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Heavy Metals Contamination in Soil and Vegetables in the Sekenke Gold Mine: Levels, Transfer and Potential Human Health Risk Analysis

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Abstract

Background: The main goal of this study is to evaluate the potential human health risks associated with consuming vegetables contaminated by heavy metals at Sekenke gold mine.
Methodology: Five heavy metals (Pb, Cd, Fe, Zn and Cr) were analyzed in soil and in green leafy vegetables (Amaranthus sp and cucurbita moschata) by XRF Rigaku Nex CG instrument, while Arsenic was examined by Atomic Absorption spectrometry (AAS) equipped with a continuous flow of Vapour Generation Accessory (VGA).
Results: The average heavy metal concentrations in soils sample with mean average concentrations ± standard error (mg/kg) 204.646 ± 28.671 for Fe, 163.116 ± 16.658 for Cr. 52.403 ± 15.806 for Zn, 23.392 ± 18.049 for Pb, 21.331 ± 7.503 for As and 3.018 ± 0.842 for Cd. In GLV was observed that the average concentrations of As, Pb, Cd and Zn exceeded the maximum acceptable limit by FAO/WHO (2001) while Fe and Cr concentrations are lower than maximum acceptable limits. On average, Amaranthus species can contribute between 1.04% (Fe) to 7.15% (As) of the recommended daily intake (RDI) for these metals. While in Cucurbita moschata it ranges from 1.09% (Cr) to 5.47% (Cd).

Conclusion: This study shows the contribution of non-essential elements (As, Pb, Cd and Cr) is high than essential elements (Fe and Zn). The HQ of Amaranthus sp ranges from 0.298 (Fe) to 9.930 (As) where about 67% of the analyzed metals have HQ > 1, reveals probable adverse health effects. In cucurbita sp the HQ ranges from 0.383 (Fe) to 4.41 (As). For the heavy metals analyzed the trend for HQ via ingestion, were observed that 50% of the analyzed metals have HQ > 1. Though, vegetable intake is just a proportion of food consumed, supplementary or complementary food that may include fish, rice and tobacco that are consumed can also contribute and/ increase amounts of heavy metals.
Novelty: This study is beneficial to the individuals around the mine sites dealing with mineral materials associated with heavy metal contamination that affects their health through vegetable ingestion.
Keywords: Heavy metals, Contamination, Health risk assessment, Sekenke, Amaranthus, *Cucumbita moschata*

Introduction

The modern world heavily depends on minerals and metals extracted from the earth (Basem, et al., 2024). From construction and electronics to medical equipment and countless other products, mining plays a fundamental role in human life (Soltani, et al., 2017). However, this essential activity comes with a high environmental cost: pollution (Li et al., 2023). Toxic elements such as arsenic, cadmium, lead, zinc, and mercury are released into the soil, water, and air during mining and mineral processing. Mining activities, including prospecting, exploration, construction, operation, maintenance, expansion, abandonment, decommissioning, and repurposing, can impact social and environmental systems in multiple ways, both positively and negatively, as well as directly and indirectly (Haley et al., 2011). These operations disrupt natural ecosystems by altering soil, vegetation, and burying organisms beneath excavation areas (Haddaway et al., 2019). As a result, gold mining sites pose significant toxicological risks to surrounding ecosystems and human health (Ngole-Jeme & Fantke, 2017). Similar to other extractive activities, mineral excavation negatively affects the hydrospheric, atmospheric, and lithospheric components of the environment (Rasmussen, 1998). In gold mining, as with many metallurgical processes, crystallographic bonds within the ore mineral must be broken to extract the desired element or compound (Migliorini et al., 2004).

The impacts of mining, both positive and negative, are indisputable, leading to the classification of mining externalities into two types: positive (beneficial) and negative (harmful). Beneficial effects include mineral extraction, contributions to GDP through employment, sectoral linkages, and local economic multiplier effects (Sonter et al., 2018). However, over the years, numerous fatal incidents have been reported near large gold mines, linked to the leakage of toxic chemicals into water sources relied upon by local communities. Empirical studies reveal that the concentrations of these chemicals and heavy metals often exceed WHO-recommended thresholds, with particularly severe health effects, especially in children (Ako, et al., 2014). During gold mining, large quantities of waste are produced. Over 99% of extracted ore in gold mining are released into the surrounding environment as waste (Da Silva et al., 2004). One of the wastes that have been implicated around mining sites is heavy metals. In addition to releasing particulate matter and gases, gold mines are known to generate hazardous pollutants and heavy metals such as arsenic, cadmium, zinc, lead, copper, manganese, and cyanide. In low concentrations, these pollutants are dispersed and absorbed by the surrounding environment (Borrelli, et al., 2020).

