



## Mobility of Heavy Metals associated with the Natural Weathering of Coal Spoils: A case Study of Okaba Coal Mine, Kogi State Nigeria

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### ABSTRACT

The mobility of heavy metals associated with natural weathering of coal spoils in three different mining sites was investigated using sequential extraction procedure and flame atomic absorption spectrophotometric detection. Results of this analysis indicated that the heavy metals under study (Pb, Cd, Cu and Ni) had concentration range from 0-29.623 µg/g (Pb) for Ogbo Systec mining site, 0-4.219 µg/g (Enejoh mining site) and 0-0.925 µg/g (Alhaji mining site). Ogbo Systec mining site showed a very high lead (Pb) value above EPA guideline than Enejoh and Alhaji mining site. Cd, Cu and Ni were all below the EPA value guideline. Copper in all the samples are highly mobile in the exchangeable phase and therefore available for bioaccumulation. Cd and Ni occurrence was attributed to their natural occurrence in the soil. The result of contamination factor for Pb in Ogbo Systec mining site indicates a moderate concentration with contamination factor value of 2.01. The Pb contamination factor for Enejoh Alhaji mining sites together with Cd, Cu and Ni showed a low contamination values of >1. The geo-accumulation index analysis at the three mining sites was categorized as unpolluted to moderately polluted for Pb, Cd, and Cu. Ni was categorized as unpolluted.

## 1. INTRODUCTION

Acid mine drainage (AMD) from abandoned coal mine spoils has long been identified as a potential source of heavy metal (HM) pollution to the environment. The HM contaminants more often pollute our surface and ground waters thereby rendering them unfit for consumption and agricultural purposes. It is important to determine the mobility of these metals in both the soil and aquatic media from the AMD, hence taking into cognizance the factor that affects the mobility. Heavy metal contamination in aquatic environments has drawn worldwide attention due to

its deleterious effects, persistence and presence in the environment and subsequent their accumulation in aquatic habitats. Sources of Heavy Metal in aquatic environments may come from various sources such as volcanism, erosion, weathering of rocks and anthropogenic activities such as industrial, agricultural, mining, metal smelting and refining. Contaminated water pose a health risk due to the fact that excess accumulation of Heavy Metal in humans could result to phototoxic effects [1].

Coal is part of an array of mineral resource with important and valuable economic benefits to humans. However, it is a source of many

ecological/environmental problems that are associated with its use [2]. Coal mine spoils is part of several kinds of metal-rich industrial solid wastes that are a problem to the environment. Through various kinds of mining activities with coal inclusive, objectionable quantities of this metal-rich waste have been excavated to the surface of the earth. Through the process of weathering large amounts of coal mine spoils may be released to the environment within a short period of time. Sulfides constitutes a major part of coal mine spoils which can be oxidized during the natural weathering of coal mine spoils [3].

Mining activities can result in degradation of land and can cause severe changes in the ecological conditions. Such mining activities may ultimately result in disruption of the soil profile, disturbance of soil microbial populations and the general ecosystem. The mine overburden dumps are usually characterized by increase in the bioavailability of metals, depletion of moisture, elevated compaction and low organic moisture content. Mine spoils are mostly acidic due to pyrite and metal sulphides which are present in the coal. Land reclamation involves the use of humus layer which serves as a barrier to further oxidation of the overburden layers thereby facilitating the process of re-vegetation of the mine site. Re-forestation or biological reclamation initiates soil-forming processes in surface coal mine spoils [4].

The environmental pollution of the mine tailings is a worldwide problem. Extremely huge amount of coal mine tailings have been generated since the advent of industrialization. These mine tailings eventually lead take to land degradation and induce potential geological disasters. They also give rise to drainage, leakages and windblown dust to seriously pollute the environment [5]. Release of Heavy Metal to the environment occur through a wide range of processes and pathway, including to the air (e.g during combustion, extraction and processing), to surface water (via runoff and releases from storage and transport) and to the soil. People may be exposed to potentially harmful

chemical, physical and biological agents in air, food, water or soil.

The aim of this work is to assess the mobility of heavy metals around a coal mining area in Okaba, Kogi state.

## 2. MATERIALS AND METHODS

### 2.1 Sampling

The sampling Sites are Enejoh, Alhaji, and Ogbo Systec Mining Sites at Okaba, Kogi State. Soil samples were collected using an Eckman sampling device from the different minning sites. The samples were immediately air-dried and stored in plastic containers. Other materials such as stones and plant fragments were removed by passing the dried sample through a 2-mm sieve. The sieved samples were ground to powdered form using a mortar and pestle. These powdered samples were then passed through a 75  $\mu\text{m}$  sieve to filter the silt/clay fraction. The silt/clay fraction are most recommended for soil/sediment speciation studies because they generally contain the highest concentrations of pollutants, and are most readily transported in suspension in natural waters.

