Review Article

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A Systematic Review of Ecological and Human Health Risk Associated with Metals in Soils around Mining Areas in Nigeria

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Abstract

Mineral deposits are important to the economic growth of any nation. However, the exploitation of this valuable resources can cause damage to the environment and people health due to the release of heavy metals into the surrounding. This review was carried out to access the extent of contamination, ecological and health impact of heavy metals in soils around mining areas in Nigeria. The review uncovered that the range of metals in the soils were as follow: Arsenic: 0.14-43.42 mg/kg; Cadmium: 0.03-19.00 mg/kg; Cobalt: 0.17-902.70 mg/kg; Chromium: 0.09-126.00 mg/kg; Copper: 0.003-204.04 mg/kg, Mercury: 0.05-0.85 mg/kg; Nickel: 0.95-79.20 mg/kg, Lead: 0.20-959.30 mg/kg, Zinc: 0.004-1693.10 mg/kg and Iron: 1.01-51700 mg/kg. Contamination assessment of these soils showed that they were slightly to very highly contaminated by these heavy metals. The review also uncovered that metals in soils around the mining areas in the country are deleterious to the ecosystem. This review also unraveled that Pb play a significant role in carcinogenic health risk through oral ingestion of contaminated soils while non-carcinogenic health risks are promoted by dermal contact with Co and oral ingestion of Fe in the area. Children are more susceptible to these risks than adult because of their low immunity. It is suggested that proper legislation and its enforcement should be carried out to reduce the impact of mining on the environment and human health.

Keywords: Ecological Health Risks; Human Health Risks; Mining; Nigeria; Soil

1.0 Introduction

Minerals develop under a wide variety of chemical and physical conditions, such as temperature and pressure, in all geologic settings (Haldar, 2020). These minerals' primary building components are elements, particularly metals. Sphalerite, for example, is a zinc ore with the chemical formula (Zn, Fe)S. Nigeria has a wealth of mineral resources, including gold, lead/zinc, cassiterite, tantalite, magnesite, uranium, iron ore, phosphate, manganese, and barite. Because of their persistence, indestructibility, and deadly properties, toxic metals in soils have become a serious environmental hazard (Adewumi and

Oretade, 2012). Metals that are potentially poisonous, such as Cr, Cu, Cd, Pb, and As, are clearly the most harmful in the ecosystem (Lei *et al.,* 2010). Mineral extraction, processing, purification, refining, and the removal of deposit wastes are examples of anthropogenic activities that have a key role in increasing the availability of these elements in the environment (Fashola *et al.,* 2016). They can also be introduced by geogenic processes, such as rock weathering (Finkelman *et al.*, 2018).

In the areas resulting from these operations, dangerous metals connected with ores and inactive mining locations are transferred into soils (Oyebamiji *et al.,* 2018), sediments (Adewumi and Laniyan, 2020), and dusts (Shevchenko *et al.*, 2003). Crops produced on contaminated soils absorb components from the environment and, when consumed by humans, can cause serious health problems (Adewumi and Laniyan, 2020). Humans are exposed to these metals through polluted soils, garbage, tailings, dust, and plants (Yasmin, 2010).

Human health risk assessment is a procedure that determines the nature and likelihood of adverse health outcomes in humans exposed to metals in polluted media from the environment (USEPA, 2016), whereas ecological risk assessment is a procedure that determines the likelihood of adverse ecological outcomes as a result of exposure to one or more stressors (Jain *et al.*, 2012). Many studies, like Proshad *et al.* (2019) and Kormoker *et al.* (2019), have studied human health and ERs linked with hazardous metals in environmental media. The HRA of metals defines the potential danger of these metals in the entire ecosystem, whereas the HRA of people primarily evaluates health hazards associated with individuals and does not take nonhumans into account (Roba *et al.* 2016). The simultaneous calculation of ecological and health hazards indicators can help provide a more comprehensive picture of pollution in the environment (Proshad *et al.*, 2019).

This study examines the amount, contamination, environmental, and health risks associated with toxic metals in soils around mining sites in Nigeria. This report is intended to give an insight into the impact of heavy metals emanating from mining activities on soils across the country. It also involves exploring the ecological and health dangers associated with these anthropogenic activities.

2.0 Study Area

The altitude of Nigeria varies from 600 to 700 meters along the coastline to over 1,200 meters in the Jos Plateau and sections of the eastern highlands near the Cameroon demarcation line. The climate of Nigeria is tropical, with wet and dry seasons that differ depending on where you are. For the majority of the year, the southeast is hot and humid, whilst the southwest and deeper interior are dry. The rainy season in the south runs from March to November, whereas it runs from mid-May to September in the north. Every year, the southeast receives roughly 3,000 mm of rain, whereas the southwest receives just about 1,800 mm. Temperature and humidity are normally consistent throughout the year in the south, while seasons vary substantially in the north; the daily temperature range is much larger during the northern dry season. Nigerians are anticipated to number 216.7 million by 2022. Nigeria's geology is classified into three litho-petrological components, according to Obaje (2009): the Basement Complex, Younger Granites, and Sedimentary Basins. Precambrian rocks include the Migmatite-Gneiss Complex, the Schist Belts, and the Older Granites. The younger granites, which are mostly Jurassic magmatic rings, are mostly found in Jos and parts of North-central Nigeria, whereas the Sedimentary Basins, which include the Dahomey Basin, Sokoto Basin, Chad Basin, Benue Trough, Mid-Niger (Bida/Nupe) Basin, and Niger Delta Basin, are made up of Cretaceous to Tertiary sediments.

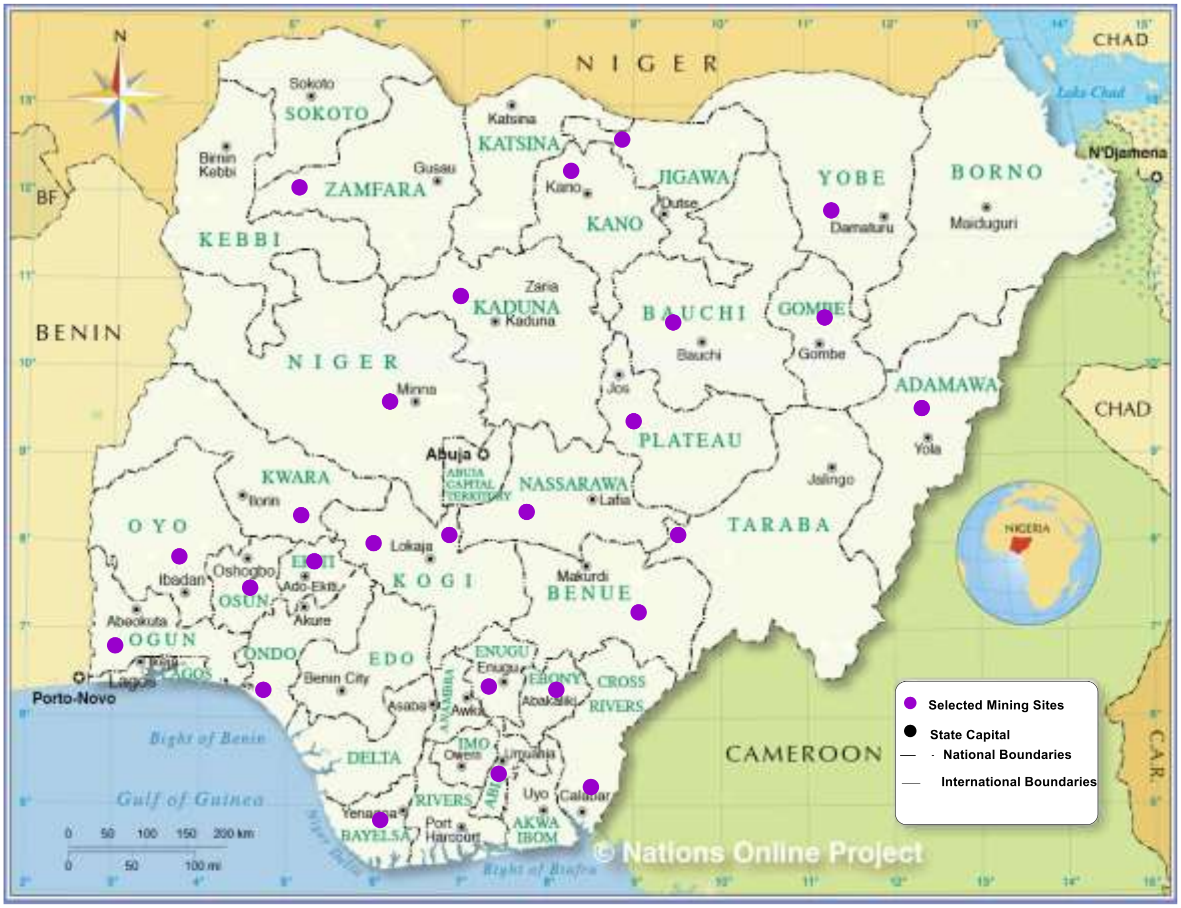

Figure 1: Map of Nigeria showing mining areas covered in this review

3.0 Review Methodology

The area of review interest was correctly identified for the purposes of this evaluation. Heavy metals in urban soils in Nigeria were subjected to a thorough examination of their ecological and health risks. Following that, important cities of interest were chosen to be included. Thirty-three large cities were chosen, including Abuja, the Federal Capital Territory. Online searches were conducted for related studies published in peer-reviewed publications in specific cities. Accessing related publications published in national and international peer reviewed journals was done using Google search, Google scholar, Africa Journal Online (AJOL), and SCOPUS archives. After that, the criteria for data extraction were appropriately established. Depth of sampling, heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, and Fe), and sources were all key aspects considered for this study. The data was then extracted. The average concentration of heavy metals in soils was used. Data was also examined using widely accepted methods for assessing pollution, environmental, and human health concerns. The contamination factor and contamination degree (CD) (Equation 1) were used to determine the level of heavy metal contamination in Nigerian urban soils. Equation was used to compute the ecological risk assessment of heavy metals in Nigerian urban soils (2). The health hazards of heavy metals in Nigerian urban soils were calculated using equation (3). SURFER^{TM} was used to create spatial maps.

