

1 Multivariate statistical analysis and distributional characteristics of heavy metal
2 contamination of soil around Okaba coal mines.

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5 **ABSTRACT:**

6 Soil samples were collected during dry season from Okaba coal mine areas to establish
7 the level of impact. Impact evaluations were carried out using correlation analysis, factor
8 and cluster analyses, determination of enrichment factor (EF), contamination factor (CF),
9 pollution load index (PLI), anthropogenic factor (AF) and index of geo-accumulation
10 (Igeo). The AF gave this order: Pb>Ni>Cu>Zn>Fe>Cd. The Igeo index, EF and CF also
11 revealed the same rank as AF. The pollution load index indicated that all sampled sites
12 have been polluted with locations Ok06, Ok16, Ok17, Ok03, Ok10 and Ok08 as the most
13 impacted.

14 At $P < 0.01$ level, very strong correlations exist between Na-K, K-Mg, Ca-Zn while at P
15 $= 0.05$ level, strong correlations were recorded between Na-Mg, Ca-Fe, Na-Pb, Pb-Cd and
16 Ni-Pb.

17 The R-mode factor suggested that factors one and three were both natural and
18 anthropogenic while factor two was due to natural processes. The R-mode cluster
19 analysis suggested that cluster one was anthropogenic and clusters two and three were
20 pseudo anthropogenic.

21 Based on the indices, Pb, Ni, and Cu were the most impacted heavy metals on soils.

22 While detailed study is apt, the author recommend immediate and total reclamation of the
23 ponds/mines and treatment of all affected areas.

24 **Key words:** Okaba; Enrichment factor; Contamination factor; Index of geo-
25 accumulation; Pollution load index.

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27 **1.0 INTRODUCTION:**

28 Coal was discovered by the Geological Survey of Nigeria (GSN) along Otukpa stream
29 near Okaba. Okaba is situated 16km NE of Ankpa at the base of Enugu escarpment.
30 Exploratory boreholes sunk revealed the presence of coal seams with an average
31 thickness of 2.30m. Okaba coal is sub bituminous and occurs in lower and upper coal
32 measures. Total reserve of Okaba coal is put at 73 million tones [1].

33 There were two mine sites- one for Nigeria Coal Cooperation (NCC) and the other for
34 Nordic. Both mines were closed and hardly distinguished from each other. On the entrant
35 to the NCC mine was an abandoned mine and two other mine ponds left by these
36 companies. Surface method of mining was used.

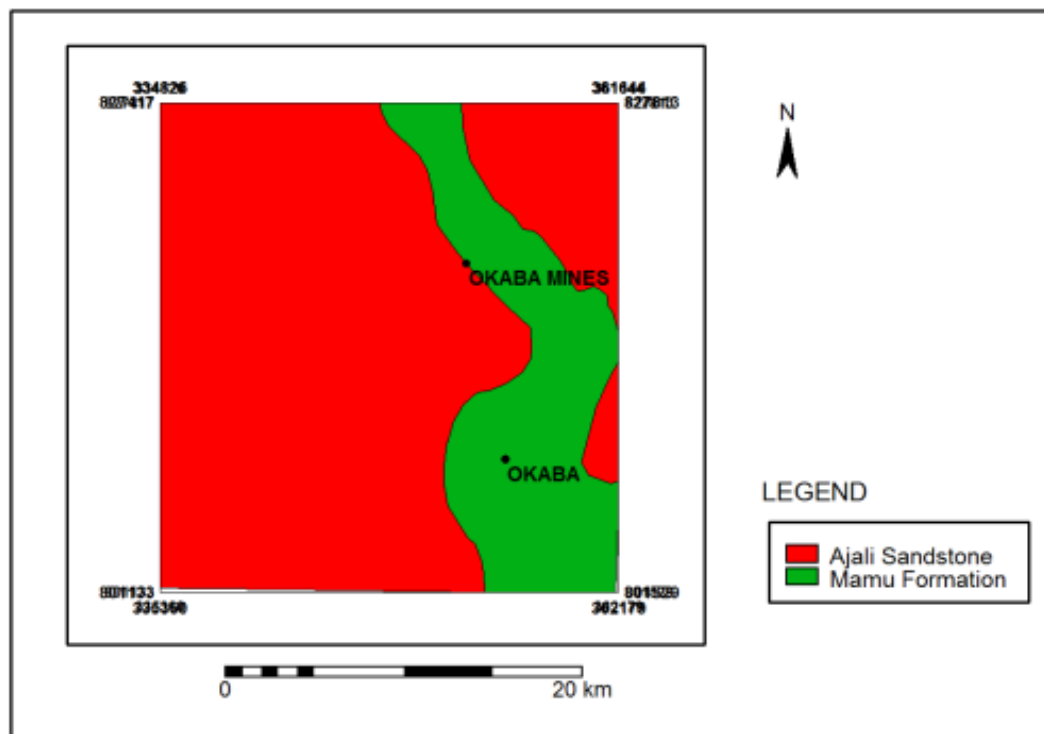
37 Coal mining has adverse effects on the environment. Mining involve exploration for and
38 removal of minerals from the earth. Mining leads to physical, chemical and biological
39 alterations of soil/sediment, drainage patterns, erosion and siltation of streams [2]. Coal
40 mining releases heavy metals into the ecosystem [3,2].

