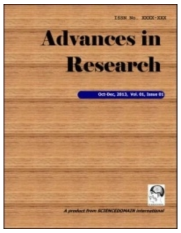

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Utilization of Environ Metric and Index Methods as Water Quality Assessment Tools Focusing on Heavy Metal Content of Water Around Okaba Coal Mines, Kogi state, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author EGA designed the study, performed the analysis and interpretation and wrote the first draft of the manuscript. Author DOO wrote the protocol and participated in the fieldwork. Author TDA provided transportation, logistics and took part in the fieldwork. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

This study became imperative given the importance of water to our lives and particularly those in the rural areas, vis-à-vis the exploitation for coal.
Dry season surface water samples were analyzed for heavy metals and major ions.
Correlation, factor and cluster analyses, anthropogenic factor (AF), heavy metal pollution (HPI) and metal indices (MI) were adopted to help in assessing the degree of water pollution.
At $P< 0.01$ and $P<0.05$ levels, strong to moderate correlations exist. This indicates same origin for these variables. The R-mode factor suggests that factor one and two were anthropogenic while factor three was natural. The R-mode clusters revealed also that cluster two was anthropogenic and cluster one was a mixture of natural and anthropogenic sources. The Q-mode factor indicated that while some locations were directly influenced others were not. The Q-mode cluster showed that cluster one was natural, clusters two and three were anthropogenic.

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The AF rank was: Cd>Zn>Ni>Fe>Pb> Cu. The HPI value of 56.21 obtained was below the critical pollution level of 100 at which the water is said to be contaminated. Metal indexing value of 460.46 obtained suggested seriously affected water.

This study has shown that heavy metal pollution of water resources around Okaba coal need to be re-evaluated in details. Control measures should be put in place for a sustainable development while preventive measures and awareness are strongly recommended.

Keywords: Anthropogenic factor (AF); heavy metal pollution indexing; metal indexing; multivariate analysis and Okaba.

1. INTRODUCTION

Okaba is located 16km NE of Ankpa, the base of Enugu escarpment. Boreholes sunk for depth and reservoir determination showed the presence of coal seams with an average thickness of 2.30m. The Geological Survey of Nigeria (GSN) carried out analysis on the Okaba coal and revealed the following results: moisture content 6.9%, volatiles 41%, fixed carbon 42.6% and ash 7.0%. Okaba coal is sub bituminous and occurs in lower and upper coal measures. Total reserve of Okaba coal was put at 73 million tones [1,2].

There are two mine sites at Okaba-one for Nigeria Coal Cooperation (NCC) and the other for Nordic. Both mines were closed and hardly distinguished from each other. On the entrant to the NCC mine was an abandoned mine and two mine ponds. The quantity of coal mined by the various companies cannot be easily quantified. What is obvious is the stark reality of the various mining related activities and its environmental impact.

Coal mining either by surface or underground methods has consequences on the environment. These mining methods involve exploration for and removal of minerals from the earth. Mining causes physical, chemical and biological alterations of soil, sediment, it alter drainage patterns, causes erosion, siltation of streams and heavy metal pollution of soil/sediment and water bodies [3,4].

This study is necessary to evaluate the degree of contamination of surface water, provide data for policy makers, companies and to create awareness on the dangers of these heavy metals on our health.

1.1 Study Area

The Nigeria coal measures occur within the geological units represented by the Mamu Formation (Lower Mastritchtian) and Nsukka Formation (Upper Mastritchtian to Danian) [2]. Okaba coal mine is located in the Lower Anambra Basin, North Central, Nigeria. The area is underlain by two Formations: the Mamu (Early to Late Maestritchtian) and Ajali (Middle to Late Maestritchtian) Formations [5,2]. The coal bearing sequence is found in Mamu Formation (Lower Maestritchtian). This Formation is underlain by Enugu shales (Campanian) and overlain by the false-bedded Ajali sandstones of Middle Maestrichtian age. Mamu Formation (Lower Coal Measures) consists of sandstone bands, mudstones, sandy/carbonaceous shales and coal measures at several horizons [2]. The shales and mudstones often alternate with thin bands and lenses of siltstones [5]. The Ajali Formation (false bedded sandstones) is made up of friable, coarse-grained, white sandstones and sometimes iron stained. The Formation consists of gravelly and coarse sandstone within the upper horizons and grades into medium, fine-grained at greater depths. Clay and coal units occur towards the bottom indicating transition between Ajali and Mamu formations (Fig.1). Red earthy sands due to weathering and ferruginisation overlay this Formation [2,5].

