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STUDIES OF SOIL POLLUTION IN NSUKKA URBAN, SOUTHEASTERN, NIGERIA

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Abstract

Several studies have shown that soils within urban areas can be severely contaminated by heavy metals. In present study, 11surface soil sampleswere collected from dumpsites, mechanic village, agricultural farmland, sewage lodge, major market, motor park and major abattoirs throughout the Nsukka urban for analysis.The concentration levels of Fe, Mn, As, Pb, Zn, Cd, Cr, Ni, Cu, and Hg in these samples were measuredand statistically analysedusing standard procedures. The spatial distribution of heavy metals was analysed by the inverse distance weighted (IDW) interpolation method. Pearson correlation matrix was used to ascertain contamination sources of ten heavy metals and to determine the contribution of each source. Results of the analysis show that theconcentrations of heavy metals in many samples exceeded thevalues defined by the World Health Organization/Food Agricultural Organization (WHO/FAO). However, theconcentration of all heavy metals were also higher than their control sample values. The sequence of heavy metals in the soils of Nsukka urban was in following order Fe >Zn > Cr>Cu > Cr > Pb > As> Ni >Mn >Cd> Hg. The results show that contribution from land use in Nsukka urban are in the order of dumpsite > abattoirs > sewage lodge > mechanic village > agricultural farmland > motor park > market.This clearly demonstrates that anthropogenic activitieshave markedly higher contribution rates to heavy metal pollution in soils of Nsukka urban than geogenic sources.

Keywords: Nsukka urban. Heavy metals. Spatial distribution. Statistical analysis. Soil samples

Introduction

Heavy metal contamination has triggered growing concern in recent times as a potential threat to the environment and to publichealth (Mergler et al., 2007). Heavy metal pollution in soils, particular in urban areas, has emerged as a major environmental issue worldwide, owing to rapid population growth and industrialization(Wang et al., 2018).Heavy metals in soils are entirely non-degradable and quickly accumulate in organisms via the food supply chain(Wcislo et al., 2016).Furthermore, they can be conveyed to faraway areas via atmospheric dispersion and to rivers via surface runoff during rainfall conditions (Han et al., 2018). As a result, heavy metal pollution of soil has become a major threat to public health and regional ecosystem functions.

Natural and anthropogenic activities are widely acknowledged to be the two major sources of heavy metals. Natural sources are mostly trace elements found in the crust (Liu et al., 2015), while the anthropogenic sources are primarily associated with dumpsites, mechanic workshop, sewage system, abattoirs, metal smelting, fuel and coal combustion, coal mining, and agricultural fertilization.

Multivariate statistics coupled with statistical approaches were commonly used to identify heavy metal sources and fully comprehend the spatial heterogeneity of heavy metals in soils.Geostatistical approaches are commonly used to investigate the spatial variation characteristics of heavy metals in soils.The inverse distance weighted method is the most commonly utilized interpolation technique to investigate the spatial pattern characteristics of heavy metals in soils(Wang et al., 2020).It predicts unknown spots using measured data and a semivariogram model (Ahmed et al., 2014).

Several studies on Nsukka soilsinclude Kalu et al.,(2014) who worked on determination of the presence and concentration of heavy metals in cattle hides singed in Nsukka Abattoir. Ekere et al., (2016) measured the levels, spatial distributions and ecological risk assessment of cadmium and lead in surface soils of Nsukka industrial cluster areas.Uzochukwu (2019) investigated heavy metal pollution of a residential area in Nsukka and its associate risks. Ohanu et al., (2020) studied the evaluation of some heavy metals and physicochemical properties of public refuse dumpsites in Nsukka metropolis.Mama et al., (2020) researched on the assessment of heavy metal pollution of soils of Nsukka metropolis. Therefore, the aim of this study was to examine the heavy metal concentrations, spatial distributions, and sources in surface soils of Nsukka urban. This study will build on past works conducted in various parts of Nsukka urban by presenting concrete and reliable data from the analysis of soil samples in selected sites that will serve as a benchmark for future studies on soils in Nsukka urban.