3.1 Contamination Factor (CF)

In the examination of soil contamination, the contamination factor (CF) in equation 1 was also employed. All four classes are recognized by the CF, which is a single-element index (Hakanson, 1980). The different contamination factor classes and levels are depicted in Table 1 below.

$$Contamination\ Factor = \frac{Metal\ Concentration}{Concentration\ of\ Element\ in\ Background\ Soils} \quad (1)$$

Table 1: Classification of Contamination Factor (Hakanson, 1980)

S/N	CF Value	Contamination Factor Level
1.	CF < 1	Low contamination factor indicating low contamination
2.	1 ≤ CF < 3	Moderate contamination factor
3.	3 ≤ CF < 6	Considerable contamination factor
4.	6 ≥ CF	Very high contamination factor

3.2 Contamination Degree (CD)

The CF of the environment is the total of contamination factors for all substances studied (Hakanson, 1980). The CD's purpose is to provide a measure of overall contamination in surface layers at a given sample location. The CD is divided into four categories. Equation 2 shows the formula for calculating CD. The CD classification is presented in Table 2.

$$C_d = \sum_{i=1}^{n} C_f^i \quad (2)$$

The Contamination Degree is Cd, and the Contamination Factor is Cf.

Table 2: Classification of Contamination Degree (Hakanson, 1980)

S/N	CF Value	Contamination Factor Level
1.	CD < 8	Low degree of contamination
2.	8 ≤ CD < 16	Moderate degree of contamination
3.	16 ≤ CD < 32	Considerable degree of contamination
4.	CD ≥ 32	Very high degree of contamination

3.3 Assessment of Potential Ecological Risk

To relate ecological and environmental implications to toxicity, the ecological risk index is used to measure heavy metal pollution in soil, and the toxic-response factors (Tri) for Cu, Zn, Cd, Cr, Ni, and Pb are 5, 1, 30, 2, 5, and 5 (g/g) respectively (Hakanson, 1980). ERI is calculated using Equation 3.

$$E_R^i = T_R^i \times C_f^i \quad (3)$$

The toxic-response factor is Tr, while the single-element pollution factor is CF.

3.4 Potential Ecological Risk Index (PERI)

A semi-quantitative evaluation of regional pollution levels is calculated using PERI. It may be expressed using Equation 4 (Wang *et al.*, 2015):

$$RI = \sum_{i=1}^{m} E_R^i \quad (4)$$

Where ERi is the potential ecological risk of a single element. (TR for Zn = 1, Cr = 2, Cu = 5, Pb = 5, Cd = 30).

3.5 Heavy Metals in Soils: A Health Risk Assessment

The pathways of heavy metal exposure in contaminated soils are calculated following guidelines from many American publications. The following exposure equations 5 to 11 were used to calculate ADI (mg/kg/day) for the various routes, as recommended by (USEPA, 1989).

3.5.1 Heavy Metal Ingestion Through Soil

The following equation may be used to estimate average daily heavy metal consumption from soil ingestion:

$$ADI_{ing} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT} \quad (5)$$

The average daily intake of heavy metals from soil is measured in mg/kg-day, while the heavy metal concentration in mg/kg for soil is measured in mg/kg. The average dosage is measured in days, the ingestion rate is measured in milligrams per day, the exposure frequency is measured in days per year, the exposure length is measured in years, the exposed individual's body weight is measured in kilograms, and the ingestion rate is measured in milligrams per day. CF is the kg/mg conversion factor.

3.5.2 Soil Particulate Inhalation of Heavy Metal

Equation 6 is used for predicting average daily heavy metal ingestion through soil breathing:

$$ADI_{inh} = \frac{C_s \times IR_{air} \times EF \times ED}{BW \times AT \times PEF} \quad (6)$$

where ADIinh represents the average daily intake of heavy metals inhaled from soil in mg/kg/day, CS represents the heavy metal concentration in soil in mg/kg, IRair represents the inhalation rate in m^3/day, and PEF represents the particle emission factor in m^3/kg. The terms EF, ED, BW, and AT are specified in Equation 5.

Equation 7 shows the dermal contact with soil equation for estimating average daily heavy metal intake by dermal contact with soil:

$$ADI_{dems} = \frac{C_s \times SA \times FE \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (7)$$

where ADIdems is the exposure dosage in mg/kg/day via dermal contact. CS represents the heavy metal concentration in soil in mg/kg, SA represents the exposed skin area in cm^2, FE represents the proportion of the dermal exposure ratio to soil, AF represents the soil adherence factor in mg/cm^2, and ABS is the fraction of the applied dosage absorbed across the skin. EF, ED, BW, CF, and AT are defined in Equation 6 before. The exposure parameters utilized for the health risk assessment for a conventional home exposure scenario along various exposure paths are shown in Table 3.

Table 3: Health risk parameters used in this review

S/N	Parameters	Unit	Child	Adult	References
1.	Body Weight (*BW*)	Kg	15	70	DEA, 2010
2.	Exposure Factor (*EF*)	days/year	350	350	DEA, 2010
3.	Exposure Duration (*ED*)	Year	6	30	DEA, 2010
4.	Ingestion Rate (*IR*)	mg/day	200	100	DEA, 2010
5.	Inhalation Rate (*IRair*)	m^3/day	10	20	DEA, 2010
6.	Skin Surface Area (*SA*)	cm^2	2100	5800	DEA, 2010
7.	Soil Adherence Factor (*AF*)	mg/cm^2	0.2	0.07	DEA,2010
8.	Dermal Absorption Factor (*ABS*)	none	0.1	0.1	DEA, 2010
9.	Dermal Exposure Ratio (*FE*)	none	0.61	0.61	DEA, 2010
10.	Particulate Emission Factor (*PEF*)	m^3/kg	1.3×10^9	1.3×10^9	DEA, 2010
11.	Conversion Factor (*CF*)	kg/mg	10^{-6}	10^{-6}	DEA, 2010
12.	Average Time (*AT*)				
	For-Carcinogens	days	365×70	365×70	DEA, 2010
	For Non-Carcinogens		365×ED	365×ED	DEA, 2010

3.5.3 Risk Assessment of Non-Carcinogenic Substances

The hazard quotient is a term used to indicate non-cancerous risks (HQ). The probability of a person experiencing a negative effect is expressed as HQ, which is a unit less number. As shown in Equation 8 (USEPA, 1989), the chronic reference dose (RfD) in mg/kg/day of a given heavy metal is defined as the quotient of ADI or dosage divided by the toxicity threshold value, which is referred to as the chronic reference dose (RfD) in mg/kg-day:

$$HQ = \frac{ADI}{RfD} \qquad (8)$$

The total of all the HQs owing to individual heavy metals is the non-carcinogenic effect on the population for n number of heavy metals. This is referred to as the Hazard Index (HI) in a study issued by the USEPA (USEPA, 1989). Equation 9 shows the mathematical description of this parameter:

$$HI = \sum_{k=1}^{n} HQ_k = \sum_{k=1}^{n} \frac{ADI_k}{RfD_k} \qquad (9)$$

Heavy metal k values are HQk, ADIk, and RfDk. If the HI value is less than one, the exposed population is unlikely to incur unfavorable health consequences. If the HI value is more than one, non-carcinogenic implications may be a concern (USEPA, 1989).

3.5.4 Assessment of Carcinogenic Risk

The incremental risk of a person developing cancer over their lifetime as a result of exposure to a suspected carcinogen is used to quantify the dangers of carcinogens. The calculation for calculating the increased lifetime cancer risk is as follows:

$$Risk_{pathway} = \sum_{k=1}^{n} ADI_k CSF_k \qquad (10)$$

where A lifetime risk is the probability of an individual acquiring cancer during their lifetime. ADIk (mg/kg/day) and CSFk (mg/kg/day) are the average daily intake and cancer slope factor for the kth heavy metal, respectively, for n number of heavy metals. The slope factor directly relates an individual's projected daily intake of heavy metal over the course of a lifetime of exposure to their incremental risk of developing cancer (USEPA, 1989).

