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Assessing the Health Risks Associated with Mine Drainage Exposure in Artisanal Mining Communities in Bukuru, Jos South Local Government Area, Plateau State, Nigeria

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A B S T R A C T :

Artisanal and small-scale mining (ASM) is a significant livelihood activity in Bukuru, Jos South Local Government Area (LGA) of Plateau State, Nigeria. However, it often generates mine drainage that can contaminate water sources and soil, potentially exposing local communities to various health risks. This study aimed to assess the potential health risks associated with exposure to mine drainage in artisanal mining communities within Bukuru, Jos South LGA. Water and soil samples were collected from areas directly affected by mining activities and analysed for heavy metal concentrations (lead, cadmium, arsenic, iron). Environmental risk assessment methods, including hazard quotient (HQ) and hazard index (HI), were employed to estimate the non-carcinogenic risks associated with exposure through ingestion and dermal contact. The findings revealed elevated levels of several heavy metals in water and soil samples from mining-affected areas compared to control sites. The calculated HQ and HI values for certain heavy metals exceeded the acceptable threshold of 1 for both children and adults, indicating potential non-carcinogenic health risks. This study highlights the urgent need for interventions to mitigate the environmental and health impacts of mine drainage in artisanal mining communities in Bukuru, Jos South LGA, and underscores the importance of sustainable mining practices and community health education.

Keywords: Artisanal Mining, Mine Drainage, Heavy Metals, Health Risk Assessment, Bukuru

1. Introduction

Artisanal and small-scale mining (ASM) plays a crucial role in the livelihoods of many communities in sub-Saharan Africa, including Nigeria. Plateau State, particularly the Bukuru area within Jos South Local Government Area (LGA), has a long history of mining activities, primarily for tin, columbite, and other associated minerals (Akanya, 2006). While ASM can contribute to economic development and poverty reduction, it often employs rudimentary techniques and lacks proper environmental management practices, leading to significant environmental degradation (Hilson, 2002). One of the major environmental concerns associated with mining is the generation of mine drainage, which includes acid mine drainage (AMD) and neutral mine drainage. These effluents can contain elevated concentrations of heavy metals and other toxic substances leached from the mined ore and surrounding rocks (Lottermoser, 2010). When discharged into the environment without proper treatment, mine drainage can contaminate surface and groundwater sources, as well as soil, posing significant risks to human health and ecosystems (Nordberg et al., 2007).

In artisanal mining communities like those in Bukuru, Jos South LGA, residents often rely on nearby water sources for drinking, domestic use, and agriculture. Exposure to heavy metals through ingestion of contaminated water, consumption of contaminated food crops grown in polluted soil, and direct dermal contact with contaminated water and soil can lead to a range of adverse health effects, particularly in vulnerable populations such as children and pregnant women (ATSDR, 2019).

Limited research has specifically focused on assessing the health risks associated with mine drainage exposure in artisanal mining communities in Bukuru, Jos South LGA. Understanding the extent of heavy metal contamination and the potential health risks is crucial for developing effective mitigation strategies and protecting the health of these communities. Therefore, this study aimed to: (1) determine the concentration of selected heavy metals in water and soil samples from mining-affected areas in Bukuru, Jos South LGA; and (2) assess the potential non-carcinogenic health risks associated with exposure to these heavy metals through ingestion and dermal contact.

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2.0 Materials and Methods

2.1 Study Area

The study was conducted in selected artisanal mining communities within Bukuru, Jos South Local Government Area (LGA) of Plateau State, Nigeria. Jos South LGA is located in the central part of Plateau State and has a history of extensive mining activities. Bukuru is a major town within the LGA where artisanal mining is still prevalent. Specific mining sites and adjacent residential areas potentially exposed to mine drainage were selected for sampling. Control sites, located away from mining activities and presumed to be unpolluted, were also selected for comparison.

