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Assessment of Concentration and Potential Health Risks of Heavy Metals in Vegetable Samples Cultivated in Toro Mining Site, Bauchi State Nigeria

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Abstract

Heavy metals are dense metallic elements with significant environmental and health impacts. The risk of exposure to the population from heavy metals in an area that had witnessed long-term mining activities was evaluated in the current study. Leafy vegetable samples from Toro Local Government Area, Bauchi State, Nigeria, were evaluated for the presence of heavy metals using Atomic Absorption Spectrophotometry. The health risks of the evaluated heavy metals in the samples to the population were assessed using the Target Hazard Quotient (THQ) and Health Risk Index (HRI)) to assess the possible non-carcinogenic effect and the Incremental Lifetime Cancer Risk (ILCR). Pb concentration in the samples falls above the Maximum Allowable Concentrations (MAC) of 2.680mg/kg, 0.220mg/kg, 3.670mg/kg, 4.900mg/kg, and 4.280mg/kg for Amaranthus, Onion, Cabbage, Pepper, and Tomato respectively, while Cu, Cr, Co, Fe, Mn, Ni, and Cd were within the permissible values. The results of the Target Hazard Quotient (THQ) associated with the evaluated heavy metals exposure through consumption of vegetables for adults and children were all lower than 1. The combined health risks for all the metals in the sample for the adults and children population represented as HRI were also below 1.0. The result of the Incremental Life Cancer Risk (ILCR) for both the adult and children population revealed that the heavy metals were beyond the threshold safety limit for cancer risk. The consumption of vegetables poses a health risk concern regarding Pb because of its high concentration, and this may contribute to disease burden in the population upon long time exposure, necessitating control measures.

Keywords: Heavy Metals, Health Risks, Vegetables Contamination, Incremental Life Cancer Risk, Maximum Allowable Concentration

INTRODUCTION

Heavy metals are heavy and dense metallic elements that are found in the earth's crust and can also be released into the environment by human activities like factories, mining, burning fossil fuels, and farming (Tiwari *et al.,* 2019). Some common heavy metals are Lead, Cadmium, Iron, Copper, Chromium, and Nickel, and these metals can pollute soil, water, and air, which can be harmful to living things (UNEP, 2013). For example, mercury in vegetables can build up in our bodies and make us sick. People can be exposed to these metals by breathing them in, eating them, or touching them, which can cause serious health problems (UNEP, 2013). Lead can hurt kids' brains and nerves, while mercury can affect how kids' brains develop and cause problems for babies before they are born (CDC, 2012). Arsenic, found in dirty water, can cause skin problems, cancer, and heart issues (Rahman *et al.,* 2016). Humans have made the problem worse by releasing more heavy metals into the environment through things like factories and mining. This can make the air, water, and soil more polluted and dangerous for both animals and people (Alloway, 2013). Mining, which is important for getting valuable materials from the earth, can spread heavy metals into the environment and harm plants, animals, and people (Plumlee and Morman, 2011). Eating vegetables grown in contaminated soil can make us sick because the plants can absorb the heavy metals. Some plants can take in more heavy metals than others, depending on the type of metal and the soil they grow in (UNEP, 2017). Eating vegetables with a lot of heavy metals can cause health problems like brain issues, kidney damage, and cancer (UNEP, 2017).

Because of the fast progress in countries all over the world and the rise of factories during the industrial revolution, there is a lot more waste being produced that is hurting the environment, as highlighted by Afkhami *et al.* (2013). Mining is a big part of this problem, as it releases harmful metals into the air, water, and soil. These metals can stay in the environment for a long time and can be dangerous to animals and people. They can cause diseases and harm the soil and water that we need to survive(Dhaliwal *et al.,* 2020).

The health implications for both ecosystems and living beings, particularly humans, have raised concerns among health professionals (Park *et al.,* 2011). Heavy metals find their way into aquatic systems through natural processes or human activities, such as mining, smelting, and the discharge of municipal and industrial waste, along with the use of fertilizers and pesticides in agriculture (Li *et al.,* 2013). The practice of irrigating crops with wastewater, while initially reducing soil pH and increasing organic carbon levels, ultimately boosts the concentration of toxic metals in the soil, which then accumulate in crops (Joseph *et al.,* 2019). Given that groundwater is a crucial drinking water source worldwide, contamination with heavy metals is of widespread concern, as even trace amounts can be hazardous (Singh and Kamal, 2017). Heavy metals, due to their carcinogenic and mutagenic nature, pose significant risks to human health by accumulating in cellular structures and interacting with nucleic acids and proteins, which can lead to DNA damage, disrupt biological functions, and cause carcinogenesis (Tchounwou *et al.,* 2012). Consuming food tainted with heavy metals can severely deplete essential nutrients, weakening the immune system, delaying growth, and causing malnutrition (Sardar *et al.,* 2013).

The push towards industrialization and the increasing focus on food safety are prominent issues in both advanced and developing countries worldwide (Singh and Kamal, 2017). There is a growing concern about environmental pollution and the safety of food due to the potential health risks it poses to the population (Ugulu, 2015). Heavy metals, stemming from geological and human activities and other sources, have garnered significant attention for their adverse health effects on humans when accumulated in concentrations exceeding physiological needs (Ugulu, 2015). Literature highlights the rising demand and consumption of vegetables globally, as they are an essential component of human nutrition and diet (Sachdeva *et al.,* 2013). However, there's a noticeable gap in research regarding the levels of heavy metals in vegetables grown using water from mining-affected areas, specifically in the Toro local government region of Bauchi State. It's vital to determine the degree of heavy metal pollution in these vegetables to evaluate the safety of local food production and to devise plans to counteract potential health risks. This study is being done to learn more about how heavy metals can affect our health.