41 This study is imperative in order to determine the degree of contamination arising from
42 coal mining on soils.

43 **1.1 Study area:**

44 The Nigeria coal measures occur within the geological units represented by the Mamu
45 Formation (Lower Maastrichtian) and Nsukka Formation (Upper Maastrichtian to
46 Danian) [4]. Okaba coal mine is located in the Lower Anambra Basin, Norht Central,
47 Nigeria. The area is underlain by two Formations: the Mamu (Early to Late
48 Maestrichtian) and Ajali (Middle to Late Maestrichtian) Formations [4]. The coal
49 bearing sequence is found in Mamu Formation (Lower Maestrichtian). This Formation is

50 underlain by Enugu shales (Campanian) and overlain by the false-bedded Ajali
 51 sandstones of Middle Maestrichtian age. Mamu Formation (Lower Coal Measures)
 52 consists of sandstone bands, mudstones, sandy shale/carbonaceous shale and coal
 53 measures at several horizons [5]. The shales and mudstones often alternate with thin
 54 bands and lenses of siltstones [1]. Ajali Formation (False bedded sandstones) is made up
 55 of friable coarse-grained, white sandstones and sometimes iron stained. The Formation
 56 consists of gravelly and coarse sandstone within the upper horizons and grades into
 57 medium, fine-grained at greater depths. Clay and coal units occur towards the bottom.
 58 There exists a transition between Ajali and Mamu Formations. Overlaying Ajali
 59 Formation is the red earthy sands [1].



60
 61 Fig.1: Geological map of the study area [4].

2.0 MATERIALS AND METHODS:

2.1 Soil sample collection:

The study area covers about 9 km². A total of eleven (11) soil samples were collected. Soil samples were collected from 0- 20 cm depth. Between 1-3kg of samples were collected. Soil samples were generally dry except in few cases where samples were wet. Most samples were collected from layer A of the soil profile. Samples were collected using shovel and stainless spoon. The samples were located using GARMIN III global positioning system (GPS) and recorded. Three shovel or hoe bites of soil samples were collected from a given location, homogenized in a steel bowl and a sub sample of about 1.0g was taken as representative and analysed for the various parameters. The samples were collected randomly and fairly distributed around the mines (Fig. 2). The soil samples were sun-dried, disaggregated (not crushed) using a pestle and mortar and sieved through minus 80 meshes (0.177mm) with cellulose nitrate filter. Control points were carefully chosen to eliminate influence arising from coal mining and to have same geology with the study area. Control point is located on Lat. 07°27'57.2" and Long. 07° 50' 2.0" at elevation of 224m above sea level. Four to five grab samples collected from each control point and homogenized. Sub samples were collected from the homogenized samples to serve as control point.

2.2 Analytical methods:

A gramme (1.0g) of each sample was digested with 3ml of 1:2 mixtures of perchloric and hydrofluoric acids. The concentrations of heavy metals and major cations were determined using Atomic Absorption Spectrophotometer (AAS). Analytical procedures, operational parameters, calibration and standardization used were according to [1]. All

analyses were performed in Agriculture Faculty, Soil Science Dept., Kogi State University, Anyigba.

In situ 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.

2.3 Environmentrics technique: Principal component analysis (PCA), factor analysis (FA) and hierarchal cluster analysis (HCA) were performed to determine the sources of the variables. The Kaiser-Meyer-Olkin (KMO) and Barlett's tests of sphericity were initially carried out to confirm the appropriateness of the data for PCA. The main aim of PCA is data reduction to better describe the relationship among variables. The PCA, correlation and varimax rotated factor analysis based on Kaiser's normalization were performed on the variables for better interpretation [7,8]. Cluster analysis was also carried out for identification of relatively homogeneous groups of variables based on their similarities. A dendrogram is constructed where cohesiveness and correlations among variables can be clearly observed [9].

2.4 Determination of enrichment factor: The magnitude of contaminants in the soils was evaluated from the EF computed for each location relative to the abundances of species in source materials to the control/background value. The following equation as proposed by [10,11, 12] was employed to assess the degree of contamination and distribution of elements of anthropogenic origin. The $EF = (C_m/C_{Fe})_{\text{sample}} / (C_m/C_{Fe})_{\text{control/background value}}$. Where $(C_m/C_{Fe})_{\text{sample}}$ is the ratio of concentration of heavy metal (C_m) to that of Fe (C_{Fe}) in the soil sample and $(C_m/C_{Fe})_{\text{control/background value}}$ is

the reference ratio in the control/background value. Iron (Fe) was selected as reference element because of its abundance and is one of the widely used reference elements [13, 12, 8].