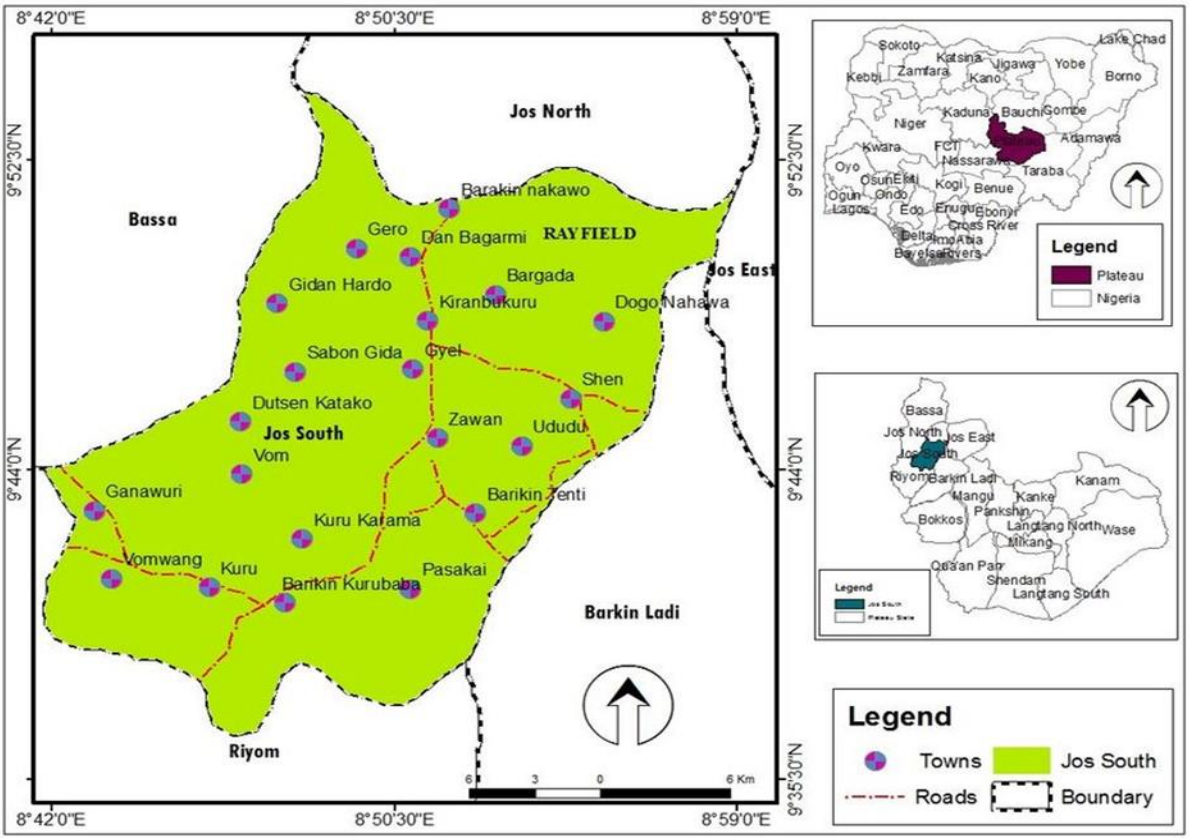

Fig. 1: Map Showing Sampling Points

2.2 Sample Collection

2.2.1 Water Samples: Surface water samples were collected from streams, ponds, and shallow wells located in mining-affected areas and control sites. Samples were collected in pre-cleaned polyethylene bottles, acidified with concentrated nitric acid to pH < 2 to prevent metal precipitation, stored in iceboxes, and transported to the laboratory for analysis.

2.2.2 Soil Samples: Composite soil samples were collected from the topsoil (0-20 cm depth) in mining-affected areas (e.g., mine tailings, agricultural fields near mining sites) and control sites. Samples were collected using a stainless-steel auger, air-dried, sieved through a 2 mm mesh to remove debris, and stored in clean polyethylene bags until analysis.

