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Assessment of Some Potentially Toxic Inorganic Contaminants in Soil of the Obi Coalfield, Middle Benue Trough, Nigeria

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Abstract: The study area has occurrences of coal, limestone and sulphide minerals, with ubiquitous artisanal mining activities. This research assesses heavy metal accumulation in soil of the area, using pollution indices such as geo-accumulation index (I_{geo}), enrichment factor (EF), contamination factor (CF) and pollution load index (PLI). A total of 13 soil samples were analyzed for As, Ba, Co, Cr, Cu, Mo, Ni, Pb, Sc, Sr and Zn, using ICP-OES geochemical technique. Results show that soil in the area are extremely polluted by Ni, Cr and Zn, having I_{geo} values of 5.88, 3.56 and 2.43 respectively, going by geo-accumulation index. I_{geo} levels of Pb, Cr and Ba indicate moderate to no pollution. Enrichment factor analysis, again show that Ni and Cr have EF of 147.17 and 79.66 respectively, indicating the two are extremely severely enriched in the environment, while Zn, Co and Sr with EF between 6 and 15, indicate moderate enrichment. Cu, Mo and As levels in soil remain very low, indicating the media are not contaminated by these elements. Most of the locations showed a PLI less than one (1) in the ranking, indicating no serious pollution occurring. The high I_{geo} and EF values recorded for some heavy metals are related to mining, mineral processing as well as the sub-standard practice dumping of mine wastes and tailings, in addition to natural weathering, releasing these elements into the environment. The nature and source of enrichment of these elements can therefore be said to be anthropogenic. Pathways of exposure of the human population to the heavy metals were found to be through dust inhalation, from the mouth through the ingestion of food and water as well as through the skin, resulting from the close association of the population to the land/soil due to farming and water used for drinking and other domestic uses. These can result to varied human health risks if the population is continually exposed. High doses of Ni and Cr can cause lung, nasal and possible stomach cancer may develop. Also, elements such as Pb and As, are known to be toxic even at very low exposure, also, with carcinogenic effects. It is recommended here that the quality of drinking and irrigation water as well as some crops grown from the area be investigated and quality determined, with regards to the levels of heavy metals in such media, thereby determining whether the population is safe or not. This should include massive awareness campaign for the miners and the mining communities, so as to forestall any negative eventuality.

Keywords: Environment**,** Heavy metals, Contamination, Health

1. Introduction

Environmental issues such as soil contamination have become a serious concern in many advanced societies with high industrial activities and high population density as well as developing countries where the population is mostly rural and land is intensely used for subsistent agricultural activities. Soil is regarded as polluted when trace metals are present above normal abundances or when other alterations have been made to its natural environment [1],[2]. The presence of the different mineral occurrences in the area and the subsequent natural and human activities, have generally affected the baseline levels of the inorganic contaminants, leading to the very high concentration (of elements such as Ni, Zn, Cr) recorded in the study area.

Soil pollution is usually caused by accidental releases of chemicals (pesticides, etc) or the indiscriminate/improper disposal of hazardous mine wastes and tailings, as well as natural processes trough weathering activities, practically releasing potentially toxic trace elements into agricultural soils, sediments and natural waters, coupled with inadequate environmental management practices. These chemical elements in the terrestrial environment may become absorbed by plants and subsequently into human body through the food chain, thereby posing a significant risk to the environment, human and animal health [3]-[8].

It has been established that trace elements such as Cu, Zn, I and Se are essential for normal plant and human growth and well-being but are however toxic in high concentrations. Also, concentrations of some heavy metals such as Pb, As and Cd above permissible limits are known to be toxic and deleterious to living organisms. Soluble metal compounds and metals held in metal exchange complexes are considered to be available for vegetation uptake and the bio-availability itself is influenced by physico-chemical characteristics such as pH, temperature, redox potential, cation-exchange potential of the solid phase, competition with other metal ions, composition and quality of the soil solution [9].