Study Area

Nsukka urban is made up of small popular towns like Agu-Echara (Barracks), Onuiyi, Alor-Uno, Edem, Eziani, Ihe U.N.N, Nru (Ikpa), Umakashi and Ebulummiri. It is located between latitudes 6^{0} 49'0''N to 6^{0} 53'0''N and longitudes 7^{0} 19'0''E to 7^{0} 26'0''E with an estimated population of about 1,205,131 people.Nsukka area is a plateau surface with isolated outliers of oolithic iron stone-capped hills whose peak elevation attains 525m.The mean elevation is 350m above sea level. Two main seasons exist in the area, namely, the dry season that runs through the months of October to March, and the rainy season that begins in March and ends in October. Inyang (1975) shows that the annual rainfall in Nsukka town varies from 986 mm - 2,098 mm. Amospheric temperature is moderately high, with values ranging from 21°C- 27^0 C. The vegetation is mainly the forest type.

Geology and Hydrogeology

Nsukka urban constitutes part of Anambra basin of Nigeria and is underlain by twoformations namely, the Ajali Formation, and Nsukka Formation (all Upper Cretaceous to Lower Paleocene) in upward succession.The Ajali Formation, also known as False Bedded Sandstone, consists of thick friable, poorly sorted sandstones, typically white in colour but sometimes iron stained. The thickness averages 300m and is often overlain by considerable thickness of red, earthy sands, formed by the weathering and ferruginization of the formation.The Nsukka Formation lies conformably on the Ajali Formation. The lithology is very similar to that of Mamu Formation and consists of an alternating succession of sandstone, dark shales and sandy-shale, with thin coal seams at various horizons.

The study area is made up of a multi-aquifer system. The first system is a local perched aquifer (LPAS). The results from the entrapment of vertical flow through the regolith of the Nsukka Formation by an impermeable layer, usually shalelclay horizon within the formation.The underlying aquifer systems, which are separated from the LPAS by as much vertical distances as 120m constitute the Regional Groundwater System (RGS). The RGS is considered a multi-aquifer system, being made up of semi-confined and unconfined aquifers.

