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Research Article

Geochemical Distribution of Heavy Metals in Soil around Itakpe Iron-ore Mining Area-a Statistical Approach

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Abstract: This study becomes imperative in order to determine the degree of soil contamination due to iron-ore mining. Ten surface soil samples were collected and analyzed for major ions and heavy metals during the dry season. Average cation concentration observed was: Ca>K>Na>Mg while the heavy metal average were: Fe>Ni>Cd>Zn>Cu>Pb. The regression analysis result indicates generally weak associations among the variables though moderate relationships were observed between Ni-K, Pb-Mg, Pb-Fe and Zn-Cu. Five indices were used for data evaluation: Anthropogenic Factor (AF), Index of Geo-accumulation (Igeo), Enrichment Factor (EF), Contamination Factor (CF) and Pollution Load Index (PLI). Except EF which gave the order of enrichment: Fe>Ni>Pb>Cu>Zn>Cd, AF, Igeo and CF reveals this order of contamination: Fe>Pb>Ni>Cu>Zn>Cd. PLI shows that the locations experienced various degrees of deterioration in this order: ITK14>ITK10>ITK04>ITK02> ITK01>ITK07>ITK06>ITK05 (ITK17) >ITK03. R-mode factor analysis suggests that factor one is due to natural and anthropogenic influence while factors two and four are due to natural processes. Factor three points to anthropogenic origin. Q mode factor reveals anthropogenic factor as the dominant influence. R-mode cluster indicates that cluster four is anthropogenic and three natural while clusters two and three are a mixture of natural and anthropogenic sources. Q-mode cluster analysis shows that clusters one, two and three are directly influenced by iron ore mining while four were not. The soils around Itakpe iron ore have experienced various degrees of contamination particularly with reference to Fe, Pb and Ni and locations ITK14, ITK10, ITK04, ITK02 and ITK01. This area needs to be reclaimed and soils treated appropriately while further and a detailed study on the ecosystem is recommended.

Keywords: Contamination factor, enrichment factor, index of geo-accumulation, Itakpe, pollution load index

INTRODUCTION

The Nigerian Steel Development Authority (NSDA) was established to explore and exploit iron ore deposits in Nigeria. The NSDA reported the discovery of an iron ore deposit at Itakpe ridge, Okene, Kogi State in 1975. This iron ore deposit has proven and estimated reserves of 250,000,000 and 400,000,000 tones respectively. The Itakpe iron ore deposit is located approximately 16 km northeast of Okene and forms the impressive of a series of iron-bearing quartzites ridge in the area. The ridge formed by the Itakpe deposit is approximately 1 km wide and 5 km long and reaches a maximum elevation of about 500 m above the surrounding lowland, which is 200 m (Olade, 1978). The Itakpe iron ore deposit consists of eastern and western mines.

Mining and its activities have great consequences on the environment, if not properly planned. The soils, sediments, air, water, flora and fauna can be greatly affected. Heavy metals are also released into the environment during mining activities.

The objective of this study is to use geo-statistical methods and few indices to evaluate the degree of contamination due to mining activities.

Geology: Itakpe Iron-Ore mine sites are located within the Nigerian Basement Complex rocks (Fig. 1). Associated rocks in the area are migmatitic gneisses, schists and igneous intrusions (Ezepue and Odigi, 1993, 1994). The gneisses and schists include quartz-biotite-hornblende-pyroxene gneiss, quartz-biotite garnet gneiss, amphibolite schist, quartzitic schist and muscovite schist. The gneisses and schists are intruded by igneous bodies such as monzodiorites, granodiorites granites and pegmatites (Rahaman, 1976; Chuk, 1998a, b; Ezepue and Odigi, 1993).

MATERIALS AND METHODS

Soil sample collection: Soil samples were collected from the iron-ore mining area (Fig. 2). Sample points were located and recorded using GPS. The samples were collected randomly but evenly distributed around the mines. The soil samples were sun-dried, disaggregated (not crushed) using a pestle and mortar and sieved to minus 80 meshes (0.177 mm) with cellulose nitrate filter. (1.0 g) of each sample was digested with 3 mL of 1:2 mixtures of perchloric acid and hydrofluoric acid. The concentrations of six heavy metals and four major cations were determined by

