni	1.000	.945
Pb	1.000	.950
Extraction Method: Principal Component Analysis.		

A factor analysis was carried out. Initially, a scree plot was created (see Fig. 4), which demonstrated that three factors were adequate to explain the total variability. As a result, we executed the factor analysis employing the varimax rotation technique (refer to Table 7). The first factor was responsible for roughly 46.3% of the total variation, while the second and third factors accounted for 19.4% and 6.1% of the variation, respectively.

Table 7: Total Variance Explained

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.174	88.200	88.200	6.174	88.200	88.200
2	.717	10.241	98.441			
3	.058	.822	99.263			
4	.036	.512	99.775			
5	.007	.102	99.877			
6	.006	.087	99.964			
7	.003	.036	100.000			
Extraction Method: Principal Component Analysis.						

A scree plot, which is a line graph that displays the eigenvalues of each principal component (PC) in descending order, is used in soil multivariate analysis to determine how many PCs to keep by locating a "elbow" where the rate of variance explained drops off significantly see Fig. 3. Since they identify the most important patterns and correlations in the soil data, the PCs before the elbow are usually retained once it has been found. According to eigenvalues, the curve changes its slope at the breakpoint created by the plot's values because of a notable shift in variance 4; as a result, the curve becomes roughly flat after point 6 (Fig. 3). It was shown to be consistent with four previously identified characteristics and developed into a crucial indicator for tracking these elements' changes.

It is believed that there may be a large number of variables influencing the study area because the curve's breakpoints are not sharp.

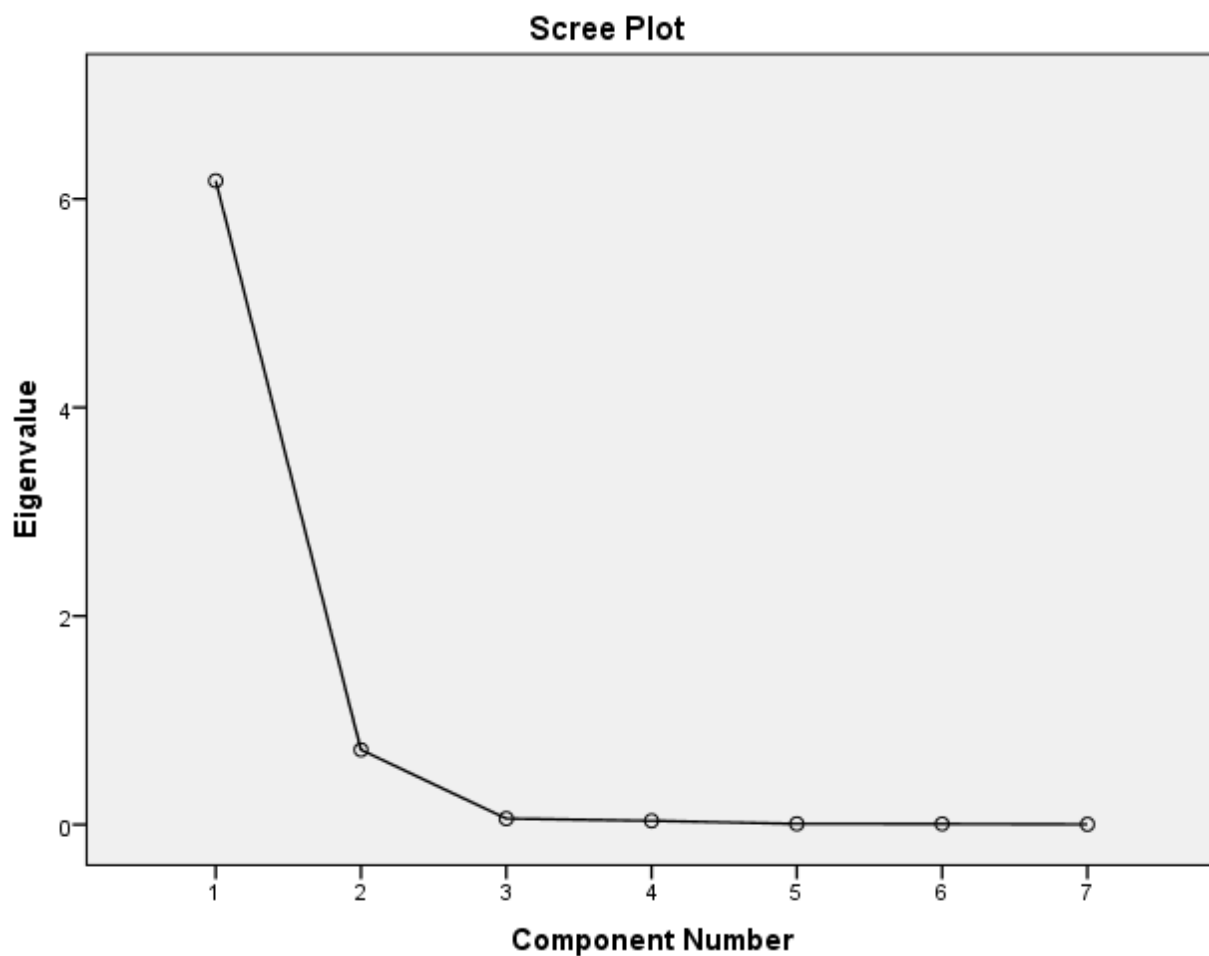


Fig.3: Scree plot of the Principal components.

Table 8: Component Matrix

Component Matrix^a	
	Component
	1
Fe	.673
Mn	.954
Zn	.986
Cr	.985
Cd	.987
Ni	.972
Pb	.975
Extraction Method: Principal Component Analysis.	
a. 1 components extracted.	

Rotated Component Matrix^a

a. Only one component was extracted. The solution cannot be rotated.

Component score coefficient matrix

In the realm of soil research, a matrix known as the component score coefficient matrix, typically produced through Principal Component Analysis (PCA), illustrates the degree to which each original variable (such as ion concentration) influences the various extracted components (or factors). This matrix serves as a valuable tool for elucidating the fundamental relationships among diverse soil parameters and pinpointing the primary factors that affect soil quality.

Table 9:

Component Score Coefficient Matrix	
	Component
	1
Fe	.109
Mn	.155
Zn	.160
Cr	.159
Cd	.160

Ni	.157
Pb	.158
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.	

Component Score Coefficient Matrix (CSCM)

CSCM, which is produced by Principal Component Analysis (PCA), groups several heavy metals in soil into fewer, uncorrelated principal components (PCs) that each represent different pollution sources or behaviors see Table 10. This allows for the discovery of underlying patterns and interactions among the various heavy metals. While the "score matrix" gives the actual scores (or coordinates) of each sample in the new component space, indicating the degree to which each sample is connected to particular sources or pollution types, the "component matrix" itself displays the loading of each original heavy metal variable onto these new PCs.