This study has been necessitated by the many years of exposure of the rural population living in the mining areas of Obi and also in view of the dearth of information (data) on trace elements levels in soil, sediments and water as the people continue to depend on these basic life support media for their survival. The main objective of this study is therefore to assess the level of soil contamination (of elements such as Se, I, Pb, As, Zn, Cd, and Cr) and to identify possible sources of contamination in the area.

It is clear from the study that the proliferation of mining activities characterized by indiscriminate dumping of mine

wastes, tailings and other foreign materials, coupled with the intense weathering in the area (which predisposes the minerals hosting the trace elements), have contributed to the re-mobilization and re-distribution of the heavy metals into the surrounding soil and sediments, suggesting the anthropogenic source of the heavy metals.

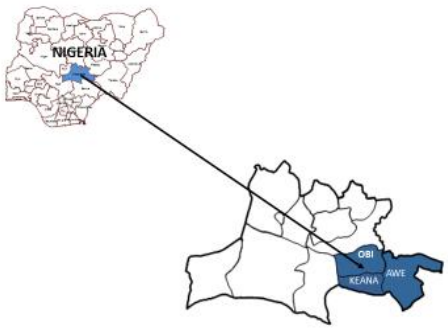

Fig. 1: Map of Nigeria showing the study area

1.2 The study area, geology and mineral occurrences

The Obi area is located in the mineralized zone of the Benue trough and known to have widespread mineral occurrences such as limestone, lead-zinc and baryte as well as coal, with artisanal mining activities which have occurred in the area for more than three decades. This area is located between Longitudes 8° 45′ 00″E and 9° 00′ 00″E and Latitudes 8° 15′ 00″ N and 8° 25′ 00″ N in the topographical degree sheet 231, Lafia southeast (Fig. 2).

The mineralization is believed to be associated with the tectonic rifting that led to the emplacement of the Benue Trough, connected with the stress that developed following the continental separation of Africa and the South American plates [10]-[12].

The Benue Trough is geologically divided into the upper, middle and lower depositional sub basins, stretching from the Gombe area in the north to the Abakaliki area in the south, towards the Niger Delta. The Obi coalfield is located in the middle and is part of a long narrow stretch of sedimentary basin, extending from the Gulf of Guinea upwards to the northeast. Stratigraphically, the area is made up of five rock units which are essentially continental and marine sediments. These include the Asu River group of sediments (sandstone-shale series) which are the oldest, the Awe formation (sandstone-shale-siltstone), the cretaceous Keana formation (sandstones), EzeAku formation (sandstone-shale-mudstone) and Awgu formation as the youngest is entirely shale. The major structural feature in the area is the Keana anticlinorium with Awe and Keana areas located along the east and western limbs of the anticline.

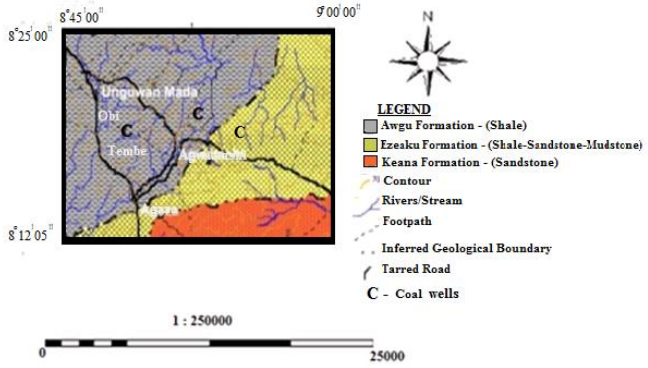

Fig. 2: Geological map of the Obi Coalfield

2. Materials and methods

Thirteen soil samples were collected from mining areas and cultivated farmlands (sample locations shown in Fig 2) in clean, sterilized polythene sample bags, zipped and well labeled according to the location, date of collection for easy referencing as well as adequate precautionary measures taken during the collection, packing, transportation and storage, to avoid possible contamination.