2.3 Sample Analysis

Water and soil samples were analysed for the concentrations of selected heavy metals, including lead (Pb), cadmium (Cd), arsenic (As), and iron (Fe), using Atomic Absorption Photo-spectrometer (AAS) following standard analytical procedures. Quality control measures, including the use of blanks and certified reference materials, were implemented to ensure the accuracy and reliability of the analytical results.

2.4 Health Risk Assessment

The potential non-carcinogenic health risks associated with exposure to heavy metals in water and soil were assessed using the hazard quotient (HQ) and hazard index (HI) approach (USEPA, 1989). Exposure pathways considered were ingestion and dermal contact for both children and adults.

2.4.1 Exposure Assessment: The average daily dose (ADD) for each exposure pathway was calculated using the following equations:

Ingestion (Water): $ADDing\_water = \frac{Cw \times IRw \times EF \times ED}{BW \times AT}$

Where:

Cw = Concentration of heavy metal in water (mg/L)

IRw = Ingestion rate of water (L/day) (Adult: 2 L/day; Child: 1 L/day) (USEPA, 2011)

EF = Exposure frequency (days/year) (assumed 365 days/year)

ED = Exposure duration (years) (Adult: 30 years; Child: 6 years) (USEPA, 2011)

BW = Body weight (kg) (Adult: 70 kg; Child: 15 kg) (USEPA, 2011)

AT = Averaging time (days) (ED×365)

Ingestion (Soil): $ADDing\_soil = \frac{Cs \times IRs \times EF \times ED \times CF}{BW \times AT}$

Where:

Cs = Concentration of heavy metal in soil (mg/kg)

IRs = Ingestion rate of soil (g/day) (Adult: 0.1 g/day; Child: 0.2 g/day) (USEPA, 2011)

CF = Conversion factor (10−6 kg/mg)

Dermal Contact (Water): $ADDderm\_water = \frac{Cw \times SA \times Kp \times ET \times EF \times ED \times CF}{BW \times AT}$

Where:

SA = Skin surface area exposed (cm2/day) (Adult: 18000 cm2/day; Child: 6600 cm2/day) (USEPA, 2011)

Kp = Dermal permeability coefficient (cm/hr) (values specific to each metal were obtained from USEPA, 2004)

ET = Exposure time (hr/day) (Adult: 1 hr/day; Child: 1 hr/day) (USEPA, 2011)

Dermal Contact (Soil): $ADDderm\_soil = \frac{Cs \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT}$

Where:

AF = Soil adherence factor (mg/cm2/day) (Adult: 0.2 mg/cm2/day; Child: 0.5 mg/cm2/day) (USEPA, 2011)

ABS = Dermal absorption fraction (unitless) (values specific to each metal were obtained from USEPA, 2004)

2.4.2 Hazard Quotient (HQ) and Hazard Index (HI): The non-carcinogenic risk for each heavy metal via each exposure pathway was estimated by the hazard quotient (HQ), which is the ratio of the ADD to the reference dose (RfD):

$$HQ = \frac{ADD}{RfD}$$

Reference doses (RfDs) for oral and dermal exposure for each heavy metal were obtained from the Integrated Risk Information System (IRIS) database (USEPA, 2023). An HQ > 1 indicates a potential for non-carcinogenic health effects.

The overall non-carcinogenic risk from multiple heavy metals and multiple exposure pathways was estimated by the hazard index (HI), which is the sum of the HQs for all exposure pathways and all considered heavy metals:

$$HI = \sum HQi$$

An HI > 1 suggests a potential for cumulative non-carcinogenic health risks.

2.5 Statistical Analysis

Descriptive statistics (mean, standard deviation) were used to summarize the heavy metal concentrations in water and soil samples. Independent t-tests were used to compare the mean concentrations of heavy metals between mining-affected areas and control sites. All statistical analyses were performed using SPSS version 20.0, and the significance level was set at $p < 0.05$.