MATERIALS AND METHODS

Study Area

This study was conducted in Toro. Toro is a Local Government Area in Bauchi State, Nigeria. The local government headquarters is in the town of Toro. It has three districts: Toro, Jama'a, and Lame. The local government makes Boundaries with Plateau, Kaduna, and Kano States. It has an area of 6,932^{2}km and a population of 350,404 as at2006 census.

With an average yearly temperature of 29.87°C, 88.52 millimeters of precipitation, and 119.3 rainy days, Toro generally has a tropical wet and dry climate. Farming (both dry and rainy seasons) is an important occupation of the people of Toro LGA with crops such as potatoes and onions grown in substantially large quantities within the area. A number of minerals are also deposited within the area. Other important economic activities engaged in by the people of Toro LGA include food processing, trade, and animal rearing (Weather Spark, 2023)

Sample Collection

The vegetable cultivation plots were segmented into various distinct sampling zones. From each zone, specimens were collected and amalgamated to form a composite sample, from which representative aliquots were derived. These samples, encompassing Cabbage, green paper, tomatoes, Onion, and Amaranthus, were assigned unique identifiers and stored in hermetically sealed glass containers to prevent moisture ingress and contamination. These samples were then refrigerated at a temperature of 4˚C until further analysis, as described by Yar'adua *et al.* (2023).

Sample Processing

The vegetable specimens were initially rinsed under tap water to remove extraneous materials such as dust, soil, and unicellular algae. Successive washes with distilled and deionized water followed this. Post-washing, the vegetables were dried using blotting and filter papers at ambient temperature to remove surface moisture. After that, the specimens were placed in desiccators to prevent further moisture loss. Each vegetable type was then individually chopped and subjected to drying in a Gallenkamp hotbox oven (CHF097XX2.5) at a controlled temperature of (55±1) ˚C for a predetermined period. The dried specimens were subsequently ground into a fine powder using an electric blender and stored in hermetically sealed polyethylene packets, each labeled with its corresponding identifier, at ambient temperature pending the digestion and subsequent metal analysis (Yar'adaua *et al.*, 2023).

Digestion and Determination of Heavy Metals Concentration

Vegetable sample digestion was conducted according to the methodology described by Yaradua *et al.* (2023). Specifically, 0.5g of the powdered specimen was accurately weighed and transferred into a 100 mL beaker, followed by the addition of 5 mL of concentrated nitric acid (HNO_3) and 2 mL of per-chloric acid ($HClO_4$). The mixture was then heated on a hot plate at 95˚C until a clear solution was obtained. This solution was filtered into a 100 mL volumetric flask and diluted to the mark with distilled water for subsequent analysis by Atomic Absorption Spectrophotometry (AAS). AAS detected the heavy metals by measuring the absorption of light by metal atoms vaporized in a flame or graphite furnace. The technique quantifies the concentration of metals by analyzing the specific wavelengths of light absorbed by the metal atoms in the sample (Welz and Sperling, 2008).

Assessment of Health Risks from Heavy Metals

Daily Metal Intake Calculation

The method for calculating the daily metal intake (DMI) from the studied samples involves the formula: $DMI = \frac{Cm \times Cf \times Ddaily}{Bw}$...eqn. (1)(Jan *et al.*, 2010)

In this equation, Cmetal denotes the measured heavy metal concentration in the sample. Cf is the conversion factor, fixed at 0.085 for adjusting the sample weight to a dry basis. D-daily represents the average daily consumption rate of the sample, reported as 0.527 kg per person per day (Balkhaira and Ashraf, 2015). Bw is the average body weight, set at 60 kg for adults (Orisakwe *et al.*, 2015) and 24 kg for children (Ekhator *et al.*, 2017). These figures are also used in calculating the Health Risk Index (HRI).

Non-Cancer Risk Assessment

To assess non-carcinogenic risks from heavy metals through vegetable consumption by the local population, the Target Hazard Quotient (THQ) is calculated as follows:

$THQ = RfD \times CDI$ .... eqn. (2) (Li and Zhang, 2010).

CDI stands for the chronic daily intake of heavy metals (mg/kg/day), and RfD is the reference oral dose (mg/kg/day), indicating the maximum acceptable exposure level over a lifetime without adverse effects (Li and Zhang, 2010). Reference doses are taken from existing studies (Pb = 0.6, Cd = 0.5, Zn = 0.3, Fe = 0.7, Ni = 0.4, Mn = 0.014, Cu = 0.04) (Li *et al.*, 2013; Yaradua *et al.*, 2023).

Furthermore, the cumulative non-carcinogenic risk from multiple heavy metals is assessed using the Chronic Hazard Index (HI), calculated as:

$HI = THQ1 + THQ2 + THQ3 + \cdots + THQn$.......... eqn (3) (Guerra *et al.*, 2012).

Here, each THQ corresponds to a different heavy metal. An HI below 1 suggests a safe level of exposure, whereas an HI above 1 indicates potential health risks (Guerra *et al.*, 2012).

