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Human Health Risk Assessment of Heavy Metal Contamination in an Artisanal Gold Mining Community of Kogi State, Nigeria

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ABSTRACT: Artisanal and small-scale gold mining (ASGM) is known to improve the standard of living in the host communities and economic performance of countries involved. However, despite the positive impact on the economy, ASGM is a significant point source of uncontrolled mobilization of hazardous chemicals, notably heavy metals into the environmental media such as soil, air and water. This study assessed human health risk of exposure to heavy metals in soil around artisanal gold mining in Ike community of Kogi State. Twelve (12) soil samples obtained from the gold mining area were analysed for heavy metals (As, Cd, Ni, Pb and Zn) using Atomic Absorption Spectrometry (AAS). Measured concentrations of these metals were used to calculate health risk of children and adults using health risk assessment models. The results showed that mean values of heavy metal concentrations in the soil reflected low metal load (<1) with decreasing order of As>Pb>Zn>Ni>Cd. The results obtained from analysis of non-carcinogenic risk demonstrated that hazard index values of various heavy metals for three exposure pathways (ingestion, dermal and inhalational) were < 1 for children and adults populations. However, As recorded hazard index values > 1 for ingestion pathway for both populations. It was found that As recorded carcinogenic risk of 1.85E-03 for children and 9.86E-04 for adults and Cd recorded 4.67E-04 for children. These values exceeded the safety limit, ranging from 1E-06 to 1E-04, as stated by US Environmental Protection Agency. The study showed that As might pose carcinogenic and non-carcinogenic risks for both populations. Also, Cd might pose carcinogenic risk for children. Hence, As and Cd would be regarded as elements of serious concern in the study area.

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Elevated levels of heavy metals in the environmental media associated with increasingly anthropogenic activities, including artisanal and small-scale gold mining (ASGM) activities has been a matter of global concern in recent years owing to human health implications. It has been well documented that ASGM brings about economic benefits such as job creation in the host communities and increased standard of living of the countries involved (Olujimi *et al*., 2015; Wilson *et al*., 2015; Nguyen *et al*., 2018). However, despite the positive impacts on the economy, the mining operations have been identified as a significant point source of uncontrolled mobilisation of heavy metals into the soil, air and water, especially where low quality ores are mined (Fashola *et al*., 2016; Nurcholis *et al*., 2017; Dorkelu *et al*., 2018). Heavy metals is a generic term for non-biodegradable metallic elements capable of inducing deleterious effects on living organisms subsequent to exposure (Ali *et al*., 2019). Although essential heavy metals [copper (Cu), iron (Fe), nickel (Ni), zinc (Zn) etc.] at low concentration are important for living organisms as they take part in electron transfers, redox reactions and other metabolic processes, while non-essential heavy metals [cadmium (Cd), mercury (Hg), lead (Pb), arsenic (As) etc.] do not have any biological function and are harmful to life even at lower concentrations (Jan *et al*., 2015; Ali *et al*., 2019). Literature evidence testify that heavy metals emitted from anthropogenic sources are more harmful to life due to their instability and solubility with resultant high bioavailability compared to those of geogenic origins (Onakpa *et al*., 2018). Humans are exposed to heavy metals in the soil, air and water via oral, nasal and dermal routes. Scientific sources