2.5 Assessment of pollution load index (PLI): The pollution load index (PLI) proposed by [14] was used to measure PLI in soils. 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: $CF = C_{\text{metal concentration}} / C_{\text{control point concentration of same metal}}$ and PLI for a site = $\sqrt[n]{CF_1 * CF_2 * \dots * CF_n}$. Where n is the number of heavy metals study (six in this study) and CF= contamination factor. Other anthropogenic indices include: geo-accumulation index and anthropogenic factor as used by [15, 16, 8].

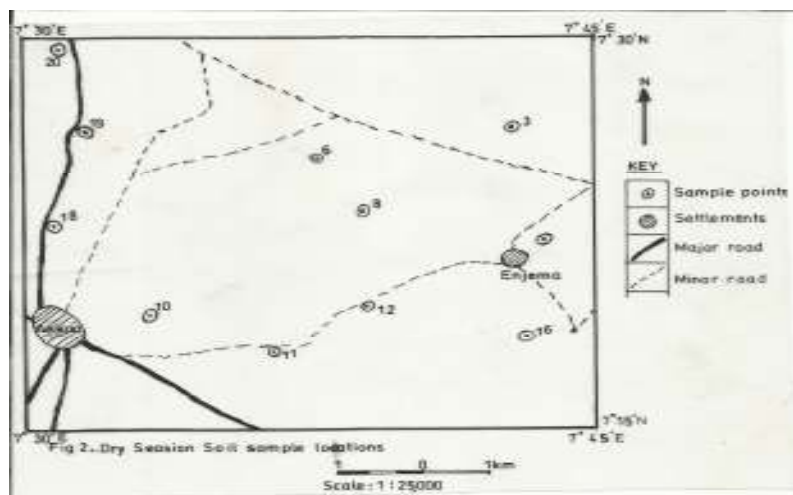


Figure 2: Sample location map of Okaba.

3.0 RESULTS:

Presented below is the result of the raw data and control points value for Okaba dry season soils. The results are expressed in Mg/l (Table 1).

Table 1: Okaba soil sample concentrations (mg/l) at confidence level of 95% (0-20 cm).

Sample location	Na	K	Ca	Mg	Fe	Cu	Zn	Pb	Ni	Cd
Ok11	94.72	26.65	21.25	0.02	97.75	0.25	0.22	0.44	5.81	0.52
Ok12	126.43	29.10	36.00	0.15	195.25	0.29	1.72	0.52	3.66	0.45
Ok03	211.63	44.82	28.15	5.68	220.25	0.95	0.93	0.51	3.78	0.62
Ok06	106.21	33.41	42.72	4.09	507.50	0.66	2.39	0.36	5.83	0.79
Ok08	189.64	45.67	33.25	3.21	279.25	0.23	1.74	0.49	5.56	0.51
Ok10	196.83	37.88	32.75	4.16	203.75	0.36	1.11	0.94	3.35	0.84
Ok16	172.15	31.21	34.71	1.25	100.10	1.31	1.68	0.68	5.47	0.74
Ok17	181.31	27.05	25.63	0.78	150.20	0.58	1.93	0.54	5.07	0.63
Ok18	100.05	25.62	19.32	1.03	89.47	0.23	0.69	0.51	3.78	0.51
Ok19	80.56	26.04	35.38	0.31	210.30	0.55	1.75	0.32	1.46	0.36
Ok20	99.60	20.72	30.44	0.42	95.07	0.47	1.76	0.38	1.31	0.12
Cp value	36.73	15.27	30.41	4.12	86.52	0.18	0.54	0.05	0.86	0.35

Cp = control point values

Calcium-Zn, Ni and Cd revealed moderately to high negative skewness values indicating that the bulk of the values were on the higher right side of the frequency distribution curve. Potassium and magnesium showed high, positive, skewed behaviour. This is an indication of common source of origin for these elements as they approach normal distribution with their lower skewness. Higher, positive, skewed values which indicate bulk of the values on the lower left side of the distribution curve was observed for Fe, Pb and Cu. Based on their frequency distribution, we have two groups: Ca-Zn-Ni-Cd-K-Mg and Fe-Pb-Cu. Similar trend is also revealed by the kurtosis values (Table 2).

Table 2: Basic statistics of measured parameters.

Variable	Mean	Std. Deviation	Range	Minimum	Maximum	Skewness	Kurtosis	T	95% conf. int. of the diff. (Lower)	95% conf. int. of the diff. (Upper)
Na	141.7391	48.65076	131.07	80.56	211.63	0.191	-1.929	9.663	109.0551	174.4231
K	31.6518	8.07511	24.95	20.72	45.67	0.776	-0.376	13.000	26.2269	37.0767
Ca	30.8727	6.87031	23.40	19.32	42.72	-0.238	-0.195	14.904	26.2572	35.4883
Mg	1.9182	1.99133	5.66	0.02	5.68	0.844	-0.814	3.195	0.5804	3.2560
Fe	195.3518	121.36656	418.03	89.47	507.50	1.842	4.239	5.338	113.8167	276.8870
Cu	0.5345	0.33954	1.08	0.23	1.31	1.375	1.626	5.221	0.3064	0.7627

