

A Study of the Distribution pattern of Heavy metals in surface soils around Arufu Pb-Zn mine, Northeastern Nigeria, Using Factor Analysis

Adamu Christopher Iorfa¹, Nganje Therese Ntonzi¹, Ukwang E.E.¹, IBE Keneth Abara² and Peter Neji³

¹Department of Geology, University of Calabar. P.M.B 1115, Calabar, NIGERIA

² Dept. of Chemistry, Federal University of Petroleum Resources, Effurum, Delta State, NIGERIA

³ Department of Chemistry, Cross River State University of Technology, NIGERIA

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Abstract

Surface soil samples at depth of 0-15cm were collected from the Arufu Pb-Zn mining district within the Middle Benue Trough for this study. The aim was to determine the levels and spatial variability of heavy metals in the surface soil as well as the factors controlling the overall pattern of surface soil variability in the mining district. The soil samples were digested with 4M HNO₃ and analysed for Fe, Zn, Mn, Cu, Pb, Cr, Cd, As and Ag using atomic absorption spectrophotometer (AAS) model 210. Organic matter content (OM) and pH of the soil samples were also determined.

The resulting data was subjected to both descriptive and factor analyses. Results showed elevated levels of trace metals (Pb, Zn and Cd) and erratic distribution of trace metals in the surface soil. The factor analysis in R-mode was used to integrate the geochemical data. Factor 1 revealed the significant lithologic controls through oxidation of bedrock and sulphide minerals, as well as environmental controls through weathering and decomposition of organic matter. Factor 2 revealed anthropogenic controls through mining activities. Factor 3 revealed control by deposition under alkaline condition. Eigenvalues that accounted for about 70.56% of the total variance were also obtained. Clastic decomposition was identified to be more effective on the alkaline soil developed on carbonate host rocks. Lateral dispersion trains of heavy metals are limited to mine adits. These findings could play a key role to effective management of surface soil quality in the study area.

Keywords: Factor analysis, heavy metals, surface soils, North Eastern Nigeria.

Introduction

In environmental geochemical studies, geochemical surveys require standardization of field data collection, storage and retrieval of these and resulting analytical data and most importantly the interpretation of the information. Statistical methods depict the overall geochemical variability and also record useful variability patterns of study areas. Nevertheless, the recognition of factors controlling geochemical contaminants in a given medium is not easily revealed by most statistical methods.

The assessment of factors influencing geochemical patterns in surface soils has been undertaken by many investigators using different statistical techniques. The commonest among the techniques is

the descriptive statistics in terms of mean, standard deviation, range and coefficient of variation for a small body of data set¹⁸. Analysis of variance and cluster analysis have also been used in evaluating factors controlling geochemical patterns in the surface soil^{9,5}. Though these techniques could depict the overall variability and also reveal some useful geochemical patterns in surface soil they could not account adequately for the sources and controls of variability in surface soil geochemistry especially in contaminated soils^{12,22}.

Different contaminated sites are usually characterized by particular elemental association. The recognition of these elemental associations offers greater value than single element distribution

in identifying the sources and controls of variability of geochemical parameters in contaminated areas^{2,8,10}.

Arp⁴, therefore suggested factor analysis as one of the statistical techniques that could reveal the factors contributing to the overall pattern of variability, thereby improving upon the interpretation of geochemical data. Factor analysis technique enables us to see whether some underlying pattern of relationship exist such that data may be reduced to a small set of factors that may be taken as sources of variation accounting for the observed interrelations in the data thereby improving the interpretation of the data.

For several decades, the area around Arufu in Middle Benue Trough (fig. 1) was widely known for its substantial lead-zinc production, which was derived mainly from hydrothermal veins in carbonate host rocks¹⁵. These mining activities have led to the occurrence of many abandoned mines and tailings scattered around the open pits in the Arufu mining districts. Besides being eye sour, toxic metals leached from the mine waste could contaminate the soil and other media. A sound knowledge of the factors controlling the geochemistry of toxic metals in the surface soil of the mining district could play a key role in planning of control strategies to achieve better environmental quality, as well as a key to effective management of soil quality in the area.

This contribution attempts to highlight the levels and variability of selected geochemical parameters in the surface soil in Arufu mining districts as well as to determine the specific factors contributing to the overall pattern of surface soil variability using factor analysis.

