IOSR Journal of Applied Chemistry (IOSR-JAC)
e-ISSN: 2278-5736.Volume 14, Issue 3 Ser. I (March. 2021), PP 48-61
www.iosrjournals.org

Ecological and Human Health Risks of Toxic Metals in Tailings and Soil from a Lead Mine Area in NassarawaEggon, Nigeria

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Abstract

Mining activities produce waste tailings that can be a significant source of pollution in the surrounding environment. This study was designed to assessed the ecological and human health risks of toxic metals (Cu, Zn, Cr, Ni,Cd, Pb, Hg, As) in mine tailings and soil from a lead mining area in Nasarawa-Eggon, Nasarawa State, Nigeria. The concentration of the selected metals were analysed in triplicate using AAS and the results for heavy metals in tailings samples ranged from 901.6 – 3475 mg/kg for Cu, 2026.8 – 3296 for Zn, 8.85 – 401.6 for Cd, 54.8 – 61.2 mg/kg for Cr 44.5 – 92.8 mg/kg for Ni, 42.3 – 4706.2 mg/kg for Pb, 0.023 – 0.041 mg/kg for Hg and 0.022 – 0.034 for As. Concentration of toxic metals reported for farm land soil samples also ranged from 20.8 – 57.8 mg/kg for Cu, 191.9 – 877.8 mg/kg for Zn, 20.6 – 23.8 mg/kg for Cd, 50.2 55.0 mg/kg for Cr, 2.67 – 95.8 mg/kg for Ni, 443.6 – 1087.5 mg/kg for Pb, 0.010 – 0.012 mg/kg for Hg and 0.012 – 0.015 mg/kg for As. The test results of tailings and soil samples showed that the concentration of Pb, Zn, Cd, Ni and Cu in tailings were higher than the standard limit set by WHO and NESREA. While concentration of Cr, Hg, As and Cu in soil were lower than the standard limit set by WHO and NESREA respectively.Total Cancer risk (TCR) for both adults and children were $1.18x10^{-1}$ and $9.3x10^{-3}$, these values are higher than the acceptable safe range of ($1x10^{-5}$-$1.13x10^{-4}$). This indicated that there is a risk of potential health problem in humans working and living in the vicinity of the Pb mining area The potential ecological risk factor (Er) for metal determined from soil (FLS) metal concentration was highest for Hg (424) and moderate for Pb (75.10) whereas Cr(1.74) was the lowest. From mine tailings, Er values for Hg (1270) and Cu (394.05) was extremely high while Er values for Cd (203.40) and Pb (188.1) was high. Cr (1.90) was still the lowest in tailing. The respective risk index (RI) for both soil and tailings are 573.05 and 2154.37 respectively. Indicating high ecological risk in soil farm land and extremely high ecological risk in mine tailings.

***Keywords**: Mine tailings, Heavy metals, Ecological, Human Health Risks*

Date of Submission: 20-03-2021 Date of Acceptance: 04-04-2021

I. Introduction

Mining activities are known to release high levels of toxic metals into the surrounding environment[1]. The emitted toxic metals are highly mobile in the soil environment with increase potential to cause ecological and human health complications[2].In Nigeria, considerable attention has been shifted towards lead mining becauseof its economic importance andalso negative impacts on the quality of the environment.previous studies on lead ore occurrences in Keana and Awe area of NasarawaState and part of Benue State focused on the geological, mineralogical and structural aspects rather than environmental aspect [3]. The current lead mine site in Alizaga community, NasarawaEggon area of NasarawaState constitutes some of the largest lead mines in Nigeria.

The mining and processing of lead ore generates large amounts of mineral waste such as waste rocks, tailings and waste water. This is due to the fact that the leadmine is often surrounded by other ores and rocks. The material surrounding the ore that must be removed in order to access the desired mineral is referred to as waste rock. Tailings are waste materials that emanate from the “ore processing phase”. Tailings always contain toxic substances left over from the ore separating process together with small amounts of heavy metals (most of which are highly toxic) [4].Additionally, in most cases, mine tailings contain materials and minerals that can lead to dangerous runoff, and when stored improperly,can spread to various ecological receptors, water bodies and atmosphere when particles of the tailings are dispersed to surrounding environments through various environmental fate pathways. In most of the developing countries like Nigeria, small-scale mines, waste rock and tailing dump sites are usually not structurally sound[5,6]. This allows contaminants to “spill over the surrounding environment and have the capacity to bio accumulate in the food chain as a result of the non-degradable state of the contaminants or toxic metals presenting health risk to humans, animals and the ecosystem.Acute widespread lead poisoning took place in Zamfara and Niger State, Nigeria in 2010 and 2015 [7,8].Unfortunately, what the local miners found was gold ore laced with high concentrations of lead (concentrations as high as 10% in most cases). Consequently, thousands of villagers were exposed to mass lead contamination[6]. Over 735 children died and thousands were sickened by the neurotoxin in what is believed to be the worst lead poisoning epidemic in modern history. Until then, lead poisoning in children was rare and had never been linked to mining activity in Nigeria [7].

The present study was aimed at assessing potential ecological and human health risks of toxic metals in mining tailings and soil from a lead mine area, in central Nigeria.

II. Materials And Methods

Study area and site description

The study was carried out in NasarawaEggon ($8^{o}43^{'}$ N and $8^{o}32^{'}$ E) the area cover a total of 247.2 km^2 with a population of 148,405 and population density of 165.8 persons per km^2 (NPC 2016, NBS 2016). The area is located in the tropical rainy climate with seven months of rainy season (April to October) and five month of dry season (November – March). The annual rainfall is about 1000 – 1500 mm, while annual temperature is 22^{o}C – 25^{o}C. The terrain is generally hills which host most of the mines.

The Pb mine area is located behind Eggon Community Secondary School in Alizaga Community. The study area is prominent for local mining for the past five years and the most frequent ore mineral are galenite (PbS) and SphaleriteZnS.

The tailings in the mining area remain exposed to various agents of erosion permitting a wide spatial dispersion of tailing particle. The drainage from the tailings pond runs off into streams and rivers which are used to irrigate farm land for vegetables. Communities around the mines also uses the mine tailings, waste rock and mine waste water as construction materials. Surrounding communities are therefore at potential risk from increased levels of toxic metals exposure. Figure 1 shows the map of the study area.