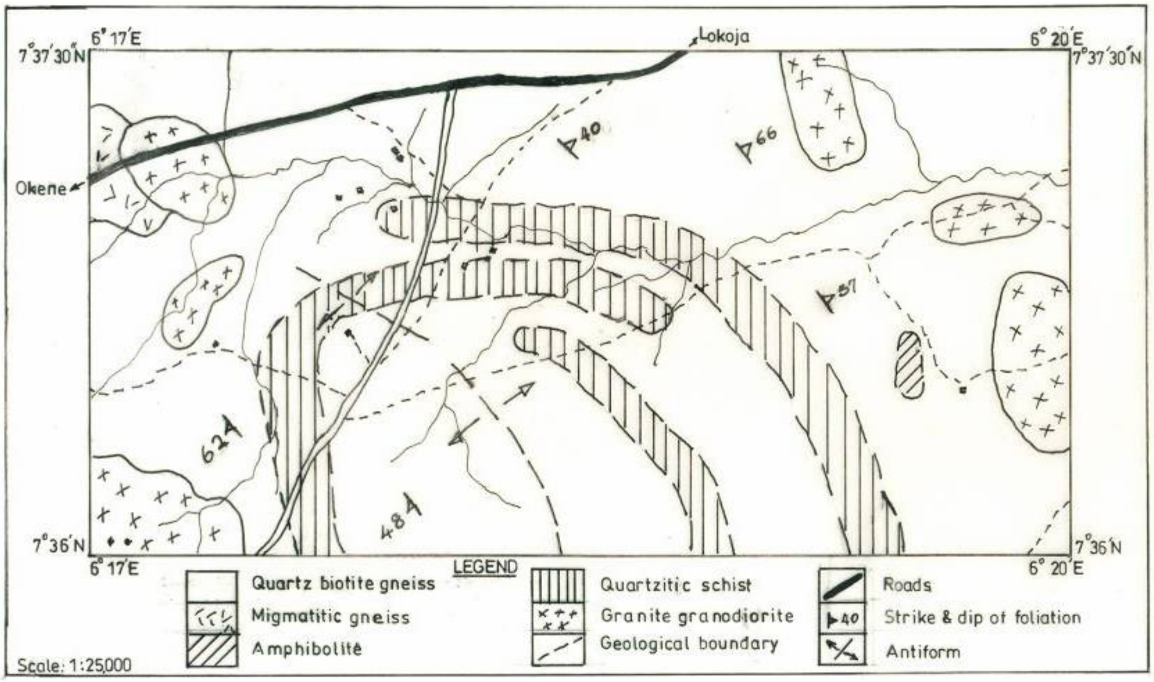


Fig. 1: Geological map of Itakpe (Odigi, 2002)

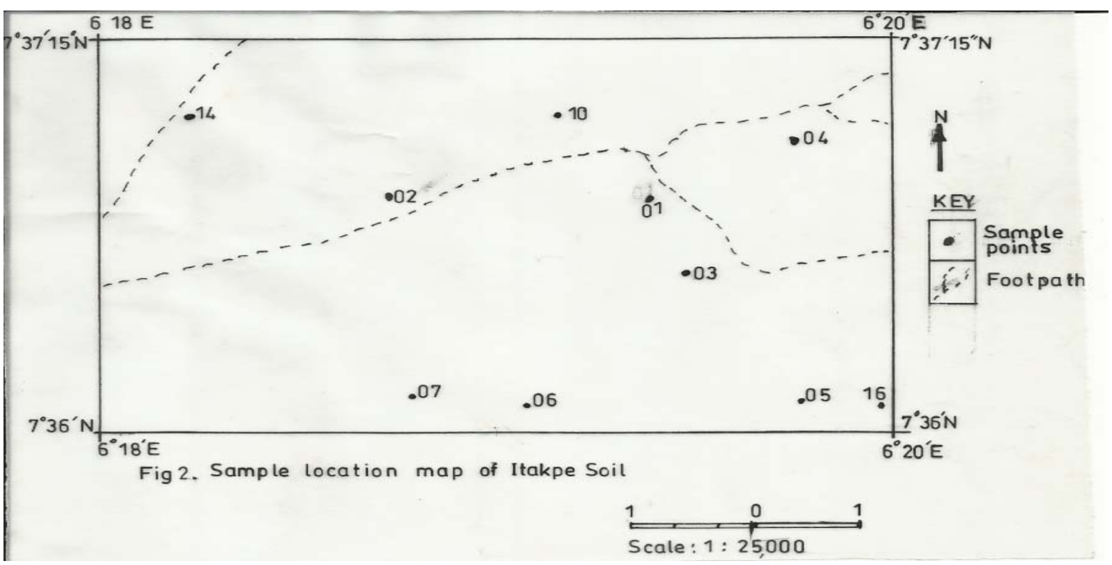


Fig. 2: Sample location map of Itakpe soil samples

AAS. Analytical procedures, operational parameters, calibration and standardization used in this study were according to APHA (2000).

Analytical methods: Insitu measurements of temperature, pH, Tds and Ec were determined intrusively with appropriate probes. Spectrophotometer (Model Genesys 20) was used to determine the concentrations of K, Na and Ca Atomic absorption spectrophotometer (Model 210 VGP) was used to determine the concentrations of Mg, Pb, Zn, Ni, Cu, Cd and Fe. All analyses were performed at Soil Science Dept, Faculty of Agriculture Laboratory, Kogi State University, Anyigba according to APHA (2000).

