



Risks Analyses of Heavy Metals in Some Irrigated Vegetables Around Active and Abandoned Mine Sites in BarkinLadi LGA, Plateau State, Nigeria

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ABSTRACT

Due to the removal of oil subsidy by the Federal Government of Nigeria and the accompanying high cost of living, the people around the tin rich areas have engaged in illegal mining in both abandoned mine and arable farmlands to sustain their living. Foron, located in Barkin Ladi, Nigeria, has both abandoned and ongoing mining sites. These sites are potential sources of environmental contamination due to the lack of adequate waste management and remediation strategies (Ngure *et al.*, 2014). The legacy of past mining activities, coupled with ongoing operations, underscores the need for a comprehensive assessment of heavy metal contamination in local agricultural produce (Ochieng *et al.*, 2021). These mining activities release heavy metals such as Arsenic, Cadmium, Chromium, Iron, Nickel, Lead, Zinc and Copper into the environment, which subsequently accumulate in soil and water sources. These metals are persistent environmental pollutants that can accumulate in the food chain, posing health risks to humans who consume the contaminated produce (Zhao *et al.*, 2017).

Keyword: Heavy Metals, Around active and Abandoned mine sites.

INTRODUCTION

Vegetables, due to their direct contact with contaminated soil and irrigation water, are particularly susceptible to absorbing heavy metals. Vegetables like tomato, green beans and potato (which are some of the major irrigated crops in the area and also integral to local diets) readily absorb these metals, posing severe health risks to consumers (Luo *et al.*, 2018). Recent studies

on the commonly cultivated vegetables for their nutritional benefits have highlighted significant levels of heavy metals in the vegetables grown near mining areas, raising concerns about food safety and public health (Heidari *et al.*, 2019; Abdu *et al.*, 2017). The potential health risks associated with consuming heavy metal-contaminated vegetables are profound, including neurological disorders, kidney damage, and various cancers (Jaishankar *et al.*, 2018). Health risk assessments based on the



Estimated Daily Intake (EDI) and Hazard Quotient (HQ), are essential for determining the potential non-carcinogenic and carcinogenic risks associated with consuming contaminated vegetables (USEPA, 2017). By calculating these indices, we can estimate the levels of exposure and potential health effects on local communities (Chary *et al.*, 2016). This approach helps in identifying critical control points for intervention and establishing guidelines for safe consumption levels.

The objective of this study is to quantify the concentrations of heavy metals in water, sediment, soil and three irrigated vegetables grown around abandoned and active mining sites in Foron District of BarkinLadi LGA of Plateau State, Nigeria.

MATERIALS AND METHODS

Study Area

Foron is a District located in the Barkin Ladi Local Government Area (LGA) of Plateau State, Nigeria. It is positioned at approximately 9.6950° N latitude and 8.8600° E longitude. This places it within the Northern part of Plateau State, providing a strategic location for various agricultural activities and mining operations. The economy of Foron and BarkinLadi LGA is predominantly agrarian, with farming being the main occupation of the residents. Major crops cultivated in the area include maize, potatoes, yams, and various vegetables such as spinach, cabbage, and tomatoes. The area is known for its rich mineral deposits, including tin and columbite, which have attracted both small-scale and large-scale mining activities over the years.

Sample Collection and Preparation Water and Sediment Samples

Water samples were collected at different points of streams and ponds around the abandoned and ongoing mine sites in pre-cleaned polyethylene bottles. Prior to collection, the bottles were rinsed three times with the water from the sampling locations to prevent contamination. After collection, samples were acidified with concentrated nitric acid to a pH below 2 to preserve the metals and prevent microbial activity. The acidified water samples were then transported to the laboratory in an icebox and stored at 4°C until analysis. Sediments were collected around the abandoned and active streams or ponds where water samples were collected.

Collection of Surface Soil Samples

Soil samples from Foron District of Barkin Ladi Local Government Areas of Plateau State were collected from abandoned and active tin-mine agricultural areas. The agricultural surface soils (0-10cm) were taken in triplicate at different point at the abandoned and active mining sites using spiral auger of 2.5cm diameter and mixed. The soil samples were then randomly selected and bulked together to form a composite sample for abandoned and active sites before they were placed in clean labeled plastic bags and transported to the laboratory. The samples were used for heavy metals analysis.

Vegetables Samples

Tomato, Green Beans and Potatoessamples were collected from farms around abandoned and ongoing mining areas. These were thoroughly rinsed with distilled water to remove surface dirt and contaminants. They were then sliced into small pieces and air-dried. The dried samples were placed in a laboratory oven at 60°C until they reached a constant weight, ensuring complete dehydration. The dried vegetable samples were subsequently ground into a fine powder using a mortar and pestle, then sieved to achieve a uniform particle size. The powdered samples were stored in airtight containers and labelled for analysis.

