Original Research

Assessment of Heavy Metals in Nigerian Agricultural Soils

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Abstract

Safety issues and potential health implications associated with the uptake of heavy metals in agricultural soils are matters of grave concern. This study assessed the level of heavy metal contents in agricultural soils of Minna. Twenty-five surface soil samples were analyzed for Ni, Cd, Cr, Pb, Zn, Ag, Hg, As, and Cu. The heavy metals were analyzed using atomic absorption spectrometry (AAS). Mean heavy metals content were higher in Gidan-Kwano and Bosso than in Maitumbi, Chanchaga, and Maikunkele. Principal components analysis (PCA) showed the sequence of paramount importance as follows: Cr>Zn>Cu>Ni>Pb>Ag>Cd>As>Hg. Results indicated that all the heavy metal contents except Cu were lower than the threshold values used.

Keywords: heavy metals, agricultural soil, principal components analysis, threshold value, Minna

Introduction

Heavy metals uptake in agricultural soils is of increasing concern due to food safety issues and potential health risks, as well as detrimental effects on soil ecosystems. Sources of these elements in soils mainly include natural occurrences derived from parent materials, volcanic eruptions, marine aerosols, forest fires, and human activities [1]. The anthropogenic sources of heavy metals include traffic emissions (vehicle exhaust particles, tire wear particles, weathered street surface particles, brake lining wear particles), industrial emissions (power plants, coal combustion, metallurgical industry, auto repair shops, chemical plants, etc.), domestic emissions, and weathering of building and pavement surfaces [2-4]. Heavy metal pollution of agricultural soil can result not only in decreased crop output and quality and hurt human health through the food chain, but also further deterioration of air and water environmental quality [5-7]. Studies of heavy metal uptake by plants have often revealed their accumulation at a level toxic to human health [8]. Generally, uptake is increased in plants that are grown in areas with increased soil contamination. Among the metals, Cd and Zn are fairly mobile and readily absorbed by plants [9]. Since a survey of trace heavy metal contents might provide some vital information for environmental planning, vast investigations of agricultural soils have been carried out in some countries and regions in recent years [10-17]. Agricultural soil contamination with heavy metals through the use of untreated or poorly treated wastewater from water bodies and the application of organic and inorganic fertilizers and pesticides is part of the most severe ecological problems in Minna.

Though past work on heavy metals has been carried out in Minna, they were limited in scope. Pb, Fe, Cu, and As were investigated by [18], while Pb, Ni, Cu, and Zn were determined by [19]. More importantly, the soils previously studied were not spatially distributed within the Minna area. Thus, the objectives of this study were to determine the concentration of heavy metals in agricultural soils of Minna, including Cr, Cd, Ni, Pb, Zn, Cu, Ag, Hg, and As; to determine their spatial distribution characteristics; and to identify their possible sources in order to proffer solutions for heavy metal pollution control.

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Experimental Procedures

Description of the Study Area

The study area consists of some catchment areas (Bosso, Chanchaga, Gidan-kwano, Maikunkele, and Maitumbi) of Minna, Niger state, Nigeria. Minna is the capital of Niger state. Fig. 1 shows a map of Niger state indicating the study sites. Niger state lies in the Savannah zone of the tropics between latitude 8º10'N and 11º3'N and longitude 3º20'E and 7º30'E. Minna has two distinct seasons: rainy and dry. The rainy season begins in April and ends in October, while the dry season starts in November and ends in March. This study was undertaken during the dry season. The average annual rainfall, temperature, and relative humidity of Minna are 1,312 mm, 27.3ºC and 50.2%, respectively. Like most alluvial soils, the soil in Niger state is the flood plain type and is characterized by considerable variations. The soil has two main types, which are soils with little hazards and soils with good water holding capacity.

Soil Sampling

Twenty-five soil samples were collected from 0-20 cm depths (plough layer) of cultivated farmland with a hand auger from five different locations within Minna and environs (Bosso, Chanchaga, Gidan-Kwano, Maikunkele, and Maitumbi). Five samples were collected randomly from each location. The distance from one sampling point to another was approximately 50 m at each location. About 250-300 g of the soil was sampled and put into a polyethylene container in accordance with the method adopted by [16]. The samples were properly labelled and were taken to the laboratory for analysis.