Heavy metals have gained global research attention due to their harmful effects on plants, particularly on vegetative and reproductive parts (Ekaterina & Jeliazkova; Anwar et al., 2016). Variations in the physical and chemical properties of soil can cause heavy metals in tailings to be translocated and accumulated in plants and animals. Even at low concentrations, heavy metals can persist in the soil and enter the food chain through plant uptake (Hapke, 1996). Some heavy metals, such as lead, arsenic, mercury, and cadmium, are not essential for plant growth as they perform no known physiological functions. Conversely, metals like iron, copper, nickel, manganese, cobalt, molybdenum, and zinc are essential for normal plant growth and metabolism. However, when present in concentrations higher than necessary, they can become toxic to plants and humans (WHO, 2001).

Heavy metals such as arsenic is a ubiquitous, naturally occurring metalloid that may be a significant risk factor for cancer after exposure to contaminated drinking water, cigarettes, foods, industry, occupational environment, and air. which mainly causing the peripheral vascular disease, along with lung, skin, kidney, and bladder cancer, as well as severe disturbances in the cardiovascular and central nervous systems which can potentially result in death may occur. Other conditions include bone marrow suppression, hemolysis, hepatomegaly, melanosis, polyneuropathy, and encephalopathy (WHO, 2001). Cadmium (Cd) is an extremely toxic metal for plants, animals, and humans. It primarily enters the soil-plant system through human activities. High levels of cadmium in soils can reduce soil productivity, even at very low concentrations (Sobolev & Begonia 2008).

Lead is causing blood related disorders such as colic, constipation and anemia, high blood pressure, decrease of hemoglobin production, kidney, joints, reproductive and cardiovascular systems disorder, long-lasting injury to the central and peripheral nervous systems, loss of IQ, low sperm count, loss of hearing (Martınez & Motto 2000). Studies have also shown the genotoxic effect of chromium on cells. Cr (VI) has been found to 100 times more toxic and 1000 times more mutagenic and carcinogenic compared to Cr (III) (Bagchi et al., 2002; Sharma et al., 2022).

Iron (Fe) is a fundamental component for all living organisms and plays a key role in maintaining cellular homeostasis. It is essential for chlorophyll synthesis and activates various respiratory enzymes in plants. Iron deficiency can cause severe chlorosis in plant leaves. However, high levels

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of exposure to iron dust may lead to respiratory issues, such as chronic bronchitis and difficulty in breathing. This study found that iron concentrations in the vegetables were within the WHO permissible limits, indicating no risk of acute toxicity.

Zinc is a chemical element present in the earth's crust, including soils, and is a crucial trace element for growth and metabolic functions in living organisms. However, zinc toxicity has been linked to adverse effects such as tachycardia, vascular shock, dyspeptic nausea, headaches, nasal cavity and lung cancer, asthma, vomiting, diarrhea, hypoglycemia, pancreatitis, liver damage, and impaired growth and reproduction (Martínez & Motto, 2000). Similarly, while iron is the most abundant trace element in the body and essential for many biological processes (Sane et al., 2018), it can become toxic at the intracellular level. Iron disrupts mitochondrial function by diverting electrons from the electron transport chain and uncoupling oxidative phosphorylation, leading to anaerobic metabolism (Singhi & Baranwal, 2003). Iron poisoning in adults is uncommon, with most reported cases occurring in children (Mowry et al., 2015).

Environmental exposure to cadmium became a significant problem in Toyama Prefecture, Japan, beginning in 1912, as many people consumed rice irrigated with Cd-contaminated water. The cadmium was released into the Jinzu River basin by a zinc mine, which was later sued for the damage (Hagino & Yoshioka, 1960). This led to an outbreak of Itai-Itai disease, characterized by severe pain in individuals with spinal and joint injuries (Kumar & Sharma 2019). Patients exhibited a range of symptoms, including reduced bone mineralization, severe skeletal decalcification, a high incidence of fractures and bone deformities, osteomalacia, intense bone pain, and osteoporosis, marked by low bone mass and bone tissue deterioration. Other complications included coughing, anemia, and kidney failure, eventually leading to death Geng & Wang, 2019). Cadmium (Cd) has no known biological functions in the body, but it interferes with some essential functions of zinc (Zn), thereby inhibiting enzyme reactions and nutrient utilization (Genchi, et al., 2020).