### 2.2 Materials and reagents

Soil Sample, Flame Atomic absorption spectrophotometer (AAS) (Buck Scientific Model AVG 210 UK), Weighing balance, Sample container, pH Meter, 250 ml of beaker, Measuring Cylinder, Glass Stirrer, Filter paper, Conical Flask, Heating Mantle. Acetic acid, Nitric acid, Hydrogen peroxide, Hydroxylamine Hydrochloride, Ammonium acetate, Distilled water.

### 2.3 Sample Preparation

The European Bureau of Community Reference (BCR) Sequential extraction method was used to evaluate the mobility of heavy metals from the soils [3]. The analytical procedure involving sequential chemical extraction for the partitioning of particulate. Heavy metals (Pb, Ni, Cd, Co,) can be divided into the following four steps

**Table 1: BCR SEQUENTIAL EXTRACTION PROTOCOL [6].**

Fraction	Components Extracted	Extraction Reagent	Extraction Method
Fraction 1, <b>Acid soluble</b>	Exchangeable and bound to carbonates	20 ml 0.11 mol/L of HOAc	Shaking at $22 \pm 5^\circ\text{C}$ for 16 h.
Fraction 2, <b>Reducible</b>	Bound to Fe/Mn oxides	20 ml 0.5 mol/L $\text{NH}_2\text{OH.HCl}$ (adjusted to pH 1.5 with $\text{HNO}_3$ )	Shaking at $22 \pm 5^\circ\text{C}$ for 16h.
Fraction 3, <b>Oxidizable</b>	Bound to organic matter and sulphides	5 ml 8.8 mol/L $\text{H}_2\text{O}_2$ (adjusted to pH 2.0 with $\text{HNO}_3$ /another 25 ml 1 mol/L $\text{NH}_4\text{OAc}$ (adjusted to pH 2.0 with $\text{HNO}_3$ ))	Digesting at room temperature for 1 h with occasional manual shaking, then cover the tube and heat at $85 \pm 2^\circ\text{C}$ for 1 h, and then remove the cover and reduce the volume to a few milliliters/cover the tube and heat at $85 \pm 2^\circ\text{C}$ For 1h, and then remove the cover and reduce the volume to near dryness/shaking at $22 \pm 5^\circ\text{C}$ for 16h
Fraction 4, <b>Residual</b>	Metals within lithogenic minerals	Aqua regia	

During each step of the analytical procedure as stated above and after the equilibrium was obtained, separation was achieved by centrifugation at 4800 g for 30 min. The supernatant was then removed by a pipette and placed in an acid-cleaned tube for concentration analysis. The residue left in the centrifuge tube was washed with 8 ml of distilled-de-ionized water and then extracted. The extractants acquired during each step of the analytical procedure were finally analyzed for Pb, Ni, Cd, Co, using FAAS [3].

#### 2.4 Geo-accumulation Index

Approach to estimating the enrichment of metal concentrations above background or baseline concentrations is to calculate the geo-accumulation

index (Igeo) [7]. Sediment Igeo is a measure of heavy metal pollution in aquatic sediments. This index is a single metal approach to determining the quantity of metal pollution in sediments when the concentration of toxic heavy metal is 1.5 or more times greater than their lithogenic background values [8].

$$I_{geo} = \log_2 (C_n/1.5B_n)$$

where  $C_n$  is the measured concentration of the element n and  $B_n$  is the geochemical background value element n in average crust [9]. The factor 1.5 is used to compensate possible variations in the sediment. Geochemical background values of Fe and Mn were taken from Wedepohl [9].

**Table 2: Classification for Geo-Accumulation Index [10].**

Igeo value	Class	Sediment quality
< 0	0	Unpolluted
0 -1	1	From unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	From moderately polluted to strongly polluted
3- 4	4	Strongly polluted
4-5	5	From strongly polluted to extremely polluted

The Geochemical Background Value of the measured metals are Pb (14.8 µg/g), Cd (0.1 µg/g), Cu (25 µg/g) and Ni (56 µg/g).