Chemical Analysis of Soil Samples

Soil samples were dried at room temperature for five days and pebbles, stones, and large debris were removed from the soils before it was passed through a 2 mm polyethylene sieve. All glassware and plasticware were soaked in 10% nitric acid for 24 hrs. and rinsed thoroughly with

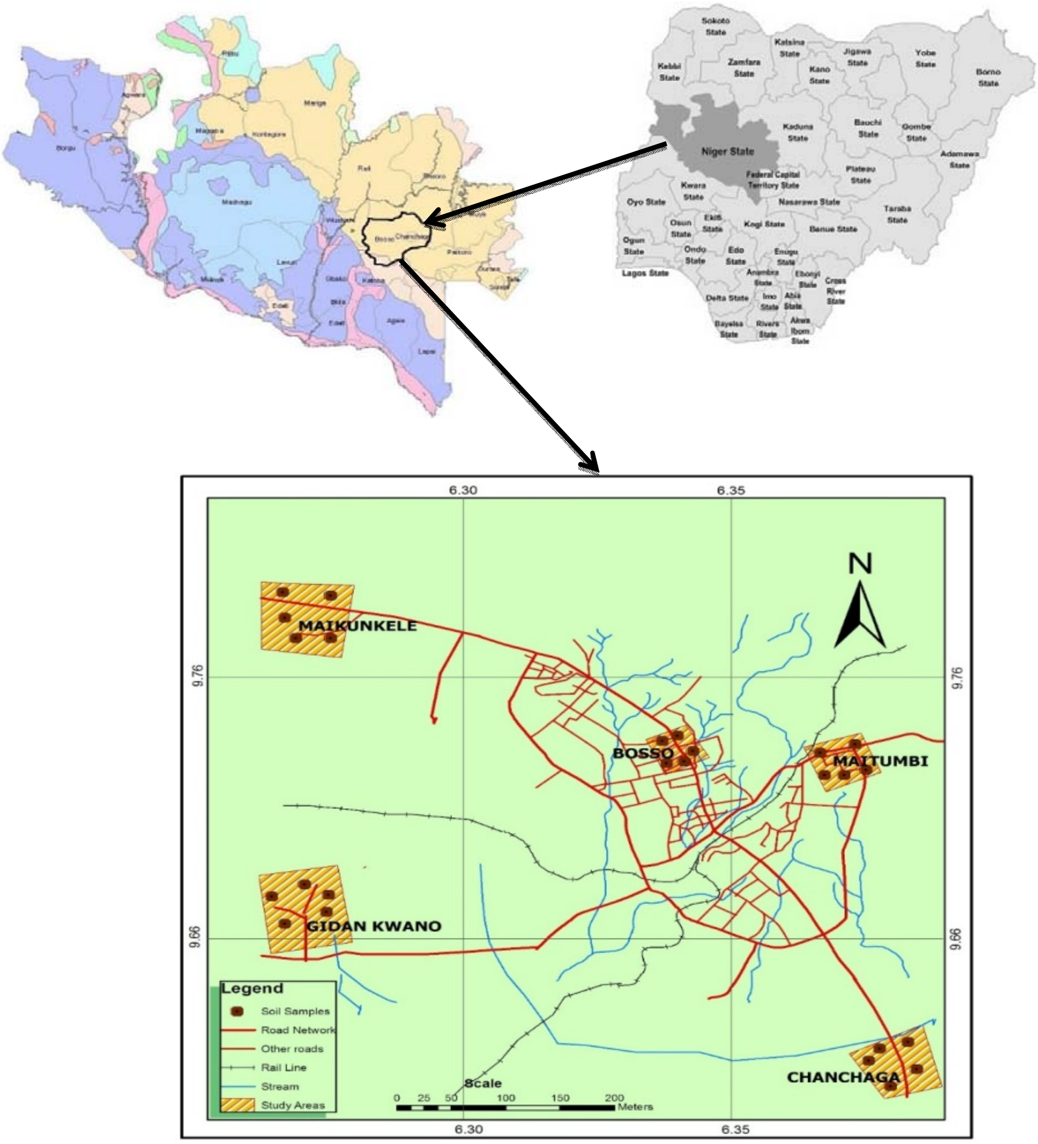

Fig. 1. Map of Niger state showing the study sites.

Table 1. pH and particle size distribution of study sites.