Zn	1.4473	0.63138	2.17	0.22	2.39	-0.676	-0.060	7.602	1.0231	1.8714
Pb	0.5173	0.17176	0.62	0.32	0.94	1.573	3.238	9.988	0.4019	0.6327
Ni	4.0982	1.63037	4.52	1.31	5.83	-0.670	-0.642	8.337	3.0029	5.1935
Cd	0.5536	0.20593	0.72	0.12	0.84	-0.647	0.726	8.917	0.4153	0.6920

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153

154 Kaiser-Mayer-Olkin (KMO) and Barlett's tests of sphericity were performed to
155 determine data appropriateness for PCA. The KMO test is a measure of sampling
156 adequacy and its values lies between 0 and 1 [7]. Smaller values close to zero (0) indicate
157 PCA not appropriate whereas, higher values close to one (1) increase the reliability of
158 PCA. Values from 0.421 are considered satisfactory [7]. Barlett's test was used to
159 determine whether the correlation matrix is an identity matrix. The $P = .05$ is considered
160 significant for Barlett's test [7]. Barlett's test produced a highly significant value of
161 $P < 0.01$, an indication that correlation matrix was not an identity matrix and significant
162 relations exists between the variables (Table 3). These tests confirm the suitability of the
163 data for PCA.

164

165 Table 3: The KMO and Bartlett's tests.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.421
Bartlett's Test of Sphericity	Approx. Chi-Square	132.8
		8.0
	Degree of freedom	45.0
	Significance	0.000

166

167 Correlation analysis (Table 4) showed very strong correlation between Na-K($r =$
168 0.765), K-Mg ($r = 0.844$), Ca-Zn ($r = 0.788$) at $P < 0.01$ level forming a group of Na-K-
169 Mg-Ca-Zn. This major cations and Zinc showing strong correlation indicate same source.
170 At $P < 0.05$ level, Na-Mg ($r = 0.641$), Ca-Fe ($r = 0.71$), Na-Pb ($r = 0.654$), Pb-Cd (r
171 $= 0.614$) and Ni-Cd ($r = 0.644$) showed positive, moderate relationship. This group: Na-
172 Mg-Ca-Fe - Pb- Cd- Ni comes mainly from coal mining related source except the major
173 cations which are abundant in rocks in the area.

174 Table 4: The Correlation matrix between measured variables.

Variables	Na	K	Ca	Mg	Fe	Cu	Zn	Pb	Ni	Cd
Na	1	.765**	.034	.641*	.047	.347	.017	.654*	.307	.536
K		1	.246	.844**	.459	.156	-.011	.341	.375	.514
Ca			1	.285	.718*	.306	.788**	-.051	-.019	.211
Mg				1	.587	.266	.046	.316	.215	.581
Fe					1	.032	.564	-.218	.294	.406
Cu						1	.267	.117	.133	.346
Zn							1	-.228	-.037	.009
Pb								1	.140	.614*
Ni									1	.644*
Cd										1

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

The anthropogenic factor revealed AF of 91.19% for Pb; 82.65% for Ni; 74.81% for Cu; 72.83% for Zn; 69.31% for Fe and 61.27% for Cd (Table 5 and Fig.3). This showed that metal contamination exist in the soil.

Table 5: The anthropogenic factor of heavy metals in Okaba soils.

Heavy metals (mg/l)	Mean measured concentration	Control point concentration	Anthropogenic factor (AF)	% AF	% Geogenic
Fe	195.3536	86.52	2.26	69.31	30.69
Cu	0.5345	0.18	2.97	74.81	25.19
Zn	1.4473	0.54	2.68	72.83	27.17
Pb	0.5173	0.05	10.35	91.19	8.81
Ni	4.0982	0.86	4.77	82.65	17.35
Cd	0.5536	0.35	1.58	61.27	38.73

The $AF = C_m / C_p$; C_m = mean measured concentration; C_p = control point concentration

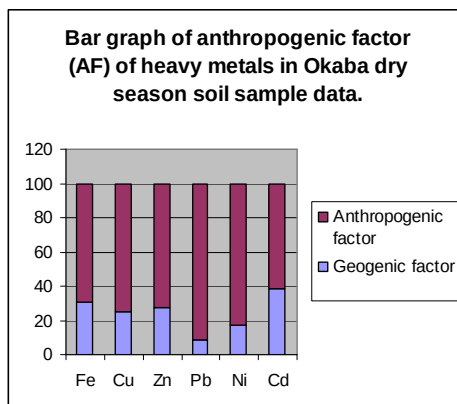


Fig 3: A plot of AF of heavy metals in Okaba soils.