Table 10: Component Score Covariance Matrix

Component Score Covariance Matrix	
Component	1
1	1.000
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.	

Table 11: Descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	Analysis N
Fe	277.202000	62.9274116	15
Mn	72.116000	59.5823021	15
Zn	124.405333	68.4887345	15
Cr	63.701333	40.9538318	15
Cd	24.356867	24.7631935	15
Ni	18.315733	11.9717861	15
Pb	38.951933	34.8866986	15

Distribution of heavy metals**Table 12:** WHO heavy metal standard for soil

S/No	Heavy Metal	Target value of soil (mg/kg)
1	Zinc (Zn)	50
2	Chromium (Cr)	100
3	Copper (Cu)	36
4	Lead (Pb)	85
5	Nickel (Ni)	35
6	Arsenic (As)	4.5
7	Cobalt (Co)	24
8	Cadmium (Cd)	0.8

The concentration of Zinc (Zn) in soil within the study area

Zinc is a naturally occurring element found in all types of soils, deriving from the materials of parent rocks. However, its concentration is influenced by the composition of the soil; it tends to be more abundant in clay-heavy or organic soils, whereas sandy soils typically exhibit lower concentrations (Eyankware, et al., 2024; Odesa, et al., 2024). Natural geogenic sources provide a baseline level of zinc, while human activities, such as atmospheric deposition and various agricultural or industrial methods, augment the overall zinc content in the soil. According to Osisanya, et al., (2025), in the soil matrix, zinc exists in several chemical forms, which include dissolved states, exchangeable sites, mineral-bound fractions, and those bound to organic matter. Deductions from Fig.4, suggested that high concentrations of Zn was observed within selected parts of southwestern, and southeastern parts of the study area. The concentration of Zn in soil within the study area ranges from 52.98 to 240.4 mg/kg, with an average value of 127.04 mg/kg. Further findings from Table 1, showed that average of Zn in soil (127.04 mg/kg) were below the average obtained from control points (135.8 mg/kg). The high concentration of Zn within the aforementioned area could be attributed to human activities within the Petroleum Training Institute (P.T.I). Findings from Table 12, suggested that the concentration of Zn in soil were above WHO target limit, based on the findings soil within the study area is considered to be contaminated. similarly, studies conducted elsewhere by Osisanya, et al., (2025); Ogunbanjo, et al., (2016), revealed that one of the major sources of Zn in soil within the Niger Delta region of Nigeria is linked to human activities,

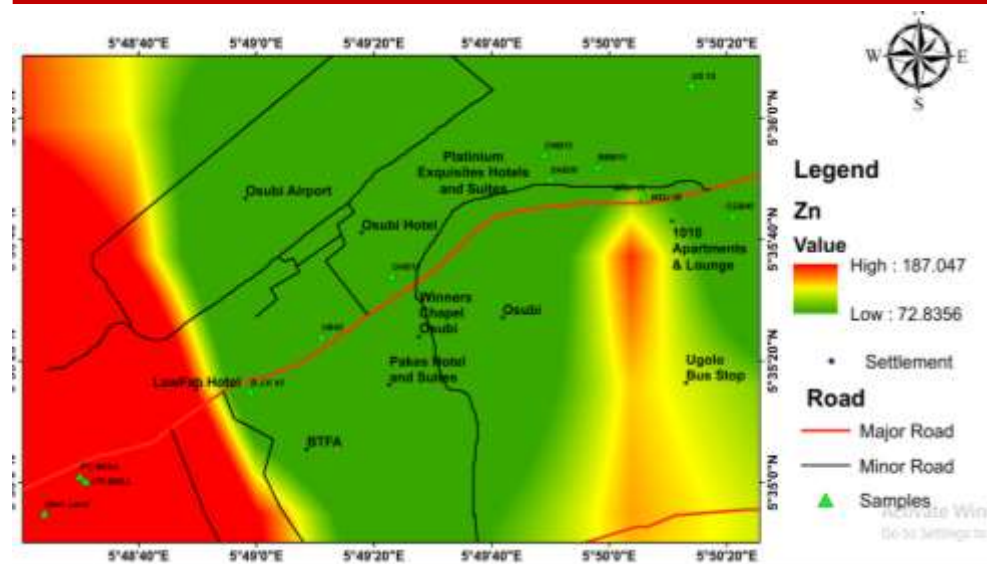


Fig.4: Spatial distribution of Zn within the study area.

The concentration of Manganese (Mn) in soil within the study area

Manganese is commonly found in the Earth's crust and soils, manifesting as insoluble oxide minerals such as pyrolusite, silicate minerals, or in the form of soluble ions. Within the soil, manganese appears in several forms, including exchangeable Mn^{2+} , manganese oxides, organic complexes, and as part of silicate structures. Its availability is affected by various factors, including soil pH, organic content, moisture levels, and aeration. Moreover, soluble manganese is liberated from rocks through the process of weathering and is taken up by plants primarily in its divalent state (Mn^{2+}). From Table 1, the concentration of Mn for this study ranges from 6.28 to 160.7 mg/kg, with an average value of 72.51 mg/kg, further findings from Table revealed that the average value of Mn (72.51 mg/kg) for this study, were below average value of control points (88.4 mg/kg). WHO does not define a singular, universal "permissible limit" for manganese levels in soil. Findings from Fig. 5, revealed that high concentrations of Mn was noticeable around the southwestern parts of the study area. According to Ogundele, et al., (2020), high concentrations of Mn in soil could be attributed indiscriminate soil, and liquid waste disposal.