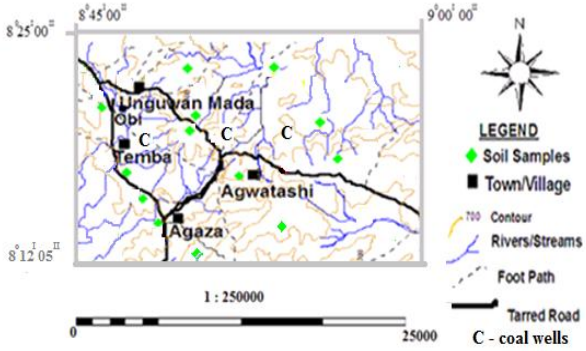

Fig. 3: Map of the area showing sample locations

In the geochemical laboratory, the soil samples were pulverized and made to pass through a 0.067mm mesh size, after which a 100 mg of the now powdered soil sample was weighed into a teflon crucible and then dissolved in aqua regia after 6 hours of heating the solution to dryness on a hot plate (250°C). The crucible containing the sample is then allowed to cool, 2 ml of 2 M HCl is added and then topped with de-ionized water to about ¾ full. It is re-heated on the hot plate and again allowed to cool. The content is diluted to 100 ml and filtered using size 42, 125 mm diameter, ashless filter paper into a flat bottom flask ready to be run on the analytical equipment. The instrument was calibrated prior to the introduction of sample by measuring in-house standards and blank solutions, the results turn-out have an accuracy range of ± 2–5 % depending on the number of standards and concentrations used.

Samples were analyzed using the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) at the Geology Department of the University of Jos. This technique was chosen because of its numerous advantages in multi-media tolerance, multi element and low detection limits, its precision and accuracy, among others. A total of 17 elements were analyzed and include As, Cd, Co, Cr, Cu, Mo, Ni, Pb, I, Se, Sr, Ba, K, Na, La, Zn, and SC.

2.1 Evaluation of analytical data

The assessment of the levels of enrichment or contamination of the trace elements was carried out using standard pollution measurement indices such as the index of

geo-accumulation (I_{geo}), enrichment factor (EF), contamination factor (CF) and the pollution load index (PLI).

2.1.1 Geo-accumulation index (I_{geo})

The geo-accumulation index is generally used to determine the anthropogenic contamination in soils [13],[14] and corroborated by other prominent workers[15]-[17]. This index allows us to evaluate the contamination levels by comparing present concentrations with background levels. The I_{geo} is expressed using the following Muller equation:

$$I_{geo} = \log_2 \left(\frac{C_n}{1.5B_n} \right) \quad (1)$$

Where C_n is the measured concentration of the given heavy metal examined in the soil or sediment, B_n is the geochemical background value of the element, 1.5 is incorporated in the relationship to account for possible variation in background data (the background matrix correction factor) owing to lithogenic effects, according to [16].

The geo-accumulation index, consist of seven grades (0 to 6) based on the increasing numericalvalue of the index and ranges from unpolluted to extremely polluted. The standard I_{geo} values are presented below.

I_{geo} Value	Grade	Classification
≤0	0	Unpolluted
0-1	1	Unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	Moderately to strongly polluted
3-4	4	Strongly polluted
4-5	5	Strongly polluted to extremely polluted
>6	6	Extremely polluted

2.1.2 Enrichment factor (EF)

Enrichment Factor (EF) is another parameter used to evaluate the level of soil contamination and seeks to know the possible natural or anthropogenic input and impact in soils and sediments. Enrichment factor is a useful indicator reflecting the condition of general environmental contamination. This helps to identify anomalous metal contamination and geochemical normalization of the heavy metal to an immobile element such as Al, Fe and Si. EF is usually used to compare with and also to verify/certify the geo-accumulation status of geologic materials such as soil. In this assessment, aluminum (Al) was used as the immobile element to differentiate between natural and anthropogenic components and is associated with crustal rocks. Metal to aluminum ratios are widely adopted, presumably because the concentration of Al in weathering products and their parent material are generally comparable. Al is also the normalizing element assumed not to be consequentially enriched owing to local contamination. Baseline values were adopted from [18].

