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The Effect of Heavy Metal Concentration on the Soil of Odagbo Area, Kogi State Nigeria

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ABSTRACT

The study is aimed at evaluating the effect of coal mining on the soil of Odagbo area, Kogi State, Nigeria. Twenty-eight (28) soil samples were collected each in the wet and dry seasons where twenty-one of the samples were from a mining site while seven samples were from the control site at depths of 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 m respectively. The heavy metal concentration of the samples were determined using Flame Atomic Absorption Spectrophotometer (FAAS). Standard pollution indices such as I-geo and Pollution Indices were deployed to assess the level of heavy metal contamination in the soil. The result showed the order of dominance of the heavy metals monitored as Fe>Ni>Zn>Mn>Cr>Pb>Cd>Cu>Co. The mean concentration levels of all the heavy metals were lower than mean background values except Cu and Fe during the dry season. The results of the study revealed that the soil of the Odagbo is polluted by all the tested heavy metals based on the calculated PI and I-geo for the heavy metals. The PI was mostly $1 \leq$ PI ≤ 2(moderate pollution) for all the depths except for the elevated case of copper thus indicating practically low to moderate contamination. The I-geo was mostly less than 0 at all the depths except for the elevated cases of copper, iron and zinc during the dry season and Copper and Iron during the wet season thus indicating uncontaminated condition. In conclusion, the data obtained from the study demonstrated that the distribution of metal concentration in the study area when compared to the control site was largely influenced by anthropogenic activities particular from the coal mining site.

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1. Introduction

The presence of heavy metals has no doubt been found to abound in several climes [1], and these climes include soil, water, plants, air particulates etc. They can sometimes be deposited through certain kinds of natural or anthropogenic activities (coal mining) as practiced in the area under study. The actions of extraction and processing of raw materials for industrial and consumer consumption have immensely contributed to heavy metal presence in the soil. More worrisome is the fact that developing countries of the world pay little or no attention to the enormous effects of heavy metal contamination and also their research efforts in monitoring the environment is not encouraging at all [2]. To buttress this, the coal mining site located at Okaba district of Kogi State Nigeria was in operation for a very long time before been sealed up by the Federal Government of Nigeria, after which the activities of illegal miners progressed with no confrontation from the relevant authorities [3]. These unconstrained actions further deteriorated and contaminated the soil. Coal mining on an industrial scale is relatively low in developing countries such as Nigeria, even at that, our soils have become exposed to heavy metal contamination [4]. Heavy metal presence in the soil is majorly momentous because of the non-degradable state of the metals and their ability to collocate over a period of time [5]. When heavy metals are accumulated in the soil over a period, it is likely to pose threat to the quality of the soils, plants, natural water and even human health [6].

The processes of coal mining are known to transfer several heavy metals to the soil, leading to heavy metal presence in mining sites [7–9]. This impact can be directly through the series of activities such as survey exploration, site development, ore extraction, mineral dressing, smelting, refining/metallurgy, transportation, post mining activities and indirectly through the impact of the degradation on the socio-cultural development of communities [10]. Heavy metal concentrations are usually compared with references and standards and the degrees of soil contamination assessed using relevant indices [11]. The research was therefore carried out to evaluate the impact of heavy metals resulting from illegal coal mining activities on the soils within and around Odagbo coal mining site.

2. Methodology

2.1. Study area

The coal mining site is actually located at Odagbo, which is a sub-district in Okaba town of Kogi State. Okaba district lies some 16 km NE of Ankpa town, headquarters of Ankpa Local Government Area, Kogi State. The study area is located between latitudes 7^o 20′ – 7^o 43′ N and longitudes 7^o 22′ – 7^o 52′ E (Figure 1). The area is situated within the tropical frontier. The total annual rainfall ranges from 100 - 200 cm, spreading over 6 - 8 months [3]. De Swart and Casey [12] indicated that coal obtained from the lower parts of the earth at Odagbo town contains high proportion of shale and sandy shale. False-bedded sandstones occurs as part of the rock formation materials that is seen on the surface of the soils in the study area. The soils are observed to exhibit clayey and muddy characteristics which makes traversing of the environ difficult especially when it rains. [13]. The activities of mining in Odagbo community got cracking in the mid-1960's. It commenced with the primary purpose of exploration, though a little amount was required for household energy generation and cooking in the community [14]. The exploration of coal within the community was done through the use of heavy equipment as it created disturbance of the overburden layer of the earth. The adverse effect of the mining activities resulted in deforestation and other forms of pollution. The coal from Odagbo mining site was investigated to have chemical composition as given below:

Table 1
Chemical composition of coal from Odagbo coal mine.