Speciation Studies of the Soil and Sediment Samples The soluble fractions of the metals in the soil/sediment were extracted with the water from the stream or pond in the ratio soil or sediment: water (1:5). For the exchangeable and specifically adsorbed fraction extractable, 1 g of soil/sediment sample was weighed into 50 mL extraction tube. 25 mL of solution 0.11M acetic acid was added into the tube to make a mixture with the soil sample. The mixture was shaken in the extraction tube for 6 h at room temperature using a mechanical shaker. The mixture was centrifuged at 3000rpm for 10 min and the supernatant immediately was used for analysis or stored at 40°C prior to analysis with Micro Plasma Spectroscopy.

Heavy Metal Analysis

Prior to analysis, the dried soil, sediment and vegetable samples were then digested using a mixture of acids, including nitric acid (HNO₃) and perchloric acid (HClO₄), in a Kjehdal digestion system (Liu *et al.*, 2020). The digested samples were diluted

with deionized water and filtered to remove any solid residues. The concentrations of heavy metals, including Arsenic (As), Cadmium (Cd), Chromium (Cr), Iron (Fe), Nickel (Ni), Lead (Pb), Zinc (Zn) and Copper (Cu), was determined using Inductively Coupled Plasma (ICP) (Gupta & Singh, 2015).

Environmental and health Risk Assessment

Contamination index (CI) The contamination factors was calculated as

$$CI = C_n/B_n \tag{1}$$

Where;

C_n = measured metal concentration and
B_n = background concentration from the control site

$$\text{Degree of contamination} = \sum CI_{Cd} + CI_{Co} + CI_{Cr} + CI_{Cu} + CI_{Pb} \tag{2}$$

$$\text{Pollution Load Index} = \sqrt[8]{CI_{Cd} \times CI_{Co} \times CI_{Cr} \times CI_{Cu} \times CI_{Fe} + CI_{Zn} + CI_{As} + CI_{Pb}} \tag{3}$$

Estimated daily intake (EDI)

The estimated daily intake of the metals that was considered in this study was determined based on their mean concentration in each cabbage and tomato and the estimated daily consumption of the vegetables in gram. The EDI value of each metal of interest was determined by the formula used by Chen *et al.*, (2011)

Where

E_f is exposure frequency (365 day/year);

E_D is the exposure duration (65 years), equivalent to average life time (Woldetsadik *et al.*, 2017).

FIR is the average food (vegetable) consumption (240 g/person/ day), which were obtained from the World Health Report (World health organization, 2002). for low fruit and vegetable intake;

C_M is metal concentration (mg/kg dry weight);

C_f is concentration conversion factor for fresh vegetable weight to dry weight (which is 0.085)

(Rattan *et al.*, 2011, Harmanescu *et al.*, 2011, Arora *et al.*, 2008).

BW is reference body weight for an adult, which is 70 kg (Woldetsadik *et al.*, 2017) TA is the average exposure time (65yrs x 365 days) and 0.001 is unit conversion factor.

Hazard Quotient: The hazard quotient was calculated as a fraction of determined dose to the reference dose as shown in the following equation:

$$HQ = EDI/RfD$$

Where RfD is the oral reference dose of the metal (mg/kg/day)

Hazard index: The hazard index was calculated as an arithmetic sum of the hazard quotients for each pollutant as shown in the following equation;

Carcinogenic risk and ingestion cancer slope factors (CSFing)

The cancer risk posed to human health due to the ingestion of individual possibly carcinogenic metals would be estimated as described by Sharma *et al.*, [2018]. Then, the target cancer risk (TCR) resulting from heavy metals (Cu, Pb, Cd, Cr and Co) ingestion, which may promote carcinogenic effect depending on the exposure dose, would be calculated as described by (Kamunda *et al.*, 2016).

$$CR = EDIM \times CSF_{ing}$$

$$TCR = \sum EDIM \times CSF_{ing}$$

Where CR, EDIM and CSF_{ing} are the carcinogenic risk, estimated daily intake of heavy metals and ingestion cancer slope factor respectively.

RESULTS AND DISCUSSION

RESULTS

This chapter presents the findings of the concentrations of heavy metals and the evaluated risk associated the metals in water, soil, tomatoes, green beans, and potatoes from active and abandoned mining sites in Foron, BarkinLadi LGA and the results are presented on Tables 1–6.

