Geoenvironmental and health risks associated with toxic metals in goldmine site of Iperindo, southwestern Nigeria

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Abstract

Mineral exploitation enhances the nation’s economic growth and development but poses serious threats to the environment thereby leading to ecological imbalances and public health risks. This study evaluates heavy metal pollution in an abandoned gold mining site of Iperindo, Southwest Nigeria and associated environmental and health risks were investigated. Soil samples collected at the site were subjected to a total digestion technique and analyzed for metals (As, Pb, Cd, Cr, Cu, Zn, Co, Ni, and Fe) using AAS. Only SS15 had a baseline pollution level while all other sampling points had significant heavy metal pollution. Generally, the analysis showed that 33.3% and 66.7% of the sites are included in the unpolluted and moderately polluted classes respectively for As, Cr, Cu, Co, and Ni. For Cd and Zn, 13.3% of the sites were in unpolluted class while it was 40.0% and 66.7% for Pb and Fe respectively. By implication, the highest ecological risk was at SS3 while metal that posed the highest ecological risk was Cd. HQ estimated for all metals via ingestion and dermal pathways for both adults and children were > 1 but < 1 via inhalation pathways in both age groups. However, the values were greater in children than adults. This suggested that oral and dermal exposures to As, Pb, Cd, Cr, Cu, Zn, Co, Ni and Fe in the soil of the study area would elicit non-carcinogenic adverse health hazard. This result shows the critical need to carry out remediation of the study site despite the abandonment of mining operations to protect possible health hazards, particularly to children.

Keywords: Heavy metals, Mining, Pollution, Environmental risks, Health risks

1. INTRODUCTION

Mineral exploitation contributes significantly to economic growth and development in most world economies. No doubt, this is not different in Nigeria but mining activities have created a major burden on the environment. Mining operations usually create a negative environmental impact, both during the mining activity and after the mine has closed. Hence, most of the world's nations have passed regulations that would mitigate the impacts. Whatever may be the amount of wealth generated from mining, it should not be at the detriment of the environment that would lead to serious ecological imbalances and human health risks (Goswami et al., 2008). The exploitation of minerals influences different environmental domains of the exploited areas affecting the land, air, water, socio-economic and cultural environment. Besides this, mining greatly influences the health and sanitation condition of the area creating occupational health hazards. Mining sites are a serious environmental issue. Wastes generated from mining activities
contain high concentrations of metals and metalloids which can be mobilized, resulting in leaching into groundwater, surface water, soil, and vegetation.

The majority of heavy metals are toxic to living organisms and even those considered as essential can be toxic if present in high concentration. Heavy metals can impair important biochemical processes posing threat to human health, plant growth and animal lives (Glover-Kerkvliet, 1995). As toxic as heavy metals are, they are also non-biodegradable. Consequently, they must be removed from polluted streams, plants, and soils in order to meet increasingly stringent environmental quality standards (Ahluwalia, 2007). Heavy metals are hazardous to life and their release to the environment during mining is deleterious to the environment. Effects of their presence can be felt in the environment for hundreds of years thus imprinting untold hardship on communities bordering mining sites in the form of toxicological and environmental degradation. It is now known that exposure to some heavy metals has been linked with developmental retardation and cancer of various body organs which ultimately result in death. In this present study, the extent of heavy metals contamination in abandoned Iperindo gold mining sites was evaluated and associated contamination, ecological and health risks were investigated.

2. Study Area

The study area, Iperindo, is located within 07°30′N – 07°31′N and 04°48′E – 04°49′E of the Greenwich meridian (figure 1). Iperindo lies within the rainforest belt with the vegetation controlled by seasonal changes, which characterize the dry and wet seasons. The average temperature reaches a peak of about 29.4°C in March and the lowest of 23.8°C in August with a relative humidity range of 69% in January to 5% in July. The general area topography of the study area is undulating with elevations ranging between 300m and 580m above mean sea level. Locally, north-eastern striking steep valley incisions were developed and topography shows a general slope towards the south. The drainage system flows north into the Osun River and south towards into the Oni River. Weathering is typically tropical and penetrates down to 15 m depending on the parent rock types and the morphology. Where exposed, the rocks are reddish-brown and are decomposed to clay minerals with quartz relics. Fresh rocks are found in the steep north-south striking valleys whereas the heavily weathered meta-sediments occur at higher levels.