Cancer Risk Analysis

The Incremental Lifetime Cancer Risk (ILCR) is used to evaluate potential cancer risks from long-term consumption of vegetables containing carcinogenic heavy metals:

$ILCR = CDI \times CSF$... eqn (4) (Yang *et al.*, 2018)

CDI here represents the chronic daily intake of carcinogenic metals (mg/kg BW/day), and CSF is the cancer slope factor for each metal, reflecting the risk of cancer per unit of exposure (Li and Zhang, 2010). The study employs specific CSFs for different metals (Pb = 0.0085 mg/kg/day, Cd = 0.38 mg/kg/day, Ni = 1.7 mg/kg/day) (Yang *et al.*, 2018; Javed and Usmani, 2016).

The acceptable risk range for ILCR is between 10^{-6} and 10^{-4}, with values within this range considered tolerable for lifetime exposure (Micheal *et al.*, 2015). The CDI for this purpose is calculated using:

$$CDI = \frac{EDI \times EFr \times EDtot}{AT}$$ ... eqn. (5) (Yang *et al.*, 2018)

Where EDI is the estimated daily metal intake, EFr is the exposure frequency (365 days/year), EDtotis the total exposure duration (average lifespan of 60 years for Nigerians), and AT is the total duration of exposure for assessing non-carcinogenic (EFr x EDtot) and carcinogenic effects (60 years).

Cumulative cancer risk from multiple carcinogenic metals is evaluated as follows:

$$\Sigma \mathbf{ILCR} = \mathbf{ILCR1} + \mathbf{ILCR2} + \cdots + \mathbf{ILCRn}$$... eqn (6) (Javed and Usmani, 2016)

Each ILCR value corresponds to a different carcinogenic heavy metal.

RESULT AND DISCUSSION

Concentration of Heavy Metals in the Vegetables

Table 1 presents the concentrations of various heavy metals measured in milligrams per kilogram (mg/kg) found in vegetables grown in the mining area of Toro Local Government in Bauchi State. The data covers eight heavy metals: Cu, Cr, Co, Fe, Mn, Ni, Pb, and Cd across five different vegetables: Amaranthus, Onion, Cabbage, Pepper, and Tomato. Cr concentrations are notably high in Cabbage (4.316 mg/kg), indicating potential health risks as Cr can be toxic. Pb levels are alarmingly high in Pepper (4.900 mg/kg) and Tomato (4.280 mg/kg), far exceeding those in other vegetables, which is similar to a study conducted by Yaradua *et al.* (2023), thereby posing serious health concerns due to Pb's toxicity. Shibdawa *et al.*, 2019 also reported a similar concentration of heavy metals in Barikin Ladi Jos, Plateau State. Cd and Cu levels are relatively lower compared to other metals but vary across vegetables, with Tomato showing the highest Cu concentration (0.295 mg/kg). Fe shows the highest concentration in Amaranthus (6.157 mg/kg), which is also similar to the previous study by Yar'adua *et al.* (2019). There is a wide variation in heavy metal concentrations among the vegetables, suggesting differential uptake and possibly different levels of exposure to contaminated soil or water (Yang *et al.*, 2018). This analysis underscores the importance of monitoring and managing heavy metal concentrations in vegetables cultivated in mining areas to mitigate health risks.

Table 1: Concentrations of Heavy Metals (mg/kg) in Vegetables Cultivated from the Mining Area

Heavy meals(mg/kg)	Amaranthus	Onion	Cabbage	Pepper	Tomato
Cu	0.16±0.0002	0.20±0.0002	0.11±0.0026	0.16±0.0006	0.29±0.0008
Cr	2.37±0.0012	3.38±0.0008	4.32±0.0010	2.19±0.0002	1.52±0.0005
Co	1.29±0.0007	0.20±0.0013	0.06±0.0003	0.76±0.0015	2.17±0.0014
Fe	6.16±0.0060	2.72±0.0010	3.12±0.0004	1.88±0.0018	3.97±0.0005
Mn	1.39±0.0050	0.45±0.0028	0.85±0.0005	0.74±0.0006	1.72±0.0007
Ni	0.59±0.0010	0.50±0.0026	2.22±0.0013	0.27±0.0008	1.72±0.0007
Pb	2.68±0.0016	0.22±0.0008	3.67±0.0020	4.90±0.0018	4.28±0.0011
Cd	0.14±0.0002	0.16±0.0011	0.19±0.0005	0.18±0.0001	0.18±0.0005

Values are mean ± standard deviation.

Estimated Daily Intake of Heavy Metals from Consumption of Amaranthus

Table 2 presents the estimated daily intake of various heavy metals through the consumption of

Amaranthus (a leafy vegetable), which has been irrigated using water from mining-induced holes in Toro Local Government of Bauchi State. The estimations are provided separately for adults and children. The daily intake of all heavy metals is higher in children than in adults. This is a significant concern given the higher vulnerability of children to heavy metal toxicity, and this study was similar to a study conducted by Yar'adua *et al.* (2019). Fe shows the highest daily intake for both groups (3.07074×10^{-3}mg/kg/day for adults and 8.147523×10^{-3}mg/kg/day for children), which could be attributed to its higher natural abundance and the necessity for biological functions, though excessive intake remains a concern. Cr and Pb have notably high intake levels as well, with 1.25331×10^{-3}mg/kg/day (adults) and 3.128799×10^{-3} mg/kg/day (children) for Cr, and 1.33653×10^{-3} mg/kg/day (adults) and 3.549433×10^{-3} mg/kg/day (children) for Pb, indicating significant health risks due to their toxicity. The estimated daily intake of Cd and Cu, though lower compared to other metals, still poses a risk, especially in children due to their smaller body size and higher susceptibility as also reported by Yar'adua *et al.* (2019) and Micheal *et al.* (2015).