In order to evaluate the damages that gold mining activities exert on the environment, especially in areas in which crude methods of mining is still largely used, there lies the need to assess the extents of pollution. These must be based on studies about heavy metals content and their relation to soil and plant. The main goal of this study is to evaluate the potential human health risks associated with consuming vegetables contaminated by heavy metals. The vegetables are the one grown in gold mining areas of the Iramba district. The findings will be compared to international regulatory standards. This research aims to address critical environmental issues in gold mining regions, with a specific emphasis on Tanzania, where metal contamination may negatively impact soil quality, crop production, and human health.

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Materials and Methods

Study Area

The study was conducted at Sekenke Small scale gold mine in Iramba District Singida Region. This mine is situated on a low rise in the Wembere depression, located at Latitude -7.956º and longitude 38.972º. The mines extend on the west to Kinyeleli on the east of the Iramba plateau, trending approximately south-east for a distance of about thirty miles along the line of the broken belt of ancient rocks of the Ubendian belt.

Sample Collection

Samples of two GLV (*Amaranthus sp,* and *Cucurbita moschata)* identified commonly used in Iramba district were taken in an interval of seven days making a batch total of six samples. About 1 kg of each GLV samples were obtained from gardens of local farmers at Sekenke Small scale gold mine, Iramba district, over a period of five weeks from 1st June – 6th July 2024 and kept in pre-cleaned polyethylene bags. Each day the samples were transferred to GST Laboratory for analysis.

Five soil samples (about 500 g each) from garden where the GLV is grown were collected during GLV sampling were collected at a depth of about 15 cm using a hand auger, stored in in pre-cleaned polyethylene bags and sent to GST laboratory where it is oven-dried at 60°C for two days.

Sample Preparation

Soil Sample Preparation

The samples were dried at 50-105˚C for 24 hours to remove the moisture. The samples ground and then sieved to remove coarse debris and rubbles with a size greater than 75microns. A non-metallic sieve was used to avoid contamination of metals. A 10g of each fine soil sample pressed in a plastic cup, then covered well with polypropylene thin film and taken for analysis of five heavy metals (Pb, Cd, Fe, Zn and Cr) by XRF Rigaku Nex CG instrument.

The determination of Arsenic was conducted in different method where by 1g of each fine soil sample undergo strong acidic digestion in aqua regia (HCl/HNO_3: 3/1) to attack a wide range of soil and geological materials, heated slowly near dryness. After the process of digestion, 20ml of distilled water was added to each sample, filtered and kept in 100 ml volumetric flask, which then diluted to the mark. The sample solutions stored well in Teflon examined by Atomic Absorption spectrometry (AAS) equipped with a continuous flow of Vapour Generation Accessory (VGA).

In order to maintain the accuracy of the machine, three blank samples of silica sand collected from Coastal region prepared to the size below 75 microns and then analysed simultaneously with the collected soil samples from the mine site.

Green Leafy Vegetable Preparation

One (1) gram of grounded sample of the two vegetables in triplicate weighed and transferred to 150 ml conical flask followed by adding 15 ml di-acid mixture (Nitric acid and Perchloric acid in the ratio of one to one) and thereafter kept for 12hours for partial digestion. The mixture heated at

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160^0C for 1 hour in a fume hood and then cooled to room temperature followed by addition of 20ml of distilled water. The solution filtered by filter papers Whatman No. 42 and then the filtrate transferred to a 50ml volumetric flask diluted to the mark. The solution was again left to settle for 15 hours. The black samples of distilled water undergo the same process of preparations and then analysed by Atomic Absorption spectrometry (AAS) equipped with a continuous flow of Vapour Generation Accessory (VGA) simultaneously with GLV samples collected in soils around the tailings reprocessing plants.

Quality Assurance

Calibration of the instrument was done by using standard values to ensure quality control. Quality control was ensured through the use of standard laboratory measurements and quality control methods, including replication, the use of standards for each metal investigated, and verification of instrument accuracy. Standard solutions for arsenic (As), lead (Pb), cadmium (Cd), iron (Fe), zinc (Zn), and chromium were supplied by Merck (Germany) with a purity level of 99.98%. A 1000 mg/L standard solution for As, Pb, Cd, Fe, Zn and Cr was prepared, and an average standard concentration of 100 mg/L was obtained. Subsequently, working standards of 0.001, 0.015, 0.15, 1.00 and 2.50 mg/L were prepared using 1% HNO_3. The detection limits ranged from 0.001 to 0.0015 mg/L. In this way, deionized water was used throughout the work. The average range recoveries for soil, wastewater and GLV were As (92 – 115%), Pb (93 -107%), Cd (89 - 110%), Cr (96 - 99%), Zn (89 - 90%) and Fe (94 – 105%).