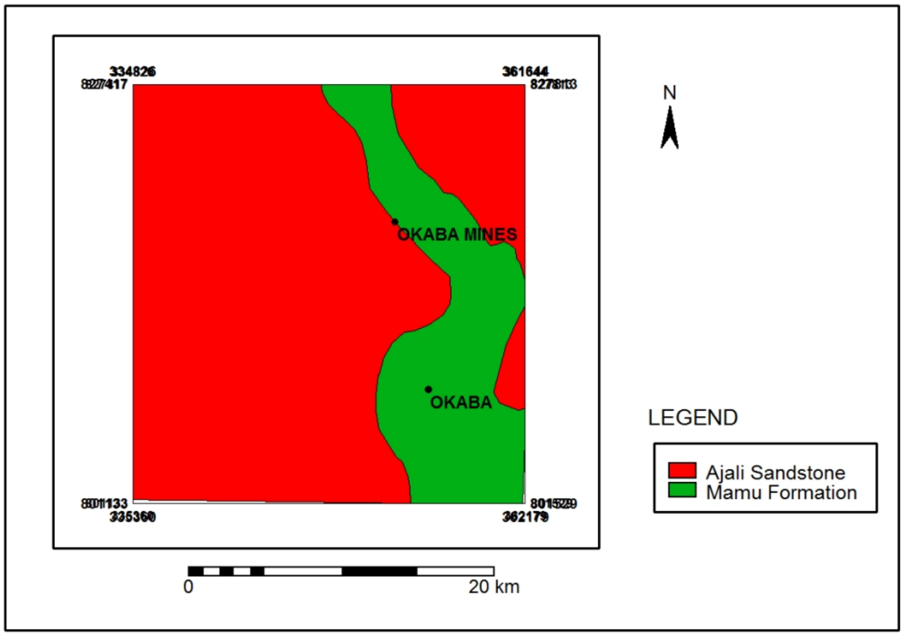

Fig. 1. Geological map of study area [2].

2. MATERIALS AND METHODS

Water samples were collected during the dry season (Fig. 2). Sampling was random but evenly distributed. Samples were collected from mid-point and a foot below the surface water in duplicates for heavy metal and anion analyses. Samples were filtered as soon as they were collected using cellulose nitrate filter with pores of 0.45 micron diameter. Polyethylene plastic bottles were used as sample containers. New bottles were cleaned with strong- metal free acid. The containers were rinsed with sample water prior to collection. Sufficient air space was allowed and sample stored upright. Teflon lined caps were screwed on tightly to prevent leakage. Water samples for cations and heavy metal analyses were acidified with HNO_3 to a pH of 1-2. The samples were stored between 1ºC and 4ºC on cool ice packs from the field to the laboratory for analyses [6].

2.1 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 (AAS) (Model 210 VGP) was used to determine the concentrations of Mg, Pb, Zn, Ni, Cu, Cd, and Fe. Titration method was used for the determination of Cl, NO_3, SO_4 and alkalinity concentrations. All analyses were performed according to [6] in the Dept. of Soil Science Laboratory, Faculty of Agriculture, Kogi State University, Anyigba.

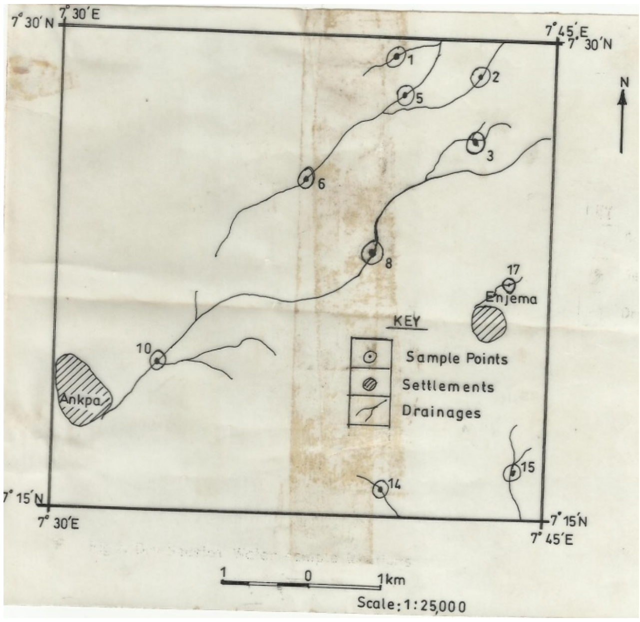

Fig. 2. Sample location map of Okaba.

2.2 Data Evaluation

2.2.1 Heavy metal pollution index (HPI)

The HPI is a method that rates the aggregate influence of individual heavy metal on the overall quality of water. It is defined as Wi, taken as inversely proportional to the recommended standard (Si) for each parameter. The HPI model is given as $HPI=\sum WiQi/\sum Wi$…….. (1).

Where Qi = sub-index of the ith parameter. Where Wi is the unit weightage of ith parameter and n is the number of parameters considered.