Study area description: Arufu mining district of Middle Benue Trough is located between longitudes 9°10' and 9°20'E and latitudes 7°40' and 7°45'N (figs 1). The area which is undulating lies roughly between 200-300m above sea level. Laterite scarps which have resulted from prolonged dissection of former laterite sheets are dominant features in the

area. Many small seasonal streams including Rivers Pii, Kutaji, Kiri and Ubaver, that are all tributaries of River Benue controls the drainage in the area. The streams are structurally controlled and generally join to form dendritic drainage pattern.

The area is characterized by the tropical wet-dry climate and the rainfall is generally moderate, about 100-120cm per annum. The temperature ranged from 30-35°C and the relative humidity is in the order of 30-60 %¹¹. The vegetation in Arufu is the savannah wood type, typified by tall grasses, lots of shrubs and a few tall trees ranging in height from 3-6 m.

Geology of study area: The Arufu mining district is within the Benue Trough (fig. 1). The Benue trough is about 600km long and 80-90 km wide. It contains up to 5000 m thick of slightly deformed Cretaceous sedimentary and volcanic rocks¹⁷. Detailed geological mapping of the study area^{19,20} shows that it is underlain dominantly by Cretaceous sediments comprising shales, sandstone, and limestone. The sediments are intruded by diorite and granites. There are also the quaternary sediments represented by the alluvial deposits found along stream courses as well as laterite scarps. The sediments are highly folded and faulted into gentle pitching anticlines and domes that usually trend north-south. Faults and fractures strike north-south or northwest- southeast^{17,16}.

The mineralization in the area is structurally controlled. The ore bodies occur in fault zones, which served as channels for hydrothermal solutions and depositing the metallic and non-metallic minerals. The main mineralization in Arufu occurs as Pb-Zn lodes and veins along sheeted zones within carbonate host rocks¹⁷. The principal ore minerals are galena, sphalerite and chalcopyrite with minor bornite, marcasite and pyrite within a gangue of manganiferous siderite, dolomite, calcite, quartz, barite and sericite. In the supergene zone, the primary minerals are replaced by secondary minerals that include cerussite, pyromorphite, anglesite, calamine, malachite, azurite, ferric oxides and minor smithsonite¹.

Material and methods

A transect, 1000 meters long was demarcated within a 2 hectare plot in the Arufu Pb-Zn mining district within an area of relatively uniform topography. Surface soil samples were collected from fifty points at regular intervals of 125m over the transect (fig.1). Composite samples were collected at intersects of a grid with the aid of cylindrical plastic auger and thoroughly homogenized and stored in polyethylene bags.

Samples were air-dried at room temperature for 72 hours and later oven-dried at 100°C for three hours to obtain a constant weight. They were then ground using agate mortar and pestle and sieved using – 80 mesh nylon sieve. The resulting powders were then digested with concentrated 4MHN₃ and analyzed for Fe, Zn, Pb, Cu, Mn, Cr, Cd As and Ag using bulk scientific atomic absorption spectrophotometry (AAS) model 210. Soil pH was determined in the laboratory by a Philips digital pH meter at a soil water ratio of 1:1. Soil organic matter content (OM) was estimated from loss on ignition (LOI)⁶.

Results and discussion

The statistical summary showing the mean, range and coefficient of variation for the analytical parameters as well as the average levels normally encountered in remote or recently settled area soils by Siegel,²¹ are presented in table 1. The table reveals that the values of analytical parameters are within the normal range encountered in the soil except for Zn, Pb and Cd. The mean concentrations of these metals in soils of the study area are 760 mg/kg Pb, 3420 mg/kg Zn and 68 mg/kg Cd while their concentration levels normally encountered in remote or recently settled area soils are 10 –30 mg/kg Pb, 20 – 50 mg/kg Zn and 0.1 – 0.5 mg/kg Cd⁷. This is an indication of enrichment of these metals in soils of the study area.

The levels of variation shown by the values of coefficient of variation (CV) reveal the difference in levels of variation of analytical parameters in soil of the study area. Thus Pb, Cu and Cd exhibited high levels of variability (CV >60%) pH is the least

variable (CV 2%). Other variables exhibited moderate levels of variability with CV values ranging from 20-50%. Variations in soil variables may be related to such factors as soil forming processes, sources of variables (geogenic and anthropogenic), geochemical characteristics of the soil as well as soil biology¹². High variability of soil attributes indicates multiple sources, heterogeneity in sources or geochemical process controlling the distribution of the variable.

