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Geochemical and Mineralogical Characteristics of Mine Wastes from Gadaeregi Artisanal and Small-Scale Gold Mining Area, North-Central Nigeria: Implications on Human Health

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ABSTRACT

The chemical and mineralogical characteristics of wastes from artisanal and small-scale gold mining (ASGM) in the Gadaeregi area, Nigeria were assessed to determine their potential human health risks. Mine wastes were sampled and subjected to X-ray diffraction and X-ray fluorescence analyses to enable us assess the human health risk. The results show albite, quartz, actinolite, dolomite and annite as the major phases in the wastes. Fe, Si and Ti are present at concentrations above the upper crustal abundances; while Al, Na, K and Ca are depleted. The wastes are enriched in nine trace elements (Ni, Cu, Ga, V, Cr, Ce, As, Pb and W) and depleted in five others (Ba, Rb, Y, Zr and Nb). Cr, As and Pb are the most dosed trace elements in these wastes for both children and adults for the two exposure scenarios. While all three elements have HQi values of > 1 for children in the ingestion model, only As has a value of > 1 for adults. The inhalation route does not appear to have any potential health effects for both children and adults. The overall hazard index reveals that both children and adults may be vulnerable to adverse non-cancer health effects. However, children appear to be several orders of magnitude more vulnerable, because of their low body weights and hand-to-mouth habits. These data have shown that ASGM wastes have the potential to cause harmful health effects in populations within mining communities. Therefore, characterisation and proper management of these wastes are necessary to ensure sustainable mining.

Keywords: Geology, Gold Mining, Environmental Geochemistry, Medical Geology, Sustainable minerals

INTRODUCTION

The schist belt of Nigeria is endowed with a large number of mineral occurrences, including gold. Gold exploitation in this belt has been ongoing since the colonial era and still continues, mostly in the form of artisanal and small scale gold mining (ASGM). Mining in this region targets mainly gold, due perhaps to generally high gold prices in the global market (Sako and Nimi, 2018) which guarantees a ready market for the mineral locally. This is further influenced by the fact that even minute quantities of gold can readily be sold on to merchants, thus, serving as a source of quick cash for people in the local communities. While fully mechanised or industrial-scale gold operations are not common in Nigeria, artisanal mining is widespread across the country (Ikenna *et al*., 2015; Idris-Nda *et al*., 2018). Unskilled workers, including women and children from local communities engage in the extraction of gold from primary quartz-sulfide-gold vein and placer deposits. Most of these people are agrarian, but practice mining as a source of additional income, especially during the dry season when they are not engaged in their farms. This has been reported in other domains, especially in the West African region, such as Mali (Hilson, 2016). Economic hardship in many of the countries where ASGM is practiced provides a further boost to this activity, where families see it as means to satisfy basic needs. However, because ASGM activities are generally informal and unregulated, the operations result in unwholesome practices, leading to serious or potentially serious environmental and human health effects. These local miners lack the knowledge or skills, capital and other incentives to care for the environment, especially in terms of reclamation of abandoned mines and regulatory requirements, such as the management of mine wastes (Dales and Ramasamy, 2019).

Mine wastes are part of the mining environmental legacies (MEL) that pose potential risks for human health and the environment (Salgado-Almeida *et al*., 2022). Wastes from ASGM operations, including waste rock piles, processing tailings and wastewater constitute serious environmental ecological and human health problems. Unlike in the formal mining industry, wastes from ASGM are not properly managed and have been found in most cases to be disposed close to population areas, in farmlands, in surface water bodies or within the mine pits (Velasquez et al., 2021). In fact, in some communities in many parts of the developing world, including Nigeria, some of the wastes have been found to be used by people as construction materials (Waziri, 2014; Velasquez et al., 2021;). Improper management of these waste streams may pose serious ecological and human health consequences in communities where artisanal mining and processing of gold is practised. The wastes contain potentially toxic elements (PTEs) naturally associated with the gold ores and other harmful contaminants such as mercury introduced as a processing chemical. The mobilisation of these contaminants from mine waste through processes like enhanced weathering due to exposure to elements at the surface environment and the direct ingestion and inhalation of fine particles are among the exposure pathways of the local populations to PTEs in the wastes.