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suggest that human health risks suffered following exposure to heavy metals are functions of routes, dose and duration of exposure as well as age**,** sex, genetic polymorphism and nutritional and health status of individual (Jan *et al*., 2015; Bose-O'Reilly *et al*., 2016; Anyanwu *et al*., 2018). Rajkumar and Gupta (2021) noted that clinical manifestations of heavy metal-induced toxicity vary from one metal to another. Cutaneous lesions are consistent findings, typically develop after years of exposure to As and are characterized by thick, hard, rough hyperkeratotic skin, especially of the palm and sole as well as a "raindrop" pattern of pigmentation on covered areas, mainly of the chest, back and limbs (Chakraborti *et al*., 2013; Mehta *et al*., 2019). Tchounwou *et al.* (2012) pointed to significantly higher standardized mortality rate and cancers of skin, lung, liver, urinary bladder, kidney and colon in many areas with history of As pollution. Cd toxicity is known to mainly affect liver, lung, kidney and bone. Epidemiological data suggest that exposure to Cd might precipitate various types of cancers (Genchi *et al*., 2020). Several authors have documented that neurocognitive deficits are associated with Pb toxicity, particularly in children (Hauptman *et al*., 2017; Debnath *et al*., 2019). In severe toxicity, convulsions, coma and even death can occur. A case in point is Pb poisoning associated with ASGM that resulted in the death of 25% of children under 5 years of age in two villages of Zamfara, Northwest Nigeria, unprecedented in modern times (Dooyema *et al*., 2012). Human health risk assessment is a technique used to estimate carcinogenic and non-carcinogenic risks that might result from exposure to hazardous chemicals such as heavy metals (Kamunda *et al.*, 2016; Adesuyi *et al*., 2021). Four steps of risk assessment paradigm include: (i) hazard identification (ii) hazard characterization (iii) exposure assessment and (iv) risk characterization. Human health risk assessment of heavy metal contamination in soil around ASGM area is gaining more attention in recent times. This might be attributed to dramatic growth in ASGM operations, especially in low-income countries, including Nigeria. Some researchers have assessed health risk pose by ASGM in different sites in Nigeria (Olujimi *et al*., 2016; Awomeso *et al.*, 2017; Johnbull *et al*., 2019). However, there is no such study for ASGM in Ike community of Kogi State, Nigeria and that necessitated this work. This study assessed human health risk of exposure to heavy metals in soil around artisanal gold mining in Ike community of Kogi State.

MATERIALS AND METHODS

Study Area: This study was carried out in Ike community of Kabba / Bunu Local Government Area, Kogi State, Northcentral Nigeria. It is located approximately in latitude $7^{0}49'$ N and longitude 6^{0} 04' E. The area experiences the wet and dry season's climate regimes, wet season usually span from the middle of March to October, while the dry season cover the period between November and early March. The vegetation of the area comprise of derived savannah and rain forest. Agriculture is the principal economic activity in the community with crops such as coffee, cassava, maize grown as well as domestic animals such as cattle and goats reared and sold in the community. A significant number of farmers often engage in full time artisanal gold mining after the planting season.

Sampling: Soil samples were randomly collected from twelve points around ASGM in Ike community. The samples were collected using standard auger at a depth of 0–30 cm and were carefully packed in well labelled polyethylene bag and then transported to laboratory for analysis.

Pre-treatment and Digestion of Soil Samples: The soil samples were air-dried at room temperature for about 72 hrs, afterward the sample were ground into fine particles using laboratory mortar and pestle. The fine particles was sieved using 2 mm mesh, thoroughly homogenized and packed in properly labelled bottles for digestion. 1 g each of the samples were weighed into digestion flask and 30 cm^3 of aqua regia (a mixture of HNO_3 and HCl in the ratio of 1:3) was added and digested in a fume-cupboard until clear solution was obtained, it was cooled, filtered and then made up to 50 ml mark in a standard volumetric flask with de-ionized water. The concentrations of metals in sample solution were determined using Atomic Absorption Spectrometer model AA-7000 Shimadzu, Japan ROM version 1.01, S/N A30664700709. A blank sample was prepared to zero the instrument before running other series of samples. This was done in order to remove occurrence of metal ions present in the aqua regia.

Health Risk Assessment: Health risk associated with human exposure to heavy metals is estimated by average daily dose (ADD). As noted above, exposure to metal contaminants in the soil occurs via three main routes viz: direct ingestion (ADD_{ing}), inhalation (ADD_{inh}) and dermal absorption through skin contact (ADD_{derm}). In this study, the ADD (mg/kg/day) through each pathway was calculated using equations (1) – (3) (USEPA, 2001). The exposure assessment parameters adopted in this study are presented in Table 1.

$$ADD_{ing} = \frac{C \times R_{ing} \times EF \times ED \times 10^{-6}}{BW \times AT} \quad (1)$$

$$ADD_{inh} = \frac{C \times R_{inh} \times ED}{PET \times BW \times AT} \quad (2)$$

$$ADD_{derm} = \frac{C \times SA \times SL \times ABS \times EF \times ED \times 10^{-6}}{BW \times AT} \quad (3)$$

