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Heavy Metal and Carcinogenic Risk Assessment of a Gold Mine Turned Residential Area in Mokuro Area of Ile-Ife, Osun State, Nigeria

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Abstract

Artisanal gold mining along the Ife-Ijesa axis in Osun State, Nigeria, is widespread, and many abandoned mining sites are now being repurposed into residential areas without a prior assessment of the risks associated with heavy metals. This study examines the carcinogenic and non-carcinogenic health risks associated with heavy metal contamination in soil, water, and plant samples from a reclaimed gold mine in Mokuro, Ile-Ife. Twelve (12) samples consisting of soil, water, and plants were collected across the reclaimed mining site using standard sampling methods. Concentrations of arsenic (As), lead (Pb), cadmium (Cd), and zinc (Zn) were determined by atomic absorption spectroscopy (AAS). Results indicated that mean soil concentrations of As, Pb, Cd, and Zn were 0.70±0.278, 1.03±0.104, 2.07±0.236, and 2.47±0.202 mg kg^{-1}, respectively, within regulatory limits. However, drinking water contained 0.012±0.006, 0.007±0.004, 0.019±0.006, and 0.023±0.007 mgL^{-1} as mean ± standard deviation, respectively, of As, Pb, and Cd, with cadmium levels exceeding the WHO limit of 0.003 mg L^{-1}. In plant samples, cadmium in bitter and guava leaves (0.34 and 0.49 mg kg^{-1}, respectively) surpassed FAO/WHO limits (0.2 mg kg^{-1}), suggesting potential dietary exposure risks. Risk assessments revealed that the non-carcinogenic hazard risk index (HRI) varied from 0.174 in cassava leaf to 4.342 in cassava tuber. The total carcinogenic risk (TCR) also varied from 6.86 x 10^{-5} in cassava leaf to 1.10 x 10^{-3} in cassava tuber, thus presenting cassava tubers grown on the site as a major source of exposure to both non-carcinogenic and carcinogenic risks since its HRI >1 and TCR > 10^{-4} due to arsenic contamination. Although most contamination levels are within limits, the high cadmium in water and arsenic in cassava warrant precautionary measures such as water treatment and dietary monitoring.

Keywords: Heavy metals; carcinogenic risk; soil contamination; drinking water; cassava; gold mining.

I. Introduction

Heavy metals are persistent environmental contaminants with severe health implications for humans, plants, and animals. Among them, lead (Pb), arsenic (As), and cadmium (Cd) are of particular concern due to their toxicity, bioaccumulation potential, and carcinogenic effects. Chronic exposure to Pb is linked to neurological impairments, cognitive deficits, and kidney dysfunction, particularly in children [1], [2]. Arsenic, classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC), has been associated with skin, lung, and bladder cancers [3]. Cadmium similarly accumulates in kidney tissues, resulting in irreversible damage. Moreover, it elevates lung cancer risk by directly damaging DNA, impeding DNA repair, inducing oxidative stress, and inhibiting apoptosis [4]. Collectively, lead, arsenic, and cadmium are ranked among the World Health Organization's top ten chemicals of public health concern due to their ubiquitous environmental presence and significant toxicity [5].

While trace levels of heavy metals naturally occur in geological formations, anthropogenic activities such as mining, industrial processes, and agricultural practices have significantly increased their environmental distribution. Gold mining, particularly artisanal and small-scale operations, is a major contributor to heavy metal pollution. Gold ores often contain high levels of toxic metals, which are released into the environment through ore processing, tailing disposal, and wastewater discharge [6]. The 2010 lead poisoning crisis in Zamfara, Nigeria, is a stark example of the devastating effects of unregulated gold mining, where hundreds of children died due to severe Pb exposure from mining activities [6], [7]. Subsequent research efforts in Zamfara report on the continued influence of artisanal gold mining on both the soil and plants around the mining sites [8], [9].