Sites		Parameters				Textural class
		pH	% Sand	% Silt	% Clay	
Bosso	Range	5.40-5.80	64.80-72.90	10.00-20.10	16.50-20.20	Sandy loam
	Mean	5.50	69.02	15.24	15.74	
	SD	0.141	3.486	3.993	5.088	
Chanchaga	Range	5.00-5.60	69.40-77.30	4.20-16.40	13.20-18.50	Sandy loam
	Mean	5.32	74.10	10.16	15.74	
	SD	0.228	3.129	4.318	2.100	
Gidan-Kwano	Range	5.50-5.80	78.54-88.92	6.52-13.84	3.06-14.02	Loamy sand
	Mean	5.62	82.63	9.14	8.23	
	SD	0.120	4.243	3.011	4.751	
Maikunkele	Range	5.20-5.50	79.82-89.62	2.82-16.14	2.24-11.14	Loamy sand
	Mean	5.38	84.85	10.16	4.99	
	SD	0.120	3.845	4.763	2.015	
Maitumbi	Range	5.00-5.40	78.27-90.96	5.86-19.79	1.48-9.66	Loamy sand
	Mean	5.20	84.60	11.79	3.61	
	SD	0.141	5.702	6.765	3.442	

SD – Standard deviation.

deionized water. Soil pH was measured in a 1:1 ratio of soil to water by a pH meter (Model PHS 25) with a glass electrode, and particle size was determined using the hydrometer method of soil mechanical analysis. The soil samples were digested by mixed acid ($HCl-HNO_3$) for Ni, Cd, Cr, Pb, Zn, Ag, Hg, As, and Cu analyses. The concentrations of the heavy metals were measured by an atomic absorption spectrometer (AA500F).

Statistical Analysis

In order to establish the relationship among/between heavy metals and pH value of agricultural soils from the different locations, Pearson correlation, descriptive statistics, and non-equilibrium one-way analysis of variance (ANOVA) were carried out using SPSS for windows (version 20.0). The Duncan multiple range test was used to separate means that were significantly different. Principal components analysis (PCA) and factor analysis (FA) were employed using MINITAB 14.0 to extract the most significant components/factors and reduce the variables with less significant contributions.

Results and Discussion

Particle Size Distribution

Soil particle size distribution and the pH value of the study sites are presented in Table 1. The pH value ranged from 5.00 to 5.80. This range is lower than that reported by [14], whose pH values ranged from 6.50 to 7.20 in their study. Soil pH regulates almost all biological and chemical reactions in soil [20], thus the distribution of soil pH may provide a useful index for the potential soil holding capacity for heavy metals, nutrients, and fertility of soil types. According to [21], use of fertilizers in farming increases soil pH. Solomon [22] reported that pH value of less than 5.5 is considered problematic for most microbial activities, and this affects the availability of soil heavy metals. The result of the particle size distribution indicates that Bosso and Chanchaga have the same textural class (sandy loam), while Gidan-Kwano, Maikunkele, and Maitumbi have the same textural class (loamy sand). The values of particle size distribution of Chanchaga (74.10% of sand, 10.16% of silt, and 15.74% of clay) are similar to those reported by [23] (75.1% of sand, 7.7% of silt, and 17.6% of clay), and [14] (71.77% of sand, 12.27% of silt, and 15.97% of clay).

Contents of Heavy Metals

Descriptive statistics of heavy metal concentration and soil pH of agricultural soils in Minna are presented in Table 2. The mean content of soil pH was 5.42, and ranges from 5.00-5.80. Mean contents of heavy metals were significantly ($p<0.05$) lower than the threshold value of the Soil Environment Quality Standard of China [24]. The concentrations of all the heavy metals were lower than the threshold values [24-26]. However, the Cu content of a few samples was more than the threshold value and the maximum

Table 2. Heavy metal concentrations (mg/kg) and pH value of agricultural soils in Minna.