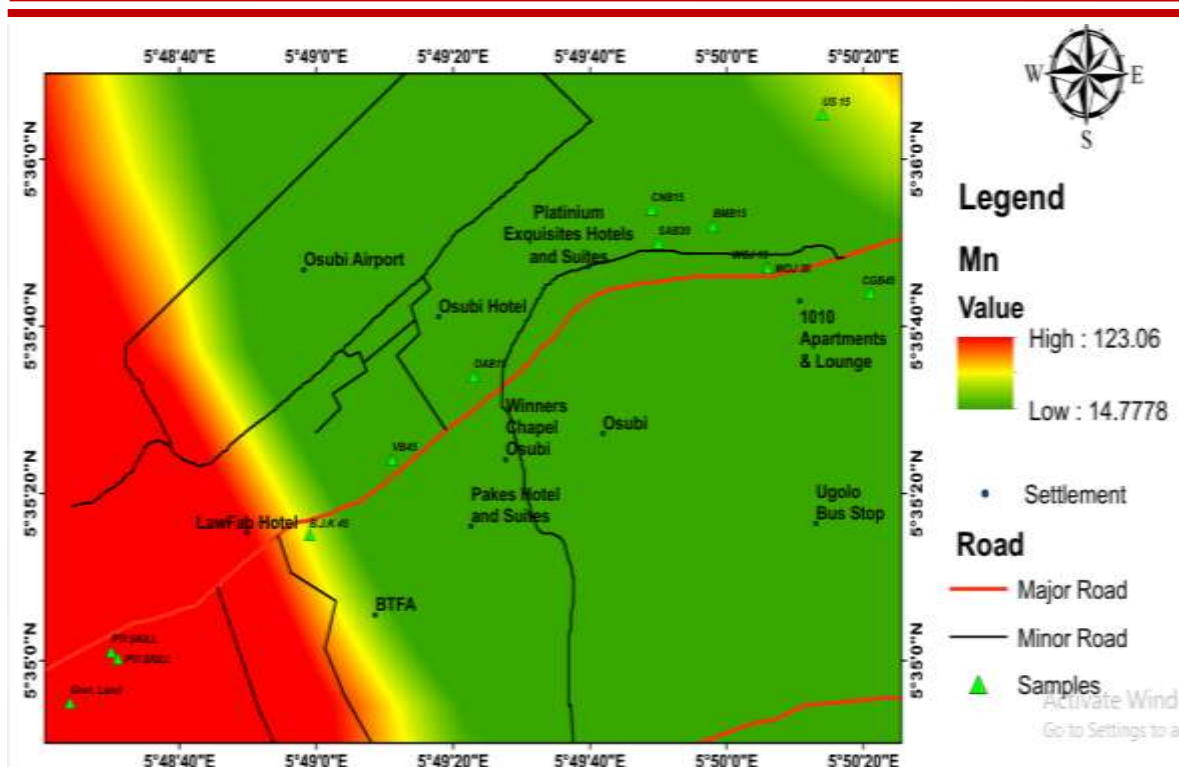


Fig.5: Spatial distribution of Mn within the study area.

The concentration of Nickel (Ni) in soil within the study area

Nickel is commonly found in soils, with its natural concentrations varying according to the type of parent rock (Ogunkunle and Fatoba, 2013). The concentration of nickel is further enhanced by atmospheric deposition resulting from volcanic eruptions, wildfires, and anthropogenic activities such as fuel combustion and incineration. According to Osisanya, et al., (2024), the availability of nickel to plants is significantly affected by soil characteristics, particularly pH, as well as by processes such as weathering and leaching. Ultimately, nickel can be absorbed by plants and subsequently transferred to humans via the food chain. Deductions from Fig.6, suggested that concentrations of Ni within the study area was high around the southwestern parts of the study area. Findings from Table 1, revealed that the concentrations of Ni for this study ranges from 7.526 to 44.5 mg/kg, with an average value of 19.98 mg/kg. The results of Ni obtained from Table 1, showed that average value of Ni (18.98 mg/kg) were slightly above average value obtained at the control points (14.35 mg/kg) see Table 1. The concentration of Ni were below the WHO target except for sample PTI skill, and WOJ 30 with values of 39.1 mg/kg, and 44.5 mg/kg respectively. That's implies that aforementioned sampled points (PTI skill, and WOJ 30) are considered to be slightly contaminated.

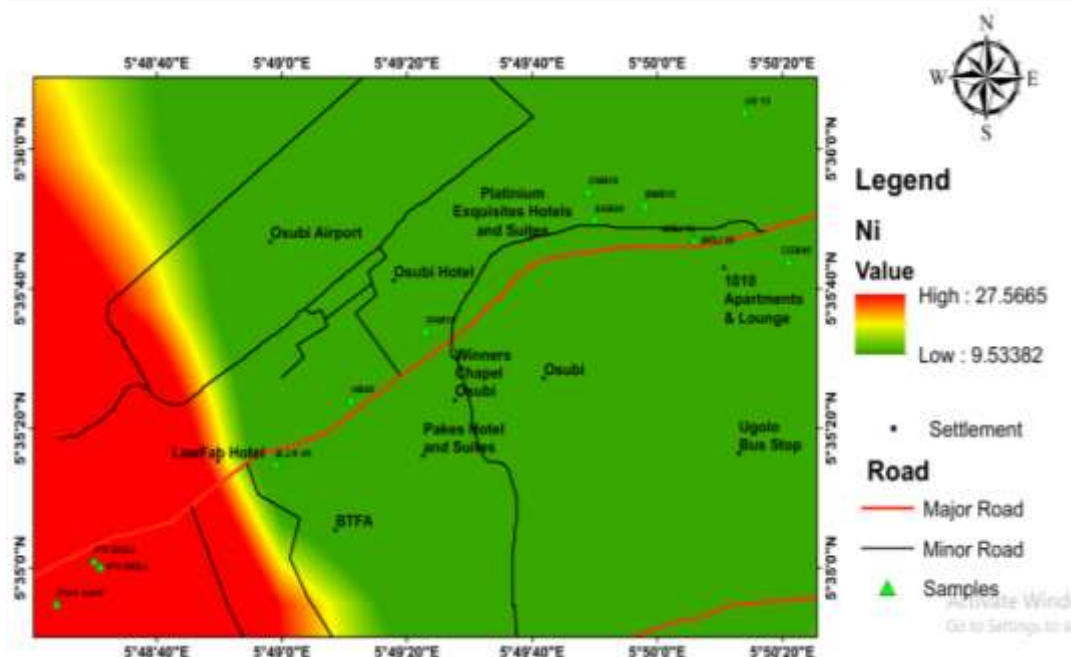


Fig.6: Spatial distribution of Ni within the study area.

The concentration of Fe in soil within the study area

In soil, iron primarily exists as insoluble Fe (III) oxides, such as goethite and ferricrete; however, it may also be present in its soluble Fe (II) form under anaerobic conditions (Osisanya, et al., 2025). The concentration of Fe for this study ranges from 201.5 to 377.1 mg/kg, with an average value of 284.04 mg/kg see Table 1. The average concentrations of Fe (284.045 mg/kg) in soil for the study, were slightly above the control point's value of 226.2 mg/kg. Although, the permissible limit for iron in agricultural soil, as established by the WHO/FAO guideline, is set at 5000 mg/kg (equivalent to 5g/kg). This standard is primarily concerned with the possible health hazards that may arise for both humans and animals as a result of excessive iron buildup from polluted soils into agricultural produce. That implies that concentrations of Fe were below WHO/FAO set limit. Findings from Fig.7, showed that high concentrations of Fe were within the southwestern parts of the study area. According to Ozobeme, et al., (2025), high concentration of Fe in soil can be linked to anthropogenic and geogenic factors.