The Gadaeregi area in parts of Bida sheet 186 falls within the Nigerian Schist Belt. It is one of the many areas known for artisanal mining and processing of a variety of minerals, especially gold. Gold occurrence in this area is similar to what obtains in most parts of the Schist belt, where primary gold mineralisation occurs in quartz veins, often, together with base metal sulfides (Woakes and Bafor, 1982; Akande *et al*., 1988; Garba, 2003; Oke *et al*, 2014). Most previous workers in the area have focused on the geology and mineralisation potential of the area and the larger Basement Complex environment. Very few studies have been carried out on the environmental effects of artisanal extraction and processing of gold ores in the area (e.g. Omanayin *et al*., 2016). However, no work has been done on the characteristics of mine wastes and the potential environmental and potential human health problems posed by contaminant metal in the mine wastes from artisanal mining and processing of gold-bearing ores in the area. The aim of this work therefore is to determine the mineralogical and chemical composition of mine wastes with a view to assessing the possible human health risks they portend.

MATERIALS AND METHODS

The Study Area

The study area is part of Bida Sheet 184 NE and is located between Latitudes 09º22 ' N and 09º24 ' N and Longitudes 006º18 ' E and 006º22 ' E along the Minna-Kataeregi-Bida. The topography of Gadaeregi area is generally gentle, with an elevation of between

111 m and 137 m, which is punctuated by occasional hills. The major surface water body in the area is the Chanchaga River which takes its source further northeast in the Minna area (Figure 1). It is however joined by many tributaries, which drain the area and serve as sources of water for domestic, agricultural and mineral processing activities. There are two distinct seasons associated with this area, namely, the rainy and the dry seasons. It has an average total annual rainfall of about 133 mm, spread between April and October peaking between August and September (Ejepu *et al.,* 2015). Day time temperatures average about 35°C in the months of March and April, while the minimum temperature achieved is about 21°C which is recorded in the months of December and January (Ejepu *et al.,* 2015). The dry season is marked by harmattan which is a result of north-east trade winds that are often laden with dust particles that lead to hazy conditions. During the dry seasons much of these areas are reduced to bare land, resulting from the dryness of soil and from burning of the bush. Vegetation in the area includes various species of shrubs and high forest plants along the streams, along with short grasses.