Sample description	Parameters								
	Ni	Cd	Cr	Pb	Zn	Ag	Hg	As	Cu	pH
Bosso										
A	0.031	0.04	0.32	23.62	23.60	1.01	0.02	ND	12.20	5.6
B	0.020	0.01	0.16	24.00	25.40	0.98	0.04	ND	15.24	5.4
C	0.016	T	0.24	26.32	34.50	1.02	0.06	ND	14.52	5.6
D	0.014	0.01	0.18	22.52	35.40	2.02	0.06	ND	16.50	5.8
E	0.011	0.01	0.12	24.40	34.60	1.04	0.06	ND	14.40	5.6
Chanchaga										
A	0.012	0.08	0.36	14.52	21.30	0.64	0.02	0.01	13.40	5.2
B	0.016	0.04	0.28	12.16	23.00	0.58	0.02	T	12.54	5.4
C	0.016	0.02	0.23	10.52	18.50	0.52	0.02	T	11.68	5.0
D	0.015	0.01	0.52	11.62	19.40	0.44	0.02	T	14.32	5.6
E	0.016	0.01	0.22	10.24	20.80	0.32	0.02	T	13.44	5.4
Gidan-Kwano										
A	0.018	0.01	0.18	16.32	38.60	1.12	0.03	0.011	22.46	5.6
B	0.014	0.04	0.14	14.42	36.40	3.14	0.02	0.013	23.74	5.8
C	0.012	0.02	0.12	14.60	38.40	1.14	0.02	0.011	24.00	5.6
D	0.011	0.01	0.21	17.24	35.50	2.40	0.02	0.011	22.20	5.5
E	0.014	0.03	0.36	16.20	32.80	1.18	0.04	0.011	24.52	5.6
Maikunkele										
A	0.013	T	0.52	6.42	19.50	1.02	0.01	ND	32.40	5.2
B	0.013	T	0.62	8.90	16.30	0.98	T	ND	36.80	5.5
C	0.014	T	0.48	12.16	18.00	1.12	T	ND	34.62	5.4
D	0.013	T	0.39	8.60	16.40	0.68	T	ND	33.48	5.4
E	0.013	0.01	0.42	13.40	20.40	1.10	T	ND	36.32	5.4
Maitumbi										
A	0.024	0.04	0.012	18.24	32.40	0.66	0.04	ND	24.52	5.2
B	0.018	0.01	0.011	16.62	30.60	0.42	0.02	ND	20.32	5.0
C	0.016	0.01	0.14	14.32	34.80	0.36	0.04	ND	21.40	5.4
D	0.914	T	0.16	15.42	32.80	0.24	0.02	ND	19.68	5.2
E	0.012	T	0.13	14.72	33.40	0.66	0.01	ND	20.52	5.2
Mean	0.051	0.016	0.261	15.500	27.704	0.992	0.024	0.003	21.409	5.424
S.D	0.180	0.019	0.161	5.282	7.773	0.666	0.018	0.005	7.993	0.217
Medium	0.014	0.010	0.220	14.600	30.600	0.980	0.020	0.000	20.520	5.400
Range	0.01-0.91	0.00-0.08	0.01-0.62	6.42-26.32	16.30-38.60	0.24-3.14	0.00-0.06	0.00-0.01	11.68-36.80	5.00-5.80
Threshold value	≤40	≤0.20	≤90	≤35	≤100	-	-	-	≤35	<6.5
RSHPS	200	5	250	500	600	-	2	60	200	-
USEPA	420	39	-	300	2800	-	17	41	1500	-

ND – not detected, T – trace, S.D – standard deviation, Threshold value – A part of environmental standards for soil of China [24], RSHPS – Regulatory Standards of Heavy metals Pollutants in Soil of Taiwan [25], USEPA – United States Environmental Protection Agency, 2010.

Table 3. Heavy metals content of agricultural soils in different locations (mg/kg).

Parameters		Location				
		Bosso	Chanchaga	Gidan-Kwano	Maikunkele	Maitumbi
Ni	Range	0.011-0.031	0.012-0.016	0.011 - 0.018	0.013-0.014	0.012-0.914
	Mean±S.D	0.018±0.008[a]	0.015±0.002[a]	0.014±0.003[a]	0.013±0.000[a]	0.197±0.401[a]
Cd	Range	0.000-0.040	0.010-0.080	0.010-0.040	0.000-0.010	0.000-0.040
	Mean±S.D	0.014±0.015[ab]	0.032±0.030[a]	0.022±0.013[ab]	0.002±0.044[b]	0.012±0.016[ab]
Cr	Range	0.120-0.320	0.220-0.520	0.120-0.360	0.390-0.620	0.110-0.160
	Mean±S.D	0.204±0.078[bc]	0.322±0.124[b]	0.202±0.095[bc]	0.486±0.090[c]	0.091±0.073[c]
Pb	Range	22.52-26.32	10.24-14.52	14.42-17.24	6.420-13.40	14.32-18.24
	Mean±S.D	24.17±1.390[c]	11.81±1.705[c]	15.76±1.208[b]	9.896±2.835[b]	15.84±1.590[a]
Zn	Range	23.60-35.40	18.50-23.00	32.80-38.60	16.30-20.20	30.60-34.80
	Mean±S.D	30.70±5.706[b]	20.60±1.742[c]	36.34±2.377[a]	18.08±1.768[c]	32.80±1.530[ab]
Ag	Range	0.980-2.020	0.320-0.640	1.120-3.140	0.680-1.120	0.240-0.660
	Mean±S.D	1.214±0.451[ab]	0.500±0.125[c]	1.796±0.927[a]	0.980±0.177[bc]	0.468±0.187[c]
Hg	Range	0.020-0.060	0.020-0.020	0.020-0.040	0.000-0.010	0.010-0.040
	Mean±S.D	0.048±0.018[c]	0.020±0.000[b]	0.026±0.009[b]	0.002±0.004[c]	0.026±0.013[a]
As	Range	0.000-0.000	0.000-0.010	0.011-0.013	0.000-0.000	0.000-0.000
	Mean±S.D	0.000±0.000[b]	0.002±0.004[b]	0.011±0.001[b]	0.000±0.000[b]	0.000±0.000[a]
Cu	Range	12.20-16.50	11.68-14.32	22.20-24.52	32.40-36.80	19.68-24.52
	Mean±S.D	14.57±1.567[d]	13.08±1.003[d]	23.38±1.007[c]	34.72±1.859[a]	21.29±1.909[c]