Oxide	Percentage Composition
Silica or Silicon Oxide (SiO_2)	14.77
Aluminum Silicon Oxide (Al_2O_3)	45.53
Sulfur trioxide (SO_3)	0.67
Calcium Oxide (CaO)	1.78
Magnesium Oxide (MgO)	2.50
Potassium Oxide (K_2O)	2.34
Soduim Oxide (Na_2O)	0.65
Ferric Oxide (Fe_2O_3)	9.43
Loss on Ignition (LOI)	27.33

Source: Ekwule et al. [3]

Other properties of Odagbo coal are, Inherent moisture (14.9 %), Ash content (5.3 %), Volatile matter (38.7 %), Fixed carbon (41.1 %), Carbon (62.16 %), Hydrogen (5.87 %), Nitrogen (1.37 %), Total sulphur (1.07 %), Oxygen (9.34 %) and Calorific value (MJ/kg) [15].

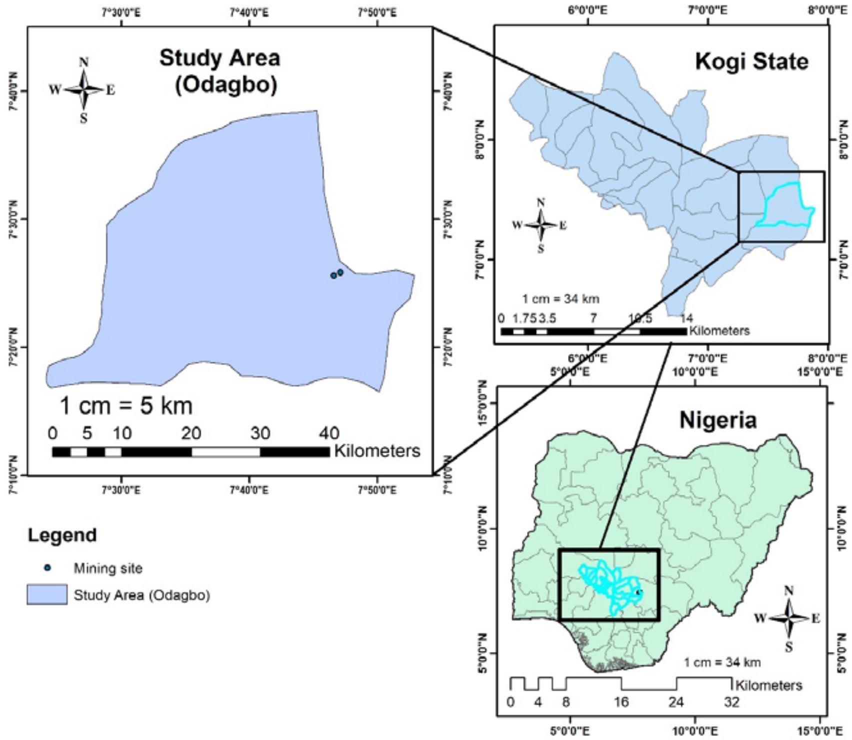

Fig. 1 Location of the Mining Site at Odagbo, Okaba District.

2.2. Soil sample collection, preparation, and analysis

Twenty-eight (28) soil samples were randomly collected per season from the coal mining site and the control site at depths of 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 m respectively, to determine the composition and possible coal waste effects on the soil. The samples were stored in plastic bags, air dried in laboratory condition, hand crushed, and sieved through a sieve with a 2 mm size opening. The soil samples were then macerated in a mixture of 2.5 ml of 65% HNO_3 Suprapur and 7.5 ml of 37% HCl Suprapur and the mixture heated gently at low heat on a hot plate for about 2 hrs according to EPA method 3050B [16]. After digestion, the samples were filtered and the volumes adjusted to 100 ml with deionized water. The total content of heavy metals Cd, Cr, Cu, Mn, Ni, Pb, Fe, Zn, and Co was determined in triplicate using flame Atomic Absorption Spectrophotometer (AA6500).

2.3. Data handling and statistical analysis

In order to enhance the understanding and interpretation of the results obtained from the laboratory experiment, the results were subjected to statistical analysis. Microsoft excel, SPSS version 20, Graphpad prism 8 were deployed in the analysis of the results. The mean, standard deviation (SD), variance, % coefficient of variation and correlation were obtained. Pollution index and geo-accumulation index were used to express the risk assessment of heavy metals in the study area.

