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Geochemical Evaluation of Wastes and Soil Samples around Cassiterite Mine Sites in Plateau State, Nigeria

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ABSTRACT

The distribution of acidity and heavy metals in mine wastes and soil samples in the vicinity of cassiterite mine sites in Plateau State, Nigeria had been carried out. Samples of mine wastes were collected from the mine sites while soil samples were collected from farmlands beyond 450 m, 80 m, 330 m, 70 m, 430 m and 330 m from the mine sites of Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi and Barkin Ladi respectively. These samples were analysed for pH and heavy metals at the Geochemistry Laboratory of the Nigerian Geological Survey Agency (NGSA) in Kaduna, Nigeria. The geo-accumulation index (Igeo) of heavy metals in soil and mine waste samples were thereafter determined. The pH values of the samples indicated that they were all acidic. The Igeo in the samples of the study area were of the order Fe > Mn > Cu > Cd > As > Pb > Cr. The average geo-accumulation indices (Igeo) of 2.1 $\pm$ 0.3, 1.4 $\pm$ 0.7, 1.6 $\pm$ 0.4 and 1.4 $\pm$ 0.4 for cadmium, arsenic, lead and chromium respectively in soil could lead to their accumulation in food crops due to water intake by plants from the soil. This could have serious health implication especially in children. The acidity as well as the heavy metal contamination reduced as distances from the mine increased for all samples collected from all the locations of the study area except copper. In habitants in close proximity to the mines should also be advised to relocate.

Keywords: *Acidity, Heavymetals, Cassiterite, Mine Sites, Igeo, Toxic Contaminants*

1. INTRODUCTION

Plateau State is reknown since pre-independence period not only for the abundance of minerals endowment but also for the exploitation of ore deposits. Local Government Areas (Bassa, Mangu, Barkin Ladi, Riyom, Bokkos and Jos North and South) are widely known for mining activities and these areas are referred to as Jos-Plateau tin fields. The study area played host to a lot of mining activities by foreign companies which rendered the area derelict with numerous waste dumps. The numerous mounds of mine dumps and mill tailings resulting from mining activities that were carried out without consideration to the environment has led to soil, water and air pollution and loss of biodiversity. Today, hand methods by a single person or a group of people are used for mining near-surface, high grade deposit in the study area. Hence, the area was described as a "disaster area" by the Plateau State government because of its devastated landscape as a result of indiscriminate mining activities over the years, (Jaiye, 2013). Similarly, many contaminated mine sites in the United States have been classified as superfund sites (Pierzynski *et al*, 2004). Mining is characterised by mineral extraction, processing and waste disposal which are known to initiate conditions that facilitate the release of heavy metals, most of which are toxic (Forstner and Salomong, 1991; Armah *et al.*, 2010; Pappoe *et al*., 2011). Most heavy metals are carcinogenic and non-biodegradable in the environment (Pappoe *et al*., 2011). A similar study by Amonooneizer *et al.* (1996) has shown that soils, plants and crops around the Obuasi gold mine in Ghana have high concentrations of mercury and arsenic as a result of the mining operation. Alshaebi *et al.* (2009) opined that Pb which resides in large quantities with the remnant of mining can bio-accumulate in food-chain, and thus results in long-term biological effects. It was discovered in the course of this research that the mine wastes (overburden and tailings) in the study area were being used for building construction, as foundry sand for steel casting, road fill for road maintenance, for frying groundnuts and as recreational facilities in Jos wild life park for sand bathing by children. Occasionally, the heaps of mine tailings are exposed to weathering and leaching. They thereby constitute a source of pollution to the nearby and soil water bodies. There is therefore the possibility of direct ingestion. It had therefore become necessary to determine qualitatively and quantitatively the toxic effect of the waste on the soil in order to be able to assess how safe or unsafe possible direct ingestion could be. It is against this background that this research is being proposed.

2. MATERIALS AND METHODS

2.1. Soil and Mine Wastes Sampling and Analyses

Simple random sampling technique was used to collect representative samples of mine wastes and soil into sample bags from the upper layer (0 -15cm) of the sampling field with the aid of a soil auger (Davies, 1998). Samples of soil were collected from beyond 450 m, 80 m, 330 m, 70 m, 430 m and 330 m from the mines of Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi and Barkin Ladi respectively. The GPS locations of

sampling points were recorded in the field note book and located on the map. The pH values of samples as well as the digestion of samples were carried out in accordance with the provisions of the United States Environmental Protection Agency, USEPA SW – 845, 1996 using an Orion 310 pH meter. The determination of heavy metals (Cu, Fe, Mn, As, Cd, Cr, Pb) in the soil and mine waste samples was achieved with the use of the Atomic Absorption Spectrophotometer (AAS) in accordance with the provisions of ASTM (2008) D5435-03 at the Geochemistry Laboratory of the Nigerian Geological Survey Agency (NGSA), Kaduna. The pH values were rated in accordance with Bruce and Rayment (1982) shown in Table1.

Table 1: General Interpretation of pH

pH	Rating
4.5 - 5.0	Very Strongly Acidic
5.1 – 5.5	Strongly Acidic
5.6 – 6.0	Moderately Acidic
6.1 – 6.5	Slightly Acidic
6.6 - 7.3	Neutral
7.4 – 7.8	Mildly Alkaline
7.9 – 8.4	Moderately Alkaline
8.5 – 9.0	Strongly Alkaline
> 9.0	Very Strongly Alkaline

Source: Bruce and Rayment (1982)

2.2. Determination of Geo-Accumulation Indices of Heavy Metals in Soil and Mine Waste Samples

The geo-accumulation Indices (Igeo) of heavy metals in mine waste and soil samples were calculated using Equation 1 as previously determined by (Muller, 1981; Manjunatha *et al*., 2001; Tijani *et al.,* 2004; Lokeshwari and Chandrappa, 2006; Pappoe *et al.,* 2011).

$$Igeo = \ln(\frac{Cn}{1.5Bn}) \quad \text{..... (1)}$$

Where Cn is the measured concentration of element in soil
Bn is the geochemical background value (mg/kg).1.5 is the factor used for lithological variations of trace metals.
The geo-accumulation classes of the samples were gotten by comparing each result with the geo-accumulation classification stated in Muller (1981).