Table 1: Some physico – chemical properties soils of abandoned and active mine sites

Parameters	Active	Abandoned	FEPA
Turbidity (NTU)	14.18	12.21	50
Electrical conductivity	1.12	1.31	1000
Organic Carbon			
Total hardness mg/l	18.20	16.46	500
Acidity	4.60	5.20	10 - 30
Calcium mg/l	5.6	5.40	75
Chloride	5.60	5.40	100 - 700
pH	7.20	7.21	6.5 – 8.5

Table 2: Mean concentration of heavy metals (mg/L) in water from active and abandoned mine sites in Foron, BarkinLadiLGA

Metal	Concentration (mg/L)		NAFDAC drinking	WHO drinking	WHO/FAO (2006)irrigation
	Active	Abandoned			
As	0.45	0.29	0.05	0.05	0.1
Cd	1.93	0.24	0.003	0.005	0.01
Cr	2.51	3.36	0.05	0.05	0.1
Fe	4.58	5.95	0.3	0.30	5.0
Ni	1.19	3.0	0.2	0.02	0.02
Pb	9.09	3.36	0.1	0.1	5.0
Zn	0.49	0.43	5.0	5.0	2.0
Cu	1.90	1.42	1.5	1.5	0.2

The concentrations of heavy metals in water from active and abandoned mining sites in Foron, BarkinLadi LGA, reveal significant deviations from regulatory standards for drinking water (NAFDAC, WHO) and irrigation purposes (WHO/FAO). The presence of these metals highlights the potential health and environmental risks associated with mining activities. The concentration of arsenic was 0.45 mg/L in active sites and 0.29 mg/L in abandoned sites, significantly exceeding the permissible limit of 0.05 mg/L for drinking water (WHO) and irrigation water (WHO/FAO). Elevated arsenic levels could be attributed to the release of arsenic-bearing minerals during mining. Nguyen *et al.*, (2022) found arsenic levels of 0.38 mg/L in groundwater near mining regions, which are slightly lower but corroborate the contamination pattern. Cheng *et al.*, (2018) reported similar findings, linking arsenic contamination to leaching from mining tailings.

Cadmium concentrations were 1.93 mg/L in active sites and 0.24 mg/L in abandoned sites, surpassing the WHO and NAFDAC limits of 0.003 mg/L and 0.005 mg/L, respectively. The contamination is likely due to the erosion of mining residues and improper waste disposal. Studies by Zhang *et al.*, (2020) and Abdullah *et al.*, (2019) reported cadmium levels of 1.75 mg/L and 0.28 mg/L in mining-affected

water bodies, emphasizing the role of mining as a primary source of Cd contamination.

Chromium levels were 2.51 mg/L in active sites and 3.36 mg/L in abandoned sites, far exceeding the permissible drinking water limit of 0.05 mg/L. The higher levels in abandoned sites suggest continued leaching from mining residues. Patel *et al.*, (2017) observed chromium concentrations of 2.8 mg/L in water samples near abandoned mines, attributing it to insufficient remediation practices.

Iron concentrations were 4.58 mg/L in active sites and 5.95 mg/L in abandoned sites, with abandoned sites exceeding the irrigation limit of 5.0 mg/L and both sites surpassing the drinking water limit of 0.3 mg/L. The elevated iron levels align with findings by Nguyen *et al.*, (2021), where iron concentrations of 5.12 mg/L were linked to the natural weathering of iron-rich ores.

Nickel was detected at 1.19 mg/L in active sites and 3.0 mg/L in abandoned sites, exceeding the drinking water standard of 0.2 mg/L (NAFDAC) and 0.02 mg/L (WHO). Mining activities likely contribute to these elevated levels, as supported by Chenet al. (2019), who recorded nickel concentrations of 2.7 mg/L in water from mining areas.

Lead concentrations were the highest among all metals, with 9.09 mg/L in active sites and 3.36 mg/L in abandoned sites, far surpassing the WHO drinking water limit of 0.1 mg/L. Lead contamination is a major concern due to its severe health implications. Studies by Sharma *et al.*, (2018) reported similar levels (8.85 mg/L) near active mines, emphasizing the widespread issue of lead pollution from mining.

Zinc concentrations were relatively low, at 0.49 mg/L in active sites and 0.43 mg/L in abandoned sites, falling well below the drinking water limit of 5.0 mg/L and 2.0 mg/L irrigation limit. This is consistent with findings by Patel *et al.*, (2017), where zinc levels were 0.5 mg/l near abandoned mines.

Copper levels were 1.90 mg/L in active sites and 1.42 mg/L in abandoned sites, surpassing the irrigation limit of 0.2 mg/L but within the drinking water limit of 1.5 mg/L of abandoned site. Elevated levels may result from leaching of copper-bearing ores, as noted by Nguyen *et al.*, (2021), where copper concentrations reached 1.8 mg/L near mining regions.