Table 1: Exposure parameters used for health risk assessment of heavy metals via various pathways

Factor	Definition	Value		References
		Children	Adults	
C	average concentration of each metal in soil (mg/kg)			
R_{ing}	ingestion rate (mg/day)	250	100	(USEPA,2001)
EF	exposure frequency (days/year)	250	250	(Ferreira-Baptista and De Miguel, 2005)
ED	exposure duration (years)	6	25	(USEPA. 2001)
BW	average Body weight (kg)	15	70	(USEPA,1997)
AT	average time (days)	365	365	(USEPA, 1997)
R_{inh}	inhalation rate (m^3/day)	7.6	20	(Zheng *et al*., 2010)
PEF	particle emission factor (m^3/kg)	$1.32X10^9$	$1.32X10^9$	(USEPA, 2001)
SA	exposed skin surface area (cm^2)	2800	3300	(USEPA, 2001)
SL	skin adherence factor of soil (mg/cm^2/h)	0.2	0.7	(USEPA, 2001)
ABS	dermal absorption factor (chemical specific)	0.001	0.001	(Olujimi *et al*., 2015)

Non-Carcinogenic Risk Assessment: Hazard quotient (HQ) is the ratio of potential exposure to a substance and the dose at which no adverse effects are expected. HQ is expressed as:

$$HQ = \frac{ADD}{RfD} \quad (4)$$

Where; ADD is estimated average daily dose of a given metal and R*f*D is the chronic reference dose of the metal, above the threshold, daily human exposure through any of the routes could result in adverse effect during a life time. Hence, if an ADD of a given metallic element is higher than its corresponding R*f*D (HQ > 1), there is likelihood that non-carcinogenic effect will occur irrespective of the exposure route [27]. The R*f*D for each of metals are presented in Table 2.

Table 2: R*f*Ds *(*reference dose) and CPFs (cancer potency factor) of heavy metals (mg kg−1 day−1) adopted in this study

Mental	RfD_{ing}	Rfd_{inh}	RfD_{derm}	CPF_{ing}
As	3.00E-04	3.00E-04	3.00E-04	1.50E+00
Cd	5.00E-04	5.70E-05	5.00E-04	1.38E-02
Ni	2.00E-02	2.06E-02	5.60E-03	
Pb	3.60E-03	3.52E-03	5.25E-07	4.20E-02
Zn	3.00E01	3.00E01	6.50E-02	

The sum of more than one HQ for multiple metal pollutants and/or multiple exposure pathways is known as hazard index (HI) and is expressed as:

$$HI = \sum_{k}^{n} HQ = HQ_{ing} + HQ_{inh} + HQ_{derm} \quad (5)$$

If the value of HI < 1, the risk of non-carcinogenic effects is negligible. HI > 1 means there is chance of developing systemic effects, the probability increases with increasing value of HI (USEPA, 2001).

Carcinogenic Risk Assessment: Carcinogenic risk is estimated as the incremental probability of an individual developing any kind of cancer in a lifetime as a result of exposure to potential carcinogens. In this study, carcinogenic risk for exposure via ingestion route was calculated using equation (6):

$$\text{Cancer risk} = ADD_{ing} \times CPF_{ing} \quad (6)$$

Where; ADD_{ing} and CPF_{ing} are average daily intake and cancer potency factor respectively through oral route for a given metal. The safety limit ranged from 1E-06 to 1E-04, as stated by US Environmental Protection Agency (USEPA, 2004). The CPF for metals considered in this study are presented in Table 2.