Table 2: Estimated Metal Daily Intake in Adults and Children from Consumption of Amaranthus Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	7.93×10^{-5}	1.98×10^{-4}
Cr	1.25×10^{-3}	3.13×10^{-3}
Co	6.86×10^{-4}	1.72×10^{-3}
Fe	3.07×10^{-3}	8.15×10^{-3}
Mn	6.98×10^{-4}	1.83×10^{-3}
Ni	2.97×10^{-4}	7.85×10^{-3}
Pb	1.33×10^{-3}	3.55×10^{-3}
Cd	6.75×10^{-5}	1.79×10^{-4}

Estimated Daily Intake of Heavy Metals from Consumption of Onion

Table 3 provides an analysis of the estimated daily intake levels of several heavy metals for both adults and children derived from consuming onions watered with contaminated sources from mining activities in Toro Local Government Area, Bauchi State. The study focuses on eight heavy metals: Cu, Cr, Co, Fe, Mn, Ni, Pb, and Cd, with intake levels quantified in scientific notation for the two groups analyzed. It reveals that children are exposed to higher levels of these metals compared to adults, notably for Cr, Fe, Mn, Ni, and Pb, indicating a greater vulnerability among the younger population. Notably, the intake levels of Chromium and Lead in children, marked at $2.28\times10^{-3}$and 1.94×10^{-3} respectively, are of particular concern when contrasted with the adult intake figures of $1.68805\times10^{-3}$for Cr and $1.61\times10^{-3}$for Pb. This aligns with findings by Orish *et al.* (2017), highlighting the health implications of consuming vegetables, including onions, grown in contaminated settings. Furthermore, the significant exposure of children to these metals underscores the urgent need for addressing the contamination sources and implementing safer agricultural practices. The resemblance of these findings with those reported by Yaradua *et al.* (2019) in their assessment of various vegetables further substantiates the widespread nature of this issue and the critical need for intervention to protect vulnerable populations, particularly children, from the adverse health effects of heavy metal contamination

Table 3: Estimated Metal Daily Intake in Adults and Children from Consumption of Onion Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	1.02×10^{-4}	5.48×10^{-5}
Cr	1.69×10^{-3}	2.28×10^{-3}
Co	1.00×10^{-5}	3.14×10^{-5}
Fe	1.35×10^{-4}	1.65×10^{-3}
Mn	2.26×10^{-4}	4.47×10^{-4}
Ni	1.09×10^{-4}	1.18×10^{-3}
Pb	1.61×10^{-3}	1.94×10^{-3}
Cd	8.15×10^{-5}	9.78×10^{-5}

Estimated Daily Intake of Heavy Metals from Consumption of Cabbage

Table 4 illustrates the estimated daily consumption of various heavy metals by adults and children, specifically from eating Cabbage watered with contaminated sources in Toro Local Government of Bauchi State. The data is quantified using scientific notation to represent the daily intake in grams. For example, the daily intake of Cu by adults is noted as 6.22×10^{-5}, whereas children exhibit a considerably higher consumption rate at 1.37×10^{-4} grams per day, indicating that children's intake of copper from such Cabbage is more than double that of adults.

This observation aligns with the findings by Orish *et al.* (2017) and is further corroborated by the research of Yar'adua *et al.*(2023), who reported nearly identical figures. This trend of increased heavy metal intake by children extends across the spectrum of metals listed, including Cr, Co, Fe, Mn, Ni, Pb, and Cd. Such patterns highlight a significant health risk for children who are more susceptible to the adverse effects of these metals due to higher consumption rates of contaminated Cabbage, as emphasized by Orish *et al.* (2017).

Table 4: Estimated Metal Daily Intake in Adults and Children from Consumption of Cabbage Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	6.22×10^{-5}	1.37×10^{-4}
Cr	2.42×10^{-4}	5.70×10^{-3}
Co	3.56×10^{-6}	7.26×10^{-5}
Fe	1.76×10^{-4}	4.13×10^{-3}
Mn	4.76×10^{-5}	1.12×10^{-3}
Ni	1.25×10^{-4}	4.86×10^{-3}
Pb	2.07×10^{-4}	4.86×10^{-3}
Cd	1.04×10^{-5}	2.45×10^{-4}

Estimated Daily Intake of Heavy Metals from Consumption of Peppers

Table 5 focuses on the estimated daily intake of heavy metals from the consumption of peppers, which, like the Cabbage, were irrigated with water from mining-induced holes within the same Toro Local Government area. This table, structured similarly to Table 4, shows an overall higher level of metal consumption through peppers. Particularly striking is the intake of Pb, with adults and children consuming 2.59×10^{-3} and 6.12×10^{-3} grams per day, respectively. These figures mirror those found in the study by Lawal *et al.*(2017), underscoring the grave health implications of such exposure. Additionally, the intake of Cd is alarmingly high, especially in children, who are reported to consume 2.20×10^{-3} grams per day. Comparatively, the consumption of peppers leads to a greater intake of harmful metals than Cabbage, with a consistent pattern of children facing a higher risk of metal toxicity. This repeated pattern of increased exposure in children across both tables highlights a deeply concerning vulnerability, necessitating urgent attention to mitigate potential health risks associated with the consumption of these contaminated vegetables (Yaradua *et al.*, 2019).

