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Heavy Metal Concentrations and Accompanying Health Risks in Irrigated Vegetables Cultivated Around Abandoned Mine of Sabon Gida, Plateau State, Nigeria

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Abstract

The consumption of vegetables grown around abandoned mine areas has been of great concern worldwide for human health. ICP-OES was used to study the accumulation and hence environmental and health potential risks of eight heavy metals in soil, water, sediment and vegetables cultivated around the abandoned mines of Sabon Gida in Jos South LGA, Plateau State. Majority the heavy metals studied in water had molar concentration above the WHO/FAO and NAFDAC recommendations on drinking water and irrigation. All the metals were below threshold effects level for sediment. The soil presented CI>1, CD<8 and no contamination pollution load index. Cabbage accumulated all the heavy metals examined with Zn, Pb, Cd, and Cr concentrations above the WHO/FAO range for edible plants. The results of the estimated daily intakes, health quotients (HQ < 1), and health index of all heavy metals in vegetables consumed from the study area would not be the basis of a non-carcinogenic risk to the residents. The cancer risk analysis indicated that there is no risk of contracting cancer from eating vegetables. According to this study, growing these vegetables in Sabon Gida is safe, but further anthropogenic activities may increase the concentration of the metals, which would have of potential adverse health effects. We therefore recommend strict regulation of safety of vegetable crops grown near abandoned mine areas.

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***Related declarations are provided in the final section of this article.*

Introduction

Mine exploration and exploitation of several minerals because of population explosion and for economic growth in Nigeria has rapidly extended (Edun and Davou, 2013). The need for minerals is great, a huge number of wastes is often associated with mining, ore milling, and ore processing (Owolabi and Daramola, 2024). This was noted because the tailings were scattered periodically throughout large cities around the working tin and worse; residents reworked these tailings, used them to construct the structures and farmed the landscape (Ibeanu, Date unknown). Metallurgical mines in Sabon Gari - a Second mining zone in the State whose mounds of mine tips, mining ponds, abandoned mining sites are partly deserted mining settlements are found along the coast and several pilot ponds (Ajaegbu 1985). Considering the mine fields of the Jos Plateau, Edun and Davou (2013) estimated that nearly 1,000 ponds were contained across the mine field of the Jos Plateau and that 325km2 of the land on the Jos Plateau is destroyed due to mining. Some mining ponds are located near major roads or near farmlands. Liquid wastes from mining/mineral processing waste are deposited into the nearest stream, and gases that are released pollute the atmosphere (Nwadialor, 2011).

Heavy metals are said to have its way into the environment mainly through mining of solid minerals, therefore contaminating several components of the ecosystem (Mafuyai *et al*., 2019). Soil pollution have been reported worldwide to account for over 50% of the sites (more than 10 million) contaminated with heavy metals and/or metalloids, of, with (such as arsenic (He *et al*., 2015). As anthropogenic activities rise, particularly with the use of new technologies, pollution and adulteration of the human food chain will be unavoidable. These elements, at concentrations exceeding the physiological demand of vegetables, not only could administer toxic effect in them but also could enter into the food chains by the consumption, get biomagnified and pose a potential threat to human health as well as animals (Sharma *et al*., 2008).

Vegetables are the fresh and edible components of herbaceous plants and are harvested commonly in Nigeria. 'Gwates', portages of different vegetables leave combined, are prominent in the routines, ethnicities, and food culture of residents of Plateau State, especially the Beroms households (Mensah et al., 2008). Other cultural groups in Nigeria use different kinds of traditional vegetables for different festivities at months of the year. In rainy season its production is lower than dry season. Most vegetables are grown in the dry season in Sabon Gida with water coming from tin mine ponds that contain different contaminants, even from farmlands.

