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Modeling of soil quality in Umonyeche Milieu Southern Region of Nigeria using Heavy Metal Index and Spatial Distribution

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Abstract: *This study examined the presence of heavy metals (HMs) in soil samples collected from Umuonyeche in Owerri, Imo State, southeastern Nigeria. Metal concentrations were determined using Atomic Absorption Spectroscopy. To assess pollution levels, multiple indices were applied, including the Potential Ecological Risk Index (ERI), Geo-accumulation Index (Igeo), Contamination Degree (Cdeg), and Nemerow Pollution Index (PNI). Statistical tools such as the Pearson correlation matrix and Principal Component Analysis (PCA) were also used to evaluate the relationships among metals and identify their possible sources. The results showed that heavy metal contamination in the study area largely originates from anthropogenic activities, including automobile repairs, solid waste disposal, and agricultural practices. While the ERI suggested that the soil is mostly unpolluted, the Igeo results indicated the influence of human activities, highlighting a contrast between the two indices. The Cdeg values revealed a low level of contamination across the samples. Additionally, PNI assessments categorized the soils as 25.8% clean, 28.2% slightly clean, and 10.7% moderately polluted. Findings from PCA and the Pearson correlation matrix further confirmed that the heavy metals present in the soil are primarily linked to human activities.*

Keywords: metals, index, pollution, statistics, analysis

INTRODUCTION

Heavy metals (HMs) in soils are commonly associated with fine-grained particles to which they readily adsorb, facilitating their dispersion across different environments (Eyankware et al., 2024; Osisanya et al., 2025). In recent decades, soil contamination by heavy metals has become a major global environmental concern, particularly in areas characterized by intensive artisanal and small-scale mining (ASM) activities (Wedepohl, 1995). Owing to their toxicity, persistence, and strong tendency to bioaccumulate, heavy metals pose significant risks to aquatic ecosystems and terrestrial environments (Ulakpa et al., 2021). Once deposited in sediments, these contaminants can be re-suspended into the water column, prolonging their environmental residence time and enabling repeated reabsorption by biota (Igwe et al., 2021).

The adverse effects of heavy metals on human health are well documented in the literature (Eyankware and Obasi, 2021). Consequently, assessing soil quality with respect to heavy metal contamination is essential for evaluating pollution levels, ecological integrity, and potential health risks within aquatic and terrestrial systems. Such assessments commonly employ pollution indices, sediment quality guidelines (SQGs), and ecological risk indices (RI) to quantify contamination levels and associated risks (Poté et al., 2008; Liu et al., 2005; Igwe et al., 2022; Odesa et al., 2024a). The environmental behavior of heavy metals is largely governed by their chemical speciation and binding forms, which control their mobility, bioavailability, and toxicity to living organisms (Eyankware and Ephraim, 2021; Odesa et al., 2024b). Sediments, in this context, serve as both sinks and secondary sources of heavy metal pollution (Eyankware et al., 2019).

Numerous studies have investigated the sources, distribution, and ecological impacts of heavy metal contamination, highlighting their detrimental effects on ecosystems and human health (Eyankware et al., 2020; Eyankware et al., 2025). In tropical developing regions, including Nigeria in Sub-Saharan Africa, the discharge of untreated urban wastewater into river systems constitutes a serious threat to environmental sustainability and public health. Urban waterways are increasingly impacted by anthropogenic activities that introduce a wide range of contaminants, such as heavy metals, persistent organic pollutants (POPs), pharmaceuticals, and pathogenic microorganisms. Additionally, the expansion of industrial activities and intensified agricultural practices, including irrigation and fertilizer application, has further aggravated heavy metal accumulation in soils (Onwe et al., 2024).

Heavy metal contamination in soils is particularly concerning due to its persistence, cumulative behavior, and high toxicity (Ike et al., 2021; Eyankware et al., 2016). The buildup of heavy metals in soil presents substantial ecological challenges, adversely affecting soil functionality, ecosystem stability, and biodiversity (Osisanya et al., 2025). Elevated concentrations of heavy metals impair

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agricultural productivity and pose significant health risks to humans and animals through ingestion and inhalation pathways (Omene et al., 2015). Therefore, understanding the spatial distribution and pollution status of soil heavy metals is critical for safeguarding food security, environmental quality, and public health (Eyankware et al., 2020).

Although several studies have focused on predicting the spatial distribution of soil heavy metals across different parts of the Niger Delta region of Nigeria, limited attention has been given to the direct impacts of heavy metals on soil quality within the present study area. This knowledge gap underscores the need for targeted investigations. Accordingly, this study examines the concentration and distribution of heavy metals in soils from Umuonyeche, Owerri, Imo State, southeastern Nigeria, with the aim of assessing soil quality and potential ecological and health risks.

Climate, vegetation, and Topography

Imo State, particularly its capital, is characterized by a high population density and a prevalent practice of intensive agriculture, which has resulted in soil degradation and the loss of much native flora. This deforestation has initiated soil erosion, exacerbated by heavy seasonal rainfall, leading to the destruction of infrastructure such as homes and roads. The soil in this region is well-drained. Among the prominent rivers and streams in the state are the Imo, Nwaorie, Otamiri, Njaba, and Oguta Lake as shown in Fig.1. The area is situated within the tropical zone, with early rains typically beginning in January or February, followed by the onset of the full rainy season in March, which lasts until November annually. The dry season spans approximately four to five months annually. The peak rainfall occurs from July to October, with minimal interruption noted in August. The average annual maximum rainfall is roughly 1952 mm (Igbokwe et al., 2008). In terms of temperature, the mean daily and annual figures are recorded at 28°C and 27°C, respectively.

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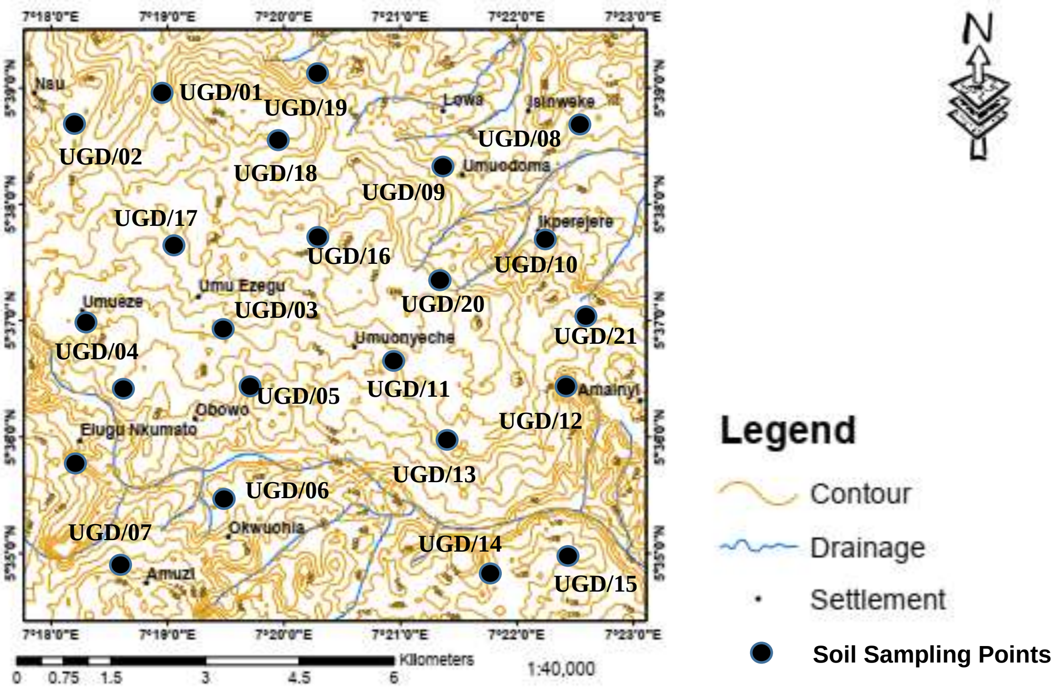

Fig.1 :

Topographic Map/soil sampling points within the study area

Geology of the study area

The research area encompasses two geological formations: the Ogwashi–Asaba formation and the Benin formation, previously referred to as Coastal Plain Sands (Reyment, 1965) see Fig.2. The Ogwashi–Asaba formation is distinguished by a sequence of alternating clays, sands, grits, and lignites (Desavvagie and Fayose, 1970; White, 1982). This formation is primarily located in the regions of Asaba, Benin, Onitsha, and Owerri. Reyment (1965) proposed that this formation dates back to the Oligocene–Miocene era. In contrast, the Benin formation consists of sands and sandstones that range from coarse to fine grains, typically exhibiting a granular texture. Additionally, this formation is composed of loose sand interspersed with occasional shale and clay lenses found at varying depths (Short and Stauble, 1967). The formation has origins that are estuarine, lagoonal, deltaic, and fluvid lacustrine in nature (Reyment, 1965). Within this formation, the sands and sandstones exhibit coarse granularity, ranging from very granular and pebbly to very fine grained. Their coloration can be described as either white or yellowish brown, with the presence of hematite grains and feldspars noted as well. The shale found in this formation displays a greyish to brown hue, has a sandy to silty texture, and includes some plant remnants along with dispersed lignites (Short and Stauble, 1967). The average thickness of this formation measures approximately 600 feet (196.85 meters) (Kogbe, 1976). The Benin formation is of continental origin and serves as a precise representation of the delta plain facies.