Data analysis

Data analysis was conducted using Microsoft Excel 2010. Descriptive statistics including means, standard deviations, minimum and maximum values of heavy metal concentrations for the various samples were calculated. Pearson's correlation was used to determine specific relationships among the different metals at level of significance (α=0.05). One-way analysis of variance (ANOVA) was conducted to test for significance differences between metals and between vegetables at $p < 0.05$. Variability was computed for heavy metals as coefficient of variations (CV, %) to test for variations in vegetables from the different market, according to equation (1).

$$C_v = \frac{STD}{X_i} x100 \quad (1)$$

where STD is the standard deviation and Xi is the mean. Variation ranking was considered to be: CV less than 20 as little variation; CV between 20 to 50 as moderate variation and CV greater than 50 as high variation.

Soil to Vegetable Transfer Coefficients

Soil-to-plant transfer is a major pathway for human exposure to metals through the food chain. The Transfer Factor (TF) is a parameter used to describe the movement of trace elements from soil to plants, and it is influenced by both soil and plant properties (Opaluwa, et al., 2012). The transfer

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coefficient is calculated by dividing the concentration of heavy metals in vegetables by the total heavy metal concentration in the soil (Equation 2).

$$TF = \frac{Conc_{GLV}}{Conc_{Soil}} \text{ x } 100 \quad (2)$$

This coefficient quantifies the relative differences in metal bioavailability to plants and depends on the properties of both soil and plants. A higher transfer coefficient indicates either poor retention of metals in soils or a greater efficiency of plants in absorbing metals, while a low coefficient suggests strong sorption of metals to soil colloids (Wilson & Pyatt, 2007).

Assessment of Human Health Risk

Target hazard quotients (THQs) and hazard index (HI) were used to evaluate human health risks from metal-contaminated GLV consumption.

Average daily intake (ADI) of heavy metals

Heavy metals have a toxic impact, but the detrimental effects become evident only with long-term consumption of contaminated vegetables. Chronic exposure to toxic heavy metals through vegetable consumption can lead to apparent health impacts after years of exposure (Ikeda et al. 2000). It has also been reported that consuming food contaminated with heavy metals can significantly reduce essential body nutrients. This reduction can lead to growth retardation, immunodeficiency, disabilities, and an increased prevalence of upper gastrointestinal cancers (Türkdoğan et al. 2003).

The Average Daily Intake (ADI) of heavy metals was calculated based on their concentration in the vegetable samples using equation (3) (Ahmed et al., 2015).

$$ADI = \frac{C_{conc}(mg/kg) x C_f x Av_{\text{int}}}{BW(kg)} \quad (3)$$

Where: C_{conc} is the average heavy metal concentration in GLV (mg/kg); C_f C_{factor} is the conversion factor. The conversion factor of 0.085 is used to convert the weight of fresh vegetable to weight of dry substance. The Av_{int} is the average daily intake of vegetables. According to Weinberger and Swai (2006) vegetable consumption values for Tanzanian adult are 0.280 kg/person/day).The BW is an average body weight of Tanzanian adult is 60.7 kg for adults (Muhihi, et al., 2012).

Non-carcinogenic Risk Assessment

The non-carcinogenic risk was evaluated using the hazard quotient (HQ), which was calculated by dividing the exposure value by the reference dose (eq 4) (Custodio *et al.*, 2020).

$$HQ == \frac{ADI}{RfD} \quad (4)$$

Where ADI is the average vegetables intake per day (mg/kg/day) and RfD is the oral reference dose of the metal (mg/kg/day). The R_fD 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. The

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R_fD (mg/kg/day) for Pb, Cd, Zn, As, Cr and Fe is 0.004, 0.001, 0.3, 0.001, 0.003 and 0.7, respectively (USEPA, 2022; FAO/WHO, 2013). A value of HQ ≤ 1 indicates that adverse health effects are unlikely. When HQ > 1, reveals probable adverse health effects and when HQ > 10 indicates high chronic risk. The general potential for non-carcinogenic effects has been assessed by integrating the HQs calculated for each element and expressed as a hazard index (eq 5).

$$HI = \sum_{i=1}^{n} HQ = HQ_{Pb} + HQ_{Cd} + HQ_{Zn} + HQ_{Cu} + HQ_{Fe} \quad (5)$$

where HI is the hazard index for ingestion, n is the total number of chemical elements considered. If HI < 1, the non-carcinogenic adverse effect due to consumption of heavy metal is assumed to be insignificant.