Table 2: Geo-Accumulation Classification

Igeo Class	Description
< 0	Uncontaminated
0 - 1	Uncontaminated to Moderately Contaminated
1 - 2	Moderately contaminated
2 - 3	Moderately to Strongly Contaminated
3 - 4	Strongly contaminated
4 - 5	Strongly to Extremely contaminated
> 5	Extremely Contaminated

Source: Muller (1981)

2.3. Determination of the Distribution of pH and the Igeo of Heavy Metals in Soil and Mine Waste Samples

Polynomial regression models were generated. This was achieved by plotting the spatial distribution of the pH and Igeo of heavy metals in the soil samples using Surfer 12 software. A section line was drawn to pass across all contour intervals to obtain a representative model. The edges of the section line were digitized. The grid was then sliced to obtain the coordinates as well as the parameter values of all the points the section line passed through. The resultant differences between the coordinates of all points and the reference point were converted to distances and the parameter values were plotted against distances. Samples labels R, G, S, K, B and BL indicated samples collected from Rayfield, Gero, Sabongida kanar, Kuru Jantar, Bisichi and BarkinLadi respectively.

2.4. Data Analyses

Analysis of variance (ANOVA) was carried on the data obtained using Minitab 17 Software. Tukey test was used for subsequent post Hoc Tests at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1. Distribution of pH in Mine Waste and Soil of the Study Area

Figure 1 shows the distribution of pH in the mine wastes and soil of the study area. The mean pH values of mine waste samples from Rayfield was 5.4 $\pm$ 0.3. The soil samples collected from 450 m to 1000 m from the mine were moderately acidic while those beyond 1000 m were slightly acidic. The mean pH values of mine waste samples from Gero was 6.0 $\pm$ 0.06. The soil samples within 280 m from the mine were moderately acidic while those beyond 280 m from the mine were slightly acidic. The mean pH values of mine waste samples from Sabongida Kanar was 5.2 $\pm$ 0.3. These values show that the samples were slightly, moderately and strongly acidic while a little portion of the location was very strongly acidic. The pH values of mine waste samples from Kuru Jantar was 5.2 $\pm$ 0.2. These values of pH show that the soil samples were slightly, moderately and strongly acidic. The soil samples within 150 m from the mine were strongly acidic while those between 150 - 300 m from the mine site were moderately acidic and those beyond 300 m were slightly acidic. The mean pH values of samples from Bisichi was 5.3 $\pm$ 0.2. The soil samples around 520 m from the mine site were moderately acidic while those between 520 and 1300 m from the mine were slightly acidic and those beyond 1300 were neutral. The mean pH values of mine waste samples in BarkinLadi was 5.3 $\pm$ 0.2. The soil samples around 512 m from the mine were strongly acidic while those between 512 m and 620 m from the mine site were moderately acidic and those within 620 and 630m were slightly acidic.

The acidity decreased (pH increased) as distances away from the mine sites increased in all locations of the study area. It is therefore clear that the mine sites were the sources of the acidity. The distribution of pH in the samples around Rayfield, Gero,

Sabongida Kanar, Kuru Jantar, Bisichi and Barkin Ladi mines with distance, x (m) are as expressed by Equations 2 - 7 respectively:

$pH = 0.0007\,x + 5.1948$ ($R^2 = 0.94$; $p - value = 3.5x10^{-89}$)

---------- (2)

$pH = 0.0004\,x + 5.8988$ ($R^2 = 0.96$; $p - value = 1.1\,x10^{-39}$)

---------- (3)

$pH = -\,2x10^{-6}\,x^2 + 0.004\,x + 4.7329$ ($R^2 = 0.88$; $p - value = 1.9x10^{-18}$) ---------- (4)

$pH = -5x10^{-6}\,x^2 + 0.0047x + 5.026$, ($R^2 = 0.98$; $p - value = 1.9x10^{-10}$) ---------- (5)

$pH = 0.0005\,x + 5.7621$, ($R^2 = 0.95$; $p - value = 2.9x10^{-105}$) ---------- (6)

$pH = 0.0014\,x + 4.9923$, ($R^2 = 0.79$; $p - value = 1.2\,x10^{-34}$) ---------- (7)