The frequency distribution plots of most trace elements except As, Cu, Ag and Cd in soil samples (fig. 2) generally show unimodal distribution indicating that most trace elements in the soil samples belong to a common geochemical population. (i.e. the parent material). The positive skewness of the frequency distribution plots reveals the general low levels of trace elements in the soil samples which most probably represent outliers and extremes not belonging to the main population.

To facilitate the assessment of geochemical patterns, geochemical maps were drawn to show the distribution of analyzed selected heavy metals of environmental significance (fig. 3).

A preliminary examination of the single element distribution plots (geochemical maps) revealed that enhanced levels of trace elements are associated with known mineralization and mine adits in the south east except for Fe, Mn and Cr. It is apparent however that the dispersion trains for the trace elements in soils are limited and these are most probably related to the release or leaching of metals from mine adits as well as the relative immobility of elements in soils developed on the carbonate host rocks^{7,21}. In the study area, the occurrence of sulphide mineralization has been reported¹⁵ and the enhanced levels of heavy metals may be related to these features. Iron, Mn and Cr on the other hand showed erratic distribution patterns with enhanced values confined mainly to the northwest from which occurrence of diorites have been reported¹. This implies that the distribution of heavy metals in the soils is probably controlled by both geogenic and anthropogenic factors. Enrichment of heavy metals

in soil samples may suggest that in-situ leaching from weathering bedrock (or mineralization) and mine adits may be significant. Leaching of metals from bedrock and overburden into the environment has been reported elsewhere^{5,14,23} noted that the occurrence of metaliferous mineralization tend to give high concentration of heavy metals in the secondary environment because of increased solubility of ore minerals relative to silicate minerals. This view is consistent with this study and explains the enhanced levels of some trace metals (Pb, Zn, and Cd) in soils developed over mine adits.

Adikwu-Brown and Ogezi³ and Chukwuma⁶ have reported higher values of heavy metals in soils developed over Pb - Zn mineralization in upper and lower Benue Troughs respectively. The difference may be attributed to the different host rocks and gangue minerals associated with the Pb-Zn mineralization in the various parts of the trough. In Abakiliki and Ishiagu areas of lower Benue Trough, shale, siderite quartz and calcite are common. In the study area (middle Benue Trough) the silicified host rock is associated with calcite, fluorite and barite. While in Zurak (upper Benue Trough) sandstones and Quartz dominate. Though, it is difficult to compare results from different places and workers since they are often based on different sampling and analytical procedure.

Statistical analysis (table 2) shows positive correlations between metals except for Ag which correlates positively with only Cu, Mn and Pb. Although the correlation between metals is not particularly high it may be an indication of some similar source or geochemical control for the trace elements. The table and figure also show positive correlation between soil organic matter content and heavy metals except for Ag, Cu and Cr. Similarly there was positive correlation between pH and heavy metals except for Ag. Positive correlation between trace elements and soil properties (pH and OM), though generally low, may be an indication of their influence on trace elements dispersion and concentration in soils.

Factor Analysis: Mean, standard deviation (range) and coefficient of variation were computed for each parameter and data subjected to goodness of fit statistics test before subjecting it to factor analysis. The data was subjected to factor analysis in order to reduce the sources of variation into few distinct factors. R- Mode factor analysis was carried out using (SPSS) programme.

R-mode factor analysis is a method of resolving a large number of elements into a small number of new combinations, which may be examined for significance in terms of process, type of samples or other geological and geochemical information. The data was first treated to a condescriptive analysis during which data that tend to be log-normally distributed were identified and log-normally transformed in order that meaningful statistical parameters could be computed. Thus, all variables but pH and OM were log-normally transformed. The correlation of variables was established by the computation of the correlation coefficient for each pair of variables (table 2). The procedure enabled the understanding of the type and extent of relationship between geochemical parameters in the study area.

The data was then subjected to a varimax rotated factor analysis (table 3). The geochemical associations obtained from the R-Mode factor analysis are mathematically independent¹³. The factor solutions provide information on (a) loading – the strength of a particular parameter in a factor (b) communality – the amount of the total variability of each parameter explained in a given factor model and (c) eigen values (expressed in percent) – the amount of total data explained in each model. As suggested by Kaiser¹³, only the factors with eigen values greater than unity and have been thought to simplify the data to predetermined degree of geochemical simplicity and could be interpreted in terms of the local geochemistry were chosen. The three factors model (table 4) accounting for more than 70% data variability was considered the most appropriate, in view of know geologic, mineralogical and environmental evidence as well as land use pattern in the area.