Results and Discussion

Heavy Metal Concentrations in Soil and in Green Leafy Vegetables Samples

The concentrations of heavy metals (mg/kg) detected in the collected soil samples are summarized in Table 1. Six metals arsenic (As), lead (Pb), cadmium (Cd), iron (Fe), zinc (Zn), and chromium (Cr) were identified, and their levels quantified. The Concentrations of 6 different heavy metals (As, Cr, Cd, Pb, Zn and Fe) in frequently consumed green leafy vegetable species are determined (Table 2).

Table 1 Concentration of Heavy Metals in Garden Soils (mg/kg)

S/N	As	Pb	Cd	Fe	Zn	Cr
Max	41.191	78.333	4.961	240.614	78.846	189.818
Min	10.287	10.872	2.203	144.886	33.640	128.372
Mean	21.331	23.392	3.018	204.646	52.403	163.116
STD (±)	7.503	18.049	0.842	28.671	15.806	16.658
CV%	35.17	77.16	27.90	14.01	30.16	10.21
FAO/WHO (2001)	20	100	3	50,000	300	100

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Table 2 Heavy Metal Concentration in Green Leafy Vegetables Samples

	Amaranthus sp						*Cucurbita moschata*					
HM	**As**	**Pb**	**Cd**	**Fe**	**Zn**	**Cr**	**As**	**Pb**	**Cd**	**Fe**	**Zn**	**Cr**
Max	2.500	0.988	0.852	61.100	156.300	0.655	1.600	0.921	0.924	90.400	181.400	0.512
Min	1.860	0.712	0.320	33.200	144.100	0.648	0.400	0.642	0.328	12.500	122.200	0.436
Mean	2.153	0.852	0.529	45.300	149.033	0.652	0.957	0.737	0.711	58.200	148.433	0.471
STD (±)	0.264	0.113	0.232	11.687	5.247	0.003	0.494	0.130	0.271	33.204	24.633	0.031
WHO/FAO	0.2	0.3	0.2	425.5	99.4	2.3	0.2	0.3	0.2	425.5	99.4	2.3

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Soil to Vegetable Transfer Coefficients

The soil-plant transfer coefficient is a crucial factor in human exposure to heavy metals via the food chain, as it describes the movement of contaminants from soil to plants (Tasrina et al., 2015). In respective to this, the transferability of heavy metals from soil to GLV this study considered vegetables commonly consumed in study area and data for percentage bioconcentration factor (BFC) of the heavy metals analyzed has been given in Table 3

Table 3 The Percentage Bioconcentration Factor (BFC) of the Heavy Metals

	As	Pb	Cd	Fe	Zn	Cr
Cucurbita moschata	4.486	3.151	23.56	28.439	283.253	0.289
Amaranthus sp	10.093	3.642	17.528	22.136	284.398	0.4

Average Daily Intake (ADI) of Heavy Metals through GLV

Assessment of dietary intake of foods is a essential tool for measuring the amount of nutrients intake which may be lead to deficiencies or health risks. The total estimated mean daily intake rate for green leafy vegetables calculated is shown in Table 4.

Table 4 Mean Adults Daily Intake (DIR) for the Analyzed GLV (mg/day)

	As	Pb	Cd	Fe	Zn	Cr
Amaranthus sp	0.00993	0.00393	0.00244	0.20884	0.6870	0.00301
% Cont. in DIR	7.15	1.87	4.07	1.04	3.44	1.51
Cucurbita moschata	0.00441	0.00340	0.00328	0.26830	0.68430	0.00217
% Cont. in DIR	3.39	1.62	5.47	1.34	3.42	1.09
MTDI	0.13*	0.21*	0.06*	**20.0	**2.0	0.20*

MTDI=Maximum tolerable daily intake (mg/day), *Ullah et al, (2017), ** Bagdatlioglu et al., (2010)

Human Health Risks Assessment

The non-carcinogenic health risk owing to ingestion exposure to the studied heavy metals is shown in Table 5.

Table 5 Non-carcinogenic Risk by Ingestion (HQ) of Heavy metals in GLV

Vegetable	**As**	**Pb**	**Cd**	**Fe**	**Zn**	**Cr**	$\sum_{i=1}^{n} HQ$ **(HI)**	**Mean HQ**
Amaranthus sp	9.930	0.983	2.440	0.298	2.29	1.003	16.944	2.824
Cucurbita moschata	4.410	0.850	3.280	0.383	2.281	0.723	11.928	1.988

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Hazard Index

The hazard index is calculated by summing the target hazard quotients of all analyzed elements. The potential adverse effects of toxic metals in a given sample increase proportionally with the cumulative exposure to multiple metals. Therefore, it is crucial to assess the health risk associated with exposure to multiple metals. Target hazard quotient and hazard index values below one indicated that the level of exposure is lower than the reference dose, implying that daily exposure at this level does not pose any threat to the consumer over their lifetime. When the hazard index (HI) exceeds 1.0, there is concern for potential health effects (Zhuang et al., 2004).

