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Heavy Metal Contamination Risks in Environmental and Vegetable Samples around a Metal Workshop in Kofar Marusa, Katsina Metropolis

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Abstract

Heavy metal contamination from Metal workshop activities poses health risks by accumulating in crops and entering the food chain. This study quantified heavy metal concentrations and health risks in commonly consumed vegetables irrigated near a metal workshop in Kofar Marusa, Katsina Metropolis. Samples from the cultivation areas of Cabbage, lettuce, tomatoes, spinach, and cress were analyzed. After acid digestion, the amounts of heavy metals were measured by Atomic Absorption Spectrometry. Copper (0.123 mg/kg), manganese (0.431 mg/kg), and nickel (0.539 mg/kg) were greatest in spinach. Manganese (0.374 mg/kg) and cobalt (1.474 mg/kg) levels were higher in cress. Lettuce had the highest iron concentration (6.028 mg/kg) and the lowest metal levels. Lead (11.68 mg/kg) and chromium (2.276 mg/kg) were both high in Cabbage, and nickel (0.526 mg/kg) and lead (4.24 mg/kg) were noteworthy in tomatoes. Among th e Health Risk Index (HRI) calculated, cress reached 17.967 for adults. Children's exposure to heavy metals for Cobalt (Co) and Lead (Pb) through cabbage consumption showed the Target Hazard Quotient (THQ) values for Co (0.089) and Pb (0.036), significantly higher than those for adults. The Cumulative Lifetime Cancer Risks showed that Cress posed the highest risk for both adults and children, followed by spinach. The study revealed significant variations in heavy metal concentrations taken up among different types of vegetables, portraying potential health risks associated with its consumption. It also suggested that the consumption of vegetables cultivated through irrigation near the metal artisanal site may contribute to the bioaccumulation of heavy metals burden among the population. The study brought to light the wide range of heavy metal uptake in vegetables as well as the possible health hazards associated with eating produce grown close to the metal workshop.

Keywords: Heavy Metals, Vegetable Contamination, Health Risks, Atomic Absorption Spectrometry, Katsina

INTRODUCTION

Because of their enduring presence and detrimental effects even at low concentrations, heavy metals represent serious risks to human health as well as the environment (Ali *et al.*, 2019: Wojtkowska et al., 2022). Various anthropogenic and natural activities are blamed for the rising concentrations of environmental heavy metals (Khan & Hosna, 2021). This is an issue that is especially severe in third-world nations with lax environmental regulations and monitoring (Chowdhury *et al.*, 2016). The origins, distribution, and possible risks of heavy metals in sediment, soil, water, and agricultural products have all been studied in fast-developing areas (Junianto *et al.*, 2017; Mortuza & Al-Musnad, 2017; Mahfuza *et al.*, 2017). When ingested in excess through food, heavy metals pose serious health hazards since they are persistent environmental pollutants with lengthy biological half-lives and the ability to bio-accumulate in biological chains (Haware & Pramod, 2011). According to Bempah *et al.* (2011), industrial pollutants, fertilizers, metal-based insecticides, tainted irrigation water, and procedures including harvesting, transportation, storage, and sale are all potential sources of heavy metal toxicity. These metals mostly impact the brain and kidneys, but they can also cause hypertension from lead exposure, carcinogenic consequences from arsenic, and renal toxicity from cadmium exposure (Gottipolu et al., 2012). Studies have shown that agricultural lands in Katsina State, Nigeria, are experiencing heavy metal accumulation from pollution sources such as agricultural practices, mining, and vehicular emissions (Yaradua et al., 2020; Yaradua et al., 2022).

Water is vital to agriculture, industry, and human survival, and it is also important for sustainable development. However, fast urbanization, population expansion, and financial restrictions frequently drive people in developing countries to rely on low-quality water supplies, which has detrimental effects on sustainability and public health. Many people in both urban and rural areas lack access to safe water due to a shortage of clean water and contamination of freshwater supplies (Yaradua et al., 2022). Urbanization and industrialization lead to pollution, which makes this problem worse. Heavy metals are a major source of pollution (Karavoltsos, 2008; Reza &Gurdeep, 2009). To lessen the negative impacts of heavy metals on the environment and human health, levels must be continuously monitored (Ganeshamurthy, 2008).