Vegetables will not only pick up the nutrients from both soil and water but may also take on harmful pollutants that are not specifically needed and can be very dangerous including heavy metals at low concentration levels (Negussie & Endale, 2015). When vegetables are exposed to a wide variety of metal-containing components, consumption of vegetables causes a loss of several important nutrients in the body, and reduces immune defense, prenatal development retardation, poor psychosocial behaviors, malnutrition and high rates of upper gastrointestinal cancer. This study was designed to examine the heavy metal concentrations in water, soil, vegetables surrounding abandoned mine areas of Sabon Gida in Jos South, Plateau State, Nigeria and their environmental and human health implications

MATERIALS AND METHODS

The Study Area

This work was carried at Sabon-Gida in Jos South LGA in Plateau State, Nigeria. the Governor's office is situated in Rayfield in the LGA. 'It has latitudes 9° 36' 41.5915" N and 9° 51' 14.2973" N, while longitudes 8° 38' 24.4785" E and E. 57° 140.4240" E. Bukuru, the LGA headquarters is fifteen kilometers away from the State's capital. it had 306,716 people in July 2007, and area of 1,037 km^2, situated at 1,217 m (3,993 ft) above sea level. Jos Plateau, whose climate is more temperate than the majority of Nigeria, is highly convex and has a relatively high altitude and ITCZ elevation that provides the climate most strongly. Average monthly temperatures range from 21-25 °C (70-77 °F) to 9 °C (45 °F) in mid-November to late January, with night temperatures dropping to 7 °C (45 °F) at mid-November through late January. The city of Jos receives about 1,400 millimeters of rainfall each year due to its location on the Jos Plateau, either conventional and orographic precipitation" (Owolabi and Daramola, 2024).

Collection of Samples

Water, Sediment and Soil Samples Collections

Water was sampled from mine ponds using acid washed plastic containers. To avoid uncertainty of characteristics as usual due to normal processes, 5ml of nitric acid was poured to the water to avoid deposition of heavy metals (Milam *et al.*, 2022). The water samples were stored at a temperature of 5^{o}C before being transported to the laboratory to be analyzed (Salano, 2013).

Sediment samples were collected from streams and mine ponds used for irrigation. Soil samples from Sabon Gida in Jos South Local Government Areas of Plateau State were collected around abandoned tin mine farmlands in triplicate, at 0-10 cm depths at different locations using spiral auger of 2.5 cm diameter. The soil samples were mixed and bulked according to their locations to form a representative sample and kept in labeled plastic bags and conveyed to the laboratory (Daniel *et al*., 2021, Daniel et al., 2022) .

Vegetable Samples Collection

'The edible part of cabbage (*Brassica oleracea*), tomato (*Lycopersicon esculentum Miller,* and green beans (*Phaseolus vulgaris*) were separately collected into already washed, sterilized polyethylene bags around abandoned mine farmlands Sabon Gida. About one kilogram of the tomato and green beans each were collected by random sampling at minimum of 10 locations. A total of ten kilogram of cabbage were gathered by harvesting one-kilogram portions randomly from different location on the farmlands. These subsamples were then combined and mixed and the representative samples of each sample was taken' (Daniel *et al*., 2021; Daniel *et al.*, 2022; Hailu and Leta, 2020)

Digestion and analysis of Samples for inductively Coupled Plasma

The soil and sediment samples were air-dried, mechanically ground using a mortar and pestle and sieved to obtain <200 μm. Plant edible samples were thoroughly rinsed with deionized water to remove soil particles attached to the plant surfaces. After rinsing, the samples were air dried. The dried samples ground into fine powder using a mortar and pestle. Exactly 1g of the sample was weighed, transferred into test tubes and 10 ml of nitric acid was added. The digestion block was set at around 80-90^{0}C for 120mins. After the digestion was completed, digestate was made up to approximately 5ml for each sample, and the final volume of the digestate was recorded. The digestate was then filtered and diluted to 25ml using ultra-pure deionized water for ICP-OES analysis. Reagent blanks and internal standards were used where appropriate to ensure accuracy and precision in the ICP–OES analyses of elements. Calibration and Quality Control (QC) solutions were prepared from Accustandard QCSTD-27 multi-element solution. Ultrapure Merck Lichrosolv water was used for dilution of standards and QC solutions (Daniel *et al.*, 2022). These were also stabilized in high purity 2% v/v concentrated nitric acid (HNO_3) (Kachenko & Singh, 2006). The analyses of samples were carried out at CTX -ION ANALYTICS, Lagos.