The overall increased lifetime cancer risk for a person is calculated using the following calculation, which takes into account the average effect of individual heavy metals across all pathways:

$$Risk_{(total)} = Risk_{(ing)} + Risk_{(inh)} + Risk_{dermal} \qquad (11)$$

Risk(ing), Risk(inh), and Risk(dermal) are three types of risk contributions: ingestion, inhalation, and dermal. As indicated in Table 4, RfD and CSF values acquired mostly from the South African Department of Environmental Affairs and the USEPA are used to construct both non-carcinogenic and carcinogenic risk assessments of heavy metals.

Table 4: Reference doses (RfD) in (mg/kg-day) and Cancer Slope Factors (CSF) for the different heavy metals

S/N	Heavy Metal	Oral RfD	Dermal RfD	Inhalation RfD	Oral CSF	Dermal CSF	Inhalation CSF	References
1.	As	3E-4	3E-4	3E-4	1.50E+00	1.50E+00	1.50E+01	DEA, 2010
2.	Pb	3.6E-3	-	-	8.50E-03	-	4.20E-02	DEA, 2010;
3.	Hg	3E-4	3E-4	8.6E-5	-	-	-	DEA, 2010
4.	Cd	5E-4	5E-4	5.7E-5	-	-	6.30E+00	DEA, 2010
5.	Cr(VI)	3E-3	-	3E-5	5.00E-01	-	4.10E+01	DEA, 2010
6.	Co	2E-2	5.7E-6	5.7E-6	-	-	9.80E+00	DEA, 2010
7.	Ni	2E-2	5.6E-3	-	-	-	-	DEA, 2010
8.	Cu	3.7E-2	2.4E-2	-	-	-	-	DEA, 2010
9.	Zn	3E-1	7.5E-2	-	-	-	-	DEA, 2010
10.	Fe	7E-3						

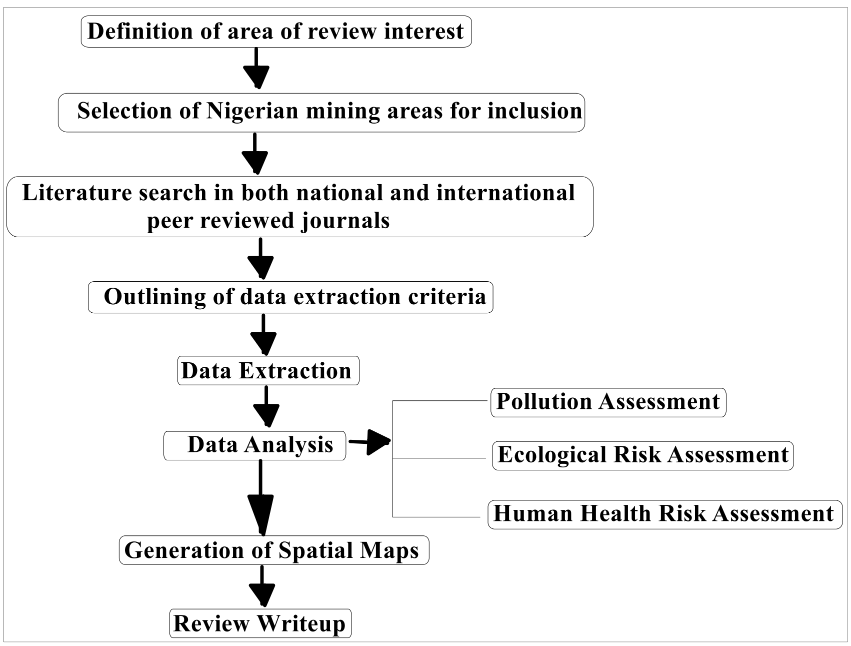

Figure 2: Steps in writing the review paper

4.0 Heavy Metals in Soils around Mining areas in Nigeria

This study uncovered that soils around mining areas in Nigeria are collected at a depth of between 0 and 30 cm below the surface (Table 5). For heavy metals analysis in urban soils of the country, aqua regia, HNO_3-H_2O_2-HCl, HCl-HNO_3-HF-$HClO_4$, HNO_3-$HClO_4$-HF, HNO_3-H_2SO_4, $HClO_3$-HNO_3-H_2SO_4 and BCR sequential extraction digestions were employed while Atomic Absorption Spectrometer (AAS), Inductively Coupled Plasma – Mass Spectrometer (ICP-MS), Flame Atomic Absorption Spectrometer (FAAS) Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES), Inductively Coupled Plasma – Atomic Emission Spectrometer (ICP-AES); X-Ray Fluorescence (XRF) (Table 5). Artisanal, subsurface and mechanized mining techniques are used in the extraction of natural deposits in the country (Table 5). However, artisanal mining outweighs mechanized mining in the country.

Average concentration of heavy metals in soils around mining areas in Nigeria are presented in Table 5. The concentration of As in soils around mining areas in Nigeria are between 0.14 mg/kg and 43.42 mg/kg. The concentration of As in soils around Abakaliki (Obasi, 2020), Birin Gwari (Bello *et al.*, 2019) and Igun (Bello *et al.*, 2019) are above the recommended South Africa standard for As in soils (DEA, 2010). Arsenic in soils of Birin Gwari (Bello *et al.*, 2019) and Igun (Olujimi *et al.*, 2015) are above those reported in China by Li *et al.* (2018) and Ghana by Kazapoe *et al.* (2022). The amount of Cd in soils around mining sites in Nigeria is between 0.03 mg/kg and 19.00 mg/kg. Soils around mining areas in Yelu are above the recommended South Africa standard for Cd in soils (DEA, 2010). Cadmium in soils of Umunneochi, Mubi, Yelu, Imirijin, Abakaliki, Kazaure, El-Anim University proposed site, Ologbun, Igun and Olode are higher than those reported by Li *et al.* (2018) while only Cd in soils of Birin Gwari, Shanono and Anka are lower than those reported by Kamunda *et al.* (2016). The amount of Cobalt in soils around mining areas in Nigeria is between 0.17 mg/kg and 902.70 mg/kg. Cobalt in soils around Dorowa mining sites are lower than the recommended South Africa standard for Cobalt in soils (DEA, 2010). Chromium in soils around mining sites in Nigeria is between 0.09 mg/kg and 126.00 mg/kg. The concentration of Cr in soils around mining sites of Imirijin, Akampa, Abakaliki, Kazaure, Birin Gwari, Oke-ere, Iludun-Oro, Itakpe, Ologbun, Ode-Aye, Igun, Olode, Dorowa, Arufu and Anka are above the recommended South Africa standard for As in soils (DEA, 2010). The concentration of Cu in soils around mining area in Nigeria is between 0.003 mg/kg and 204.04 mg/kg. Copper in soils around Yelu, Abakaliki, Oke-Ere, Iludun-Oro, Itakpe, Ode-Aye, Olode, Dorowa and Anka are above the recommended South Africa standard for As in soils (DEA, 2010). The amount of Cu in soils of Yelu, Abakaliki, Oke-Ere, Iludun-Oro, Itakpe, Olode, Dorowa and Anka are higher than those reported in China by Li *et al.* (2018), South Africa by Kamunda *et al.* (2016) and Ghana by Kazapoe *et al.* (2022). Mercury in soils around mining areas in Nigeria are between 0.05 mg/kg and 0.85 mg/kg. The amount of Hg in these soils are lower than the recommended South Africa standard (DEA, 2010). The amount of Ni in soils around mining sites in Nigeria are between 0.95 mg/kg and 79.20 mg/kg which are lower than the South Africa standard (DEA, 2010). The amount of Pb in soils of around mining areas in Nigeria is between 0.20 mg/kg and 959.30 mg/kg. Lead in soils of Yelu, Iludun-Oro, Ode-Aye, Arufu and Anka exceed the recommended South Africa standard for Pb in soils (DEA, 2010). The amount of Zn in soils around mining areas in Nigeria is between 0.004 mg/kg and 1693.10 mg/kg. Soils of Yelu, Udege, El-Anim University proposed site and Olode are above recommended South Africa standard for Zn in soils and those reported in China by Li *et al.* (2018), South Africa by Kamuda *et al.* (2016) and Ghana by Kazapoe *et al.* (2022)