Gold mining has been a longstanding activity in Osun State, Nigeria, particularly concentrated in the Ife-Ijesa region. The impact of this mining activity on the soil quality in Ido-Ijesa has been documented [10], while its repercussions on water quality have been established in Igun-Ijesa [11]. Furthermore, artisanal gold mining in Ido-Ijesa has been linked to decreased crop yields [12]. Most mining sites are abandoned post-extraction, lacking proper remediation procedures due to inadequate governmental oversight or the inefficacy thereof. Over time, many of these sites become enveloped by community expansion and necessitate repurposing. Nevertheless, several abandoned mining locations have been repurposed for residential or agricultural purposes without undergoing comprehensive environmental risk assessments. Consequently, local inhabitants may face exposure to residual heavy metals through the contamination of soil, water, and food crops [13]. Despite the potential hazards, there remains a scarcity of studies evaluating the enduring environmental and health ramifications of residing in these reclaimed mining zones.

This study investigates the levels of As, Pb, Cd, and Zn in soil, water, and plants from a reclaimed gold mining site in Mokuro, Ile-Ife, and evaluates the associated health risks. By providing critical data on heavy metal contamination and health risks in a post-mining environment, this study aims to provide the necessary information required in public health interventions, land-use policies, and environmental monitoring strategies regarding gold mining regions of Nigeria.

II. Materials And Methods

A. *The study Area*

The study was conducted in Mokuro, Ile-Ife, Osun State, Nigeria, at a former artisanal gold mining site that has since been repurposed for residential and agricultural use. The area consists of residential buildings, backyard gardens, and water sources, all of which may be susceptible to residual heavy metal contamination. Four key locations within the site were identified for sampling (Fig. 1):

- Location A – A former dumping ground for mining tailings, now used for vegetable and cassava cultivation. A well at the boundary of Location A serves as a primary domestic water source, also used as drinking water.
- Location B – A natural spring that receives runoff from the garden in Location A.
- Location C – The primary mining site, now converted into a residential area with citrus trees.
- Location D – An abandoned mining site with no further development.

B. *Sample Collection and Preparation*

Twelve samples of soil, water, and plant materials (cassava tubers, cassava leaves, guava leaves, bitter leaves, citrus fruits) were collected following standardized procedures to prevent contamination [14]. Soil samples were systematically collected from Locations A, B, C, and D at a depth of 0–20 cm using a stainless-steel auger. Sampling took place in February 2023 during the 2022/2023 dry season. Three subsamples were collected per location, mixed to form a composite sample, air-dried, sieved (2 mm mesh), and stored in labeled polyethylene bags for analysis. Drinking water samples were collected from the well at Location A, the spring at Location B and well at location D. Each sample was filtered on-site using 0.45 μm membrane filters, acidified with nitric acid (HNO_3) to a pH < 2 to prevent metal precipitation, and stored at 4 °C in pre-cleaned polyethylene bottles until analysis, while plant samples were selected based on local consumption patterns.

C. *Sample Digestion and Heavy Metal Analysis*

All samples were digested using standard wet digestion techniques prior to Atomic Absorption Spectroscopy (AAS) analysis.

For soil, Hydrofluoric acid (HF) and nitric acid (HNO_3) were employed. The process of soil sample digestion necessitates the breakdown of the sample matrix. Hydrofluoric acid (HF) is an effective choice for this task due to its exceptional capability to achieve complete or nearly complete digestion of the samples [15]. HF interacts with silicates, creating SiF_4, which enhances the digestion process by facilitating better dissolution. Moreover, it can dissolve minerals without disrupting the chemical bonds present in the organic matter of the soil [16]. Nonetheless, caution and stringent control measures are imperative when utilizing HF in this context, given its corrosive properties. Therefore, 1 g of dried, sieved soil was placed in a Teflon digestion vessel, and 5 mL concentrated hydrofluoric acid (HF) and 20 mL nitric acid (HNO_3) were added. The mixture was then heated in a fume hood at 160 °C for 1 hour, until complete digestion. The cooled digest was filtered, diluted to 50 mL, and refrigerated, pending AAS analysis.

For plant digestion, 1 g of dried plant material was digested using 2 mL of aqua regia (HCl: HNO_3, 3:1). The mixture was heated to near dryness, cooled, and reconstituted with 20 mL of distilled water. The digest was filtered, diluted to 25 mL, and refrigerated pending AAS analysis.