EF of a heavy metal in sediments can be calculated using the following equation;

$$EF = \frac{\left(\frac{M}{Al} \right)_{Sample}}{\left(\frac{M}{Al} \right)_{Background\ (crust)}} \quad (2)$$

Where EF is the enrichment factor, M_{sample} and $M_{background}$ are the concentrations of the investigated elements in the sample and crustal materials (background) while Al_{sample} and $Al_{background}$ are the concentrations of Al in the sample and crustal abundance respectively.

According to [19], EF values lower than and around 1.0 indicates that the element in the sediment originated predominantly from the crustal/background material and /or weathering process. EF values greater than 1.0 displays anthropogenic origin of the element [20].

According to [21];

EF = < 3 indicates minor or minimal enrichment,
EF = 3-5 indicates moderate enrichment,
EF = 5-10 indicates moderately severe enrichment,
EF = 10-25 indicates severe enrichment,
EF = 25-50 indicates very severe enrichment,
EF > 50 indicates extremely severe enrichment.

As the EF values increases, the contribution of the anthropogenic origins also increases [22].

2.1.3 Pollution load index (PLI)

Also used in the assessment of soil contamination, were Pollution Load Index (PLI) and Contamination Factor (CF). PLI is obtained as a product of the measured contamination factors of the different trace elements, while CF itself is the quotient obtained by dividing the concentration of the elements. Generally, the PLI is calculated by obtaining the n-root from the n-CFs measured.

The pollution load index and contamination factor are expressed, as developed by [23], by the following equation:

$$CF = C_{metal} / C_{background\ value} \quad (3)$$

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \ldots \times CFn} \quad (4)$$

Where;

CF = contamination factor

n = number of metals

C_{metal} = metal concentration in polluted sediments

$C_{background}$ = background value of the metal

According to the equation, PLI value of > 1 is polluted whereas PLI value of < 1 indicates no pollution.

Contamination factor and level of contamination advanced initially by [24] and modified by several other workers and universally used, is shown below;

Contamination Factor		Level of Contamination
$Cf < 1$	=	Low contamination
$1 \leq Cf < 3$	=	Moderate contamination
$3 \geq Cf < 6$	=	Considerable contamination
$Cf > 6$	=	Very high contamination

3. Results and discussion

Average concentrations or background values used in the various equations for geo-accumulation index (I_{geo}), enrichment factor (EF), contamination factor (CF) and pollution load index (PLI) referred here are taken from [18]. These values are obtained from literature as average crustal abundance or determined from geologically similar areas. Summary of the I_{geo}, EF, CF and PLI of soil in the Obi area is shown in tables 2, 3 and 4.

3.1 Geo-accumulation index (I_{geo}):

Results of the geo-accumulation index using the Muller scale for I_{geo}, shows that nickel (Ni), chromium (Cr) and zinc (Zn) are the most accumulated heavy metals in the Obi soil, having I_{geo} value of 5.88, 3.56 and 2.43 respectively (Table 2, Figure 3), and an I_{geo} classes of 6, 4 and 3, indicating that the soil of the Obi area is extremely to strongly polluted, by Ni, Cr and Zn. The I_{geo} values for Co (0.61, Cu (0.52), As (0.49) and Pb (0.41) are in the I_{geo} class 0-1 indicating the soil of the area is unpolluted to moderately polluted with the elements while Ba, Sr and Mo are in the unpolluted levels, having I_{geo} class zero.

3.2 Enrichment Factor (EF):

Trace elements assessment using EF in the Obi soil shows that soil of the area is extremely severely enriched with nickel and chromium with EF values of 147.17 and 79.66 respectively. These EF values of >50, according to Chen et al., 2007 indicate the soil of the area is extremely enriched with the two elements. Zinc has an EF value of 14.97 in the soil, indicating, also, severe enrichment (not as extreme as Ni and Cr). The EF values of cobalt (Co) and strontium (Sr) were 8.12 and 6.68 respectively, falling within the EF=5-7, indicating the soil is moderately severely enriched with the two elements, while copper (Cu), lead (Pb) and arsenic (As) have EFs 4.25, 3.68 and 2,56, showing moderate enrichment. Barium (Ba) and molybdenum, on the other hand show EF values of less than 3 (Table 3), indicating minor or minimal enrichment in soil of the area.