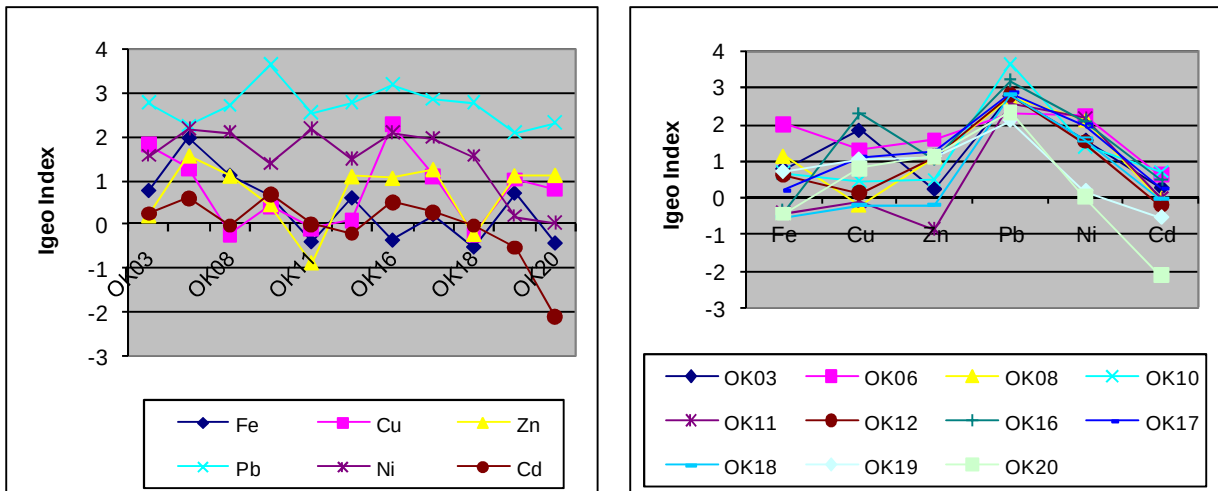
Also, the average Igeo index of accumulation revealed Pb to be moderately to highly polluted, Ni moderately polluted while Cu, Zn, Fe and Cd were unpolluted (Table 6 and Figs. 4a&b).

Table 6: The Igeo index of Okaba soils.

Heavy metals	Sample location										
(mg/l)	OK03	OK06	OK08	OK10	OK11	OK12	OK16	OK17	OK18	OK19	OK20
Fe	0.76	1.97	1.11	0.65	-0.42	0.59	-0.38	0.21	-0.54	0.70	-0.45
Cu	1.82	1.29	-0.23	0.42	-0.11	0.10	2.28	1.10	-0.23	1.03	0.80
Zn	0.20	1.56	1.10	0.45	-0.88	1.09	1.05	1.25	-0.23	1.11	1.12
Pb	2.77	2.26	2.71	3.65	2.55	2.79	3.18	2.85	2.77	2.09	2.34
Ni	1.55	2.18	2.11	1.38	2.17	1.50	2.08	1.97	1.55	0.18	0.02
Cd	0.24	0.59	-0.04	0.68	-0.01	-0.22	0.50	0.26	-0.04	-0.54	-2.13

The $I_{geo} = \log_2 [(C_m) / (1.5 * C_p)]$: C_m = measured concentration; C_p = control point concentration; 1.5 = a factor for possible variations in reference concentration due to lithologic differences.

Igeo index	Pollution intensity	[17]
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	



Figs. 4a&b: The Igeo index of Okaba soils.

Factor 1 was the dominant with eigenvalues of 33.977%. Factor 1 consists of K-Mg-Ni-Cd-Na-Fe with Fe-Na showing moderate loadings which is an indication of their independency within the factor. Factor two consists of strong factor loadings on Ca-Zn-Fe. In factor three, Pb-Cu showed strong loadings while Na revealed moderate and Cd weak loadings. This is also an indication of degree of independency on the prevailing factor. All factors extracted were attributed to anthropogenic and to some degree, natural sources. The PCA finding is in agreement with correlation matrix, skewness and kurtosis. Worthy of note is the fact that Cd-Fe was affected by more than a factor (Table 7). Strong correlations and strong factor loadings within a given factor indicate same source for the variables.

Table 7: The R-mode varimax factor analysis of Okaba soils.

Factor				
Variable	1	2	3	Communalities
Na	.625	-6.497E-02	.638	.856
K	.891	.050	.163	.895
Ca	.124	.929	.343	.872
Mg	.853	.204	.165	.880
Fe	.577	.717	-.335	.971
Cu	.280	.377	.674	.743
Zn	-.110	.918	.308	.837
Pb	.296	-.275	.748	.714
Ni	.744	.021	.181	.924
Cd	.693	9.482E-02	.458	.867

Eigenvalue	3.398	2.510	1.814
% of variance	33.977	25.102	18.142
Cumulative %	33.977	59.080	77.222

From the dendrogram depicted above (Figure 5), cluster 1 consists of K-Mg-Na-Ni-Cd-Pb-Cu and cluster two consists of Ca-Zn-Fe. Cluster 1 was joined to cluster two at a significantly large linkage distance which shows relatively high independency of each

group. While cluster one was attributed to anthropogenic sources, cluster two could be a mixture of natural and anthropogenic sources.