The following conclusions were reached after an examination of the three factor model (table 4) on soils in Arufu which explained more than 70% of the total data variability.

Factor 1: Cr, Cu, Pb and OM: The first factor accounts for 30% of explained data variability and exhibit high positive loading on Cr, Cu, Pb and OM. This factor is regarded as the “organic matter factor” and apparently represents the effect of organic matter on the composition of the surface soil. Although organic matter levels are generally low (< 10%) in soil samples, this association may not be casual or due to extensive metallo-organic complexing, but may reflect a feature of the carbonate host rock for the Pb –Zn mineralization. Organic matter appears to be the vehicle through which metals are incorporated into the soil⁷. In this study the contents of Pb, Zn and Cd are above values normally found in soils but only Pb is associated with OM in this factor, suggesting that adsorption mechanism may vary between the metal species. Other workers have reported that there is no correlation between organic matter and levels of trace metals in soils²¹. The relationship between organic matter and heavy metal concentrations is not completely understood⁸. It is most probable that the elevated levels of Pb in soil samples are related to both the relatively enhanced levels from source (mineralization) and complexing by OM.

Factor 2: As, Mn, Pb and Zn: This factor accounts for 23% of explained data variability and shows high positive loading on As, Mn, Pb and Zn. The association of chalcophile elements in this factor suggests an ore factor and identifies patterns due to known Pb –Zn mineralization and exposed by the mining activities in the area. The presence of As in this factor is indicative of the occurrence of arsenopyrite with the Pb - Zn mineralization. The association of these metals in the secondary environment with Mn suggests restricted hydromorphic dispersion of elements and coherence even in the surface environment. Thus the trace elements with positive loading in the factor originates from the sulphide minerals (galena, sphalerite and arsenopyrite, e.t.c) and that they are

associated with secondary minerals due most probably to mechanical weathering in the surface environment .

Factor 3: As, Cu, Cd and pH: Factor 3 accounts for 18% of explained data variability or data variance of the three-factor model and associated As, Cu, and Cd, with pH. Factor 3 is termed the “alkalinity factor” and reflects the influence of pH on the mobility of As, Cu, and Cd especially in areas underlain by carbonate rocks. Most metals are mobile at low pH due to dissolution and decomposition in the soil⁷. The moderate to low pH values reported in this study indicate some interaction with the carbonate host rocks. According to Kabata Pendias and Pendias¹² metals are bond to carbonate phase at high pH conditions due to settling as carbonate deposit in alkaline environment. In this study, the carbonates most probably interfered with oxidation processes or to the binding of metals to colloids and Fe-Mn oxides. Under such alkaline condition in-situ leaching of cations and migration in the surface environment are less effective. Thus, the low pH values reported by most workers from metaliferous soil⁷⁻⁹ are associated with mine drainage where oxidation of sulphides produces acidity by oxidation of sulphides and hydrolysis of ferrous iron to ferric hydroxides which precipitate. In Arufu mining district, the non association of low pH values with Fe-Mn hydroxide precipitates suggests that such reactions are not effective in soils of the study areas. This may imply that scavenging by Fe-Mn hydroxides, is not significant.

Conclusion

The surface soil of Arufu mining district is enriched in some heavy metals (Pb, Zn and Cd) most probably leached from mine tailings. The distribution of the heavy metals is subjected to strong anthropogenic, lithologic and environmental controls. The high background concentrations and the variability in abundance of heavy metals could most probably be attributed to the variation in composition in bedrock and mineralization in the area.

R-mode factor analysis revealed the significant controls of the soil samples composition to include lithologic and environment controls through weathering of rocks and decomposition by organic matter as well as precipitation under alkaline conditions developed over carbonate rocks. Clastic dispersion was identified to be most effective under the alkaline environment. The environmental significance of these findings is that hydromorphic dispersion trains of heavy metals in the surface soil of the Arufu mining district are limited and this can play a key role to the effective management of soil quality in the area.