The geology of Iperindo consists of Precambrian rocks that are typical for the basement complex of Nigeria (Rahaman, 1976) Figure 2. The basement complex of southwestern Nigeria predominantly composed of migmatite and granitic gneiss host rock, feldspar, and pyrite, which are associated with gold mineralization in Ilesha schist belt; quartzite; slightly migmatised to unmigmatised metasedimentary schist and metaigneous rocks; charnockite; gabbro and diorite. A system of auriferous quartz veins occurs in the biotite granite gneiss between Odo and Iperindo.
villages in this section of the schist belt. Both the granite gneiss host rock at Iperindo and the lode gold deposit have not been dated.

Figure 1: Map of the study area
3. MATERIALS AND METHODS

3.1 Sampling and Analysis

Soil samples were taken in the study area from fifteen sampling points at uniform depth into black polyethylene plastic and transported to the laboratory. The soil samples were air-dried at room temperature, pulverized and sieved through a 2mm mesh-size sieve. Acid digestion was done with the sieved fraction and the derived treated solutions were analyzed using Atomic Absorption Spectrometer (AAS). Quantification was done for heavy metals; As, Pb, Cd, Cr, Cu, Zn, Co, Ni and Fe in the samples. Data obtained were statistically analyzed with SPSS v.20 using analysis of variance (ANOVA) followed by Duncan’s Multiple Range Test to compare means and Pearson Correlation Test to assess source-association between the metals.
3.2 Contamination Assessment

Contamination assessment was done by evaluating the contamination factor, degree of contamination, pollution load index, geoaccumulation index, and enrichment factor

3.2.1 Contamination Factor (CF), Degree of Contamination (CD) and Pollution Load Index (PLI)

Contamination factor (CF) was determined for each metal in each sampling point and the summation of all contamination factors per sampling point gives the degree of contamination. The CF is calculated as in Eq. (i) and DC is calculated as in Eq. (ii).

\[ CF = \frac{C_{metal}}{C_{background}} \]  
\[ CD = \sum CF_i \]  

\( C_{metal} \) = concentration of metal in the study area, \( C_{background} \) = concentration of metal in the reference site and \( \sum CF_i \) = summation of all CF in a sampling point. CF \(< 1\) = low contamination; \( 1 \leq CF \leq 3 \) = moderate contamination; \( 3 \leq CF \leq 6 \) = considerable contamination and; CF \( > 6 \) = very high contamination. CD \(< 8\) = low degree of contamination; \( 8 \leq CD < 16 \) = moderate degree of contamination; \( 16 \leq CD \leq 32 \) = considerable degree of contamination and; CD \( > 32 \) = very high degree of contamination. Pollution load index (PLI) reveals the composite influence of individual heavy metal in a site. It is calculated by:

\[ PLI = \sqrt{(CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)} \]  

CF is the contamination factor of metal and n is the total number of metal analysed. PLI \(< 1\) = no heavy metal pollution; PLI \( = 1 \) = baseline level of pollution and; PLI value \( > 1 \) = heavy metal pollution.

3.2.2 Geoaccumulation Index (IGeo)

Geoaccumulation index (IGeo) was originally defined by Muller in 1981 to determine metal contamination in sediments (Antunes et al., 2017). It is calculated as:

\[ I_{Geo} = \log_2 (\frac{C_{metal}}{C_{background} \times 1.5}) \]  

\( C_{metal} \) = concentration of metal in the study area, \( C_{background} \) = concentration of metal in the reference site and 1.5 is a variation factor of lithology. IGeo \(< 1\) = unpolluted; \( 1 \leq I_{geo} \leq 2 \) = moderately polluted; \( 3 \leq I_{geo} \leq 4 \) = strongly polluted and; IGeo \( \geq 5 \) = extremely polluted.
3.2.3 Enrichment Factor (EF)

Enrichment factor (EF) measures the metal loading in a site. It is calculated as:

\[ EF = \frac{C_{\text{metal}}}{C_{\text{background}}} \times \frac{C_{\text{mi}}}{C_{\text{bi}}} \]  

\[ = \frac{\text{ratio of heavy metal to immobile element in the analysed sample}}{\text{ratio of heavy metal to immobile element in the background sample}} \]  

Iron (Fe) was chosen as the element of normalization. EF \(<2 = \text{no or minimal enrichment}; 2\leq EF \leq5 = \text{moderate enrichment}; 5\leq EF \leq20 = \text{significant enrichment}; 20\leq EF \leq40 = \text{very high enrichment and; EF} \geq 40 = \text{extremely high enrichment.} \]

3.3 Ecological Risk Assessment

Ecological risk assessment was done by the potential ecological risk index (PERI). PERI establishes the effects of heavy metals on biota.