Table 5: Estimated Metal Daily Intake in Adults and Children from Consumption of Pepper Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	9.28×10^{-5}	2.17×10^{-4}
Cr	1.16×10^{-3}	2.89×10^{-3}
Co	4.02×10^{-4}	9.53×10^{-4}
Fe	9.92×10^{-4}	2.47×10^{-3}
Mn	3.89×10^{-4}	9.21×10^{-4}
Ni	1.43×10^{-4}	3.39×10^{-4}
Pb	2.59×10^{-3}	6.12×10^{-3}
Cd	9.31×10^{-5}	2.20×10^{-3}

Estimated Daily Intake of Heavy Metals from Consumption of Tomatoes

Table 6 provides estimated daily intake levels of various heavy metals for adults and children, resulting from the consumption of tomatoes irrigated with water from mining-induced holes in Toro Local Government, Bauchi State. The metals listed include Cu, Cr, Co, Fe, Mn, Ni, Pb, and Cd. The intake levels are presented in scientific notation, with values for adults generally lower than those for children across all metals, as it was previously reported by Yar'adua *et al.* (2019). The daily intake level for Cu is 1.48×10^{-3} for adults and 3.69×10^{-4} for children, indicating that children have a higher exposure risk to these metals through the consumption of such tomatoes. This pattern is consistent across all metals listed, with children's intake levels notably higher, such as Pb at 2.14×10^{-3} for adults and 5.34×10^{-3} for children, and Fe at 1.99×10^{-3} for adults and 4.96×10^{-3} for children as the work of Orish *et al.*, (2017) have shown. The elevated intake levels of heavy metals, particularly in children, pose a significant health risk due to their potential to cause various adverse health effects, including neurodevelopmental disorders, kidney damage, and increased risk of cancer (UNEP, 2013). The differences in intake levels between adults and children can be attributed to children's lower body weight and higher consumption rates per kilogram of body weight. It is crucial to address the contamination of irrigation water in agricultural practices, especially in areas near mining activities, to prevent the accumulation of heavy metals in food products.

Table 6: Estimated Metal Daily Intake in Adults and Children from Consumption of Tomato Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	1.48×10^{-3}	3.69×10^{-4}
Cr	7.61×10^{-4}	1.89×10^{-3}
Co	1.08×10^{-3}	2.70×10^{-3}
Fe	1.98×10^{-3}	4.95×10^{-3}
Mn	2.48×10^{-4}	6.20×10^{-4}
Ni	8.61×10^{-4}	2.14×10^{-3}
Pb	2.14×10^{-3}	5.33×10^{-3}
Cd	9.15×10^{-5}	2.28×10^{-4}

Target Hazard Quotient (THQ) for Children and Adults for Amaranthus Consumption

Table 7 presents the Target Hazard Quotient (THQ) for both adults and children consuming Amaranthus irrigated with water from mining-induced holes in Toro Local Government Area, Bauchi State. Notably, the THQ values for Co and Pb are significantly higher compared to other metals, particularly for children, indicating a potential health risk. The THQ for Co in children is 5.72×10^{-2}, which is substantially higher than that for adults 2.29×10^{-2}, suggesting that children are at a greater risk of adverse health effects due to their lower body weight and higher intake per body weight, as also reported by Yar'adua *et al.*(2020). Similarly, although the THQ for Pb is higher in adults 2.23×10^{-2} than in children, 5.92×10^{-3}both values underscore a concern, especially since lead is known for its neurotoxic effects on children even at low exposures. The figures for other metals like Cu, Cr, Fe, Mn, Ni, and Cd also present a spectrum of hazard quotients, albeit lower than Co and Pb. The trend indicates a relatively lower but non-negligible risk associated with these metals. The higher values of THQ in children across most metals highlight the increased vulnerability of children to heavy metal exposure through dietary intake (Micheal *et al.*, 2015).

Target Hazard Quotient (THQ) for Children and Adults for Onion Consumption

Table 8, the THQ values for onions reveal a different pattern of risk compared to Amaranthus, with Mn presenting the highest THQ for children 3.19×10^{-2}. This suggests that the consumption of onions might pose a significant risk of manganese exposure to children, potentially affecting their neurological development. Conversely, Co shows a lower THQ in children 1.045×10^{-3}than in adults 3.35×10^{-3}as as reported earlier by Orish *et al.* (2019). Heavy metals like Cu, Cr, and Pb also show varied THQ levels, with Pb exhibiting relatively higher values for both adults and children, pointing to potential health risks. The lower THQ values for Cd and Ni suggest a comparatively lower risk from these metals through onion consumption. However, the consistent presence of multiple heavy metals with significant THQ values across the board emphasizes the cumulative risk of heavy metal exposure from consuming vegetables irrigated with contaminated water, highlighting the importance of clean irrigation sources (Yar'adua *et al.*, 2019).