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Table-1: Mean, range of values and CV of chemical analysis of soil samples from Arufu

Variables	Mean(x)	Range	CV %	Gen. Average abundance in soil*
Fe (%)	2.6	1.5 – 3.2	28	2.1%
Zn(mg/kg)	3420	360- 8220.86	49	30-1,000
Mn(mg/kg)	2720	200-5840.80	38	120-400
Pb(mg/kg)	760.37	247-2100	74	1-30
Cu(mg/kg)	400	80-1118.5	70	30-100
Cd(mg/kg)	68	26-210	63	0.1-0.5
As(mg/kg)	52	22-100	30	0.2-10
Cr(mg/kg)	30	16-56	20	40-60
Ag(mg/kg)	7	0.20-50	42	0.20-0.50
OM (%)	4.91	2.00-10.00	23	-
pH	6.99	6.39-7.95	2	6.5-8.5

* Siegel, 2002

Table-2: Correlation matrix of soil physio - chemical composition in Arufu

	Ag	As	Cd	Cr	Cu	Fe	OM	Mn	Pb	pH	Zn
Ag	1.00										
As	-0.31	1.00									
Cd	-0.02	0.21	1.00								
Cr	-0.02	0.02	0.01	1.00							
Cu	-0.15	0.06	0.28	0.31	1.00						
Fe	-0.22	0.06	0.14	0.04	0.22	1.00					
OM	-0.05	0.22	0.05	0.42	0.42	0.38	1.00				
Mn	-0.15	0.30	0.20	0.23	0.30	0.35	0.08	1.00			
Pb	1.00	0.42	0.17	0.55	0.37	0.37	0.04	0.45	1.00		
pH	-0.12	0.45	0.30	0.31	0.03	0.01	0.14	0.15	0.08	1.00	
Zn	-0.02	0.32	0.01	0.13	0.15	0.12	0.31	0.21	0.50	0.10	1.00

Table 3: R-Mode Varimax factor matrix for soils of Arufu

	Factor 1	Factor 2	Factor 3	Communality
Ag	-.18901	-.44457	-.21272	.27862
As	.05651	.63348	.45040	.60734
Cd	.00990	.08446	.82644	.69024
Cr	.76628	.17838	.08353	.6908
Cu	.67607	.19474	.41398	.6638
Fe	.37807	.31460	.03490	.24313
OM	.42762	.07325	.10471	.19919
Mn	.38774	.63696	.21955	.60426
Pb	.70060	.51408	.14213	.77533
PH	.36295	-.00428	.57520	.46261
Zn	.11855	.68316	.01087	.48088
Eigenvalue %	30.48	22.82	18.26	

Table-4: Chemical property association of the three factor model

Factors	Elemental associations	Eigen values (%)
Factor 1:	Cr, Cu, Pb, OM	30.48
Factor 2:	As, Mn, Pb, Zn	22.82
Factor 3:	As, Cu, Cd, pH	18.26