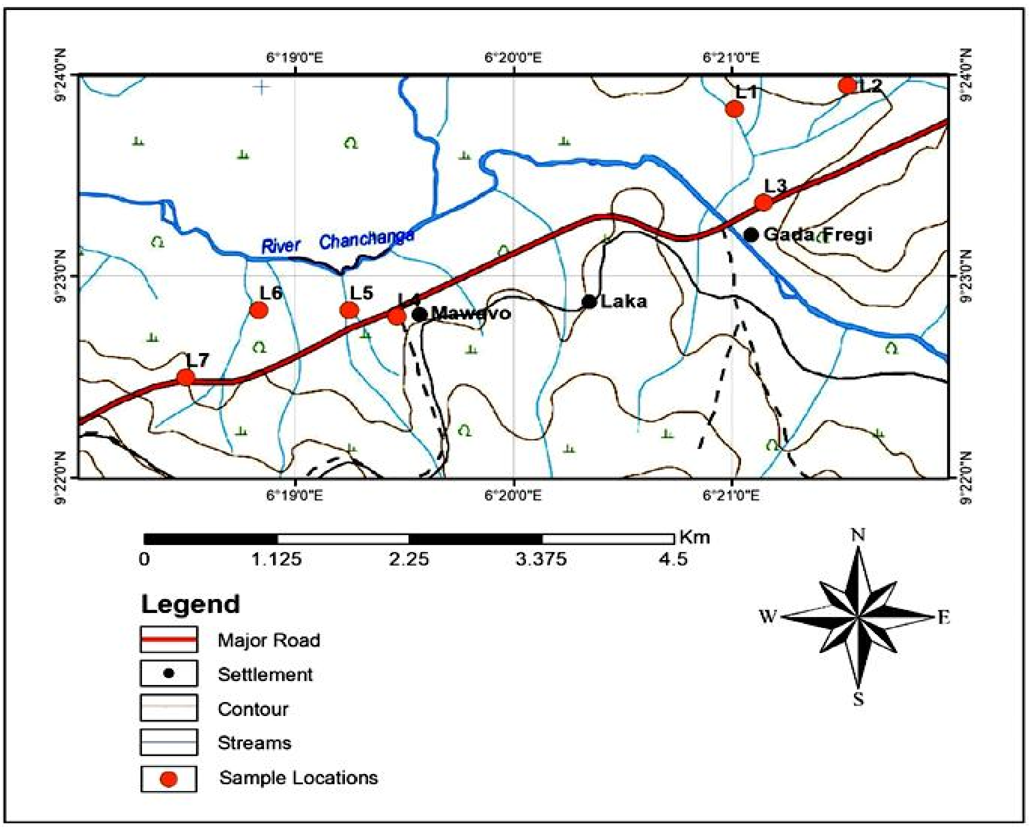

Figure 1: The Study Area

The Gadaeregi area lies within the north-central Nigeria Basement Complex and it is generally underlain by granites, schists and migmatite-gneisses. The migmatite-gneiss complex is the oldest lithology in the area and it is highly jointed and moderately weathered. Mica schist belonging to the metasedimentary series of the Nigerian Schist Belt underlie the central portion of the area and it and the older lithology have been cut intricately by granitites of Pan-African age. The mica schists appear to be the main host of auriferous quartz

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veins in the area, which are exploited by artisanal and small-scale miners for mainly gold (Omanayin *et al.,* 2016).

Fieldwork and Sampling of Artisanal Mine Wastes

A field campaign was conducted in the Gadaeregi area to map out artisanal gold mining and processing areas and collect wastes for further studies. Seven areas were identified where local artisanal miners were mining and processing gold ores from veins within the mica schist and amphibolites. As usual, mining in this area was found to be highly labour-intensive, using simple tools, without regard to any safety measures. The miners targeted veins and mineralised fractures within the metasedimentary host rocks and these were dug and blasted where necessary to obtain the ore for processing. As in all artisanal mining sites in Nigeria and other developing countries, the materials were subjected to crushing, milling and eventual concentration using gravity methods. The concentrate fraction was treated with acid to remove iron oxides and other heavy minerals before amalgamation, which is often the final process. For this work, waste materials from all the stages were targeted for sampling and further laboratory analyses. A total of seven samples, which were adjudged to be representative of the materials encountered in the area were collected from mine sites, mine tailings and mineral processing chambers. The location of each sample was marked on the field map, with the aid of a handheld global positioning system device from Garmin.

Chemical and Mineralogical Analysis

The chemical and mineralogical composition of the mine wastes were determined using X-ray fluorescence spectrometry (EDXRF Analyser, Minipal 4 model from PANalytical) and powder X-ray diffraction (XRD) respectively. Prior to analysis, the samples were air-dried for forty-eight hours in a clean laboratory environment and approximately 1 Kg of each sample was milled using a porcelain pestle and mortar and passed through a 75 µm sieve. For mineralogical analysis, approximately 5 g of the thoroughly mixed powder was placed in a sample holder, while ensuring that the grains assumed random orientation. The samples were subsequently fed into the Empyrean X-ray Diffractometer and continuously scanned between 4 and 75 2θ, with a scan step size of 0.06261. Analysis was carried out using CuKα primary X-ray beam with a wavelength (λ) of 1.540598. Individual powder diffraction patterns were interpreted using DIFFRACAT software by comparing them with patterns from the International Centre for Diffraction Data (ICDD). Major and trace element concentrations were measured using XRF technology on pressed powder pellets, prepared by mixing 10 g of sample with 1 g of stearic acid binder and pressing to a pellet in a 40 mm steel disc. Instrument calibration and quality control were achieved using a standard reference material (IAEA Soil_7).