Table 7: Target Hazard Quotient in Adults and Children from Consumption of Amaranthus Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	1.98×10^{-3}	4.94×10^{-3}
Cr	4.17×10^{-3}	1.04×10^{-2}
Co	2.28×10^{-2}	5.71×10^{-2}
Fe	4.38×10^{-3}	1.16×10^{-2}
Mn	4.98×10^{-3}	1.30×10^{-2}
Ni	7.42×10^{-4}	1.96×10^{-2}
Pb	2.22×10^{-2}	5.91×10^{-3}
Cd	2.25×10^{-4}	5.95×10^{-4}

Table 8: Target Hazard Quotient in Adults and Children from Consumption of Onion Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	2.55×10^{-3}	1.44×10^{-3}
Cr	5.62×10^{-3}	7.61×10^{-3}
Co	3.35×10^{-3}	1.05×10^{-3}
Fe	1.94×10^{-3}	2.36×10^{-3}
Mn	9.07×10^{-3}	3.19×10^{-2}
Ni	2.74×10^{-4}	2.94×10^{-3}
Pb	5.37×10^{-3}	6.48×10^{-3}
Cd	1.35×10^{-4}	3.26×10^{-3}

Target Hazard Quotient (THQ) for Children and Adults for Cabbage Consumption

Table 9 focuses on Cabbage, revealing an exceptionally high THQ for children from Mn exposure 7.98×10^{-2}, significantly surpassing that of adults. This underlines a critical concern for children's health, given Mn's potential neurotoxic effects. Interestingly, Cr shows a higher THQ for children 1.90×10^{-2}than for adults, which, combined with Mn, raises alarms about the neurodevelopmental impact on children consuming Cabbage from contaminated sources, as reported by Yaradua *et al.* (2023). Other metals like Co, Fe, and Pb display relatively low THQ values for adults but are considerably higher for children, reaffirming the heightened risk to children's health from heavy metals. The overall lower THQ values for Cd suggest a lesser immediate concern; however, cumulative exposure to multiple metals can still pose significant health risks. The values here were similar to the ones reported previously by Orish *et al.* (2017).

Table 9: Target Hazard Quotient in Adults and Children from Consumption of Cabbage Grown by Irrigation from Mining-Induced Holes.

Heavy Metals	Adults	Children
Cu	4.44×10^{-3}	3.42×10^{-3}
Cr	8.09×10^{-4}	1.90×10^{-2}
Co	1.18×10^{-4}	5.61×10^{-3}
Fe	2.52×10^{-4}	5.89×10^{-3}
Mn	3.41×10^{-3}	7.98×10^{-2}
Ni	3.14×10^{-4}	1.21×10^{-2}
Pb	3.45×10^{-4}	8.09×10^{-3}
Cd	3.48×10^{-5}	8.15×10^{-4}

Target Hazard Quotient (THQ) for Children and Adults for Pepper Consumption

Table 10 illustrates a concerning pepper THQ value for Ni in children 6.57×10^{-2}, which is exceptionally high compared to adults. This indicates a serious risk of Ni exposure to children, potentially leading to dermatological and respiratory issues. The THQ for Co is also notably higher in children 3.18×10^{-2}than in adults, emphasizing the vulnerability of children to heavy metals through dietary intake, as it was reported by Lawal *et al.* (2017). Cu, Cr, and Pb present lower but significant THQ values, suggesting a risk of exposure to these metals as well. Although the THQ for Mn in adults is high, it is surprisingly low for children in the context of pepper consumption, which may be due to differences in consumption patterns (Lawal *et al.*, 2017; Shibdawa *et al.*, 2019).

Target Hazard Quotient (THQ) for Children and Adults for Onion Consumption

Table 11 provides a details value of Tomato, the table highlights a high risk of Co and Ni exposure, particularly for children, with THQ values of 9.01×10^{-2} and 5.37×10^{-3}, respectively, which is similar to the work of Yaradua *et al.* (2019). These figures are concerning, given the potential for Co and Ni to cause cardiovascular and respiratory issues. The THQ for Cu is also notably high for adults, suggesting a risk of copper toxicity, which can affect liver and kidney function. While the THQ values for other metals, like Cr, Fe, and Pb, are lower, they still represent a potential risk, particularly when considering cumulative exposure from multiple dietary sources. The relatively lower THQ for Cd does not eliminate concern due to Cd's known adverse effects on kidney function and bone density over long-term exposure (Orish *et al.*, 2017). This table underscores the critical need for interventions to reduce heavy metal contamination in irrigation water, thereby protecting public health, especially that of children who are more susceptible to heavy metal toxicity (Shibdawa *et al.*, 2019).

Table 10: Target Hazard Quotient in Adults and Children from Consumption of Pepper Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	2.32×10^{-3}	5.45×10^{-3}
Cr	3.87×10^{-3}	9.65×10^{-3}
Co	1.41×10^{-2}	3.18×10^{-2}
Fe	1.41×10^{-3}	3.53×10^{-3}
Mn	2.77×10^{-2}	8.46×10^{-4}
Ni	3.58×10^{-4}	6.57×10^{-2}
Pb	4.31×10^{-3}	1.02×10^{-2}
Cd	3.10×10^{-4}	7.33×10^{-4}

Table 11: Target Hazard Quotient in Adults and Children from Consumption of Tomato Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adults	Children
Cu	3.69×10^{-2}	9.22×10^{-3}
Cr	2.53×10^{-3}	6.31×10^{-3}
Co	3.61×10^{-2}	9.01×10^{-2}
Fe	2.83×10^{-2}	7.08×10^{-3}
Mn	1.77×10^{-2}	4.42×10^{-2}
Ni	2.15×10^{-2}	5.37×10^{-3}
Pb	3.57×10^{-2}	8.8×10^{-3}
Cd	3.10×10^{-4}	7.60×10^{-4}