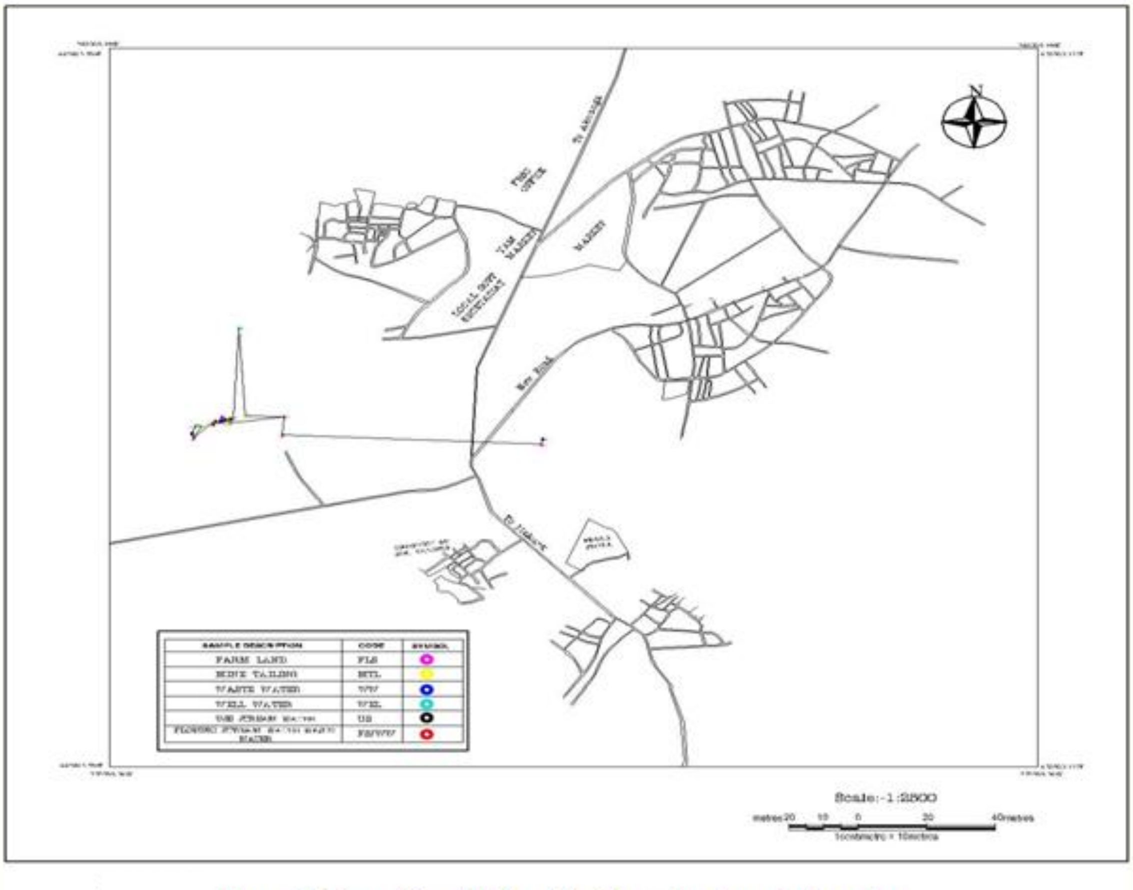

Figure 1: Map of lead Mine Site Showing Sample Locations

Samples Collection and Preparation

Mine tailings samples were collected from eight sampling points within the Pb mining area. Five samples of the top soil at depth 0 – 15cm were collected from the farm land around the mining area with a steel augar. At each sampling location five replicate samples were collected within a 2 m by 2 m grid thoroughly mixed to obtain a homogenous sample out of which 2 kg were packed in labeled polyethylene sample bags. One soil sample was collected 3 km away from the study site. All the collected samples were properly mark and taken to the laboratory for further processing.

The samples were air-dried for 14 days, crushed with a mortar and pestle then sieved through a 0.5 mm nylon mesh to obtain a homogeneous sample matrix and stored in polyethylene containers until analysis of physicochemicalproperties and heavy metals concentration[9].

Digestion of tailings and soil samples

One gram (1.0 g) each of dried and sieved soil and tailing samples was weight into a 25 mL 20 – mL beaker. 12 - mL aliquot of freshly prepared aqua – reqia (3 mLHNO$_3$ + 9 mL HCl i.e. ratio 1:3) was added[10,11].The beaker was covered with a filter paper to enable the digestion to take place under constant volume. The content was heated for 1 hour on a hot plate. The mixture was allowed to cool and then filtered through a Whatman No. 42 filter paper into a 50 - mL standard volumetric flask. The filtrate was diluted to 50 mL with de-ionized water.

Heavy Metal Assay

The digested soil and tailings samples were analyzed for the presence of Cd, As, Zn, Hg, Pb, Cr, Cu, Niusing FAAS Phoenix 986 Atomic Absorption Spectrophotometer, at the Soil Science Laboratory, ABU, Zaria. The calibration curves were prepared by running different concentrations of the standard solution and were used as a standard for sample measurement. The instrument was set to zero by running the respective reagent blanks air-acetylene, cold vapors are the flame type and hallow cathode lamp of the corresponding element was the resonance, the wavelength for the determination of the elements with their detection limits were shown. The digested soil and tailings were analyzed; the concentration of the metals present being displayed in mg/L by the instrument.

Potential Ecological Risk Index (Ei)

The potential ecological risk index (PERI) method proposed by Swedish Scholar Liar Hakanson (1980) [33]was employed to evaluate environmental pollution and the ecological damage caused by heavy metals in the mining area soil [12,13].The potential ecological risk index is related to the individual pollution coefficient, the heavy metal toxicity response coefficient, and the potential ecological risk individual coefficient, and is expressed as follows [14].

$$\mathrm{RI} = \sum_{i=1}^{n} Er^{\,i} = \sum_{i=1}^{n} \mathrm{T}r^{\,i} \text{ x } \sum_{i=1}^{n} \mathrm{T}r^{\,i} \text{ x} \frac{\mathrm{C}s^{\,i}}{\mathrm{C}n^{\,i}} \qquad (1)$$

Where PERI is the sum of individual potential ecological risk for all heavy metals, Er^i is the potential ecological risk index value of an individual element, Tr is the toxic response factor a given heavy metal Cs is the present concentrations of heavy metals in soil and Cn is the reference or background value of heavy metals. The toxic-response factors (Tr) for As, Pb, Cd, Zn, Cu, Cr, Hg and Ni are 10, 5, 30, 1, 5, 2, 40 and 5 respectively. Table 1 provides the grading standards of potential ecological risk from heavy metals.

Human Health Risks

Human health risks associated with toxic metals in soil were examined based on the risk assessment methodology adopted from the USDOE and USEPA [15,16].