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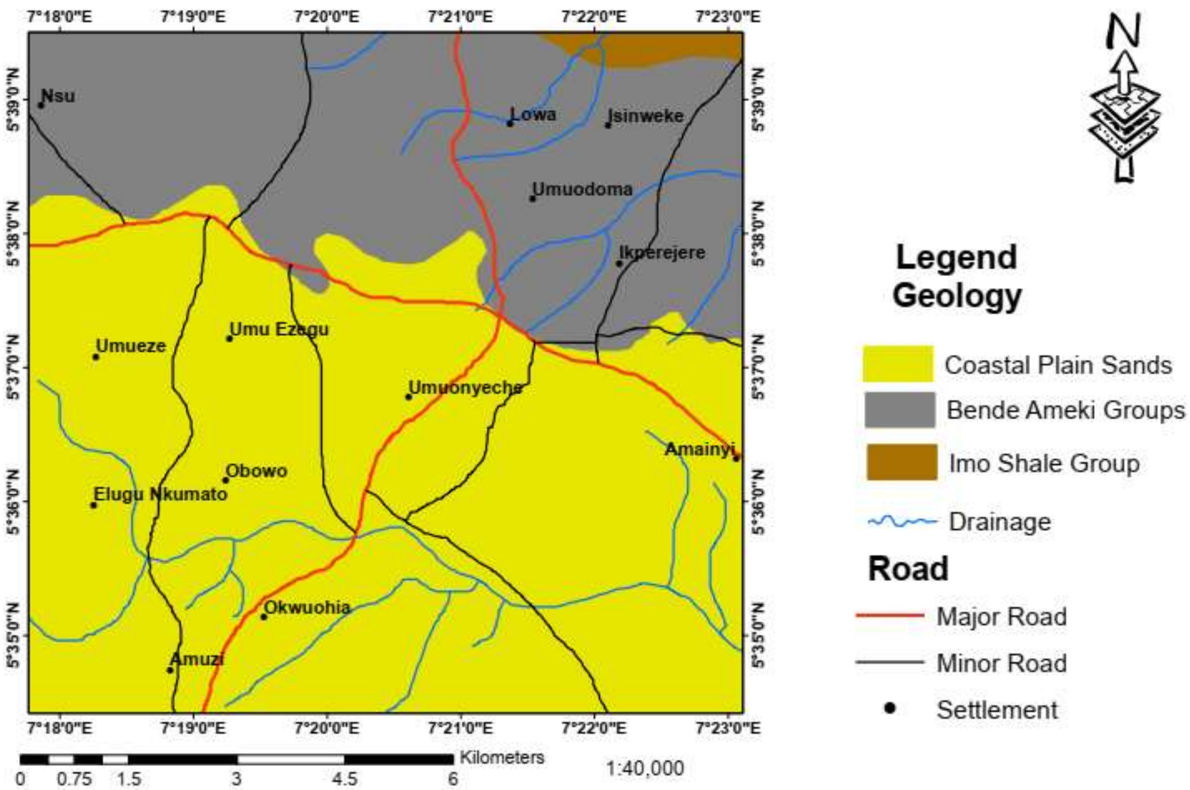

Fig. 2: Geological Map of the study area.

METHODOLOGY

Evaluation of Soil Pollution Indices

The presence of heavy metals in the soil was determined through the application of several metrics: the potential ecological risk index, the geoaccumulation index (Igeo), the contamination factor, and the Nemerow pollution index.

Data Analysis

In order to carry out Pearson correlation analysis and Principal Component Analysis (PCA), the data were examined utilizing the SPSS statistical software package.

(i). Potential ecological risk index

$$E_r^i = C_f^i * T_r^i = T_r^i * {}^{C_i}/_{C_b} \qquad \text{Equation 1}$$

The potential ecological risk index was first proposed by Hakanson, (1980)

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where E_r^i denotes the potential ecological risk index of metal i^{th}; T_r^i is the toxic response factor of the ith metal. In this study, the T_r^i of Zn, Cr, Pb, Cu, Ni, and Cd are 1, 2, 5, 5, 5 and 30, respectively (Weihua et al. 2010; Islam et al. 2015). The C_f^i values of each heavy metal are obtained from (Eq. 1). To quantitatively express E_r^i, five criteria grades were employed: $E_r^i < 40$, $40 \leq E_r^i < 80$, $80 \leq E_r^i < 160$, $160 \leq E_r^i < 320$ and ≥ 320 signifying low, moderate, considerable, high and very high risk, respectively (Hakanson 1980; Ogunkunle and Fatoba 2013; Riyad et al. 2015).

The index for potential ecological risk associated with different heavy metals in the soil is calculated by summing the individual potential ecological risk factors. This index reflects the vulnerability of diverse biological communities and the potential hazards posed by heavy metals. The potential ecological risk index for all assessed heavy metals was derived using (Equation 2).

$$RI = \sum_{i}^{n} E_r^i \qquad \textit{Equation } 3$$

(ii). The geoaccumulation index (Igeo)

$$I_{geo} = log_2 \left({}^{C_n}/_{kB_n} \right) \qquad \text{Equation 4}$$

As proposed by Muller, (1979)

where Cn is the measured concentration (μgg-1) of element n, and Bn is the geochemical background concentration (mg/kg).

(iii). Contamination factor (C_{deg})

$$C_{deg} = \sum_{i=1}^{n} C_f^i \qquad \textit{Equation } 5$$

As proposed by Devanesan, et al., (2017); Ogundele, et al., (2020)

(iv). Nemerow pollution

$$NP = \sqrt{{}^{(p_{ave}^1 + p_{max}^2)}/_2} \qquad \textit{Equation } 6$$

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

Pave and Pmax represent the average and maximum values of the single pollution index (SPI) for all heavy metals. The NP indices for each individual metal were computed and categorized into five distinct grades: NPs < 0.7, 0.7 ≤ NP ≤ 1.0, 1.0 ≤ NPs ≤ 2.0, 2.0 ≤ NPs ≤ 3.0, and NPs > 3.0. The classifications align with the concepts of safety, precaution, slight pollution, moderate pollution, and severe pollution, in that specific order (Cheng & Zhu 2007; Ogunkunle and Fatoba 2013).

Principal component analysis

Within the framework of PCA, the concept of component loading refers to the method of condensing an extensive dataset that contains multiple variables into a smaller set of linear combinations. These combinations account for a significant portion of the total variance in the data and establish effective connections between the variables and their respective sources or processes, as demonstrated in Equation (7).