SPSS15.0 was used to perform all data analysis after auto-scaling for all parameters. Mathematically, PCA and PFA involve the following five major steps:

- Code variables to have zero means and unit variance
- Calculate covariance matrix
- Find eigen values and corresponding eigenvectors
- Discard any component that account for small proportion of variation in data set

- Develop the factor loading matrix and perform varimax rotation on the factor loading matrix to infer the principal parameters (Aprile and Bouvy, 2008; Ata *et al*., 2009)

In this study only components or factors exhibiting an eigenvalue greater than one were retained.

Hierarchical cluster analysis: Cluster analysis is a series of multivariate methods used to define true groups of data (Harikumar and Jisha, 2010). Objects are grouped such that similar objects fall into the same class. Hierarchical clustering which joins the most similar observations and successively the next most similar observations was employed. The levels of similarity at which observations are merged are used to construct dendrogram. The squared Euclidean distance method is used to construct dendrogram. Low distance shows that the two objects are similar or close together whereas a large distance indicates dissimilarity (Praveena *et al*., 2007; Sekabira *et al*., 2010; Harikumar and Jisha, 2010).

Factor analysis: The raw data were treated first to Z-scale transformation for standardization (Praveena *et al*., 2007). Multivariate data analysis was utilized to identify the correlations among the measured parameters. Principal component analysis was used to reduce the number of input variables. Spearman's correlation matrix was performed to illustrate the correlation coefficients among variables.

Determination of Enrichment Factor (EF): To evaluate the magnitude of contaminants in the soils, EF were computed for each location relative to the abundances of species in source materials to the control/background value and the following equation as proposed by Atgin *et al*. (2000), Aprile and Bouvy (2008) and Ata *et al*. (2009) was employ to assess degree of contamination, understand the distribution of elements of anthropogenic origin. EF = (C_m/C_{Fe}) sample/ (C_m/C_{Fe}) control/background value. Where (C_m/C_{Fe}) sample is the ratio of concentration of heavy metal (C_m) to that of Fe (C_{Fe}) in the soil sample and (C_m/C_{Fe}) control/background value is the reference ratio in the control/background value. Fe is selected as reference element because of its abundance and is one of the widely used reference elements (Mohiuddin *et al*., 2010; Sekabira *et al*., 2010).

Assessment of Pollution Load Index (PLI): the Pollution Load Index (PLI) proposed by Hakanson (1980) was used in this study to measure PLI in soils around Itakpe iron ore area. The PLI for a single site is the nth root of n number multiplying the contamination factors (CF values) together. The CF is the quotient obtained as follows: CF = $C_{metal\ concentration}/C_{control\ point\ concentration\ of\ same\ metal}$ and PLI for a site = nth√ CF1*CF2….*CFn. Where n is number of heavy metals study (six in this study) and CF = contamination factor. Other anthropogenic indices applied are geo-accumulation index (Fagbote and Olanipekun, 2010) and Anthropogenic Factor (AF) by Moshood *et al*. (2004).

Table 1 is the summary of all parameters measured. Na range from 13.69 to 30.82 mg/L and a mean value of 19.40 mg/L. K has a mean value of 149.09 mg/L and range from 28.75 to 751.00 mg/L. Mg range from 3.52 to 4.93 mg/L and has a mean value of 4.04 mg/L. Order of major cations concentration is: Ca>K>Na>Mg. The heavy metal on the other hand reveals that, Fe has the highest mean of 60924.50 mg/L and range from 11737.50 to 142420.00 mg/L. Cu has a mean value of 0.46 mg/L and range from 0.14 to 0.80 mg/L. Zn has a mean value of 1.17 mg/L and range from 0.53 to 1.63 mg/L. Pb has a mean of 0.28 mg/L and range from 0.05 to 0.64 mg/L. Ni range from 0.01 to 6.86 mg/L with a mean of 1.69 mg/L. Cu range from 0.45 to 1.89 mg/L with a mean value of 1.24 mg/L. Order of heavy metal mean concentration is: Fe>Ni>Cd>Zn>Cu>Pb.