To digest the water samples, 25 mL of the filtered water sample was mixed with 15 mL of aqua regia and heated to near dryness. The sample was then reconstituted with 10 mL of distilled water, reheated briefly, filtered, and diluted to 25 mL for analysis.

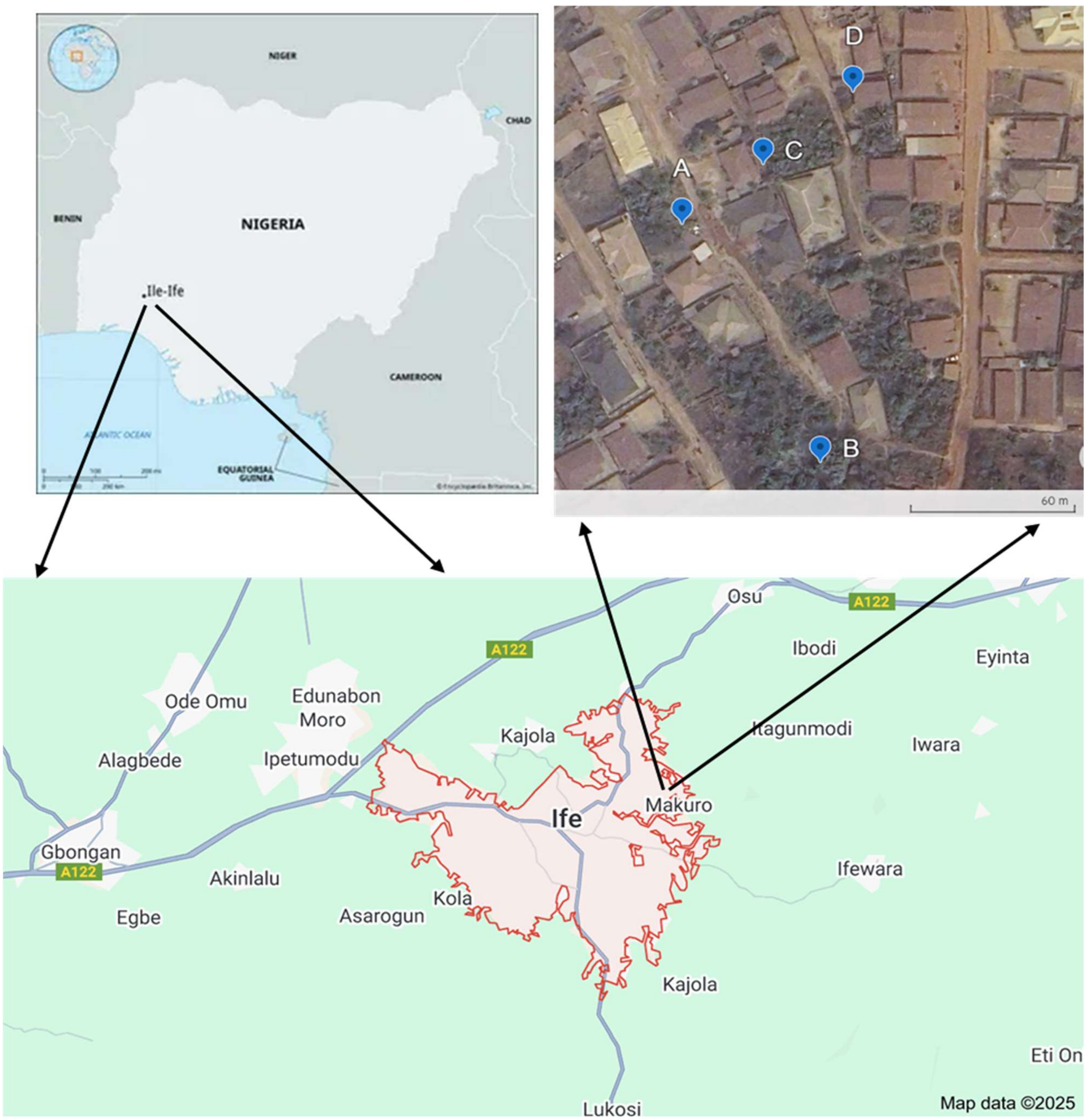

Fig. 1. The study area map: locations A, B, C, and D at the repurposed mining site in Mokuro, Ile-Ife, Nigeria.