3.3 Contamination factor (CF) and pollution load index (PLI):

Both CF and PLI values in soil of the Obi area are less than one (Table 4), except in locations 60 and 64. This indicates that the soil is generally not contaminated by these elements.

In summary, the assessment of the degree of accumulation of heavy metals such as Ni, Cr, Pb, Zn, As, etc, in soil of the Obi area, calculated using index of geo-accumulation(I_{geo}), enrichment factor (EF), contamination factor (CF) and pollution load index (PLI), shows that soil in the area are highly polluted by Ni, Cr and Zn, going by geo-accumulation index. Ni and Cr are also similarly severely enriched in the same media when EF is measured. In all indices measured, Mo, Co, Cu, Ba, Sr and Sc levels in soil remain at minimal or minor enrichment levels (compared with Ni, Cr and Zn), indicating the soil not contaminated by these elements. The contamination factor as well as the pollution load index of < 1 recorded for most locations (Table 4) indicate no overall contamination of the area, except when I_{geo} or EF are considered.

It is to be observed that iodine (I) was zero value for most (>70%) of the locations because the element was found below detection limit and therefore depleted in soil of the area. The elementhowever appear to be very high in four of the locations, for all indices measured. These locations were found to be cultivated farmlands which had fertilizers, probably containing iodine, applied in the sample locations.

The study area is characterized by occurrence of large coal deposit (with both industrialized and artisanal coal mining going on) in a geology dominated by shale, mudstone and sandstone with high clay and organic matter content. The high enrichment of Ni could be related to the fact that organic matter exhibits a strong ability to absorb Ni, thus it is likely to be concentrated in coal and coal-containing materials [25]. This concentration is apparently an effect of the precipitation of Ni as sulfides in sediments rich in organism and under reducing conditions [26].

Soil Cr is inherited from parent material and higher contents are generally found in soils derived from argillaceous sediments and mafic rocks. The sorption of Cr in soil is primarily associated with the clay content as well as with organic matter and to a lesser extent with Fe hydroxides[27],[28]. The concentration of some elements (such as Cu, Cr, Ni, Sr) in locations 60, 61 and 65 (Table 1) are very high due to the closeness of those locations to the main coal

wells from where coal seams are being mined, compared with lower concentrations from farmlands and other locations within the mining area.

The proliferation of mining activities characterized by indiscriminate dumping of mine wastes, tailings and other foreign materials, coupled with the intense weathering in the area (which predisposes the minerals hosting the trace elements), have contributed to the re-mobilization and re-distribution of the heavy metals into the surrounding soil and sediments. The main source of these trace elements is therefore anthropogenic.

The distribution of these elements by both natural and anthropogenic processes can result in deficiency or toxicity of these trace elements (such as Ni, Cr, Pb, As, Se) in the environment and can be detrimental to plants and animals. For example, when excess Ni and Cr compounds are inhaled these can cause lung, nasal and possible stomach cancer may develop [29]. Also, Pb, is known to be toxic even at low exposure levels and has acute and chronic effects on humans (neurological, renal gastrointestinal and reproductive effects), especially children and pregnant women who are very vulnerable in nature, particularly in the tropics.

Deficiencies in water or soil of iodine, selenium, and zinc, in the same vein, are attributable to iodine deficiency disorders - IDDs (such as goiter), human immune-deficiency syndrome and slow or stunted growth rate respectively [7].