The sub-index (Qi) of the parameter is calculated by $Qi =\sum (Mi\ (-)\ Ii)/ (Si-Ii)$…….. (2). Where Mi is the monitored value of heavy metal of the ith parameter; Ii is the ideal/baseline value of ith parameter; Si is the standard value of ith parameter. In this study, the Nigerian Standard for Drinking Water Quality (NSDWQ, NIS: 554, 2007) was used.

The sign (-) indicates the numerical difference of the two values, ignoring the algebraic sign [7]. The critical pollution index value is 100 [8,9,10].

2.2.2 Metal index (MI)

The MI for drinking water [8] takes into account possible additive effect of heavy metals on the human health that helps to quickly evaluate the overall quality of drinking waters. The $MI =\sum[Ci/(MAC)i]$ as proposed by [11,8] was used. Where MAC is maximum allowable concentration and Ci is the concentration of each metal. The higher the concentration of a metal compared to its respective MAC value, the worse the quality of water. Metal index (MI) value > 1 is a threshold of warning [8,12].

2.2.3 Univariate and multivariate statistical methods of analysis

The software SPSS version 17.0 was used for statistical analysis. The correlation matrix is based on the Pearson's correlation coefficient. It displays relationships between variables [13,15]. The PCA and PFA involve these steps: code variables to have zero means and unit variance; calculate covariance matrix; find eigenvalues and corresponding eigenvectors; discard any component that account for small proportion of variation in the data set; develop the factor loading matrix and perform varimax rotation factor analysis to infer the principal parameters [13,15]. Components or factors exhibiting an eigenvalues greater than one were retained.

Factor analysis which explains an observed relationship between numerous variables was applied. Cluster analysis was also used for investigating the similarities between variables. Evaluation of similarity was based on the average linkage between groups [14,15].

3. RESULTS

The summary statistics of Okaba water samples were shown in Table 1 & 2. Temperature ranged from 25.40–27.00ºC with 26.15ºC as mean value. The pH has a mean value of 6.37. This indicates slightly acidic water. The TDS ranged from 1.80 – 1999.00 and has a mean value of 886.38. The EC has a mean value of 1.70; alkalinity was 1.09; Potassium (K), 9.81mg/l; Sodium (Na), 4.38mg/l; Calcium (Ca),6.42mg/l and Mg, 0.13mg/l. Average concentrations rank among major cations was: K>Ca>Na>Mg. Chlorine has a mean value of 0.73mg/l; NO_3 has a mean value of 8.27mg/l and SO_4 has a mean value of 3.99mg/l. Average trend among major anions was: NO_3>SO_4>Cl.Iron (Fe) ranged from 0.35–20.17mg/l with a mean value of 2.87mg/l, Cu has a mean value of 0.11mg/l and ranged from 0.03 – 0.5mg/l. Zinc ranged from 0.29–1.65mg/l with a mean value of 0.85mg/l. Lead (Pb) has a mean value of 0.54mg/l and ranged between 0.21–0.92mg/l. Nickel ranged from 2.55 – 7.81mg/l but has a mean of 4.13mg/l and Cd ranged from 0.40–0.87mg/l with a mean value of 0.57mg/l. The average rank was Nickel>Fe>Zn>Cd>Pb>Cu.

The pH, Na and Ca showed low to moderately high negative, skewed values. This indicates that the bulk of the values were on the lower right side of the frequency distribution curve (Table 1). While TDS, K, Cl and Zn showed positive, low-moderately skewed behaviour, Alk, Mg, NO_3, SO_4, Fe, Cu, Pb and Cd showed high skewed behaviour. The low to high positive skewness on the left side of the curve form a group of same source, the low-moderately high form another group from same source. The kurtosis also revealed similar pattern.