### 2.5 Contamination Factor

A contamination was described as the contamination of a given toxic substance in a basic environment by Hakanson [11]. Contamination factor ( $C_f$ ) is ratio of the concentration of the element in samples to pre-industrial reference value for the element.

$$C_f = C_e/C_{pi}$$

Where  $C_e$  is the concentration of the element,  $C_{pi}$  is the preindustrial reference concentration value. According to Hakanson [11],  $C_f$  has been classified into four groups:  $C_f < 1$  low contamination factor,  $1 \leq C_f < 3$  moderate contamination factor,  $3 \leq C_f < 6$  considerable contamination factor and  $C_f > 6$  very high contamination factor.

## 3. RESULTS AND DISCUSSION

### 3.1 Result

**Table 3:** Results of speciation of soil sample at Ogbo Systec Mining Site (µg/g)

Fractions	Pb	Cd	Cu	Ni
Exchangeable	0.070± 0.0	ND	0.265± 0.001	0.139± 0.001
Bound to carbonates	29.623± 0.006	ND	0.444± 0.0	ND
Organic	0.032± 0.001	ND	0.322± 0.003	ND
Residual	ND	0.053± 0.001	0.169± 0.001	0.370± 0.001
Total	29.725	0.053	1.2	0.509
EPA Value	16	0.38	36	30

**Table 4:** Results of speciation of soil sample at Enejoh Mining Site (µg/g)

Fractions	Pb	Cd	Cu	Ni
Exchangeable	ND	ND	2.859± 0.0	ND
Bound to carbonates	4.219± 0.001	ND	0.370± 0.0	ND
Organic	0.584± 0.0	ND	3.611± 0.001	ND
Residual	0.373±0.0	0.059± 0.0	0.208± 0.001	0.314± 0.0
Total	5.176	0.059	7.048	0.314
EPA Value	16	0.38	36	30

**Table 5:** Results of speciation of soil Sample at Alhaji Mining Site (µg/g)

Fractions	Pb	Cd	Cu	Ni
Exchangeable	ND	0.025± 0.0	0.527± 0.001	ND
Bound to carbonates	0.925± 0.001	ND	0.619± 0.0	ND
Organic	0.511± 0.004	ND	0.371±0.003	ND
Residual	0.483±0.0	0.057± 0.0	0.129±0.0	0.228± 0.001
Total	1.919	0.082	1.646	0.228
EPA Value	16	0.38	36	30

**Table 6:** Results of Geo-accumulation of Pb, Cd, Cu and Ni in the study area

	<b>Pb</b>	<b>Cd</b>	<b>Cu</b>	<b>Ni</b>
Ogbo Systec Mining Site	0.40	0.11	0.01	0.00
Alhaji Mining Site	0.03	0.17	0.01	0.00
Enejoh Mining Site	0.07	0.12	0.06	0.00

**Table 7:** Contamination Factor of Pb, Cd, Cu and Ni in the study area

	<b>Pb</b>	<b>Cd</b>	<b>Cu</b>	<b>Ni</b>
Ogbo Systec Mining Site	2.01	0.52	0.05	0.01
Enejoh Mining Site	0.35	0.59	0.28	0.01
Alhaji Mining Site	0.13	0.82	0.07	0.00

**Table 8:** EPA Sediment Quality Guidelines (SQG) ( $\mu\text{g/g}$ )

<b>Metal</b>	<b>Non polluted</b>	<b>Moderately Polluted</b>	<b>Heavily polluted</b>	<b>Present study</b>		
				<b>Ogbo systec mining site</b>	<b>Enejoh mining site</b>	<b>Alhaji mining site</b>
Pb	<40	40-60	>60	0.000-29.623	0.000-4.219	0.000-0.925
Cd	*	*	>6	0.000-0.053	0.000-0.059	0.000-0.057
Cu	<25	25-50	>50	0.169-0.444	0.000-3.611	0.129-0.619
Ni	< 20	20-50	>50	0.000-0.370	0.000 -0.314	0.000-0.228

The analysis of soil samples obtained from three different mining sites in Ankpa, Kogi State Nigeria are shown on Table 3-5. The heavy metals concentration in geochemical fraction of the sediment samples at Ogbo Systec mining site is presented in Table 3 while Table 4 and 5 are for Enejoh and Alhaji mining sites respectively. From the results on Table 3 (Ogbo Systec Mining site) the lead (Pb) concentration in the fractions ranged from 0-29.623  $\mu\text{g/g}$ . Cadmium (Cd) was not detected in the first-three fractions but was observed in the residual fraction with a concentration of  $0.053 \pm 0.001$   $\mu\text{g/g}$ . The observed concentration of Copper (Cu) ranged from 0.169-0.444  $\mu\text{g/g}$ . The Nickel (Ni) observed ranged from 0-0.37  $\mu\text{g/g}$ .