Soil and Vegetable Risk Analysis Indices

The existence and levels of anthropogenic contaminants deposition on soils were evaluated by risk indicators. The following pollution risks indices were used in this work: 'Contamination Index (CI), Pollution Load Index (PLI), Degree of Contamination (CD), estimated daily intake (EDI), hazard quotient (HQ), health index (HI), and cancer risk factor (CF)' (Aigberua *et al*., 2020)

Contamination index (CI)

'The contamination factor was calculated as

$$CI = Cn/Bn \quad (1)$$

Where;

Cn = measured metal concentration and

Bn = Nigerian background soil concentration (DPR, 2002)

Degree of contamination (CD)

$$CD = CICd + CICo + CICr + CICu + CIPb + CIAs + CIZn + CIFe$$

Pollution Load Index (PLI)

$$PLI = \sqrt[8]{CICd \text{ X } CICo \text{ X } CICr \text{ X } CICu \text{ X } CIPb \text{ X } CIZn \text{ X } CIFe \text{ X} As}$$ (Aigberua *et al*., 2020)

Estimated daily intake (EDI)

The EDI of the metals evaluated in this work was based on the mean concentration in each vegetable and the estimated daily consumption of the vegetables in gram. The EDI value of each metal of determined was calculated from the formula used by Chen *et al*., (2011)

$$EDI = \frac{Ef\ x\ Edx\ Fir\ x\ Cm\ x\ Cf}{Bw\ x\ Ta} \text{ x } 0.001$$

Where;

Ef is exposure frequency (365 day/year);

Ed is the exposure duration (65 years), equivalent to average life time

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;

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

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

Bw is reference body weight for an adult, which is 70 kg;

Ta is the average exposure time (65yrs x 365 days) and 0.001 is unit conversion factor' (Arora *et al*., 2008; Rattan *et al*., 2011; Harmanescu *et al*., 2011; Woldetsadik *et al*., 2017; Gebeyehu and Bayissa, 2020).

Hazard Quotient (HQ)

The hazard quotient (HQ) is the ratio of EDI to the reference dose (RfD) as shown below:

$HQ = EDI/RfD$

RfD is an approximation of daily tolerable exposure to which a person is expected to have without any significant risk of harmful effects during a lifespan.

Hazard index (HI)

The hazard or health index (HI) was calculated as an arithmetic sum of the hazard quotients for each pollutant as shown in the following equation;

$HI = \sum HQs$

Carcinogenic risk and ingestion cancer slope factors (CSFing)

The risk of contracting cancer due to the ingestion of Cu, Pb, Cd, Cr and Co as carcinogenic metals would be calculated as:

$CR = EDIM \times CSFing$

$TCR = \sum EDIM \times CSFing$

CSFing is ingestion cancer slope factor (Kamunda *et al*., 2016; Sharma *et al*. 2018).

RESULTS AND DISCUSSION

Heavy metals in water

The results of the analysis of the heavy metals in water with drinking and irrigation limits are presented in Table 1

Table 1: Mean concentration of heavy metals (mg/kg dry weight) in water around abandoned mine areas of Sabon Gida.

Metal	Concentration	NAFDAC Drinking	WHO drinking	WHO/FAO (2006) irrigation
Fe	3.46	0.3	0.3	5.0
Zn	0.48	5.0	5.0	2.0
Cu	1.42	1.5	1.5	0.2
Pb	7.87	0.1	0.1	5.0
Cr	2.96	0.05	0.05	0.1
Cd	2.07	0.003	0.005	0.01
Co	2.59	0.01	0.01	0.05
As	0.10	0.05	0.05	0.1

The findings revealed the concentrations of iron, lead, cadmium, chromium, cobalt, and arsenic as 3.46, 7.87, 2.07, 2.96, 2.59, and 0.10 mg/l, respectively. These concentrations were higher than the thresholds established by the WHO and the NAFDAC for drinking water. While Pb, Cd, Cr, and Co concentrations exceeded the WHO/FAO allowed thresholds for irrigation water, the values of Fe and As were within the acceptable ranges.