3.3.1 Potential Ecological Risk Index (PERI) is calculated by:

\[ \text{Potential Ecological Risk Index (PERI)} = \sum E_f \]

\[ E_f = C_{\text{Fs}} \times T_f \]

CF = contamination factor for each heavy metal; \( T_f \) = response coefficient for the toxicity of single heavy metal; \( E_f \) = potential ecological factor for single heavy metal and; \( \sum E_f \) = sum for all the metals. PERI \(< 150 = \text{low risk}; 150 \leq \text{PERI} < 300 = \text{moderate risk}; 300 \leq \text{PERI} < 600 = \text{considerable risk} \) and \( \text{PERI} \geq 600 = \text{very high risk} \) (Alfred et al., 2013). Toxic response values \( (T_f) \) for As, Pb, Cd, Cr, Cu, Zn, Co and Ni are: 10, 5, 30, 2, 5, 1, 5 and 5 respectively.

3.4 Health Risk Assessment

Non-carcinogenic health risk associated with the study area was assessed using Target Hazard Quotient (THQ) and Health Hazard Index (HHI) via the three possible exposure pathways, that is, ingestion, inhalation and dermal routes for adults and children. Carcinogenic risk which is the probability of developing cancer over a stated period of time was assessed using the Cancer Risk Index (CRI).
3.4.1 Non-Carcinogenic Risks

THQ for each exposure pathway was estimated for the average concentration of metals of all the sampling points using equations 9 to 14 and parameters in Appendix 1.

\[
\text{THQ}_{\text{ingestion}} = \frac{\text{CDI}_{\text{ingestion}}}{\text{RFD}} 
\]

\[
\text{CDI}_{\text{ingestion}} = \frac{C_{\text{metal}} \times \text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} 
\]

\[
\text{THQ}_{\text{inhalation}} = \frac{\text{CDI}_{\text{inhalation}}}{\text{RFD}} 
\]

\[
\text{CDI}_{\text{inhalation}} = \frac{C_{\text{metal}} \times \text{InhR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times \text{PEF}} 
\]

\[
\text{THQ}_{\text{dermal}} = \frac{\text{CDI}_{\text{dermal}}}{\text{RFD}} 
\]

\[
\text{CDI}_{\text{dermal}} = \frac{C_{\text{metal}} \times \text{SA} \times \text{SAF} \times \text{DAF} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} 
\]

HHI for each exposure pathway was estimated using Equation 14

\[
\text{HHI}_{\text{ingestion/inhalation/dermal}} = \sum \text{THQ}_{\text{ingestion/inhalation/dermal}} 
\]

Where THQ_{\text{ingestion/inhalation/dermal}} = Target Hazard Quotient via ingestion/inhalation/dermal route; CDI_{\text{ingestion/inhalation/dermal}} = chronic daily intake via ingestion/inhalation/dermal route; RFD = reference dose for each metal; C_{\text{metal}} = concentration of metal; ingR = ingestion rate; EF = exposure frequency; ED = exposure duration; BW = body weight; AT = average time; InhR = inhalation rate; PEF = particulate emission factor; SA = surface area; SAF = soil adherence factor; DAF = dermal absorption factor and; is the Health Hazard Index via ingestion/inhalation/dermal route.

3.4.2 Carcinogenic Risks

CRI for each exposure pathway was estimated for the average concentration of metals for all the sampling points using equation xv.

\[
\text{CRI}_{\text{ingestion/inhalation/dermal}} = \text{CDI}_{\text{ingestion/inhalation/dermal}} \times \text{SF} \text{ (mg/kg/day)} 
\]

\[
\text{CRI}_{\text{ingestion/inhalation/dermal}} = \text{Cancer Risk Index via ingestion/inhalation/dermal route; and; SF = slope factor for a heavy metal. Acceptable cancer risk range according to US Environmental Protection Agency is } 1 \times 10^{-6} \text{ to } 1 \times 10^{-4}. \text{ Due to non-establishment of slope factor for all the metals via all the three possible routes; CRI was calculated for the following:}
\]
Ingestion route: As (SF = 1.50E+0); Pb (SF = 8.5E-3) and Cr (SF = 5.00E-1).