For Table 4, the metals concentration in geochemical fractions at Enejoh mining sites indicated that Pb was observed with concentration range of 0-4.219  $\mu\text{g/g}$ , while the concentration

range of 0-0.059  $\mu\text{g/g}$  was observed for Cd. The observed result for Cu ranged from 0.208-3.611  $\mu\text{g/g}$  and Ni was detected with a range 0-0.314  $\mu\text{g/g}$ . The metal concentration in the geochemical fraction at Alhaji mining site (Table 5) showed observed concentration of 0-0.925  $\mu\text{g/g}$  (Pb), 0.057  $\mu\text{g/g}$  (Cd), 0.129-0.619  $\mu\text{g/g}$  (Cu) and 0-0.228  $\mu\text{g/g}$  (Ni).

### 3.2 Discussion

The high concentration of lead (Pb) observed in Table 2 (bound to carbonate fraction) may be attributed to incorporation to its natural presence in the soil. Coal deposits are known to contain Pb particles in their matrix. However, leaching and the influence of hydrological cycle may contribute to this unhealthy presence of Pb in fraction 2 from Ogbo Systec mining site. The high presence of Pb in bound to carbonate fraction may

equally be attributed to pH changes [12]. Reduction of pH often leads to desorption of metal ratio due to competition with hydrogen ion, and also leads to the dissolution of carbonate and hydroxides [13]. In the exchangeable fraction, Pb was quickly observed on the surface of the sediment and can be released when water ionic composition changes [14]. Previous reports has indicated that heavy metal in the fraction from geochemical standpoint are weakly bound to organic and inorganic complexes of the sediment and they are readily available to aquatic organism [15]. Nickel was not observed in the first- three fractions but the observed concentration of  $0.053 \pm 0.001 \mu\text{g/g}$  may be linked to its natural presence in the soil and plausibly may be attributed to weak carbonate complexes.

From the result on Table 3, Pb in fraction 2 has the potential to bioaccumulate in plants and therefore pose a significant risk to plants and animals. The result observed in Table 4 from Enejoh mining site showed that the Pb observed in fraction 2 may be associated with formation of Pb complexes. The observed Pb in organic residual is not significant enough and therefore may not be bioavailable. However, the concentration observed in the bound to carbonate fraction may bioaccumulate with time. Cadmium and Ni were not detected in the first-three fractions and therefore the concentration observed in residual phase may be attributed to its natural occurrence in the soil. The observed Cu in residual phase may be attributed to its natural occurrence in the soil. Being an area of high vegetation, the Cu concentration observed at Enejoh mining site may also be attributed to the natural occurrence and weathering of soils in runoff.

The concentration of Pb at Alhaji mining site (Table 5) show that pH may have played a significant role in Pb observed at bound to carbonate. Nickel and Cd may be attributed to weathering and leaching at Alhaji mining site. It is important to note that some of these heavy metals are incorporated in coal matrix during its liturgical

formation. From the whole results of the analysis they are lower than the value for heavy metals in the soil as prescribed in the soil quality guideline (Table 8).

From the geo-accumulation index classification on Table 2, the three mines sites can be categorized as unpolluted to moderately polluted for Pb, Cd and Cu. For Ni, the mine sites can be categorized as unpolluted. The contamination factor (Table 7) for Pb in Ogbo Systec mining site indicates a moderate contamination with a  $C_f$  value of 2.01. The Pb contamination factor for Enejoh and Alhaji mining Site showed a low contamination. Other heavy metals (Cd, Cu and Ni) showed a low contamination values of  $<1$ . From the EPA sediment quality guidelines [16] as presented on Table 8 all the heavy metals studied are  $<40$  and therefore non-polluted.

#### 4. CONCLUSION

From the analysis of the soil samples at Ogbo site in comparison with the United States environmental protection Agency (EPA) value for Sediment quality, the soil sample at Ogbo Systec mining site is heavily polluted with Pb and therefore not a good soil for agricultural purpose. The soil samples at Enejoh mining site and Alhaji mining sites are all far below the Sediment quality guidelines and therefore may be considered good for agricultural purpose.

#### COMPETING INTERESTS

There are no competing interests in this work.