D. Atomic Absorption Spectroscopy (AAS) Analysis

Heavy metal concentrations were determined using a PG 990 Atomic Absorption Spectrometer at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria. The Spectrometer employs flame atomization (air-acetylene flame) and single-element hollow cathode lamps for Pb, Cd, As, and Zn detection. Calibration was performed using standard solutions prepared from 1000 ppm stock solutions to generate linear calibration curves for each metal. For all the elements of interest, aliquots from samples were analysed in triplicate, from which mean and standard deviation values were returned for each element per sample. The elemental concentration in samples was determined using (1).

$$C_f = \frac{C_m \times V}{m_s} \quad (1)$$

The objective is to determine the final concentration (C_f) of elements in a sample expressed in units such as µg g^{-1} or mg kg^{-1} (ppm), where C_m represents the elemental concentration of the digested sample in units like µg/ml or mg L^{-1}, V denotes the volume to which the digested sample is adjusted in mL, and m_s is the mass in "g" of the sample digested.

E. Calculations of Parameters

The following parameters were calculated.

1) Transfer Ratio (TR):

The mobility of heavy metals from soil to plants was estimated using the transfer ratio (TR), calculated as in (2).

$$TR = \frac{C_f \text{ in plant}}{C_f \text{ in soil}} \quad (2)$$

Higher TR values indicate greater metal bioavailability and potential dietary risk.

2) Daily Metal Intake (DIA):

The daily intake of metals (DIA) through food consumption was calculated using (3).

$$DIA = \frac{C_f \times CRT}{BW} \times 10^{-3} \quad (3)$$

Where C_f is the metal concentration in food (mg kg^{-1}), CRT is the average food consumption rate (cassava: 273.97 g day^{-1} [17], vegetables: 17.8 g day^{-1} [18], BW is the body weight (children: 20 kg, adults: 70 kg), and 10^{-3} = unit conversion factor.

3) Hazard Quotient (HQ):

The Hazard Quotient (HQ) assesses non-carcinogenic risk, given as;

$$HQ_i = \frac{DIA}{RfD_i} \quad (4)$$

Where RfD is the reference oral dose (mg kg^{-1} day^{-1}) from the USEPA guidelines (see Table I) [19].

The Hazard Risk Index (HRI) is the human health risk associated with the ingestion of foods contaminated with toxic metals [20] and is calculated as the sum of HQ values for all metals:

$$HRI = \sum HQ_i \quad (5)$$

Where for HI < 1: there is no significant health risk, and for HI > 1: there is a potential non-carcinogenic health risk.

4) Carcinogenic Risk (CR):

The lifetime probability of developing cancer from metal exposure was estimated using (6).

$$CR = DIA \times Csf \quad (6)$$

Where Csf is the cancer slope factor (mg kg^{-1} day^{-1}) from the USEPA (see Table I) [19].

CR < 10^{-6} implies negligible cancer risk, $10^{-6} \leq$ CR < 10^{-4} implies an acceptable cancer risk range, and CR > 10^{-4} implies High cancer risk.

Table I. Oral reference dose (RfD) and cancer slope factor (Csf) [19].

Metal	RfD (mg kg^{-1} day^{-1})	Csf (mg kg^{-1} day^{-1})
As	0.0003	1.5
Cd	0.0005	0.38
Pb	0.0035	0.0085
Zn	0.3000	-

III. RESULTS AND DISCUSSION

This section presents the findings from the analysis of heavy metal concentrations in soil, water, and plant samples, alongside statistical comparisons and health risk assessments.

A. Statistical Analysis

Data collected from various sampling points were subjected to a t-test to determine significant differences between sample means. The results indicated no statistically significant differences (p-values: 0.35–0.40), suggesting uniform distribution of heavy metal contamination across the study area.