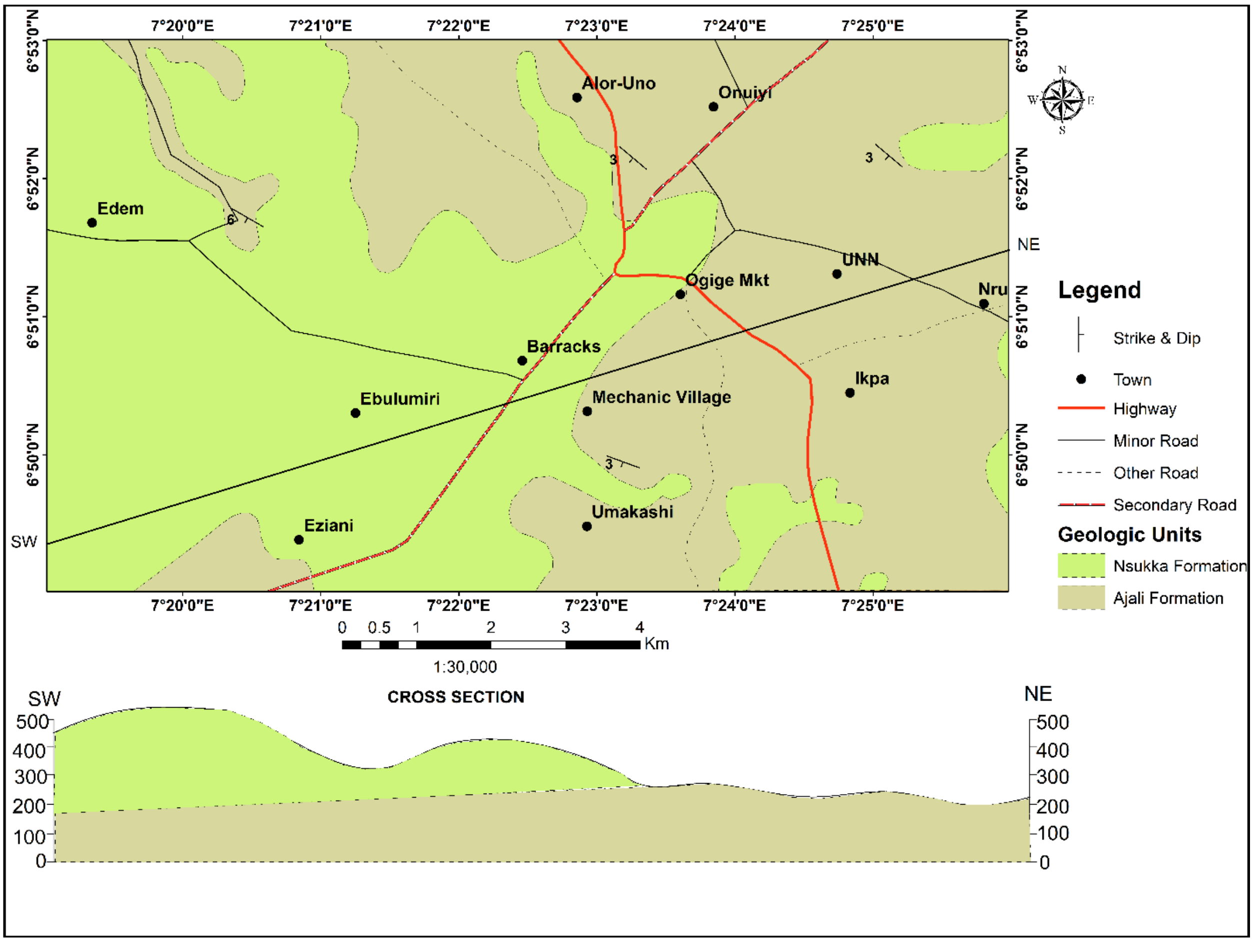

Figure 1: Geologic map of the study area

Materials and methods

Soil Sampling and preparation

A total of elevensoil samples were collected from Ogige market, UNN central dumpsite, mechanic village, Nsukka central dumpsite, agricultural farmland, UNN central sewage lodge, Peace mass transit park and Ikpaabattior during June 2022 (Table 1). At each sampling site, soil samples were collected separately by random selection, from surface (0.5cm soil layer) with a small hand trowel.The soil samples collected from following locations as mentioned above, were kept in clean polyethylene bags, labeled, and brought to the laboratory for analyses.

Table 1: Summary of soil sample collections

Location	**Sample ID**	**Latitude (N)**	**Longitude (E)**	**Elevation (M)**
Abattoir Ikpa	SS 1	6°50'53.60"	7°25'2.32"	511
Abattoir Ikpa 2	SS 2	6°50'53.16"	7°25'1.13"	509
Peace Motor Park Nsukka	SS 3	6°50'40.86"	7°23'58.33"	457
Ogige Market Nsukka	SS 4	6°50'34.05"	7°23'30.28"	432
Nsukka Central Dumpsite Eziani	SS 5	6°52'28.42"	7°21'39.94"	450
Ebulummiri Agricultural Farmland	SS 6	6°50'30.45"	7°21'49.20"	402
Nsukka Mechanic Village	SS 7	6°50'23.03"	7°23'28.25"	426
UNN Central Dumpsite	SS 8	6°51'52.49"	7°25'7.31"	464
UNN Sewage Lodge	SS 9	6°52'29.61"	7°24'52.38"	485
Alor-Uno	SS 10	6°52'46.82"	7°22'47.07"	376
Edem	SS 11	6^{0} 51'14.51"	7^{0} 20'36.05"	345
Control sample 1 (Ovoko)	CRT 1	6^{0} 54'20.19"	7^{0} 19'47.48"	452
Control sample 2 (Ovoko)	CRT 2	6^{0} 54'51.23"	7^{0} 20'01.22"	449

Laboratory analysis

The soil samples (10.0 g) were sieved through a 100- mm mesh and put into a 50 mL beaker containing 25 mL of distilled water. The solution was sharply agitated for 2 min and kept undisturbed for 30 min.