Table 1: Concentrations (mg/kg) of Trace Elements in the Obi Soil

Location #	I	Mo	Zn	As	Pb	Co	Cr	Cu	Ba	Ni	Sr
57	0.00	0.00	3345	0.00	55.68	57.40	86.40	91.05	105.10	101.30	37.53
58	0.00	0.00	0.00	0.00	71.75	0.00	310.40	48.50	73.63	40.63	34.45
59	0.00	0.00	991.10	0.00	55.34	18.66	117.60	42.39	207.20	38.13	268.50
60	0.00	0.00	0.00	0.00	52.05	0.00	386.90	28.00	142.20	22.12	34.15
61	0.00	0.00	0.00	0.00	66.63	87.20	7708.00	34.51	72.36	6466.00	101.80
64	0.00	0.00	309.10	10.73	16.40	6.01	62.76	10.86	79.41	9.35	23.06
65	1119.00	0.00	0.00	10.78	93.96	15.93	311.80	37.15	397.60	12.28	81.99
66	0.00	0.00	642.40	8.47	34.39	11.38	76.24	20.76	141.30	20.29	29.80
67	0.00	0.00	679.30	10.48	73.33	38.33	261.70	57.77	230.40	38.06	260.00
68	1372.00	0.00	962.80	9.11	37.97	13.16	84.29	25.40	98.00	17.59	85.43
69	1046.00	0.00	0.00	10.78	28.99	8.28	104.50	24.28	169.40	22.74	44.48
70	0.00	0.00	1680	48.81	49.22	5.47	128.80	38.98	240.90	61.91	274.70
71	3106.00	0.00	1156	36.45	30.59	11.88	50.09	15.56	61.01	11.87	77.21
Average	511.00	0.00	751.00	11.20	51.25	21.05	745.34	36.55	155.27	527.87	104.08

Table 2: Index of Geo-accumulation of Trace Elements in the Obi Soil

Location #	I	Mo	Zn	As	Pb	Co	Cr	Cu	Ba	Ni	Sr
57	0.00	0.00	10.83	0.00	0.45	1.67	0.41	1.31	0.06	1.13	0.05
58	0.00	0.00	0.00	0.00	0.58	0.00	1.48	0.70	0.04	0.45	0.05
59	0.00	0.00	3.21	0.00	0.44	0.54	0.56	0.61	0.11	0.43	0.37
60	0.00	0.00	0.00	0.00	0.42	0.00	1.85	0.40	0.08	0.25	0.05
61	0.00	0.00	0.00	0.00	0.53	2.54	36.83	0.49	0.04	72.08	0.14
64	0.00	0.00	1.00	0.46	0.13	0.17	0.30	0.16	0.04	0.10	0.03
65	93.56	0.00	0.00	0.46	0.75	0.46	1.49	0.53	0.22	0.14	0.11
66	0.00	0.00	2.08	0.46	0.28	0.33	0.36	0.30	0.08	0.23	0.04
67	0.00	0.00	2.20	0.46	0.59	1.11	1.25	0.83	0.13	0.42	0.35
68	114.71	0.00	3.12	0.46	0.30	0.38	0.40	0.36	0.05	0.20	0.12
69	87.46	0.00	0.00	0.46	0.23	0.24	0.50	0.35	0.09	0.25	0.06
70	0.00	0.00	5.44	2.08	0.40	0.16	0.62	0.56	0.13	0.69	0.37
71	259.70	0.00	3.74	1.56	0.25	0.35	0.24	0.22	0.03	0.13	0.11
Average	42.73	0.00	2.43	0.49	0.41	0.61	3.56	0.52	0.09	5.88	0.14

Table 4: Contamination Factor (CF) and Pollution Load Index (PLI) of Trace Elements in the Obi Soil