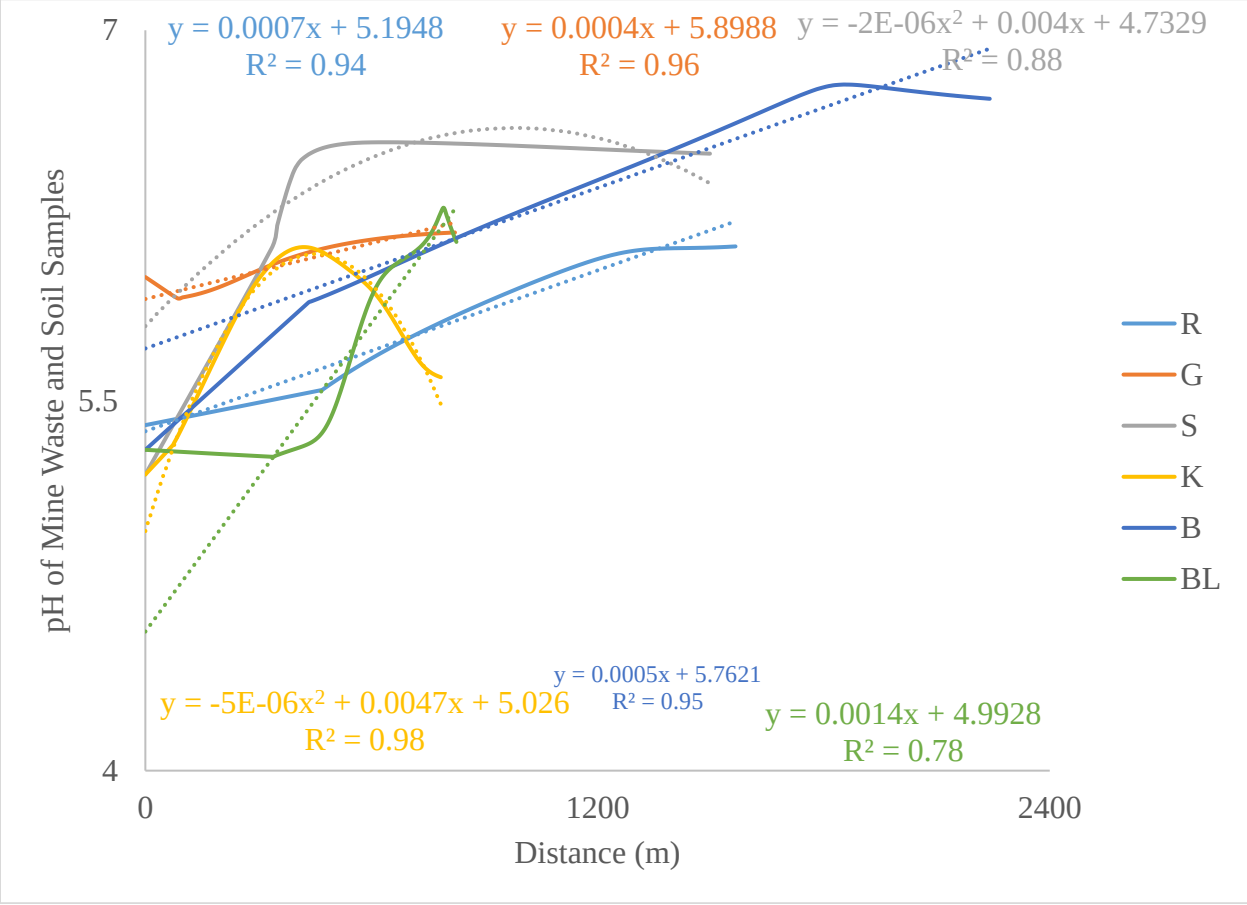

Figure 1: pH of Mine Waste and Soil Samples in the Study Area

2.5. Geo-accumulation Indices of Arsenic in Mine Waste and Soil of the Study Area

Figure 2 shows the geo-accumulation indices of arsenic in the mine wastes and soil of the study area. The mean geo-accumulation index of arsenic in mine waste samples from Rayfield was 2.3 ± 0.2. The geo-accumulation indices of arsenic in soil samples from Rayfield show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with arsenic around 516 m from the mine site while those beyond 516m were moderately contaminated ($1 < I_{geo} < 2$) with arsenic. The mean geo-accumulation index of arsenic in mine waste samples from Gero

was 2 ± 0.04. The geo-accumulation indices of arsenic in the soil samples from Gero show they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with arsenic around 184 m from the mine while those beyond 184 m were moderately contaminated ($1 < I_{geo} < 2$) with arsenic. The mean geo-accumulation index of arsenic in mine waste samples from Sabongida Kanar was 1.9 ± 0.04. The geo-accumulation indices of arsenic in soil samples from Sabongida Kanar show that they were moderately contaminated ($1 < I_{geo} < 2$) with arsenic. However, the arsenic contamination decreased as distance away from the mine increased. The mean geo-accumulation index of arsenic in mine waste samples from Kuru Janatr was 2.1 ± 0.3. The geo-accumulation indices of arsenic in soil samples from Kuru Jantar show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with arsenic around 188 m from the mine while those beyond 188 m were moderately contaminated ($1 < I_{geo} < 2$) with arsenic. The mean geo-accumulation index of arsenic in mine waste samples from Bisichi was 2.3 ± 0.09. The geo-accumulation indices of arsenic in the soil samples from Bisichi show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with arsenic around 529 m from the mine site while those between 529 – 583 m from the mine site were moderately contaminated ($1 < I_{geo} < 2$) with arsenic and those between 583 – 821 m were only uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) with arsenic and those beyond 821 m were uncontaminated ($I_{geo} < 0$) with arsenic. The mean geo-accumulation index of arsenic in mine waste samples from Barkin Ladi was 2.1 ± 0.2. The geo-accumulation index of arsenic in soil samples from Barkin Ladi show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with arsenic around 500 m from the mine while those between 500 - 1500m from the mine were moderately contaminated ($1 < I_{geo} < 2$) with arsenic and those beyond 1500 m were only uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) with arsenic.