B. Heavy Metal Concentrations in Plant Media

Fig. 2 shows the levels of arsenic (As), lead (Pb), cadmium (Cd), and zinc (Zn) in leafy vegetables, cassava tubers, and citrus fruits from the reclaimed gold mine site. Guava leaves recorded the highest arsenic concentration at 0.201±0.050 mg kg^{-1}, followed by cassava tubers (0.179±0.070 mg kg^{-1}) and bitter leaves (0.159±0.020 mg kg^{-1}). Cadmium levels in bitter leaves (0.34±0.051 mg kg^{-1}) and guava leaves (0.486±0.080 mg kg^{-1}) surpassed the FAO/WHO limit of 0.2 mg kg^{-1}, indicating potential dietary risks. Although guava leaves had the highest lead concentration at 0.168±0.030 mg kg^{-1}, all lead values were below regulatory limits. Zinc was detected at levels within regulatory limits in all plant samples. These values are comparable with those of a similar study in Igun Ijesa, which measured As, Cd, Pb, and Zn in plant samples around the gold mine to be 0.003, 0.015, 0.202, and 1.205 mg kg$^{-1,}$ respectively [21].

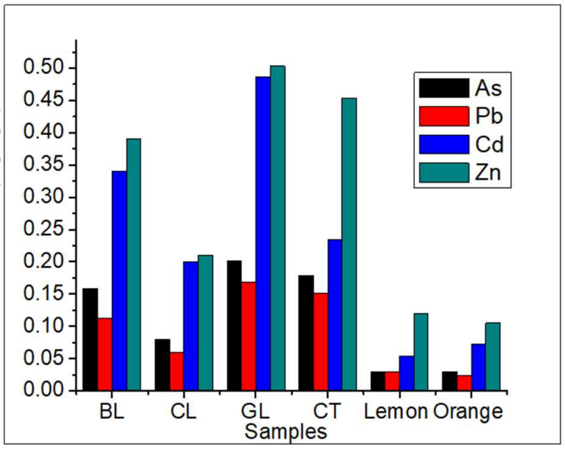

Fig. 2. Heavy Metal concentration in different plant samples across the reclaimed mining site (BL=Bitter Leaf, CL = Cassava Leaf, GL = Guava Leaf, and CT = Cassava Tuber)

C. Heavy Metal Contamination in Soil and Water Samples

Table II presents the outcomes of the assessment conducted to determine the extent of soil and water contamination. The average concentration of arsenic in the soil was 0.700±0.278 mg kg^{-1}, a value significantly lower than the World Health Organization's (WHO) permissible threshold of 20 mg kg^{-1}. Similarly, the mean level of lead recorded was 1.033±0.104 mg kg^{-1}, well below the WHO recommended limit of 100 mg kg^{-1}. Additionally, the average concentration of cadmium in the soil was measured at 2.067±0.236 mg kg^{-1}, falling within the WHO's advised range of 3–6 mg kg^{-1}. Consequently, the levels of heavy metals detected in the soil samples remained compliant with the WHO guidelines for agricultural soil. Comparable findings were observed in other gold mining sites within the vicinity of Ilesa, as reported in previous studies [21], [22].

In contrast, the analysis of drinking water samples indicated alarming levels of cadmium, with an average concentration of 0.019±0.006 mgL^{-1}, surpassing the WHO's maximum permissible limit of 0.003 mgL^{-1}. This elevated cadmium content in drinking water, a known carcinogenic metal with a high potential for bioaccumulation, necessitates immediate attention from policymakers to ensure the safety of the general populace. Arsenic levels in water were recorded at an average of 0.012±0.006 mgL^{-1}, nearing the WHO's specified threshold of 0.01 mg L^{-1}, while lead concentrations stood at 0.007±0.004 mgL^{-1}, remaining within acceptable boundaries but still posing potential health risks. The heightened presence of cadmium in water sources underscores a significant long-term health hazard associated with sustained consumption.