In Kofar Marusa, Katsina Metropolis, artisanal pursuits like metalworking make a substantial contribution to the local economy and cultural legacy. However, through procedures like smelting and welding, these activities frequently release heavy metals and other pollutants into the environment, raising worries about the effects on the environment and public health (Rangel et al., 2017). The expansion of this industry emphasizes the necessity of critically analyzing its effects on the environment to make sure that financial gains don't come at the expense of ecosystem and community health.

The relationship between artisanal metalworking and environmental and public health issues has become increasingly important in recent years, necessitating thorough scientific research (Yar'adua et al., 2020). The community's health may be at risk if traditional metalworking methods unintentionally contribute to environmental deterioration while Kofar Marusa adapts to economic and sociological shifts. Due to its central Katsina Metropolis position, Kofar Marusa serves as a dynamic hub for the fusion of traditional customs with urban development.

The artisanal metal crafting activities in Kofar Marusa have the potential to harm soil, water sources, and the food supply chain in addition to the immediate vicinity. This means that in order to fully comprehend the complex relationships that exist between traditional handcraft, urbanization, and environmental sustainability, a thorough examination of heavy metal contamination from these activities is required. The significance of these research lies in their ability to pinpoint the precise health and environmental risks associated with heavy metals introduced through artisanal methods (Rangel et al., 2017).

Furthermore, this study's relevance goes beyond the local setting and resonates with international conversations about environmental protection, traditional customs, and sustainable development. Understandings from Kofar Marusa can offer insightful viewpoints to more general discussions on balancing cultural preservation, economic activity, and ecological responsibility in academia, legislation, and the community. This study intends to close knowledge gaps, support evidence-based decision-making, and advance sustainable development practices in Kofar Marusa, Katsina Metropolis, Katsina State, by examining the complex relationship between artisanal metalworking and environmental health.

MATERIALS AND METHOD

Study Area

The research was conducted in 2023 in Katsina State, Nigeria, situated within the North West Zone of Nigeria at latitude 12°15'N and longitude 70°30'E, covering an area of 24,192 km2 (9,341 square meters). Katsina State experiences two distinct seasons, namely rainy and dry. The rainy season spans from April to October, while the dry season lasts from November to March. This study specifically took place during the dry season. Katsina State has an average annual rainfall, temperature, and relative humidity of 1,312 mm, 27.3℃, and 50.2%, respectively (Yaradua et al., 2019). Similar to the majority of alluvial soils, the soil in Katsina state is of the floodplain type and exhibits notable variations. The soil can be broadly categorized into two main types, distinguishing between soils with minimal hazards and soils possessing excellent water retention capacity (Yaradua et al., 2019). Notably, the research was conducted in Kofar Marusa within Katsina Metropolis.

Vegetable Sampling

Sampling for this research involved dividing the plots designated for vegetable cultivation into twenty sampling areas. From each of these areas, samples were gathered and combined to create a bulk sample, from which a representative subset was extracted. Each of these samples (Cabbage, Lettuce, Tomatoes, Spinach, and Cress) received unique codes and were stored in glass bottles with secure lids to protect them from moisture and contamination. Subsequently, they were placed in a refrigerator at 4°C until ready for use.

Sample Identification

The samples (vegetables) were labeled and categorized within the herbarium of the Department of Biology at Umaru Musa Yar'adua University in Katsina, Nigeria.

Vegetable Sample Preparation

The samples underwent thorough washing with tap water to eliminate dust particles, soil, unicellular algae, etc. The edible portions were additionally washed with distilled water and, finally, with deionized water. After washing, the vegetables were dried using blotting paper and filter paper at room temperature to eliminate surface water. Subsequently, the vegetables were promptly placed in desiccators to prevent further moisture evaporation. Following this, each of the vegetables was finely chopped and subjected to oven drying separately at (55±1) °C for a specified duration using a Gallenkamp hotbox oven (CHF097XX2.5). The dried vegetables were then processed in an electric blender, resulting in a powder stored in airtight polythene packets (with each sample maintaining its unique code) at room temperature before the digestion and analysis of metals.

Digestion of Vegetable Sample

The plant samples underwent digestion following the method outlined by Yaradua *et al.* (2023). In this process, 0.5 g of the powdered sample was measured and placed in a 100 mL beaker, to which 5 mL of concentrated HNO_3 and 2 mL of $HClO_4$ were introduced. The mixture was heated on a hot plate at 95°C until achieving a clear solution. Subsequently, it was filtered into a 100 mL volumetric flask and brought to the mark with distilled water.