Values with different letters indicate means are significantly different from each other at $p \leq 0.05$ within each row.

was 36.80 mg/kg at Maikunkele. This is due to contamination by wastewater from irrigation, which leads to soils and plant pollution in the area [27]. The content of heavy metals in soil can reach levels that restrict the normal growth and developmental process of plants and cause functional disturbance in environmental components [28].

Spatial Distribution of Heavy Metals Content

The Minna area is divided into five catchments (Bosso, Chanchaga, Gidan-kwano, Maikunkele, and Maitumbi) according to spatial location. Ranges, means, and standard deviations (S.D) of heavy metals for each catchment area are presented in Table 3. Mean content of all heavy metals in all the areas were lower than the threshold value [24-26].

The mean content of Ni in each area followed the order Maitumbi>Bosso>Chanchaga>Gidan-Kwano>Maikunkele, while Cu followed as Maikunkele>Gidan-Kwano >Maitumbi>Bosso>Chanchaga. Mean contents of Zn, Ag, and As in Gidan-Kwano were the highest among all sites. However, the metals Pb, Hg, and Cr, Cu in the Bosso and Maikunkele areas, respectively, had the highest mean contents, whereas Ni, Cd, Pb, Zn, Hg, and Cr, Ag in the Maikunkele and Maitumbi areas, respectively, had the lowest mean contents.

The fluctuation of heavy metals in the five agricultural locations could be attributed to differences in agricultural activities and environmental factors in the sampled areas [29]. Moderate concentrations of most metals were detected in the soils of all the catchment areas. This may be due to the large doses of fertilizers, herbicides, pesticides, and fungicides used extensively in the Minna area, whose residues infiltrate the soil. This result is in agreement with the findings of [18] in a similar environment.

Correlation Analyses

Heavy metal pollution is a frequent and complicated pollution in practice. Correlation analyses will assist to reveal the relationship between pH content and heavy metals. The significant relationship between pH content and concentration of heavy metals results are presented in Table 4. Results indicate that almost all heavy metals, especially Cd, Pb, Zn, Ag, Hg, As, and Cu, were significantly correlated ($p<0.05$) with pH content in all the catchment areas. Ag, Cu, and Zn were positively correlated with pH in Bosso, Chanchaga, and Maitumbi areas, respectively. In Gidan-Kwano, both Cd and As were positively correlated, and Pb correlated negatively with pH. However, there was significant negative correlation between Hg and pH.

Table 4. Correlation coefficients (r) between the pH and heavy metals of agricultural soils tested.