The non-Carcinogenic chronic daily exposure doses through the three exposure pathways (oral ingestion, dermal absorption and inhalation were calculated using question [15].

$$\mathrm{ADD_{ing}} \frac{Cs\ X\ IR\ X\ EF\ X\ ED\ X\ CF}{BW\ X\ AT} \qquad (2)$$

$$\mathrm{ADD_{inh}} = \frac{C_s \text{ X IR}_{air} \text{ X EF X ED}}{BW\ X\ AT\ X\ PEF} \qquad (3)$$

$$\mathrm{ADD_{derms}} = \frac{C_s \text{ X SA X FE X AF X ABS X EF X ED X CF}}{BW\ X\ AT} \qquad (4)$$

where $\mathrm{ADD_{ing}}$is the average daily intake of heavy metals ingested from soil in mgkg^{-1} day, C_s = concentration of heavy metal in mgkg^{-1} for soil.$\mathrm{IR_{ing}}$ in mg/day is the ingestion rate, EF in days/year is the exposure frequency, ED is the exposure duration in years, BW is the body weight of the exposed individual in kg, AT is the time period over which the dose is averaged in days. CF is the conversion factor in kg/mg.

where $\mathrm{ADD_{inh}}$is the average daily intake of heavy metals inhaled from soil in mg/kg-day, $\mathrm{IR_{air}}$ is the inhalation rate in m^3/day, PEF, is the particulate emission factor in m^{3}kg^{-1}

where $ADD_{dems}$is the exposure dose via dermal contact in mg/kg/day. SA is exposed skin area in cm^2, FE is the fraction of the dermal exposure ratio to soil, AF is the soil adherence factor in mg/cm^2, ABS is the fraction of the applied dose absorbed across the skin.

Non-carcinogenic risk assessment

Non-carcinogenic hazards are characterized by a term called hazard quotient (HQ). HQ is a unit less number that is expressed as the probability of an individual suffering an adverse effect. It is defined as the quotient of ADI or dose divided by the toxicity threshold value, which is referred to as the chronic reference dose (RfD) in mg/kg-day of a specific heavy metal as shown in Equation [17].

$$HQ = \frac{ADD}{RfD} \quad (5)$$

For n number of heavy metals, the non-carcinogenic effect to the population is as a result of the summation of all the HQs due to individual heavy metals. This is considered to be another term called the Hazard Index (HI) as described by USEPA, [17].

The Hazard Index (HI) is used to assess the overall non-carcinogenic risk posed by more than one toxicant. For multiple hazardous substances, the hazard index is the sum of HQ of the individual toxic element [15].

Equation 6 shows the mathematical representation of this parameter:

$$\mathrm{HI} = \sum_{k=1}^{n} \mathrm{H}Q_k = \sum_{k=1}^{n} \frac{\mathrm{AD}D_k}{\mathrm{R}fD_k} \quad (6)$$

If the HI value is <1, the exposed individual is unlikely to experience obvious adverse health effect the HI value is >1, there could be a risk of non-carcinogenic effects [17].

Carcinogenic risk assessment

For carcinogens, the risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The equation for calculating the excess lifetime cancer risk is as follows:

Cancer risk = CDI ×CSF or

$$\mathrm{Risk}_{pathway} = \sum_{k=1}^{n} \mathrm{AD}D_k \mathrm{CS}F_k \quad (7)$$

where Risk is a unit less probability of an individual developing cancer over a lifetime. ADD_k(mg/kg/day) and CSF_k(mg/kg/day) are the average daily dose of cancinogens (mg/kg/day) and the cancer slope factor, respectively for the kth heavy metal, for n number of heavy metals. The slope factor(SF) converts the estimated daily intake of the heavy metal averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer [17]. The cancer risk caused by a variety of carcinogens is the sum of carcinogenic risk of individual carcinogens in the possible exposure pathways, which is the total cancer risk. According to the U.S. EPA, the value of cancer risk in the range of 10^{-6} to 10^{-4} is an acceptable or tolerable risk, a risk of less than 10^{-6} can be ignored, and a risk exceeding 10^{-4} is considered to be unacceptable. The total excess lifetime cancer risk TCR for an individual is finally calculated from the average contribution of the individual heavy metals for all the pathways using the following equation:

$$\mathrm{Risk}_{(total)} = \mathrm{Risk}_{(ing)} + \mathrm{Risk}_{(inh)} + \mathrm{Risk}_{(dermal)} \quad (8)$$

where $\mathrm{Risk}_{(ing)}$, $\mathrm{Risk}_{(inh)}$, and $\mathrm{Risk}_{(dermal)}$ are risks contributions through ingestion, inhalation and dermal pathways.:

III. Results And Discussion

Physiochemical Parameters of Soil and Tailings Samples

Physiochemical characteristics of soil and mining tailings samples are summarized in Table 1

Particle size distribution: Particle size distribution in top soil of the study area showed 60.4 ±2.6 % for sand, 28.4 ±2.2 % for silt and 10.2 ±1.8 % for clay, while in mining tailings showed 52.3 ±9.6 % for sand, 37.8 ±9.2 % for silt and 4.8 ±0.01 % for clay. Particle size distribution in this study showed that sand fraction was predominant follow by silt fraction. While claywas very low in all the sample location.

The high sand – silt contents obtained in this study agrees with the report of [18]. in a similar studied in Mongolia.

The **pH** of the farm land soil varied from 5.4 – 6.1 with a mean pH value of 5.8±0.3, indicating that the farm land soil in the study area, have an acidic pH surrounding it. Meaning that anthropogenic activities brought much extrinsic input of acid and toxic metals into the soil [19]. pH value of the mining tailings was observed to be slightly acidic with pH ranged of 5.5 – 5.8 and a mean pH of 5.7 ±0.12.

The ranged values of pH obtained in both soil and tailing samples agreed with the reports of [20,21]. in the IshiaguPb/Zn mining area. The pH values in this study were lower than those reported by Adamu and Nganje [22].

Electrical Conductivity: the EC value obtained in this study was low and similar for both soil and tailings (Table 1). **Organic carbon contents (OC).** The organic carbon contents of tailing were determine as 0.13 ±0.02 % while OC of the soils was determined as 1.35 ±0.42 %. **Cation exchange capacity** has a mean value of 5.3 ±1.2 % for the tailing while CEC mean value for the soil is 12.6 ±7.7 C mol/kg. The high CEC observed in the farm land soil may be attributed to the presence of organic matter and high clay contents in the soil.

Table1: Statistical Analysis of Physicochemical Properties of Mine Tailings and Farm Land Soil from Mine Site

Parameters	Sample		95% CI		Range	
ID		Mean +SD	LB	UB	Min.	Mix.
Clay (%)	FLS	10.2±1.8	8.98	13.4	10.0	14.0
	MTL	4.8±0.01	6.23	8.26	2.30	7.50
Silt (%)	FLS	28.4±2.2	30.1	45.4	22.0	50.0
	MTL	37.8±0.01	29.0	39.3	22.0	50.0
Sand (%)	FLS	60.4±2.6	57.2	63.6	38.0	50.0
	MTL	52.3±9.63	44.1	60.2	38.0	66.0
pH	FLS	5.75±0.27	5.42	6.08	5.43	6.13
	MTL	5.67±0.12	5.57	5.78	5.49	5.84
EC (ds/m)	FLS	0.01±0.001	0.010	0.01	0.01	0.01
	MTL	0.01±0.002	0.010	0.01	0.01	0.01
OC (%)	FLS	1.35±0.42	0.80	1.46	0.58	1.60
	MTL	0.13±0.02	0.47	1.26	0.18	1.96
CEC(cmol/kg)	FLS	12.6±7.67	3.05	22.1	6.20	25.8
	MTL	5.30±1.15	2.80	10.1	3.40	9.40

Metal contents in soil and tailings samples

The results of the investigation of toxic metals contents in mine tailings (MTL) and the farm land soils (FLS) around the lead mining area are given in Table 2. The order of abundance of these toxic metal analyzed in the soil following the pattern Pb> Zn > Cr> Ni > Cu> Cd> As >Hg. On the other hand, the order of abundance of these toxic metals in the mine tailings were as follows Pb> Cu > Zn > Cd > Ni > Cr > Hg > As. Toxic heavy metals such as Zn, Cu, Cd and As are associated with mining of the Pb deposits. The Influence of lead mining activity in this area can be currently perceived by high concentration of other toxic heavy metals in the surrounding farm land soil, which are clearly predominated by abnormal values related to waste weathering, aerial transport of fine particles and emissions from the tailings heaps.