Location #	I	Mo	Zn	As	Pb	Co	Cr	Cu	Ba	Ni	Sr	PLI
57	0.00	0.00	0.17	0.00	0.02	0.24	0.01	0.09	0.00	0.06	0.00	1.00
58	0.00	0.00	0.00	0.00	0.02	0.00	0.04	0.05	0.00	0.03	0.00	1.00
59	0.00	0.00	0.05	0.00	0.02	0.08	0.01	0.04	0.00	0.02	0.00	1.00
60	0.00	0.00	0.00	0.00	0.02	0.00	0.04	0.03	0.00	0.01	0.00	2.00
61	0.00	0.00	0.00	0.00	0.02	0.37	0.88	0.04	0.00	4.00	0.00	1.00
64	0.00	0.00	0.02	0.10	0.01	0.03	0.01	0.01	0.00	0.01	0.00	29.00
65	38.98	0.00	0.00	0.10	0.03	0.07	0.04	0.04	0.00	0.01	0.00	1.00
66	0.00	0.00	0.03	0.10	0.01	0.05	0.01	0.02	0.00	0.01	0.00	1.00
67	0.00	0.00	0.04	0.10	0.02	0.16	0.03	0.06	0.00	0.02	0.00	1.00
68	47.80	0.00	0.05	0.10	0.01	0.06	0.01	0.03	0.00	0.01	0.00	1.00
69	36.44	0.00	0.00	0.10	0.01	0.03	0.01	0.02	0.00	0.01	0.00	1.00
70	0.00	0.00	0.09	0.44	0.02	0.02	0.01	0.04	0.00	0.04	0.00	1.00
71	108.21	0.00	0.06	0.33	0.01	0.05	0.01	0.02	0.00	0.01	0.00	1.00
Average	17.80	0.00	0.04	0.10	0.02	0.09	0.08	0.04	0.00	0.33	0.00	

Table 3: Enrichment Factor of Trace Elements in the Obi Soil

Location #	I	Mo	Zn	As	Pb	Co	Cr	Cu	Ba	Ni	Sr
57	0.00	0.00	112.87	0.00	4.66	17.40	4.30	13.61	0.61	11.77	4.36
58	0.00	0.00	0.00	0.00	3.52	0.00	9.07	4.25	0.25	2.77	2.35
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	4.43	0.00	19.62	4.26	0.84	2.62	4.04
61	0.00	0.00	0.00	0.00	14.00	66.37	963.78	12.94	1.05	1886.4	29.70
64	0.00	0.00	10.44	4.80	1.37	1.82	3.13	1.62	0.46	1.09	2.68
65	1344.6	0.00	0.00	6.61	10.84	6.66	21.41	7.65	3.17	1.97	13.14
66	0.00	0.00	11.36	2.52	1.51	1.81	1.99	1.63	0.43	1.24	1.82
67	0.00	0.00	10.78	2.26	2.89	5.46	6.13	4.06	0.63	2.08	14.21
68	682.61	0.00	18.54	2.74	1.81	2.28	2.40	2.17	0.32	1.17	5.67
69	316.79	0.00	0.00	1.67	0.84	0.87	1.81	1.26	0.34	0.92	1.80
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	2126.3	0.00	30.63	12.74	2.01	2.83	1.96	1.83	0.28	1.08	7.05
Average	343.88	0.00	14.97	2.56	3.68	8.12	79.66	4.25	0.64	147.17	6.68