Locations	Items	pH	Ni	Cd	Cr	Pb	Zn	Ag	Hg	Cu	
Bosso N= 5	pH	1.000									
	Ni	-0.273	1.000								
	Cd	0.000	0.853*	1.000							
	Cr	0.091	0.839*	0.660	1.000						
	Pb	-0.376	-0.158	-0.451	0.095	1.000					
	Zn	0.620	-0.884*	-0.725	-0.502	0.193	1.000				
	Ag	0.815*	-0.338	-0.153	-0.178	-0.652	0.492	1.000			
	Hg	0.395	-0.965*	-0.885*	-0.674	0.257	0.955*	0.398	1.000		
	Cu	0.284	-0.738	-0.743	-0.692	-0.246	0.601	0.680	0.727	1.000	
		pH	Ni	Cd	Cr	Pb	Zn	Ag	As	Cu	
Chanchaga N= 5	pH	1.000									
	Ni	0.026	1.000								
	Cd	-0.342	-0.638	1.000							
	Cr	0.609	-0.176	0.033	1.000						
	Pb	-0.041	-0.657	0.930*	0.390	1.000					
	Zn	0.289	-0.172	0.487	-0.161	0.451	1.000				
	Ag	-0.421	-0.167	0.841*	0.107	0.793*	0.326	1.000			
	As	-0.294	-0.869*	0.910*	0.172	0.888*	0.225	0.627	1.000		
	Cu	0.812*	-0.487	-0.062	0.750	0.246	0.065	-0.331	0.181	1.000	
		pH	Ni	Cd	Cr	Pb	Zn	Ag	Hg	As	Cu
Gidan-Kwano N= 5	pH	1.000									
	Ni	0.272	1.000								
	Cd	0.840*	-0.057	1.000							
	Cr	-0.317	0.051	0.097	1.000						
	Pb	-0.785*	0.009	-0.679	0.539	1.000					
	Zn	0.092	0.292	-0.390	-0.873*	-0.349	1.000				
	Ag	0.513	-0.322	0.443	-0.304	-0.178	-0.128	1.000			
	Hg	-0.153	0.479	0.086	0.865*	0.336	-0.567	-0.575	1.000		
	As	0.919*	0.042	0.772	-0.365	-0.618	0.014	0.810*	-0.375	1.000	
	Cu	0.430	-0.127	0.754	0.308	-0.609	-0.400	-0.192	0.374	0.198	1.000
		pH	Ni	Cd	Cr	Pb	Zn	Ag	Hg	Cu	
Maikunkele N= 5	pH	1.000									
	Ni	0.102	1.000								
	Cd	0.102	-0.250	1.000							
	Cr	0.167	-0.037	-0.408	1.000						
	Pb	0.479	0.446	0.691	-0.363	1.000					
	Zn	-0.596	-0.025	0.670	-0.263	0.312	1.000				
	Ag	-0.103	0.442	0.379	0.334	0.491	0.641	1.000			
	Hg	-0.919*	-0.250	-0.250	0.210	-0.685	0.449	0.126	1.000		
	Cu	0.826*	-0.031	0.480	0.318	0.616	-0.115	0.347	-0.699	1.000	

Table 4. Continued.

Locations	Items	pH	Ni	Cd	Cr	Pb	Zn	Ag	Hg	Cu
Maitumbi N= 5	pH	1.000								
	Ni	-0.002	1.000							
	Cd	0.000	-0.399	1.000						
	Cr	0.625	0.524	-0.718	1.000					
	Pb	-0.512	-0.147	0.834*	-0.860*	1.000				
	Zn	0.971*	-0.004	-0.179	0.736	-0.657	1.000			
	Ag	-0.114	-0.681	0.498	-0.456	0.394	-0.063	1.000		
	Hg	0.527	-0.243	0.726	-0.250	0.329	0.317	-0.024	1.000	
	Cu	0.200	-0.463	0.962*	-0.562	0.689	0.051	0.613	0.728	1.000

*p<0.05 (1-tailed)

Cu and pH were positively correlated in the Maikunkele area, which is similar to the result reported by [23] in their study.

Principal Components Analysis (PCA)

Principal components analysis (PCA) was adopted to assist in the interpretation of elemental data. This method allows identifying the different groups of metals that correlate and thus can be considered to have similar behavior and common origin [1]. The results showed that heavy metal contents in agricultural soils of Minna could be represented with the prior three principal components, which accounted for 89.8%, 95.6%, 88.4%, 85.5%, and 94.2% of the total variance for the soils of Chanchaga, Bosso, Gidan-Kwano, Maikunkele, and Maitumbi areas, respectively. According to the variance of the three principal components, the multiple equations of principal components are as follows:

$$PC_{\text{Chanchaga soils}} = 0.473PC1 + 0.297PC2 + 0.128PC3 = 0.359Ni - 0.472Cd + 0.483Cr + 0.077Pb + 0.027Zn - 0.374Ag + 0.246As + 0.596Cu \quad (1)$$

$$PC_{\text{Bosso soils}} = 0.578PC1 + 0.254PC2 + 0.124PC3 = 0.421Ni + 0.372Cd + 0.326Cr + 0.567Pb - 0.400Zn + 0.003Ag + 0.108Hg + 0.331Cu \quad (2)$$

$$PC_{\text{Gidan-Kwano soils}} = 0.417PC1 + 0.298PC2 + 0.169PC3 = 0.036Ni + 0.038Cd + 0.261Cr + 0.414Pb + 0.472Zn + 0.482Ag + 0.240Hg + 0.095As - 0.437Cu \quad (3)$$