For heavy metals analysis, the soil samples were homogenized by coning and quartering were dried at 75 °C for 48 hours and then ground to fine powder. The dried and sieved soil samples were digested by HCl and concentrated HNO_3 in 3:1 ratio. The solution was cooled, filtered, and diluted with 25 ml of distilled water. The digested liquid was filtered through a Whatman No. 0.5 filter paper, and the total heavy metal content of the filtrate was analyzed by using atomic absorption spectrometry (210/211 AAS 220GF graphite Furnace).

Statistical analysis

Multivariate statistical analysis was applied for 10 heavy metals using Pearson correlation coefficient and principal component analysis (PCA) to evaluate factors influencing the soil pollution and sources of pollution in Nsukka urban. First, the relationships between different soil variables were determined using Pearson’s correlation coefficient. The classification was based on Guildford’s rule of thumb for interpreting the Pearson product moment correlation (Guildford, 1973) (Table 2).

Table 2: Guildford's rule of thumb for interpreting correlation coefficient (Guildford, 1973).

***r*-value**	**Interpretation**
0.0 to 0.29	Negligible or little correlation
0.3 to 0.49	Low correlation
0.5 to 0.69	Moderate or marked correlation
0.7 to 0.89	High correlation
0.9 to 1.00	Very high correlation

Results and Discussion

The results of the heavy metals analysis of the soil samples are presented in Table 3 and was compared with the maximum permissible limits for agricultural soils as recommended by theWorld Health Organization/Food and Agricultural Organization (WHO/FAO, 2001).The Fe content of the soil ranged from 306 to 1124 mg/kg while the control samples varied from 99 to 106 mg/kg. The Fe content recorded for the soils in this study is above the WHO/FAO permissible limits of 300 mg/kg.Mn values ranging from 20.19 to 35.89 mg/kg were observed in the soil samples and it exceeded the permissible limit for agricultural soils in 2.1% of the samples while a very lowMn values between 0.87 to 10.62mg/kg was obtained in the control samples. Arsenic content measured in samples SS 1 (50.50 mg/kg), SS 2 (51.11 mg/kg) and SS 5 (63.72 mg/kg) exceededboth the WHO/FAO allowable limit and control samples. The Pb levels varied from 20.34 to 95.83 mg/kg in the soil samples while values ranging 36.01 to 48.54 mg/kg was obtained in the control samples. The Zn value was very high in the SS 1 (311.41 mg/kg), SS 2 (324.11 mg/kg), SS 8 (347.92 mg/kg), SS 5 (387.54 mg/kg), and SS 9 (399.33 mg/kg). These values are higher than the control samples and exceeded WHO/FAOsoil standard of 300 mg/kg. The Cd content of the soil ranged from 0.001 to 0.063 mg/kg while the control samples varied from 0.001 to 0.008 mg/kg. The Cd content recorded for the soils in this study is below the WHO/FAO permissible limits of 0.02 mg/kg most of the sampling points.Concentration of Cr ranges from 75.28 to 112.79 mg/kg in the soil samples. However,Cadmium concentrations in the control samplesranges from 20.01 to 43.17 mg/kg. These values are low than WHO/FAO standard limit of 100 mg/kg for agricultural soils except in SS 1, SS 2, SS 5, SS 8, and SS 9. The concentration of Ni increased from a range of 16.75 to 49.18 mg/kg in soil samples and from 0.58 to 27.11 mg/kg in the control samples. In the study area, the values of Cu and Hg were higher than the control samples and mostly lower than the WHO/FAO accepted limit of 73 mg/kg and 0.01 mg/kg Cd except in few soil sample locations.