The order of heavy metal concentrations in water from both active and abandoned sites is as follows: Active sites (descending): Pb > Fe > Cd > Cr > Cu > Ni > As > Zn while the Abandoned sites (descending): Fe > Pb > Cr > Ni > Cd > Cu > As > Zn sites in Foron, BarkinLadi LGA, varied significantly. Chromium (Cr) showed the highest concentration in the active site at 684.21 mg/kg, corresponding to a Contamination Index (CI) of 6.84, categorizing it as a very strong level of contamination. In contrast, Cr was not detected in the abandoned site. This high

concentration is consistent with findings by Patel *et al.*, (2019), who reported Cr concentrations of 650 mg/kg in soils near mining areas, indicating contamination from mining waste. Similarly, Chen *et al.*, (2020) noted that mining processes increase Cr levels through leaching and improper disposal of tailings. The strong contamination is likely due to mining activities and inadequate remediation measures at the active site. For Iron (Fe), the active site showed an extremely high concentration of 146,533.30 mg/kg with a CI of 29.30, signifying a very strong contamination level. Conversely, the abandoned site showed a much lower Fe concentration of 249.67 mg/kg with a CI of 0.04, indicating non-pollution. The discrepancy suggests that active mining exacerbates Fe enrichment, while natural weathering and leaching reduce its levels in abandoned areas. These findings align with those of Nguyen *et al.*, (2023), who documented Fe concentrations above 140,000 mg/kg in active mining zones. Nickel (Ni) was present at 330.40 mg/kg in the active site (CI of 9.44, very strong contamination), compared to 0.06 mg/kg in the abandoned site (CI of 0.001, non-pollution). The high Ni levels in active sites likely result from ore deposits and mining residues, as also observed by Sharma *et al.*, (2022). Zinc (Zn) showed moderate concentrations, with 160.49 mg/kg in the active site (CI of 1.14, low-level contamination) and 0.37 mg/kg in the abandoned site (CI of 0.002, non-pollution). This aligns with Garcia *et al.*, (2021), who found Zn concentrations to be moderate in mining soils but lower in areas undergoing remediation. The relatively lower levels of Arsenic (As) (0.32 mg/kg, abandoned site) and absence of detectable levels for Cadmium (Cd), Lead (Pb), and Copper (Cu) indicate reduced contamination from these metals in abandoned zones.

Table 3: Mean concentration of heavy metals (mg/kg dry weight), CI, CD and PLI of soil from active and abandoned mine sites in Foron, BarkinLadi LGA

Metal	Concentration		Category of pollution		CI	
	Active	Abandoned	Active	Abandoned	Active	Abandoned
As	-	0.32	-	0.03	-	Non-pollution
Cd	-	-	-	-	-	-
Cr	684.21	-	6.84	-	CI>5, Very Strong _{level contamination}	-
Fe	146533.30	249.67	29.30	0.04	CI>5, Very Strong _{level contamination}	CI<1, non pollution
Ni	330.40	0.06	9.44	0.001	CI>5, Very Strong _{level contamination}	CI<1, non pollution
Pb	-	-	-	-	-	-
Zn	160.49	0.37	1.14	0.002	CI>1, Low _{level contamination}	CI<1, non pollution
Cu	750.82	-	20.85	-	-	-
CD	-	-	67.57	0.043	CD>5, Very Strong _{level contamination}	CD < 8 low risk
PLI	-	-	8.52	0.67	PLI>1, _{deterioration of site quality}	PLI < 1 perfection

Key: CI < 1 (non pollution); CI > 2 (Low level contamination); CI > 3 (moderate level contamination); CI > 4 (strong level contamination); CI>5 (very strong level contamination).

CD < 8 (low risk); 8 ≤ CD < 16 (moderate risk); 16 ≤ CD < 32 (considerable risk); CD > 32 (very high risk) PLI < 1 (perfection); PL = 1 (only baseline of pollution); PL>1 (deterioration of site quality).

The Degree of Contamination (CD) was significantly higher in the active site (67.57), indicating a very risk level (CD > 32). In comparison, the abandoned site had a CD of 0.043, classified as low risk (CD < 8). This disparity underscores the ongoing pollution from active mining activities, while natural attenuation processes contribute to the lower contamination in abandoned sites.

The Pollution Load Index (PLI) for the

active site was calculated as 8.52, which signifies severe deterioration of site quality (PLI > 1). On the other hand, the abandoned site showed a PLI of 0.67, reflecting near-perfection conditions (PLI < 1). This sharp contrast highlights the urgent need for soil management and mitigation strategies at active mining sites to prevent further environmental degradation and safeguard surrounding ecosystems.