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

RESULTS AND DISCUSSIONS

Table 1: Results of heavy metal samples within the study area

Sample site	Co	Pb	Cd	Zn	Cr	Cu	As	Ni
UGD /01	6.40	6.44	0.50	10.49	8.55	8.34	0.000	0.49
UGD /02	8.51	2.50	0.15	14.49	11.31	5.91	0.000	0.97
UGD /03	5.33	5.13	2.06	9.58	7.40	10.30	0.000	4.02
UGD /04	9.49	6.05	0.06	11.40	9.35	5.39	0.000	2.58
UGD /05	7.48	4.30	0.56	17.15	3.07	6.34	0.000	4.95
UGD /06	6.21	6.49	0.29	14.02	8.29	7.79	0.000	0.48
UGD /07	7.84	4.45	0.14	10.11	11.39	10.33	0.000	2.58
UGD /08	6.39	6.41	0.23	29.20	9.11	6.33	0.000	3.86
UGD /09	9.11	5.48	0.05	18.61	13.89	6.94	0.001	2.58
UGD /10	8.29	1.95	0.03	10.37	6.24	9.44	0.0001	1.93
UGD /11	5.18	4.03	0.07	14.01	8.38	10.59	0.001	4.30
UGD /12	9.33	3.24	0.19	11.95	4.34	7.96	0.0000	2.51
UGD /13	10.57	1.96	0.07	8.45	5.34	9.75	0.0001	5.30
UGD /14	7.44	3.10	0.69	12.59	10.28	11.48	0.000	0.11
UGD /15	9.45	5.04	0.05	18.33	9.43	14.17	0.001	1.84
UGD /16	12.88	0.87	0.75	13.54	5.34	10.49	0.0000	0.95
UGD /17	5.43	0.39	0.02	10.37	5.60	3.54	0.000	0.84

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UGD /18	6.99	0.53	0.43	18.39	9.14	7.08	0.000	2.45
UGD /19	7.82	0.98	0.55	15.33	11.69	9.16	0.000	4.58
UGD /20	11.79	1.74	0.16	21.97	9.87	12.04	0.001	2.11
UGD /21	8.39	3.01	0.59	24.37	8.14	10.35	0.001	3.59
Min	**5.18**	**0.87**	**0.03**	**8.45**	**3.07**	**5.39**	**0**	**0.11**
Max	**12.88**	**6.49**	**2.06**	**29.2**	**13.89**	**14.17**	**0.001**	**5.3**
Aver	**8.22**	**4.155**	**0.443**	**14.55**	**8.259**	**8.950**	**0.0002**	**2.492**

Concentration (mg/kg) of heavy metals in soil samples within the study area

Table 2: Results of Ecological Risk Index

	Ti*PI							
Pb	Zn	As	Cu	Co	Cd	Cr	Ni	**∑ Ti*PI**
785.457	2.493E-05	0	2017.866	5859.741	119494.3	18.3939	184.388	129374.11
391.581	0	0.04747	1915.869	4987.373	39594.47	11.90383	103.321	30384.39
684.332	0	0	1053.751	238271	749449.2	3.04932	72.373	594742.33
294.493	2.432E-02	0.003732	698.163	4992.212	60405	9.49932	3304.483	60485.49
294.484	0	0	583.086	8792.382	140959	4.59932	209.3873	15959.43
1294.583	7.494E-01	0.027252	1985.074	109373	4038381	7.37272	69.59554	294832.43
194.483	0	0	1394.075+	1572.842	18574.4	2.49492	109.3831	20848.3
583.02	0	0	1374.076	7937.371	45959.1	17.39381	113.2938	494372.2
204.333	0.000012	0.03811	1578.987	19372.034	5034949	20.30133	94.2843	575468.2
395.532	0.000385	0	1291.837	6014.855	547471.3	3.03423	183.3921	62826.39
294.432	0	0.027377	932.191	3974.877	584384.44	5.59839	91.3883	528652.1
503.322	1.94E-05	0.01918	1198.371	5667.975	594843	1.37474	300.3822	52372.2
489.321	4.33E-02	0.02727	1091.393	12436.987	174848.14	2.31383	401.494	185613.2
294.432	0	0	987.373	3657.987	302839.4	4.9337	297.273	426265.3
693.222	1.28E-04	0.011997	1985.382	5767.976	160549.3	10.3731	137.7321	17352.2
289.104	1.335E-02	0.58373	1391.392	7145.768	84023.5	5.3924	227.3772	73565.32
403.432	0	0	393.382	3998.755	64849.3	1.3948	124.4932	63527.13
198.483	0	0.00372	390.283	17866.086	163949.4	3.9449	298.48292	148637.3
489.483	2.93E-03	0.01837	2593.022	1754.651	20985.8	6.8627	197.423	31709.87
1129.421	4.29E-02	0.003262	1930.382	2747.202	705868.5	7.3040	214.493	71765.87
908.483	0	0	2279.192	1994.481	159686	2.9948	392.493	186554.87
403.183	2.939E-05	0.007362	1394.392	4585.594	51949.59	7.38821	298.494	56767.977

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Table 3: Results of Geo-accumulation Index

Cu	Pb	Cd	Co	Ni	As	Zn	Cr	**Geo-accumulation**
0.10485	0.03933	0.278453	0.05859	0.004653	0	0.05781	0.020203	0.50944
0.08639	0.006112	0.142989	0.070661	0.002455	1.1E-05	0.07654	0.03494	0.04883
0.10840	0.01493	1.279377	0.05465	0.001573	0	0.01569	0.03929	1.38224
0.04049	0.01128	0.142989	0.11469	0.00577	5.01E-06	0.07650	0.018374	0.39282
0.0609	0.01484	0.35371	0.07965	0.00656	0	0.07648	0.01293	0.49224
0.16049	0.016048	0.57572	0.06865	0.007655	1.67E-02	0.02445	0.02838	0.749323
0.10154	0.004948	0.101598	0.05145	0.004665	0	0.01466	0.03840	0.49432
0.05049	0.010484	0.605823	0.02455	0.004765	0	0.08654	0.04042	0.59403
0.04968	0.011947	0.92943	0.058807	0.003246	0	0.04775	0.05993	1.03484
0.06944	0.00604	0.233298	0.067755	0.005675	0.00015	0.03655	0.04940	0.47494
0.0594	0.00860	0.176855	0.068758	0.01565	0	0.01457	0.04494	0.39494
0.19403	0.003838	0.387576	0.05143	0.00764	5.37E-04	0.068877	0.01493	0.39493
0.08594	0.01283	0.481648	0.06885	0.0046	1.28E-08	0.019766	0.02333	0.4994
0.03040	0.01048	1.508913	0.05774	0.0067	0	0.08686	0.02339	1.3843
0.149443	0.010174	0.425205	0.046538	0.00469	0	0.08875	0.02116	0.7384
0.158593	0.00658	0.349947	0.06644	0.00379	4.82E-07	0.08647	0.04849	0.38493
0.058433	0.01285	0.139226	0.02437	0.00575	0	0.03676	0.05994	0.4993
0.069949	0.005184	0.52304	0.14533	0.00533	4.6E-08	0.046549	0.04942	0.3994
0.158494	0.005944	0.124175	0.044741	0.00565	1.6E-05	0.02453	0.02958	0.28459
0.194748	0.011849	1.471284	0.06543	0.00367	7.11E-03	0.03653	0.05658	1.39493
0.494943	0.00495	0.722472	0.075541	0.00565	0	0.019665	0.03949	1.4949
0.139494	0.005858	0.142989	0.14653	0.00354	5.98E-02	0.02568	0.05584	0.95933

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Table 4: Results of Contamination Factor, Pollution Load Index and Nemerow pollution

Cr	Cu	Pb	Co	Ni	Zn	Cd	As	**Cdeg**	**PNI**	**PNI**
0.1144	0.29595	0.0305	0.1844	0.01345	0.3664	0.076	0	1.65378	0	0.69888
0.1575	0.20484	0.0294	0.59594	0.00687	0.1986	0.254	0.00001	1.75679	2.48E-04	0.36569
0.0686	0.39401	0.0504	0.13947	0.006224	0.08987	2.48	0	5.09878	0	2.88651
0.1564	0.19494	0.0118	0.2843	0.04009	0.12558	0.291	0.000008	1.25567	5.39E-02	0.65586
0.0364	0.24004	0.0925	0.19473	0.08648	0.1966	1.939	0	1.98574	0	0.75767
0.1177	0.59592	0.0381	0.29331	0.00687	0.2678	1.393	0.00008	1.91146	6.49E-03	1.20338
0.0354	0.33049	0.0184	0.39932	0.0143	0.03612	0.984	0	1.0979	0	0.19494
0.1356	0.19494	0.0385	0.15757	0.01244	0.9869	1.9373	0	2.56469	0	1.17574
0.8659	0.12484	0.023	0.24894	0.009714	0.5789	2.3932	0.00008	3.97658	1.39E-03	2.65391
0.0965	0.19493	0.0651	0.23933	0.076436	0.25679	0.3499	0.00001	1.47679	1.17E-08	0.46654
0.8988	0.18373	0.0494	0.93932	0.00409	0.876	0.4931	0	1.22457	0	0.88789
0.0131	0.59584	0.0393	0.39499	0.01033	0.04772	1.9392	0.000007	2.25679	7.75E-02	0.86557
0.0594	0.49932	0.0854	0.10083	0.05954	0.04776	1.399	0.000003	2.47869	2.65E-01	1.865456
0.0778	0.29483	0.0585	0.374	0.04941	0.17563	3.9381	0	5.86898	0	3.098649
0.1353	0.59941	0.0697	0.14947	0.0048	0.3667	1.3359	0	2.98797	2.15E-03	1.08764
0.1086	0.39456	0.0395	0.3943	0.09914	0.15812	1.9931	0	1.25647	3.02E-05	0.86468
0.0754	0.65408	0.0285	0.39913	0.00494	0.05971	0.6831	0	1.78989	0	0.467674
0.0397	0.25609	0.0183	0.3949	0.03021	0.07989	1.3791	0.000004	2.75759	6.94E-02	1.7889
0.1362	0.14681	0.0301	0.6051	0.03059	0.19117	0.3758	0.000001	1.87689	1.94E-04	0.87654
0.0859	0.75379	0.0391	0.39052	0.02951	0.10897	3.0461	0.000005	6.80871	4.94E-03	2.88759
0.0851	1.01185	0.0294	0.39403	0.03958	0.08081	1.976	0	3.90888	0	1.65786
0.1095	0.53578	0.0595	0.49485	0.09202	0.13775	0.456	0.000003	1.68857	1.39E-02	0.35438