Table 1. Descriptive statistics of variables measured

Variable	Range	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance	Skewness	Kurtosis	T
Temp	1.60	25.40	27.00	261.50	26.15	0.61	0.37	0.04	-1.93	135.24
pH	4.20	3.50	7.70	63.70	6.37	1.35	1.81	-1.09	0.79	14.96
TDS	1997.20	1.80	1999.00	8863.80	886.38	969.36	939667.13	0.41	-2.24	2.89
EC	3.95	0.02	3.97	16.96	1.70	1.75	3.07	0.20	-2.25	3.06
ALK	6.19	0.01	6.20	10.99	1.10	1.88	3.52	2.70	7.68	1.85
K	15.90	3.00	18.90	98.14	9.81	5.57	31.06	0.45	-0.69	5.57
Na	6.14	0.44	6.58	43.84	4.38	2.05	4.19	-0.77	-0.28	6.78
Ca	10.25	0.50	10.75	64.24	6.42	3.71	13.76	-0.33	-1.38	5.48
Mg	0.48	0.02	0.50	1.27	0.13	0.14	0.02	2.44	6.41	2.84
Cl	1.74	0.03	1.77	7.34	0.73	0.84	0.71	0.48	-2.17	2.76
NO_3	33.05	1.84	34.89	82.69	8.27	9.61	92.32	2.86	8.61	2.72
SO_4	13.18	0.45	13.63	39.92	3.10	3.95	15.63	1.80	3.70	3.19
Fe	19.82	0.35	20.17	28.72	2.87	6.12	37.30	3.12	9.74	1.49
Cu	5.97	0.03	6.00	7.03	0.70	1.87	3.48	3.13	9.85	1.19
Zn	1.36	0.29	1.65	8.49	0.85	0.46	0.21	0.51	-0.80	5.85
Pb	0.71	0.21	0.92	5.40	0.54	0.29	0.08	0.17	-1.84	5.97
Ni	5.26	2.55	7.81	41.34	4.13	1.89	3.58	1.26	0.33	6.91
Cd	0.47	0.40	0.87	5.65	0.57	0.14	0.02	1.03	1.02	12.47

At $P<0.01$ level, TDS-Ec, Na-Ca, Ec-Cl, NO_3-SO_4, SO_4-Fe, NO_3-Fe, pH-Fe, Ec-Pb, TDS-Pb showed very strong correlations. At $P<0.05$ level, K-Ca, Ec-Ca, TDS-Cl, pH-Cl, pH-NO_3, pH-SO_4, Cl-Pb, SO_4-Ni, Na-Cd, K-Cd showed moderate to strong At $P<0.01$ level, TDS-Ec, Na-Ca, Ec-Cl, NO_3-SO_4, SO_4-Fe, NO_3-Fe, pH-Fe, Ec-Pb, TDS-Pb showed very strong correlations. At $P<0.05$ level, K-Ca, Ec-Ca, TDS-Cl, pH-Cl, pH-NO_3, pH-SO_4, Cl-Pb, SO_4-Ni, Na-Cd, K-Cd showed moderate to strong correlation. These correlations revealed two groups: TDS-Ec-Na-Ca-Cl-NO_3-SO_4-Fe-pH-Pb and the second group: K- Ca-EC-TDS-Cl-pH-NO_3-SO_4-Pb-Ni-Na-Cd. Both groups suggest mixture of natural and anthropogenic sources.

Table 2. Correlation matrix of measured variables

	Temp	pH	TDS	EC	ALK	K	Na	Ca	Mg	Cl	NO_3	SO_4	Fe	Cu	Zn	Pb	Ni	Cd
Temp	1	-.199	.310	.208	-.161	-.271	.176	-.001	-.152	.299	.193	.226	.265	.331	-.429	.292	.547	-.245
pH		1	-.376	-.580	.379	.183	-.019	-.117	.235	$-.749^{*}$	$-.709^{*}$	$-.708^{*}$	$-.766^{**}$	$-.777^{**}$	.271	-.515	-.402	.492
TDS			1	$.903^{**}$	-.328	.469	.262	.576	-.449	$.665^{*}$	.432	.370	.407	.438	.096	$.934^{**}$	.420	.074
EC				1	-.492	.514	.405	$.668^{*}$	-.437	$.866^{**}$	.490	.387	.494	.492	.160	$.807^{**}$	.397	.079
ALK					1	-.418	-.595	-.321	-.104	-.404	-.257	-.221	-.236	-.226	.281	-.203	-.053	-.160
K						1	.498	$.705^{*}$	-.276	.305	-.250	-.180	-.331	-.366	.206	.297	.034	$.635^{*}$
Na							1	$.768^{**}$	-.161	.226	.291	.221	.250	.196	.113	-.008	.381	$.649^{*}$
Ca								1	-.407	.488	.257	.255	.238	.197	.187	.366	.456	.532
Mg									1	-.324	-.129	-.149	-.102	-.131	-.079	-.508	-.361	-.398
Cl										1	.410	.416	.474	.470	-.050	$.652^{*}$	.484	-.249
NO_3											1	$.885^{**}$	$.978^{**}$	$.963^{**}$	.062	.454	.547	-.195
SO_4												1	$.849^{**}$	$.843^{**}$	-.242	.478	$.753^{*}$	-.276
Fe													1	$.992^{**}$	-.002	.430	.526	-.310
Cu														1	-.078	.482	.524	-.357
Zn															1	-.071	-.212	.431
Pb																1	.445	-.140
Ni																	1	-.053
Cd																		1

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

The R-mode varimax rotated factor analysis extracted three factors. Factor one was the dominant factor with eigenvalues of 1.881 and total variance of 31.351%. Factor one was characterized by high factor loadings on Ni, Fe and weak loading on Pb. Factor two consists of Zn and Cd with eigenvalues of 1.521 and total variance of 25.345%. High, positive loadings on Cu and Pb were recorded in factor three. This factor has eigenvalues of 1.458 and 24.304% total variance (Table 3).While factor one is anthropogenic, factors two and three implies mixture of natural and anthropogenic sources.