2.3.1. Pollution index

the ratio of the mean concentration of each heavy metal detected to the baseline or background concentration [17], and is expressed;

$$\mathrm{PI} = \frac{\mathrm{C_i}}{\mathrm{S_i}} \tag{1}$$

Where C_i is the average concentration of individual metal in the dumpsite and S_i is the baseline concentration. PI values < 1 indicate low level of pollution, $1 \leq \mathrm{PI} \leq 2$ indicate moderate level of pollution, $2 \leq \mathrm{PI} \leq 5$ indicate high level of pollution, while $\mathrm{PI} \geq 5$ indicate extreme pollution level.

2.3.2. Geo-accumulation index

This index is widely used to assess sediment contamination [18]. The geo-accumulation index value was calculated thus:

$$\mathrm{I_{geo}} = \mathrm{Log_2}\left(\frac{\mathrm{C_i}}{1.5\mathrm{S_i}}\right) \tag{2}$$

$I_{geo} < 0$ indicates pristine or uncontaminated state, $0 \leq I_{geo} \leq 1$ indicates uncontaminated to moderately contaminated state, $1 \leq I_{geo} \leq 2$ indicates moderately contaminated state, $2 \leq I_{geo} \leq 3$ indicates moderately to heavily contaminated state, $3 \leq I_{geo} \leq 4$ indicates heavily contaminated state, $4 \leq I_{geo} \leq 5$ indicates heavily to extremely contaminated state, and $I_{geo} > 5$ indicates extremely contaminated state.

3. Results and discussion

The result presented in Table 2 is the descriptive statistics of seasonal heavy metal concentration. It was revealed that Iron (Fe) is the most predominant heavy metal within the study area with an average value of 75 mg/kg from both seasons (i.e. Wet and Dry seasons). Nine heavy metals were tested for within the vicinity of the coal mining site and their order of abundance is Fe>Ni>Zn>Mn>Cr>Pb>Cd>Cu>Co. Chromium (Cr) and cobalt (Co) were not detected in the wet season, but in the dry season, only cobalt was not detected. The order of abundance of heavy metals as affected by seasonal variation is shown thus: Fe>Ni>Mn>Zn>Cd>Cu>Pb>Cr>Co (rainy season) and Fe>Ni>Zn>Cr>Mn>Pb>Cu>Cd>Co (dry season). A higher amount of metallic contamination was observed when compared with the soils collected from the control site. This is an indication that the anthropogenic activity prevalent in that vicinity have contributed to the levels of elemental presence in that area [19]. The resultant effect of the mining activities in the study area has impacted negatively on the soil by leaving deposits of heavy metals such as Pb and Cd. From observation, sparse vegetation leaving only metal-tolerant strains grow was observed around the mining site. It was also observed that the quality of the atmosphere of the area seem to be affected. According to Tchounwon et al. [20], the concentration of heavy metals are hazardous to human life depending on the mode of exposure, dose, chemical constituent, and sometimes the gender, age difference, genetic configuration and alimentation condition of the exposed individual.

Table 2
Descriptive Statistics of Seasonal Heavy Metal Concentration.

Heavy metal	Rainy season						Dry Season					
	Mean	**S.D.**	**Max.**	**Min.**	**Variance**	**% CV**	**Mean**	**S.D.**	**Max.**	**Min.**	**Variance**	**% CV**
Copper	0.188	0.200	0.422	0.0674	0.041	1.064	0.067	0.242	0.0948	0.050	0.001	3.612
Chromium	0.000	0.000	0.000	0.000	0.000	0.000	0.469	0.274	0.7113	0.172	0.075	0.584
Manganese	0.560	0.106	0.681	0.4805	0.011	0.189	0.399	0.508	0.443	0.344	0.003	1.273
Cadmium	0.230	0.001	0.024	0.0208	0.000	0.004	0.004	0.004	0.010	0.000	0.000	1.000
Cobalt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Iron	36.23	5.50	41.82	30.80	30.35	0.15	114.72	41.813	159.96	77.49	1748.37	0.364
Lead	0.10	0.176	0.305	0.000	0.031	1.743	0.211	0.115	0.3424	0.128	0.013	0.545
Zinc	0.412	1.197	0.531	0.292	0.140	2.905	0.815	0.389	1.246	0.488	0.151	0.477
Nickel	0.66	0.106	0.188	0.000	0.110	0.161	0.894	0.694	0.160	0.021	0.005	0.776