Arsenic contamination decreased as distances away from the mine sites increased in all the locations of the study area. It is therefore clear that the mine sites were the sources of the arsenic contamination. It also agreed with the postulation of Pappoe *et al.,* (2011) that arsenic in soil result from mining and other anthropogenic activities. The geo-accumulation indices of arsenic, Igeo (As), in the samples around Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi and Barkin Ladi mine sites with distance, x (m) are expressed by Equations 8 – 13 respectvely:

$$Igeo\ (As) = -0.0005x + 2.3123\ (R^2=0.77;\ p - value = 3.1x10^{-52})\ \text{----------} \quad (8)$$

$$Igeo\ (As) = 2x10^{-6}x^2 - 0.0022 + 2.18\ (R^2=0.75;\ p - value = 1.5\ x10^{-6})\ \text{----------} \quad (9)$$

$$Igeo\ (As) = -\ 0.0002x + 1.8063,\ (R^2=0.78;\ p - value = 1.2x10^{-32})\ \text{----------} \quad (10)$$

$$Igeo\ (As) = 3x10^{-6}x^2 - 0.0031x + 2.36,\ (R^2=0.80;\ p - value = \ 1.1x10^{-36})\ \text{----------} \quad (11)$$

$$Igeo\ (As) = -\ 0.0034x + 3.36832.2234,\ (R^2=0.79;\ p - value = 3.5x10^{-46})\ \text{----------} \quad (12)$$

$$Igeo\ (As) = -0.001x + 2.4097,\ (R^2=0.95;\ p - value = 3.3\ x10^{-87})\ \text{----------} \quad (13)$$