Concentration of Cu, Zn, Cd, Cr and Pb in tailing sample were extremely higher than the standard limits prescribed by WHO and NESREA [23,24].

Table 2: Total Mean Concentration of Toxic Metal (mg/kg) in tailing and soil from Pb Mining Area with Standard Limit

Elment	**Tailings (MTL)**		**Farm Land Soil (FLS)**			**Standard Limit**	
(mg/kg)	**Range**	**Mean + SD**	**Range**	**Mean** ±SD	**Control**	**WHO**	**NESREA**
Cu	902 – 3475	1745±5.43	20.8 – 57.8	36.4±3.18	34.8	100	100
Zn	2027– 3296	1685±3.63	192 – 878	441±4.22	120	300	400
Cd	8.85 – 402	159±27.5	20.6 – 23.8	22.6±2.32	23.5	1.0	3.0
Cr	54.8 – 61.2	59.2 ± 0.87	50.2 – 55.0	54.2±0.75	62.4	100	100
Ni	44.5 – 92.8	69.7±3.32	2.67 – 95.8	47.6±3.2	88.3	50	70
Pb	45.3 – 4706	1997±30.3	444 – 1088	798±12.1	53.1	100	164
Hg	0.023– 0.041	0.032±0.002	0.010 – 0.012	0.011±0.001	0.001	4.0	0.3
As	0.022– 0.034	0.028±0.002	0.012 – 0.015	0.013±0.001	0.004	20	20

The results of this study showed that toxic metals concentration in the soils were conditioned by both lithogenic and anthropogenic source as the concentration of the different toxic metals (Pb, Zn, Cu, Hg and As) are higher than the background value of (sample collected) 3 km away from the mining site but lower than the WHO and NESREA standard limit indicating that mining activities had influence in the farmland soil. The concentration of Pb, Zn, Cr, Ni and Cu varies greatly across the farm land soil. Hg and As were relatively low and slightly homogenous in all the soil sample analysed (Table 2). Comparing the concentration of toxic metal in different location of the mine tailings (MTL)and farm land soil (FLS) (Figure 2-9). Sample location FSL$_1$, FSL$_2$ and FSL$_5$ are adjacent mine and tailings dump while location FSL$_3$ –FLS$_4$ are nearer to the gate of the mining site. It was observed that the Pb, Zn, are Cu mean concentration were higher at location FLS$_1$ FLS$_2$ and FLS$_5$. While Cd, Cr, Ni means concentration increase in location FLS$_3$ –FLS$_4$ (Figure 4,5, 6,). The reason for the higher metal concentration in these locations may be attributed to the presence of these metals in closed concentration between soil and mine tailings reflecting their mobilization from tailings to the soil floor. The other reason may be the scattering of the metal from the mine area and tailings piles by wind transport of dust may be important factor influencing the spread down of these metals in to the soil. The high concentration of Zn, Pb, Cd and Cu at certain locations due to their close concentration between soil and mine tailings agrees with high concentration of the metals (Zn, Pb, Cd and Cu) in the soil closed to the tailings heap reported by [25,31]. from a similar study in China and Nigeria. These results also indicated that soil metal concentration decreased with increasing distance from the tailings heap.