The presences of heavy metals in the soil depend on a number of factors such as soil pH, Matrix, and geochemical nature of the soil as well as the anthropogenic factors [21]. The high amount of iron (Fe) observed in the soil samples may have been the leached proponent from the anthropogenic activity of mining within the vicinity. The abundance of iron (Fe) above other investigated heavy metals indicates that the soils around the site can support plant growth. This is evident in the study conducted by Singh and Kalamdhad [22] where heavy metals such as Fe, Zn and Ca were recommended for daily medicinal and dietary allowances due to their bio-importance to man. But due to the presence of other heavy metals such as Pb and Cd sparse plant growth is eminent as an indication of heavy metal presence. Research conducted on the subject matter by other researchers have also confirmed the predominance of Iron (Fe) amongst other heavy metals. Akpoveta et al. [23] obtained the abundance of heavy metals as Fe > Zn > Cr > Cu > Pb > Co > Ni > Cd while authors like Mnolawa et al. [24], Baba et al. [25] and Salmamanzadeh et al. [26] obtained Fe > Al > Ni > Mn > Pb > Zn > Cu > Co, Fe > Mn > Pb > Cr > Zn > Cu and Fe > Mn > Zn > Pb > Cu > Ni > Cr > Cd > Li respectively.

3.1. Correlation of seasonal heavy metal contamination

The association and linear relationships between the metallic contaminants as well as their possible source of occurrence were determined using the Pearson's correlation (PC) matrix and presented in Table 3. The result revealed a very strong positive correlation between Mn and Cu (r = 0.985, P > 0.05), Cd and Mn (r = 0.734, P > 0.05), Fe and Cu (r = 0.869, P > 0.05), Zn and Cu (r = 0.871, P = 0.05), Ni and Cu (r = 0.998, P > 0.05) all through the rainy season. A very positive correlation was also noticed between Cd and Mn (r = 0.743, P = 0.05), Fe and Mn (r = 0.772, P =0.05), Zn and Mn (r = 0.942, P = 0.05), Ni and Mn (r = 0.973, P = 0.05), while the correlation between Pb and Mn was a moderately negative correlation with r = - 0.655 which is greater than P = 0.05. Also, Zn and Cd, Ni and Fe, Ni and Zn all had strong positive correlations with r values 0.925, 0.898 and 0.839 respectively. During the dry season, the results revealed positive correlation between Cu and Cr (r = 0.838, P = 0.05), Cu and Mn (r =0.086, P > 0.05), Pb and Cu (r = 0.925, P > 0.05), Mn and Fe (r = 0.929, P > 0.05) and Mn and Zn (r = 0.903, P > 0.05). Other positive correlations were Zn and Cd (r = 0.810, P >0.05), Ni and Cd (r = 0.988, p > 0.05) Pb and Fe (r = 0.091, P > 0.05), and finally Zn and Fe (r = 0.998, P >0.05).

3.2. Seasonal Variation of geo-accumulation ($\mathbf{I_{geo}}$) and pollution indices (PI)

The evaluation of the presence of heavy metals in an environment could be ascertained by determining the geo-accumulation and pollution indices. In the soil collected from the mine site, it was observed that the soil was seriously polluted with copper. During the dry season, the mean pollution index and geo-accumulation index for the soil sample at the various sampled depths as presented in Figures 2 and 3 apparently placed copper on a maximal pollution level of contamination (PI > 5, $I_{geo} > 5$) category. In the wet season, copper was found to be highly contaminated and moderately contaminated with respect to pollution index and geo-accumulation index respectively. The implication of copper pollution is that it poses the risk of anaemia, liver and kidney damage, and stomach intestinal irritations [27]. It is ingested indirectly when it finds its way into human food chain causing negative effects to human health. Nickel recorded low concentration with no trace of it found in the control soil during the dry season and all the recorded concentrations at the given sampled depths fell within World Health Organization (WHO) permissible limit as observed by [28]. However, during the wet season, the metal recorded slightly higher concentration. Aside the concentrations at the depth of 3.0 m, every other measured concentration fell below what was obtained from the control site. This places nickel as a trace element in the sampled area. During the dry and wet seasons, the

Pollution and Geo-accumulation indices for the soil at the sampled depths placed nickel at low contamination and uncontaminated categories respectively.

Table 3
Correlation of Seasonal Heavy Metal Contamination

	Rainy season						
	Cu	**Mn**	**Cd**	**Fe**	**Pb**	**Zn**	**Ni**
Cu	1						
Mn	0.985	1					
Cd	0.618	0.743	1				
Fe	0.869	0.772	0.147	1			
Pb	-0.516	-0.655	-0.992	-0.025	1		
Zn	0.871	0.942	0.925	0.513	-0.871	1	
Ni	0.998	0.973	0.568	0.898	-0.463	0.839	1