Iron (Fe) levels were below the values of Nwineewii et al. (2019) and Haxhibeqiri et al. (2015), however were consistent with the findings of Asonye et al. (2007) in similar studies. The levels of Pb concentrations in this work were below those recorded by Asonye et al. (2007), but agreed with that of Haxhibeqiri et al. (2015). The Pb concentration of 7.8 mg/l was the 0.1 mg/l limit set by the two regulatory bodies. Pb metal is a poisonous that can cause significant health concerns when consumed, affecting various cellular functions such as cell bonding, neuronal signalling, protein cell compactness, cell maturation, electrolyte transport, and enzyme activity regulation (Tirkey et al., 2012; Puri et al., 2015).

Cadmium (Cd) concentrations in this study were lower than those observed by Edori et al. (2019) in the Elelenwo River in Rivers State, Nigeria. When Cd accumulates in human, animal, or plant tissues, it can disrupt essential amino acids and accumulate in the proximal tubular cells of the kidneys, leading to bone fragility and damage to the kidney and lungs. Elevated Cd levels can also impair liver function, reduce newborn birth weight, and cause premature delivery in pregnant women (Adelekan & Alawode, 2011). Additionally, prolonged exposure to Cd has been associated with reproductive disorders, behavioral changes, cardiovascular and neurological issues, and liver damage (Hanser & Marrion, 2009).

The concentrations of As and Co in this study were within the thresholds of two regulatory bodies for both drinking and irrigation water. However, they were lower than the levels reported by Nwineewii et al. (2019) and Ekpete et al. (2019) in the New Calabar River and Silver River, Bayelsa State respectively. Various physiological effects, including severe lung infections has been seen in laboratory animals by high exposure to Co (ATSDR, 2010). The various stations of the Silver River presented lower As concentrations (Ekpete et al., 2019).

The concentrations of Zn and Cr were below the WHO and NAFDAC recommended drinking water limits. Zinc (Zn) concentrations were consistent with those reported by Odoemelam et al. (2019), though lower than those found by Marcus & Edori (2016) in the Bomu and Oginigba Rivers. Zinc is a vital element in human metabolism and plays a critical part in cellular function and tissue growth. While high concentrations of Zn in water may cause temporary symptoms like intestinal irritation, nausea, and cough, there is no substantial scientific evidence linking it to long-term health issues at concentrations above 5 mg/L. However, high Zn concentrations can cause water to have a bitter taste and increased opacity, especially at higher pH levels (Tepe, 2014).

The concentrations of Chromium (Cr) in this work were below those reported in some rivers in the Niger Delta (Marcus & Edori, 2016; Nwineewii et al., 2019; Ekpete et al., 2019). Although Cr is an essential micronutrient, it becomes a pollutant when present in the environment at elevated concentrations. Chromium III is vital for proper glucose and lipid metabolism in humans, and its deficiency can cause metabolic disturbances. In contrast, chromium VI is carcinogenic (Rajappa et al., 2010; Salano, 2013).

The observed copper (Cu) concentration of 1.5 mg/l was within the 2.0 mg/l of NAFDAC (1.5 mg/l) and WHO. This concentration is lower than that observed by Marcus & Edori (2016) in the Bomu and Oginigba Rivers. Copper metal is very vital for the breakdown and synthesis of cells. However, excessive Cu in water and food can lead to nervous system irritation, depression, and necrosis in liver and kidney cells (Edori & Kpee, 2016). Copper plays a key role in metabolic processes and helps prevent certain conditions that disrupt DNA functions, such as heart muscle injury, spinal cord myelination issues, and abnormal skin pigmentation and bone formation (Anderson, 1997). The levels of Fe, Pb, Cr, Cd, Co and As that were above the recommended limits for drinking water, highlighting the possible health dangers associated with their consumption. These findings emphasize the necessity for consistent assessment and regulation of water quality to ensure the safety and health of the public.