Inhalation route: As (SF = 1.50E+1); Pb (SF = 4.20E-2); Cd (SF = 6.30E+0); Cr (SF = 4.10E+1) and Co (SF = 9.80E+0).

Dermal route: As (SF = 1.50E+0).

4. RESULTS AND DISCUSSION

4.1 Concentration of Metals

Analysis of the levels of heavy metals in the study area is summarized in table 1. Based on mean heavy metal concentration, the order of metal load was found to be As < Cd < Ni < Cr < Cu < Pb < Zn < Co < Fe while it was in the order of SS3 < SS1 < SS14 < SS15 < SS6 < SS10 < SS2 < SS5 < SS13 < SS8 < SS4 < SS7 < SS11 < SS9 < SS12 based on sampling point. This could mean that there were great depositions and/or retention of the metals in the SS12 than others. Highest level of As, Pb, Cd, Cr, Cu, Zn, Co, Ni, and Fe were recorded at SS1, SS8, SS3, SS10, SS4, SS13, SS7, SS8, and SS12 respectively. These variations of point of highest concentration could be linked to source differences or differences of adhesion between the metals and the deposition points (Adewoye et al., 2017). The concentration of Fe which was the highest among all the metals analyzed in the study area with an average of 5514.17mg/kg and it ranged between 1501.25mg/kg at SS3 and 9730.21mg/kg at SS12. The mean value of the Fe concentration is within the WHO/FAO limit but its values at SS9 and SS12 are above the limit. The high level of iron in the study area could be attributed to the high level of the metal in the natural bedrock that produced the surface soil (Ewusi et al., 2013). In addition, it could mean that there were great depositions of Fe in those two points during the active mining period in the study area. Fe has been implicated to induce histopathological effects of several organs in the body (Baby et al., 2010).

Arsenic records the lowest level of concentration and were found within the standard limit but the metals have been implicated to be genotoxic and carcinogenic (Minatel et al., 2017). Its value ranged between 0.1 mg/kg at SS15 and 0.63 at SS1 with a mean concentration of 0.25mg/kg. Pb is a known carcinogen and has been known to induce mental retardation in children even at low concentrations (Surendran et al., 2008). Although the mean value (35.46mg/kg) of Pb in the study area was found to be within the acceptable limit but this was not the case at SS3, SS4, SS6 and SS8 as the values (62.13mg/kg, 54.08mg/kg, 65.03mg/kg and 75.03mg/kg respectively) exceeded the WHO/FAO limit. Mean Cd was found to be above the permissible limit while Cr was below the standard limit and they showed the following ranges; Cd (4.53mg/kg – 35.02mg/kg) and Cr (14.91mg/kg – 64.02mg/kg) with mean of 17.60mg/kg and 26.22mg/kg respectively. Cd is one of the most toxic heavy metals and causes impairments in several organs and the central nervous system (Yilmaz et al., 2007; Castro-Gonzalez and Mendez-Armenta,
Cr is not only a carcinogen but it also causes a death that usually results from the cardiovascular shock that it induces (ATSDR, 2012).

Cu and Zn were found to range between 10.37mg/kg – 68.31mg/kg and 12.91mg/kg – 67.08mg/kg respectively. Their respective mean values (32.81mg/kg, 40.29mg/kg) in the study area were within the limit. These two metals are essential metals in the human body but at high concentrations, Cu interferes with normal conversion of thyroid hormone while Zn inhibits respiratory function (Mohammed and Gad, 2008; Cooper, 2008). Co and Ni were also within the permissible limit with mean values of 44.07mg/kg and 18.99mg/kg respectively. Co ranged between 20.11mg/kg – 66.21mg/kg and Ni ranged between 11.08mg/kg – 25.34mg/kg.