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Potential Ecological Risks Assessment

The potential ecological risk index, conceived by the Swedish scientist Hakanson in 1980, serves as a tool for assessing the detrimental impacts of contaminants on both the environment and human health. This index indicates the toxicity levels and ecological vulnerability associated with various concentrations of pollutants (Hakanson, 1980; Weihua et al. 2010; Suresh et al. 2012). Initially, it was specifically designed to evaluate sediment pollution in aquatic ecosystems. Over time, its application has extended successfully to the risk assessment of soils, atmospheric dust, and air quality (Osisanya, et al., 2025; Eyankware, et al., 2024). The data presented in Table 2 indicate that all samples from the study area exceed the threshold of 600, suggesting that the soils are at a significantly high ecological risk. The contamination of soil by heavy metals poses a substantial danger to both environmental integrity and food security, driven by the rapid expansion of industrial activities and agriculture, as well as the disturbance of natural ecosystems due to human pressures linked to population growth (Sarwar et al., 2017). The pollution of the environment and the associated human exposure to heavy metals stem from various human activities, including mining, industrial manufacturing, and the application of metal-containing substances in both domestic and agricultural practices (Tchounwou et al., 2012).

Table 5: Ecological Risk Index set limit in Soil (Hakason, 1980).

2S/No	Range	Remarks
1	$R_i \; or \; E_r^i$	Ecological Pollution Degree
2	$E_r^i < 40 \; or R_i < 150$	Low Ecological Risk
3	$40 \leq E_r^i < 80 \; or 150 \leq R_i < 300$	Moderate Ecological Risk
4	$80 \leq E_r^i < 600 \; or 300 \leq R_i < 600$	Considerable Ecological Risk
5	$160 \leq E_r^i < 320 \; or \; 600 \leq R_i$	Very high Ecological Risk

Index of Geoaccumulation

The geoaccumulation index (Igeo), introduced by Muller in 1979, serves as a tool for assessing the extent of contamination of elemental concentrations in various mediums such as sediment, water, dust, and soil. Its application in evaluating pollution levels has been widespread across the globe (Hazzeman et al., 2017). The Igeo classifications along with their interpretations are as follows: Igeo ≤ 0 indicates a condition of practically unpolluted, 0 < Igeo ≤ 1 signifies unpolluted to moderately polluted, 1 < Igeo ≤ 2 reflects moderately polluted, 2 < Igeo ≤ 3 denotes moderately to strongly polluted, 3 < Igeo ≤ 4 represents strongly polluted, 4 < Igeo ≤ 5 indicates strongly to extremely polluted, and Igeo ≥ 5 categorizes as extremely polluted. For further details, refer to Table 2 (Wei and Yan 2010; Olujimi et al. 2014). The findings from the geoaccumulation index presented in Table 3, indicate that all sample values fall within the range of 0 to 2, suggesting that these samples are free from pollution. This observation contrasts with the conclusions drawn from the potential ecological risk index, which indicated significant pollution levels in the soils. Overall,

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the Igeo analysis demonstrates that the majority of heavy metals have not distinctly impacted the soils in the study area.

Table 6: Geoaccumulation Index scale (Igwe, et al., 2020; Igwe, et al., 2022; Hazzeman, et al., 2017).

I_{geo} value	I_{geo} Class	Designation of sediment quality
>5	6	Very highly polluted
4-5	5	Highly populated
>3-4	4	Moderate to highly polluted
2-3	3	Moderately polluted
>1-2	2	Moderated to unpolluted
0-2	1	Unpolluted
0<	0	Background concentration

Degree of contamination(C_{deg})

The contamination factor serves as an indicator of the pollution characteristics present in the examined region. It represents a singular pollution index for a specific metal within an environmental medium. This factor is calculated by taking the ratio of the concentration of the heavy metal to the background concentration of the same metal (Ogundele et al. 2017). The degree of contamination (Cdeg) can be categorized according to a scale that ranges from 32: < 8, 8–16, 16–32, to > 32, which correspond to low, moderate, considerable, and very high levels of contamination, respectively (Chen et al. 2012; Ogundele et al. 2017; Devanesan et al. 2017). The findings regarding the degree of contamination, as illustrated in Table 4, indicate that all samples scored below 8, signifying a low level of contamination. These findings align with the geoaccumulation index results for the samples in the region; however, they contrast with the assessments conducted for the potential ecological risk index in the area.

Nemerow pollution (PNI)

The PNI, developed by Nemerow in 1974, serves as a numerical index that amalgamates various factors into a singular metric. In contrast, the NPI value reflects the overall water quality level derived from multiple pollution indicators. From an empirical standpoint, employing an integrated water quality index for assessing intrinsic groundwater risk is more advantageous than simply analyzing the concentrations of one or two specific pollutants (Kowalska et al. 2018; Kong et al. 2019). The PNI determines the relative contribution of each parameter to the pollution levels in a water sample, thereby allowing for the identification of the parameter(s) that dictate the quality status. PNI value of ≤ 0.7 indicates that the water is clean, PNI value of 0.7< PNI ≤ 1.0 implies

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slightly clean, PNI value of 1.0< PNI≤ 2.0 implies slightly polluted, PNI value of 2.0< PNI≤ 3.0 implies moderately polluted, while PNI value of > 3.0 implies heavy pollution (Table 4). The data presented in Table 4 reveals that 36.4% of the total sample exhibited values below 0.7, signifying that these samples are considered clean. Additionally, 19.4% of the samples recorded values under 1, which suggests they are slightly clean. Conversely, 18.6% of the samples had values of 3, indicating significant pollution levels. The elevated pollution observed in this study may be attributed to anthropogenic influences. This observation stands in contrast to findings from research conducted in Nigeria by Egbueri et al. (2020) and Eyankware et al. (2022).

Pearson correlation matrix

The correlation matrix is a valuable tool for assessing the interactions between two variables. Generally, the correlation coefficient can vary from -1 to +1. An r-value that approaches -1 signifies a negative correlation, indicating an inverse relationship. On the other hand, an r-value close to +1 suggests a positive correlation, reflecting a direct relationship. A correlation value of zero implies that the variables are not correlated (Srivastava et al., 2014), as illustrated in Table 8, the correlation matrix indicates a positive correlation between Zn and Cr (0.511), as well as between Zn and Pb (0.029). According to Table 7, a weak correlation is observed among the elements, with most of them showing no correlation at all. This indicates a lack of relationship between the two variables; as one variable changes in a certain direction, the other tends to move in a completely unrelated manner. Furthermore, this implies that human activities are the primary contributors to the presence of heavy metals in soils (Ugbome, et al., 2018; Anegbe, et al., 2018).

Table 7: Pearson correlation matrix

	Zn	Cr	Cu	Pb	Cd	Co	Ni	As
Zn	1							
Fe	0.01932							
Cr	0.483*	1						
Cu	-0.1483	-0.29947	1					
Pb	0.5113*	0.248301	-0.30382	1				
Cd	0.02943	-0.00118	0.203939	0.169541	1			
Co	-0.2941	-0.19437	-0.15058	-0.16049	-0.16043	1		
Ni	-0.07943	-0.31030	0.39574	-0.29575	0.161142	0.149693	1	
As	0.018375	0.079149	-0.14939	-0.06949	-0.15096	0.069594	-0.15993	1

* Moderate Correlation

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Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a classification technique that aims to elucidate the variations among a multitude of interrelated variables (Eyankware and Akakuru, 2022c; Akakuru et al., 2021a&b). This method illustrates the relationships between variables, thereby simplifying the complexity of the dataset. PCA derives eigenvalues and eigenvectors from the covariance matrix of the initial data. The principal components (PCs) are the orthogonal variables that result from the multiplication of the originally correlated variables by the eigenvectors (loadings). The eigenvalues associated with the PCs measure their respective variances, while the loadings reflect the contribution of the original variables to these PCs. Additionally, the modified observations are known as scores.