Assessment of Health Risks from Heavy Metals

Evaluation of Daily Metal Intake Calculation

The method for calculating the daily metal intake (DMI) from the studied samples involves the formula:

DMI = Cmetal x Cf x 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 noncarcinogenic risks from heavy metals through vegetable consumption by the local population, the Target Hazard Quotient (THQ) is calculated as follows:

THQ = RfD x 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 noncarcinogenic risk from multiple heavy metals is assessed using the Chronic Hazard Index (HI), calculated as:

HI = THQ1 + THQ2 + … + 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 x 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= (EDI x EFr x EDtot) / AT… eqn. (5) (Yang *et al.*, 2018)

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

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

ΣILCR = ILCR1 + ILCR2 + … + ILCRn… eqn. (6) (Javed and Usmani, 2016)

Each ILCR value corresponds to a different carcinogenic heavy metal.

RESULTS

The current study (Table 1) showed the analysis of heavy metal concentrations in vegetables cultivated near the Kofar Marusa metal artisanal site, revealed significant disparities in metal uptake among different types of vegetables, with specific attention to spinach, lettuce, and tomato. Spinach showed higher concentrations of Cu (0.123 mg/kg), Mn (0.431 mg/kg), Ni (0.539 mg/kg), and Co (1.692 mg/kg) compared to lettuce and tomato, which exhibit lower levels of these metals, lettuce's Cu (0.030 mg/kg) and tomato's Mn (0.210 mg/kg). These differences hint at the inherent biological factors, including root system diversity and leaf surface area, which might influence the capacity of these vegetables to absorb and accumulate heavy metals from their environment. Moreover, the results point to an alarming level of Pb in Cabbage (11.68 mg/kg) and a significant variation in Cr concentration across the vegetables, with cabbage (2.276 mg/kg) and spinach (1.969 mg/kg) on the higher end. These findings suggested that soil conditions, particularly pH, organic matter content, and metal bioavailability, play an important role in the differential uptake of heavy metals by these plants.

Table 2 presents data on the estimated daily intake (EDI), target hazard quotient (THQ), and health risk index (HRI) for adults and children consuming Cabbage cultivated around a local metal artisanal site in Kofar Marusa, Katsina Metropolis. For adults, the EDI values for Cu, Mn, Ni, Co, Fe, Cr, Cd, and Pb are 0.000048, 0.000167, 0.000003, 0.001066, 0.000256, 0.001667, 0.000135, and 0.008555 mg/kg/day, respectively. The THQ values for these metals in adults are relatively low, ranging from 0.00023 for Ni to 0.03554 for Co. The overall HRI for adults is 0.693, indicating that the combined risk from all these metals is below the threshold of concern (HRI < 1). For children, the EDI values for Cu, Mn, Ni, Co, Fe, Cr, Cd, and Pb are 0.000012, 0.000042, 0.000267, 0.002666, 0.002108, 0.004167, 0.000103, and 0.002139 mg/kg/day, respectively. The THQ values for children show higher potential risks compared to adults, particularly for Co and Ni, with values of 0.08887 and 0.01910, respectively. The HRI for children is 0.164, which is within the safe limit, suggesting that children consuming Cabbage from this area are at significant health risk due to metal long-term exposure (UNEP, 2013). The Table 3 shows that children have significantly higher Estimated Daily Intakes (EDIs) and Target Hazard Quotients (THQs) for all metals tested; the EDI and THQ for Copper (Cu) are notably higher in children than in adults. Generally, children's health risk score (0.109) is much greater than that of adults (0.0437), indicating they are more vulnerable to potential health issues from metal exposure.