Table 3: Results of heavy metals analysis of the soil samples

Sample ID	Fe (mg/kg)	Mn (mg/kg)	As (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Hg (mg/kg)
SS 1	681	26.10	50.50	83.67	311.41	0.021	109.12	34.36	80.27	0.010
SS 2	546	30.62	51.11	85.63	324.11	0.028	104.27	46.09	73.32	0.008
SS 3	355	20.19	30.36	20.34	286.09	0.016	98.41	16.75	29.19	0.000
SS 4	278	19.79	22.17	29.67	280.53	0.001	96.52	27.37	63.37	0.001
SS 5	1124	35.89	63.72	95.83	387.54	0.047	107.33	43.72	96.46	0.008
SS 6	451	20.99	40.16	71.40	289.36	0.020	99.01	37.23	67.03	0.001
SS 7	512	23.40	40.06	85.33	291.12	0.001	91.35	29.50	58.14	0.005
SS 8	438	29.05	44.24	90.18	347.92	0.063	112.79	49.18	96.97	0.011
SS 9	440	27.39	40.08	91.59	399.33	0.023	109.89	23.42	58.21	0.010
SS10	306	18.22	20.96	75.24	278.45	0.002	87.96	29.39	19.77	0.000
SS 11	311	20.87	36.28	66.71	244.12	0.018	75.28	22.54	48.49	0.000
CTR 1	106	0.87	9.23	48.54	101.31	0.008	20.01	0.58	22.11	0.000
CTR 2	99	10.62	19.64	36.01	178.42	0.001	43.17	27.11	18.23	0.000
WHO/FAO (2001)	**300**	**20**	**40**	**85**	**300**	**0.02**	**100**	**35**	**73**	**0.01**

Spatial distributions of heavy metals in the soils of Nsukka urban

The spatial distribution trend of the Fe^{3+},As, Pb, Zn, Cr, and Ni in the soil samples werevisualized utilizing the inverse distance weighted (IDW) method on ArcGIS 10.5 software platform. Figure 2reveals the spatial distribution trend of heavy metals in the soil.

The hotspots of Fe occur mosty in the southwestern part of Nsukka. In this region, Fe had an extreme value of more than 20 times the control value, far exceeding its standard limit value as stipulated by WHO/FAO (2001). Given the history of dumpsite activities in this area, it islikely that large quantity of metallic objectshas been generated, whichrelease Fe-rich effluents into the surrounding environment.The hotspots of As in soils were mainly distributed in the southwestern parts of Nsukka where Nsukka Central dumpsite is located. Therefore,the dumpsite and its associatedactivities are likely the primary contributors to Aspollution.The Pb hotspots were located in southwestern and southwestern parts of Nsukka. These areas were proximal tothe major dumpsites and sewage lodge. The highest concentrationswas associated with the dumpsite. Dumping of auto-mechanic wastes, paints, print materials, wielding, and otherrelated water that can release lead in the environment.Zn hotspot, located in the southwestern part of Nsukka, was also associated with dumpsite. In addition to the hotspot in the southwestern area, another Zn hotspot occurred within the northeastern area where UNN Central sewage are located.Spatial distributions of Cr and Ni in soils were highlysimilar, indicating that Cr and Ni mayoriginate from thesame source. Vast areas having soils polluted with Cr and Ni were situated in the southeastern andsouthwestern parts of Nsukka where Nsukka Central dumpsite, UNN Central dumpsite and Ikpa abattoir are situated. We speculate that Cr and Ni contamination ofthe soil were caused byvarious kindsof anthropogenic and natural activities that take place inthe dumpsites,and animals deterioration particles.