In the analysis of Principal Component 1 (PC1), 61.8% of the variables exhibit loadings, which include Zn (0.531), Cr (0.647), Cu (0.487), Pb (0.544), and Ni (0.467). Meanwhile, Principal Component 2 (PC2) accounts for 42.4% of the loadings, with variables such as Cu (0.26), Cd (0.98), and Co (0.75). In Principal Component 3 (PC3), only 11.7% of the variables are represented, notably As (0.869). The findings from Table 8, this PCA validate earlier research and further indicate that ongoing human activities in the region have significantly impacted the local soil conditions (Akpoveta, et al., 2010; Osakwe, 2014; Osakwe, et al., 2012). The contamination of soil by heavy metals poses a significant concern due to their detrimental effects on living organisms. The persistent and non-biodegradable characteristics of these metals contribute to their accumulation in the environment. Agricultural soils are increasingly receiving substantial quantities of pollutants from various sources. Beyond acceptable limits, heavy metals can have hazardous impacts on human health, disrupting the normal functioning of biological systems. The considerable volume of waste generated must be managed properly, taking into account the environmental considerations linked to land treatment. The elevated levels of heavy metals in agricultural soils are influenced by the soil's properties and the rate of application by the supplier alongside its primary concentration (Eyankware et al. 2021; Agidi et al. 2022; Akakuru et al. 2022).

Table8: Table PCA

		Component		
	Communalities	1	2	3
Zn	.547	**.694**	.295	.148
Cr	.529	**.695**	.015	.199
Cu	.528	**-.523**	**.496**	-.083
Pb	.519	**.532**	.187	.013
Cd	.503	-.017	**.613**	-.132
Co	.505	-.295	**-.598**	.048
Ni	.582	**-.593**	.297	.298
As	.517	.127	-.174	**-.576**
	Eigenvalues	.694	1.1058	-.1013
	Variance (%)	32.2114	17.29584	7.75993
	Cumulative var. (%)	28.793	47.295	61.595

SPATIAL DISTRIBUTION OF SOIL WITHIN THE STUDY AREA

Cobalt (Co) concentration in soil within the study area

Co is an element that occurs naturally and shares similar properties with iron and nickel. Trace amounts of cobalt can be found in soil (Igwe et al., 2021). In the region under investigation, Co concentrations range from 5.18 **to 12.88** mg/kg, with an average of 8.22 mg/kg (refer to Table 1). Deduction from Fig. 3 suggests that the concentration of Co within the study area tends to be high in Umuonyeche, Umueze, Amainyi, Ikperejere, Isimweke, and Umuodoma. HMs such as Co, which are emitted by lead-zinc mining under particular conditions, can stimulate, transfer, and build up in various target media such as soil, impacting plants, animals, and humans directly or indirectly, according to Igwe et al. (2021).

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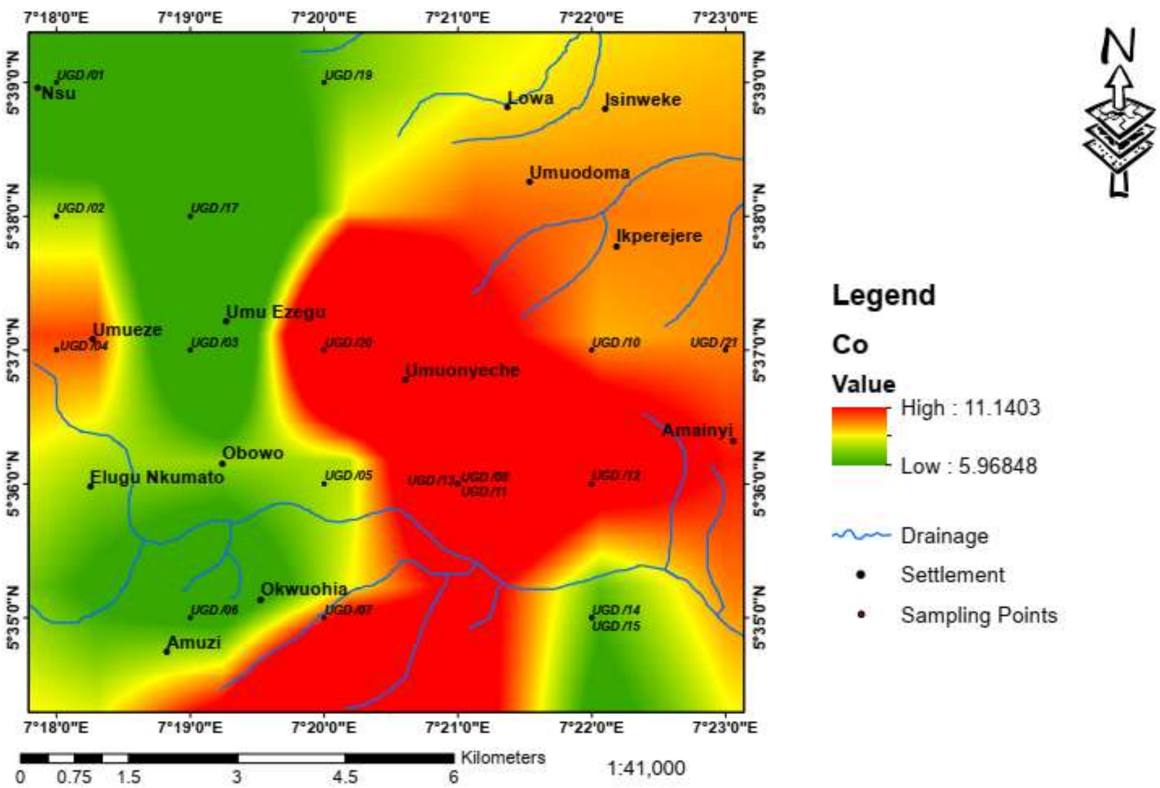

Fig. 3: Spatial distribution of Co within the study area.

Copper (Cu) concentration in soil within the study area

Deduction from the study revealed that larger part of the study showed the occurrence of Cu in soil see Fig. 4. Cu significantly contributes to environmental pollution, thereby impacting both environmental quality and ecosystem resources. During the processes of ore mining or processing, certain metal pollutants, including Cu, can be released and spread over much larger distances, adversely affecting the quality of soil sediments (Eyankware et al., 2022a). An analysis comparing the concentration of Cu in the study area against the Reference Guide for Toxic Substances (RGTS) revealed that all collected soil samples exhibited concentrations exceeding the Maximum Permissible Allowance (MPA). Despite being classified as moderately hazardous according to Akakuru et al. (2022a), it remains imperative to exercise caution.

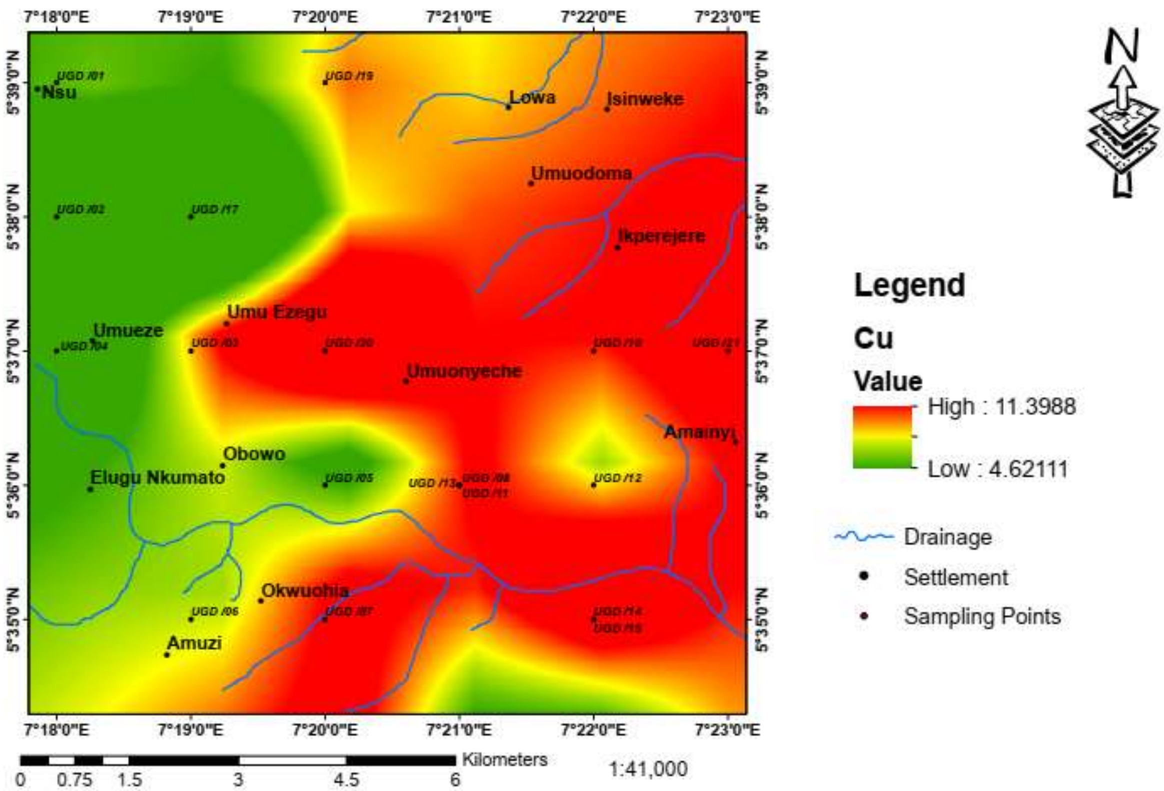

Fig. 4: Spatial distribution of Cu within the study area.