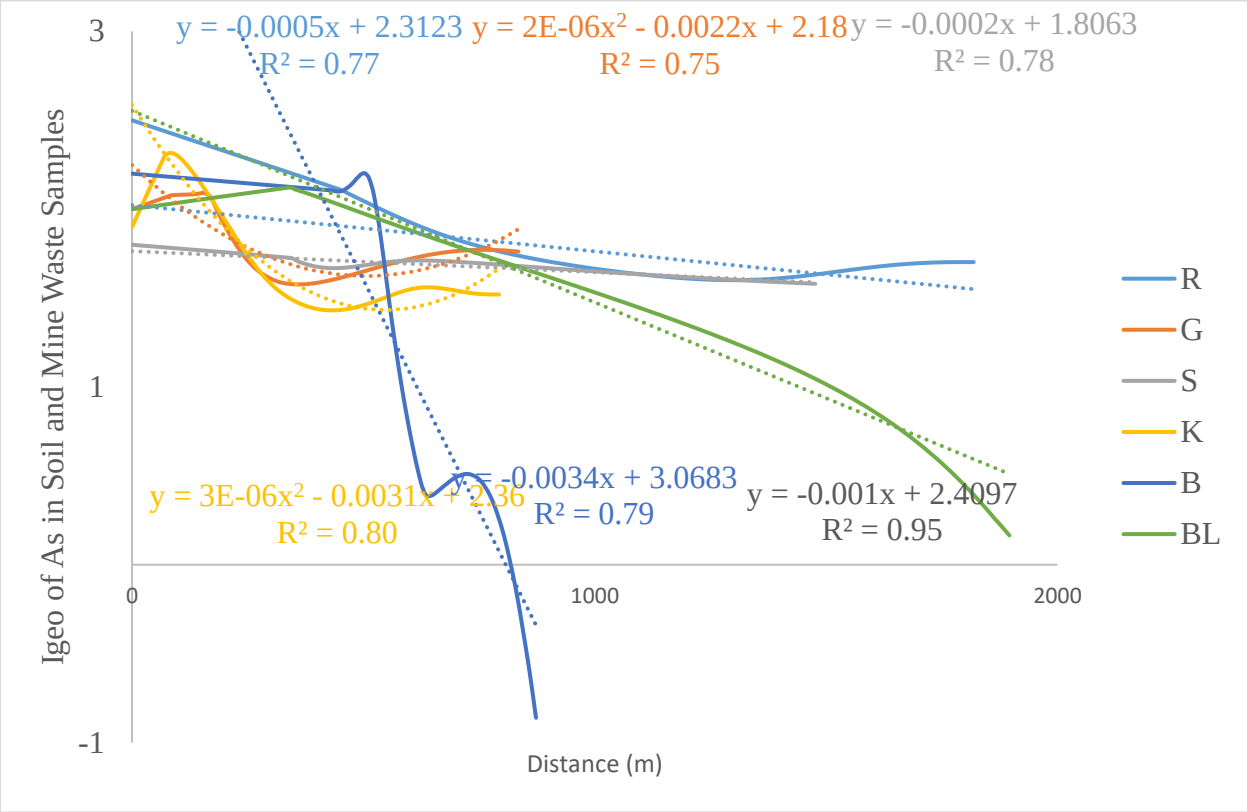

Figure 2: Igeo of Arsenic in Mine Waste and Soil Samples in the Study Area

2.5. Geo-accumulation Indices of Cadmium in Mine Waste and Soil of the Study Area

Figure 3 shows the geo-accumulation indices of cadmium in the mine wastes and soil of the study area. The mean geo-accumulation index of cadmium in mine waste samples from Rayfield was 2.2 $\pm$ 0.02. The geo-accumulation indices of cadmium in the soil samples from Rayfield show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with cadmium around 540 m from the mine site while those beyond 540 m were only moderately contaminated ($1 < I_{geo} < 2$) with cadmium. The mean geo-accumulation index of cadmium in mine waste samples from Gero was 2 $\pm$ 0.07. The geo-accumulation indices of cadmium in the soil samples from Gero show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with cadmium around 310 m from the mine while those beyond 310 m were only moderately contaminated ($1 < I_{geo} < 2$) with cadmium. The mean geo-accumulation index of cadmium in mine waste samples from Sabongida Kanar was 2.1 $\pm$ 0.06. The geo-accumulation indices of cadmium in the soil samples from Sabongida Kanar show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with cadmium around 360 m from the mine site while those beyond 360 m were only moderately contaminated ($1 < I_{geo} < 2$) with cadmium. The mean geo-accumulation index of cadmium in mine waste samples from Kuru Jantar was 2.7 $\pm$ 0.04. The geo-accumulation index of cadmium in the soil samples from Kuru Jantar show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with cadmium around 440 m from the mine while those beyond 440 m were only moderately contaminated ($1 < I_{geo} < 2$) with cadmium. The mean geo-accumulation index of cadmium in mine waste samples from Bisichi was 2.4 $\pm$ 0.3. The geo-accumulation indices of cadmium in the soil samples from Bisichi show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with cadmium around 500 m from the mine while those beyond 500m were only moderately contaminated ($1 < I_{geo} < 2$) with cadmium. The mean geo-accumulation index of cadmium in mine waste samples from Rayfield was 2.4 $\pm$ 0.08. The geo-accumulation indices of cadmium in the soil samples from Barkin Ladi show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with cadmium around 870 m from the mine while those beyond 870m were only moderately contaminated ($1<I_{geo}<2$) with cadmium.

The samples from all locations of the study were moderately and moderately to strongly contaminated ($1 < I_{geo} < 2$; $2 < I_{geo} < 3$) with cadmium. However, cadmium contamination decreased as distance away from the mine increased in all locations of the study area. This is because the mine sites were the sources of the contamination. The geo-accumulation indices of cadmium, Igeo

(Cd), in the samples soil around the Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi and Barkin Ladi mines with distance, x (m) are expressed by Equations 14–19 respectively:

$Igeo\ (Cd) = 3x10^{-7}x^2+0.0009x + 2.345$, ($R^2$=0.89; $p - value = 4.1x10^{-61}$) ---------- (14)

$Igeo\ (Cd) = -0.0002x + 2.069$ (R^2=0.93; $p - value = 9.7\ x10^{-42}$) ---------- (15)

$Igeo\ (Cd) = 5x10^{-7}x^2+ 0.001x + 2.1854$, ($R^2$=0.80; $p - value = 3.3x10^{-11}$) ---------- (16)

$Igeo\ (Cd) = -0.0025x + 3.0931$, ($R^2$=0.95; $p - value = 3.3x10^{-74}$) ---------- (17)

$Igeo\ (Cd) = -9x10^{-8}x^2+0.0018x + 2.7875$, ($R^2$=0.83; $p - value = 2.1x10^{-37}$) ---------- (18)

$Igeo\ (Cd) = 2x\ 10^{-7}x^2-0.0007x + 2.4651$, ($R^2$=0.83; $p - value = 2.3\ x10^{-43}$) ---------- (19)