Table 3. The R-mode varimax rotated factor of heavy metals

Variable	Factor			Communalities
	1	2	3	
Fe	.839	-.104	.088	.723
Cu	-.313	-.335	.867	.962
Zn	-.027	.857	-.062	.739
Pb	.527	.041	.819	.950
Ni	.883	-.080	-.062	.790
Cd	-.144	.810	-.142	.696
Eigenvalue	*1.881*	*1.521*	*1.458*	
% total variance	*31.351*	*25.345*	*24.304*	
Cumulative %	*31.351*	*56.696*	*81.000*	

The R-mode cluster analysis of the heavy metals extracted two clusters. Cluster one consists of Fe, Ni, Cu and Pb with Fe and Ni showing the highest similarities. Cluster two was an association between Zn and Cd. This cluster was linked to cluster one at a farther distance to indicate its high level of independency (Fig. 3).

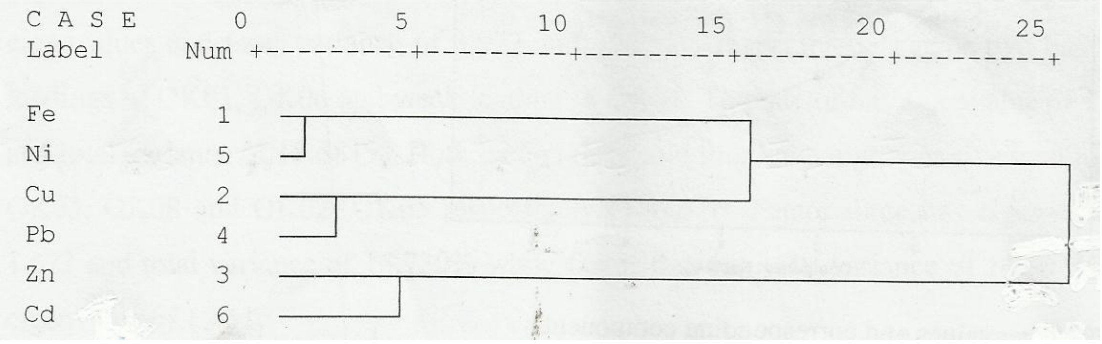

Fig. 3. The R-mode cluster analysis of heavy metals

The Q-mode factor analysis of the heavy metals yielded four factors. Factor one consist of high, positive loadings on OK10, OK15, OK14 and OK17.This factor has significant eigenvalues and total variance of 3.977 and 39.768% respectively indicating its dominance. Factor two has high loadings on OK01, OK06 and weak loading on OK05. This factor has eigenvalues of 1.858 and total variance of 18.581%. Both factors three and four have high, positive loadings on OK03, OK08 and OK02, OK05 respectively (Table 4). Factor three has eigenvalues of 1.573 and total variance of 15.730% while factor four has total variance of 14.507% and eigenvalues of 1.451.

Table 4. The Q-mode varimax rotated factor analysis

Variable	Factor				Communalities
	1	2	3	4	
Ok01	-.269	.873	-.105	.070	.850
Ok02	-.265	-.326	-.352	.823	.977
Ok03	.076	-.034	.884	-.016	.789
Ok05	.038	.480	.016	.844	.944
Ok06	.272	.858	-.065	.015	.815
Ok08	-.221	-.127	.778	-.185	.705
Ok10	.991	.035	.012	-.027	.984
Ok15	.991	.035	.012	-.027	.984
Ok14	.871	-.049	-.214	-.143	.828
Ok17	.991	.035	.012	-.027	.984
Eigenvalue	*3.977*	*1.858*	*1.573*	*1.451*	
% total variance	*39.768*	*18.581*	*15.730*	*14.507*	
Cumulative %	*39.768*	*58.349*	*74.079*	*88.586*	

**OK = Okaba*

The Q-mode cluster analysis extracted three distinctive clusters. Cluster one consist of OK15, OK17, OK10 and OK14. Location OK14 was linked at Euclidean distance of 5 to the rest cluster. Cluster two was an association between locations OK01, OK06, OK02 and OK05. The last cluster consists of only OK03 and OK08. This showed the independency/ dissimilarity of clusters one and two (Fig. 4).