Table II. Heavy Metal Concentrations in Soil and Water

Sample	As	Pb	Cd	Zn
Water (mg L^{-1})	0.012±0.006	0.007±0.004	0.019±0.006	0.023±0.007
Soil (mg kg^{-1})	0.700±0.278	1.033±0.104	2.067±0.236	2.467±0.202

D. Transfer Ratio (Metal Mobility in Plants)

Table III presents the transfer ratios (TR), which indicate the extent of metal uptake from soil into plants. Arsenic and Cd showed the highest transfer ratios, indicating high mobility from soil to plants. Guava leaf had the highest transfer ratio for all metals, suggesting it absorbs metals more efficiently than other plants. Bitter leaf, which is widely consumed as food and medicine, exhibited a high transfer ratio, raising concerns about dietary exposure to Cd and As.

E. Health Risk Assessment

Health risk assessments were calculated based on Equations (4) and (5). Table V shows that cassava tuber posed the highest non-carcinogenic risk, with an HRI of 4.342 (HRI > 1), indicating a significant health concern, while other vegetables had an HRI < 1, suggesting a lower risk of non-carcinogenic effects. Also, cassava tuber consumption poses the highest cancer risk from all the metals, with a total carcinogenic risk (TCR) of 1.10×10^{-3}, exceeding the acceptable limit (10^{-4}), while other samples had lower CR values but still indicated potential long-term risks.

Table III. Transfer ratios of metals in vegetables and fruits.

Sample	As	Pb	Cd	Zn
Bitter Leaf	0.23	0.11	0.16	0.16
Cassava Leaf	0.11	0.06	0.10	0.09
Guava Leaf	0.29	0.16	0.24	0.20
Lemon	0.04	0.03	0.03	0.05
Orange	0.04	0.02	0.03	0.04

Table IVCarcinogenic and Non-carcinogenic risk involved in the consumption of vegetables; TCR is the total carcinogenic risk due to all the metals.

Sample	Non-Carcinogenic Risk				Carcinogenic Risk (x10^{-5})			
	HQ As	HQ Pb	HQ Cd	HRI	CR As	CR Pb	CR Cd	TCR
Bitter Leaf	0.135	0.008	0.173	0.316	6.07	0.0244	6.46	12.50
Cassava Leaf	0.068	0.004	0.102	0.174	3.05	0.0130	3.80	6.86
Guava Leaf	0.170	0.012	0.247	0.430	7.67	0.0363	9.23	16.90
Cassava Tuber	2.335	0.169	1.832	4.342	105.0	0.5020	4.45	110.00

IV. CONCLUSION

This study evaluated heavy metal contamination and the associated health risks in a reclaimed gold mine site in Mokuro, Ile-Ife, Osun State, Nigeria. Analysis of soil samples revealed the mean concentrations of arsenic, lead, and cadmium were within the WHO limits for agricultural soils. In plant samples, arsenic levels were generally low; however, cadmium concentrations in bitter and guava leaves exceeded FAO/WHO limits, indicating potential dietary exposure risks. Although lead levels in plant samples remained below regulatory thresholds, the water analysis raised concerns: the mean cadmium concentration in drinking water exceeded the WHO limit (0.003 mgL^{-1}), while arsenic and lead were close to or within regulatory limits. Risk assessments based on hazard quotient and carcinogenic risk calculations further highlighted that, despite overall compliance with soil and most food safety guidelines, the consumption of cassava tubers poses significant non-carcinogenic and carcinogenic risks, likely due to high ingestion rates and the cumulative effects of cadmium and arsenic exposure. In summary, while the reclaimed site appears relatively safe in terms of soil and most food contamination, elevated cadmium levels in drinking water and cassava tubers present a potential health hazard. These findings underscore the need for targeted interventions such as improved water treatment, regular monitoring, and dietary advisories to mitigate long-term health risks. The relevant government body, such as the National Environmental Standards and Regulations Environmental Enforcement Agency (NESREA) and the Environmental Health Officers (EHOs), should be proactive in the oversight of any abandoned mining site and supervise its remediation before being converted to residential areas.

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