$$PC_{\text{Maikunkele soils}} = 0.388PC1 + 0.290PC2 + 0.177PC3 = 0.147Ni + 0.303Cd + 0.191Cr + 0.478Pb + 0.003Zn + 0.180Ag - 0.466Hg + 0.469Cu \quad (4)$$

$$PC_{\text{Maitumbi soils}} = 0.494PC1 + 0.305PC2 + 0.143PC3 = 0.263Ni + 0.189Cd + 0.433Cr - 0.425Pb + 0.525Zn + 0.599Ag + 0.433Hg + 0.301Cu \quad (5)$$

The result of principal components analyses from the above equations showed that Cr and Zn in soil were the most paramount factors for soil environment quality in Minna, followed by Cu, Ni, Pb, Ag, Cd, As, and Hg in that order. The correlation coefficients between principal components and heavy metals are presented in Table 5. The combination of correlation analyses and circumstances of factor loadings in the above equations indicate that the first principal components majorly responded to the situation of Zn content in Gidan-Kwano and Maikunkele soils. This result is in conformity with the findings of [7] in a similar soil in China. The second and third principal components also dominated the situation of Pb and As contents in Maikunkele and Gidan-Kwano soils, respectively. However, few heavy metals were significantly correlated (p<0.05) with principal components in Gidan-Kwano and Maikunkele soils, whereas in all other soils (Bosso, Chanchaga, and Maitumbi) both the heavy metals and principal components were not significantly correlated.

Factor Analysis (FA)

Multivariate data often includes a large number of measured variables that sometimes overlap, because some of them depend on others. Factor analysis (FA) is a way to fit the model to multivariate data to estimate their interdependence. Factor analysis was done using the maximum likeli-

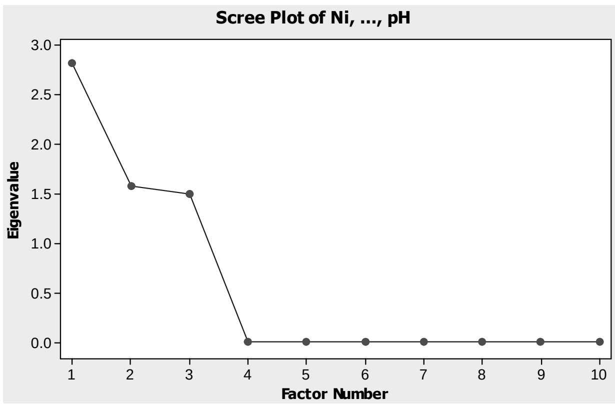

Fig. 2. Scree plot for the factor analysis.

Table 5. Correlation coefficients (r) between prior three principal components and heavy metals.

PC	Ni	Cd	Cr	Pb	Zn	Ag	Hg	As	Cu
Bosso (n=5)									
PC1	-0.496	-0.799	-0.401	0.193	0.325	0.274	0.525	-	0.795
PC2	-0.738	-0.395	-0.843	0.008	0.495	-0.042	0.562	-	0.279
PC3	-0.042	-0.530	-0.033	0.706	0.120	-0.499	0.096	-	0.117
Chanchaga (n=5)									
PC1	-0.063	0.602	0.329	0.708	0.774	-0.685	-	0.327	0.138
PC2	-0.754	0.358	0.763	0.600	-0.137	0.106	-	0.643	0.796
PC3	0.354	-0.844	0.433	-0.635	-0.707	-0.710	-	0.612	0.397
Gidan-Kwano (n=5)									
PC1	-0.449	0.350	0.732	0.384	-0.958*	0.356	0.329	0.088	0.230
PC2	0.624	0.662	0.446	-0.273	-0.369	-0.047	0.677	0.397	0.549
PC3	-0.347	-0.460	0.636	0.597	-0.447	-0.628	0.464	-0.875*	0.089
Maikunkele (n=5)									
PC1	0.104	0.559	0.070	0.316	0.901*	0.858	0.439	-	0.056
PC2	-0.686	-0.368	0.046	-0.906*	-0.081	-0.580	0.700	-	-0.652
PC3	0.627	0.299	0.088	0.501	0.692	0.935*	0.183	-	0.081
Maitumbi (n=5)									
PC1	0.608	0.174	-0.352	0.599	-0.716	-0.384	-0.060	-	-0.055
PC2	0.136	0.781	-0.188	0.551	0.201	0.095	0.792	-	0.789
PC3	0.514	0.266	0.411	0.070	0.520	-0.052	0.385	-	0.373

*$p<0.05$ (2-tailed), (-) – there is no correlation.

hood estimate as the extraction method. The factor analysis generated three significant factors with eigenvalues greater than unity, as shown by the scree plot (Fig. 2). The three factors explained 58.8% of the variation in the data set. The results of the factor loadings and communalities are presented in Tables 6 and 7. Factor 1 explained 28.2% of the variance, factor 2 explained 15.7% of the variance, and factor 3 explained 14.9% of the variance. Factor loadings (correlation coefficients) greater than 0.6 were used in the interpretation of the data [30].