Table 1: Itakpe dry season soil samples and summary statistics

Sample location	Na	K	Ca	Mg	Fe	Cu	Zn	Pb	Ni	Cd
ITK01	25.47	22.24	28.75	3.78	81000.00	0.45	0.66	0.32	6.86	0.52
ITK02	20.64	46.18	34.00	4.93	54750.00	0.44	1.38	0.64	3.66	0.45
ITK03	30.82	95.42	144.27	3.73	42550.00	0.18	1.51	0.10	0.01	1.16
ITK05	16.68	81.62	53.75	3.56	63712.50	0.38	0.64	0.13	0.01	1.04
ITK06	13.69	54.61	31.75	4.18	11737.50	0.18	0.81	0.05	0.39	1.83
ITK07	23.62	52.61	176.32	4.10	45600.00	0.80	1.63	0.15	0.01	1.78
ITK10	15.78	56.21	182.42	3.58	54900.00	0.75	1.58	0.26	2.74	1.76
ITK04	18.08	85.42	751.00	4.75	142420.00	0.59	1.49	0.54	0.60	1.89
ITK14	14.20	38.31	50.64	3.52	72345.00	0.68	1.43	0.36	2.50	1.51
ITK16	15.02	30.04	38.01	4.31	40230.00	0.14	0.53	0.21	0.15	0.46
Min.	13.69	22.24	28.75	3.52	11737.50	0.14	0.53	0.05	0.01	0.45
Max.	30.82	95.42	751.00	4.93	142420.00	0.80	1.63	0.64	6.86	1.89
Mean	19.40	56.27	149.09	4.04	60924.50	0.46	1.17	0.28	1.69	1.24
Cp value	14.52	60.13	37.30	3.41	307.75	0.17	0.83	0.04	0.55	1.68
Std. dev.	5.65	24.29	220.30	0.50	34443.59	0.24	0.45	0.19	2.26	0.60

Table 2: Correlation coefficients matrix of Itakpe dry season soils

	Na	K	Ca	Mg	Fe	Cu	Zn	Pb	Ni	Cd
Na	1.000									
K	0.261	1.000								
Ca	0.018	0.518	1.000							
Mg	-0.039	-0.017	0.396	1.000						
Fe	0.033	0.210	0.783	0.225	1.000					
Cu	-0.081	-0.094	0.325	-0.137	0.417	1.000				
Zn	0.266	0.364	0.444	0.088	0.226	0.644	1.000			
Pb	-0.058	-0.166	0.387	0.609	0.643	0.339	0.306	1.000		
Ni	0.171	-0.610	-0.246	-0.063	0.219	0.230	-0.102	0.472	1.000	
Cd	-0.248	0.428	0.517	-0.152	0.125	0.479	0.546	-0.232	-0.430	1.000

Table 3: Anthropogenic factor of heavy metals in Itakpe dry season soils

Heavy metals (mg/L)	Mean measured concentration	Control point concentration	Anthropogenic Factor (AF) value	AF factor (%)	Geogenic factor (%)
Fe	60924.5000	307.75	197.97	99	1
Cu	0.4590	0.17	2.70	73	27
Zn	1.1660	0.83	1.40	58	42
Pb	0.2760	0.04	6.90	87.34	12.66
Ni	1.6930	0.55	3.08	75.48	24.52
Cd	1.2400	1.68	0.74	42.47	57.53

AF = C_m/Cp: C_m: Measured concentration; Cp: Control point concentration

Table 4: Igeo index of heavy metals from Itakpe soils and classes (Muller, 1979)

Heavy metals (mg/L)	Sample locations ITK1	ITK2	ITK3	ITK4	ITK5	ITK6	ITK7	ITK10	ITK14	ITK16
Fe	7.46	6.89	6.53	4.95	7.11	4.67	6.63	6.89	7.29	6.45
Cu	0.82	0.79	-0.50	1.21	0.58	-0.50	1.65	1.56	1.42	-0.87
Zn	-0.92	0.15	0.28	0.26	-0.96	-0.62	0.39	0.34	0.20	-1.23
Pb	2.42	3.42	0.74	3.17	1.12	-0.26	1.32	2.12	2.59	1.81
Ni	3.06	2.15	-6.37	-0.46	-6.37	-1.08	-6.37	1.73	1.60	-2.46
Cd	-2.28	-2.49	-1.12	-0.42	-1.28	-0.46	-0.50	-0.52	-0.74	-2.45

Igeo index	Pollution intensity
0	Background concentrations
0-1	Unpolluted
1-2	Moderately to unpolluted
2-3	Moderately polluted
3-4	Moderately to highly polluted
4-5	Highly polluted
>5	Very highly polluted

I_{geo} = log2 [(C_m) / (1.5*Cp)]; C_m: Measured concentration; Cp: Control point concentration; 1.5: A factor for possible variations in reference concentration due to lithologic differences

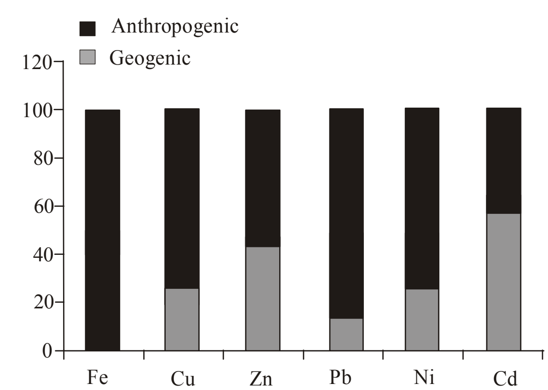


Fig. 3: AF of heavy metals

Correlation coefficient (Table 2) of all the parameters shows that moderate correlation (r = 0.6-0.7) exists between these pairs of parameters: Ca-Fe, Mg-Pb, Fe-Pb, Cu-Zn. Weak correlations (r = 0.4 - 0.5) were observed between K-Ca, K-Cd, Ca-Zn, Ca-Cd, F-Cu, Cu-Cd, Zn-Cd and Pb-Ni. Na shows no correlation with all parameters measured.