Heavy Metals in Sediment

Table 2: Average concentration of heavy metals (mg/kg dry weight), TEL and PEL values of sediment around abandoned mine areas of Sabon Gida.

Metal	**Concentration**	**TEL**	**PEL**	**Category**
Fe	354.91	-	-	-
Zn	23.25	123	315	Safe
Cu	6.71	35.9	197	Safe
Pb	3.50	35	91	Safe
Cr	0.03	42	160	Safe
Cd	ND			
Co,	ND			
As	0.02	5.9	17	Safe

Key: 'Below TEL= acceptable (threshold effect level), Above PEL= unacceptable (probable effect level)' Harikumar et al., (2010)

The data presented (Table 2) illustrates the average concentrations of heavy metals (mg/kg dry weight) in the sediment, along with their corresponding sediment quality guidelines. The concentrations of the metals in the sediment were in the descending order: Fe > Pb > Zn > Cu > Cr > As > Cd > Co. The mean concentrations of these heavy metals in the sediment ranged from not detected (ND) for Co and Cd to 354.91 mg/kg for Fe. From the results of the analysis, all of the metals analyzed in the sediment from the abandoned Sabon Gida mine area were found to be below the Threshold Effect Level (TEL), suggesting that the sediment is safe for aquatic life, in accordance with sediment quality guidelines.

Heavy Metals in Soil

Table 3 shows the average concentrations of Fe, Zn, Cu, Pb, Cr, Co, Cd and as (mg/kg dry weight),and three pollution indices.

Table 3: Soil's average levels of heavy metals (mg/kg dry weight), CI, CD and PLI of abandoned mine areas of Sabon Gida.

Metal	**Concentration**	**CI**	**Category of pollution**
Fe	450.96	0.0902	CI>1, non-pollution
Zn	0.67	0.0048	CI>1, non-pollution
Cu	0.84	0.0234	CI>1, non-pollution
Pb	0.52	0.0061	CI>1, non-pollution
Cr	0.51	0.0061	CI>1, non-pollution
Co	ND	-	CI>1, non-pollution
Cd	ND	-	CI>1, non-pollution
As	0.1502	0.0051	CI>1, non-pollution
CD		0.1357	CD>8 Low contamination
PLI		0.0044	PLI<1 No contamination

Key: ‘CI < 1 (non pollution); 1 < CI < 2 (Low level contamination); 2 < CI < 3 (moderate level contamination); 3<CI< 5 (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)’ (Aigberua et al., 2020)

The results showed that the order of the levels of the heavy metals as follows: Fe >> Cu > Zn > Pb > Cr > As > Cd > Co. The contamination index (CI) was below 1 for all the metals tested, signifying that the soil is not polluted. The degree of contamination (CD) was less than 8 for all the metals, classifying the soil as having low contamination, which is considered safe for aquatic life and sediment organisms. The pollution load index (PLI) was also below 1, placing the soil is in the "no contamination" category. Overall, the pollution indices considered suggest that the soil quality in the Sabon Gida remains close to natural and is consistent with the background concentrations (DPR, 2002).

Heavy metals concentrations in vegetables

Table 4 is average levels of heavy metals (mg/kg dry weight) in cabbage, tomato and green beans cultivated around abandoned mines of Sabon Gida and the FAO/WHO limits in edible plant.