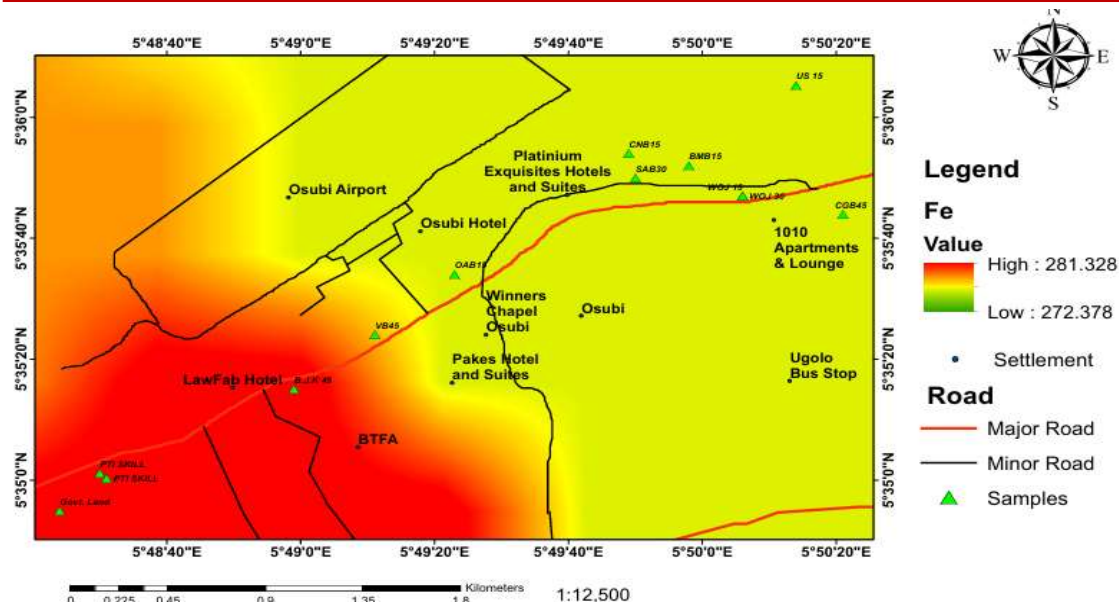


Fig.7: Spatial distribution of Fe within the study area.

The concentration of Cd in soil within the study area

Cadmium is found in soils as a result of the natural weathering of parent rocks that are rich in cadmium, especially sedimentary rocks and black shales. Additionally, anthropogenic activities such as mining, the application of phosphate fertilizers, and the use of wastewater for irrigation significantly contribute to the contamination of soils. The concentration of Cd in soil ranges from 0.68 to 24.85 mg/kg, with an average value of 24.85 mg/kg, further findings suggested that the average value of Cd (24.85 mg/kg) in soil were slightly above the average value of 24.35 mg/kg as shown in Table 1. Although the concentrations of Cd were observed to be far above target of WHO as shown in Table 12. Findings from Fig. 8, showed that high concentration of Cd in soil was high around selected areas of southwest (PTI), and northwest of the study area. Furthermore, atmospheric deposition resulting from the burning of fossil fuels and industrial outputs also increases soil cadmium levels. The accumulation of cadmium in the soil raises concerns regarding its absorption by plants, thereby posing potential risks to the food chain and public health (Osisanya, et al., 2023).

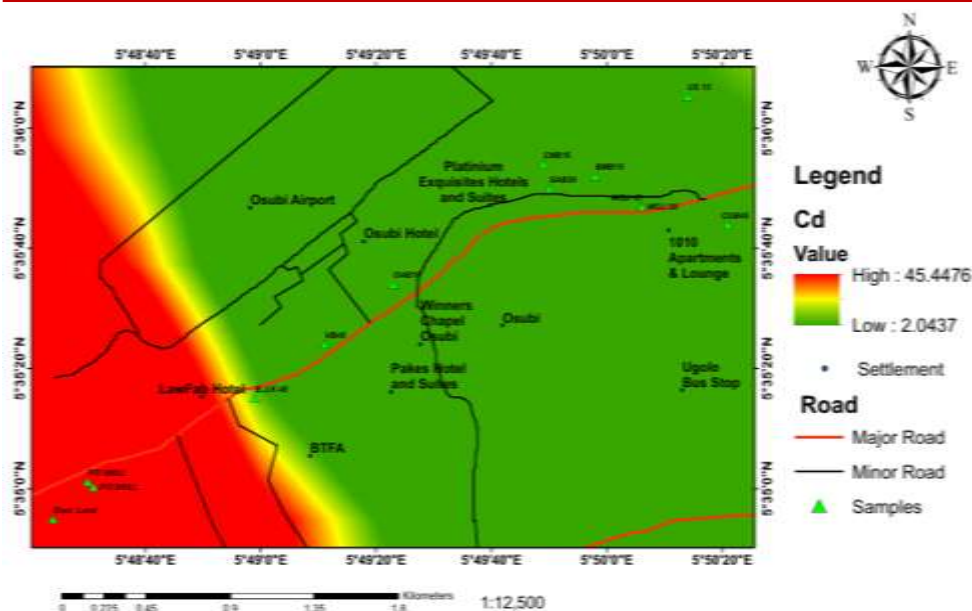
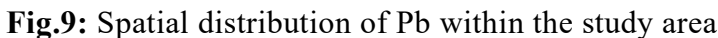


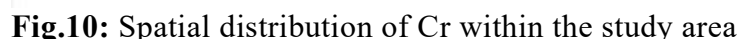
Fig.8: Spatial distribution of Cd within the study area

The concentration of Pb in soil within the study area

Lead is a naturally occurring element found in all types of soils, but it tends to be present in higher concentrations near roadways, industrial facilities, and structures that contain lead-based paint, largely as a result of historical human practices such as the use of leaded gasoline and mining operations (Ogunkunle and Fatoba, 2013). The concentration of Pb in soil for this study ranges from 2.16 to 91.7 mg/kg, with an average value of 39.70 mg/kg see Table 1, further findings revealed that the average concentrations of Pb (39.70 mg/kg) was below the average concentration of control points value of Pb (45 mg/kg) as shown in Table 1. Findings from Fig.9, showed that high concentration of Pb in soil was high around selected areas of southwest (PTI), and northwest of the study area, The primary contributors to elevated lead levels in soil are anthropogenic activities, which frequently raise lead concentrations to dangerous levels that can pose significant health risks. Additionally, various chemical processes occurring within the soil, which are influenced by factors such as pH, the presence of organic matter, and metal oxides, play a crucial role in determining the solubility and availability of lead for absorption by plants.



The concentration of Cr for this study ranges from 20.23 to 144.4 mg/kg, with an average value of 65.31 mg/kg. The value of Cr for this study of 65.31 mg/kg, was above the average value of control points (64.85 mg/kg) see Table 1.