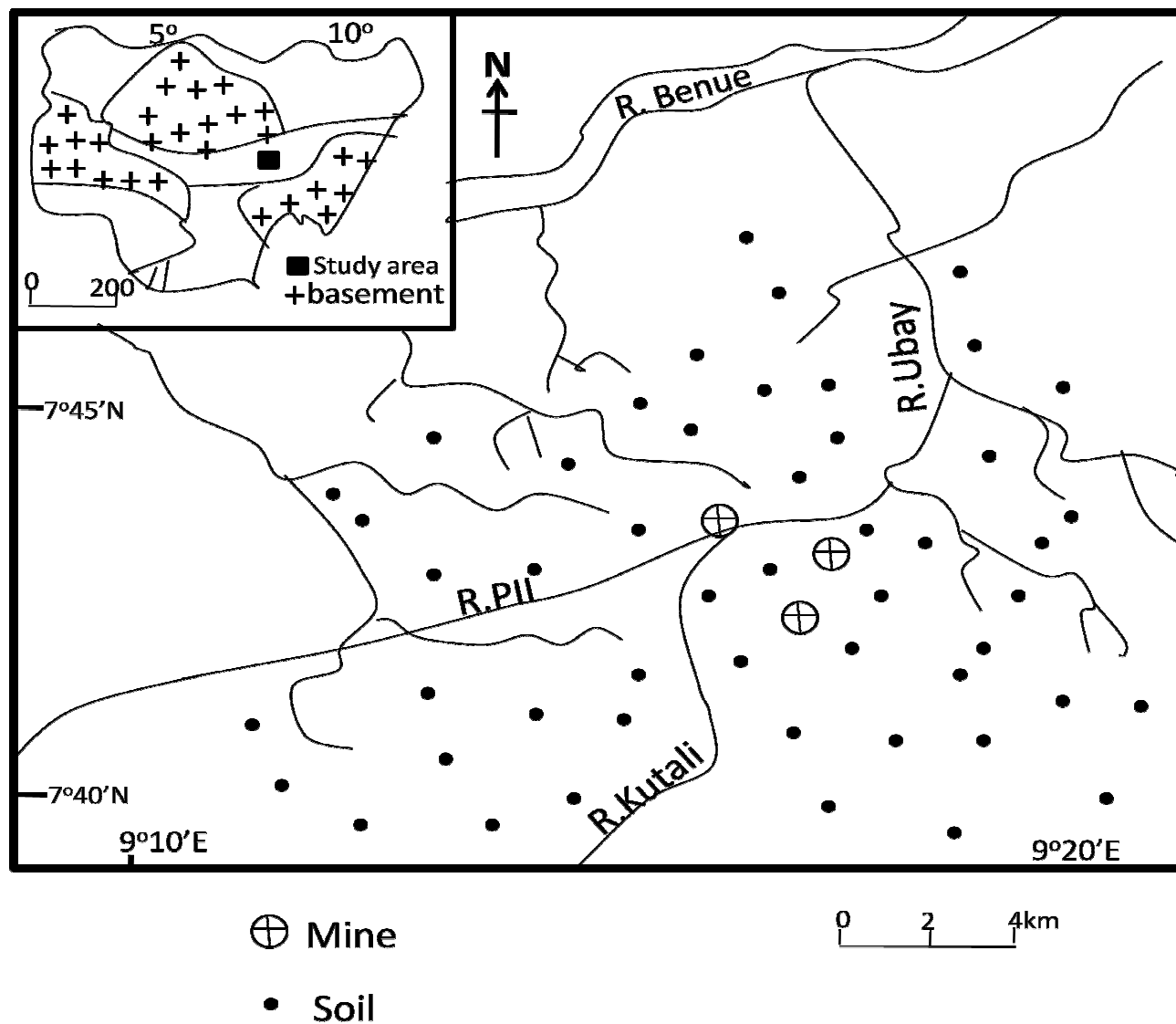
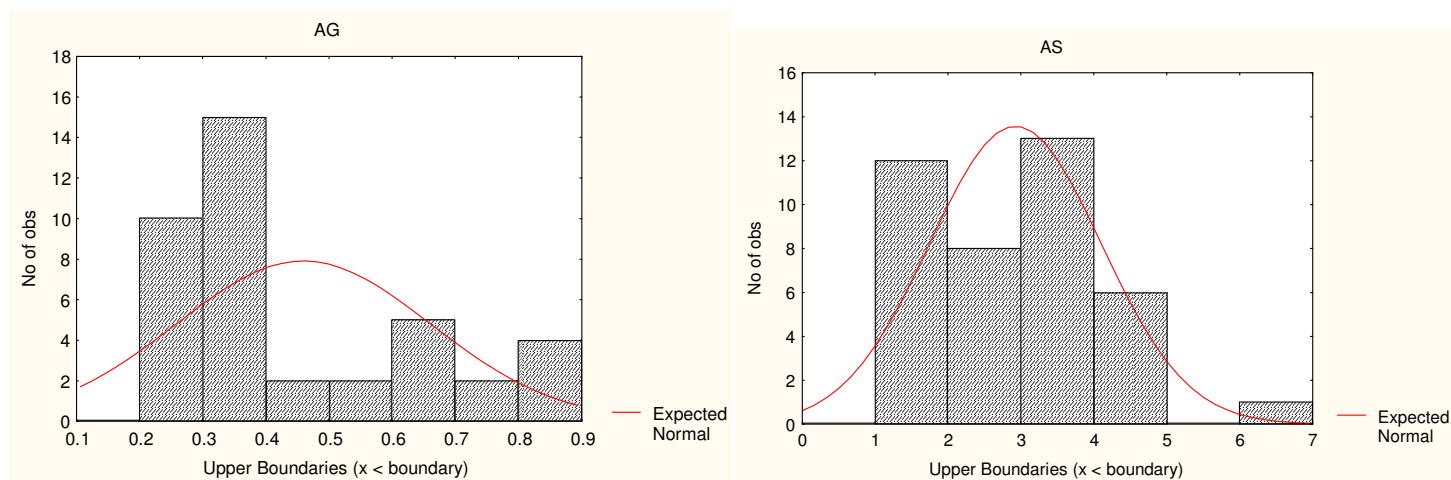