4.2 Correlation Analysis

The result of the analysis of the Pearson Correlation test is presented in table 2. There were positive but moderate correlations (P > 0.05) between Cd and Pb; Co and Zn and; Fe and Zn. As showed a negative correlation with Pb, Cd, Cr, Cu, and Ni while Pb showed a negative correlation with Zn, Co, and Fe. Meanwhile, Cr showed a negative correlation with Zn and Co while no correlations were recorded among the rest of the metals. Positive correlation depicts that there was source association and relatedness in geochemical behavior between the metals while a negative correlation indicates that the source of a metal reversibly affects the other. No correlation was attributed to variance in the source of metals and their geochemical behaviors (Florea et al., 2005).
4.3 Contamination Risk Assessment

The results of contamination risk assessment indices are presented in figures 1 to 5. Figure 1 revealed the results of the calculated CF.

(CF)- Contamination Factor, (Igeo)- Geo-accumulation and (EF)- Enrichment factor, (ACV)- Average Crustal Values, (SBV)- Soil background value. Rudrick and Gao (2003)

Table 2: Correlation Matrix between Heavy Metals in the Study Area

|     | As  | Pb  | Cd  | Cr  | Cu  | Zn  | Co  | Ni  | Fe  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| As  | 1.00* |     |     |     |     |     |     |     |     |
| Pb  | -259 | 1.00* |     |     |     |     |     |     |     |
| Cd  | -229 | 0.722* | 1.00* |     |     |     |     |     |     |
| Cr  | -278 | 0.250 | 0.284 | 1.00* |     |     |     |     |     |
| Cu  | -258 | 0.126 | 0.330 | 0.137 | 1.00* |     |     |     |     |
| Zn  | 0.108 | -0.86 | 0.290 | -0.094 | 0.441 | 1.00* |     |     |     |
| Co  | 0.125 | -0.177 | 0.115 | -0.023 | 0.356 | 0.712* | 1.00* |     |     |
| Ni  | -0.68 | -0.257 | 0.364 | 0.37 | 0.306 | 0.335 | 0.361 | 1.00* |     |
| Fe  | 0.33 | -0.247 | 0.032 | 0.012 | 0.290 | 0.534* | 0.426 | 0.179 | 1.00* |

*Correlation is significant at the 0.05 level (2-tailed). Correlation rating: ≥ 0.91 = very strong; 0.81 – 0.90 = strong; 0.51 – 0.80 = moderate and; ≤ 0.50 = no correlation.

The range of CF for As, Pb, Cd, Cr, Cu, Zn, Co, Ni and Fe were 1.00 – 6.30, 0.97 – 4.68, 0.86 – 7.73, 1.00 – 4.29, 0.79 – 5.21, 0.84 – 4.40, 1.00 – 3.29, 1.00 – 2.28 and 0.36 – 2.31 respectively. Furthermore, SS1, SS8, SS3, SS10, SS4, SS13, SS7, SS8, SS12 recorded the highest (CF) for As, Pb, Cd, Cr, Cu, Zn, Co, Ni, and Fe respectively. In all the sampling stations, 5.9% points were recorded to have low metal contamination while 1.5% had very high contamination. This means that 92.6% of all the sites had between moderate to a considerable level of metal contamination of any sort. The result of the CD (figure 2) revealed that the site has a significant degree of contamination since all sampling points have values above 8 (i.e CD ≥ 8). CD of heavy metals ranges between 9 and 26.01 with the lowest value in SS15 and highest in SS9. SS1 and SS15 have a moderate degree of contamination while other sampling points have a considerable degree of contamination. This indicated that the earlier anthropic activities resulting from mining had contributed to the contamination of the studied site in line with the submission of Likuku et al. (2013). Results of PLI in the sampling points of the study area are presented in figure 3. Only SS15 had a baseline pollution level while all other sampling points had significant heavy metal pollution. The order of level of heavy metal pollution was SS15 < SS1 < SS14 < SS2 < SS13 < SS12 < SS8 < SS3 < SS5 < SS10 < SS4 < SS11 < SS7 < SS9 < SS6. This implied that the abandoned mine site has significant pollution levels by heavy metals (Mmolawa et al., 2011).
Nowrouzi and Pourkhabbaz (2014); Adewoye et al. 2017; Adegbola and Adewoye (2017) reported that $I_{\text{geo}}$ provides an essential index of soil pollution. As shown in figure 4, Cd had the highest $I_{\text{geo}}$ at SS3 (1.64) and the lowest was Fe (1.44) at the same point. Generally, the analysis showed that only 33.33% points of the study area had $I_{\text{geo}} < 0$. In addition, across all the sampling points, Fe recorded the lowest $I_{\text{geo}}$ (-0.22) while the remaining metals contributed moderately to pollution load in the study area. For As, Cr, Cu, Co, Ni, 33.3% of the sites are included in the unpolluted class while 66.7% are in moderately polluted class. Meanwhile, it was 13.3% of the sites were in unpolluted class as for Cd and Zn. As for Pb and Fe, 40.0% and 66.7% respectively were in the unpolluted class. This implied that the majority of the sampling points of the study area were practically unpolluted to moderately polluted.