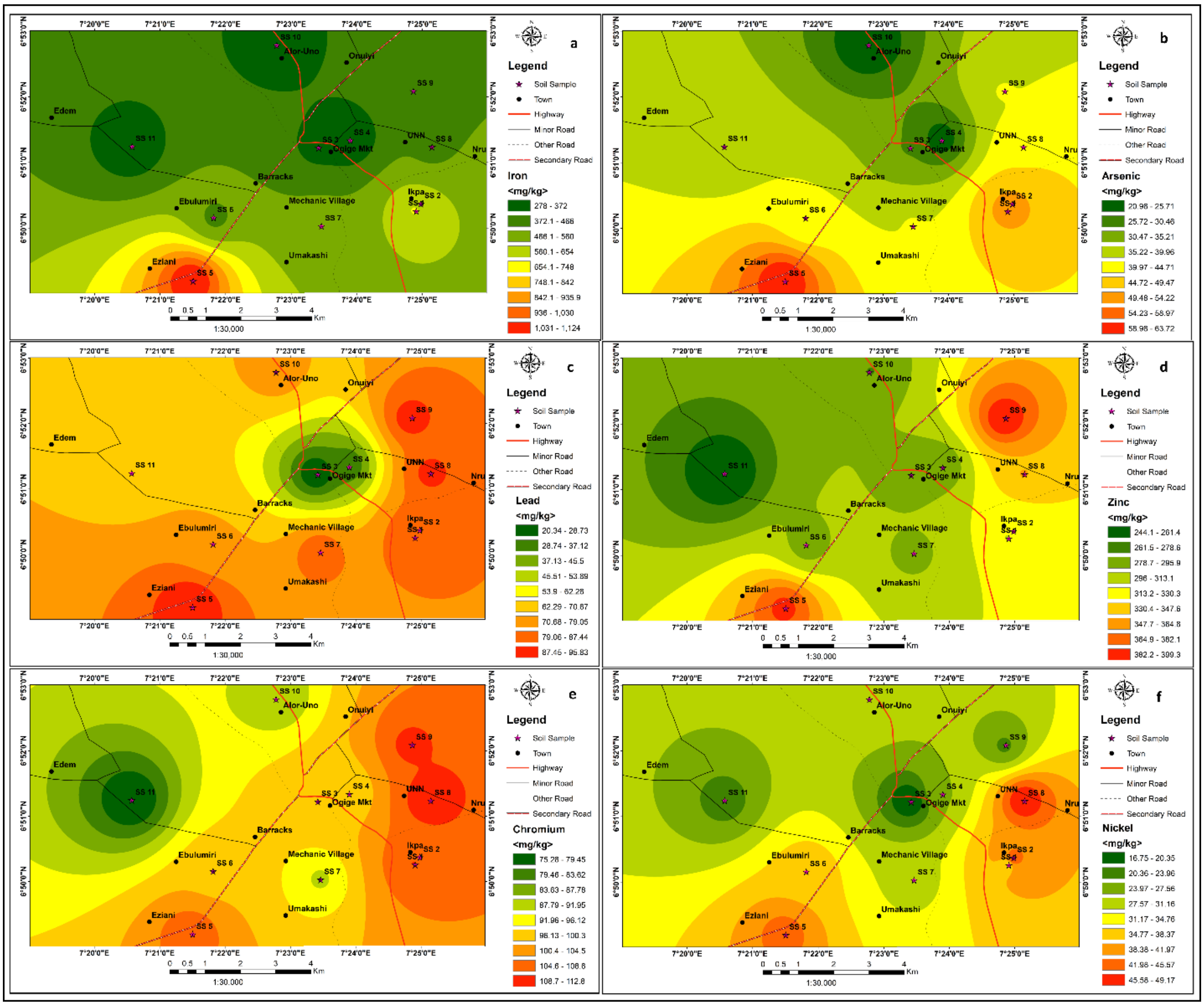

Figure 2: Spatial distribution map of heavy metals. **a** Iron (Fe^{3+}). **b** Arsenic (As). **c** Lead (Pb). **d** Zinc (Zn). **e** Chromium (Cr). **f** Nickel (Ni)

Statistical analysis

Correlation

The correlation matrix (Table 4) describes the interrelationships between variables and the results for 10 heavy metals show that very high positive correlation exist between As-Mn (r = 0.93, $p < 0.01$), Cr-Mn (r = 0.92, $p < 0.01$), Cr-As (r = 0.95, $p < 0.01$), Cd-Mn (r = 0.99, $p < 0.01$), Zn-Mn (r = 0.92, $p < 0.01$), Hg-As (r = 0.95, $p < 0.01$), Hg-Pb (r = 0.90, $p < 0.01$), Cr-Pb (r = 0.90, $p < 0.01$), Cu-As (r = 0.95, $p < 0.01$) and Pb-As (r = 0.90, $p < 0.01$) and very high negative correlation exists between Ni and Fe (r = -0.96, $p < 0.01$). A moderate positive correlation exists between Ni-Cd (r = 0.69, $p < 0.01$), Cd-Fe (r = 0.51, $p < 0.05$).From Table 4 it is quite clear that most of the parameters were significantly correlated with Mn, which may be due to deposition of garbage containing bottle caps, pharmaceutical wastes, galvanized wastes, blades, pigments, insecticides, cosmetics, and paints in both UNN and Nsukka central dumpsites which may leach into the soil.