Zinc (Zn) concentration in soil within the study area

The highest concentrations of Zn in soil were found in areas such as Isinweke, Ikperejere, Umuonyeche, Amainyi and Obowo as depicted in Fig. 5. Per the WHO guidelines for soil (refer to Table), the Maximum Permissible Addition (MPA) of Zinc in this locality is relatively low, yet it still presents minimal risks. The increased levels of Zn in these particular areas are linked to waste disposal practices and the geochemical properties of the riverine zone in the study area (Oli et al., 2022; Obasi et al., 2022; Usman et al., 2022; Omoko et al., 2023).

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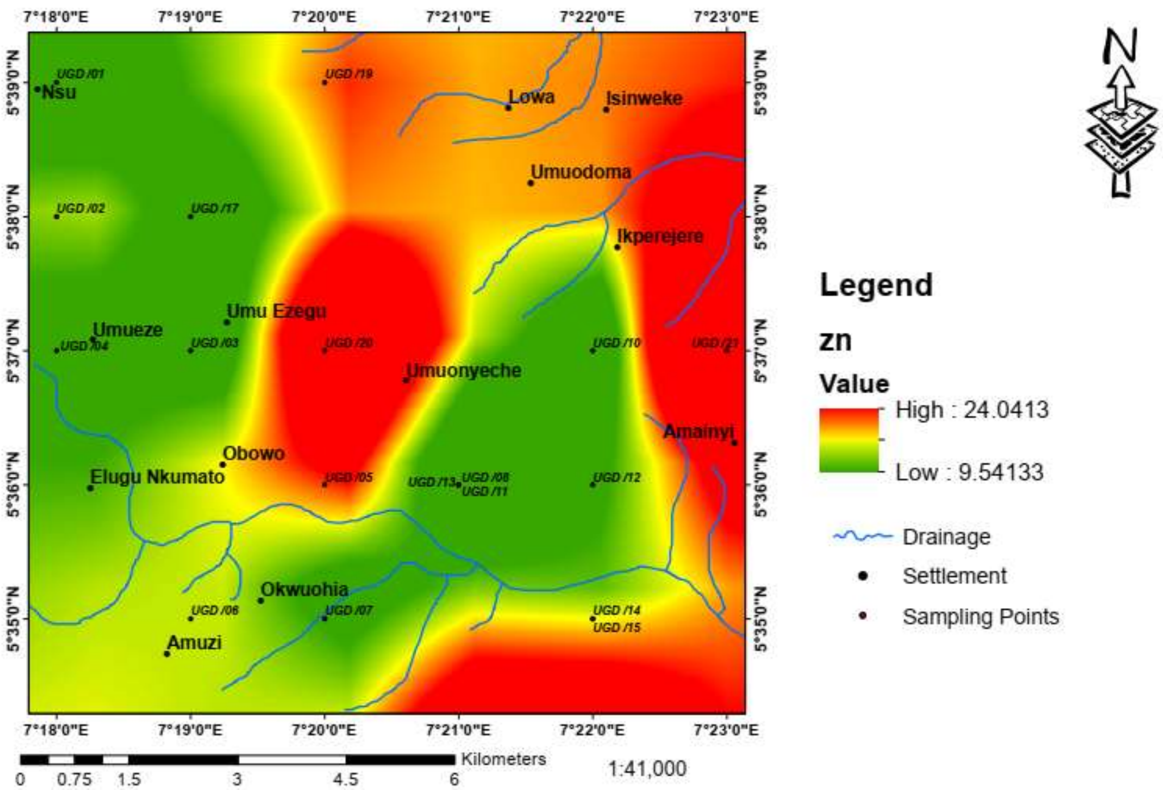

Fig. 5: Spatial distribution of Zn within the study area.

Arsenic (As) concentration in soil within the study area

As is a naturally occurring substance that can be found throughout the earth's crust. As is a highly toxic metalloid that is widely distributed on the Earth's surface and in its hydrosphere (Emilie et al., 2017; Igwe et al., 2022). It is a well-known poison, and even a small amount of arsenic trioxides, such as 0.1 g, can be extremely harmful to the environment. Although persistent arsenic poisoning as a result of occupational exposure is well-known, high arsenic toxicity is now rare (WHO, 1981). It was observed from Fig. 6, that concentration of As in soil increases towards Isinweke, Ikperejere, Umuonyeche, Amainyi, Obowo, and southwest axis of the study area see Fig. 6.

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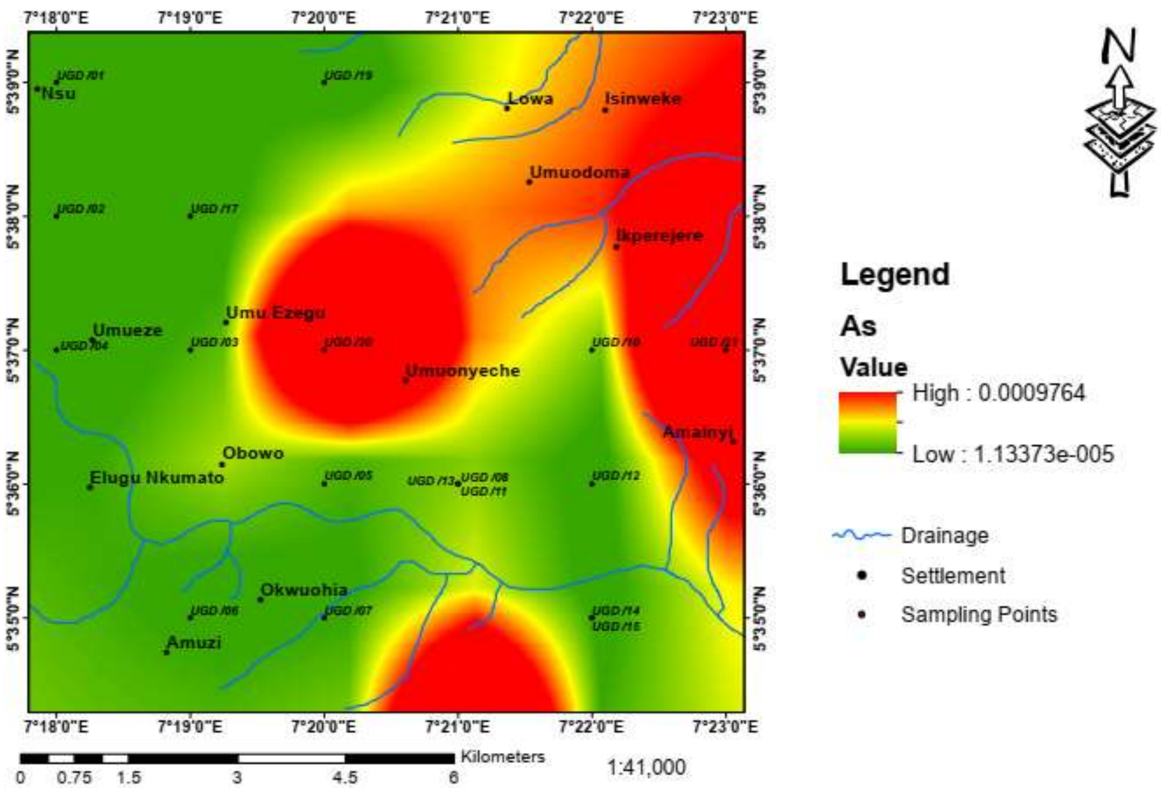

Fig. 6: Spatial distribution of Zn within the study area.