The spatial distribution of PLI in soil within the study area

PLI in soil serves as a quantitative approach for evaluating the total extent of heavy metal contamination at a particular location. This index highlights the degree of pollution's impact and acts as an essential instrument for environmental researchers and decision-makers. When the PLI exceeds 1, it signifies the presence of soil contamination, whereas a PLI of less than 1 reflects superior soil quality. These specific PLI measurements facilitate the categorization of soil contamination levels, aiding in the identification of vulnerable areas and the tracking of pollution patterns. PLI values for this study were below the value of 1 for sample locations (BMB 15, CNB 15, OAB 15, SAB 30, CGB 45, and VB45) indicate soil of good quality, in other words the aforementioned locations are free from contamination. While sample locations (Govt land, B.J.K 45, US 15, P.T.I Skill 30, P.T.I Skill 45, P.T.I Junction 30, WOJ 15, and, WOJ 30) were above the 1, that implies that aforementioned are considered contaminated. Results from Fig. 11, further outline with results obtained from Table 2. Findings from Fig. 11, depicted that PLI values was found to be at its peak around the selected parts of the southwestern, and northwestern of the study area. Studies conducted else by Osisanya, et al., (2025), areas where human activities is high, the level of soil contamination is usually high within such area.

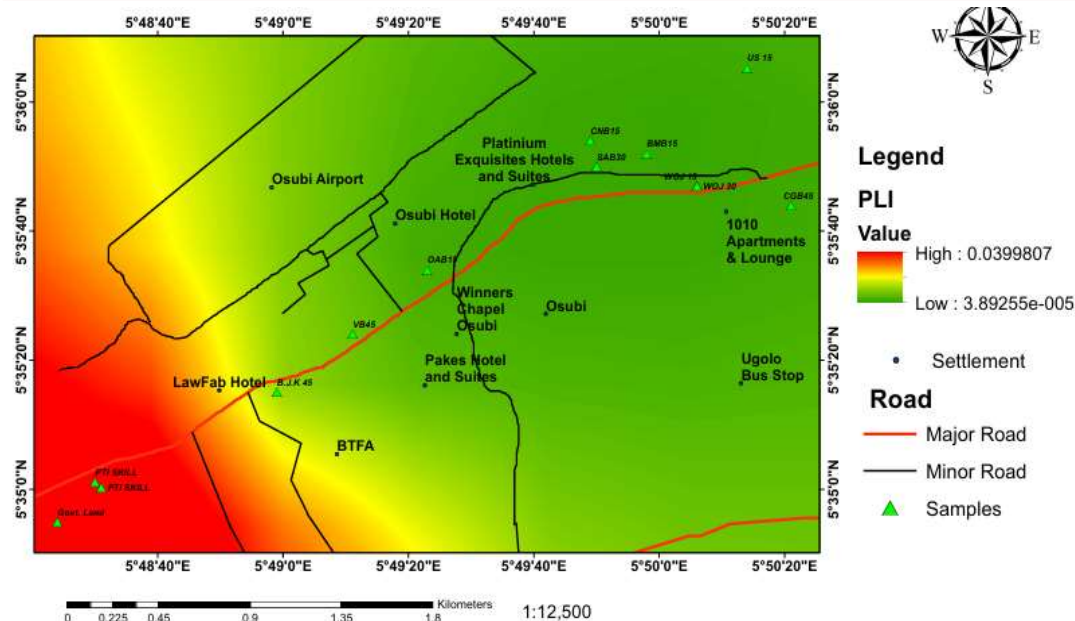


Fig.11: Spatial distribution of PLI within the study area

Nemerow Index (PNI)

The spatial distribution of PNI in soil within the study area

PNI, as established by Nemerow in 1974, is a numerical measure that aggregates various factors into a single metric. Conversely, the NPI value reflects the overall soil quality by accounting for multiple pollution parameters. When assessing the empirical validity of soil risk, it is more effective to utilize a comprehensive soil quality index rather than focusing solely on the concentrations of one or two contaminants (Eyankware et al., 2025). Results from Fig. 12, depicted that PNI values was found to be at its peak around the selected parts of the southwestern of the study area. The PNI assesses the relative contribution of each parameter to the pollution level in a soil sample, thus allowing for the identification of the factors affecting soil quality. A PNI value of ≤ 0.7 signifies that the soil is clean, while a PNI value between 0.7 and 1.0 indicates that it is slightly clean. A PNI in the range of 1.0 to 2.0 suggests slight pollution. Deduction from Table 2, suggested that the value of PNI were considered to be slightly high and extremely. That implies that soil samples are considered to be polluted based on PNI values of the study area.

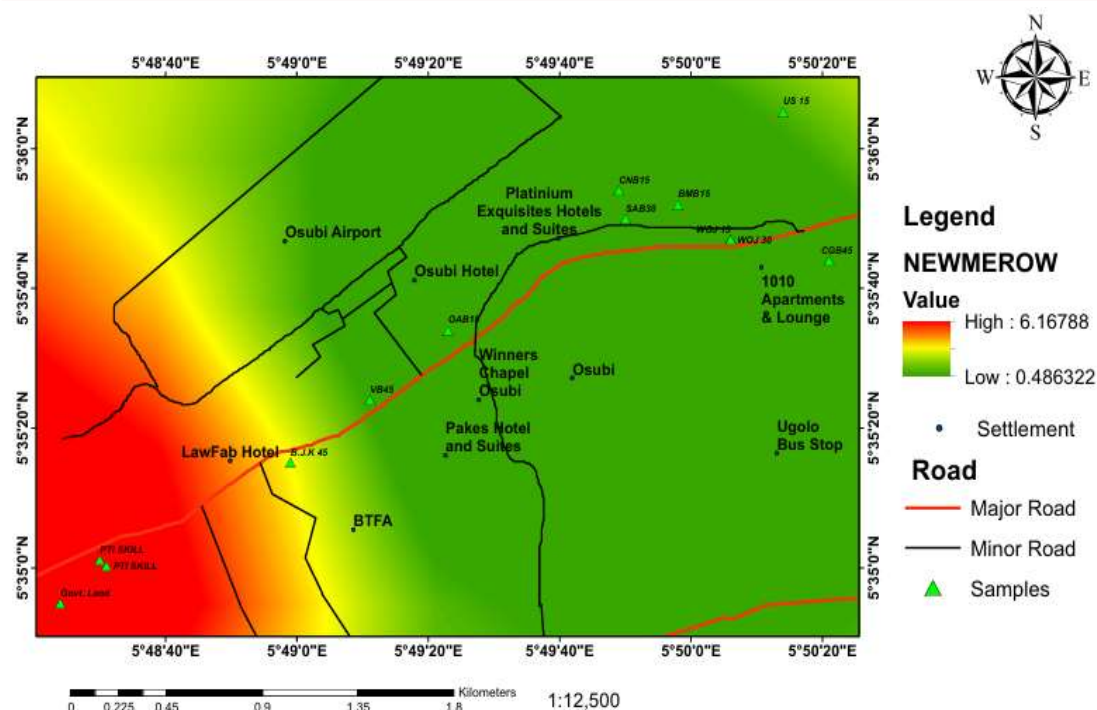


Fig.12: Spatial distribution of PNI within the study area

Modified Degree of Contamination (mCd)