Table 4:Correlation matrix of the heavy metals.

	Fe	Mn	As	Pb	Zn	Cd	Cr	Ni	Cu	Hg
Fe	1									
Mn	0.700 **	1								
As	0.606 **	0.931 **	1							
Pb	0.524 *	0.853 **	0.949 **	1						
Zn	0.737 **	0.920 **	0.731 **	0.632 *	1					
Cd	0.713 **	0.994 **	0.897 **	0.809 **	0.950 **	1				
Cr	0.550 *	0.924 **	0.954 **	0.904 **	0.743 **	0.899 **	1			
Ni	-0.056	0.101	0.164	0.440	0.036	0.691	0.127	1		
Cu	0.688 **	0.990 **	0.955 **	0.913 **	0.878 **	0.976 **	0.941 **	0.206	1	
Hg	0.689 **	0.992 **	0.954 **	0.909 **	0.881 **	0.978 **	0.942 **	0.195	1.000 **	1

****** Correlation is significant at the 0.01 level (2-tailed). ***** Correlation is significant at the 0.05 level (2-tailed).

Principal Component Analysis

The PCA result comprises four PCs that cumulatively account for 87% of the overall variance in the soils heavy metals (Table 5). The first component, PC1, which normally accounts for the most significant process, explains 52.99% of the total variance with an eigenvalue of 9. The PC consists of all the major ions with the exception of Ni. These metals show strong positive loading with Mn, As, Zn, Cd, Cr, Cu and Hg, suggesting that these metals depend on contributions from the dumpsite, sewage lodge and abattoir. PC2 accounts for 15.9% of the variance, which consists of a strong positive loading of Fe andstrong negative loading of As with a weak loading of Pb. This is because Fe is directly or indirectly responsible for deposition of old dry batteries, rubber products, paint containers, and waste combustion in the dumpsites. The third PC has 1.6 eigenvalue, explains 9.7% of the total variability and consists of strong positive loading of Ni and strong negative loading of As. This suggests anthropogenic pollution. PC4 accounts for 8.4% of the total variability with 1.4 eigenvalue. It consists of strong loading of Cr and moderate loading of Cd and As.

Table 5:Results of principal component anaysis.

Variables	**PCA 1**	**PCA 2**	**PCA 3**	**PCA 4**
Fe	**0.752**	**0.966**	-0.280	0.132
Mn	**0.991**	0.017	-0.004	-0.081
As	**0.934**	**-0.968**	**-0.762**	**0.503**
Pb	**0.865**	**0.444**	0.364	-0.232
Zn	**0.912**	0.036	-0.130	0.093
Cd	**0.987**	0.045	-0.049	**0.635**
Cr	**0.922**	0.154	0.091	**0.848**
Ni	0.123	0.007	**0.908**	0.001
Cu	**0.989**	-0.004	0.100	-0.091
Hg	**0.989**	0.001	0.089	-0.098
Eigenvalue	9.009	2.719	1.653	1.436
Variability (%)	52.993	15.995	9.726	8.450
Cumulative %	52.993	68.988	78.714	87.164

Conclusions

This examined pollution levels, spatial distributioncharacteristics, and contributions ofvarious sources ofheavy metals in soils of Nsukka urban, byusing inverse distance weighted interpolation model and statistical analysis.It was observed that, the concentrations of heavy metals in many samples exceeded the regulatory values. Also,concentration of heavy metals in soils within Nsukka urban is higher than the control sample values. The most seriousheavy metal contaminations in this area occur in the following order Fe > Zn > Cr > Cu > Cr > Pb > As > Ni > Mn > Cd > Hg.Spatial distributions and source deduction suggest thatheavy pollution levels of Fe, Zn, As and Pbare proximal to the dumpsite, sewage lodge, and abattoir activities in the soils of Nsukka urban. Generally, anthropogenic sources were the predominant factors influencing heavy metal pollution in the study area.

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