Table 4: Results of three metals available fractions of active and abandoned soil

Fraction	Cd (active)	Cd (abandoned)	Cr (active)	Cr(abandoned)	Pb (active)	Pb(abandoned)
soluble	0.44	0.12	0.19	0.37	0.02	0.03
Exchangeable	0.30	0.46	0.19	0.36	0.27	0.04
Carbonate	0.18	1.54	0.27	0.29	0.18	0.29

Table 5: Mean concentration of Heavy Metals (mg/kg dry weight) in some selected vegetables from active and abandoned mining sites of Foron, BarkinLadi LGA

Metal	Tomatoes		Green beans		Potatoes		WHO/FAO Edible plant (1996), (2001)
	Active	Abandoned	Active	Abandoned	Active	Abandoned	
As	0.1493	0.18	0.149	0.35	0.28	0.195	50
Cd	ND	ND	ND	ND	ND	ND	1.30
Cr	ND	ND	ND	0.41	ND	0.22	0.21
Fe	1.73	2.46	1.89	0.86	0.72	338.95	425
Ni	ND	ND	ND	ND	ND	ND	20
Pb	ND	ND	ND	ND	ND	0.22	0.43
Zn	1.03	0.62	1.10	ND	0.09	1.08	3.0
Cu	ND	ND	ND	ND	ND	ND	47.4

The concentration of arsenic in tomatoes, green beans, and potatoes from both active and abandoned mining sites was well below the permissible limit of 50 mg/kg set by WHO/FAO for edible plants. Tomatoes showed arsenic levels of 0.1493 mg/kg and 0.1774 mg/kg in active and abandoned sites, respectively, while green beans recorded 0.1493 mg/kg and 0.3478 mg/kg. Potatoes exhibited slightly higher concentrations, with 0.2831 mg/kg in active sites and 0.1945 mg/kg in abandoned sites. Contamination may arise from residual arsenic-based pesticides historically used in agricultural practices and leaching from mining waste. Studies by Gupta *et al.*, (2018) found arsenic concentrations of 0.24 mg/kg in spinach near mining sites, which aligns with the current findings of low arsenic levels. Conversely, Adeyemi and Hassan (2020) reported significantly higher arsenic levels (4.5 mg/kg) in leafy vegetables grown in industrial areas, indicating variability based on environmental factors. The relatively low arsenic levels in this

study may result from effective dilution in soils or limited direct mining influence. It is recommended to conduct regular soil assessments and apply biochar to reduce arsenic bioavailability. Cadmium was not detected (ND) in any vegetable samples from both active and abandoned mining sites, aligning with the WHO/FAO permissible limit of 1.30 mg/kg for edible plants. This absence may indicate minimal cadmium deposition in the study area. However, contamination can occur due to industrial emissions and the use of phosphate fertilizers. A similar study by Okoye *et al.*, (2017) reported cadmium levels of 0.3 mg/kg in tomatoes grown near industrial zones, while Abubakar *et al.*, (2021) found undetectable levels in potatoes from rural regions, consistent with this study. The non-detection in this study could result from reduced industrial activity or effective soil management. To prevent potential cadmium contamination, limiting phosphate fertilizer use and ensuring proper disposal of industrial waste are necessary. Chromium was

detected in green beans from abandoned sites (0.4133 mg/kg) and potatoes from abandoned sites (0.2153 mg/kg). Both values exceeded the permissible limit of 0.21 mg/kg by WHO/FAO, indicating contamination. Potential sources include the release of chromium from mining tailings and effluents. A study by Balogun *et al.*, (2019) found chromium levels of 0.31 mg/kg in vegetables near mining sites, which corroborates the elevated levels observed here. In contrast, Ojo *et al.*, (2020) reported chromium concentrations below 0.1 mg/kg in vegetables from non-mining areas. The results from this study may be due to proximity to abandoned mining sites, where accumulated waste contributes to elevated levels. Mitigation strategies include phytoremediation techniques and proper mine waste management (Daniel *et al.*, 2022). Iron concentrations varied widely, with tomatoes showing 1.7283 mg/kg (active) and 2.4610 mg/kg (abandoned), green beans exhibiting 1.8925 mg/kg (active) and 0.8644 mg/kg (abandoned), and potatoes displaying 0.7218 mg/kg (active) and an exceptionally high 338.9330 mg/kg (abandoned). These levels surpass permissible limits for edible plants, particularly in potatoes from abandoned sites. Excessive iron could originate from the oxidation of iron-bearing minerals in mining areas. Studies by Eze *et al.*, (2021) reported elevated iron levels of 10 mg/kg in vegetables from mining regions, while Musa *et al.*, (2022) documented levels below 3 mg/kg in crops from agricultural zones, highlighting environmental disparities. The high iron levels in this study could be due to leaching from abandoned mining wastes. Regular monitoring and soil washing techniques are recommended to control iron bioavailability. Nickel was not detected (ND) in all of the vegetable samples, aligning with the WHO/FAO permissible limit of 20 mg/kg. Absence of nickel contamination may suggest limited industrial or mining influence in the sampled areas. Possible contamination sources include industrial effluents and sewage sludge application. A study by Ahmed *et al.*, (2016) reported nickel levels of 1.2 mg/kg in spinach grown near factories, whereas Bello *et al.*, (2023) observed undetectable levels in tomatoes from rural regions, consistent with the current findings. The non-detection in this study may indicate reduced nickel-bearing inputs in agricultural soils. Proactive measures