The spatial distribution of mCd in soil within the study area

mCd refers to the modified degree of contamination, which is utilized to evaluate the levels of heavy metal contamination in soil, rather than denoting the presence of a substance called "mcd" within the soil. The mCd value are classify the level of contamination in the soil: Uncontaminated to very low contamination: $mCd \leq 1.5$, Low contamination: $1.5 < mCd \leq 2$, Moderate contamination: $2 < mCd \leq 4$, High contamination: $4 < mCd \leq 8$, Very high contamination: $8 < mCd \leq 16$, Extremely high contamination: $16 < mCd \leq 32$, and Ultra-high contamination: $mCd > 32$. Findings from Fig. 13, depicted that PNI values was found to be at its peak around the selected parts of the southwestern of the study area. Deduction from mCd in Table 2, revealed that results fell within low contamination to high contamination. Studies have shown that elevated contamination levels, reflected in high mCd values, are prevalent in soils located in proximity to industrial zones, mining activities, and waste disposal sites, whereas lower contamination levels are typically observed in agricultural fields and other regions (Osisanya, et al., 2025). This type of contamination is attributed to sources such as industrial emissions, the application of phosphate fertilizers, and landfill waste, all of which contribute heavy metals that remain in the soil over time.

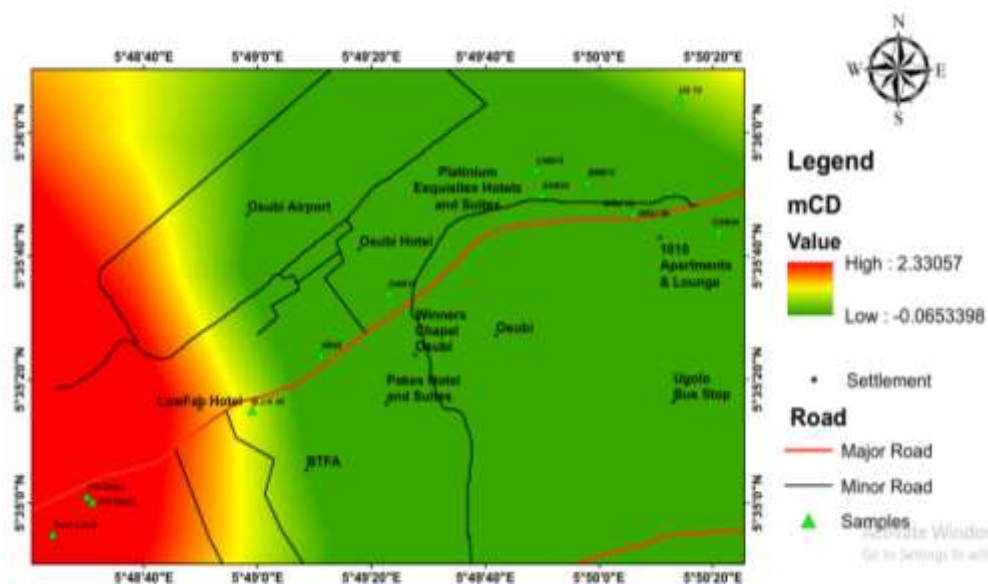


Fig.13: Spatial distribution of mCD within the study area

Metal Pollution Index (MPI)

The spatial distribution of MPI in soil within the study area

MPI serves as a measurement for assessing the levels of metal contamination in soil. An MPI exceeding 1 typically signifies the existence of pollution, whereas an MPI below 1 implies that contamination is not present. This index serves to categorize and evaluate pollution levels in various regions, offering a unified metric for determining the extent of heavy metal contamination in environments such as soil, water, or biological materials. Results from Fig. 14, depicted that PNI values was found to be high around the selected parts of the southwestern of the study area. Findings from Table 2, showed that MPI value were >1 , that implies that soil samples are considered to be contaminated based on MPI results. According to Eyankware, et al., (2024). The variation of MPI across different locations is influenced by various elements, including industrial activities, farming methods, and inherent geological characteristics, which can raise MPI scores and indicate heightened levels of pollution and associated risks. Elevated MPI scores reflect a significant presence of heavy metals like lead (Pb) and cadmium (Cd) in the soil, which may impair soil quality and present health hazards to both humans and ecosystems.