Comparable data for tomatoes grown in the same region are shown in Table 4. Children have larger THQs and EDIs for all metals, just like they do for lettuce. Adults have an EDI of 0.0000029296 mg/kg/day with a THQ of 0.00007317 for copper (Cu), but children's is 0.0000073241 mg/kg/day with a THQ of 0.0001831. Children's HRI (0.132) is likewise higher than adults' (0.0692), confirming that children are more vulnerable to health hazards associated with metal exposure from tomato eating. The metal intake and related dangers of consuming cress are listed in Table 5. Once more, compared to adults, children have higher EDIs and THQs, which indicate greater health concerns. Adults have an EDI of 0.0000432125 mg/kg/day with a THQ of 0.00108031, while children's is 0.000108031 mg/kg/day with a THQ of 0.00270078. Indicating that children are far more vulnerable to metal contamination in cress, the HRI for children (0.191) is noticeably greater than the HRI for adults (0.0765). The current study Table 6 showed target hazard quotient (THQ), health risk index (HRI), and estimated daily intake (EDI) for adults and children who eat spinach cultivated close to a local metal manufacturing site are displayed in Table 6. Compared to adults, children have greater EDIs and THQs for all heavy metals, indicating a higher possible danger to their health. Copper (Cu) EDI, for instance, is 0.000225218 mg/kg/day with a THQ of 0.00563452 in children and 0.0000900872 mg/kg/day with a THQ of 0.00222521 in adults. With an overall HRI of 0.206 for kids and 0.0827 for adults, kids are more likely to be exposed to metals through spinach eating.

The incremental lifetime cancer risk (ILTCR) associated with eating Cabbage grown near a nearby metal contamination site is shown in Table 7. For every metal, children have greater ILTCR values than adults do. For example, the risk of Chromium (Cr) in adults is 0.00083349.9, while in children it is 0.00208373. For adults, the risk of lead (Pb) is 0.0000727143, whereas for children, it is 0.000181786. This demonstrated that these heavy metals in Cabbage put children at an increased risk of cancer. The ILTCR of eating lettuce grown close to a nearby metal artisanal site is shown in Table 8. The results showed that compared to adults, children are more likely to get cancer as a result of these metals. The ILTCR for Cr is 0.000028198 for adults and 0.000070495 for children. With values of 0.000009798 for children and 0.0000035485 for adults, Pb exhibits a decreased danger. The risk differential for Ni is large; it is 0.00078753 for children and 0.00031501 for adults.

Moreover, children are more at risk from Cd (0.00013707) than adults are (0.000054858), which is alarming, indicating a potential for significant health impacts over a lifetime of exposure. The ILTCR resulting from consuming spinach is shown in Table 9. It's interesting to note that some dangers are different for adults and youngsters. For instance, the ILTCR for Ni in adults is 0.00067111, whereas in children it is 0.00078753. In contrast, children have a higher risk of Cd (0.00013707) than adults (0.00005956). Ni and Cd also present considerable risks. The ILTCR from eating tomatoes cultivated close to a nearby metal fabrication site is displayed in Table 10. For all metals, children have a greater risk of cancer than adults. In children, the risk for chromium (Cr) is 0.0006784, while in adults, it is 0.00027136. In a similar vein, Nickel (Ni) exhibits a considerable risk difference, with adult values of 0.000654926 and kid values of 0.00163731. The ILTCR associated with eating cress cultivated close to a nearby metal production site is displayed in Table 11. For every heavy metal that has been measured, children continuously face larger hazards than adults. The ILTCR for Cr is 0.000407589 for adults and 0.00101897 for children. The risk of Pb in youngsters is 0.000126689, whereas the risk in adults is 0.0000506759. Cd has the highest risk for both adults and children, with values of 0.00481490 for adults and 0.000120372 for children.

The cumulative lifetime cancer risks (CLTCR) associated with eating Cabbage, lettuce, spinach, tomatoes, and cress that are cultivated close to a local manufacturing mining site are shown in Table 12 for both adults and children. For both age groups, the largest individual cancer risks are seen in spinach and cress. The CLTCR is higher for youngsters (0.0114) than it is for adults (0.00917). This suggests that children are more likely to develop cancer over a long period of consumption as a result of the metal poisoning in these veggies.

Table 1: Heavy Metal Concentration (mg/kg) In Vegetable Samples Cultivated Around Local Metal Artisanal Site in Kofar Marusa, Katsina Metropolis

Heavy metals	Lettuce	Cress	Cabbage	Spinach	Tomato
Cu	0.030±0.0002	0.059±0.0004	0.066±0.0002	0.123±0.0003	0.004±0.0000
Mn	0.272±0.0005	0.374±0.0006	0.228±0.0005	0.431±0.0002	0.210±0.0006
Ni	0.253±0.0009	0.043±0.0005	0.043±0.0005	0.539±0.0017	0.526±0.0005
Co	0.859±0.0003	1.474±0.0009	1.456±0.0009	1.692±0.0005	1.330±0.0012
Fe	6.028±0.0006	6.591±0.0005	1.151±0.0005	3.677±0.0017	1.168±0.0007
Cr	0.077±0.0011	1.113±0.0016	2.276±0.0004	1.969±0.0006	0.741±0.0018
Cd	0.197±0.0002	0.173±0.0009	0.085±0.0007	0.214±0.0001	0.161±0.0002
Pb	0.570±0.0044	8.140±0.0011	11.68±0.0000	5.080±0.0030	4.240±0.0024

Values are expressed as mean ± standard deviation.