Chromium (Cr) concentration in soil within the study area

According to the results displayed in Fig. 7, the highest levels of Cr in the soil were detected along the northwestern, southwestern and southeastern axes of the region. Jankiewicz and Ptaszynski (2005) reported that the variability in Cr concentration within the soil is significant and is influenced by the characteristics of the underlying geological materials from which the soil has formed. In addition, human activities, particularly mining operations located in proximity to active sites, can significantly elevate the concentrations of chromium (Cr) in the soil. The uptake of heavy metals (HMs) by plants from contaminated soil can lead to detrimental effects on human health, including potential damage to the kidneys and liver (Harendra et al., 2017). When contrasted with RGTS, the chromium element, classified as moderately hazardous, is found to have its entirety of soil concentrations exceeding the maximum permissible levels (MPA).

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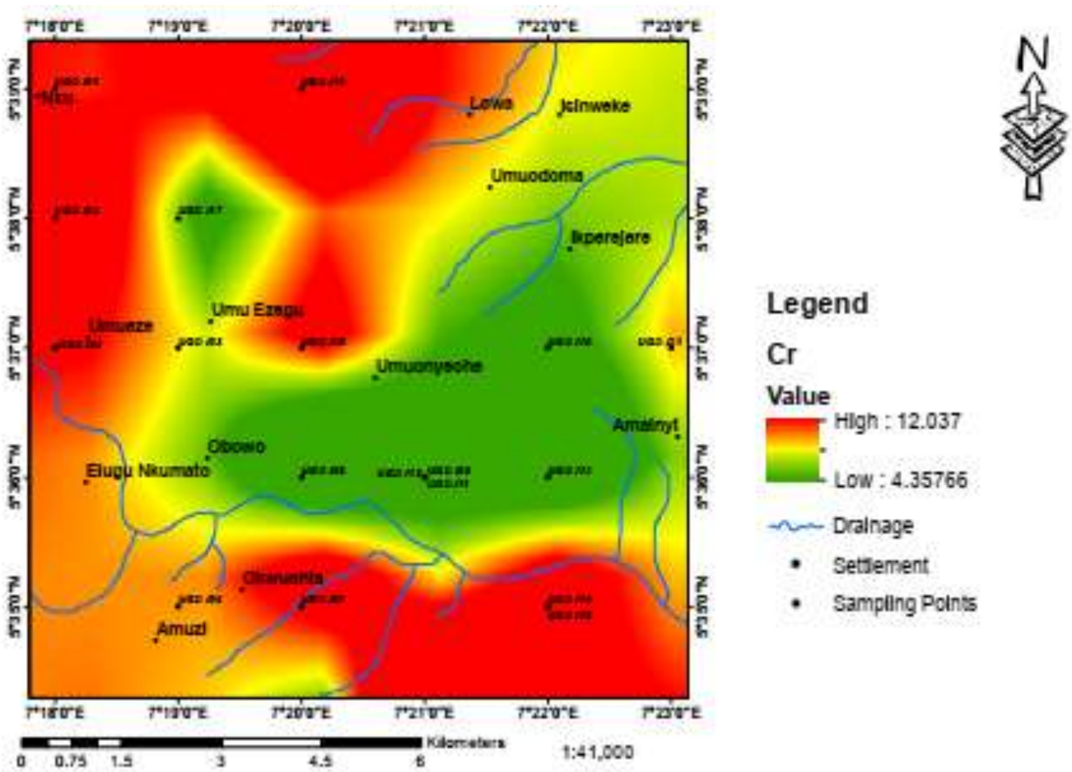

Fig. 7: Spatial distribution of Cr within the study area.

Nickel (Ni) concentration in soil within the study area

Ni is present in soils in numerous forms, such as the adsorption of complex formations on surfaces of organic or inorganic cation exchange materials, as well as within inorganic crystalline minerals or precipitates. Additionally, it can exist as water-soluble, free-ion, or chelated metal complexes dissolved in the soil solution, along with further inorganic crystalline minerals or precipitates. In the study area, the concentration of Nickel exceeds the MPA limit by approximately 50%. Deduction from Fig. 8, suggested that Ni in soil increases towards Isinweke, Ikperejere, Umuonyeche, Amainyi, Obowo axis of the study area.

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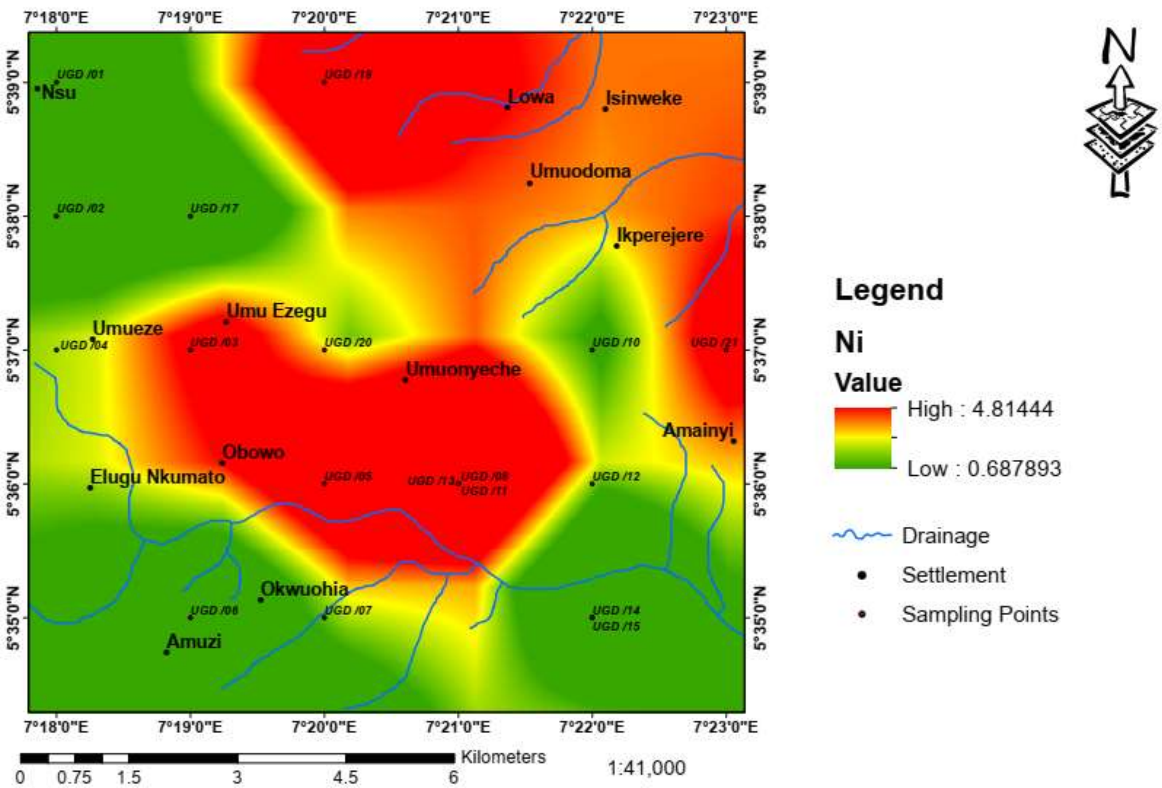

Fig. 8: Spatial distribution of Ni within the study area.

Lead (Pb) concentration in soil within the study area

Pb is regarded as a non-essential and hazardous element, and its effects have been examined in greater detail compared to other trace metals (Eyankware et al., 2022a; Igwe et al., 2021; Raikwar et al., 2008; SON, 2015). To assess the availability of Pb in soil, the pH levels of all soil samples analyzed for Pb content were recorded. In soils with a pH ranging from 6 to 8, which are considered near-neutral, Pb tends to form strong bonds with soil particles, thereby limiting its accessibility for plant absorption. The Pb concentrations observed in this study vary from 0.87 to 6.49 mk/kg, with an average concentration of 4.155 mk/kg, as presented in Table 1. Findings from Fig. 9, denoted that Nsu, Amizi, Okwuohia, Obowo, Elugu Nkumato, Umu Ezegu, and Umueze.