Table 4: Average concentrations of heavy metals (mg/kg dry weight) in three vegetables cultivated around abandoned mines of Sabon Gida

Metal	Cabbage	Tomato	Green bean	*FAO/WHO Edible plant (2001)
Fe	14.33	1.28	0.93	20
Cu	2.50	-	-	47.4
Zn	3.40	-	-	3.0
Pb	2.40	-	-	0.43
Cd	2.62	-	-	1.30
Cr	2.87	-	-	0.21

Co	3.71	-	-	50
As	1.80	0.19	0.06	5.0

The findings revealed that the order of heavy metals accumulation in cabbage, a leafy vegetable as: Fe > Co > Zn > Cr > Cd > Cu > Pb > As. But for tomatoes and green beans, only two metals were accumulated, primarily Fe and As. 'Farming vegetable on abandoned mine soils may results to the vegetable taking in heavy metals which could be above the threshold levels in edible plant tissues and enter the food chain. This creates a potential health risk for both humans and animals due to the consumption of contaminated produce such as vegetables, tubers, fruits, and nuts grown in polluted soils. Although Fe, Mn, Zn, Co, and Cu are important trace elements in the human nutrition, excessive concentrations of these metals may result to injurious systemic effects' (Avila et al., 2017).

The metal concentrations in cabbage grown around the abandoned mines of Sabon Gida were significantly higher than in the works of Amina et al. (2015) and Benti (2014). Other studies also showed similar trends in the concentration of heavy metals; 'Fe > Pb > Zn > Cr > Cu > As > Cd' (Henry et al., 2018). Moreover, the concentrations of Zinc, lead, Cadmium, and Chromium in cabbage was over the FAO/WHO permissible levels for edible vegetables. This aligns with findings that 'leafy vegetables tend to accumulate higher concentrations of metals compared to other types of plants' (Chen et al., 2014; Chowdhury et al., 2019). The accumulation of the metals in cabbage may be attributed to the application of fertilizers, pesticides, and tin mine water for irrigation (Abdulahi et al., 2021).

On the other hand, tomatoes and green beans only accumulated Fe and As in their edible parts, suggesting that these vegetables are selective in excluding other metals. The Fe concentrations in tomatoes and green beans were 1.28 mg/kg and 0.91 mg/kg, respectively, which is comparable to the '1.15 ± 0.29 mg/kg' reported by Duressa & Leta (2015) in their study on metal levels in vegetables. The As concentrations were also low, with 0.19 mg/kg in tomatoes and 0.06 mg/kg in green beans.

Non carcinogenic estimation

Table 5: Estimated daily intake, hazard quotient and hazard index in some selected vegetables around abandoned mines of Sabon Gida

Metal	Estimated Daily Intake			RfD values	Hazard quotient		
	Cabbage	Tomatoes	Green beans		Cabbage	Tomatoes	Green beans
Fe	0.00029	0.00003	0.00002	0.7000	0.0004	0.00004	0.00003
Zn	0.00005			0.0400	0.0013		
Cu	0.00007			0.3000	0.0002		
Pb	0.00005			0.0035	0.0140		
Cr	0.00005			0.0010	0.0534		
Cd	0.00006			0.0030	0.0195		
Co	0.00008			0.0003	0.2523		
As	0.00004	0.000004	0.000003	0.0003	0.1224	0.0129	0.0109
HI					0.4636	0.0130	0.0109

Table 5 presented the results of the estimated daily intake of metals (EDIM), health quotient (HQ), and health index (HI) associated with the concentrations of heavy metals in three vegetables cultivated around t abandoned mines of Sabon Gida. The EDIM values for Fe, Co, Cu, Cd, Cr, Zn, Pb, and As in cabbage, tomatoes, and green beans fell within the acceptable limits set by the US EPA for daily heavy metal intake (Table 6). This finding contrasts with the study by Mulate et al. (2022), which reported that the ‘’average daily intake of Pb (7.79 mg), Fe (2755.38 mg), Zn (55.83 mg), and Cu (639.05 mg) exceeded the permissible maximum tolerable daily intake. The daily intake of heavy metals is influenced by the concentration of metals in food samples, the weight of the individual, and the quantity of the food consumed (Adedokun et al., 2016) ’’. According to the mean values, the EDIM through vegetable consumption in Sabon Gida followed this order for cabbage: Fe < Co < Cu < Cd < Cr < Zn < Pb < As. For tomatoes, it was Fe < As, and for green beans, the order was As < Fe.