Table 5: Information of soil sampling sites around mining sites in Nigeria

	Location	State	Depth of sampling	Number of samples	Digestion process	Chemical analysis	Type of Mining	Minerals/Deposit Mined
1	Umunneochi	Abia	0-30	3	HNO_3-H_2SO_4	AAS	Quarrying	Granite
2	Mubi	Adamawa	0-30	12	Aqua Regia	AAS	Artisanal Mining	Feldspar, quartz, clays, gem minerals
3	Yelu	Bauchi	0-15	4	Aqua Regia	AAS	Artisanal Mining	Galena, pyrite, sphalerite, malachite
4	Imirijin	Bayelsa	0-15	20	Aqua Regia	AAS	Subsurface Mining	Oil and Gas
5	Yonov	Benue	0-15	18	$HClO_3$-HNO_3-H_2SO_4	AAS	Artisanal Mining	Lead-Zinc
6	Akampa	Cross River	0-30	15	Aqua Regia	ICP-MS	Artisanal Mining	Barite
7	Abakaliki	Ebonyi	0-10	58	Aqua Regia	AAS	Artisanal Mining	Lead-Zinc
8	Ijero-Ekiti	Ekiti	0-20	35	Aqua Regia	ICP-MS	Artisanal Mining	Quartz, feldspar, mica, tourmaline, beryl, aquamarine, garnet
9	Ashaka	Gombe	0-10	24	Aqua Regia	AAS	Artisanal Mining	Limestone
10	Kazaure	Jigawa	0-15	14	Aqua Regia	AAS	Artisanal Mining	Glass Sand
11	Birin Gwari	Kaduna	0-5	56		XRF	Artisanal Mining	Gold
12	Shanono	Kano	0-15	40	$HClO_3$-HNO_3-H_2SO_4	FAAS	Artisanal Mining	Gold
13	Oke-ere	Kogi	0-30	48	$HClO_3$-HNO_3-H_2SO_4	AAS	Artisanal Mining	Tin, tantalite and columbite
14	Iludun-Oro	Kwara	0-20	18	Aqua Regia	ICP-MS	Artisanal Mining	Tantalite, tin, niobium, columbite and gemstones
15	Itakpe/Agbaja	Kogi	0-10	18	HCl-HNO_3-HF-$HClO_4$	AAS	Artisanal Mining	Iron ore
16	Udege	Nasarrawa	0-15	3	HCl-HNO_3-$HClO_4$	AAS	Mechanized Mining	Cassiterite and Columbite
17	El-Anim University Proposed site	Niger	0-15	24	HNO_3-H_2O_2-HCl	FAAS	Artisanal Mining	Gold
18	Ologbun	Ogun	0-15	30	HNO_3-$HClO_4$-HF	FAAS	Not Reported	Bitumen
19	Ode-Aye	Ondo	0-10	15	Aqua Regia	ICP-MS	Not Reported	Bitumen
20	Igun	Osun	0-20	28	BCR Seq Extraction	ICP-OES	Artisanal Mining	Gold
21	Olode	Oyo	0-5	24	Aqua Regia	ICP-AES	Artisanal Mining	Beryl
22	Dorowa	Plateau	0-20	3		XRF	Mechanized/Artisanal Mining	Tin
23	Arufu	Taraba	0-10	38	Aqua Regia	ICP-MS	Artisanal Mining	Lead-Zinc-Fluorite
24	Trona	Yobe	0-15	4	HNO_3-H_2O_2	AAS	Artisanal Mining	Trona
25	Anka	Zamfara	0-25	42	HCl-HNO_3-$HClO_4$	ICP-MS	Artisanal Mining	Gold

AAS – Atomic Absorption Spectrometer; **ICP-MS** – Inductively Coupled Plasma – Mass Spectrometer; **FAAS** – Flame Atomic Absorption Spectrometer; **ICP-OES** - Inductively Coupled Plasma – Optical Emission Spectrometer; **ICP-AES** - Inductively Coupled Plasma – Atomic Emission Spectrometer; **XRF** – X-Ray Fluorescence

Table 6: Average concentration of Heavy Metals in Soils around Mining Sites in Nigeria

	Location	State	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn	Fe	Authors
1	Umunneochi	Abia	-	0.61	1.48	1.91	-	-	2.21	0.43	-	436.36	Ihejirika *et al.*, 2021
2	Mubi	Adamawa	-	0.31	-	-	1.44	-	10.52	5.03	1.40	-	Bwadanglary *et al.*, 2019
3	Yelu	Bauchi	-	16.66	-	-	150.6	-	-	324.73	294.44	-	Sanusi *et al.*, 2019
4	Imirijin	Bayelsa	-	3.3	-	79.50	-	0.07	-	6.00	1.70	42.50	Meindinyo and Agbalagba, 2012
5	Yonov	Benue	-	-	-	-	-	-	-	1.26	0.66	-	Paul and Babatunde, 2021
6	Akampa	Cross River	-	-	-	99.80	15.38	-	9.95	33.19	42.6	4500	Ochelebe *et al.*, 2020
7	Abakaliki	Ebonyi	11.19	1.08	-	9.00	13.40	0.37	-	18.49	48.07	-	Obasi, 2020
8	Ijero-Ekiti	Ekiti	1.77	0.14	8.28	4.74	59.00	0.07	6.53	30.61	22.44	56300	Laniyan and Adewumi, 2020
9	Ashaka	Gombe	-	0.10	-	0.09	0.77	0.05	0.95	0.20	0.13	1.01	Usman *et al.*, 2016
10	Kazaure	Jigawa	-	3.50	-	15.00	11.20	-	16.00	18.00	40.00	33.00	Waziri *et al.*, 2013
11	Birin Gwari	Kaduna	19.00	-	-	51.00	10.00	-	16.00	28.00	27.50	46000	Waziri, 2014
12	Shanono	Kano	0.57	0.002	0.17	4.43	0.003	-	0.27	0.36	0.004	1.38	Bello *et al.*, 2019
13	Oke-ere	Kogi	1.92	0.004	28.00	126.00	117	-	63.16	51.40	24.10	85.8	Oluwasola *et al.*, 2020
14	Iludun-Oro	Kwara	-	-	-	14.76	45.28	-	21.53	107.72	48.17	51700.00	Oyebamiji *et al.*, 2018
15	Itakpe/Agbaja	Kogi	-	1.82	-	51.83	204.04	-	-	29.67	5.37	-	Aluko *et al.*, 2018
16	Udege	Nasarrawa	1.71	-	-	4.31	0.73	-	-	1.21	10.82	25.58	Aremu *et al.*, 2010
17	El-Anim Uni. Proposed site	Niger	-	2.87	-	-	-	-	-	131.71	286.21	15735.46	Okonkwo *et al.*, 2021
18	Ologbun	Ogun	-	5.16	-	42.50	-	-	24.10	28.20	226.00	170.00	Gbadamosi *et al.*, 2018
19	Ode-Aye	Ondo	-	-	122.55	41.51	22.60	-	13.54	22.00	45.16	-	Obasi, 2015
20	Igun	Osun	43.42	3.60	61.19	33.96	10.87	-	62.00	166.95	21.43	49366.40	Olujimi *et al.*, 2015
21	Olode	Oyo	-	19.00	19.21	77.92	76.33	-	22.33	17.92	81.67	37500.00	Okonkwo *et al.*, 2021
22	Dorowa	Plateau	-	-	902.70	50.00	65.70	-	79.20	27.10	1693.10	-	Shibdawa *et al.*, 2019
23	Arufu	Taraba	0.90	0.10	7.10	27.80	8.90	0.10	8.10	959.30	109.30	11900.00	Adewumi *et al.*, 2020
24	Trona	Yobe	-	-	-	-	7.80	-	-	6.19	28.90	0.61	Zanna *et al.*, 2018
25	Anka	Zamfara	0.14	0.03	7.98	42.55	27.15	0.85	15.26	131.76	47.14	17000.00	Adewumi and Laniyan, 2020
	Range		0.14-43.42	0.03-19.00	0.17-902.70	0.09-126.00	0.003-204.04	0.05-0.85	0.95-79.20	0.20-959.30	0.004-1693.10	1.01-51700.00	
	South Africa DEA (2010)		5.80	7.50	300.00	6.50	16.00	0.93	91.00	20.00	240.00	-	DEA, 2010
	China		11.46	0.27		55.90	26.10	0.39	27.70	49.30	67.80	-	Li *et al.*, 2018
	South Africa		79.40	0.05	33.68	278.76	42.51	0.09	112.06	4.79	51.30	-	Kamuda *et al.*, 2016
	Ghana		18.37	-	7.60	86.25	12.56	-	11.24	7.85	27.86	-	Kazapoe *et al.*, 2022