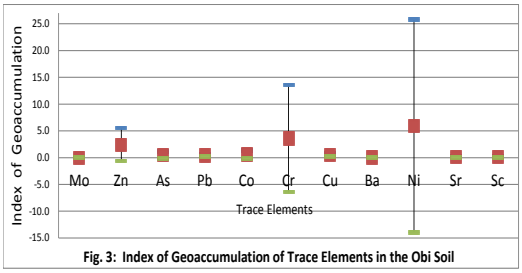

Fig. 3: Index of Geoaccumulation of Trace Elements in the Obi Soil

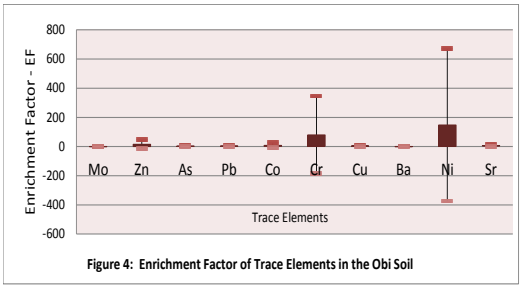

Figure 4: Enrichment Factor of Trace Elements in the Obi Soil

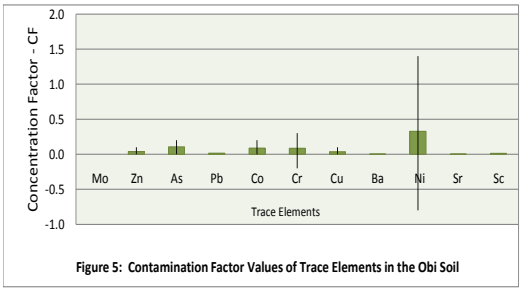

Figure 5: Contamination Factor Values of Trace Elements in the Obi Soil

Table 5: Summary of I_{geo} Values of Trace Elements in the Obi Soil

Elements	I_{geo} Value	Class	Remarks
Mo	0.00	0	Unpolluted
Zn	2.43	3	Moderately to strongly polluted
As	0.49	1	Unpolluted to moderately polluted
Pb	0.41	1	Unpolluted to moderately polluted
Co	0.61	1	Unpolluted to moderately polluted
Cr	3.56	4	Strongly polluted
Cu	0.52	1	Unpolluted to moderately polluted
Ba	0.09	1	Unpolluted to moderately polluted
Ni	5.88	6	Extremely polluted
Sr	0.14	1	Unpolluted to moderately polluted

Table 6: Summary of EF Values of Trace Elements in the Obi Soil

Element	EF Value	Classification
Mo	0.00	Minor or minimal enrichment
Zn	14.97	Severe enrichment
As	2.56	Minor or minimal enrichment
Pb	3.68	Moderate enrichment
Co	8.12	Moderate – severe enrichment
Cr	79.66	Extremely severe enrichment
Cu	4.25	Moderate enrichment
Ba	0.64	Minor or minimal enrichment
Ni	147.17	Extremely severe enrichment
Sr	6.68	Moderate – severe enrichment

4. Conclusion

The ubiquitous artisanal mining, mineral processing as well as the unprofessional dumping of mine wastes, tailings and other foreign materials, coupled with the intense weathering in the area, have contributed to the distribution and re-distribution of the heavy metals into the surrounding farmlands, soil and water, raising the concentration of these elements above baseline limits. These heavy metals are mostly transition elements which are characteristically easily oxidized to insoluble complex anions and are readily absorbed and co-precipitated in the sediments with Fe^{3+}, Al^{3+} and Si^{4+} (Lar and Tejan, 2008). Furthermore, the widespread coal and sulfides mineralization characterizing the study area, along with the host rocks, must have mobilized and remobilized these elements. Nickel, for example, has recently become a serious pollutant that is released from metal processing of coal and from phosphate fertilizers used in agricultural soils.

Geo-accumulation index and enrichment factor assessment have revealed that the soil in the area are extremely contaminated with Ni and Cr, with Zn also somewhat enriched in the soil. As, Pb and Ba are moderately contaminated while the contamination levels of Mo, Cu, Co, and Sr appear not to be of serious concern (Tables 5 and 6). CF and PLI analysis both indicate there was no overall pollution of these elements in the Obi coalfield.

Thelocal population living in the mining areas and adjacent communities, have continued to be exposedto the effects of mining and ore processing since they depend on the soil (for subsistence farming) and water from ponds, wells and boreholes (for drinking, cooking and other domestic uses), as noxious heavy metalsare continually released into the land and water systems, would result in various health risks and concerns, if not checked and controlled.

The Obi area has recorded more goiter cases in adults than the surrounding areas of Awe and Keana, due probably to the very low iodine levels in the soil and water. Similarly, there are observed high cases of dermal allergy and asthma as well as liver cancers in the area, which could be attributable to exposure to high Cr and Cr compounds. This study recommends an immediate plan for analysis of the quality of drinking water and some staple crops grown in the area to determine the levels of these noxious metals, to be ensued by a detailed study of medical cases and mitigation or remediation plan. There will be need for the mining regulatory body in the area to regulate and educate miners on the best mining and processing practices as well as the dangersuncontrollable disposal of toxic mine tailings and dumping of other wastes into the soil used for farming and water used for drinking, on the local human and animal populations.

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