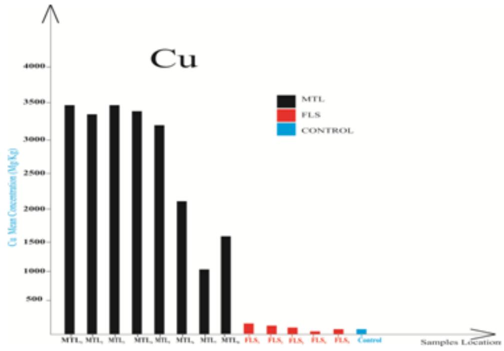

Figure 2: Total Concentration of Cu (mg/kg) in MTL and FLS

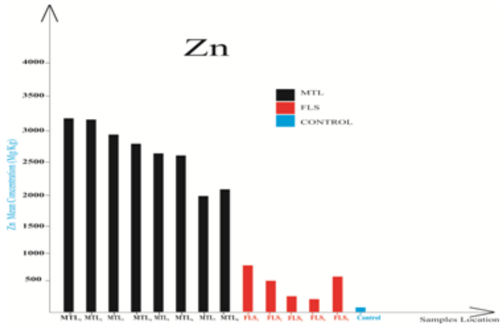

Figure 3: Total Concentration of Zn (mg/kg) in MTL and FLS

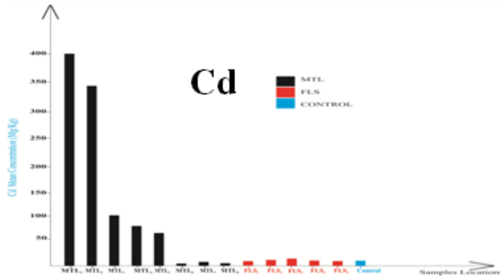

Figure 4: Total Concentration of Cd (mg/kg) in MTL and FLS

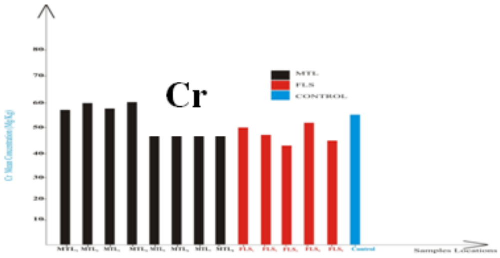

Figure 5: Total Concentration of Cr (mg/kg) in MTL and FLS

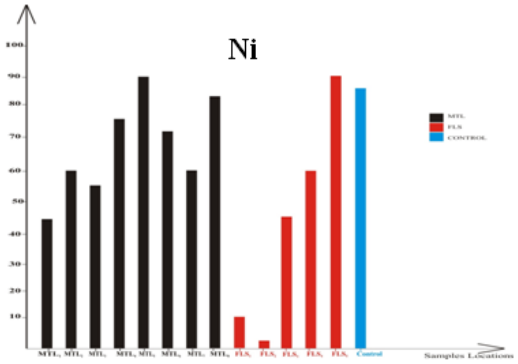

Figure 6: Total Concentration of Ni (mg/kg) in MTL and FLS

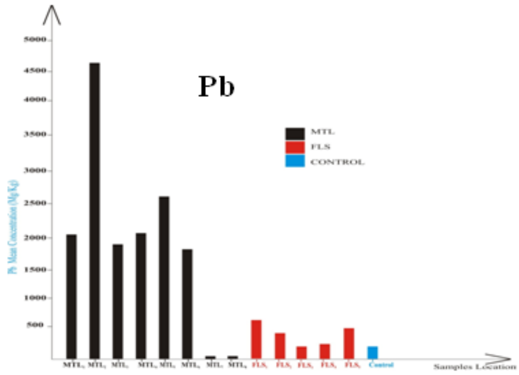

Figure 7: Total Concentration of Pb (mg/kg) in MTL and

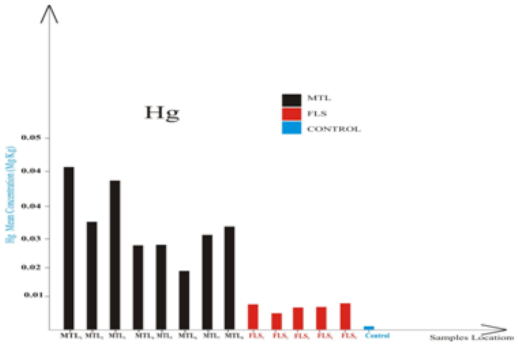

Figure 8: Total Concentration of Hg (mg/kg) in MTL and FLS

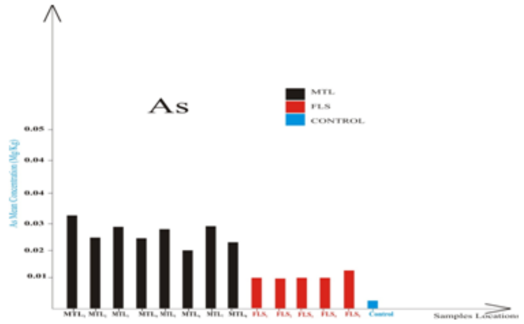

Figure 9: Total Concentration of As (mg/kg) in MTL and FLA Ecological Risk Assessment

Ecological Risk Assessment

The ecological risk factor (E_r) and the ecological risk index (RI)

The E_r and RI of toxic heavy metal in the investigated locations in the soil and tailings of the study area are given in Table 3.

In the farm land soil, the E_r of Cu, Zn, Cd, Cr, Ni, Pb, As and Hg were 5.23, 3.66, 28.98, 1.78, 2.77, 75.10, 31.50 and 424. The E_r in the soil of the study area showed low Potential ecological risk factor ($E_r< 40$) for the

Cu, Zn, Cd, Cr, Ni and As. While Pb and Hg (75.10 and 424) have moderate and extremely high Potential ecological risk factor respectively. The ecological risk sequence of the eight heavy metals in the soil were as follows: - Hg >Pb> As > Cd > Cu > Zn > Ni > Cr. The low Er values for Zn, Cu and Cd and the high Er value of Pb in farm land soil of this study agrees with low Er value of Zn, Cu and Cd Er value (Er< 40) and high Er value of Pb in a top soil reported by CaO *et al.* [25] from similar studied.

In mine tailings, the ecological risk factors of Zn, Cr and Ni were much less than 40, indicating low risk. However, the ecological risk factor of As shows moderate risk with a factor of 70.5. while Cu, Cd, Pb and Hg has high and extremely high Potential ecological risk factor of 394.05, 203.4, 188.05 and 1270 indicating that it posed a severe Potential ecological risk (Table 3).

The overall RI of the studied heavy metals in the soil of the study area showed considerable ecological risk ranges from 464 to 674 and mean index of Potential ecological risk factor was 573. In mine tailings a high value of 2154 was obtained for RI, this high value implied that mine tailing is at very high risk of contamination. The high RI obtained for mine tailings in this study agrees with RI value reported by Mandeng *et al*,[26] and in Sijin *et al.*, [27] in similar studies in Southern Cameroon and China.

Table 3: Ecological Risk Factor(Er) and Risk Index(RI) of Toxic Metals Soil and Tailings

Index Sample I.D		Potential ecological risk factor (E_r)								RI
		Cu	Zn	Cd	Cr	Ni	Pb	As	Hg	
	Min	3.00	1.08	26.4	1.60	0.15	41.8	30.0	360	464
FLS	Max	8.30	7.34	30.6	1.86	5.50	102	37.5	480	674
	Mean	5.23	3.66	29.0	1.74	2.70	75.1	31.5	424	573
	Min	127	16.9	11.4	1.82	2.50	4.25	55.0	920	1141
MTL	Max	500	27.2	513	1.96	5.25	443	85.0	1640	3216
	Mean	394	22.5	203	1.90	3.95	188	70.5	1270	2154

Correlation of Metals in Soil and Mine Tailings

Person correlation analysis was performed to reveal the interrelationship between the metal (with a level of significance P≤ 0.01 and P≤ 0.05 for soil sample from various locations of the study area so as to preliminarily determine the metals common origin source. The obtained results are given in Table 4.

The study pointed out strong positive correlations between Pb and As, Zn, Cu, Ni, Cr ($r = 0.948, 0.888, 0.947, 0.736, 0.924$) at 5% significant levels. This was also reported by Ekeleme *et al.* [3]. As shows positive correlation with Zn, Cu, Ni and Cr ($r = 0.850, 0.856, 0.692, 0.907$) at 5% significant level. Zn also shows significant Hg positive correlation with Cu, and Cr at 5% significant levels. Cu was observed to positively correlate significantly at 5% significant level with Cr ($r = 0.888$). Similarly, it shows a strong positive correlation between Cd and Zn (0.583), Cu and Ni (0.681), Ni and Cr (0.623) at 1% significant level was observed (Table 4).

The strong positive correlations between some metals signify that these metal come from the same source and are probably governed by the same physiochemical process [28]. Weak correlation could be attributed to differences in miced sources of origin and behaviors of the metals as well as an anthropogenic influence in the soil.

Table 4: Two-tailed Pearson Correlation between Metals in FML and MTL

	Hg	Pb	As	Cd	Zn	Cu	Ni	Cr	
Hg	1								
Pb	0.715**	1							
As	.835**	.948**	1						
Cd	.423	.436	.496	1					
Zn	.738**	.888**	.850**	.583*	1				
Cu	.538	.947**	.856**	.249	.754**	1			
Ni	.689**	.736**	.692**	.427	.729**	.681*	.410	1	
Cr	.723**	.924**	.907**	.274	.740**	.888**	.623*	.598*	1

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Human Health Risk Assessment

Non-carcinogenic risk of heavy metals for adults and children

The non-carcinogenic Risk for adults and children posed by Cu, Zn, Cd, Cr, Ni, Pb, Hg and As in soils of the study area were calculated, the results for the ingestion, inhalation and dermal exposures pathways are all presented in terms of HQs as shown in Table 5-6 and Figure10-11.