Potential Human Health Risk Assessment

To estimate the risk to the environment and human health due to improper management of these mine wastes, non-cancer health risks were computed for five potentially toxic elements (PTEs), namely, Zn, Cu, Cr, As and Pb. The first step for estimating the potential non-cancer health risks is to compute the average daily dose (ADD) of a contaminant element in mine waste for different exposure routes, in this case, through ingestion and inhalation pathways (Man *et al*., 2010):

$$ADD_{ing} = \frac{Cwaste\ x IngR\ x\ CF\ x EF\ x\ ED}{BW\ X\ AT} \quad \textbf{(Eq.1)}$$

$$ADD_{inh} = \frac{Cwaste\ x InhR\ x\ EF\ \ x\ ED}{PEF\ x\ BW\ x\ AT} \quad \textbf{(Eq.2),}$$

where C_{waste} is the concentration of an element in mine wastes and other terms are define in Table 1.

Similarly, the hazard quotient (HQ) was computed as:

$$HQi = \frac{\Sigma ADDi}{RfDi} \quad \textbf{(Eq.3),}$$

where RfD is the reference dose for each of the elements (Table 2).

Finally, the non-cancer health index (HI) which is an overall assessment of the health hazard due to the mine wastes is given as:

$$HI = \sum HQi \quad \textbf{(Eq.4)}$$

Table 1: Exposure factors used in CDI estimation for non-carcinogenic risk (USEPA, 1997, 2001)

S/N	Parameter	Children	Adult
1	Ingestion rate (IngR)	200 mg/day	100 mg/day
2	Exposure frequency (EF)	350 days	350 days
3	Exposure duration (ED)	6 years	24 years
4	Body weight (BW)	15 kg	70 kg
5	Average time (AT)	365days×ED	365days×ED
6	Conversion Factor (CF)	1×10^{-6} kg/mg	1×10^{-6} kg/mg
7	Inhalation rate (InhR)	7.6 mg/cm^2	20 mg/cm^2
8	Particulate emission factor (PEF)	$1.36\times10^9 m^3/kg$	$1.36\times10^9 m^3/kg$

Table 2: The Reference Dose (RfD) Values of Toxic Elements (USEPA, 2000)

Element	$R_fD_{ing\ (mg/kg/day)}$	$R_fD_{inh\ (mg/kg/day)}$
Pb	3.00E-03	3.52E-03
Zn	3.00E-01	3.00E-01
Cu	4.00E-02	4.02E-02
Cr	3.00E-03	2.86E-05
As	3.00E-04	3.1E-04
Ni	2.00E-02	2.00E-02
Mn	1.40E-01	5.00E-05
Co	2.00E-02	2.00E-02
Al	4.00E-04	4.00E-04
Fe	7.0E-01	7.0E-01

RESULTS AND DISCUSSION

Mineralogical Characteristics

Results of X-ray diffraction analysis show that the mine wastes from the Gadaeregi area are generally highly siliceous (Table 3), with the lowest amount of quartz being approximately 31 % and one sample having 100 % quartz. Only one of the seven samples, which is composed of more than 80 % albite lacks this mineral, with clinochlore and cordierite making up the remaining percentage. The abundance of quartz is not surprising, considering that gold in the area as in many other artisanal mining regions in Nigeria is won from gold-sulfide-bearing quartz veins. The presence of up to 16 % actinolite, together with goethite in one of the samples is attributed to the presence of amphibolites in the area. While no sulfide mineral has been identified in these materials, one or more are likely present, albeit at low amounts below the method detection limit. The preponderance of silicate minerals in these mine wastes signifies a high acid buffering capacity, which is capable of countering potential acid generation from the oxidation of any sulfide present in the ores. However, presence of large amounts of silicates, especially quartz in finely ground materials can pose significant human health challenges. Inhalation of silica laden dusts from the milling operations may potentially harm the mine workers and residents of the communities, through for example, silicosis of the lungs. Similarly, the asbestiform nature of some actinolite identified in one of the samples may present another potential respiratory health hazard for individuals who inhale the fine dusts from the area.

Chemical Composition

The statistical summary of the concentration of major oxides and trace elements in the mine wastes from Gadaeregi area is presented in Table 4a and 4b. The silica content of between 47.98 % and 89.97 % (mean: 69.53 %) is an indication of the generally siliceous nature of the materials, except in few locations. This is in agreement with the mineralogical data, where quartz was found to be a major phase in all the samples. Alumina content of between 8.24 and 16.37 %, with an average of 12.24 % signifies the presence of feldspars in the mine wastes, which again have been found in the XRD results. The mean Fe_2O_3 concentration of 8.06 %, coupled with the generally higher magnesia and lime contents over soda and potash may be an indication of the influence of mafic minerals, such as actinolite that was revealed by XRD analysis.