Table 2: Daily Metal Intake, Target Hazard Quotient, and Health Risk Index in Adults and Children from Consumption of Cabbage.

Heavy metals	ADULT EDI	THQ	CHILDREN EDI	THQ
Cu	4.83395E-5	1.20848E-3	1.20848E-5	3.02120E-4
Mn	1.66991E-4	1.18707E-2	4.17477E-5	2.98197E-3
Ni	3.24720E-6	2.32194E-4	2.67332E-4	1.90951E-2
Co	1.06639E-3	3.55433E-2	2.66599E-3	8.88665E-2
Fe	2.56001E-4	3.65716E-4	2.10752E-3	3.01073E-3
Cr	1.66698E-3	5.55660E-3	4.16745E-3	1.38915E-2
Cd	1.35497E-4	2.70994E-4	1.02867E-4	2.05735E-4
Pb	8.55462E-3	1.42577E-2	2.13865E-3	3.56442E-2
HRI		6.93091E-1		1.64000E-1

Keys: EDI = Estimated Daily Intake, THQ = Target Hazard Quotient, HRI = Health Risk Index

Table 3: Daily Metal Intake, Target Hazard Quotient and Health Risk Index in Adult and Children from Consumption of Lettuce.

Heavy metals	ADULT EDI	THQ	CHILDREN EDI	THQ
Cu	2.19725E-5	5.49312E-4	5.49312E-5	1.37328E-3
Mn	1.99217E-4	1.42298E-2	4.98043E-4	3.55745E-2
Ni	1.85301E-4	4.63253E-4	4.63253E-4	1.15813E-3
Co	6.29145E-4	2.09715E-2	1.57286E-3	5.24288E-2
Fe	4.41500E-3	6.30715E-3	1.103751E-2	1.57678E-2
Cr	5.63960E-5	1.87986E-4	1.409902E-4	4.69967E-4
Cd	1.44286E-4	2.88572E-4	3.607152E-4	7.81430E-4
Pb	4.17477E-4	6.95795E-4	1.152706E-3	1.92117E-3
HRI		4.37E-2		1.09E-01

Keys: EDI = Estimated Daily Intake, THQ = Target Hazard Quotient, HRI = Health Risk Index

Table 4: Daily Metal Intake, Target Hazard Quotient, and Health Risk Index in Adults and Children from Consumption of Tomato.

Heavy Metals	ADULT EDI	THQ	CHILDREN EDI	THQ
Cu	2.9296E-6	7.3170E-5	7.3241E-6	1.8310E-4
Mn	1.5380E-4	1.0986E-2	3.8451E-4	2.7465E-2
Ni	3.8525E-4	9.6312E-4	9.6312E-4	2.4078E-3
Co	9.7411E-4	3.2470E-2	2.4352E-3	8.1176E-2
Fe	8.5546E-4	1.2220E-3	2.1386E-3	3.0552E-3
Cr	5.4272E-4	1.8090E-2	1.3568E-3	4.5226E-3
Cd	1.1791E-4	2.3583E-4	2.9479E-4	5.8959E-4
Pb	3.1054E-3	5.1757E-3	7.7636E-3	1.2939E-2
HRI		6.92E-02		1.32E-01

Keys: EDI = Estimated Daily Intake, THQ = Target Hazard Quotient, HRI = Health Risk Index

Table 5: Daily Metal Intake, Target Hazard Quotient, and Health Risk Index in Adults and Children from Consumption of Cress.