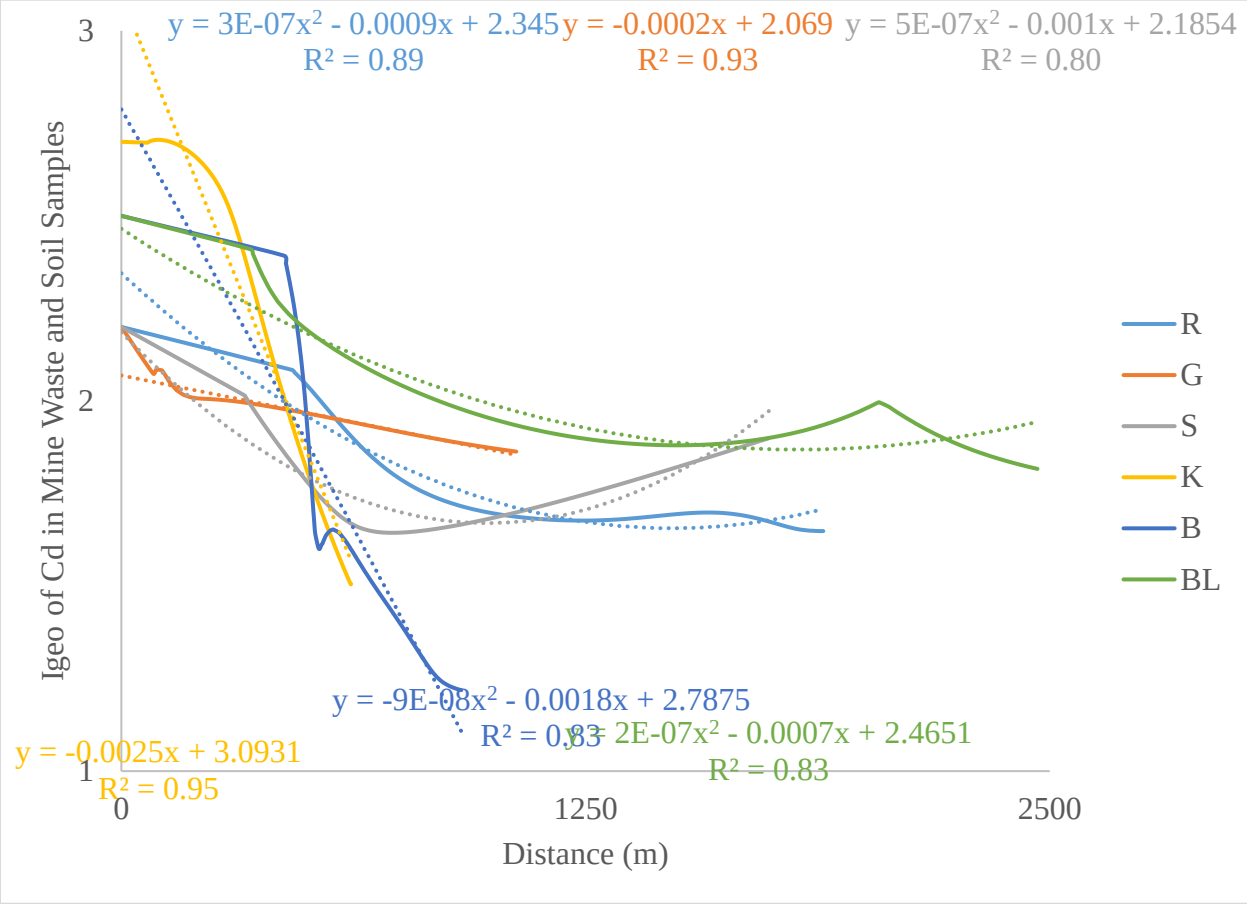

Figure 3: Igeo of Cadmium in Mine Waste and Soil Samples in the Study Area

2.6. Geo-accumulation Indices of Chromium in Mine Waste and Soil of the Study Area

Figure 4 shows the geo-accumulation index of chromium in the mine wastes and soil of the study area. The mean geo-accumulation index of chromium in the mine waste samples from Rayfield was 2.1 ± 0.3. The geo-accumulation indices of chromium in the soil samples from Rayfield show that they were moderately contaminated ($1 < I_{geo} < 2$) with chromium around 1300 m from the mine while those beyond 1300 m were only uncontaminated to moderately ($0 < I_{geo} < 1$) contaminated with chromium. The mean geo-accumulation index of chromium in the mine waste samples from Gero was 1.9 ± 0.1. The geo-accumulation index of chromium in the soil samples from Gero show that they were moderately contaminated ($1 < I_{geo} < 2$) with

chromium around 1300 m from the mine while those beyond 1300 m were only uncontaminated to moderately ($0 < I_{geo} < 1$) contaminated with chromium. The mean geo-accumulation index of chromium in the mine waste samples from Sabongida Kanar was 1.4 ± 0.3. The geo-accumulation indices of chromium in the soil samples from Sabongida Kanar show that they were moderately contaminated ($1 < I_{geo} < 2$) with chromium around 330 m from the mine while those beyond 330 m were only uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) with chromium. The mean geo-accumulation index of chromium in the mine waste samples from Kuru Jantar was 1.7 ± 0.2. The geo-accumulation indices of chromium in the soil samples from Kuru Jantar show that they were moderately contaminated ($1 < I_{geo} < 2$) with chromium around 480 m from the mine while those beyond 480m were only uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) with chromium. The mean geo-accumulation index of chromium in the mine waste samples from Bisichi was 1.8 ± 0.1. The geo-accumulation indices of chromium in the soil samples from Bisichi show that they were moderately contaminated ($1 < I_{geo} < 2$) with chromium around 740 m from the mine while those beyond 740m were only uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) with chromium. The mean geo-accumulation index of chromium in the mine waste samples from Barkin Ladi was 2 ± 0.1. The geo-accumulation indices of chromium in the soil samples from Barkin Ladi show that they were moderately contaminated ($1 < I_{geo} < 2$) with chromium around 1300 m from the mine while those beyond 1300m were only uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) with chromium.

Chromium contamination decreased as distances away from the mine sites increased in all the locations of the study area. This is because the mine sites were the sources of the contamination. The geo-accumulation index of chromium, Igeo (Cr), in mine wastes and the soil around Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi and Barkin Ladi mines with distance, x (m) are expressed by Equations 20 – 25 respectively:

$$Igeo\ (Cr) = -0.0007x + 2.1974,\ (R^2=0.91;\ p - value = 9.5\ x10^{-88}) \text{ ---------- (20)}$$

$$Igeo\ (Cr) = -2x10^{-6}x^2 - 0.0023 + 0.7568\ (R^2=0.83;\ p - value = 0.13) \text{ ---------- (21)}$$

$$Igeo\ (Cr) = 5x10^{-7}x^2 + 0.0013x + 1.4766\ \ (R^2=0.88;\ p - value = 2.7x10^{-38}) \text{ ---------- (22)}$$

$$Igeo\ (Cr) = -\ 0.0011x + 1.544,\ (R^2=0.91;\ p - value =\ 9.4x10^{-93}) \text{ ---------- (23)}$$

$$Igeo\ (Cr) = -0.0012x + 1.9864,\ (R^2=0.78;\ p - value = 1.1x10^{-49}) \text{ ---------- (24)}$$

$$Igeo\ (Cr) = -0.0007x + 2.0216,\ \ (R^2=0.88;\ p - value = 2.0\ x10^{-46}) \text{ ---------- (25)}$$