The results of the $E_F$ are summarized in figure 5. $E_F$ for As, Pb, Cd, Cr, Cu, Zn, Co and Ni ranged between $0.52 \text{–} 8.31$, $0.59 \text{–} 10.89$, $1.00 \text{–} 21.73$, $0.60 \text{–} 4.72$, $0.82 \text{–} 6.07$, $1.00 \text{–} 6.48$, $0.98 \text{–} 7.74$ and $0.63 \text{–} 5.12$ respectively. Highest $E_F$ was recorded for Cd at SS3 (21.73) which indicated very high enrichment while the lowest was at SS9 for Pb (0.48) which indicated minimal enrichment. Only 3.7% of the study area had $E_F > 5$ which showed that 96.3% of the study area had minimal to moderate enrichment. This was in congruence with the results for CD, PLI, and $I_{\text{geo}}$. Meanwhile, enrichment of metals might have been higher during the active mining period in the study area. The results of the calculated PERI are presented in table 3.
Figure 1: Contamination Factor (CF) of Metals in the Sampling Points of the Study Area

As  Pb  Cd  Cr  Cu  Zn  Co  Ni  Fe
SS1  SS2  SS3  SS4  SS5  SS6  SS7  SS8  SS9  SS10  SS11  SS12  SS13  SS14  SS15
Sampling point

Contamination Factor (CF)
Figure 2: Degree of Contamination (CD) of Metals in the Sampling Points of the Study Area

Figure 3: Pollution Load Index (PLI) of Metals in the Sampling Points of the Study Area
Figure 4: Geoaccumulation Index (IGeo) of Metals in the Sampling Points of the Study Area
4.4 Ecological Risk Assessment

The result of the ecological risk assessment by PERI analysis is presented in Table 3. The PERI value varied between 10.00 – 63 for As, 4.86 – 23.40 for Pb, 25.76 – 231 for Cd, 2.00 – 8.59 for Cr, 3.96 – 26.06 for Cu, 0.85 – 4.41 for Zn, 5.00 – 16.46 for Co and 5.00 – 11.43 for Ni. Meanwhile, due to the non-availability of TRF for Fe, PERI due to Fe was not calculated. Except for Cd at SS3, SS4 and SS8 with PERI values of 231.92, 165.50 and 166.62 respectively that were higher than 150, all other points for all the metals had PERI < 150 which indicated low ecological risk. It can be deduced that Cd poses a moderate ecological risk at SS1, SS4, and SS8. On the average, the order of PERI according to sampling points was SS15 < SS1 < SS13 < SS2 < SS14 < SS12 < SS11 < SS7 < SS10 < SS5 < SS4 < SS8 < SS9 < SS6 < SS3 while according to
the metals was Cr < Zn < Ni < Co < Pb < Cu < As < Cd. By implication, the highest ecological risk was at SS3 while metal that posed the highest ecological risk was Cd.