The HQ values for each metal were all less than one, indicating that the consumption of these metals through vegetables does not constitute a significant dander to the wellbeing of the populace (Md and Hoque, 2014). Similarly, the HI values for the heavy metals analyzed in the three vegetables were also below one, suggesting that there are no significant health effects connecting with consuming the three vegetables from the study area. ‘Although the HQ and HI do not quantify the exact health risks for an exposed population, they do provide an indication of concern' (Guerra et al., 2012; Mahmoud & Abdel-Mohsein, 2015).

The potential health risks estimated for residents in this work is just for vegetable consumption and it may be higher than is reflected here if other routes of heavy metal intake are considered, such as water or air (Adedokun et al., 2016). These findings align with the works of Jitender et al. (2017), Md and Hoque (2014), and Gebeyehu and Bayissa (2020). In contrast, the work of Adedokun et al. (2016) reported that the total hazard quotient (THQ) values for Cd, Pb, Zn, Cr, Ni, and Cu indicated high exposure to health risks, 'with the metals ranked in the order: Pb > Cu > Cd > Ni > Zn > Cr'.

Table 6: Upper USEPA tolerable daily intake limit

Metal	**Integrated risk information system (USEPA 2010)**
Fe	45
Zn	40
Cu	10
Pb	0.24
Cr	0.0105
Cd	0.064
Co	0.06
As	0.03

Source: USEPA 2010 in Adedokun *et al*., 2016

Carcinogenic Estimation

Table 7: Carcinogenic risk of heavy metals in selected vegetables around abandoned mines of Sabon Gida

Metal	**Slope factor**	**Cabbage**	**Tomatoes**	**Green beans**
Pb	8.5×10^{-3}	4.16E-07	-	-
Cr	0.5	2.9E-5	-	-
Cd	15	2.0E-5	-	-

As	1.5	\5.5E-5	5.8E-6	4.9E-6
TCR		1.05E-4	5.8E-6	4.9E-6

Carcinogenic risk of heavy metals in selected vegetables around abandoned mines of Sabon Gida is presented on Table 7.

'For controls, the values between 10^{-6} and 10^{-4} is regarded as acceptable' (Nachana'a, 2019). The cancer risk indices in this work are within the span of predictable lifetime cancer risk as defined by the US EPA (2010). The arsenic (As) concentrations in tomatoes and green beans were within the acceptable limits, indicating that consumers of these vegetables have a lower probability of developing cancer through ingestion during the 70 years compared to cabbage. Furthermore, the total cancer risk (TCR) analysis confirmed no significant cancer risk associated with the metals studied in the vegetables, as the TCR values (1.05×10^{-4} for cabbage, 5.8×10^{-6} for tomatoes, and 4.9×10^{-6} for green beans) all fall within the acceptable threshold.

CONCLUSION

This work has shown varying levels of chromium, cadmium, zinc, iron, copper, cobalt, lead, and arsenic in the samples cultivated around the abandoned Sabon Gida mine. Although the levels of heavy metals found in the studied samples were below the thresholds, the ongoing mining in Sabon Gida may cause the accumulation of these metals remains a concern for the safety and quality of the produce, especially due to the potential for chronic human exposure.

This work offers valuable information on heavy metal concentrations in water, soil, sediment, and various vegetables. The findings related to the contamination index (CI), degree of contamination (CD), pollution load index (PLI), estimated daily intake of metals (EDIM), hazard quotient (HQ), hazard index (HI), and cancer risk (CR) indicated that the consumption of vegetables grown in wastewater-irrigated soils posed minimal risks, except for a few metals in cabbage. However, the consumption of cabbage with elevated heavy metal levels could lead to significant bioaccumulation in the body, potentially causing related health issues.

Based on these findings, we recommend regular monitoring of heavy metal levels in vegetables grown in the Sabon Gida abandoned mine area. Additionally, to reduce health risks associated with consuming contaminated vegetables, it is advised to avoid consuming such produce. Furthermore, wastewater treatment processes should incorporate effective measures to remove toxic heavy metals before being used for irrigation.

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CONFLICT OF INTEREST

Authors have declared that, there is no conflicting interests.

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