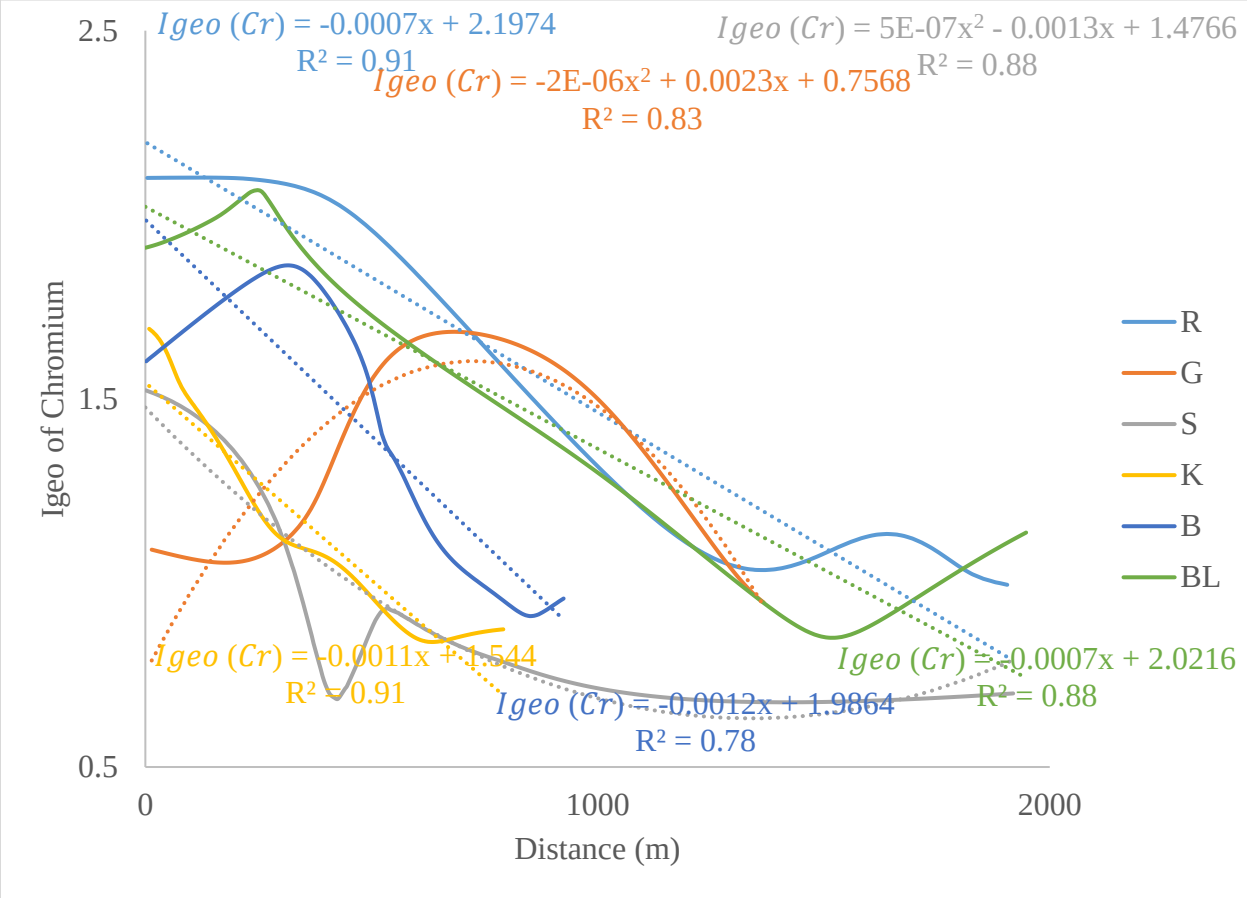

Figure 4: Igeo of Chromium in Mine Waste and Soil Samples in the Study Area

2.6. Geo-accumulation Indices of Lead in Mine Waste and Soil of the Study Area

Figure 5 shows the geo-accumulation indices of lead in the mine wastes and soil of the study area. The geo-accumulation index of lead in mine waste samples from Rayfield was 2 ± 0.2. The geo-accumulation index of lead in the soil samples from Rayfield show that the samples were moderately to strongly contaminated ($2 < I_{geo} < 3$) with lead around 1050 m from the mine while those beyond 1050 m were only moderately contaminated ($1 < I_{geo} < 2$) with lead. The geo-accumulation index of lead in mine waste samples from Gero was 1.7 ± 0.4. The geo-accumulation index of lead in the soil samples from Gero show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with lead around 600 m from the mine while those beyond 600 m were only moderately contaminated ($1 < I_{geo} < 2$) with lead. The geo-accumulation index of lead in mine waste samples from Sabongida Kanar was 2.2 + 0.1. The geo-accumulation indices of lead in the soil samples from Sabongida Kanar show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with lead around 300 m from the mine while the area between 300 - 600 m were moderately contaminated ($1 < I_{geo} < 2$) with lead those beyond 1050 m were only uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) with lead. The geo-accumulation index of lead in mine waste samples from Kuru Jantar was 1.9 + 0.2. The geo-accumulation indices of lead in the soil samples from Kuru Jantar show that were moderately to strongly contaminated ($2 < I_{geo} < 3$) with lead around 250 m from the mine while those beyond 250 m were only moderately contaminated ($1 < I_{geo} < 2$) with lead. The geo-accumulation index of lead in mine waste samples from Bisichi was 2.3 + 0.06. The geo-accumulation indices of lead in the soil samples from Bisichi show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with lead around 470 m from the mine while those beyond 470 m were only moderately contaminated ($1 < I_{geo} < 2$) with lead. The geo-accumulation index of lead in mine waste samples from Barkin Ladi was 2.1 + 0.1. The geo-accumulation indices of lead in samples from Barkin Ladi show that they were moderately to strongly contaminated ($2 < I_{geo} < 3$) with lead around 400 m from the mine while the area between 400 - 800m were moderately contaminated ($1 < I_{geo} < 2$) with lead and those beyond 800 m are only uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) with lead.