5.0 Contamination of Soils by Heavy Metals around Mining Areas of Nigeria

Contamination assessment of heavy metals in soils around selected mining sites are presented in Table 6. This review showed that soils of Ijero-Ekiti, Shanono, Oke-Ere, Udege, Arufu and Anka were lowly contaminated by As while soils of Abakaliki, Birin-Gwari and Igun are moderately, considerably and very highly contaminated by the same metal (Figure 3). Soils of Umunneochi, Mubi, Imirijin, Ebonyi, Ijero, Ashaka, Kazaure, Shanono, Oke-Ere, Itakpe/Agbaji, El-Amin University proposed site, Ologbun, Igun, Arufu and Anka are lowly contaminated by Cd while soils of Yelu and Olode are moderately contaminated by the metal. Soils in Umunneochi, Abakaliki, Birin-Gwari, Oke-Ere, Ode-Aye, Igun, Olode, Arufu, Anka are lowly contaminated by Co while the soil of Dorowa are moderately contaminated by the same metal. Also, soils of Umunneochi, Ijero-Ekiti, Ashaka, Shanono and Udege are lowly contaminated by chromium while the soils of Abakaliki, Kazaure and Iludun-Oro are moderately contaminated by Cr (Figure 3). Also soils of Igun and Arufu are considerably contaminated by Cr while soils of Imirijin, Akampa, Birin Gwari, Oke-Ere, Itakpe/Agbaja, Ologbun, Ode-Aye, Olode, Dorowa and Anka are very highly contaminated by the metal. Soils of Mubi, Akampa, Abakaliki, Ashaka, Kazaure, Birin-Gwari, Shanono, Oke-Ere, Udege, Igun, Arufu and Trona are lowly contaminated by Cu while soils Iludun-Oro, Ode-Aye, Olode, Dorowa and Anka are moderately contaminated by the metal. Soils of Ijero-Ekiti is considerably contaminated by Cu while soils of Yelu and Itakpe/Agbaja are highly contaminated by the metal. Soils of Imirijin, Abakaliki, Ijero, Ashaka, Arufu and Anka are lowly contaminated by Hg while the soils of Umunneochi, Mubi, Akampa, Ijero, Ashaka, Kazaure, Birin-Gwari, Shanono, Oke-Ere, Iludun-Oro, Itakpe/Agbaja, Ologbun, Ode-Aye, Igun, Olode, Dorowa, Arufu and Anka are contaminated by Ni. Soils of Umunneochi, Mubi, Imirijin, Yonov, Ashaka, Kazaure, Shanono, Udege, Olode and Trona were lowly contaminated by Pb while the soils of Akampa, Ijero, Birin-Gwari, Oke-Ere, Itakpe/Agbaja, Ologbun, Ode-Aye and Dorowa are moderately contaminated by the same metal. Soils of Iludun-Oro are considerably contaminated by Pb while soils of Yelu, El-Amin University proposed site, Arufu and Anka are very highly contaminated by the metal (Figure 3). All soils around selected mining sites in Nigeria are lowly contaminated by Zinc except Yelu and El-Amin University proposed site that are moderately contaminated by the metal while soils around mining sites of Dorowa are very highly contaminated by the metal. Also, contamination degree revealed that soils around mining sites in Umunneochi, Mubi, Yonov, Abakaliki, Ijero-Ekiti, Kazaure, Ashaka, Shanono, Udeje and Trona are lowly contaminated by heavy metals while soils of Imirijin, Birin-Gwari, Iludun-Oro, El-Amin University proposed site, Ologbun and Ode-Aye are moderately contaminated by toxic metals. Furthermore, this review uncovered that soils around mining sites of Yelu, Akampa, Oke-Ere, Itakpe/Agbaja, Igun, Olode, Dorowa and Anka are considerably contaminated by metals while soils of Arufu are very highly contaminated.

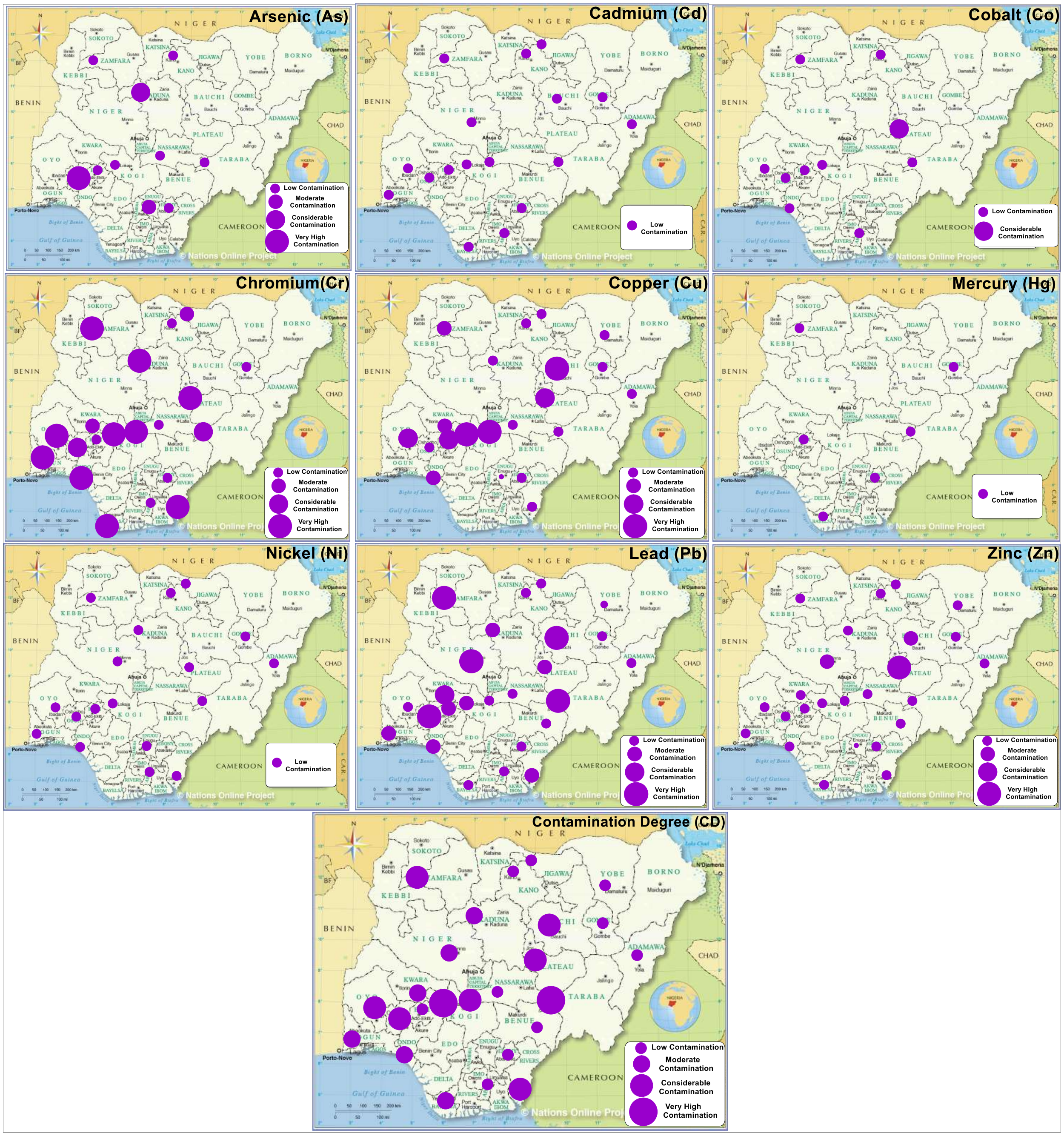

Figure 3: Contamination Factor (CF) and Contamination Degree (CD) of Heavy Metals in Soils around Mining Areas in Nigeria

6.0 Ecological Risk of Heavy Metals in Soils Around Mining Areas of Nigeria

Ecological risk index showed that Cr in soils of all selected mining sites across Nigeria pose slight ecological risk (Figure 4) while Cd poses slight ecological risks in all the mining sites except in soils of Yelu and Olode where it poses medium ecological risk. Copper in soils around the mining sites pose slight ecological risk except in Yelu and Itakpe where it poses medium ecological risk. In all the mining sites, Pb pose slight ecological risk except in Arufu soils where it pose medium ecological risk. The presence of Zn in soils around the mining sites pose slight ecological risk. Chromium is a hazardous element that interferes with plant metabolism, limiting crop development and output while also lowering vegetable and grain quality (Prasad *et al.* 2021). Cadmium affect both aquatic and terrestrial ecosystems. It tends to bioaccumulate particularly in vertebrates, invertebrates, algae and plants (Greenfacts 2022). Copper has a deleterious impact on the activity of microorganisms and earthworms, which can disrupt soil activity. Because of this, the breakdown of organic substances may be significantly slowed (Figure 4). Animals will absorb copper quantities that are harmful to their health if farming soils are contaminated with copper (Lennetech, 2022a). The presence of Pb in the environment affect soil functions especially near highways and farmlands, where extreme concentrations may be present. Also, soil organisms suffer from lead poisoning. Lead is a particularly dangerous chemical, as it can accumulate in individual organisms, but also in entire food chains (Lennetech, 2022b).

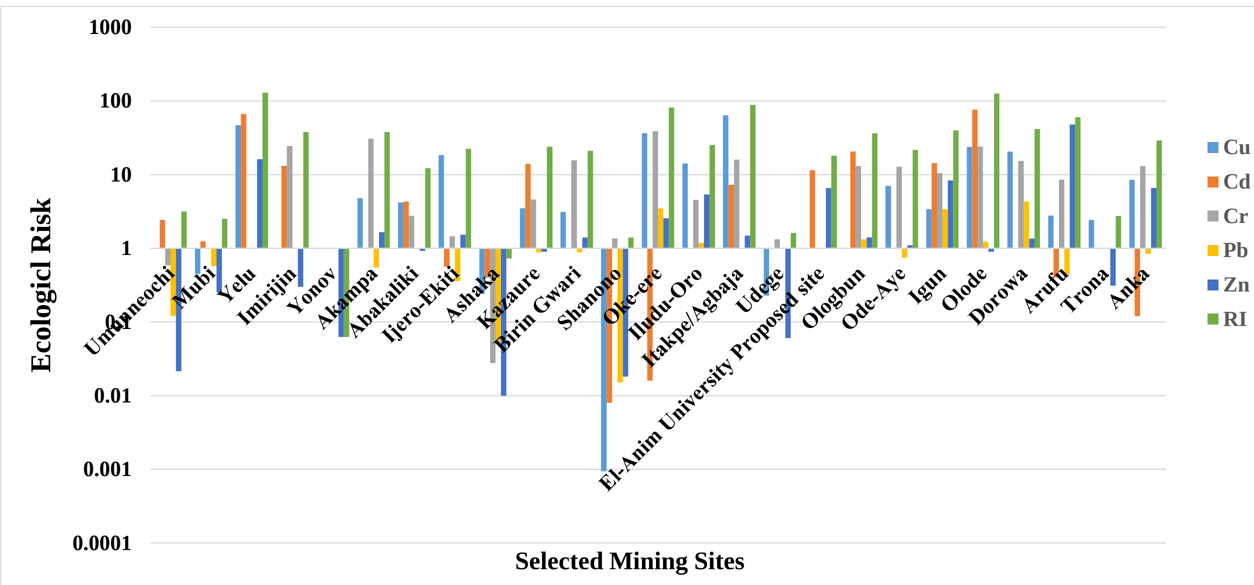

Figure 4: Ecological Risk (ER) and Risk Index (RI) of Heavy Metals in Soils around Mining Areas in Nigeria