The values of average daily intake of As, Hg and Zn for both adult and children observed to be lower than the recommended references dose (RfDs) for all the three pathways (Tables 5 and 6). Average daily dosage was highest for Pb through ingestion, but the average daily dosage through ingestion for Cu, Cr, Cd and Ni was lower than RfDs when compared.

Non-carcinogenic hazard quotients (HQ) values of heavy metals for exposure through inhalation was >1 for both adults and children except Hg and As whose HQ values for all the three exposure through inhalation for both adult and children was <1. For children, the dermal pathways had HQ value greater than 1 for Zn and Cd, but the value of HQ was observed to be less than 1 for adults. HQ values for Cr, Ni and Pb were >1 for both adults and children (Table 6, Figures 10 and 11).

The HQ ingestion values of the heavy metal decrease in the following order: Pb> Cd > Cr > Ni > Zn > Cu > Hg > As for both adults and children. Individually, the HQ, Cd, Cr, Ni and Pb for both adults and children were greater than 1 because of their high concentration or low RfD values and the total hazard quotients of Cd, Cr, Ni and Pb accounted for about 95% of the Total Hazardous Index value (THI), indicating that both adult and children are significantly exposed to Cd, Cr, Ni and Pb. This may be the main cause of chronic diseases based on high HQ values. The total non-carcinogenic hazard index (THI) value for all considered heavy metals through multiple exposure pathways were 382.6 and 1176.4 for both adults and children. These values were significantly higher than the safe level. The results of THI obtained in this study were in agreement with previous THI reported by Gevorgyan *et al.*[29]; Yaya *et al.*, [30]; Ngole – Jeme and Fanike [2] and Obasi *et al.*[31] in Armenia, China, South Africa and Nigeria. This high value indicated high heavy metal pollution that may pose a very high non cancer health risk to children and adults living around the lead mining area. The results also indicate that in both adults and children, the ingestion pathway contributes the greatest to non-carcinogenic risk followed by the dermal pathway, inhalation is the least contributor to the risk. Children are particularly more sensitive to the exposure to toxic metals in soil than adults because they may absorb much more heavy metals from soil during their outdoor play activities. The high THI value for children recorded in this study suggested that children may be at high risks than adults [29,2].

Table 5: Average Daily Dose (ADD) of Heavy Metal in mg/kg by Adult and Children in Soil for Non-carcinogenic Risk Calculation.

Heavy Metals	Average Daily intake value mg/kg/day non-cancer risk					
	Ingestion		Inhalation		Dermal	
	Adult Child	Child	Adult	Child	Adult	
Cu	$4.99x10^{-2}$	$4.65x10^{-2}$	$7.67x10^{-9}$	$1.79x10^{-8}$	$4.12x10^{-4}$	$5.96x10^{-3}$
Zn	$6.63x10^{-1}$	$5.63x10^{-1}$	$9.28x10^{-8}$	$2.17x10^{-7}$	$4.98x10^{3}$	$7.24x10^{-2}$
Cd	$3.10x10^{-2}$	$2.89x10^{-2}$	$4.76x10^{-9}$	$1.11x10^{-8}$	$2.56x10^{-4}$	$3.72x10^{-3}$

Cr	7.43x10^{-2}	6.93x10^{-2}	1.14x10^{-8}	2.67x10^{-8}	6.13x10^{-4}	8.92x10^{-3}
Ni	6.52x10^{-2}	6.08x10^{-2}	1.00x10^{-8}	2.34x10^{-8}	5.38x10^{-4}	7.82x10^{-3}
Pb	1.09 x10^{0}	.02 x10^{0}	1.68x10^{-7}	3.92x10^{-7}	9.03x10^{-3}	1.31x10^{-1}
Hg	1.51x10^{-5}	1.41x10^{-5}	2.32x10^{-12}	5.44x10^{-12}	1.24x10^{-7}	1.81x10^{-6}
As	1.78x10^{-5}	1.66x10^{-5}	2.74x10^{-12}	6.39x10^{-12}	1.47x10^{-7}	2.14x10^{-6}

Table 6: Non-carcinogenic Risk Assessment Hazard Quotient (HQ) and Hazard Index (HI)

Heavy metals	**Hazard Quotient (HQ**						**∑HI**	
	Ingestion		**Inhalation**		**Dermal**			
	Adult	**Child**		**Adult**	**Child**	**Adult**	**Child**	**Adult**
Cu	1.25 x10^{0}	1.16 x10^{0}	1.11x10^{-5}	2.59x10^{-5}	2.47x10^{-5}	4.97x10^{-1}	1.25 x10^{0}	1.68 x10^{0}
Zn	2.01 x10^{0}	1.88 x10^{0}	3.09x10^{-7}	7.23x10^{-7}	2.47x10^{-5}	1.21 x10^{0}	2.01 x10^{0}	3.09 x10^{0}
Cd	3.10 x10^{1}	69.3 x10^{0}	3.17x10^{-4}	7.41x10^{-7}	7.36x10^{-2}	7.44 x10^{0}	31.1 x10^{0}	44.1 x10^{1}
Cr	2.50 x10^{1}	23.1 x10^{0}	3.67x10^{-4}	9.34x10^{-4}	10.2 x10^{0}	14.9 x10^{1}	35.0 x10^{0}	17.2 x10^{1}
Ni	3.26 x10^{0}	3.04 x10^{0}	1.11x10^{-4}	1.17x10^{-6}	1.05 x10^{0}	1.40 x10^{0}	4.31 x10^{0}	4.44 x10^{0}
Pb	2.91 x10^{2}	3.03 x10^{2}	4.8x10^{-5}	1.12x10^{-4}	17.4 x10^{0}	252 x10^{0}	309 x10^{0}	554 x10^{0}
Hg	5.00x10^{-2}	4.70x10^{-2}	6.63x10^{-10}	6.29x10^{-8}	1.44x10^{-3}	6.03x10^{-3}	0.051 x10^{0}	0.05x10^{0}
As	6.00x10^{-2}	2.34x10^{-2}	1.83x10^{-7}	4.26x10^{-7}	9.8x10^{-3}	2.38x10^{-3}	0.07 x10^{0}	0.03 x10^{0}
THI	3.65x10^{2}	3.90 x10^{2}	8.55x10^{-4}	1.08x10^{-5}	28.8 x10^{0}	411 x10^{0}	3.83 x10^{2}	1176 x10^{0}