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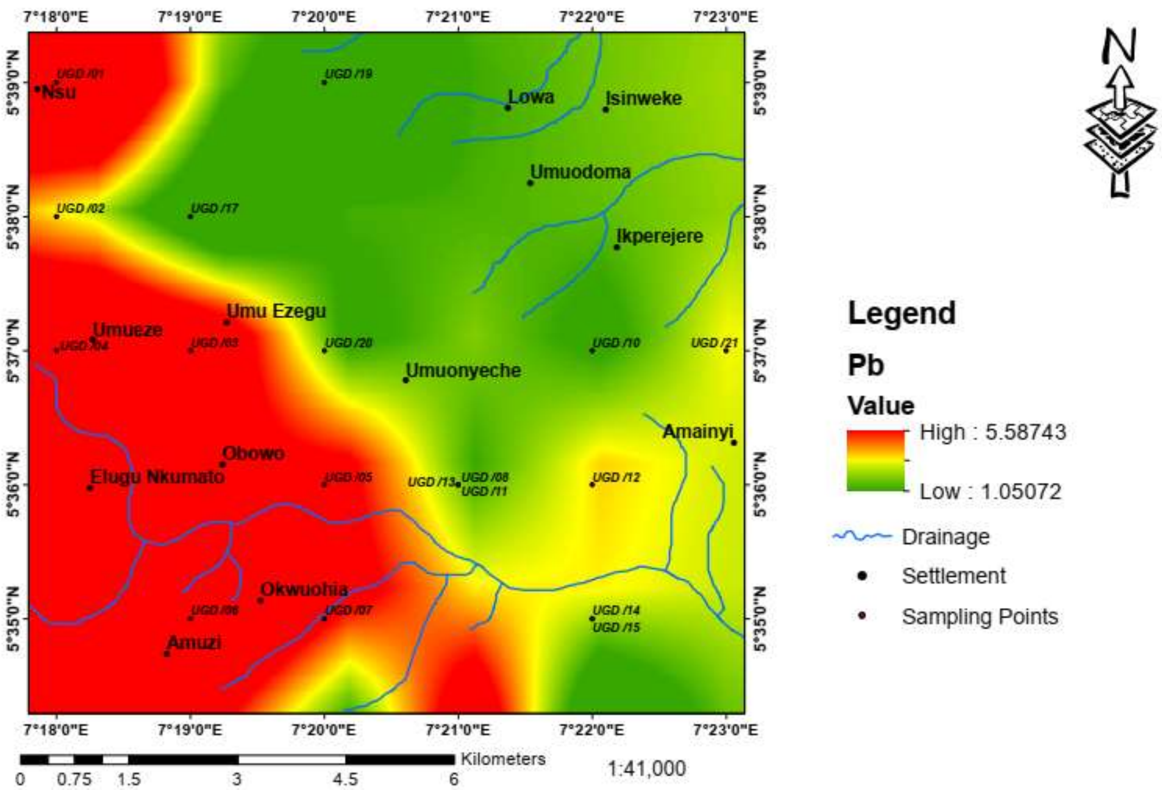

Fig. 9: Spatial distribution of Pb within the study area.

Cadmium (Cd) concentration in soil within the study area

Findings from Fig. 10 showed that Umu Ezegu, Obowo, and Elugu Nkuwato are high in Cd concentration in soil within the study area. Cadmium (Cd) is a naturally occurring element in mineral soils (Igwe et al., 2022; Segura et al., 2006). Soil concentrations of Cd vary between 0.03 and 2.06 mg/kg, with an average of 0.443 mg/kg. The highest levels of Cd were identified in the southwestern (SW) and southeastern (SE) regions, as well as certain areas in the northeastern (NE) part, likely due to geogenic sources. Research by Li et al. (2015) indicates that the concentration of Cd is influenced by the geological parent materials.

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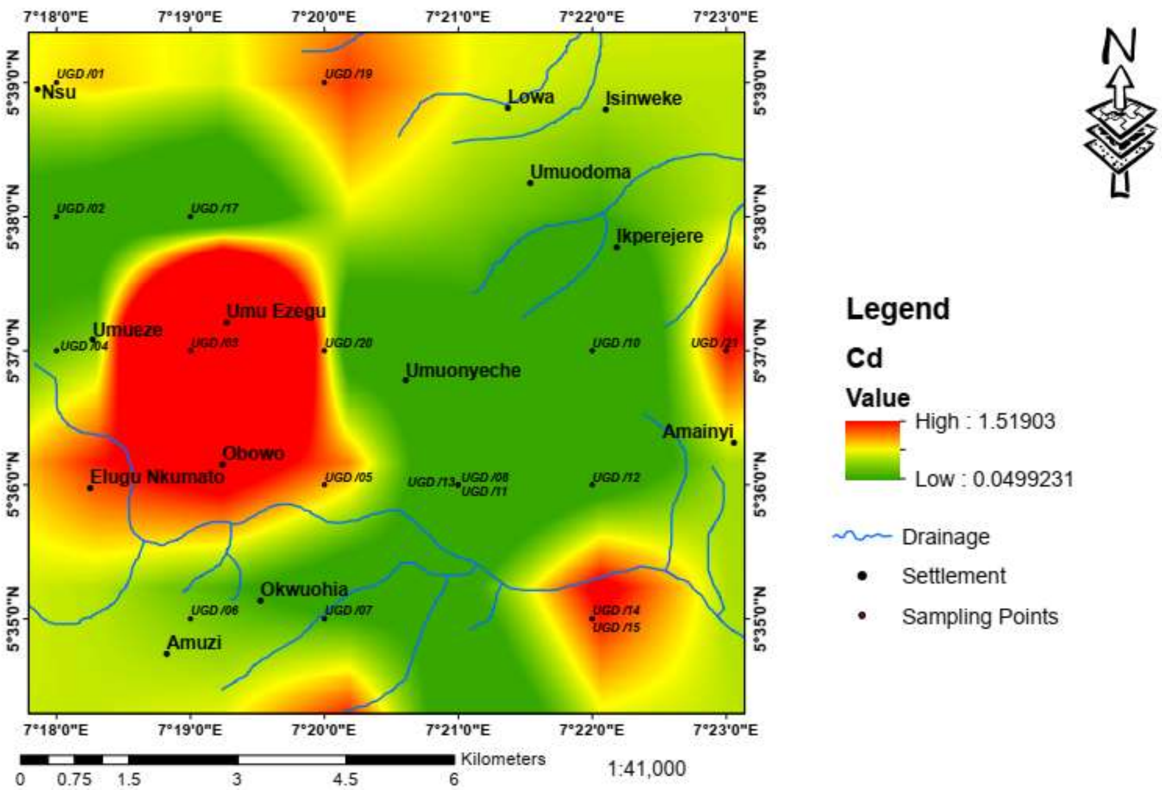

Fig. 10: Spatial distribution of Cd within the study area.

CONCLUSION

Heavy metal pollutants and their subsequent degradation within soil ecosystems are generally associated with anthropogenic activities, including the industrial revolution, the application of agrochemicals in agriculture, energy production, fuel processing, mining operations, steel manufacturing, and waste management, each of which presents risks to various life forms. In this research, the presence of heavy metals in soil was examined through statistical methods such as Principal Component Analysis (PCA) and Pearson correlation, in conjunction with heavy metal indices like the Environmental Risk Index (ERI), geoaccumulation index (Igeo), contamination degree (Cdeg), and Pollution Index (PNI).. The levels of heavy metals in the soil, specifically Co, Pb, Cd, Zn, Cr, Cu, As and Ni ranges from 5.18 to 12.88 with an average value of 8.22 mk/kg, 0.87 to 6.49 with an average value of 4.155 mk/kg, 0.33 to 2.06 with an average value of 0.443 mk/kg, 8.45 to 29.2 with an average value of 14.55, 3.07 to 13.89 with an average value of 8.25 mk/kg, 5.39 to 14.17 with an average value of 8.95 mk/kg, 0 to 0.001 with an average value of 0.0002 mk/kg, and 0.11 to 5.3 with an average value of 2.49 mk/kg respectively. Additionally, the derived values from the heavy metal index indicated that the ranges for Cdeg, Igeo, and PNI ranges from 1.097 to 6.808, 0,048 to 1.49, and 0.00 to 0,265 respectively. Further findings from spatial distribution map of HM revealed that Isinweke, Ikperejere, Umuonyeche, Amainyi, and some other parts of the study area showed occurrence of HM in soil. HM pollutants and their degradation within soil ecosystems are generally associated with human activities, including the industrial revolution, agricultural chemical usage, energy production, fuel processing, mining, steel manufacturing, and waste management. These activities collectively endanger all forms of life. The findings of this research highlight the significant impact that anthropogenic actions have had on the study area, particularly regarding soil quality. Furthermore, it is crucial to acknowledge that contaminated soil adversely affects water resources.

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