Anthropogenic Factor (AF) according to Moshood *et al*. (2004) reveals the following AF: Fe 99%, Pb 87.34%, Ni 75.48%, Cu 73%, Zn is 58% and 42.47% for Cd. Fe has the highest AF and Cd the lowest. AF order is: Fe>Pb>Ni>Cu>Zn>Cd (Table 3 and Fig. 3).

Table 4 and Fig. 4 are the Igeo index of heavy metals (Muller, 1979). Igeo index shows that Fe has 100-fold metal enrichment with respect to the baseline value (very highly polluted). Pb (Igeo index 2.20) is moderately polluted. Ni is moderately to unpolluted. Cu is unpolluted while Zn and Cd are practically uncontaminated (background concentrations). Igeo index order is: Fe>Pb>Ni>Cu>Zn>Cd (Fig. 4).

The enrichment factor (Table 5) for dry season soil samples shows that on the average, Fe has EF value of 1.84×10^2, Cu is 0.02, Zn is 0.01, Pb is 0.04, Ni and Cd are 0.21 and 0.01 respectively. EF of each sample location shows that Fe has extremely high enrichment

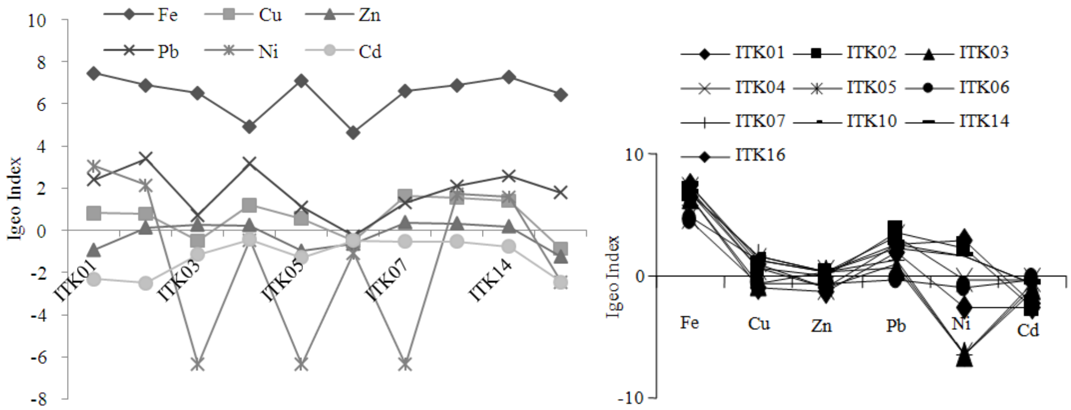
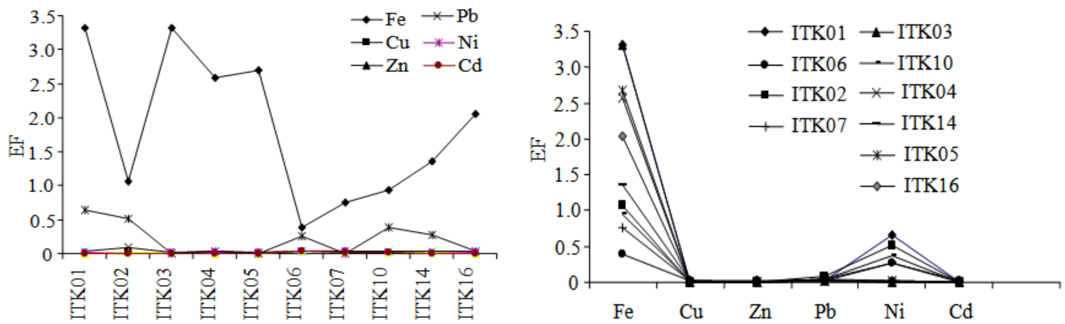


Fig. 4: I_{geo} of heavy metals from Itakpe dry season soils



(a) (b)

Fig. 5: EF Itakpe dry season soil

Table 5: Enrichment Factor (EF) of heavy metals in Itakpe soils and classes (Sutherland, 2000)