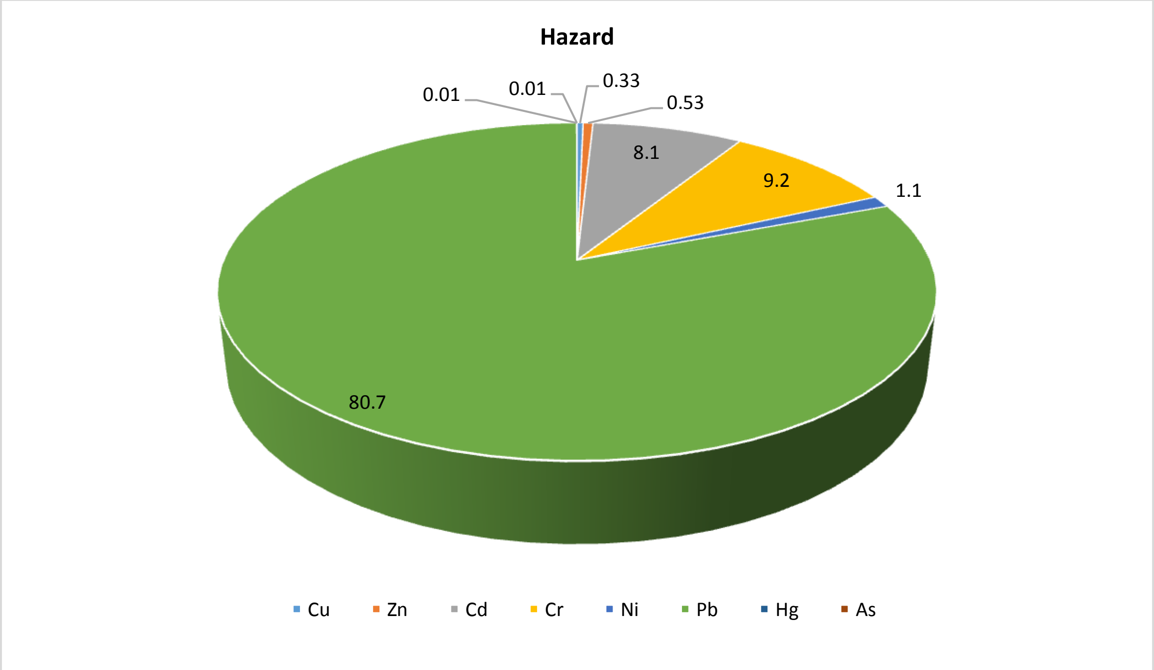

Figure 10: Hazard Index (HI) for Adults

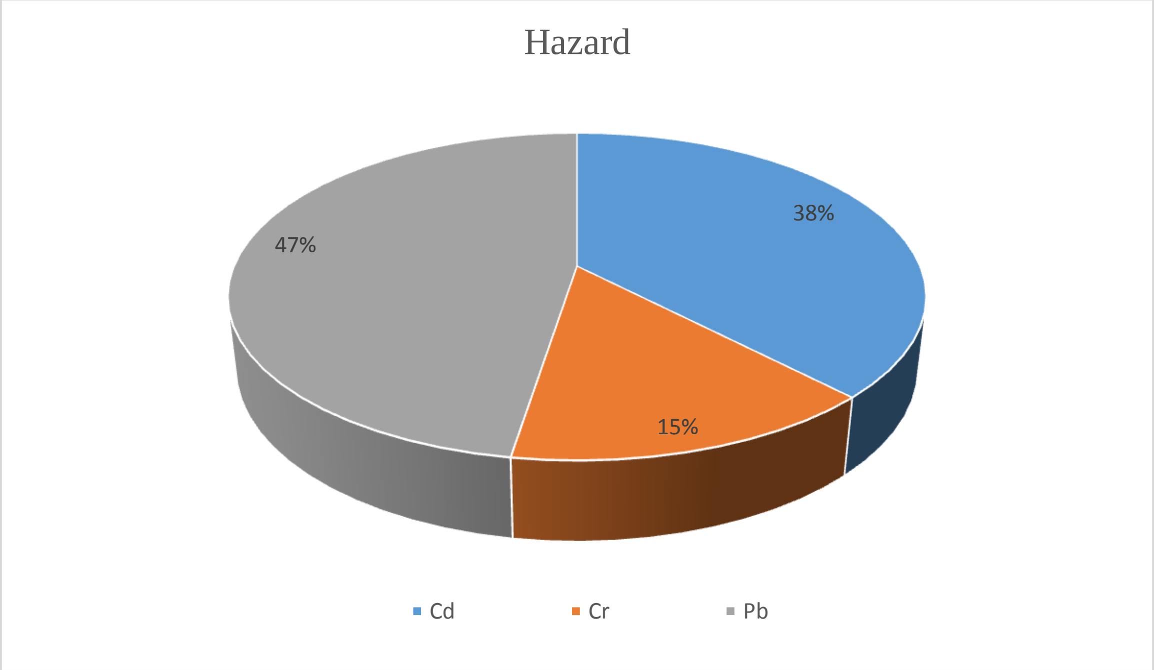

Figure 11: Hazard Index for Children.

Carcinogenic risk assessment of heavy metals for adults and children

Carcinogenic risks of the heavy metals (Cr, Ni, Pb, As and Cd) was calculated, the result are presented in Table 7 and 8 and Figure 12. Ni, Cd, Cr, Pb and As in the soils for adults and children were found to be the highest contributors to the cancer risk. The total cancer risk (TCR) was calculated by summing the individual cancer risk across all exposure pathways. The total Carcinogenic risk values (TCR) for adults and children were $1.18x10^{-1}$ and $9.50x10^{-3}$respectively, which were both higher than the acceptable range of $1x10^{-6}$to $1x10^{-4}$ set by USEPA [32]. The TCR value obtained in this study agrees with TCR value reported by Kamada *et al*. [33,2] and in South Africa but disagree with TCR value which falls below and within the safe level reported by Obasi *et al*., [31] in Ebonyi State, Nigeria.

The higher TCR values for both adults and children indicated significant long-term health effects. The TCR was ranked in the order of Cr > Ni >Pb> Cd > As, showing that this are the main contaminant source that is producing cancer among these heavy metals. Over all cancer risk value was ($1.28x10^{-1}$) higher than the acceptable range, implying great carcinogenic risk. In this study, adults are more at cancer risk than children. The ingestion pathway seems to be the major contributor to excess lifetime cancer risk followed by the dermal pathway (Table 8).

Table 7: Average Daily Dose (ADD) of Heavy Metal in mg/kg by Adult and Children in Soil for Carcinogenic Risk Calculation.