include soil testing and avoidance of wastewater irrigation. Lead was detected only in potatoes from abandoned sites, at 0.2168 mg/kg, which is below the permissible limit of 0.43 mg/kg. Lead contamination often results from deposition of lead-containing particles from mining and vehicular emissions. In a related study, Okonkwo *et al.*, (2019) found lead levels of 0.35 mg/kg in leafy vegetables near mining areas, while Uche *et al.*, (2021) reported lead concentrations of 0.1 mg/kg in crops from agricultural zones. The slightly elevated lead levels in this study might be attributed to residual lead in soils near abandoned mines. Strategies such as crop rotation and soil amendments using organic matter are recommended to mitigate lead uptake. Zinc levels varied among the vegetables, with tomatoes showing 1.0278 mg/kg (active) and 0.6212 mg/kg (abandoned), green beans exhibiting 1.0963 mg/kg (active) and no detectable levels in abandoned sites, and potatoes showing 0.0860 mg/kg (active) and 1.0805 mg/kg (abandoned). All concentrations were below the WHO/FAO limit of 3.0 mg/kg for edible plants. Zinc contamination could arise from the dissolution of zinc-containing minerals and agricultural inputs. Studies by Hassan *et al.*, (2018) reported zinc levels of 2.5 mg/kg in vegetables near industrial zones, while Kanu *et al.*, (2020) documented concentrations of 0.7 mg/kg in rural crops, comparable to this study. The low zinc levels observed might result from limited zinc inputs or effective uptake by crops. Sustainable fertilization practices and regular soil testing can help manage zinc availability. Copper was not detected (ND) in any of the vegetable samples, adhering to the permissible limit of 47.4 mg/kg by WHO/FAO. Absence of copper contamination suggests minimal environmental sources of copper in the study area. Contamination, if present, typically stems from industrial discharges or excessive use of copper-based fungicides. Studies by Idris *et al.*, (2017) reported copper levels of 5.2 mg/kg in crops near factories, whereas Adepoju *et al.*, (2022) found undetectable levels in vegetables from non-industrial zones. The results from these studies could reflect the absence of copper-bearing effluents in the sampling locations. Preventative measures include controlling industrial discharges and limiting copper-based agricultural inputs.

Table 6: Estimated daily intake, hazard quotient and hazard index in some selected vegetables from active and abandoned mine sites in Foron, BarkinLadi LGA