7.0 Health Implications of Heavy Metals in Soils around Mining Areas of Nigeria

Mining activities across the globe have negative impact on the health of human beings (Adewumi *et al.* 2021). From this review it was discovered that carcinogenic health risks for children, the average daily intake of As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn and Fe through oral ingestion are 9.8E-6 mg/kg/day, 3.8E-6 mg/kg/day, 1.3E-4 mg/kg/day, 4.3E-5 mg/kg/day, 4.7E-5 mg/kg/day, 2.7E-7 mg/kg/day, 2.4E-5 mg/kg/day, 9.4E-5 mg/kg/day, 1.4E-4 mg/kg/day and 1.8E-2 mg/kg/day respectively while through inhalation they are: 3.8E-10 mg/kg/day, 1.4E-10 mg/kg/day, 4.9 mg/kg/day, 1.6E-9 mg/kg/day, 1.8E-9 mg/kg/day, 1.1E-11 mg/kg/day, 9.2E-10 mg/kg/day, 3.6E-9 mg/kg/day, 5.5E-9 mg/kg/day and 6.8E-7 mg/kg/day each (Table 7). Also for children, the average daily intake of As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn and Fe through dermal contact for carcinogenic health risk are: 1.36E-6 mg/kg/day, 4.8E-7 mg/kg/day, 1.6E-5 mg/kg/day, 5.5E-6 mg/kg/day, 5.9E-6 mg/kg/day, 3.5E-8 mg/kg/day, 3.1E-6 mg/kg/day, 1.2E-5 mg/kg/day, 1.8E-5 mg/kg/day and 2.3E-3 mg/kg/day respectively (Table 7). For adult, the average daily intake through oral ingestion for carcinogenic health for As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn and Fe are 5.3E-6 mg/kg/day, 2.0E-6 mg/kg/day, 6.8E-5 mg/kg/day, 2.3E-5 mg/kg/day, 2.5E-5 mg/kg/day, 1.4E-7 mg/kg/day, 1.3E-5 mg/kg/day, 5.0E-5 mg/kg/day, 7.6E-5 mg/kg/day and 9.5E-3 mg/kg/day respectively while through inhalation they are: 8.1E-10 mg/kg/day, 3.1E-10 mg/kg/day, 1.1E-9 mg/kg/day, 3.5E-9 mg/kg/day, 3.8E-9 mg/kg/day, 2.3E-11 mg/kg/day, 1.9E-9 mg/kg/day, 7.8E-9 mg/kg/day, 1.2E-8 mg/kg/day and 1.5E-63 mg/kg/day respectively. Through dermal contact the average daily intake for adult for carcinogenic health risk are: 1.3E-6 mg/kg/day, 4.9E-7 mg/kg/day, 1.7E-5 mg/kg/day, 5.7E-6 mg/kg/day, 6.2E-6 mg/kg/day, 3.7E-8 mg/kg/day, 3.2E-6 mg/kg/day, 1.3E-5 mg/kg/day, 1.9E-5 mg/kg/day and 2.4E-5 mg/kg/day (Table 7).

For non-carcinogenic health risk, the average daily intake through oral ingestion for children for As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn and Fe are 1.2E-4 mg/kg/day, 4.4E-5 mg/kg/day, 1.5E-3 mg/kg/day, 5.4E-4 mg/kg/day, 3.2E-6 mg/kg/day, 2.8E-4 mg/kg/day, 1.1E-3 mg/kg/day, 1.7E-3 mg/kg/day and 2.1E-1 mg/kg/day respectively while through inhalation they are: 4.4E-9 mg/kg/day, 1.7E-9 mg/kg/day, 5.7E-8 mg/kg/day, 2.1E-8 mg/kg/day, 2.1E-8 mg/kg/day, 1.2E-10 mg/kg/day, 1.1E-8 mg/kg/day, 4.2E-8 mg/kg/day, 6.4E-8 mg/kg/day and 7.9E-9 mg/kg/day each (Table 7). Non-carcinogenic health risk through dermal contact for As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn and Fe are: 1.5E-9 mg/kg/day, 5.6E-5 mg/kg/day, 1.9E-4 mg/kg/day, 6.9E-5 mg/kg/day, 6.9E-5 mg/kg/day, 4.1E-7 mg/kg/day, 1.4E-4 mg/kg/day, 1.4E-4 mg/kg/day, 2.1E-4 mg/kg/day and 2.7E-2 mg/kg/day each (Table 7). The average daily intake through oral ingestion for children for As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn and Fe are 1.2E-5 mg/kg/day, 4.7E-6 mg/kg/day, 1.6E-4 mg/kg/day, 5.3E-5 mg/kg/day, 5.8E-5 mg/kg/day, 3.5E-7 mg/kg/day, 2.9E-5 mg/kg/day, 1.2E-4 mg/kg/day, 1.8E-4 mg/kg/day and 2.2E-2 mg/kg/day respectively while through inhalation they are: 2.7E-11 mg/kg/day, 1.0E-11 mg/kg/day, 3.5E-10 mg/kg/day, 1.2E-10 mg/kg/day, 1.3E-10 mg/kg/day, 7.6E-13 mg/kg/day, 6.6E-11 mg/kg/day, 2.6E-10 mg/kg/day, 3.9E-10 mg/kg/day and 4.9E-8 mg/kg/day each (Table 7). Non-carcinogenic health risk through dermal contact for As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn and Fe are: 3.0E-6 mg/kg/day, 1.2E-6 mg/kg/day, 3.9E-5 mg/kg/day, 1.3E-5 mg/kg/day, 1.4E-5 mg/kg/day, 8.5E-8 mg/kg/day, 7.4E-4 mg/kg/day, 2.9E-5 mg/kg/day, 4.4E-5 mg/kg/day and 5.5E-3 mg/kg/day each (Table 7).

The review also revealed that children and adults are exposed to carcinogenic health risks through oral ingestion of Pb in contaminated soils around mining areas of Nigeria (Figures 5 and 7) while they are exposed to non-carcinogenic health risks through dermal contact with Co and oral ingestion of Fe in soils of the selected mining areas (Figures 6 and 7). In Nigeria, studies such as Adewumi *et al*. (2020) showed that high amounts of heavy metals bioaccumulate in children's hairs and nails from Anka area. According to the World's Health Organization (WHO, 2021), Children are more susceptible to lead poisoning than adults because they absorb 4–5 times the amount of ingested lead from the same source. Furthermore, children's natural curiosity and age-appropriate hand-to-mouth behavior lead to them mouthing and ingesting lead-containing or lead-coated things such contaminated dirt or dust, as well as flakes from decaying lead-based paint. This pathway of exposure is exacerbated in children with pica (consistent and obsessive desires to eat non-food things), who may pick at and eat leaded paint from walls, door frames, and furniture. Once lead enters the body, it is distributed to organs such as the brain, kidneys, liver and bones. The body stores lead in the teeth and bones, where it accumulates over time. Lead stored in bone may be released into the blood during pregnancy, thus exposing the fetus. Undernourished children are more susceptible to lead because their bodies absorb more lead if other nutrients, such as calcium or iron, are lacking. Children at highest risk are the very young (including the developing fetus) and the economically disadvantaged. Excess iron in the body can lead to cirrhosis which can lead to liver cancer (Mayoclinic, 2020). It can also lead to the damage of pancreas which may instigate diabetes. The capacity of your heart to circulate enough blood for your body's demands is harmed when you have too much iron in your system. Congestive heart failure is the medical term for this condition. Hemochromatosis can also lead to irregular heartbeats (Mayoclinic, 2020).