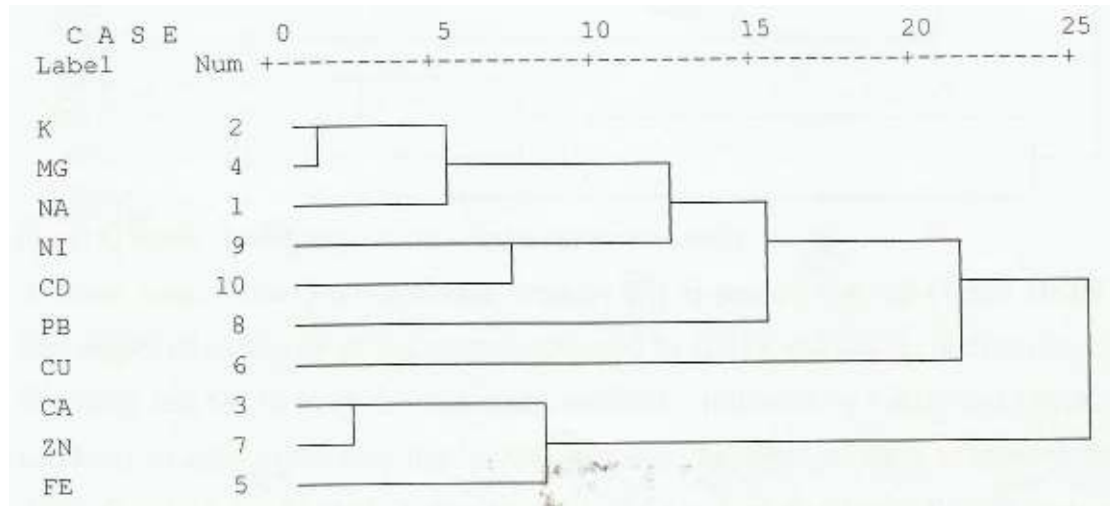


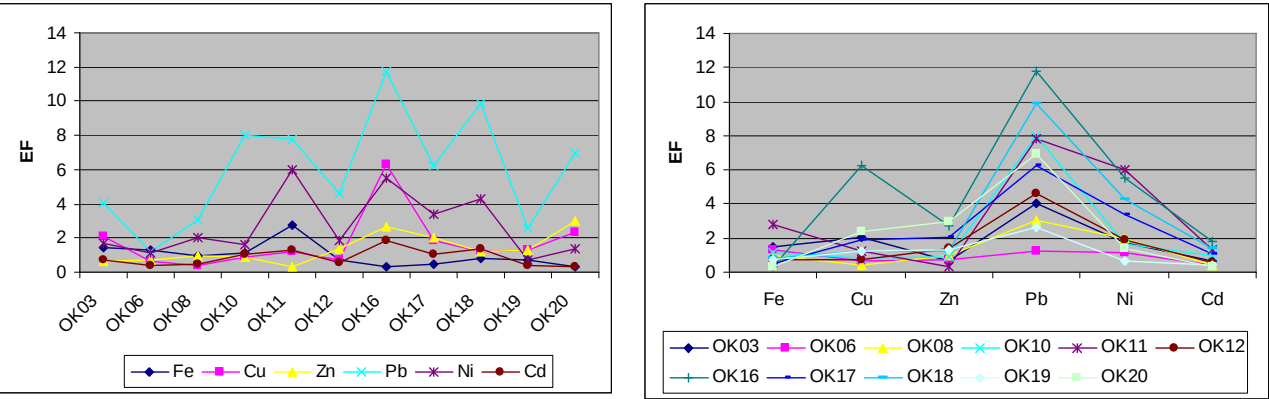
Fig 5: The R-mode cluster analysis.

The order of enrichment factor was Pb (66.04) > Ni (29.64) > Cu (18.92) > Zn (15.35) > Fe (11.15) and Cd (9.45). Except in locations OK12, OK08, OK06 and OK03, Pb has the highest value of EF in all locations (Table 8). This was followed by Ni, Zn, Cu, Fe and Cd was the least. In order of enrichment, location OK16 was the most enriched, followed by OK18, OK11 and OK17, while OK03, OK08, OK06 have the least enrichment factors with respect to all the heavy metals (Fig 6a&b). In order of three most impacted heavy metals, Pb have all six locations significantly polluted, four moderately polluted and OK06 was depleted to minimally enriched. Copper has one location (OK16), significantly enriched and the rest moderately enriched. Nickel has two locations significantly enriched, six moderately enriched and two locations depleted to minimally enriched (Fig 6a&b). The least EF was: Cd<Fe<Zn with respect to all locations.

Table 8: The Enrichment factor (EF) of heavy metals.