	Average Daily Dose value mg/kg/day cancer risk					
Heavy metals	**Ingestion**		**Inhalation**		**Dermal**	
	Adult	**Child**	**Adult**	**Child**	**Adult**	**Child**
Cu	2.1410^{-2}	$3.99x10^{-3}$	$3.28x10^{-9}$	$1.54x10^{-9}$	$5.29x10^{-3}$	$1.40x10^{-4}$
Zn	$2.58x10^{-4}$	$4.83x10^{-2}$	$3.97x10^{-8}$	$1.85x10^{-8}$	$6.41x10^{-2}$	$1.73x10^{-3}$
Cd	$1.33x10^{-2}$	$2.48x10^{-3}$	$2.04x10^{-9}$	$9.53x10^{-10}$	$3.29x10^{-3}$	$8.61x10^{-5}$
Cr	$3.18x10^{-2}$	$5.94x10^{-3}$	$4.88x10^{-9}$	$2.29x10^{-9}$	$7.88x10^{-3}$	$2.12x10^{-4}$
Ni	$2.79x10^{-2}$	$5.21x10^{-3}$	$4.28x10^{-9}$	$2.01x10^{-9}$	$6.92x10^{-3}$	$1.86x10^{-4}$
Pb	$4.68x10^{-1}$	$8.74x10^{-2}$	$7.19x10^{-5}$	$3.36x10^{-8}$	$1.16x10^{-1}$	$3.12x10^{-3}$
Hg	$6.46x10^{-6}$	$1.21x10^{-6}$	$9.9x10^{-13}$	$4.64x10^{-13}$	$1.6x10^{-6}$	$4.31x10^{-8}$
As	$7.63x10^{-6}$	$1.43x10^{-6}$	$1.17x10^{-12}$	$5.48x10^{-13}$	$1.89x10^{-6}$	$5.09x10^{-8}$

Table: 8 Carcinogenic Risk Assessments

Heavy metals	**Cancer Risk (CR)**							
	Ingestion		**Inhalation**		**Dermal**		**Total Cancer Risk**	
	Adult	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Children**
Cd			$1.29\text{x}10^{-8}$	$6.00\text{x}10^{-9}$			$1.28\text{x}10^{-8}$	$6\text{x}10^{-9}$
Cr	$1.59\text{x}10^{-2}$	$2.97\text{x}10^{-3}$	$2.05\text{x}10^{-2}$	$9.62\text{x}10^{-8}$	$4.96\text{x}10^{-2}$	$1.34\text{x}10^{-3}$	$8.6\text{x}10^{-2}$	$4.31\text{x}10^{-3}$
Ni	$2.34\text{x}10^{-2}$	$4.38\text{x}10^{-3}$	$3.60\text{x}10^{-9}$	$1.69\text{x}10^{-9}$			$2.3\text{x}10^{-2}$	$4.38\text{x}10^{-3}$
Pb	$3.98\text{x}10^{-3}$	$7.43\text{x}10^{-4}$	$3.02\text{x}10^{-9}$	$1.41\text{x}10^{-9}$			$3.98\text{x}10^{-3}$	$7.43\text{x}10^{-4}$
As	$1.15\text{x}10^{-4}$	$2.15\text{x}10^{-5}$	$1.77\text{x}10^{-11}$	$8.28\text{x}10^{-12}$	$6.92\text{x}10^{-6}$	$1.86\text{x}10^{-7}$	$1.22\text{x}10^{-4}$	$2.17\text{x}10^{-4}$
Total	**$4.34\text{x}10^{-2}$**	**$8.11\text{x}10^{-3}$**	**$2.05\text{x}10^{-2}$**	**$9.93\text{x}10^{-8}$**	**$4.96\text{x}10^{-2}$**	**$1.34\text{x}10^{-3}$**	$1.18\text{x}10^{-1}$	$9.50\text{x}10^{-3}$
TCR	$0.128 \approx 1.28\ \text{x}10^{-1}$							

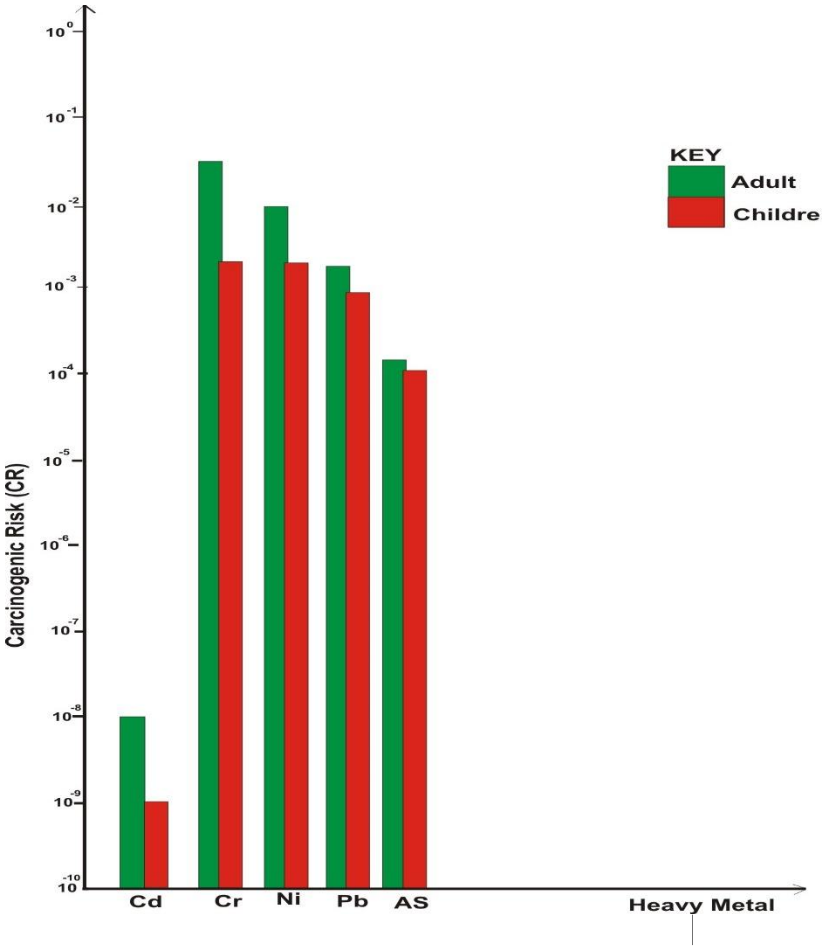

Figure 12: Carcinogenic Risk of the Heavy Metals

IV. Conclusion

Mining activity brings about serious toxic metal pollutions. This study aimed to investigate the ecological and human health risks of toxic metals in tailings and farm land soil from a lead mine area. The results of this study has shown that the farmland soil nearer to the mining area and the tailings heap was highly contaminated by Pb, Zn, and Cu this indicated that the farmland soil are polluted and highly impacted by mining activity. The value of enrichment factor (Er) and risk index (RI) of the study metal in the soil, indicated that the soil is at high risk of contamination and the sequence were as follows Hg >Pb> As > Cd > Cu > Zn > Ni > Cr. The high HQ results suggested that human in the surrounding community of mine tailings are at risk of developing cancer and non-cancer health complications linked with exposure to toxic metals through the three exposure path ways (ingestion, inhalation and dermal contact). The results also indicated that the exposure risks are higher among adults than children mainly via ingestion and dermal exposure. The higher TCR values for both adults and children indicated significant long-term health effects. The TCR was ranked in the order of Cr > Ni >Pb> Cd > As, showing that this are the main contaminant source that is producing cancer among these heavy metals.

Acknowledgement

The authors are grateful to the Chief technologist in the Soil Laboratory of ABU Zaria for the technical support during samples analysis. The first author is grateful to TETFUND for providing support for carrying out conservation work in mining area. The authors also thank anonymous reviewers for their constructive comments that improve the quality of the menu script.

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