Discussion

The heavy metal concentrations in the studied soils decreased in the following order: Fe > Cr > Zn > Pb > As > Cd with mean average concentrations ± standard error (mg/kg) 204.646 ± 28.671 for Fe, 163.116 ± 16.658 for Cr. 52.403 ± 15.806 for Zn, 23.392 ± 18.049 for Pb, 21.331 ± 7.503 for As and 3.018 ± 0.842 for Cd. The concentrations obtained are extremely lower than the one detected earlier in Nigeria (Fagbenro, et al., 2021), where the concentration ranged from 137.8 ± 22.93–605.1 ± 24.51 for Cr; 31,305.60 ± 100.18 to 159,169.30 ± 238.75 for Fe, and 44.00–203.20 ± 17.94 for Zn. This However, the detected level was higher than those detected earlier (Abiya et al., 2019) in Southwestern Nigeria mining area with mean concentrations of Zn (0.70 mg/kg), As (0.09 mg/kg), Cd (0.13mg/kg), Pb (0.216kg/mg), Ni (0.08mg/kg), Cr (0.148mg/kg), Cu (0.629mg/kg). The concentration of these selected heavy metals is lower than the maximum acceptable limit (FAO/WHO, 2001).

The presence of these elements is unsurprising, as lead (Pb) and arsenic (As) are commonly associated with gold-quartz veins (Yang & Blum, 1999). Arsenic is typically bound in sulfides like arsenopyrite, loellingite, or pyrite in many metal deposits, with pyrite-lattice-hosted As concentrations typically ranging from 100 to 5600 ppm (Yang & Blum, 1999). Their dissolution can lead to significant soil anomalies. Chromium likely originates from the weathering of mafic-ultramafic rocks, such as pyroxenites, gabbro, and amphibolites, which serve as the wall rocks for gold-quartz veins. Cadmium, commonly linked to sphalerite, was found in very low concentrations, indicating minimal sphalerite content in the gold ores (Xinyang et al., 2022). This low Cd content suggests minimal contributions from other sources, such as anticorrosive coatings, PVC stabilizers, Ni-Cd batteries, and alloys in the LGF.

It was observed that the average concentrations of As, Pb, Cd and Zn exceeded the maximum acceptable limit by FAO/WHO (2001) while Fe and Cr concentrations are lower than maximum acceptable limits. In the case of chromium (Cr), the concentration ranges from 0.648 to 0.655 mg/kg with mean 0.652 ± 0.003 mg/kg in *Amaranthus sp*, while in *Cucurbita moschata* ranges from 0.436 to 0.512 mg/kg with mean 0.471 ± 0.031 mg/kg. In the recent study Sultana et al., (2022) detected higher concentration about 10 times higher than in this study, where maximum

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Cr concentration was detected in mustard (4.70 mg/kg), coriander (3.88 mg/kg), and mint (6.18 mg/kg).

The highest Pb concentration in vegetables obtained from recorded in *Amaranthus sp* was 0.988 mg/kg and the lowest 0.712 mg/kg while the mean was 0.852 ± 0.113. In *Cucurbita moschata* the highest concentration was 0.921, the lowest was 0.642 mg/kg and the mean was 0.711± 0.271 mg/kg. All concentrations of Pb obtained in this study, were almost 3 times higher than the permissible levels by FAO/WHO (2001) in vegetables of 0.3 mg/kg. The values were lower almost one tenth of the values previously reported in leafy vegetables which include 8.194 mg/kg from Baskuy (Derra et al., 2018).

The highest concentration of cadmium (Cd) recorded in *Cucurbita moschata* was 0.924 mg/kg, while the lowest was 0.328 mg/kg, resulting in a mean concentration of 0.711 ± 0.271 mg/kg. For *Amaranthus sp.*, the highest Cd concentration measured was 0.852 mg/kg, and the lowest was 0.320 mg/kg, with a mean of 0.529 ± 0.232 mg/kg. The maximum Cd concentrations identified in this study were nearly four times greater than the permissible level of 0.2 mg/kg set by FAO/WHO (2001) for vegetables. Recent research from Bangladesh has also indicated Cd concentrations ranging from 0.001 to 1.60 mg/kg across 12 vegetable species (Islam et al., 2015), from 0.006 to 0.3 mg/kg in 16 vegetable species (Rahman et al., 2013), and reaching 0.60 mg/kg in 5 vegetable species (Ahmad & Goni, 2010).