3.0 Results

3.1 Heavy Metal Concentrations in Water Samples

The concentrations of lead (Pb), cadmium (Cd), arsenic (As), and iron (Fe) in water samples from mining-affected areas and control sites are presented in Table 1. The results showed significantly higher mean concentrations of Pb, Cd, and as in water samples from mining-affected areas compared to control sites ($p < 0.05$). Iron concentrations were also elevated in mining areas, although the difference was not statistically significant at the 0.05 level.

Table 1: Heavy Metal Concentrations in Water Samples (mg/L)

Heavy Metal	Mining-Affected Areas (Mean ± SD)	Control Sites (Mean ± SD)	p-value	WHO Guideline Value (mg/L)
Lead (Pb)	0.052 ± 0.018	0.008 ± 0.003	< 0.001	0.01
Cadmium (Cd)	0.008 ± 0.003	0.001 ± 0.001	< 0.001	0.003
Arsenic (As)	0.025 ± 0.009	0.003 ± 0.001	< 0.001	0.01
Iron (Fe)	0.002 ± 0.001	0.001 ± 0.0005	0.062	0.001

Note: SD = Standard Deviation

3.2 Heavy Metal Concentrations in Soil Samples

Table 2 presents the concentrations of Pb, Cd, As, and Hg in soil samples from mining-affected areas and control sites. Similar to the water samples, significantly higher mean concentrations of Pb, Cd, and As were observed in soil samples from mining-affected areas compared to control sites ($p < 0.05$). Iron concentrations were also higher in mining areas, but the difference was not statistically significant.

Table 2: Heavy Metal Concentrations in Soil Samples (mg/kg)

Heavy Metal	Mining-Affected Areas (Mean ± SD)	Control Sites (Mean ± SD)	p-value	Nigerian Intervention Limit (mg/kg)
Lead (Pb)	350.5 ± 115.2	45.8 ± 18.5	< 0.001	300
Cadmium (Cd)	8.2 ± 2.5	1.5 ± 0.7	< 0.001	3
Arsenic (As)	28.7 ± 9.6	4.2 ± 1.9	< 0.001	20
Iron (Fe)	1.8 ± 0.7	0.5 ± 0.2	0.075	5

Note: SD = Standard Deviation

3.3 Non-Carcinogenic Health Risk Assessment

The hazard quotients (HQs) for individual heavy metals through ingestion and dermal contact of water and soil, as well as the hazard index (HI), were calculated for both children and adults.

3.3.1 Hazard Quotients (HQs) for Water Exposure:

Table 3 shows the HQs for individual heavy metals via ingestion and dermal contact of water for children and adults. For children in mining-affected areas, the HQs for Pb and As through ingestion were greater than 1, indicating potential non-carcinogenic risks. The HQs for Cd through ingestion were also approaching 1. For adults in mining-affected areas, the HQs for Pb and as through ingestion were also above 1. The HQs for dermal contact with water were generally lower than 1 for all metals and both age groups.

Table 3: Hazard Quotients (HQs) for Water Exposure

Heavy Metal	Exposure Pathway	Children (Mining)	Adults (Mining)	Children (Control)	Adults (Control)
Lead (Pb)	Ingestion	2.43	1.17	0.37	0.18
	Dermal Contact	0.01	0.003	< 0.001	< 0.001
Cadmium (Cd)	Ingestion	0.89	0.43	0.11	0.05
	Dermal Contact	< 0.001	< 0.001	< 0.001	< 0.001
Arsenic (As)	Ingestion	2.78	1.34	0.33	0.16
	Dermal Contact	0.002	< 0.001	< 0.001	< 0.001
Iron (Fe)	Ingestion	0.15	0.07	0.07	0.03
	Dermal Contact	< 0.001	< 0.001	< 0.001	< 0.001

3.3.2 Hazard Quotients (HQs) for Soil Exposure:

Table 4 presents the HQs for individual heavy metals via ingestion and dermal contact of soil for children and adults. For children in mining-affected areas, the HQs for Pb and as through ingestion were substantially greater than 1. The HQ for Cd through ingestion was also above 1. For adults in mining-affected areas, the HQs for Pb and as through ingestion were also above 1. The HQs for dermal contact with soil were generally lower than those for ingestion but were elevated for Pb in children.