| Sampling Point | Heavy Metals | As  | Pb  | Cd  | Cr  | Cu  | Zn  | Co  | Ni  | Fe  |
|----------------|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| SS1            |              | 63.00 | 6.33 | 25.76 | 2.02 | 3.96 | 0.85 | 9.36 | 7.39 | NC  |
| SS2            |              | 17.00 | 10.61 | 101.06 | 3.63 | 7.28 | 1.52 | 6.98 | 8.72 | NC  |
| SS3            |              | 25.00 | 19.38 | 231.92 | 3.36 | 10.80 | 2.30 | 13.77 | 9.11 | NC  |
| SS4            |              | 11.00 | 16.87 | 165.50 | 2.16 | 26.05 | 3.03 | 9.00 | 7.40 | NC  |
| SS5            |              | 19.00 | 10.00 | 134.90 | 4.06 | 20.26 | 1.80 | 11.71 | 8.47 | NC  |
| SS6            |              | 47.00 | 20.28 | 146.89 | 3.49 | 16.93 | 2.38 | 14.46 | 10.34 | NC  |
| SS7            |              | 26.00 | 8.76 | 99.93 | 4.71 | 9.60 | 4.23 | 16.46 | 8.47 | NC  |
| SS8            |              | 22.00 | 23.40 | 166.62 | 3.30 | 6.20 | 2.27 | 6.43 | 11.43 | NC  |
| SS9            |              | 58.00 | 4.86 | 137.55 | 2.43 | 15.67 | 4.21 | 12.19 | 8.21 | NC  |
| SS10           |              | 13.00 | 14.06 | 136.29 | 8.59 | 16.85 | 1.78 | 6.72 | 9.96 | NC  |
| SS11           |              | 19.00 | 6.57 | 101.81 | 3.42 | 14.56 | 3.64 | 15.51 | 10.83 | NC  |
| SS12           |              | 12.00 | 6.88 | 111.19 | 4.08 | 9.41 | 3.18 | 14.96 | 7.26 | NC  |
| SS13           |              | 11.00 | 5.00 | 54.17 | 2.50 | 20.28 | 4.41 | 15.60 | 10.01 | NC  |
| SS14           |              | 25.00 | 7.91 | 104.77 | 3.00 | 4.85 | 3.11 | 6.23 | 5.94 | NC  |
| SS15           |              | 10.00 | 5.00 | 30.00 | 2.00 | 5.00 | 1.00 | 5.00 | 5.00 | NC  |

*NC – Not Calculated.

4.5 Health Risk Assessment
4.5.1 Non-Carcinogenic Health Risk Assessment

The result of chronic daily intake (CDI), hazard quotient (HQ) and hazard index (HI) for ingestion, inhalation and dermal pathways estimated for adults and children in the study area is presented in table 4. HQ estimated for all metals via ingestion and dermal pathways for both adults and children were > 1 but < 1 via inhalation pathways in both age groups. However, the values were greater in children than adults. This suggested that oral consumption of and dermal exposure to As, Pb, Cd, Cr, Cu, Zn, Co, Ni and Fe in the soil of the study area would elicit non-carcinogenic adverse health hazard. In addition, the adverse health effect would be more deleterious in children than in adults. However, inhalation of the metals in the soil matrix of the study area is within an acceptable level of non-carcinogenic adverse health risk for both adults and children in line with the report of Odukoya et al. (2017). The HHI for all metals via ingestion and dermal routes for adults were 5.60E+4 and 4.72E+5 respectively and for children were 9.75E+5 and 4.97E+5 respectively. This indicated that the dermal route poses the highest health risk in adults while oral ingestion poses the highest health risk in children. For the inhalation route, the values in adults and children were 2.85E-3 and 3.47E-3 respectively. This
also pointed to the fact that inhalation pathways would not promote health hazard upon exposure to the metals in the study area. Generally, Cd, Cr, Co, Fe, and Pb contributed the highest to the value of the hazard index in the study area.

4.5.2 Carcinogenic Health Risk Assessment

As presented in table 5, the result showed that As posed cancer risk in adults via ingestion and dermal routes with values 5.40E-1 and 6.00E-3 respectively and in children via ingestion and dermal routes with values 2.69E+0 and 1.46E-2 respectively as this value exceeded the acceptable risk of 1 × 10^-6 to 1 × 10^-4. But inhalation of As showed no carcinogenic health risks. Similar situations were found with Pb, Cd, Cr, and Co. This result is similar to the findings of Kamunda et al. (2016). Generally, the exposed population to the soil of the study area is at high cancer risk with children at higher risks than adults.