Table 7: Average daily intake (mg/kg/day) of heavy metals in soils around mining areas of Nigeria for children and adults carcinogenic health risk

		As	**Cd**	**Co**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	**Fe**
					Child						
Oral Ingestion	**Min**	1.5E-7	2.2E-9	1.9E-7	9.9E-8	3.3E-9	5.5E-8	3.0E-7	2.2E-7	4.4E-9	6.7E-7
	Max	4.8E-5	2.0E-5	9.9E-4	1.4E-4	2.2E-4	9.3E-7	8.7E-5	1.1E-3	1.9E-3	6.2E-2
	Avg.	**9.8E-6**	**3.8E-6**	**1.3E-4**	**4.3E-5**	**4.7E-5**	**2.7E-7**	**2.4E-5**	**9.4E-5**	**1.4E-4**	**1.8E-2**
Inhalation	**Min**	5.9E-12	8.4E-14	7.3E-12	3.8E-12	1.3E-13	2.1E-12	1.2E-11	8.4E-12	1.7E-13	2.6E-11
	Max	1.8E-9	8.0E-10	3.8E-8	5.3E-9	8.6E-9	3.6E-11	3.3E-9	4.0E-8	7.1E-8	2.4E-6
	Avg.	**3.8E-10**	**1.4E-10**	**4.9E-9**	**1.6E-9**	**1.8E-9**	**1.1E-11**	**9.2E-10**	**3.6E-9**	**5.5E-9**	**6.8E-7**
Dermal Contact	**Min**	6.1E-6	2.7E-7	1.3E-4	1.8E-5	2.9E-5	1.2E-7	1.1E-5	1.4E-4	2.4E-4	7.9E-3
	Max	9.8E-6	3.8E-6	1.3E-4	4.3E-5	4.7E-5	2.8E-7	2.4E-5	9.4E-5	1.4E-4	1.8E-2
	Avg.	**1.3E-6**	**4.8E-7**	**1.6E-5**	**5.5E-6**	**5.9E-6**	**3.5E-8**	**3.1E-6**	**1.2E-5**	**1.8E-5**	**2.3E-3**
					Adult						
Oral Ingestion	**Min**	8.2E-8	1.8E-9	1.0E-7	5.3E-8	1.8E-9	2.9E-8	1.6E-7	1.2E-7	2.4E-9	3.6E-7
	Max	2.6E-5	1.1E-5	5.3E-4	7.4E-5	1.2E-4	4.9E-7	4.7E-5	5.6E-4	9.9E-4	3.3E-2
	Avg.	**5.3E-6**	**2.0E-6**	**6.8E-5**	**2.3E-5**	**2.5E-5**	**1.4E-7**	**1.3E-5**	**5.0E-5**	**7.6E-5**	**9.5E-3**
Inhalation	**Min**	1.3E-11	1.8E-13	1.6E-11	8.1E-12	2.7E-13	4.5E-12	2.5E-11	1.8E-11	3.6E-13	5.5E-11
	Max	3.9E-9	1.7E-9	8.2E-8	1.1E-8	1.8E-8	7.6E-11	7.2E-9	8.7E-8	1.5E-7	5.1E-6
	Avg.	**8.1E-10**	**3.1E-10**	**1.1E-8**	**3.5E-9**	**3.8E-9**	**2.3E-11**	**1.9E-9**	**7.8E-9**	**1.2E-8**	**1.5E-6**
Dermal Contact	**Min**	2.0E-8	2.9E-10	2.5E-8	1.3E-8	4.4E-10	7.3E-9	4.0E-8	2.9E-8	5.8E-10	8.9E-8
	Max	6.3E-6	2.8E-6	1.3E-4	1.8E-5	2.9E-5	1.2E-7	1.2E-5	1.4E-4	2.5E-4	8.2E-3
	Avg.	**1.3E-6**	**4.9E-7**	**1.7E-5**	**5.7E-6**	**6.2E-6**	**3.7E-8**	**3.2E-6**	**1.3E-5**	**1.9E-5**	**2.4E-3**

Table 8: Average daily intake (mg/kg/day) of heavy metals in soils around mining areas of Nigeria for children and adults carcinogenic health risk

		As	**Cd**	**Co**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	**Fe**
					Child						
Oral Ingestion	**Min**	1.7E-6	2.6E-8	2.2E-6	1.2E-6	2.6E-3	6.4E-7	3.5E-6	2.6E-6	5.1E-8	7.8E-6
	Max	5.6E-4	2.4E-4	1.2E-2	1.6E-3	3.8E-8	1.1E-5	1.0E-3	1.2E-2	2.2E-2	7.2E-1
	Avg.	**1.2E-4**	**4.4E-5**	**1.5E-3**	**4.9E-4**	**5.4E-4**	**3.2E-6**	**2.8E-4**	**1.1E-3**	**1.7E-3**	**2.1E-1**
Inhalation	**Min**	6.9E-11	9.8E-13	8.5E-11	4.4E-11	1.5E-12	2.5E-11	3.9E-8	9.8E-11	1.8E-12	3.0E-10
	Max	2.2E-8	9.3E-9	4.4E-7	6.2E-8	1.0E-7	4.2E-10	1.4E-10	4.7E-7	8.3E-7	2.8E-5
	Avg.	**4.4E-9**	**1.7E-9**	**5.7E-8**	**1.9E-8**	**2.1E-8**	**1.2E-10**	**1.1E-8**	**4.2E-8**	**6.4E-8**	**7.9E-6**
Dermal Contact	**Min**	2.3E-7	3.3E-9	2.8E-7	1.5E-7	4.9E-9	8.2E-8	1.3E-4	3.3E-7	6.6E-9	9.2E-2
	Max	7.1E-5	3.1E-5	1.5E-3	2.1E-4	3.3E-4	1.4E-6	4.5E-7	1.6E-3	2.7E-3	9.9E-7
	Avg.	**1.5E-5**	**5.6E-6**	**1.9E-4**	**6.4E-5**	**6.9E-5**	**4.1E-7**	**3.6E-5**	**1.4E-4**	**2.1E-4**	**2.7E-2**
					Adult						
Oral Ingestion	**Min**	1.9E-7	2.7E-9	2.4E-7	1.2E-7	4.1E-9	6.9E-8	3.8E-7	2.7E-7	5.5E-9	8.4E-7
	Max	5.9E-5	2.6E-5	1.2E-3	1.7E-4	2.8E-4	1.2E-6	1.1E-4	1.3E-3	2.3E-3	7.7E-2
	Avg.	**1.2E-5**	**4.7E-6**	**1.6E-4**	**5.3E-5**	**5.8E-5**	**3.5E-7**	**2.9E-5**	**1.2E-4**	**1.8E-4**	**2.2E-2**
Inhalation	**Min**	4.2E-13	6.0E-15	5.2E-13	2.7E-13	9.0E-15	1.5E-13	8.3E-13	6.0E-13	1.2E-14	1.8E-12
	Max	1.3E-10	5.7E-11	2.7E-9	3.8E-10	6.1E-10	2.7E-12	2.4E-10	2.9E-9	5.1E-9	1.7E-7
	Avg.	**2.7E-11**	**1.0E-11**	**3.5E-10**	**1.2E-10**	**1.3E-10**	**7.6E-13**	**6.6E-11**	**2.6E-10**	**3.9E-10**	**4.9E-8**
Dermal Contact	**Min**	4.8E-8	6.8E-10	5.8E-8	3.1E-8	1.0E-9	1.7E-8	9.4E-8	6.8E-8	1.4E-9	2.1E-7
	Max	1.5E-5	6.5E-6	3.1E-4	4.3E-5	6.9E-5	2.9E-7	2.7E-5	3.3E-4	5.8E-4	1.9E-2
	Avg.	**3.0E-6**	**1.2E-6**	**3.9E-5**	**1.3E-5**	**1.4E-5**	**8.5E-8**	**7.4E-6**	**2.9E-5**	**4.4E-5**	**5.5E-3**

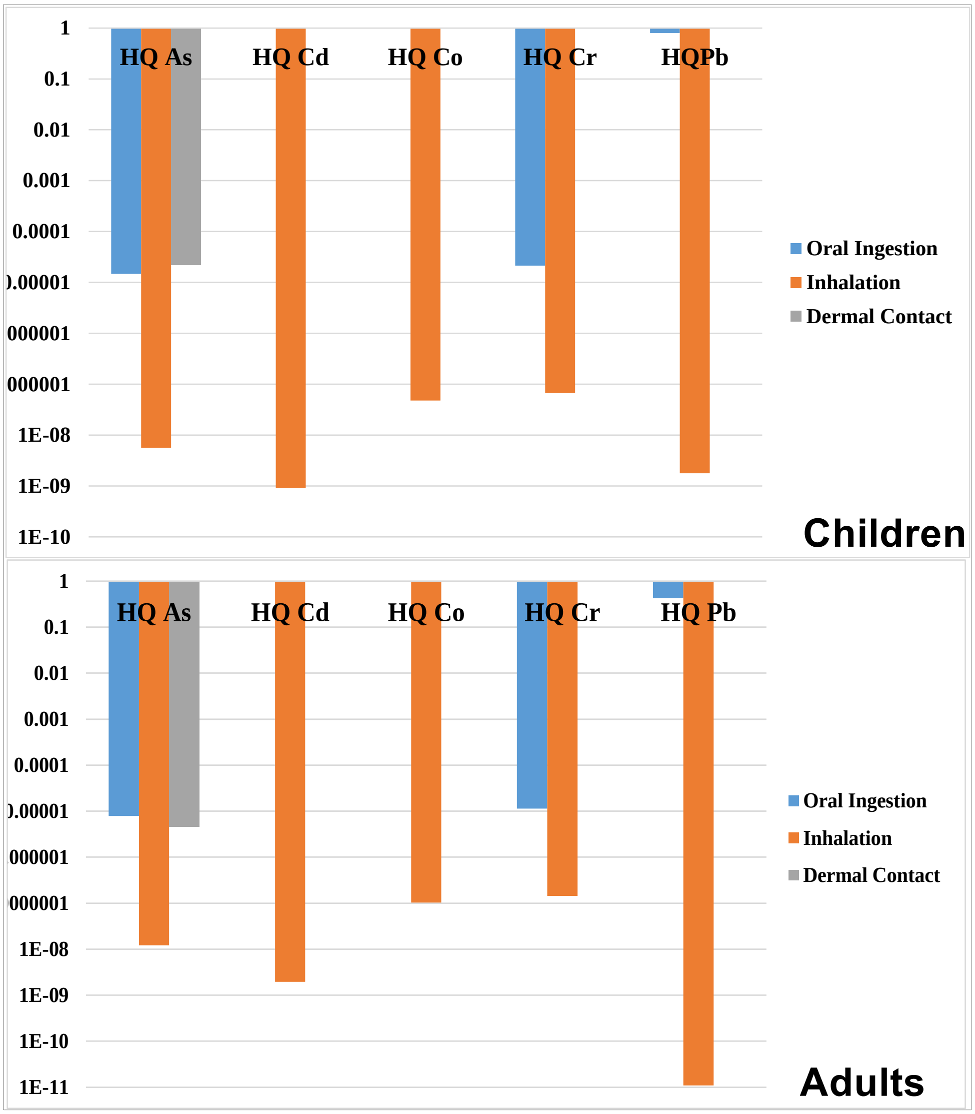

Figure 5: Carcinogenic hazard quotient (HQ) of Heavy Metals in Soils around mining areas of Nigeria for Children and Adults