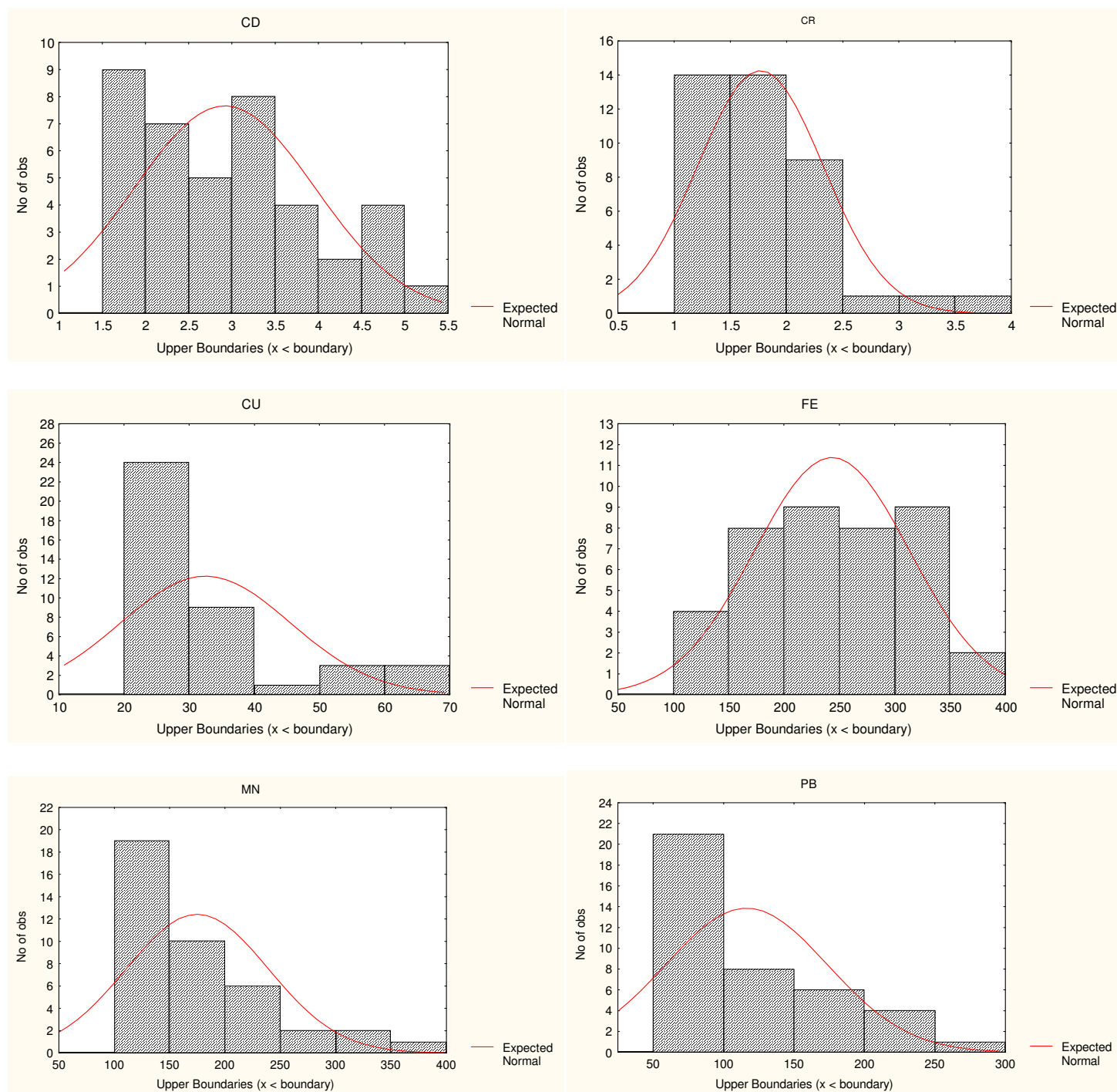