Heavy Metals	ADULT EDI	THQ	CHILDREN EDI	THQ
Cu	4.32125E-5	1.08031E-3	1.08031E-4	2.70078E-3
Mn	2.73923E-4	1.95659E-2	6.84809E-4	4.89146E-2
Ni	3.14938E-4	7.87345E-5	7.87347E-5	1.96837E-4
Co	1.07958E-3	3.59860E-2	2.69895E-3	8.99651E-2
Fe	4.82735E-3	6.89622E-3	1.20683E-2	1.72470E-2
Cr	8.15179E-4	2.71726E-3	2.03794E-3	6.79316E-3
Cd	1.26708E-4	2.53416E-4	3.16770E-4	6.33540E-4
Pb	5.96187E-3	9.93645E-3	1.49046E-2	2.48411E-2
HRI		7.65E-02		1.91E-01

Keys: EDI = Estimated Daily Intake, THQ = Target Hazard Quotient, HRI = Health Risk Index

Table 6: Daily Metal Intake, Target Hazard Quotient, and Health Risk Index in Adults and Children from Consumption of Spinach

Heavy Metals	ADULT EDI	THQ	CHILDREN EID	THQ
Cu	9.00872E-5	2.22521E-3	2.25218E-4	5.63452E-3
Mn	3.15671E-4	2.22579E-2	7.89178E-4	5.63699E-2
Ni	3.94772E-4	9.86931E-4	9.86931E-4	2.46578E-3
Co	1.23924E-3	4.13083E-2	3.09812E-3	1.03270E-1
Fe	2.69309E-3	3.84728E-3	6.73274E-3	9.61820E-3
Cr	1.44212E-3	4.80709E-3	3.60532E-2	1.20177E-2
Cd	1.56737E-4	1.03347E-3	3.91842E-4	7.83685E-4
Pb	3.72067E-3	6.20112E-3	9.30169E-3	1.55028E-2
HRI		8.270E-2		0.206E-01

Keys: EDI = Estimated Daily Intake, THQ = Target Hazard Quotient, HRI = Health Risk Index

Table 7: Incremental Lifetime Cancer Risk in Adults and Children from Consumption of Cabbage Sample

Heavy Metals	Adult	Children
Cr	8.33490E-4	2.08373E-3
Pb	7.27143E-5	1.81786E-4
Ni	5.51140E-6	4.54464E-4
Cd	5.14888E-5	3.90897E-5

Table 8: Incremental Life Time Cancer Risk in Adults and Children from Consumption of Lettuce.

Heavy Metals	Adults	Children
Cr	2.8198E-5	7.0495E-5
Pb	3.5485E-6	9.7980E-6
Ni	3.1501E-4	7.8753E-4
Cd	5.4858E-5	1.3707E-4

Keys: ILTCR = Incremental Life Time Cancer Risk

Table 9: Incremental Lifetime Cancer Risk in Adults and Children from Consumption of Spinach Sample

Heavy Metals	Adults	Children
Cr	7.2106E-4	7.0495E-5
Pb	3.1507E-5	9.7980E-6
Ni	6.7111E-4	7.8753E-4
Cd	5.9560E-5	1.3707E-4

Keys: ILTCR = Incremental Life Time Cancer Risk

Table 10: Incremental Life Time Cancer Risk in Adults and Children from Consumption of Tomato Sample.

Heavy Metals	Adults	Children
Cr	2.71360E-4	6.78400E-4
Pb	2.63962E-5	6.59907E-5
Ni	6.54926E-4	1.63731E-3
Cd	4.48092E-5	1.12023E-4

Keys: ILTCR: Incremental Life Time Cancer Risk

Table 11: Incremental Life Time Cancer Risk in Adults and Children from Consumption of Cress

Heavy Metals	Adults	Children
Cr	4.07589E-4	1.01897E-3
Pb	5.06759E-5	1.26689E-4
Ni	5.35394E-5	1.33848E-4
Cd	4.81490E-3	1.20372E-4

Key: ILTCR = Incremental Life Time Cancer Risk

Table 12: Cumulative Lifetime Cancer Risks of Adults and Children from Consumption of Cabbage, Lettuce, Spinach, Tomato and Cress

Vegetables	Adult	Children
Cabbage	9.63E-04	2.76E-03
Lettuce	4.02E-04	1.00E-03
Spinach	1.48E-03	3.71E-03
Tomato	9.97E-04	2.49E-03
Cress	5.33E-03	1.40E-03
CLTCR	9.17E-03	1.14E-02