Table 6 shows that factor 1 gives information about the variation in Hg, Pb, and Cu that originate from industrial waste (old paint, plumbing hardware, and storage batteries) dumped in and around agricultural lands, and traffic emissions transported to farms by runoff water. Factor 2 gives information on the variation of pH, Ag, and As, which are due to both natural sources and agricultural chemicals. Factor 3 provides information on the variation of Cr and Zn. Cr is from traffic-related sources transported as sediments to agricultural fields, while Zn is from industrial waste. The communality values indicate that all the variables were well represented by a significant three factors, except Ni, Cd, As, and Cu because of their low communality values (Table 6). These variables have a common origin, which is industrial waste. The results of the FA indicate that the percent of total variability represented by the three factors did not change with rotation (Table 7). Though Cu exhibited high factor loading, its communality figure (0.484) shows that its influence on pollution of agricultural soils of Minna cannot be generalized. The result of the FA goes further to support the outcome of the principal components analysis.

Conclusions

Heavy metal contents in Minna depend on spatial location due to dispersal distribution of industries and agricultural practices with different inputs. Applications of descriptive statistics, correlation analysis, and analysis of variance (ANOVA) revealed that the main cause of heavy metal pollution of the soils is anthropogenic activities. Principal components analysis and factor analysis distinguished the major sources of the heavy metals as agricultural chemicals and industrial wastes associated with dump sites.

All the heavy metal contents were lower than the threshold values used in this study, except for a few samples of Cu, which were higher than the soil environmental qual-

Table 6. Unrotated factor loadings and communalities.

Variable	Factor1	Factor2	Factor3	Communality
Ni	0.136	-0.061	0.320	0.124
Cd	0.010	0.121	-0.022	0.015
Cr	-0.743	-0.241	-0.413	0.781
Pb	0.567	0.594	-0.190	0.711
Zn	1.000	0.000	-0.000	1.000
Ag	0.385	-0.284	-0.568	0.551
Hg	0.617	0.668	-0.165	0.853
As	0.470	-0.442	-0.254	0.481
Cu	-0.231	-0.649	-0.098	0.484
pH	0.350	0.000	-0.871	0.882
Variance	2.8170	1.5730	1.4929	5.8829
% Variance	0.282	0.157	0.149	0.588

Table 7. Rotated factor loadings and communalities. Varimax rotation.

Variable	Factor1	Factor2	Factor3	Communality
Ni	-0.053	-0.106	0.332	0.124
Cd	0.117	-0.026	-0.029	0.015
Cr	-0.443	-0.093	-0.759	0.781
Pb	0.791	0.251	0.147	0.711
Zn	0.392	0.627	0.673	1.000
Ag	-0.016	0.735	-0.104	0.551
Hg	0.873	0.237	0.188	0.853
As	-0.176	0.638	0.205	0.481
Cu	-0.663	0.175	-0.120	0.484
pH	0.278	0.807	-0.393	0.882
Variance	2.3021	2.1619	1.4190	5.8829
% Variance	0.230	0.216	0.142	0.588

ity standard of China. The mean heavy metals contents were higher in Gidan-Kwano and Bosso than in Maitumbi, Chanchaga, and Maikunkele.

Correlation analyses showed that there were significant positive correlations ($p<0.05$) between pH and Ag, Cu, and Zn in the Bosso, Chanchaga, and Maitumbi areas. Cd and As were positively correlated in Gidan-Kwano, whereas Pb and Hg were negatively correlated in Gidan-Kwano and Maikunkele. Principal components analyses (PCA) showed that the sequence of importance is: Cr>Zn>Cu>Ni>Pb> Ag>Cd>As>Hg.

This study has shown the need for a constant check on the levels of heavy metals in the agricultural soils of Minna in order to ascertain their possible potential risks to life and environment. Where heavy metals are in excess of the threshold values, use of phytoextraction is recommended.

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