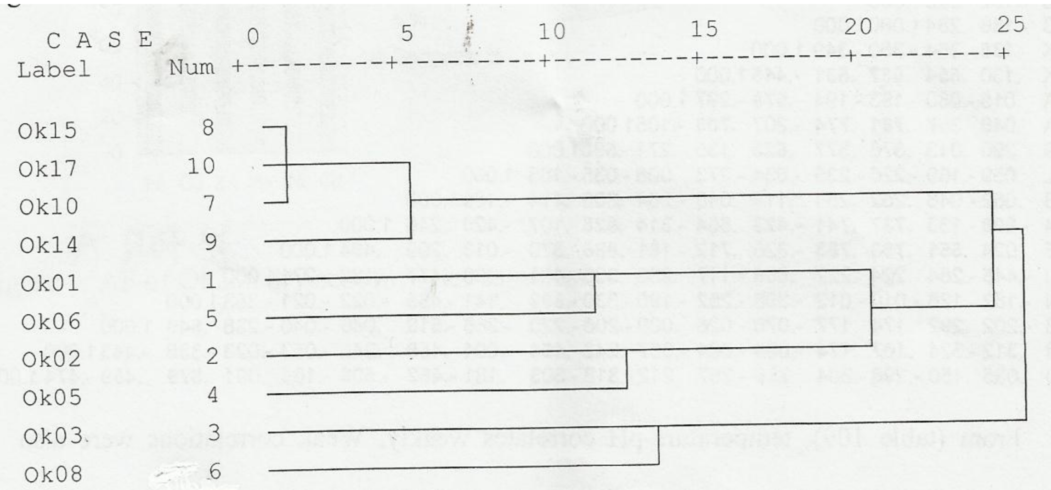

Fig. 4. The Q-mode cluster analysis

The anthropogenic factor (Table 5), using average heavy metal concentrations revealed the following percentages: Cd, 98.26%; Zn, 97.70%; Ni, 74.43%; Fe, 73.79%; Pb, 71.05% and Cu has the lowest AF of 64.50%. The AF trend was: Cd > Zn > Ni > Fe > Pb > Cu (Fig. 5). It was revealed that the AF was a more contributor of these heavy metals than the lithogenic factor.

Table 5. The anthropogenic factor (AF) of heavy metals

Heavy metals (mg/l)	Mean value	Cp value	AF value	AF %	Geogenic %
Fe	2.87	1.02	2.84	73.79	26.21
Cu	0.11	0.06	1.82	64.50	35.50
Zn	0.85	0.02	42.45	97.70	2.30
Pb	0.54	0.22	2.45	71.05	28.95
Ni	4.13	1.42	2.91	74.43	25.57
Cd	0.57	0.01	56.50	98.26	1.74

AF =C_m/C_p: C_m = measured concentration; C_p = control point concentration.

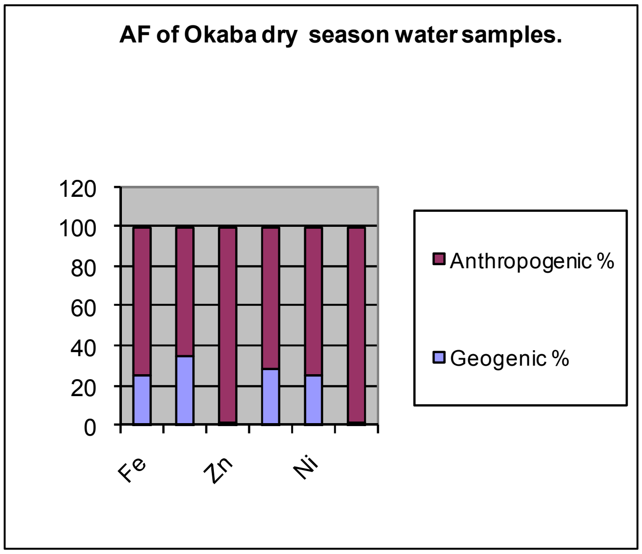

Fig. 5. Anthropogenic factor (AF) of heavy metals

The composite effect of the heavy metals revealed HPI value lower than the critical value of 100 (Table 6). The HPI values for each point recorded values below 100. But significantly high HPI values were recorded at locations Ok03, OK05, OK02, Ok17, Ok15 and OK06. While the first three locations were close to the mines, the three other points were also located around the abandoned mines (Table 7 and Fig. 6). On the average, HPI values were higher at the downstream than upstream.