#### AUTHORS CONTRIBUTION

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#### REFERENCES

[1] Nganje, T.N., Adamu .C.I., Ntekim E.E.,

- Ugbaja A.N., Neji, P. and Nfor E.N. (2010). Influence of mine drainage on water quality along River Nyaba in Enugu South Eastern Nigeria. *African Journal of Environmental Science and Technology*, **4**(3): 132-144. DOI: 10.5897/AJEST09.146.
- [2] Shi., Y., M.U., X., Li., K. and Shao, H. (2016). Soil Characterization and differential patterns of heavy metal accumulation in woody plants grown in coal gangue wastelands in Sharanxi, China. *Journal of Environmental Science*, **23**(1): 13489-13497. DOI: 10.1007/s11356-016-6432-8
- [3] Zhi, D., Congqianq, L. and Martin, J.H. (2002). Mobility of heavy metals associated with the natural weathering of coal mine spoils. *Journal of Advance Research in Applied Science*, **118**(2): 419-426. DOI: 10.1016/s0269-7491(01)00285-8
- [4] Irena, D.A., Benkova, M., Banov, M., Nenova, L. and Harizanova, M. (2018). Geochemical associations in technologic soils of contrasting hydrological characteristics from the region of maritsa – iztok coal mine in Bulgaria. *Bulgarian Journal of Agricultural Science*, **24**(2): 18-26.
- [5] Ling, W., Yan, L., Haoran, W., Xinglan, C., Xiao, W., Antihuai, L., Xin, W., Wang, C. and Gan D. (2017). Weathering behavior and metal mobility of tailings under an extremely arid climate at Jinchuan Cu-Ni sulfide deposit, Western China. *Journal of Geochemical Exploration*, **173**(1): 1-12. DOI: 10.1016/j.gexplo.2016.11.009
- [6] Rauret, G., Lopez-Sanchez, J.F., Sahuquillo, A., Rubio, R., Davidson, C., Ure, A. and Quevauviller, P. (1999). Improvement of the BCF three step sequent Extraction procedure prior to the certification of New sediment and soil reference material. *Journal of Environmental Monitoring*, **1**(1): 57-61. DOI: 10.1039/a807854h
- [7] Abraham, G.M.S and Parker, R.J. (2008). Assessment of heavy metal enrichment factors and degree of contamination in marine Sediments from Tamaki Estuary, Auckland, New Zealand. *Environmental Monitoring and Assessment*, **136**: 227-238. DOI: 10.1007/s10661-007-9678-2
- [8] Gaur, V.K., Sanjay, K.G., Pandey, S.D., Gopal, K and Misra, V. (2005). Distribution Heavy metals in Sediment and water of River Gomti. *Environmental Monitoring and Assessment*, **102**: 419-433. DOI: 10.1007/s10661-005-6395-6
- [9] Wedepohl, K. (1995). The composition of the continental crust. *Geochimica et Cosmochimica Acta*, **59**: 1217–1232. DOI: 10.1016/0016-7037(95)00038
- [10] Muller, G. (1969). Index of geoaccumulation in Sediments of the Rhine River. *Geojournal*, **2**: 108-118. Corpus ID: 128079163
- [11] Hakanson, L. (1980). Ecological risk index for aquatic pollution control, a sedimentological approach. *Water Research*, **14**: 975-1001. DOI: 10.1016/0043-1354(80)90143-8.
- [12] Dang, Z., Liu, C. and Haigh, M.J. (2002). Mobility of heavy metals associated with the natural weathering of Coal mine Spoils. *Environmental Pollution*, **118**: 419-426. DOI: 10.1016/S0269-7491(01)00285-8
- [13] Bhuiyan, M.A.H., Islam, M.A., Dampare, S.B., Parvez, L. and Suzuki, S. (2010). Evaluation of hazardous metal pollution in irrigation and drinking water systems in the vicinity of a coal mine area of Northwestern Bangladesh. *J. Hazard Mater.*, **179**(1): 1065-1077. DOI: 10.1016/j.jhazmat.2010.03.114
- [14] Agustin, G.A., Valenzuela-Gracia, J.L., Salvador, A., Diana, M.V., Jorge, R.H. and Gabriel, O. (2007). Chemical Partitioning of Sediment contamination by heavy metals in the San Pedro River, Sonora, Mexico. *Chemical Speciation and Bioavailability*, **19**(1): 25-35. DOI: 10.3184/095422907X198013
- [15] Jerry, R.M., John, P.G. and Kyle, C. (2019). Concentrations, Mobility, and Potential

ecological risks of selected metals within compost amended, reclaimed coal mine soils, tropical. South Sumatra, Indonesia. *Environmental Science*, **6**(4): 298-325. DOI: 10.3934/environsci.2019.4.298

[16] United States Environmental Protection Agency (USEPA) (1977). Guidance for the Pollutonal classification of Great Lakes Harbour Sediments, Regio V. Chicago.