Heavy Metals (mg/l)	Sample location										
	OK03	OK06	OK08	OK10	OK11	OK12	OK16	OK17	OK18	OK19	OK20
Fe	1.48	1.33	1.00	1.15	2.77	0.71	0.32	0.49	0.81	0.75	0.34
Cu	2.07	0.63	0.40	0.85	1.23	0.71	6.29	1.86	1.24	1.26	2.38
Zn	0.68	0.75	1.00	0.87	0.36	1.41	2.69	2.06	1.24	1.33	2.97
Pb	4.01	1.23	3.04	7.98	7.79	4.61	11.75	6.22	9.86	2.63	6.92
Ni	1.73	1.16	2.00	1.64	5.98	1.89	5.50	3.40	4.25	0.70	1.39
Cd	0.70	0.38	0.45	1.02	1.32	0.57	1.83	1.04	1.41	0.42	0.31

EF indices	Degree of enrichment	[18]
$EF \leq 1$	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	



Figs 6a&b: The EF and average EF of heavy metals.

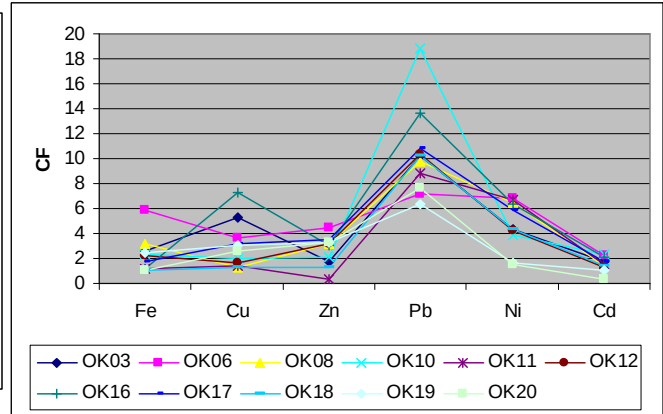
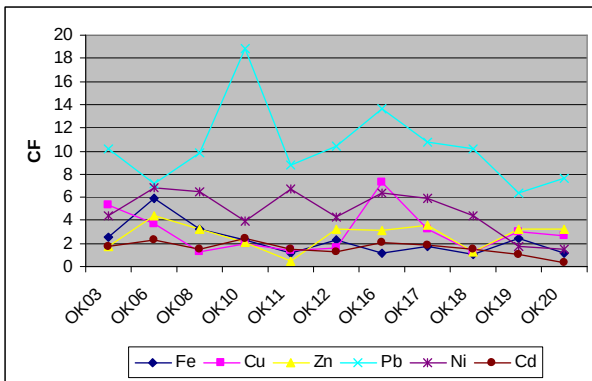
From the CF (Table 9), Pb has the highest average CF values of (113.80) from all locations, followed by Ni (52.45), Cu (32.68), Zn (29.49), Fe (24.84) and Cd (17.41). Cadmium has the least CF value of 17.41. Iron (Fe) has moderate contamination in nine locations and considerable contamination in two other locations (OK08 and OK06). Copper has moderate contamination in six locations and considerable contaminations in locations OK03, OK06, OK17 and OK19. At location OK06, Cu has very high contamination value of 7.28. Zinc has low contamination at OK11, moderate contamination at locations OK03, OK10, OK18 and considerable contamination at locations OK06, OK08, OK12, OK16, OK17, OK19 and OK20. Lead CF ranged from 6.4 to 18.8. All locations recorded very high contamination. The CF values of Ni indicate that locations OK19 and OK20 were moderately contaminated five other locations considerable contaminations while OK06, OK08, OK11 and OK16 have very high contaminations. Cadmium has the least CF values and all locations have CF values between 1 and 3, (moderate contamination) except location OK20 with low contamination. Lead has the highest CF value in all locations, followed by Ni in most locations, Cu and Zn while Fe and Cd were the least (Figs. 7a&b). The most

contaminated locations were OK10, OK16, OK17, OK18, OK12, OK08, OK03 and OK20 in decreasing order. Heavy metal CF rank was: Pb > Ni > Cu > Fe > Zn > Cd.

Table 9: The CF of heavy metals in Okaba.

Heavy Metals (mg/l)	Sample location										
	OK03	OK06	OK08	OK10	OK11	OK12	OK16	OK17	OK18	OK19	OK20
Fe	2.55	5.87	3.23	2.35	1.13	2.26	1.16	1.74	1.03	2.43	1.10
Cu	5.28	3.67	1.28	2.00	1.39	1.61	7.28	3.22	1.28	3.06	2.61
Zn	1.72	4.43	3.22	2.06	0.41	3.19	3.11	3.57	1.28	3.24	3.26
Pb	10.20	7.20	9.80	18.8	8.80	10.4	13.60	10.80	10.20	6.40	7.60
Ni	4.40	6.78	6.47	3.90	6.76	4.26	6.36	5.90	4.40	1.70	1.52
Cd	1.77	2.26	1.46	2.40	1.49	1.29	2.11	1.80	1.46	1.03	0.34
PLI	3.50	4.68	3.27	3.46	1.96	2.95	4.11	3.63	2.19	2.54	1.82

Contamination factor (CF) indices	Degree of contamination [14]
CF < 1	Low contamination
1 ≥ CF ≥ 3	Moderate contamination
3 ≥ CF ≥ 6	Considerable contamination
CF > 6	Very high contamination



Figs. 7a&b: The CF and average CF of heavy metals.