Table 6. The Mean HPI of Okaba water

Heavy metals (mg/l)	Mean value (mg/l) Mi	Standard value (Si); NSDWQ, 2007	Baseline value (Ii)	Unit weightage (Wi)	Sub-index (Qi)	Wi *Qi
Fe	2.87	0.30	1.02	3.33	2.57	8.57
Cu	0.11	1.00	0.06	1.00	0.05	0.05
Zn	0.85	3.00	0.02	0.33	0.28	0.09
Pb	0.54	0.01	0.22	100.00	1.52	152.00
Ni	4.13	0.02	1.42	50.00	1.94	97.00
Cd	0.57	0.003	0.01	333.33	80.00	26666.64
				∑Wi =487.999		∑Wi *Qi = 26924.35
			HPI = 56.21			

Table 7. HPI values of the sample locations

Sample locations	Ok01	Ok02	Ok03	Ok05	Ok06	Ok08	Ok10	Ok15	Ok14	Ok17
HPI values	42.24	60.59	84.49	67.66	52.13	38.82	45.42	53.82	43.03	58.72
					∑HPI = 54.69					

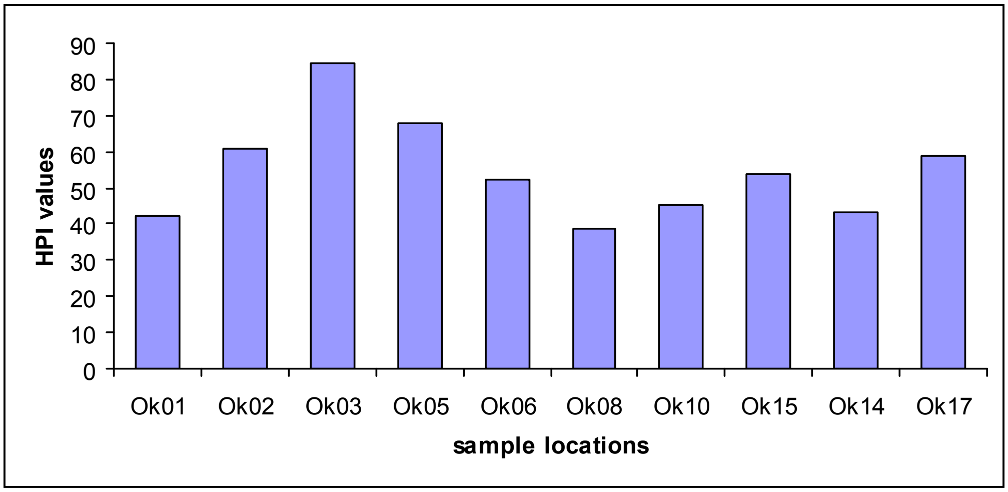

Fig. 6. A plot of HPI values against sample points

The MI value of 460.46 clearly indicates contamination of water, with Ni, Cd and Pb as the most impacted heavy metals on water (Table 8 and Fig. 7). With respect to MI pollution according to [9, 21], Ni, Cd, Pb and Fe have seriously affected the water while the water was pure with respect to Zn and Cu (Table 9).

Table 8. The Mean MI of Okaba water

Heavy metals (mg/l)	Ci	MAC	MI
Fe	2.87	0.30	9.57
Cu	0.11	1.00	0.11
Zn	0.85	3.00	0.28
Pb	0.54	0.01	54.00
Ni	4.13	0.02	206.50
Cd	0.57	0.003	190.00
	∑ MI= 460.46		

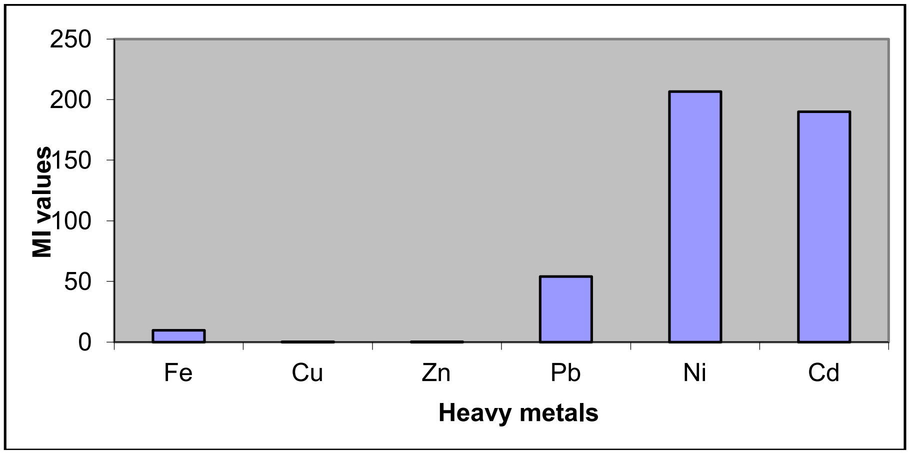

Fig. 7. A plot of MI values versus the heavy metals

Table 9. Water quality classification using MI [9,21]