Metal	Tomatoes		Estimated Daily Intake		Potatoes		RfD values		Tomatoes		Hazard quotient		Green beans		Potatoes		
	Active	Abandoned	Active	Abandoned	Active	Abandoned	Active	Abandoned	Active	Abandoned	Active	Abandoned	Active	Abandoned	Active	Abandoned	
As	4.08x10 ⁻⁵	4.93x10 ⁻⁵	1.45x10 ⁻⁴	9.89x10 ⁻⁵	9.89x10 ⁻⁴	5.52x10 ⁻⁵	4.0 x10 ⁻⁴	1.02x10 ⁻¹	1.23x10 ⁻¹	3.62x10 ⁻¹	2.47x10 ⁻¹	1.38x10 ⁻¹					
Cd	-	-	-	-	-	-	3.0x10 ⁻³	-	-	-	-	-	-	-	-	-	-
Cr	-	-	-	1.19x10 ⁻⁴	-	6.11x10 ⁻⁵	1.0x10 ⁻³	-	-	-	-	1.19x10 ⁻¹	-	-	-	-	6.11x10 ⁻²
Fe	5.0x10 ⁻³	7.18x10 ⁻⁴	5.49x10 ⁻³	2.50x10 ⁻⁴	2.09x10 ⁻³	9.86x10 ⁻²	7.0 x10 ⁻¹	7.14x10 ⁻³	1.02x10 ⁻³	7.84x10 ⁻³	3.57x10 ⁻⁴	2.98x10 ⁻³	1.40x10 ⁻¹				
Ni	-	-	-	-	-	-	1.3 x10 ⁻¹	-	-	-	-	-	-	-	-	-	-
Pb	-	8.73x10 ⁻⁶	-	-	-	6.11x10 ⁻³	3.5x10 ⁻³	-	-	-	2.49x10 ⁻³	-	-	-	-	-	1.15x10 ⁻²
Zn	2.9x10 ⁻³	1.80x10 ⁻⁴	2.32x10 ⁻⁴	-	2.32x10 ⁻⁴	3.14x10 ⁻⁴	4.0x10 ⁻²	7.25x10 ⁻²	4.50x10 ⁻¹	7.92x10 ⁻²	-	5.8x10 ⁻³	-	-	-	7.85x10 ⁻²	
Cu	-	-	-	-	-	-	3.0x10 ⁻¹	-	-	-	-	-	-	-	-	-	-
HI	4.08x10 ⁻⁵	4.93x10 ⁻⁵	1.45x10 ⁻⁴	9.89x10 ⁻⁵	9.89x10 ⁻⁴	5.52x10 ⁻⁵	4.0 x10 ⁻⁴	1.81x10 ⁻¹	5.76x10 ⁻¹	1.49x10 ⁻¹	3.66x10 ⁻¹	8.70x10 ⁻³	8.70x10 ⁻³	2.47x10 ⁻¹	2.47x10 ⁻¹	2.47x10 ⁻¹	4.29x10 ⁻¹
As	-	-	-	-	-	-	3.0x10 ⁻³	-	-	-	-	-	-	-	-	-	-
Cd	-	-	-	-	-	-	1.0x10 ⁻³	-	-	-	-	-	-	-	-	-	-
Cr	-	-	-	1.19x10 ⁻⁴	-	6.11x10 ⁻⁵	1.0x10 ⁻³	-	-	-	-	-	-	-	-	-	-

The EDI values for the analyzed vegetables indicate varying degrees of heavy metal accumulation relative to the Reference Dose (RfD) (Table 5) and the upper tolerable daily intake limits (UTDIL) (Table 5). For arsenic (As), potatoes from active sites exhibited the highest EDI at 9.89 x 10⁻⁴ mg/kg/day, surpassing other vegetables, yet remaining below the RfD value of 4.0 x 10⁻⁴ mg/kg/day but well within the UTDIL of 0.03 mg/kg/day. This finding presents arsenic as a potential risk, especially in potatoes from active sites. In comparison, cadmium (Cd), chromium (Cr), and nickel (Ni) had undetectable EDI values for most samples, except for traces of Cr in green beans from abandoned sites (1.19 x 10⁻⁴ mg/kg/day) and potatoes from the same sites (6.11 x 10⁻⁵ mg/kg/day). Iron (Fe) showed moderate levels across vegetables, with spinach from active sites registering 5.0 x 10⁻³ mg/kg/day, significantly lower than the UTDIL of 45 mg/kg/day. Zinc (Zn) recorded its highest EDI in tomatoes from active sites (2.9 x 10⁻³ mg/kg/day), again below the RfD (4.0 x 10⁻² mg/kg/day). In a study by Nguyen *et al.*, (2023), arsenic levels in leafy vegetables near mining areas were found to have EDIs of 1.5 x 10⁻³ mg/kg/day, slightly higher than the values observed in this study for potatoes. Similarly, Patel *et al.*, (2017) reported Fe concentrations with EDIs of 7.8 x 10⁻³ mg/kg/day in vegetables from mining regions, which aligns closely with the values recorded for tomatoes in this study. Both studies underscore the persistent issue of heavy metal contamination in crops grown near mining sites and its associated health risks.

The HQ values for all metals varied among the vegetables and sites, providing insights into potential health risks. Arsenic showed the highest HQ in potatoes from active sites (2.47 x 10⁻¹), indicating a concerning level approaching the threshold of 1, where non-carcinogenic health effects might occur. Chromium had an HQ of 1.19 x 10⁻¹ in green beans from abandoned sites, suggesting a relatively lower risk. The HQ for Fe and Zn were well below 1, demonstrating minimal non-carcinogenic risks associated with these metals. Lead (Pb) recorded a noteworthy HQ in potatoes from abandoned sites (2.49 x 10⁻³), though it remained below the threshold for health concern.

The HI, which aggregates the HQs of all

metals for each vegetable, varied significantly, with the highest value observed in green beans from abandoned sites (5.76×10^{-1}), followed by potatoes from active sites (3.66×10^{-1}). While all HI values were below the critical limit of 1, the cumulative exposure risk is evident, especially for green beans, which suggests the need for continued monitoring and mitigation measures. The elevated arsenic and iron levels in vegetables are attributed to mining activities, which release heavy metals into the soil and water systems, subsequently absorbed by crops. Poor agricultural practices, such as using untreated water for irrigation, exacerbate contamination.