RESULTS AND DISCUSSION

Concentration of heavy metals in soil: The concentrations of heavy metals in soil from different sampling points in the ASGM area are presented in Table 3. The mean values of concentrations of heavy metals ranged as follows: 1.599 (0.485), 0.750 (0.206), 0.589 (0.046), 0.496 (0.084) and 0.043 (0.004) for As, Pb, Zn, Ni and Cd respectively. The mean values reflected low metal load with decreasing order of As > Pb > Zn > Ni > Cd. This metal load pattern differs from pattern found in previous studies by Olujimi *et al.* (2015) and Kamunda *et al.* (2016), suggesting that concentrations of heavy metal in ASGM sites vary from one site to another. The relative high concentrations of As might be due to gold mining activities in the study area. Tun *et al*. (2020) posited that there is a substantial association between As concentrations in the environment and gold mining activities. This study showed that mean values of concentrations of heavy metals in soil from the study area were all within standard values formulated by Department of Petroleum Resources of Nigeria (DPR, 2002) and permissible limits of WHO/FAO (Khan *et al*., 2015).

Human health risk assessment: Average daily intake of metals: The average daily intake of heavy metals in soil via three exposure pathways for children and adults are presented in Table 4. The results revealed that Cd with total average daily intake of 3.30E-05 for children and 1.78E-05 for adults was the least exposed metal, while As with total average daily intake of 1.23E-03 for children and Pb with 1.33E-02 adults were major metals exposed to. Overview of the results showed that exposure to metals in soil via ingestion pathway was higher than dermal and inhalational pathways in both children and adults. Similar trend was reported by Kolo *et al.* (2018) that the daily intake of metals are 2 – 4 order of magnitude higher for ingestion pathway compared to inhalation and dermal contacts in adults

Table 3: Concentrations (mg kg^{-1}) of heavy metal concentrations in soil around the gold mining area

Sampling points	As	Cd	Ni	Pb	Zn
1	0.000	0.250	0.41	0.750	0.546
2	3.161	0.041	0.923	0.5000	0.450
3	0.677	0.055	0.615	0.000	0.597
4	0.225	0.036	1.026	0.750	0.381
5	1.806	0.066	0.615	2.000	0.597
6	0.000	0.064	0.410	0.500	0.537
7	2.258	0.042	0.103	0.000	0.805
8	1.807	0.024	0.615	0.250	0.476
9	0.226	0.044	0.513	0.000	0.580
10	5.419	0.027	0.410	1.750	0.753
11	0.452	0.500	0.103	0.750	0.442
12	3.161	0.042	0.205	1.750	0.909
Mean (SEM)	1.599 (0.485)	0.043 (0.004)	0.496 (0.084)	0.750 (0.206)	0.589 (0.046)

Table 4: Daily intake (mg kg^{-1} day^{-1}) of heavy metals for children and adults through three exposure routes

	Routes	AS	Cd	Ni	Pb	Zn
Children	ADD_{ing}	1.25E-03	3.30E-05	3.80E-04	5.75E-04	4.52E-04
	ADD_{inh}	9.79E-13	2.63E-14	3.04E-13	4.59E-13	3.61E-13
	ADD_{derm}	3.43E-6	9.24E-10	1.07E-06	1.61E-06	1.27E-06
	Total	1.25E-03	3.30E-05	3.81E-04	5.76E-04	4.53E-04
Adults	ADD_{ing}	6.57E-04	1.77E-05	2.04E-04	3.08E-04	2.42E-04
	ADD_{inh}	2.76E-05	7.42E-14	8.56E-13	1.30E-12	1.02E-12
	ADD_{derm}	2.62E-06	7.05E-08	8.13E-07	1.23E-06	9.66E-07
	Total	6.60E-04	1.78E-05	2.05E-04	1.33E-02	2.43E-04

Non carcinogenic risk assessment: The results obtained from computation of hazard quotient (HQ) for the three exposure pathways as well as hazard index (HI) for children and adults are presented in Tables 5 and 6 respectively. The results demonstrated that HQ values of various heavy metals in the three exposure pathways were < 1 for children and adults. This implies that the metals in soil of study area pose no health threat. However, As recorded HQ values > 1 for ingestion pathway for children and adults populations. This finding is an indication that As might precipitate system effect in both populations in study area. The HQ followed decreasing order of ingestion > dermal > inhalational, indicating that exposure to metals via oral route was the main pathway responsible for non-carcinogenic risk for both populations. This is in tandem with reports of studies by Du *et al.* (2013) and Kolo *et al.* (2018). It was found that HQ values for adults were consistently lower than that of the children in the three exposure routes, suggesting that children were more likely to suffer from heavy metals toxicity in the study area.