MI	Characteristics	Class
< 0.3	Very pure	I
0.3-1.0	Pure	II
1.0-2.0	Slightly affected	III
2.0-4.0	Moderately affected	IV
4.0-6.0	Strongly affected	V
>6.0	Seriously affected	VI

4. DISCUSSION

The major cations and heavy metal trends in Okaba dry season water were: K (9.81) > Ca (6.42) > Na (4.38) > Mg (0.13) and Ni (4.13) > Fe (2.87) > Zn (0.85) > Cd (0.57) > Pb (0.54) > Cu (0.11). The average pH of the water was 6.37. This is attributable to the presence of pyrite, sulphide minerals which are reactive to atmospheric oxygen and water under humid conditions. This acidity signifies susceptibility to leaching out by surface and infiltrating waters, dilution and solubility [15]. Low water pH also favours the residence of heavy metals in solution leading to an amplification of water contamination [15,11].

The two groups of correlations emerged at both levels of significant. At $P<0.01$, TDS-EC-Na-Ca-Cl-NO_3-SO_4-Fe-pH-Pb revealed very strong relations. At $P<0.05$, K-Ca-Ec-TDS-Cl-pH-NO_3-SO_4-Pb-Ni-Na-Cd also showed moderate to strong correlations. These strong correlations indicate same source of origin for the variables. While group one was dominated by natural mineralization and agricultural sources, with mining effects minimal, the second group was dominantly mining and agricultural sources of pollution.

The R-mode factor analysis yielded three factors. Factors one and two consists of Ni, Fe, Pb and Zn, Cd suggests anthropogenic source as the dominant source while factor three may be related to natural processes. The R-mode cluster extracted two clusters. Cluster one suggests a mixture of natural and anthropogenic sources while cluster two implies anthropogenic input [16,17].

Both Q-mode factor and cluster analyses were performed. Four factors and three clusters were extracted in the Q-mode analyses. In factor one, only OK17 was directly influenced while in factor two, the locations may have been influenced by mining activities. In factor three, (OK08) and in factor four, (OK02) were also not directly influenced by coal mining. This cluster indicates that all locations in cluster one were not directly linked, while in cluster two, OK01, OK06 and OK05 may have been influenced to various degrees. In cluster three, OK08 was not influenced while OK03 may have been influenced.

The anthropogenic factor (AF) revealed this trend: Cd > Zn > Ni > Fe > Pb > Cu. Dissolved Fe was lower than expected since Fe may have been oxidized, hydrolyzed and precipitated rapidly. This explains the yellow-red, ferric precipitates observed in the stream channels. According to [18], if AF > 1 for a particular metal, it means contamination exists; otherwise; if AF is ≤ 1, there is no metal enrichment of anthropogenic origin. From the AF values, metal contamination exists across all sample points. While lower acidities of water allows heavy metals such as Cd, Zn, Ni, Fe, Pb and Cu to enter into solution phase and be transported from the water, the total heavy metal content was very high in the case of Cd, Zn and Ni, high for Fe and lower for Cu and Pb as these metals appear associated with sulphides in this type of mine [18]. Heavy metals are highly mobilized under moderate acid/acidic conditions. The potential for acid mine drainage and the release of toxic heavy metals from mine wastes exists throughout Okaba area. This poses major environmental hazard to fresh water resources and has enhanced the levels of heavy metals. The implication of this is increasing bioavailability, bioaccumulation and toxicity which may result to serious health and environmental consequences [19].

The aggregate HPI values showed that it was below the critical 100 value. Location by location HPI values were 84.49 (OK03), 67.66 (OK05), 60.59 (OK02) and 58.72 (OK17). These are clearly relatively high HPI values and are traceable to areas around the mines, abandoned mine ponds and overburden. The MI value of 460.46 indicates outright contamination of the water. Based on the MI classification of [9, 21], Ni, Cd, Pb and Fe have seriously affected the water while Cu and Zn were very pure with respect to their contamination status. These heavy metals could easily be associated with coal in form of sulphides and fossil fuels used. Similar work by [22] revealed dangerous heavy metals such as Pb, Cd, Fe, Zn, and Ni in Enugu coal mine area in Nigeria. According to [23], the analysis of Nigerian coal showed the presence of heavy metals such as Cd, Cu, Cr, Ni, Zn, Pb, Fe and V. Elsewhere, [24] investigated the distribution of heavy metals in coal and revealed that As, Co, Ni, Cr, Pb, Zn and Cd were present.

5. CONCLUSION

Both heavy metal pollution and metal indices were used to aggregate the composite effects of heavy metals in Okaba water. While the HPI values showed no outright contamination of the water, the MI values showed that the water was seriously affected with these heavy metals. While Cu and Zn were very pure with respect to their contamination status, Ni, Cd, Pb and Fe have seriously affected the water.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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