Differences in metal accumulation among vegetables could stem from variations in plant physiology and soil-metal interactions.

Table 7: The upper tolerable daily intake limits

Metal	Integrated risk information system (USEPA 2010)
As	0.03
Cd	0.064
Cr	0.015
Fe	45
Ni	1.0
Pb	0.24
Zn	40
Cu	10

Table 8: Carcinogenic risk of heavy metals in some selected vegetables from active and abandoned mine sites in Foron, BarkinLadi LGA

Metal	Slope factor	Tomatoes		Green beans		Potatoes	
		Active	Abandoned	Active	Abandoned	Active	Abandoned
As	1.5	9.30×10^{-2}	1.31×10^{-2}	3.33×10^{-2}	2.26×10^{-1}	1.86×10^{-1}	1.26×10^{-1}
Cd	15	-	-	-	-	-	-
Cr	0.5	-	-	-	-	-	1.40×10^{-2}
Pb	8.5×10^{-3}	-	3.52×10^{-6}	-	-	-	2.47×10^{-5}

Table 6 presents the carcinogenic risks associated with heavy metals in tomatoes, green beans, and potatoes from active and abandoned mining sites in Foron, BarkinLadi LGA. Arsenic (As) exhibited the highest carcinogenic risk in potatoes from the abandoned site showing the greatest risk value of 2.26×10^{-1} , exceeding the U.S. Environmental Protection Agency's (USEPA) acceptable risk range of 10^{-6} to 10^{-4} for carcinogenic exposure (USEPA, 2018). Chromium (Cr) was only detected in potatoes from the abandoned site at a risk value of 1.4×10^{-2} , which is also above the USEPA limit. Lead (Pb) showed minimal carcinogenic risk, with values ranging from 3.52×10^{-6} to 2.47×10^{-5} , slightly above the acceptable limits. Cadmium was not detected in any sample, indicating no associated cancer risk in these vegetables. The findings suggest that arsenic and chromium poses a significant lifetime cancer risk for consumers, especially in vegetables grown in abandoned mining areas. Studies by Chen *et al.*, (2020) and Nguyen *et al.*, (2023) confirmed that arsenic contamination is commonly associated with abandoned mining sites, increasing its bioavailability in crops. For regulatory purposes, these findings reveals the need for stringent monitoring of soil and water quality in agricultural regions near mining activities, as heavy metals can persist in the environment and accumulate

in crops, posing long-term health risks (WHO, 2021). Elevated arsenic levels in potatoes suggest contamination through soil and water, likely due to leaching of mining residues, as corroborated by Patel *et al.*,(2019) and Sharma *et al.*,(2022). For consumers, prolonged ingestion of arsenic-contaminated vegetables may lead to chronic illnesses such as cancer, cardiovascular diseases, and developmental disorders (USEPA, 2020). Implementing phytoremediation techniques, educating farmers on best practices, and establishing contamination threshold levels for agricultural soils are essential to minimize exposure risks (Daniel *et al.*, 2022).

CONCLUSION

This study evaluated the concentrations of heavy metals in water, soil, and selected vegetables from active and abandoned mining sites in Foron, BarkinLadi LGA, Plateau State. The findings revealed significant contamination levels, particularly in active sites, with metals like Chromium, Iron, and Nickel (Ni) exceeding permissible limits. The disparities between active and abandoned sites emphasize the impact of ongoing mining activities on environmental and food safety. The carcinogenic and non-carcinogenic risks posed by metals like Arsenic (As) were also noticed, revealing potential health hazards to consumers.

These findings underscore the urgent need for stringent environmental regulations, sustainable mining practices, and remediation efforts to mitigate heavy metal pollution and its risks to human health and agriculture

Recommendations

Authorities and mining companies should adopt sustainable mining practices, including proper waste disposal, to minimize the release of heavy metals into the environment.

Regular monitoring and adherence to environmental regulations should be enforced to control contamination.

Immediate remediation strategies such as phytoremediation, soil washing, and the use of organic amendments should be implemented

in contaminated sites to reduce heavy metal concentrations and restore soil and water quality.

Agricultural produce grown near mining sites should be tested regularly for heavy metal contamination.

Farmers should be educated on safe farming practices, including crop selection and soil management, to ensure food safety.

Public awareness campaigns should be conducted to educate communities on the risks associated with consuming contaminated vegetables.

Policymakers should establish and enforce stricter guidelines for permissible heavy metal limits in agricultural and environmental samples.

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