Table 3: Mineralogical composition of artisanal mine wastes from Gadaeregi area

Mineral	L1	L2	L3	L4	L5	L6	L7
Albite	84	40		33.3			
Annite		3	11				
Almandine			6			5	
Actinolite				16.2			
Goethite				6.1			
Clinochlore	5						
Cordierite	11						
Dolomite			5	13.1			
Quartz		57	78	31.3	99	92	100
Halite					1		
Bixbyite						1	
Ilmenite						2	

Table 4a: Summary of the concentration (wt. %) of major oxides in mine wastes of Gadaeregi area

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Na_2O	K_2O	MgO	CaO	P_2O_5	SO_3
Min	47.98	8.24	2.19	0.46	0.25	0.26	1.04	0.74	0.28	0.09
Max	89.97	16.37	15.39	1.38	1.58	1.03	3.74	3.85	0.51	1.16
Mean	69.53	12.24	8.06	0.81	1.04	0.72	2.20	2.27	0.38	0.38
Median	72.78	11.71	8.57	0.79	1.29	0.80	2.14	2.33	0.37	0.23
SD	14.79	2.71	4.13	0.29	0.52	0.28	0.82	1.17	0.08	0.37
UCC	65.89	15.19	5.00	0.50	3.89	3.37	2.21	4.19	0.46	

UCC: Upper crustal concentration (Taylor and McLennan, 1995)

Overall, the concentrations of silica, iron and titania is above their upper continental crust abundances, while the materials are depleted in terms of their alumina, potash, soda and lime contents. Eight of the trace elements studied in this work (Ni, Cu, Ga, V, Cr, Ce, As, Pb and W) have concentration ranges generally above the UCC, indicating their enrichment in the mine wastes. Five others (Ba, Rb, Y, Zr and Nb) are enriched relative to their distribution in crustal environments (Table 5b). Many of these trace elements (e.g. As, Pb, Cr, Cu and Zn) are known to be generally associated with gold in ores and artisanal mining (Sako and Nimi, 2018) and are potentially toxic and may have deleterious effects to human beings. Their high concentration in these materials may present health challenges, when taken up through any of ingestion, inhalation and skin contact routes and are the subject of the health risk assessment in this work.

Table 4b: Summary of the concentration (ppm) of trace elements in mine wastes of Gadaeregi area

	Min	Max	Mean	Median	SD	UCC
Ni	10.22	52.26	29.09	27.03	14.65	20
Cu	1.60	184.21	69.18	70.86	58.76	25
Zn	40.00	106.28	71.49	61.69	25.43	71
Ga	0.37	14.66	9.83	11.68	4.81	17
W	3.50	8.88	6.24	5.46	2.05	2.0
V	56.75	310.89	166.11	173.09	79.26	60
Cr	31.68	160.10	77.39	71.29	43.28	35
Mn	568.38	3987.69	1501.49	1277.86	1152.35	1000
Ba	265.92	356.35	291.70	281.14	29.78	550
Ce	116.41	488.45	243.99	210.85	130.30	64
As	0.00	128.76	64.17	65.89	43.85	1.5
Rb	0.12	18.56	10.69	10.97	6.21	112
Y	6.54	14.17	9.25	9.06	2.38	22
Zr	51.82	148.06	93.91	74.03	41.28	190
Nb	1.96	9.51	3.70	2.73	2.67	25
Pb	0.00	88.85	40.86	45.35	36.10	20

UCC: Upper crustal concentration (Taylor and McLennan, 1995)

Human Health Risk Assessment

We estimated the potential human health risks posed by Cu, Zn, Cr, As and Pb in mine wastes of Gadaeregi area, focusing on the ingestion and inhalation exposure routes for both children (15 years and below) and adults. For the ingestion route, the HQi decreased in the order As>Cr>Pb>Cu>Zn for both children and adult populations. However, the hazard level for individual PTEs was found to be generally higher for children, compared to adults for this exposure scenario (Table 5). Similarly, the overall hazard index (HI) for this route for children is approximately 23, much higher than that for the adults at about 2.5. This shows that for the ingestion pathway, children exposed to these mine wastes are at much higher risks of PTE toxicity compared to the adults. Considering the hand-to-mouth habits of children, especially those in the lower age brackets, this finding presents some concerning situation. In both cases, the HI is greatly influenced by the HQi for arsenic, meaning the risk of As toxicity is much higher than those of other elements studied in this area.