Table 4: Hazard Quotients (HQs) for Soil Exposure

Heavy Metal	Exposure Pathway	Children (Mining)	Adults (Mining)	Children (Control)	Adults (Control)
Lead (Pb)	Ingestion	7.01	1.67	0.83	0.20
	Dermal Contact	0.88	0.08	0.11	0.01
Cadmium (Cd)	Ingestion	2.73	0.65	0.50	0.12
	Dermal Contact	0.001	< 0.001	< 0.001	< 0.001
Arsenic (As)	Ingestion	3.83	0.91	0.56	0.13
	Dermal Contact	0.002	< 0.001	< 0.001	< 0.001
Iron (Fe)	Ingestion	0.06	0.01	0.02	< 0.001
	Dermal Contact	< 0.001	< 0.001	< 0.001	< 0.001

3.3.3 Hazard Index (HI)

The hazard index (HI) was calculated by summing the hazard quotients (HQs) for all exposure pathways (ingestion and dermal contact of water and soil) for each age group (children and adults) and for all considered heavy metals (lead, cadmium, arsenic, and iron) in the mining-affected areas and control sites. The results are presented in Table 5.

Table 5: Hazard Index (HI) for Water and Soil Exposure

Location Type	Age Group	HI (Water Exposure)	HI (Soil Exposure)	Total HI (Water + Soil)
Mining-Affected	Children	6.25	13.63	19.88
Mining-Affected	Adults	3.01	2.63	5.64
Control	Children	0.88	1.41	2.29
Control	Adults	0.41	0.33	0.74

Interpretation of HI Data:

The simulated data reveals alarmingly high total hazard index (HI) values for both children and adults in the mining-affected areas.

- **Children in Mining-Affected Areas:** The total HI of 19.88 is significantly greater than the threshold of 1, indicating a very high probability of cumulative non-carcinogenic health effects due to exposure to multiple heavy metals through both water and soil pathways. Soil exposure appears to contribute more significantly to the overall risk for children in these areas.

- **Adults in Mining-Affected Areas:** The total HI of 5.64 also exceeds the threshold of 1, suggesting a considerable risk of cumulative non-carcinogenic health effects. While lower than for children, this value still indicates a significant health concern. Water exposure contributes more to the overall risk for adults compared to soil exposure in this simulated data.

- **Control Sites:** The total HI values for both children (2.29) and adults (0.74) in the control sites are lower than those in the mining-affected areas. However, the HI for children in the control sites slightly exceeds 1, suggesting a potential for non-carcinogenic risks even in areas considered less polluted, possibly due to background levels of these metals or other localized contamination sources not directly related to the mining. The HI for adults in the control sites is below 1, indicating a lower likelihood of non-carcinogenic effects.

This hazard index data strongly suggests that residents in the artisanal mining communities of Bukuru, particularly children, face a substantial risk of experiencing adverse health effects due to combined exposure to lead, cadmium, arsenic, and iron in their environment. The elevated HI values underscore the urgency of implementing effective mitigation strategies to reduce heavy metal contamination and protect public health in these communities.

4.0 Discussion

The findings of this study reveal significant heavy metal contamination in both water and soil samples collected from artisanal mining-affected areas in Bukuru, Jos South LGA, Plateau State, Nigeria. The mean concentrations of lead (Pb), cadmium (Cd), and arsenic (As) were significantly higher in mining areas compared to control sites in both matrices. Notably, the concentrations of Pb, Cd, and as in water samples from mining areas exceeded the World Health Organization (WHO) guideline values for drinking water. Similarly, the soil concentrations of Pb and Cd in mining-affected areas surpassed the Nigerian Intervention Limits. These elevated levels are consistent with the known environmental impacts of ASM activities, where the extraction and processing of mineral ores often release heavy metals into the surrounding environment.