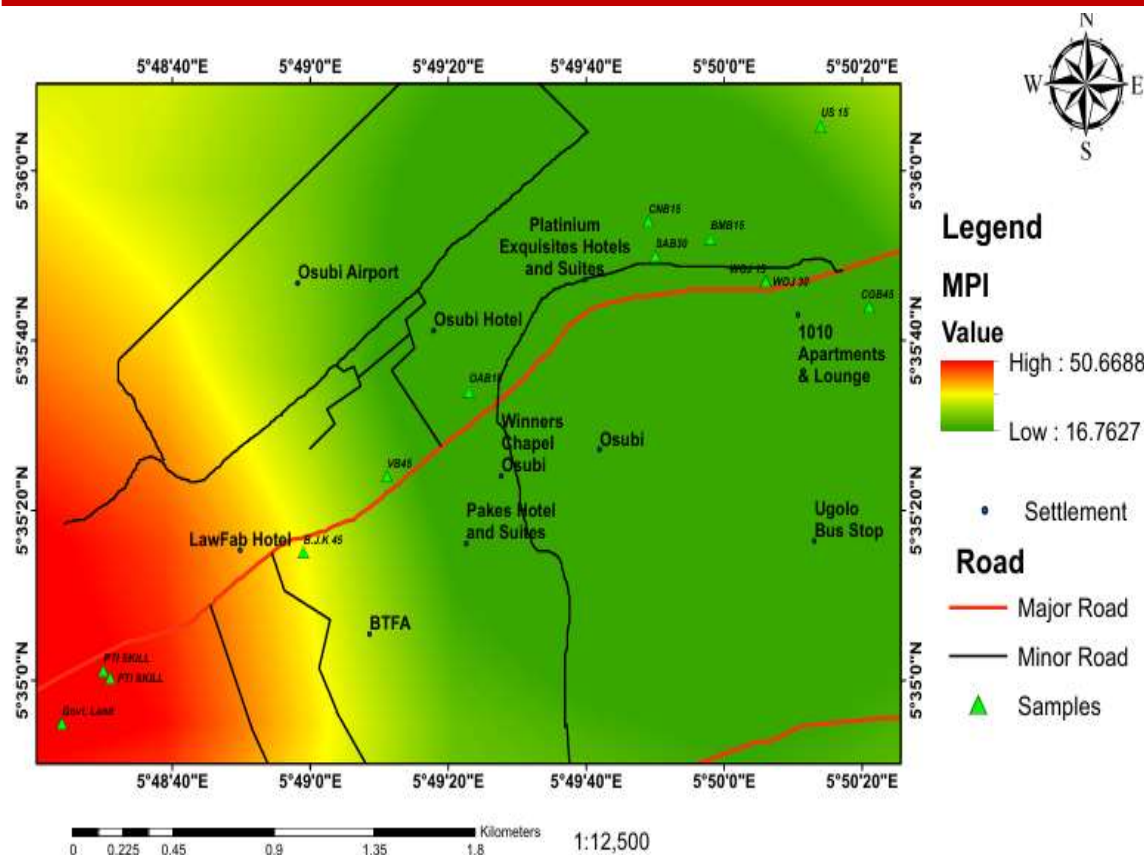


Fig.14: Spatial distribution of MPI within the study area

Potential Ecological Risk Index (PERI)

The spatial distribution of PERI in soil within the study area

PERI designates peri-urban regions and their associated soils, which are vulnerable to contamination by heavy metals and various pollutants resulting from intensive agricultural practices, industrial effluents, and urban waste. PERI serves as a framework for evaluating the ecological hazards associated with heavy metals found in soils and sediments. This methodology, established by the Swedish researcher Hakanson, (1980), takes into account both the toxic response factor of individual metals and their contamination factor—defined as the ratio of the measured concentration to the background level—in order to determine the comprehensive ecological risk. The classification of ERI values is as follows: an ERI of less than 150 denotes a low potential ecological risk to the soil ; an ERI ranging from 150 to less than 300 indicates a moderate potential ecological risk; an ERI from 300 to less than 600 reflects a considerable potential ecological risk; and an ERI of 600 or greater represents a very high ecological risk to the soil. The results illustrated in Fig. 15, indicate that the PERI values were notably elevated in specific regions of the southwestern area of the study. Deduction from PERI results, indicate that all samples were moderate potential ecological risk as shown in Table 2. The presence of PERI in soils, indicate that heavy metals found in peri-urban environments, raises considerable alarm, as such contaminants can impair soil quality, diminish agricultural productivity, and threaten human health via the food chain and direct contact.