Table 5: Non-cancer potential health indices of mine wastes from Gadaeregi area through the ingestion and inhalation pathways

	SL1	SL2	SL3	SL4	SL5	SL6	SL7	ΣADD	HQ_i	HI
				Ingestion child						
Cu	2.59E-04	1.06E-03	9.40E-04	6.55E-04	2.36E-03	9.06E-04	2.04E-05	6.19E-03	0.15	
Zn	1.36E-03	7.89E-04	7.01E-04	5.11E-04	1.16E-03	6.63E-04	1.21E-03	6.40E-03	0.02	
Cr	8.01E-04	4.79E-04	1.26E-03	2.05E-03	1.02E-03	9.12E-04	4.05E-04	6.93E-03	2.31	
As	3.21E-04	6.39E-05	1.34E-03	8.42E-04	8.81E-04	1.65E-03	7.17E-04	5.81E-03	19.36	
Pb	6.39E-05	2.21E-04	1.03E-03	1.74E-05	1.14E-03	5.80E-04	6.72E-04	3.72E-03	1.24	23.08
				Ingestion adult						
Cu	2.78E-05	1.13E-04	1.01E-04	7.01E-05	2.52E-04	9.71E-05	2.19E-06	6.63E-04	0.02	
Zn	1.46E-04	8.45E-05	0.00E+00	5.48E-05	1.25E-04	7.11E-05	1.30E-04	6.10E-04	0.00	
Cr	8.59E-05	5.14E-05	1.35E-04	2.19E-04	1.09E-04	9.77E-05	4.34E-05	7.42E-04	0.25	
As	3.43E-05	6.85E-06	1.43E-04	9.03E-05	9.44E-05	1.76E-04	7.68E-05	6.22E-04	2.07	
Pb	6.85E-06	2.37E-05	1.10E-04	1.87E-06	1.22E-04	6.21E-05	7.20E-05	3.99E-04	0.13	2.47
				Inhalation child						
Cu	7.25E-09	2.95E-08	2.63E-08	1.83E-08	6.58E-08	2.53E-08	5.71E-10	1.73E-07	4E-06	
Zn	3.80E-08	2.20E-08	1.96E-08	1.43E-08	3.25E-08	1.85E-08	3.39E-08	1.79E-07	6E-07	
Cr	2.24E-08	1.34E-08	3.53E-08	5.72E-08	2.85E-08	2.55E-08	1.13E-08	1.94E-07	0.0068	
As	8.96E-09	1.79E-09	3.73E-08	2.35E-08	2.46E-08	4.60E-08	2.00E-08	1.62E-07	0.0005	
Pb	1.79E-09	6.19E-09	2.88E-08	4.87E-10	3.17E-08	1.62E-08	1.88E-08	1.04E-07	3E-05	0.01
				Inhalation adult						
Cu	1.02E-09	4.16E-09	3.70E-09	2.58E-09	9.28E-09	3.57E-09	8.05E-11	2.44E-08	6E-07	
Zn	5.35E-09	3.11E-09	2.76E-09	2.01E-09	4.58E-09	2.61E-09	4.77E-09	2.52E-08	8E-08	
Cr	3.16E-09	1.89E-09	4.98E-09	8.06E-09	4.01E-09	3.59E-09	1.60E-09	2.73E-08	0.001	
As	1.26E-09	2.52E-10	5.26E-09	3.32E-09	3.47E-09	6.48E-09	2.82E-09	2.29E-08	7E-05	
Pb	2.52E-10	8.72E-10	4.06E-09	6.86E-11	4.47E-09	2.28E-09	2.65E-09	1.47E-08	4E-06	0.001