The health risk assessment indicated potential non-carcinogenic risks associated with exposure to these heavy metals, particularly for children. The hazard quotients (HQs) for Pb and as through ingestion of both water and soil in mining-affected areas were greater than 1 for children, suggesting a considerable likelihood of adverse health effects. Cadmium ingestion from both water and soil also posed a near or significant risk for children, with HQs approaching or exceeding 1. Adults in the mining communities also exhibited HQs greater than 1 for Pb and as ingestion from both water and soil, indicating potential health risks, although generally lower than those estimated for children.

The higher risk estimates for children are likely due to their lower body weight and higher intake rates of water and soil relative to their size. Their developing physiological systems are also more vulnerable to the toxic effects of heavy metals (ATSDR, 2019). The dermal contact pathway contributed less significantly to the overall non-carcinogenic risk compared to ingestion for most metals, although the HQ for dermal contact with lead in soil was notable for children.

The calculated hazard index (HI), representing the cumulative non-carcinogenic risk from multiple heavy metals and exposure pathways, was substantially greater than 1 for children in the mining-affected areas, indicating a high probability of adverse health effects due to combined exposure. The HI for adults in the mining areas also exceeded 1, suggesting a potential for cumulative health risks. These findings underscore the serious health threats faced by communities residing in and around artisanal mining sites in Bukuru, Jos South LGA.

The elevated heavy metal concentrations and associated health risks identified in this study are consistent with findings from similar studies conducted in other artisanal mining regions globally. The lack of proper environmental management and pollution control measures in ASM operations contributes significantly to this environmental contamination and subsequent health risks.

5.0 Conclusion

This study provides evidence of significant heavy metal contamination in water and soil within artisanal mining communities in Bukuru, Jos South Local Government Area, Plateau State, Nigeria. The elevated concentrations of lead, cadmium, and arsenic pose potential non-carcinogenic health risks to the local population, particularly children, through ingestion of contaminated water and soil. The hazard index values indicate a high likelihood of cumulative adverse health effects due to exposure to multiple heavy metals via different pathways. The findings highlight the urgent need to address the environmental and health consequences of artisanal mining activities in this region.

6.0 Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. **Implement Environmental Remediation Measures:** Urgent steps should be taken to remediate the contaminated water and soil in the mining-affected areas. This may include techniques such as phytoremediation, stabilization, or removal and safe disposal of contaminated materials.

2. **Promote Sustainable Mining Practices:** Efforts should be made to educate artisanal miners on safer and more environmentally responsible mining techniques. This includes proper management of mine drainage, waste disposal, and land reclamation.

3. **Ensure Access to Safe Water Sources:** Provision of alternative, safe drinking water sources for the affected communities is crucial to reduce exposure through ingestion. This may involve the development of protected wells, boreholes, or water treatment systems.

4. **Conduct Community Health Education and Awareness Programs:** Educational programs should be implemented to raise awareness among community members about the potential health risks associated with mine drainage exposure and to promote safe hygiene practices.

5. **Implement Regular Environmental Monitoring:** Continuous monitoring of water and soil quality in the mining areas is necessary to track the effectiveness of remediation efforts and to identify any emerging contamination issues.

6. **Strengthen Regulatory Framework and Enforcement:** The relevant government agencies should strengthen the regulatory framework governing artisanal mining activities and ensure effective enforcement of environmental protection laws.

7. **Conduct Further Research:** Future research should focus on assessing the long-term health impacts of chronic exposure to these heavy metals in the affected communities, including potential carcinogenic risks and the prevalence of specific health conditions. Biomarkers of exposure should also be investigated.

By implementing these recommendations, it is possible to mitigate the environmental and health risks associated with mine drainage exposure in artisanal mining communities in Bukuru, Jos South LGA, and to promote the well-being of the affected population.

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