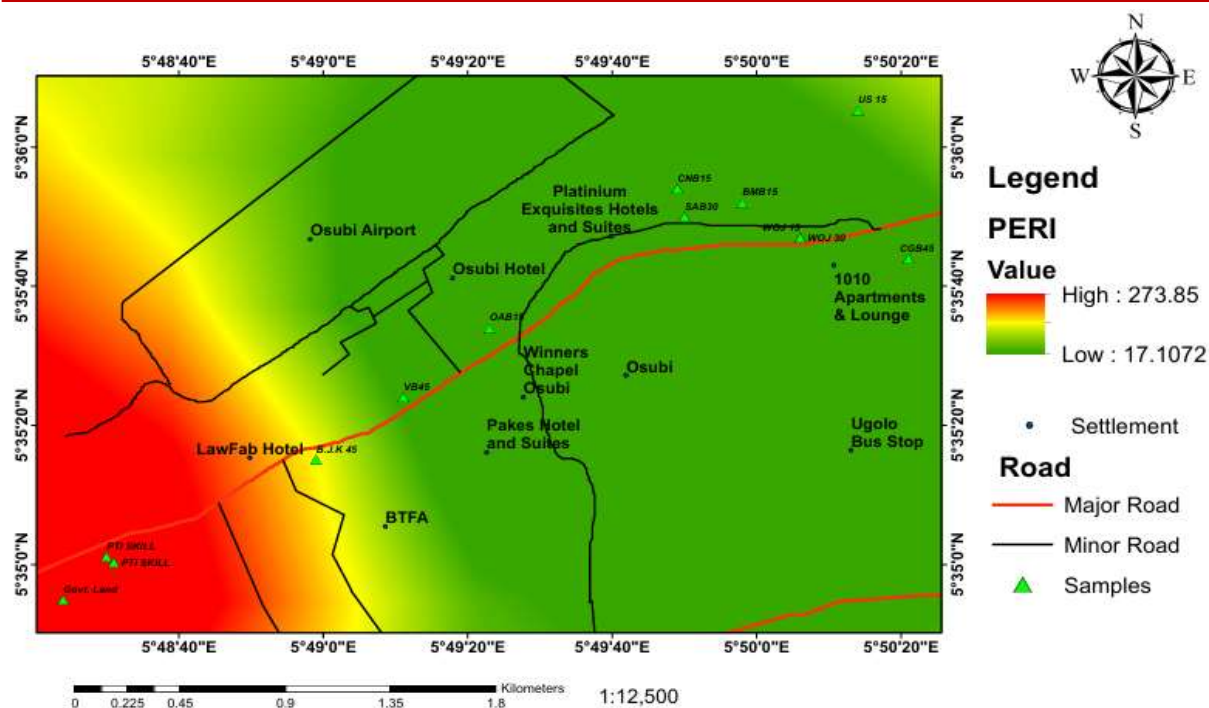


Fig.15: Spatial distribution of PERI within the study area

Table 12: The result of health risk assessment HI and HQ

	Fe(Child)	Fe (Adult)	Mn(Child)	Mn(Adult)	Zn(Child)	Zn (Adult)	Cr(Child)	Cr(Adult)	Cd(Child)	Cd (Adult)	Ni(Child)	Ni (Adult)	Pb(Child)	Pb(Adult)
BMB15	0.004207	0.001312	0.001279	0.004607	0.002453	0.001211	0.113552	0.038975	0.012487	0.006391	0.005855	0.004499	0.010731	0.008419
CNB15	0.004351	0.001357	0.001982	0.007138	0.002665	0.001316	0.109235	0.037494	0.01437	0.007355	0.007492	0.005756	0.012554	0.009849
OAB15	0.005461	0.001703	0.001471	0.005297	0.003376	0.001667	0.150771	0.05175	0.01184	0.006059	0.006644	0.005105	0.013243	0.010389
SAB30	0.006855	0.002138	0.002227	0.008019	0.004246	0.002096	0.165195	0.056701	0.010288	0.005265	0.011429	0.008781	0.015426	0.012102
CGB45	0.004461	0.001391	0.00131	0.004717	0.002832	0.001398	0.12766	0.043818	0.013963	0.007146	0.006318	0.004854	0.013692	0.010741
VB45	0.004301	0.001342	0.00162	0.005832	0.002376	0.001173	0.106497	0.036554	0.013165	0.006738	0.00757	0.005816	0.008015	0.006288
Govt. Land	0.0057	0.001778	0.024713	0.088991	0.009065	0.004475	0.491162	0.168586	0.67332	0.344601	0.022096	0.016976	0.271984	0.213371
B.J.K 45	0.003691	0.001151	0.016034	0.057738	0.004091	0.00202	0.292697	0.100465	0.305781	0.156497	0.008714	0.006695	0.135621	0.106395
US 15	0.004095	0.001277	0.019436	0.06999	0.004593	0.002268	0.409565	0.140579	0.341932	0.174999	0.012059	0.009265	0.151926	0.119186
PTI SKILL	0.006063	0.001891	0.029684	0.106892	0.009661	0.00477	0.539068	0.18503	0.753155	0.38546	0.023497	0.018052	0.288288	0.226162
PTI SKILL	0.006486	0.002023	0.030763	0.11078	0.009881	0.004878	0.643828	0.220987	0.99567	0.509578	0.030421	0.023372	0.330901	0.259592
PTI JUNCTION	0.004704	0.001467	0.020027	0.072117	0.005189	0.002562	0.423252	0.145277	0.430804	0.220483	0.012526	0.009624	0.205655	0.161337
WOJ 15	0.005555	0.001733	0.023531	0.084736	0.008567	0.004229	0.48116	0.165153	0.60403	0.309139	0.017506	0.013449	0.261979	0.205523
WOJ 30	0.006907	0.002154	0.03274	0.117897	0.010783	0.005323	0.76017	0.260921	1.060442	0.542728	0.034622	0.0266	0.339794	0.266569
FUPRE 15	0.003323	0.001036	0.013569	0.048861	0.00392	0.001935	0.216364	0.074265	0.262098	0.13414	0.007002	0.00538	0.105236	0.082558
FUPRE 30	0.004964	0.001548	0.022431	0.080774	0.008262	0.004079	0.46642	0.160094	0.471475	0.241298	0.015327	0.011776	0.228259	0.179069
HI	0.081124	0.025301	0.242817	0.874386	0.09196	0.0454	5.496596	1.886649	5.97482	3.057877	0.229078	0.176	2.393304	1.87755

The health risk assessment tool identified considerable spatial and demographic variations in exposure to heavy metal with children being the most vulnerable compared to adults. The Hazard Index (HI) of 5.50 in children and 1.89 in adults are above the USEPA safety level of 1.0, which means that it causes non-carcinogenic health hazards. The increased intake by children is put into greater risk compared to the body weight, and the growing physiological system which increases the metal absorption and toxicity. As shown in Table 12, the significant contributions to the total quotient of hazard were made by Chromium (Cr), cadmium (Cd), and lead (Pb), and the hazard quotient (HQ) of iron (Fe), manganese (Mn), zinc (Zn), and nickel (Ni) was relatively low ($HQ < 1$). The level of chromium (0.106–0.760 in children; 0.036–0.261 in adults) indicates its industrial and vehicular nature. The hazards of cadmium were very high in the regions of PTI, WOJ, and Government Land with the HQ level exceeding 1.0, which can cause kidney and skeletal conditions. Exposure to lead, especially in PTI and WOJ, had HQ values to 0.34 among children, which means breast cancer has neurological risks and developmental defects. Fe, Mn, Zn and Ni were in safe exposure limits, and could be synergistic in the cause of toxicity when in combination with more hazardous metals. Geographically, PTI Skill, WOJ 30, and Government Land were defined as areas of contamination that were associated with industrial discharges and vehicle emissions as well as improper waste management. On the whole, there is a significant threat to the health of adults and children, the latter is the most affected.

The urgent intervention measures are necessary, such as the tightening of industrial and vehicular pollution regulation, environmental monitoring, and the education of the population on health and environmental remediation using the methods that are environmentally friendly, such as phytoremediation. On both policy perspectives, the research draws attention to the need of short and long-term mitigation measures. These should include: 1. Regulatory Enforcement: tightening of industrial discharge policies, vehicular emission policies and disposal regulations of waste materials. 2. Environmental Surveillance: This involves setting up regular soil, water and air quality checking in order to monitor metal concentrations and trends. 3. Public Health Surveillance: The use of biomonitoring programs to measure the levels of blood Pb and Cd in children and adults in the high-risk areas. 4. Community Education: Carrying out awareness campaigns to educate the residents on the exposure pathways, hygiene habits, and safe sources of consumption. 5. Remediation Efforts: The implementation of green technologies, including phytoremediation and bioremediation with hyperaccumulator species (e.g., *Vetiveria zizanioides* and *Eichhornia crassipes*) as a way to get rid of heavy metal loads progressively. Finally, the paper offers valid evidence of gross heavy metal pollution and related health hazards in the examined setting. The fact that the indices of children at risk are high indicates that there is a necessity to introduce measures that will help to avoid the consequences of a long-term impact on the people. The implementation of regulatory and environmental and community-based interventions will also be necessary to reduce exposure and safeguard the vulnerable populations as well as enhance environmental sustainability within the area.

Conclusion

The research leads to the presentation of the variety of the heavy metal pollution indices developed by the scientific and research community in order to improve the understanding of the soil pollution caused by the natural and human-induced activities. Even though specific indices have been developed to use soil, the application of multi-indices approach to measuring heavy metal levels in the immediate environment is more efficient. The presence of the heavy metals in the soil has been attributed to the human activity, as indicated by the PCA and Pearson correlation findings, and degradation of HM in soil ecosystems is known to be majorly due to human activities such as industrial revolution, use of agrochemicals in farmlands, generation of energy, fuel processing, mining, steel production and disposal of wastes. In this paper, the index of heavy metal that were utilized included the following: NPI, mCd, PERI, MPI, and PLI, to examine the contamination of heavy metals in soil. Results of the study on spatial distribution of heavy metal in soil on the study area indicated that PTI skills axis of the study area was likely to have higher concentrations of heavy metal as compared to other areas of the study area. Additional data of heavy metal indexes (MPI, PLI, mCd, PNI and PERI) indicated that presence of heavy metal in the soil in the study was between slightly and higher contamination. These findings can enhance our knowledge on the magnitude of contamination of heavy metals, potential health risks, and likely factors that affect the accumulation of heavy metals in the soils within the study area. It also provides deeper and up-to-date information to manage the soil, remediation, and control of contaminants better.

Declaration

Ethical approval - Not Applicable

Consent to participate-Not Applicable

Consent to publish-Not Applicable

Data availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author contribution statement: W.O.O, Y.S.O and H.S.U conducted the field work, W.O.O and T.A.A wrote manuscript while O.V. B, H.S.U and Y.S.O reviewed the research work.

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