5. Conclusion

The result showed that the mean concentration of heavy metals in soil from the abandoned gold mining site of iperindo varied significantly and decreased in the order of As < Cd < Ni < Cr < Cu < Pb < Zn < Co < Fe while it was in the order of SS3 < SS1 < SS14 < SS15 < SS6 < SS10 < SS2 < SS5 < SS13 < SS8 < SS4 < SS7 < SS11 < SS9 < SS12 based on sampling point. The study site was assessed to have significant pollution levels due to previous anthropogenic mining activities. Minimal to moderate enrichment were reported in more than 90% of the study area due to discontinued mining but which might be extremely high at the time of active mining. Ecological risk varied between sampling points but with the majority of the sampling points posing a low ecological risk to the surrounding biota. Ingestion and dermal routes posed both non-carcinogenic and carcinogenic health risks to adults and children, while inhalation pathways revealed acceptable risk. However, the dermal route posed the highest risk to adults while it was ingestion for children. Generally, children were at a higher health risk than the adult. This result shows the critical need to carry out remediation of the study site despite the abandonment of mining operations to protect possible health hazards, particularly to children.
Table 4: CDI, HQ and HHI Analyses of Heavy Metals at Iperidindo Abandoned Mine

|            | As     | Pb      | Cd      | Cr     | Cu     | Zn     | Co     | Ni     | Fe     |
|------------|--------|---------|---------|--------|--------|--------|--------|--------|--------|
| Adult      |        |         |         |        |        |        |        |        |        |
| CDI ingestion | 3.60E-1| 5.07E+1 | 2.51E+1 | 3.75E+1| 4.69E+1| 5.76E+1| 6.30E+1| 2.71E+1| 7.88E+3|
| CDI inhalation | 8.00E-11| 1.13E-8 | 5.63E-9 | 8.39E-9| 1.05E-8| 1.29E-8| 1.41E-8| 6.08E-9| 1.76E-6|
| CDI dermal  | 4.00E-3| 6.20E-1 | 3.10E-1 | 4.60E-1| 5.70E-1| 7.10E-1| 7.70E-1| 3.30E-1| 9.65E+1|
| THQ ingestion | 1.20E+3| 1.27E+4 | 2.51E+4 | 5.63E+4| 1.05E+4| 1.29E+4| 1.41E+4| 6.08E+4| 1.76E+4|
| THQ inhalation | 2.67E-7| 1.74E-6 | 9.88E-5 | 2.80E-4| 1.40E-7| 3.69E-8| 2.47E-3| 1.35E-7| 2.20E-6|
| THQ dermal | 1.33E+1| 1.48E+3 | 5.39E+4 | 3.07E+4| 4.75E+1| 1.18E+1| 1.35E+5| 6.11E+1| 2.51E+5|
| HHI ingestion | 5.60E+4|         |         |        |        |        |        |        |        |
| HHI inhalation | 2.85E-3|         |         |        |        |        |        |        |        |
| HHI dermal  |        |         |         |        |        |        |        |        | 4.72E+5|
| RFD ingestion | 3.00E-4| 4.00E-3 | 1.00E-3 | 1.50E-3| 4.00E-2| 3.00E-1| 2.00E-2| 2.00E-2| 7.00E-1|
| RFD inhalation | 3.00E-4| 6.50E-3 | 5.70E-5 | 3.00E-5| 7.50E-2| 3.50E-1| 5.70E-6| 4.50E-2| 8.00E-1|
| RFD dermal  | 3.00E-4| 4.20E-4 | 5.75E-6 | 1.50E-5| 1.20E-2| 6.00E-2| 5.70E-6| 5.40E-3| 4.50E-2|

Table 5: CRI Analyses of Heavy Metals at Iperidindo Abandoned Mine

|            | As    | Pb    | Cd    | Cr    | Cu    | Zn    | Co    | Ni    | Fe    |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Adult      |       |       |       |       |       |       |       |       |       |
| CRI(Adult) |       |       |       |       |       |       |       |       |       |
| Ingestion  | 5.40E-1| 4.31E-1| -     | 1.88E+1| -     | -     | -     | -     | -     |
| Inhalation | 1.20E-9| 4.75E-10| 3.55E-8| 3.44E-7| -     | -     | 1.38E-7| -     | -     |
| Dermal     | 6.00E-3|       |       |       |       |       |       |       |       |
| Children   |       |       |       |       |       |       |       |       |       |
| CRI (Children) |       |       |       |       |       |       |       |       |       |
| Ingestion  | 2.69E+0| 2.15E+0| -     | 9.35E+1| -     | -     | -     | -     | -     |
| Inhalation | 1.46E-9| 5.80E-10| 4.32E-8| 4.18E-7| -     | -     | 1.68E-7| -     | -     |
| Dermal     | 1.46E-2|       |       |       |       |       |       |       |       |
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