The highest concentration of zinc (Zn) was measured in *Cucurbita moschata* found to be 181.400 mg/kg and minimum was 122.200 mg/kg with mean of 148.433 ± 24.644 mg/kg. In *Amaranthus* sp., the highest concentration was 156.300 mg/kg and minimum was 144.100 mg/kg with mean 149.033 ± 5.247mg/kg. A previously mentioned study also found the lowest concentration of Zn in carrot 0.074–4.75 mg/kg (Shaheen et al. 2016). In another study, the median concentration of Zn in common vegetables (16 vegetable species) in Bangladesh was reported to be 50.0 mg/kg (Rahman et al. 2013). In the previous study in GLV conducted in Tanzania zinc levels ranged from 26.24 mg/kg to 57.34 mg/kg with *Ipomoea sp* register the lowest while *Brassica L.* registered the highest (Saria, 2020).

Iron (Fe) concentration was significantly higher in all vegetables concerning other heavy metals that are analyzed in this study. Iron concentration in analyzed GLV ranged from 32.200 to 61.100mg/kg with mean 45.300 ± 11.687 mg/kg in *Amaranthus sp.*, and 12.500 -90.400 mg/kg with mean 58.200 ± 33.204 mg/kg in *Cucurbita moschata* (Table 2). Iron level in the GLV analyzed was below the WHO / FAO stipulated limit of 425 mg/kg (WHO / FAO 2011). Recent study in Bangladesh (Chowdhury, et al., 2024) reported high Fe concentration than in this study 95.07 ± 1.27 mg/kg (Chinese okra) and 90.28 ± 0.42 mg/kg (egg plants). One study from Tanzania has analyzed four different vegetables (potato leaves, African spinach, ladies' finger, and brinjal) and observed a mean Fe concentration of 48.40–136.40 mg/kg (Kacholi & Sahu, 2018).

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The levels of As ranged from 1.860 – 2.500mg/kg (*V. unguiculata sp*) with mean 2.153 ± 0.264 mg/kg (*Amaranthus sp*.,), while in *Cucurbita moschata* ranges from 0.400 – 1.600 mg/kg with mean 0.957 ± 0.494 mg/kg. The detected values in both GLV are higher than maximum permissible limit by FAO/WHO (0.2 mg/kg). In a previous study (Ramirez-Andreotta et al., 2013) the arsenic concentrations measured for the lettuce, onion, radish, and bean greenhouse samples ranged from 0.00843 to 5.28 mg/kg. In a similar study

Osuna- Martínez et al. (2021) conducted a study in Mexico, the arsenic (As) concentration between root vegetable and fruit vegetable they were similar, fruit vegetable average was higher (95.66 mg/kg) and root vegetable (92.33 mg/kg). The high level of arsenic in mining site and thereafter in vegetables is not surprising because arsenic (As) in mining soil is typically linked to the geological materials associated with mining activities. Arsenic is often found in sulfide minerals, such as arsenopyrite (FeAsS), and in ores containing metals like gold, copper, and lead (Zhuang, et al., 2023). During mining, the extraction, processing, and disposal of these ores can release arsenic into the surrounding environment and hence to the GLV. According to Goldhaber (2003), plants can accumulate relatively large amounts of these elements through foliar absorption.

The percentage transfer coefficient in descending order in the analyzed two GLV are in descending order Zn > Fe > Cd > As >Pb > Cr. These findings suggest that Zn has higher transferability, with *Amaranthus sp* exhibiting a high absorption capability, followed by *Cucurbita moschata*. Additionally, the transfer coefficient is influenced by the bioavailability of the metal, the levels of metal in the soil, the chemical form of the metal, plant uptake capabilities, and the growth rate of the plant species (Olowoyo et al., 2012). Moreover, the transfer coefficient depends on the metal's bioavailability, its concentration in the soil, its chemical form, the plant's uptake capabilities, and the growth rate of the plant species (Tinker, 1981). Based on the findings, the soil-to-plant transfer coefficients are directly linked to the observed levels of heavy metals. The highest coefficient values for Fe and Zn could be attributed to the higher mobility of these metals, which naturally occur in soil (Alam et al., 2003) and their lower retention in the soil compared to other cations (Zurera et al., 1987).