Lead contamination decreased as distances away from the mine sites increased in all the locations of the study area. It is therefore clear that the mine sites were the sources of the contamination. The geo-accumulation index of lead, Igeo (Pb), in mine wastes and the soil around Rayfield, Gero, Sabongida Kanar, Kuru

Jantar, Bisichi and Barkin Ladi mines with distance, x (m) are expressed by Equations 26 – 31 respectively:

$Igeo\ (Pb) = 9x10^{-7}x^2 - 0.0023x + 2.5511$, ($R^2$=0.84; $p - value = 6.9\ x10^{-28}$) ---------- (26) $Igeo\ (Pb) = -0.0014x + 1.8761$

(R^2=0.97; $p - value = 1.6\ x10^{-46}$) ---------- (27)

$Igeo\ (Pb) = 2x10^{-6}x^2 + 0.0033x + 2.5289$, ($R^2$=0.95; $p - value = 4.1x10^{-23}$) ---------- (28)

$Igeo\ (Pb) = -0.0014x + 1.6549$, ($R^2$=0.75; $p - value = 1.8x10^{-53}$) ---------- (29)

$Igeo\ (Pb) = -0.0007x + 2.3297$, ($R^2$=0.75; $p - value = 3.5x10^{-44}$) ---------- (30)

$Igeo\ (Pb) = -0.0016x + 2.3945$, ($R^2$=0.93; $p - value = 9.0\ x10^{-47}$) ---------- (31)

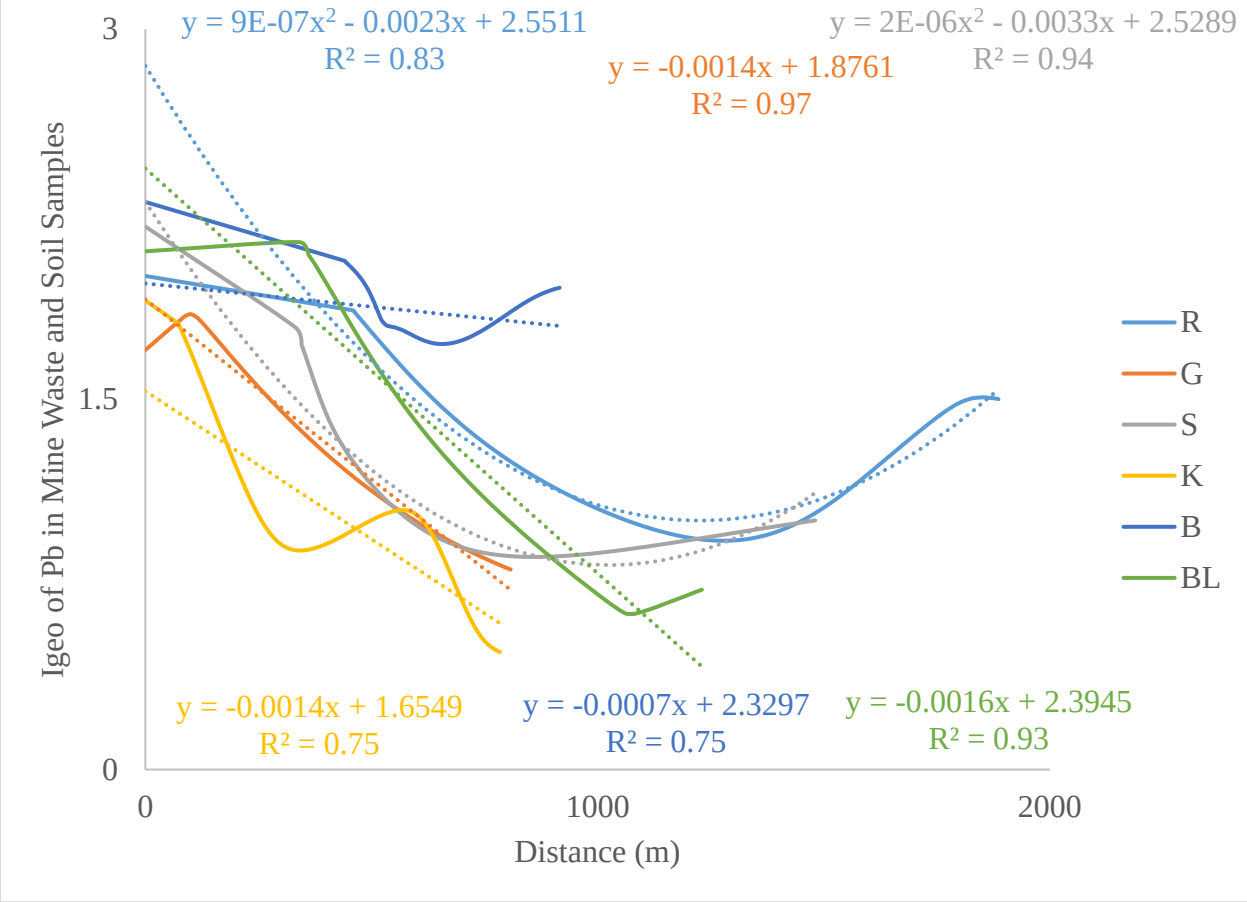

Figure 5: Igeo of Lead in Mine Waste and Soil Samples in the Study Area

4. CONCLUSION

The pH values of the samples indicated that they were all acidic. The Igeo in the samples of the study area were of the order Cd > As > Pb > Cr. The high index of geo-accumulation (Igeo) of Cd, As, Pb and Cr in soil could lead to accumulation of toxic minerals in food crops due to water intake by plants from the soil. This could have serious health effects, including mental retardation in children. It was discovered that acidity as well as heavy metal concentration reduced as distances from the mine increased in all the locations of the study area. There were however significant differences between the mean geo-accumulation indices of heavy metals in the mine wastes and those of the soil samples. It is suggested that the mine wastes in the study area should be properly controlled and confined away from the public so as not to expose those living and working in the area to chemical incidents. Inhabitants in close proximity to the mines should also

be dissuaded as this expose them to high concentrations of heavy metals.

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