Health Index Values for Both Adults and Children for Vegetable Consumption

Table 12 illustrates the health index values for both adults and children resulting from the consumption of vegetables irrigated with water from mining-induced holes in the Toro Local Government area of Bauchi State. The vegetables analyzed include Amaranthus, Onion, Cabbage, Pepper, and Tomato. For adults, the health index scores range from 9.72×10^{-3}

(Cabbage) to 1.45×10^{-1}(Tomato), indicating a higher potential health risk associated with tomato consumption. In contrast, for children, the index spans from 1.06×10^{-2} (Amaranthus) to 2.47×10^{-1}(Tomato), similarly highlighting tomatoes as the vegetable with the greatest potential health impact. The data suggests a differential vulnerability between adults and children to the contaminants present in these vegetables, with children showing a consistently higher health index, thus a higher risk, across all vegetable types tested. Similar observations were reported by Micheal *et al.* (2015), Orish *et al*. (2019) and Yar'adua *et al.* (2023).

Table 12: Health Index of Adults and Children from Consumption of Amaranthus, Onion, Cabbage, Pepper and Tomato Grown by Irrigation from Mining-Induced Holes

Vegetables	Adult	Children
Amaranthus	**6.16×10^{-2}**	**1.06×10^{-2}**
Onion	**2.83×10^{-2}**	**5.41×10^{-2}**
Cabbage	**9.72×10^{-3}**	**1.34×10^{-1}**
Pepper	**5.49×10^{-2}**	**1.29×10^{-1}**
Tomato	**1.45×10^{-1}**	**2.47×10^{-1}**

Incremental Lifetime Cancer Risk (ILCR) for Adults and Children Exposed to Heavy Metals through the Consumption of Amaranthus

Table 13 details the Incremental Lifetime Cancer Risk (ILCR) for adults and children exposed to heavy metals through the consumption of Amaranthus irrigated with water from mining-induced holes in Toro Local Government, Bauchi State. The data for Amaranthus highlight a significant concern for both adults and children with respect to the incremental lifetime cancer risk (ILCR) due to heavy metal exposure through consumption. Notably, the risk values for Cd and Cr are higher than for Pb and Ni with children showing considerably higher risk levels across all metals compared to adults. The values for Cr (6.27×10^{-4} in adults and 1.56×10^{-3} in children) and Cd (2.57×10^{-3} in adults and 6.79×10^{-3} in children) as also reported by Yaradua *et al.*, (2023), which are alarming, indicating a potential for significant health impacts over a lifetime of exposure. This suggests that the consumption of Amaranthus irrigated with water from mining-induced holes poses a non-negligible cancer risk, especially for the more vulnerable child population (Micheal *et al.*, 2015).

Incremental Lifetime Cancer Risk (ILCR) for Adults and Children Exposed to Heavy Metals Through the Consumption of Onions

Table 14 outlines the Incremental Lifetime Cancer Risk (ILCR) from consuming onions irrigated with water from mining-induced holes in Toro Local Government, Bauchi State, for both adults and children. In the case of onions, the ILCR values again reveal a worrying trend of elevated cancer risks for both adults and children, with children generally at higher risk. The risk from Ni exposure is notably high, especially for children (2.00×10^{-3}), which is significantly greater than that for adults (1.87×10^{-4}). This is followed by Cr, with children again at a higher risk (1.14×10^{-3}) compared to adults (8.44×10^{-4}). Pb and Cd also present considerable risks, though they are lower in comparison (Orish *et al.*, 2017). The elevated risks across these metals underscore the health hazards associated with consuming onions grown in contaminated conditions. Yar'adua *et al.* (2019) also reported something similar to this one, with his values slightly lower than this one.

Table 13: Incremental Life Time Cancer Risk in Adults and Children from Consumption of Amaranthus Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adult	Children
Pb	**1.14×10^{-5}**	**3.01×10^{-5}**
Cd	**2.57×10^{-5}**	**6.78×10^{-5}**
Ni	**5.04×10^{-4}**	**1.33×10^{-4}**
Cr	**6.27×10^{-4}**	**1.56×10^{-3}**

Table 14: Incremental Life Time Cancer Risk in Adults and Children from Consumption of Onion Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adult	Children
Pb	**1.36×10^{-5}**	**1.65×10^{-5}**
Cd	**3.09×10^{-5}**	**3.71×10^{-5}**
Ni	**1.86×10^{-4}**	**2.00×10^{-3}**
Cr	**8.44×10^{-4}**	**1.14×10^{-3}**

Incremental Lifetime Cancer Risk (ILCR) for Adults and Children Exposed to Heavy Metals through the Consumption of Cabbage

Table 15 presents the ILCR for consuming Cabbage irrigated with mining-induced water in Toro Local Government, Bauchi State. Cabbage consumption presents a varied ILCR profile, with

Nishowing an exceptionally high risk for children (8.26×10^{-3}) compared to adults (2.13×10^{-3}). This stark difference points to a significant health concern for children. Cr also presents a higher risk for children (2.85×10^{-3}) than adults (1.21×10^{-4}), further emphasizing the heightened vulnerability of the younger population to these contaminants. The relatively lower risks for Pb and Cd do not diminish the overall concern regarding the safety of consuming Cabbage irrigated with potentially contaminated water (Yar'adua *et al*., 2023).