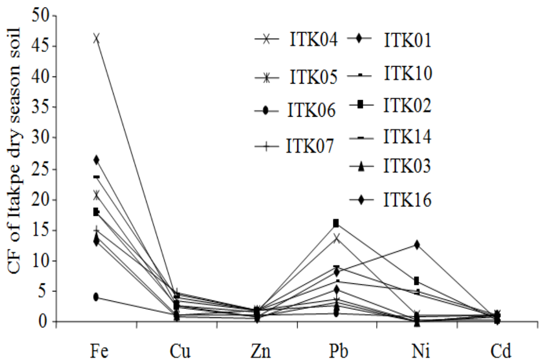
Heavy metals (mg/L)	Sample locations									
	ITK1	ITK2	ITK3	ITK4	ITK5	ITK6	ITK7	ITK10	ITK14	ITK16
Fe	3.31	1.07	3.31	2.578	2.6849	0.391	0.755	0.937	1.364	2.047
Cu	0.01	0.01	0.01	0.010	0.0100	0.030	0.030	0.020	0.020	0.010
Zn	0	0.01	0.01	0	0	0.030	0.010	0.010	0.010	0
Pb	0.03	0.09	0.02	0.030	0.0200	0.030	0.030	0.040	0.040	0.040
Ni	0.65	0.51	0	0.030	0	0.260	0	0.380	0.270	0.030
Cd	0	0	0	0	0	0.030	0.010	0.010	0	0

EF indices	Degree of enrichment
EF≤1	Background concentration
EF 1-2	Depletion to minimal enrichment
EF 2-5	Moderate enrichment
EF 5-20	Significant enrichment
EF 20-40	Very high enrichment
EF>40	Extremely high enrichment

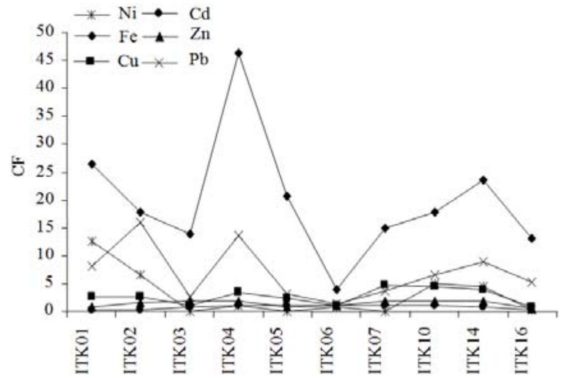
Table 6: Contamination Factor (CF) and PLI of heavy metals in Itakpe soils and classes (Hakanson, 1980)

Heavy metals (mg/L)	Sample location									
	ITK1	ITK2	ITK3	ITK4	ITK5	ITK6	ITK7	ITK10	ITK14	ITK16
Fe	26.32	17.79	13.83	46.28	20.703	3.814	14.82	17.84	23.51	13.07
Cu	2.65	2.59	1.06	3.47	2.240	1.060	4.71	4.41	4	0.82
Zn	0.80	1.66	1.82	1.80	0.770	0.980	1.96	1.90	1.72	0.64
Pb	8	16	2.50	13.50	3.250	1.250	3.75	6.50	9	5.25
Ni	12.47	6.65	0.02	1.09	0.020	0.710	0.02	4.98	4.55	0.27
Cd	0.31	0.27	0.69	1.13	1.100	1.100	1.10	1.05	0.90	0.27
PLI	5.08	5.29	1.45	6.03	1.720	1.840	2.20	6.09	6.25	1.72

Contamination Factor (CF) indices	Degree of contamination
CF<1	Low contamination
1≥CF≥3	Moderate contamination
3≥CF≥6	Considerable contamination
CF>6	Very high contamination



(a)



(b)

Fig. 6: CF of Itakpe dry season soil

Table 7: Pollution load index (Tomilson *et al*., 1980) of heavy metal classes

PLI indices	Pollution level
0	Perfection
1	Only baseline levels of pollutants present
>1	Progressive deterioration of the site

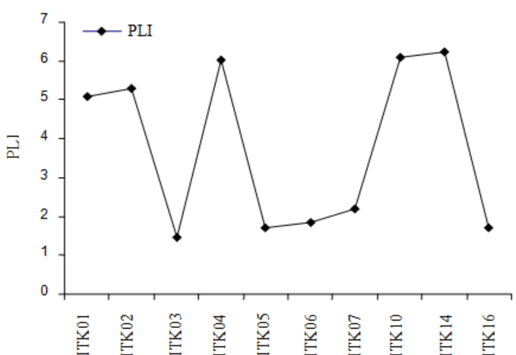


Fig. 7: PLI of Itakpe dry season soil

in all the locations (ten) sampled. Other heavy metals have background concentrations in all sampled locations (Fig. 5a). On the average, the order of heavy metal enrichment is: Fe>Ni>Pb>Cu>Zn>Cd. With respect to each metal enrichment in all locations, Fe and Ni ranked highest (Fig. 5b).