Table 5: Non-carcinogenic and carcinogenic risks for children

Element	HQ_{ing}	HQ_{inh}	HQ_{dermal}	HI = ∑ HQ
As:				
Non-carcinogenic risk	4.10E00[a]	1.13E-05	1.11E-03	4.10E00[b]
Carcinogenic risk	1.85E-03[c]			
Cd:				
Non-carcinogenic risk	6.60E-02	1.49E-06	1.85E-06	6.60E-02
Carcinogenic risk	4.67E-04[c]			
Ni:				
Non-carcinogenic risk	1.90E-02	5.15E-08	1.98E-04	1.92E-02
Pb:				
Non-carcinogenic risk	1.64E-01	4.55E-07	3.07E-03	1.67E-01
Carcinogenic risk	1.05E-05			
Zn:				
Non-carcinogenic risk	1.51E-3	4.17E-09	2.12E-05	1.53E-03
Total				4.35 E00
Mean				8.70 E-01

Note. a = HQ > 1; b = HI > 1; c = pose a carcinogenic risk

Table 6: Non-carcinogenic and carcinogenic risks for adults

Element	HQ_{ing}	HQ_{inh}	HQ_{dermal}	$HI = \sum HQ$
As:				
Non-carcinogenic risk	2.19 E00[a]	9.20E-05	8.73E-03	2.91E00[b]
Carcinogenic risk	9.86E-04[c]			
Cd:				
Non-carcinogenic risk	3.54E-02	1.30E-06	1.41E-06	3.55E-02
Carcinogenic risk	6.73E-06			
Ni:				
Non-carcinogenic risk	1.02E-02	4.16E-11	1.51E-05	1.02E-02
Pb:				
Non-carcinogenic risk	8.80E-02	3.69E-10	2.34E-03	1.12E-01
Carcinogenic risk	2.62E-06			
Zn:				
Non-carcinogenic risk	8.07E-04	3.40E-12	1.61E-05	823E-04
Total				3.07E00
Mean				6.14E-01

Note. a = HQ > 1; b = HI > 1; c = pose a carcinogenic risk

The higher potential for heavy metal toxicity in children is of serious concern owing to their frequent hand-to-mouth activities, greater gastrointestinal rate and inhalational volume and immature hepatic enzyme and neuronal systems (Carroquino *et al*., 2012). This study found that HI values of the heavy metals were > 1 for children and adults, meaning that the metals in soil around the study area has negligible system effects. However, As had HI values < 1 for both populations, indicating that there is chance of developing systemic effects related to As in both groups in studied area. HI value of As for children was about two times higher than that of adults. This further confirmed that children were more at risk of developing system diseases associated with heavy metals toxicity in study area. The trend for HI decreased in the following order: As > Pb > Cd > Ni > Zn for both children and adults. This HI pattern of the metals was consistence with pattern found in study by Du *et al*. (2013).

Cancer risk assessment: The results of excess cancer risk for children and adults are also presented in Tables 5 and 6 respectively. Carcinogenic risk of ingestion pathway was considered for As, Cd and Pb. It was found that As recorded carcinogenic risk of 1.85E-03 for children and 9.86E-04 for adults and Cd had 4.67E-04 for children. These values were found to exceed safety limit of 1E-06 to 1E-04, as stated by US Environmental Protection Agency. This is an indication that As and Cd in soil of study area pose carcinogenic risk for children. Additionally, As also pose risk for adults. It was found that among the considered metals, As was highest contributor to cancer risk. This finding collaborates the reports credited to Olujimi *et al*. (2015) and Kamunda *et al*. (2016).

Conclusion: This study established that the heavy metals in soil of study area pose no health threat for children and adults populations. However, As might precipitate systemic effects and cancer in both populations. Children were more at risk of developing carcinogenic and non-carcinogenic risks associated with As in the study area. The risks might be enhanced by their hand-to-mouth habit, whereby contaminated soil can readily be ingested. Being a first line carcinogenic agent, As would be an element of particular concern in the study area.

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