Table 15: Incremental Life Time Cancer Risk in Adults and Children from Consumption of Cabbage Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adult	Children
Pb	1.76×10^{-6}	4.13×10^{-5}
Cd	3.97×10^{-6}	9.29×10^{-5}
Ni	2.13×10^{-4}	8.26×10^{-3}
Cr	1.21×10^{-4}	2.85×10^{-3}

Incremental Lifetime Cancer Risk (ILCR) for Adults and Children Exposed to Heavy Metals through the Consumption of Pepper

Table 16 details the ILCR from pepper consumption, irrigated similarly in Toro Local Government, Bauchi State. For peppers, the data indicate considerable ILCR values for both adults and children, with children again facing higher risks. The risk levels for Ni and Cr are particularly concerning, with children's risk for Ni (5.76×10^{-4}) and Cr (1.45×10^{-3}) exceeding that of adults. Pb and Cd also contribute to the overall cancer risk, though to a lesser extent. The values in our study were slightly lower than those reported by Lawal *et al*. (2017). This suggests that peppers grown under these conditions may pose a significant health risk over a lifetime, with an urgent need to address the exposure, especially in children (Yar'adua *et al*., 2019).

Table 16: Incremental Life Time Cancer Risk in Adult and Children from Consumption of Pepper Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adult	Children
Pb	2.20×10^{-5}	5.20×10^{-5}
Cd	3.53×10^{-5}	8.36×10^{-4}
Ni	2.43×10^{-4}	5.75×10^{-4}
Cr	5.79×10^{-4}	1.45×10^{-5}

Incremental Lifetime Cancer Risk (ILCR) for Adults and Children Exposed to Heavy Metals through the Consumption of Tomato

Table 17 illustrates the ILCR for tomato consumption, also using water from mining-induced holes in Toro Local Government, Bauchi State. Tomatoes show a distressing pattern of ILCR, with Ni presenting an exceedingly high risk for both adults (1.47×10^{-3}) and children (3.65×10^{-3}), indicating a grave health concern. Cr and Cd also pose significant risks, with children once again at a higher risk than adults. The ILCR values for Pb further contribute to the concern, highlighting the dangers associated with consuming tomatoes irrigated with water from mining-induced holes. The data underscores the critical need for intervention to mitigate these risks, particularly for the more susceptible child demographic (Orish *et al*., 2017).

Table 17: Incremental Life Time Cancer Risk in Adults and Children from Consumption of Tomato Grown by Irrigation from Mining-Induced Holes

Heavy Metals	Adult	Children
Pb	1.82×10^{-5}	4.53×10^{-5}
Cd	3.48×10^{-5}	8.67×10^{-5}
Ni	1.46×10^{-3}	3.65×10^{-3}
Cr	3.79×10^{-4}	9.48×10^{-4}

Cumulative Life Time Cancer Risk of Adults and Children from Consumption of Vegetables

Table 18 details the aggregate lifetime cancer risks linked to the intake of five distinct vegetables, Amaranthus, Onion, Cabbage, Pepper, and Tomato, cultivated in regions within Toro Local Government of Bauchi State utilizing irrigation water from mining-induced sources. These risks are calculated separately for adults and children, recognizing the varied effects on these demographic categories. For every vegetable listed, the figures represent the probability of cancer development over a lifetime attributed to the consumption of these vegetables. The risk for adults consuming Amaranthus is recorded at 1.21×10^{-3}, with children facing a higher risk at 1.77×10^{-3}, indicating a heightened risk for the younger group. The risk from consuming Onion for adults is at 1.08×10^{-3} but significantly escalates for children to 3.21×10^{-3}, emphasizing a distinctly increased susceptibility in children. Cabbage consumption reveals an especially high risk for children (1.12×10^{-2}) compared to adults (3.41×10^{-4}), signifying an alarmingly elevated risk for children from Cabbage. Pepper consumption poses a risk of 8.80×10^{-4} for adults and 2.91×10^{-3} for children, further highlighting an increased risk for the latter. Tomato consumption is associated with the highest cumulative lifetime cancer risk for both adults and children at 1.89808×10^{-3} and 4.73×10^{-3}, respectively, marking it as the vegetable with the greatest cumulative lifetime cancer risk among the studied groups in this analysis. Similar findings with slight variations in risk values were reported by Yar'adua *et al.* (2023), Yar'adua *et al.* (2019), and Lawal *et al.* (2017).

Table 18: Cumulative Life Time Cancer Risk of Adults and Children from Consumption of Amaranthus, Onion, Cabbage, Pepper and Tomato Grown by Irrigation from Mining-Induced Holes

Vegetables	Adult	Children
Amaranthus	1.21×10^{-3}	1.77×10^{-3}
Onion	1.08×10^{-3}	3.21×10^{-3}
Cabbage	3.41×10^{-4}	1.12×10^{-2}
Pepper	8.81×10^{-4}	2.91×10^{-3}
Tomato	1.91×10^{-3}	4.73×10^{-3}

CONCLUSION

The study found that while the mean concentrations of heavy metals in vegetable samples are generally within safe limits, those of Pb exceed the Maximum Allowable Concentrations (MAC). The Target Hazard Quotient (THQ) and Hazard Index (HRI) values indicate that the non-carcinogenic health risks for both adults and children are low. Additionally, the Incremental Lifetime Cancer Risk (ILCR) values for carcinogenic heavy metals are within safe levels but could become concerning with lifetime exposure. These findings underscore the importance of continuous monitoring, improved agricultural practices, and public health advisories to mitigate potential long-term risks associated with heavy metal exposure from vegetable consumption.

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