Average contamination factor (Fig. 6a and Table 6) shows that Fe has the highest contamination factor of 19.80, Pb (6.9), Ni (3.08), Cu (2.70), Zn has CF value of 1.42 and Cd is 0.79. Order of CF is: Fe>Pb>Ni>Cu> Zn>Cd. From CF of each location (Table 6), Fe have very high contamination in all ten locations (Fig. 6b). Cu has low contamination at location ITK16. At locations ITK01, ITK02, ITK03, ITK05 and ITK02 the soil samples are moderately contaminated and at locations ITK04, ITK07, ITK10 and ITK14 the locations are considerably contaminated with Cu. Zn shows low contamination at ITK01, ITK05, ITK06 and ITK16. Moderate contamination was observed with respect to Zn at locations ITK02, ITK03, ITK04, ITK07, ITK10 and ITK14. CF of Pb values revealed that Pb has very high contamination at locations ITK01, ITK02, ITK04, ITK10 and ITK14 while at locations ITK03 and ITK06 moderate contamination was observed. At ITK05, ITK07 and ITK16 considerate contamination was recorded. Ni showed very high contamination at locations ITK01 and ITK02, low contamination at locations ITK03, ITK05, ITK06, ITK07 and ITK16 (Fig. 6b) while moderate and considerable contaminations were observed at locations ITK04 and ITK10 and ITK14 respectively. Low contamination was recorded for Cd at locations ITK01, ITK02, ITK03, ITK14 and ITK16 and moderate contamination at locations ITK04, ITK05, ITK06, ITK07 and ITK10. In all locations, Fe showed the highest CF value, followed by Pb and Ni respectively (Fig. 6b).

The pollution load indices indicates that all sampled locations showed progressive deterioration of all locations with locations ITK14, ITK10, ITK04, ITK02 and ITK01 mostly impacted (Table 7 and Fig. 7).

DISCUSSION

The correlation relationship among the cations is less significant in most cases and negative except the moderate relationship (r = 0.518) observed between Ca-K. This observation may be attributed to diverse sources for the major cations (Abimbola *et al*., 2005). The regression relationship between the heavy metals and major cations are low and weak but moderate relationship exist between K-Ni, Mg-Pb and strong relation between Fe-Ca. While these strong-moderate regression could imply same anthropogenic source, weak regression is attributable to natural inputs (Olayinka and Olayiwola, 2001; Moshood *et al*., 2004; Abimbola *et al*., 2005). Among the heavy metals, this same weak to moderate regression relationship was observed.

Factor one has high factor loadings for Ca, Mg, Fe and Pb in the R-mode factor analysis (Table 8). This factor suggests both natural and anthropogenic sources given their geochemistry, basic to ultra basic rocks associated with the area and iron-ore mining. Factor two also points to natural origin. Factor three has high factor loading for K, high and negative for Ni and weak factor loadings for Ca, Cd and weak and negative loadings for Pb and Ni. This factor suggests greater influence from anthropogenic input derived from iron-ore mining (Pathak *et al*., 2008) into the soil. Factor four consists of high factor loading of Na. This factor is probably natural and acted uniquely on Na (Behzad and Fazel, 2009).

High loadings of locations ITK03, ITK04, ITK05 and ITK10 were observed in factor one-suggesting same influence. All these locations are related to mining site, over burden, waste dump sites and concentrate area (ITK10). These areas are directly influenced by iron-ore mining. As observed in factor one, factor two has high factor loadings for ITK06 and ITK07; moderate loading for ITK16 and weak loading for ITK03. While their distances may vary and hence the intensity of influence, all locations in factor two are influenced by iron ore mining related activities. The same observation is applicable to factor three (ITK14) probably with minimal influence considering its distance from the concentrate area. Factor four has high factor loading of ITK01. This location is on/around the mine site and influenced by mining activities (Table 9).

R-mode cluster analysis extracted four clusters (Fig. 8). Cluster one is an association between Ca, Fe,

Table 8: R-mode varimax rotated factor analysis of Itakpe dry season soil

	Factor				
Variable	1	2	3	4	Communalities
Na	-3.148E-02	-3.409E-03	-5.239E-04	0.974	0.950
K	0.108	0.148	0.840	0.346	0.859
Ca	0.695	0.421	0.485	1.619E-02	0.896
Mg	0.797	-0.296	8.590E-02	-7.866E-02	0.737
Fe	0.747	0.394	-2.051E-02	7.841E-02	0.719
Cu	0.116	0.914	-0.232	-9.751E-02	0.913
Zn	0.185	0.766	0.211	0.293	0.751
Pb	0.852	0.169	-0.403	1.509E-02	0.917
Ni	0.135	0.103	-0.899	0.193	0.875
Cd	-0.101	0.697	0.564	-0.290	0.898
Eigenvalue	2.491	2.390	2.336	1.298	
% of variance	24.909	23.895	23.359	12.983	
Cumulative %	24.909	48.804	72.163	85.146	

Table 9: Q-mode varimax analysis of Itakpe dry season soils

	Factor			
Sample location	1	2	3	4
ITK01	-3.148E-02	-3.409E-03	-5.239E-04	0.974
ITK02	0.108	0.148	0.840	0.346
ITK03	0.695	0.421	0.485	1.619E-02
ITK04	0.797	-0.296	8.590E-02	-7.866E-02
ITK05	0.747	0.394	-2.051E-02	7.841E-02
ITK06	0.116	0.914	-0.232	-9.751E-02
ITK07	0.185	0.766	0.211	0.293
ITK10	0.852	0.169	-0.403	1.509E-02
ITK14	0.135	0.103	-0.899	0.193
ITK16	-0.101	0.697	0.564	-0.290
Eigen value	2.491	2.390	2.336	1.298
% of variance	24.909	23.895	23.359	12.983
Cumulative %	24.909	48.804	72.163	85.146