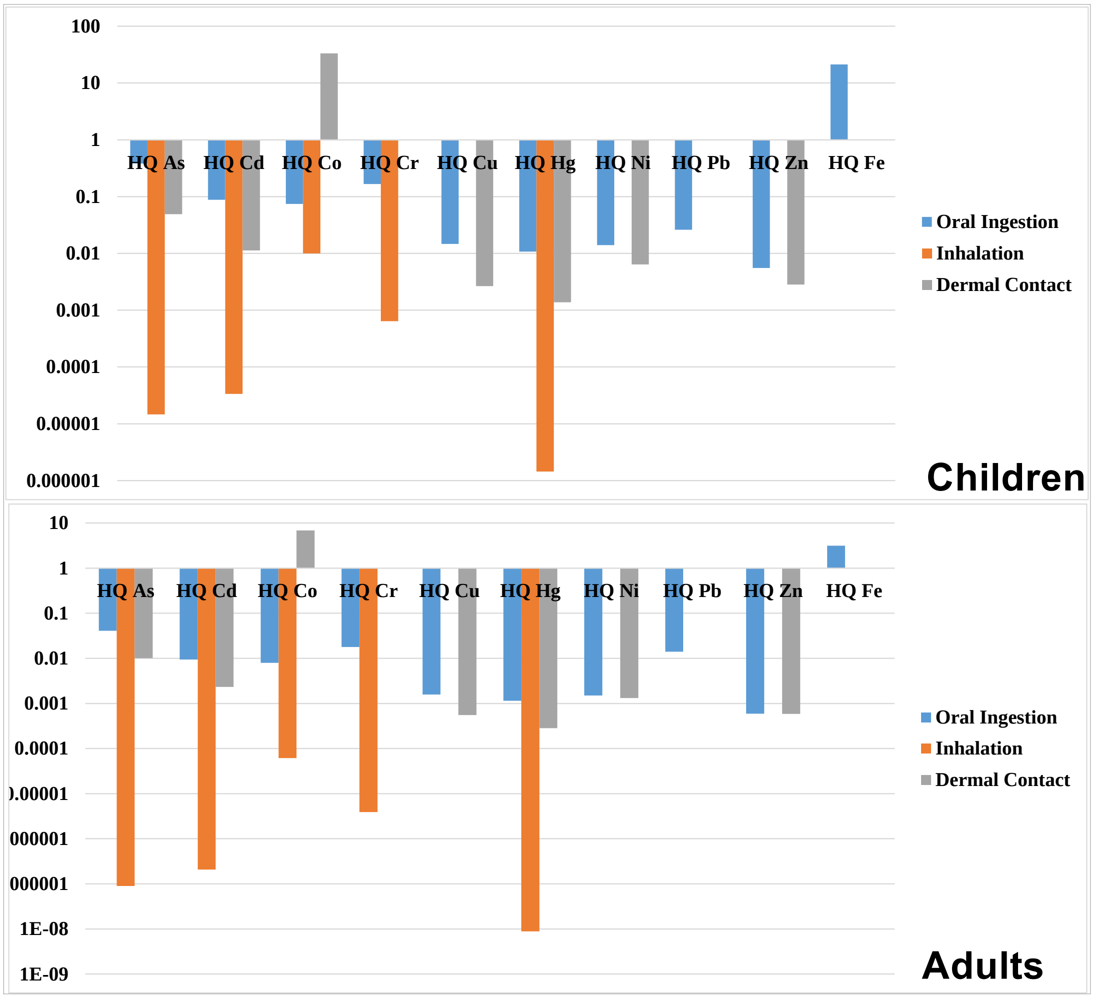

Figure 6: Non-Carcinogenic hazard quotient (HQ) of Heavy Metals in Soils around Mining Areas of Nigeria for Children and Adults

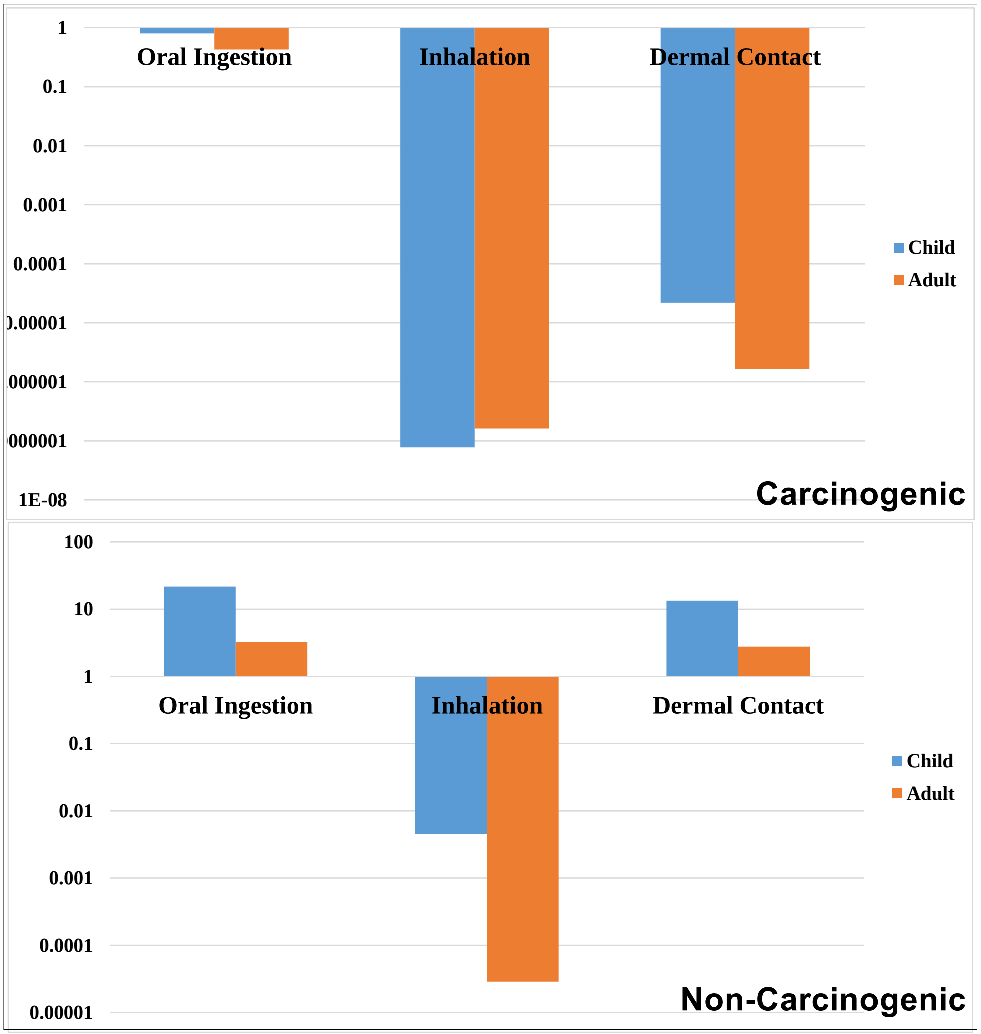

Figure 7: Carcinogenic and non-carcinogenic health index (HI) of heavy metals in soils around mining areas of Nigeria for Children and Adults

8. Conclusion

Mining activities play significant role in the release of potentially toxic metals into the environment. This review showed that soils around areas of mining and mineral processing operation in Nigeria have high content of heavy metals in them. The soils are highly contaminated by metals such as Pb and Cr which pose very high environmental risk. Health risk assessment showed that heavy metals in soils of the area may contribute significantly to carcinogenic health risk in the area especially through oral ingestion of Pb in contaminated soils while they may cause non-carcinogenic health issues through oral ingestion of Fe and dermal contact with Co in the polluted suds. It is suggested that mining activities should be properly monitored across the country to reduce their impacts on the environment. Laws should be made and enforced to prevent outbreak of diseases which may affect public health. The use of children in artisanal mining across the country should be highly discouraged, as this will reduce diseases and death rate associated with heavy metals in the contaminated soils.

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