The pollution load index (PLI), showed that all locations have PLI > 1 and were polluted (Fig. 8, Table 10).

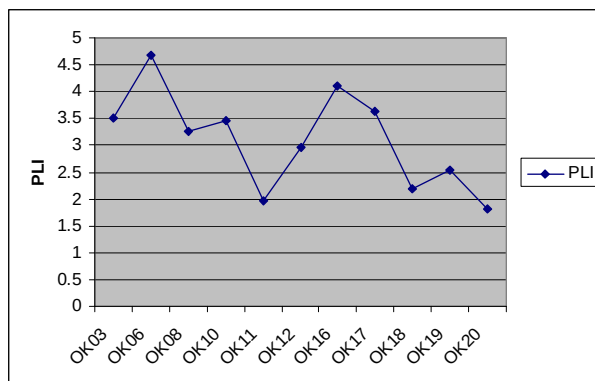


Fig 8: The PLI of heavy metals.

Table 10: Pollution load index of sample points.

Locations	Pollution load	Index
Ok03	3.50	polluted
Ok06	4.68	polluted
Ok08	3.27	polluted
Ok10	3.46	polluted
Ok11	1.96	polluted
Ok12	2.95	polluted
Ok16	4.11	polluted
Ok17	3.63	polluted
Ok18	2.19	polluted
Ok19	2.54	polluted
Ok20	1.82	polluted

4.0 DISCUSSION:

The concentrations of major cations were due to their abundance in rock forming minerals in the area. They showed this trend: Na (141.74 mg/l) > K (31.65 mg/l) > Ca (30.87 mg/l) > Mg (1.92 mg/l). The heavy metals showed this rank: Pb>Cu>Cd>Zn>Ni>Fe. Their presence is attributed to pyrite minerals and base metal deposits such as chalcopyrite (CuFeS_2), chalcocite (Cu_2S), covellite (CuS), galena (PbS), sphalerite (ZnS) [20].

At $P<0.01$ level, very strong correlations were observed between Ca-Zn-Ni-Cd-K-Mg while at $P<0.05$ level, Fe-Pb-Cu revealed moderate correlation. The presence of Pb, Ni could be from fossil fuel while Zn, Cd are associated with coal mining. Both groups resulted from natural and anthropogenic origins.

The R-mode factor analysis suggests that factor one and three were due to both natural and anthropogenic inputs while factor two could be due to natural processes as evidence in the correlation analysis, EF and CF [21, 22]. The R-mode cluster analysis generated three clusters. Cluster one was an association of K, Mg, Na, Ni, Cd and Pb. Nickel and Cd were connected to this cluster at 2nd degree while Pb was linked to this same cluster

at a farther distance (3rd order degree). Copper was the only element in cluster two. This solitary behavior was evident also in the correlation where Cu did not significantly relate to any of the parameters analyzed. This indicates uniqueness and high degree of independency. The association in cluster three was made up of Ca, Zn and Fe. While cluster one was due to anthropogenic inputs related to coal mining, cluster two and three could be due to natural processes [23].

All indices gave this order of enrichment/contamination of heavy metals present in Okaba coal mines: $Pb > Ni > Cu > Zn > Fe > Cd$. Cadmium and Fe were respectively the least contaminated. [24] investigated the distribution of heavy metals in coal and showed that As, Co, Cu, Ni, Cr, Pb, Zn, Cd etc were present. [15] also confirm the presence of heavy metals such as Pb, Cd, and Ni in Enugu coal. This study indicates that soil samples were contaminated/enriched with Pb, Ni, Cu and Zn. This observation may be due to the presence of pyrite minerals in coal. Besides pyrites, base metal deposit contain other metal sulphide minerals such as chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS), galena (PbS) and sphalerite (ZnS). In a strongly reducing environment and in the presence of sulphur, these elements form sulphides. This explains why coals which form in strongly reducing environment contain significant amounts of heavy metals [20]. Analysis of Nigerian coal shows the presence of heavy metals such as Cd, Cu, Cr, Hg, Ni, Zn, Pb, Ti, As, Ag, Al, Co, V and Si [25]. The acidic nature of the environment and the tropical climatic conditions contributed to the high concentration of these heavy metals.

While lower and generally no appreciable difference in PLI indicates less significant inputs from anthropogenic sources, $PLI > 1$ indicates progressive site deterioration. This means that all sample sites were polluted. The PLI of > 2.50 indicates appreciable enrichment/contamination and as such locations OK06, OK16, OK17, OK03, OK10, OK12 and OK19 have experienced varying degrees of heavy metal contamination from coal mining related activities.

CONCLUSION:

Based on the indices used, Pb, Ni and Cu have significantly impacted on the soil. Factor and cluster analyses also complimented the indices for proper evaluation of the contaminated soils. Efficient mining processes, improved maintenance and other practices are recommended for a sustainable environment.

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