The estimated daily intake of As, Pb, Cd, Fe, Zn and Cr through consumption of green leafy vegetables ranged from 0.00441 to 0.00993 mg/kg/day, 0.00340 to 00393 mg/kg/day, 0.00328 to 0.0.00244 mg/kg/day, 0.0.26830 to 0.0.6870 mg/kg/day and 0.00217 to 0.0.00301 mg/kg/day, respectively. The daily intake of heavy metals in all the studied samples were lower than MTDI safe limits indicates that there is no potential human risk prior to consumption of vegetables from the studied area. The daily intake of analyzed GLV shows a higher concentration of Fe and Zn if taken in large quantities although it is below the recommended acceptable values proposed by the FAO/ WHO Joint Expert Committee on Food Additives in Bagdatlioglu et al., (2010).

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On average, *Amaranthus sp*. can contribute between 1.04% (Fe) to 7.15% (As) of the recommended daily intake (RDI) for these metals. While in *Cucurbita moschata* it ranges from 1.09% (Cr) to 5.47% (Cd). This study shows the contribution of non-essential elements (As, Pb, Cd and Cr) is high than essential elements (Fe and Zn). This is contrary to study conducted in vegetables not grown in mining sites (Mubofu, 2012), showing vegetable like amaranth sp contribute 15.9% of zinc to the recommended daily intake. It is essential to monitor and manage the levels of these metals in food to ensure safety and health. Always double-check important health and safety information from reliable sources.

Hazard index (HI) values of the heavy metals studied ranged from 11.928 to 16.944 that were above 1, indicating non-acceptable level of non-carcinogenic adverse health effect. Hence, HI recorded in Sekenke gold mine area indicates the contribution of heavy metals can lead to aggregate risk via consumption of vegetables. This high HI values for all heavy metals observed in Amaranthus sp and Cucurbita moschata have great potential to pose health risk to the consumer. Similar, study conducted by Ametepey, et al., (2018) observed HI (THQ) values ranged from 6.51 to 29.30. The consequence can be more severe for special populations in the mining sites (especially old and pregnant women) the potential human health risks of heavy metal accumulation through vegetable consumption. Though, vegetable intake is just a proportion of food consumed, supplementary or complementary food that may include fish (Wang et al. 2005; Saria, 2017), meat (Zheng et al. 2007; Bortey-Sam et al. 2015), rice (Zheng et al. 2007; Hang et al. 2009), and tobacco (Dong et al. 2015) that are consumed can also contribute and/ increase amounts of heavy metals.

The HQ of Amaranthus sp ranges from 0.298 (Fe) to 9.930 (As) where about 67% of the analyzed metals have HQ > 1 reveals probable adverse health effects, while 33% have a value of HQ ≤ 1 indicates that adverse health effects are unlikely. In Cucurbita moschata the HQ ranges from 0.383 (Fe) to 4.41 (As). For the heavy metals analyzed the trend for HQ via ingestion, were observed that 50% of the analyzed metals have HQ > 1 reveals probable adverse health effects, while 50% have a value of HQ ≤ 1 indicates that adverse health effects are unlikely. The results indicated that those living around the Sekenke gold mine were exposed to some potential health risk through the intake of analyzed heavy metals except Pb and Fe via consuming locally grown *Amaranthus sp* and *Cucurbita moschata*. Even though there risk when each metal was analysed individually, the potential risk could be multiplied when considering all heavy metals. Higher HQ for heavy metals were also reported earlier in Ghana (Ametepey, et al., 2018), where heavy metals like Cd and Cr ranged from 2.54 to 3.14, 3.33 to 3.67, respectively.

Conclusion and Recommendations

The present study was performed to assess heavy metal levels of commonly consumed vegetables (*Amaranthus sp* and *Cucurbita moschata*) at Sekenke Gold mine and their associated health risks. Generally, the heavy metals concentrations in the various vegetables are all above the permissible limit of WHO / FAO. The individual hazard quotient values were all above 1 except Fe and Pb in

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adult suggest an unacceptable level of non-carcinogenic adverse risk. The hazard index exceeded 1 which may pose future risk such as cancer. Based on the findings of this study; it is recommended that further research work should be carried out to study the levels of heavy metals in other vegetables in and around Sekenke gold mine in order to maintain and/or improve measures to reduce their levels in vegetables and ultimately prevent these avoidable health problems.

Authors Contribution

Mr Priscus Roman has the contribution on conceptualization, writing of manuscript, data analysis and supported in literature review. Dr Josephat Saria has contributed on conceptualization, research methodology supported in literature review and formal data analysis. We, Authors provided final approval of the article to be published.

Conflict of Interest

Authors declare there is no conflict of interest

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