Figure 1: Map of study area showing sample locations, Insert map of Nigeria showing study area





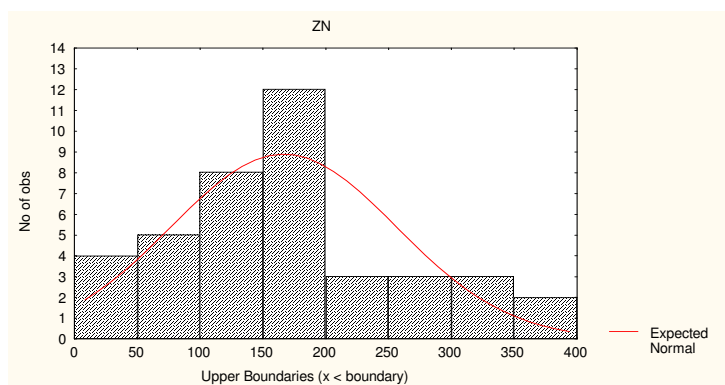


Figure-2: Histogram plots of heavy metals in soils.

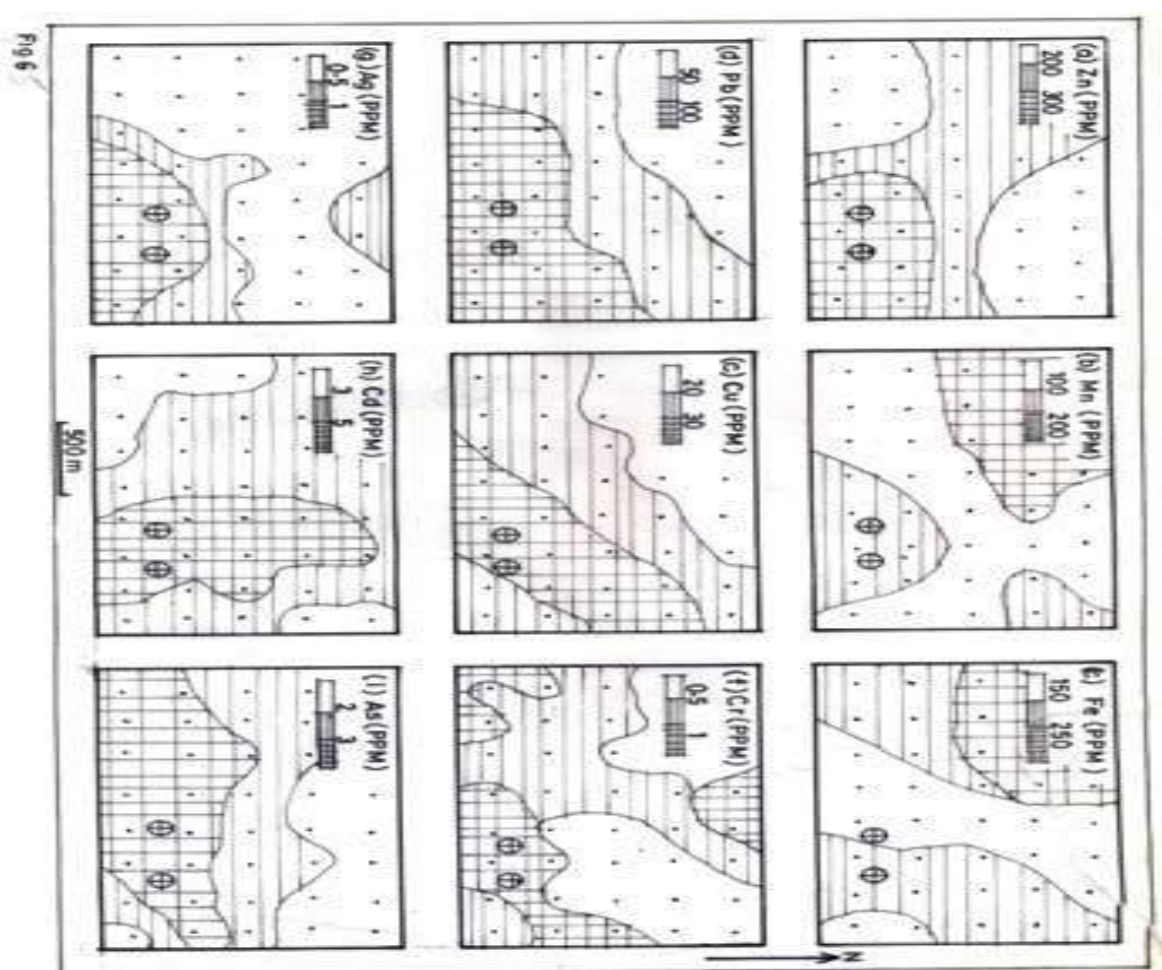


Figure-3: Single element geochemical maps of heavy metals in soil