	Dry season							
	Cu	**Cr**	**Mn**	**Cd**	**Fe**	**Pb**	**Zn**	**Ni**
Cu	1							
Cr	0.838	1						
Mn	0.086	-0.471	1					
Cd	-0.832	-1.000	0.480	1				
Fe	-0.289	-0.764	0.929	0.771	1			
Pb	0.927	0.573	0.453	-0.564	0.091	1		
Zn	-0.349	-0.803	0.903	0.810	0.998	0.027	1	
Ni	-0.907	-0.990	0.341	0.988	0.665	-0.683	0.711	1

Manganese and Cadmium measured relatively low concentrations in both the mined and control sites all through the sample seasons. The mean pollution index and geo-accumulation index for the soil sample at 0 - 3.0 m as presented in Figures 2 and 3 during the dry and wet seasons placed both metals at low contamination and uncontaminated categories. Cobalt and chromium were not detected at any depth in the sampled mined and control sites. However, while cobalt maintained zero values during the wet season, chromium was present at all the sampled depths. This placed chromium as a potential soil contaminant during the wet season. During the dry season the pollution index and geo-accumulation index placed cobalt and chromium at low contamination and uncontaminated categories. While both metals maintained their low contamination and uncontaminated categories during the wet season.

Iron recorded high concentrations at both the mined and control sites. The mean pollution index and geo-accumulation index for the soil sample at 0 - 3.0m as presented in Figures 2 and 3 during the dry season placed iron at moderately contamination and uncontaminated to moderately contaminated categories. However, during the wet season, iron was placed at high contamination and strongly to very strongly contaminated categories. Lead recorded concentrations at the given sampled depths within limit as also observed by Chiroma et al. [28].

This placed lead as a trace element in the sampled area during the dry season. However, the metal recorded slightly elevated concentrations. With the exception of the values obtained from 0 and 1.5 m, every other recorded value was below the control site concentration. The mean pollution index and geo-accumulation index for the soil sample at 0 - 3.0 m summarized in Figures 2 and 3 during the dry season placed lead at low contamination and uncontaminated to moderately contaminated categories. In the wet season, lead was placed at low contamination and Uncontaminated to moderately contaminated categories. The mean pollution index and geo-accumulation index for the soil sample at 0 - 3.0 m during the dry season placed zinc at low contamination and moderately contaminated categories. While in the wet season, zinc was placed at moderate contamination and moderately contaminated categories.

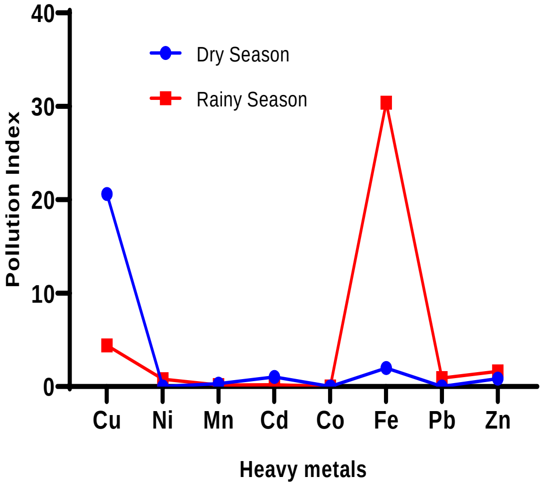

Fig. 2. Seasonal variation of Pollution index.

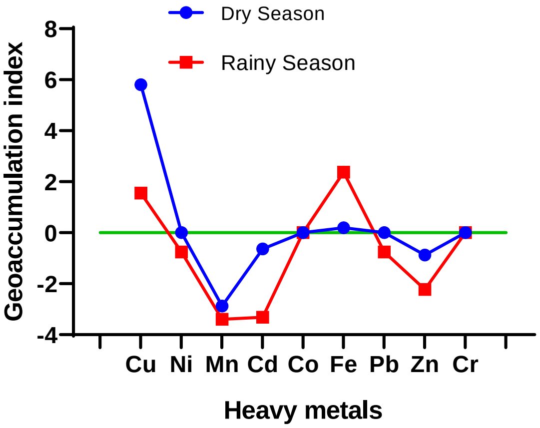

Fig. 3. Seasonal variation of Geo-accumulation index.

4. Conclusion

It was obtained that the soil within the mining area was polluted by the entire heavy metals tested for. The Data obtained demonstrated that the distribution of metal concentration in the study area when compared to the control site may have come about as a result of anthropogenic influences due to coal mining activities. The PI was mostly less than 1and below 2 ($1 \leq PI \leq 2$) for all the depths except for copper thus indicating generally low to moderately contaminated condition. The $I_{geo}$was mostly less than 0 at all the depths except for copper, iron and zinc during the dry season and copper and iron during the wet season thus indicating generally uncontaminated condition.

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Conflict of interest

The authors declare that there was no conflict of interest.

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