The inhalation pathway appears to present very low risk for both children and adults due to these mine wastes, with a HI of 0.007 for children greater than 0.001 for adults. For this exposure route, the HQi for the elements is in the order Cr>As>Pb>Cu>Zn for both children and adults. These exposure pathway does not seem to pose serious potential health risks in terms of these PTEs in the mine wastes of the area. According to Awesome *et al*. (2017) and Ondayo *et al*. (2023), HQi and HI values of less than 1 indicate low or no adverse non-cancer health risk from environmental matrices. For the ingestion exposure route, a child who consumes these mine wastes is generally at a higher risk of adverse effects than an adult. For the five PTEs studied in this work, the HQi values show that a child ingesting these materials is 7.5 to 9.5 times more likely to suffer adverse health effects than an adult. Similarly, for the inhalation pathway, though considered to be generally less significant in this study (Table 5), the possibility of children suffering adverse health effects was found to be 6.6 to 7.5 times higher than that for adults. The overall risk assessment (HI) follows the same pattern, where children are 9 to 10 times more vulnerable than members of the adult population exposed to these mine wastes through the two exposure scenarios.

CONCLUSION

This study assessed the chemical and mineralogical characteristics of wastes from ASGM in Gadaeregi area, near Minna, Nigeria. The aim was to assess the potential human health risks respect to toxic elements through ingestion and inhalation exposure pathways. The main minerals identified in the wastes are albite, quartz, actinolite, dolomite and annite. Among the major elements, Fe, Si and Ti are present at concentrations above the published upper crustal abundances; while Al, Na, K and Ca appear to be depleted. The wastes are enriched in nine of the trace elements studied (Ni, Cu, Ga, V, Cr, Ce, As, Pb and W) and depleted in five others (Ba, Rb, Y, Zr and Nb). Health risk assessment showed that Cr, As and Pb are the most dosed trace elements in these wastes for both children and adults for the two exposure scenarios. While all three elements have HQi values of > 1 for children in the ingestion model, only As has a value > 1 for the adult population. Based on the evidence in this work, the inhalation route does not appear to have any potential health effect for both children and adults because all the elements have HQ values < 1. On the whole, both children and adults may be vulnerable to adverse health effects through the ingestion exposure route. However, children appear to be several orders of magnitude more vulnerable, understandably because of their low body weights and hand-to-mouth habits. These data have shown that ASGM wastes have the potential to cause deleterious health effects in populations within mining communities, which has not been previously reported in this area. On the long run, this has the potential to affect sustainable wellbeing of the populations, if adults and children begin to come down with ailments arising from bioaccumulation of toxic elements in the body. Therefore, characterisation and proper management of these wastes is necessary to ensure sustainability in mining areas. Further research on the bioaccessibility of PTEs in mine wastes of Gadaeregi and other areas can help to enhance estimation of human health risks and make more informed decisions about management of wastes, including their possible valorisation.

REFERENCES

Akande, S.O., Fakorede, O and Mucke, A. (1988). Geology and genesis of gold-bearing quartz veins at Bini Yauri and Okolom in the Pan-African domain of Western Nigeria. *Geologie en Mijnbouw*, 67(1), 41–51, 1988.

Awesome, J.A., Taiwo, A.M., Dada, E.O. and Ayantobo, O.O. (2017). Human health and environmental assessments of small-scale and artisanal mining activities in the Gold City of Ijeshaland, Southwestern Nigeria. *Environmental Systems Research, 6:18* DOI 10.1186/s40068-017-0095-4

Dales, K. & Ramasamy, J. (2019). Mapping and Assessing the Environmental hazards of Abandoned Mines in Sub Saharan African Countries. UNESCO. Nairobi, Kenya.

Ejepu, S. J., Olasehinde, P. I., Omar D.M., Abdullahi D.S., Adebowale T. A. and Ochimana A. (2015). Integration of Geology, Remote Sensing and

Geographic Information System in Assessing Groundwater Potential of Paiko Sheet 185 North-Central *Nigeria. Journal of Information, Education, Science and Technology* (JIEST) Vol. 2(1), pp. 145-155.

Garba, I. (2003). Geochemical characteristics of mesothermal gold mineralization in the Pan- African (600±150Ma) basement of Nigeria. *Trans. Inst. Min. Metall.,* 112, 319-325.

Hilson, G. (2016). Artisanal and small-scale mining and agriculture. Exploring their limits in rural sub-Saharan Africa. Sustainable Market, Issue paper IIED, London.