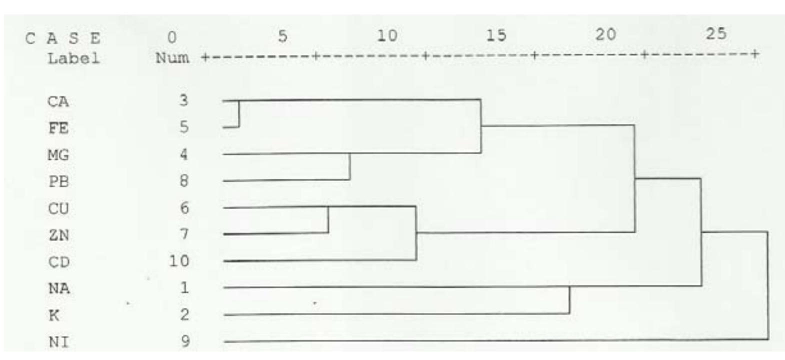


Fig. 8: R mode cluster analysis of Itakpe dry season soils

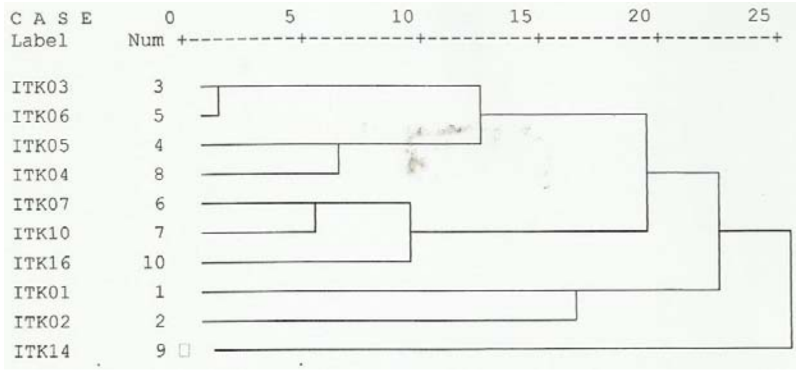


Fig. 9: Q mode cluster analysis of Itakpe dry season soils

Mg and Pb. This association suggests both natural and anthropogenic inputs. Cluster two consists of heavy metals such as Cu, Zn and Cd. This cluster also implies a mixture of natural and anthropogenic inputs. While cluster three is probably due to natural processes, cluster four is anthropogenic in nature.

Q-mode cluster also revealed four clusters (Fig. 9). Cluster one consists of ITK03, ITK06, ITK05 and ITK04. This cluster consists of locations influenced to various degrees by the mining processes. Cluster two consists of ITK07, ITK10 and ITK16. Again these locations are directly related to mining activities in the area. Cluster three is made up of locations ITK01 and ITK02 and cluster four consist of only ITK14. While ITK01 and ITK02 are directly influenced the same may not be true for ITK14 hence it's in a different and unique cluster.

All the indices gave same order as Fe>Pb>Ni>Cu>Zn>Cd except EF where Ni came before Pb. EF values ranging between 0.5 and 2.0 can be considered in the range of natural variability, whereas ratios greater than 2.0 indicates some enrichment corresponding mainly to anthropogenic input (Shakeri *et al*., 2009). Apart from Fe with EF>2.0 in five locations, all other heavy metals have EF values lower than 2.0. Given their CF also, Fe, Pb, Ni and Cu can be said to be contaminated in almost all locations sampled while Zn and Cd are not (Chakravarty and Patgiri, 2009). This same observation is revealed using Igeo index where Fe, Pb and Ni ranged between very highly polluted (Fe) to moderately to highly polluted. While Fe and Ni are expected to be high, Pb may have been enhanced also by the fuel usage, its immobile nature, because it is mostly transported in suspended and clastic materials and the fact that it is strongly hydrophobic hence concentrated in soils (Garbarino *et al*., 1995). The relatively high concentration of Cu can be attributed to the presence of chalcopyrite and possibly chemicals used in mining, blasting, beneficiation and reclamation of the iron ore (Ogbuagu, 1999; Scott *et al*., 1994).

The PLI is relatively higher in five out of ten sample points which is a reflection of impact of iron-ore mining on the soils (Table 7 and Fig. 7).

CONCLUSION

Statistics and geo-indices are powerful tools in evaluation of the ecosystem. From these indices and factor/cluster analyses, the soil samples have been contaminated especially with respect to Fe, Pb and Ni with locations ITK04, ITK01, ITK14 and ITK05 as the most affected.

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