Idris-Nda, A., Waziri, N.M., Bida, A.D. and Abdullahi, S. (2018). Socio-Economic Impacts of Artisanal and Small-Scale Mining in Parts of Niger State, Central Nigeria. *International Journal of Mining Science*, 4(3), 21-30

Ikenna, T. O., Jeremy, P., Richards, R. S., Theresa, G., & Tara, M. (2015). Artisanal and small scale mining in Nigeria. Experiences from Niger, Nasarawa and Plateau states. The Extractive Industries and Society, 2, 694–703

Man, Y.B., Sun, X.L., Zhao, Y.G., Lopez, B.N., Chung, S.S., Wu, S.C., Cheung, K.C. and Wong, M.H. (2010). Health risk assessment of abandoned agricultural soils based on heavy metal contents in Hong Kong, the world's most populated city. *Environment International*, 36, 570–576

Oke, S.A., Abimbola, A.F. and Rammlmair, D. (2014). Mineralogical and Geochemical Characterization of Gold Bearing Quartz Veins and Soils in Parts of Maru Schist Belt Area, Northwestern Nigeria. *Journal of Geological Research*, http://dx.doi.org/10.1155/2014/314214

Omanayin, Y. A., Ogunbajo, M. I., Waziri, N. M., Ako, T. A., Shuaibu, A. M. and Alaku, I. O (2016). Geochemical Investigation and Physical Impact Assessment of Artisanal Gold Mining, Kataeregi, North-Central Nigeria. *International Journal of Science for Global Sustainability*, 2(2), 21-35.

Ondayo, M.A., Watts, M.J., Hamilton, E.M., Mitchell, C., Mankelow, J. and Osano, O. (2023). Artisanal gold mining in Kakamega and Vihiga counties, Kenya: potential human exposure and health risk. *Environmental Geochemistry Health*, https://doi.org/10.1007/s10653-023-01647-z

Sako, A. & Nimi, M. (2018) Environmental geochemistry and ecological risk assessment of potentially harmful elements in tropical semi-arid soils around the Bagassi South artisanal gold mining site, Burkina Faso. *Cogent Environmental Science*, 4:1, 1543565, DOI: 10.1080/23311843.2018.1543565.

Salgado-Almeida, B.; Falquez-Torres, D.A.; Romero-Crespo, P.L.; Valverde-Armas, P.E.; Guzmán-Martínez, F.; Jiménez-Oyola, S. (2022) Risk Assessment of Mining Environmental Liabilities for Their Categorization and Prioritization in Gold-Mining Areas of Ecuador. *Sustainability*, 14, 6089. https:// doi.org/10.3390/su14106089

Taylor, S.R. and McLennan, S.M. (1995). The geochemical evolution of the continental crust. *Reviews Geophysics*, 33, 241-265.

USEPA (2000). Risk-Based Concentration Table. Philadelphia PA. Washington DC, USA:

United States Environmental Protection Agency.

USEPA, U. (1997). Exposure factors handbook Office of Research and Development, Washington.

DOI: 10.56892/bima.v8i3.763

USEPA (2001). Toxics Release Inventory Public Data Release. Office of Environmental Information (2810A) Washington, D.C. 20460. www.epa.gov/tri/tridata/tri01.

Vel´asquez, J.R, Schwartz, M., Phipps, L.M., Restrepo-Baena, O.J., Lucena, J. and Smits, K.M. A review of the environmental and health implications of recycling mine tailings for construction purposes in artisanal and small-scale mining communities. *The Extractive Industries and Society*, https://doi.org/10.1016/j.exis.2021.101019.

Waziri, N.M. (2014). Environmental Geochemistry of Soils and Stream Sediments from the Birnin-Gwari Artisanal Mining Area, North-western Nigeria. *Universal Journal of Geoscience, 2(1), 18-27*.

Woakes, M. and Bafor, B.E. (1983). Primary gold mineralization in Nigeria. In R. P. Foster, (Ed.), *GOLD 1982: The Geology, Geochemistry and Genesis of Gold Deposits*, Geological Society of Zimbabwe Special Publication no. 1, Balkema, Rotterdam.