Key: CLTCR Cumulative Life Time Cancer Risks

DISCUSSION

This study revealed significant disparities in metal uptake among different vegetable types, influenced by both biological and environmental factors. Spinach exhibited higher concentrations of copper, manganese, nickel, and cobalt compared to lettuce and tomato, likely due to its more extensive root system and larger leaf surface area, which enhance its capacity to absorb these metals. Cabbage showed alarmingly high levels of lead, indicating that soil conditions, such as pH and organic matter content, significantly affect metal availability and uptake. Similarly, chromium levels varied, with Cabbage and spinach showing elevated concentrations, reflecting how soil properties influence metal bioavailability. These findings align with some previous research of Yar'adua *et al*. (2019) but diverge in reporting higher lead concentrations than earlier studies, which noted lower nickel levels as per by (Yar'adua *et al.*, 2020). This discrepancy assured the importance of continuous monitoring and updating of contamination levels, as environmental conditions and industrial activities can evolve, impacting heavy metal concentrations in crops and thus influencing potential health risks.

For Cabbage, the EDI values for heavy metals such as copper (Cu), manganese (Mn), nickel (Ni), cobalt (Co), iron (Fe), chromium (Cr), cadmium (Cd), and lead (Pb) in Cabbage were relatively low. The THQ values were modest, with cobalt posing the highest risk. Despite these values, the overall HRI for adults was 0.693, indicating a manageable risk level below the threshold of concern. However, children had higher EDI and THQ values for nickel and cobalt, which pointed to a higher potential risk for this group. The HRI for children was 0.164, suggesting that while the overall risk remains within safe limits, the elevated values for specific metals warrant attention. This contrasts with the findings of Yaradua *et al.* (2019a; 2020), which reported different contamination levels, possibly due to variations in environmental conditions. For lettuce, children exhibited significantly higher EDI and THQ values for metals like copper (Cu), indicating a greater health risk. This increased risk is attributed to their higher relative consumption and less mature metabolic systems, which are less efficient at processing heavy metals. The elevated health risk score for children revealed their vulnerability to long-term health effects from metal accumulation, aligning with findings by Micheal *et al.* (2015), which highlighted similar risks in street foods in Kampala.

The study found that children are at higher risk from metal exposure through tomatoes compared to adults. This is due to their higher EDI and THQ values for metals such as copper, reflecting their greater vulnerability. The increased HRI for children is linked to their higher intake relative to body weight and their developing physiological systems. These results are consistent with research by Yaradua *et al.* (2019) and Lawal *et al.* (2017), emphasizing the need for stringent monitoring of metal contamination in foods, particularly for younger populations. The contamination study for spinach showed that children face higher health risks due to higher EDI and THQ values for all heavy metals compared to adults. This is primarily due to their smaller body size and greater relative consumption of spinach. The overall HRI for children was higher, indicating a greater susceptibility to potential adverse health effects. These findings highlight the increased vulnerability of children to metal contamination, consistent with previous research showing heightened risks for younger individuals due to dietary and physiological factors. The study indicated that cress also posed significant risks, particularly for children. The higher THQ values for metals in cress and the elevated risk levels underscore the need for careful monitoring of cress cultivation areas near metal workshops. The findings align with the pattern observed in other vegetables, where children consistently show higher risk levels due to their higher intake relative to body weight and developmental factors.

The study highlights a concerning disparity in Incremental Lifetime Cancer Risk (ILCR) associated with heavy metal consumption from various vegetables near a metal workshop, notably affecting children more than adults. Vegetables such as spinach and cress demonstrate a pronounced increase in ILCR values for children, indicating a higher cancer risk due to their greater relative intake and smaller body size. This is consistent with the observed trend across other vegetables like tomatoes and lettuce, where children consistently show higher ILCR values. The elevated risks in children are largely driven by their higher consumption rates and increased susceptibility to heavy metal toxicity compared to adults. The varying levels of ILCR across different vegetables suggest that the extent of contamination and resultant health risks are not uniform and are influenced by both the type of vegetable and the specific heavy metals present. These findings underscore the need for targeted risk assessment and mitigation strategies, particularly in areas with known metal contamination, to protect vulnerable populations. The results emphasize the importance of implementing stringent environmental regulations and monitoring to reduce heavy metal exposure, aligning with existing research on the heightened health risks for children (Yaradua *et al.*, 2019; Orish *et al.*, 2017).

The Cumulative Life Time Cancer Risks (CLTCR) for consuming various vegetables highlighted important principles regarding health risks for adults and children. For Cabbage, lettuce, spinach, and tomatoes, children consistently face higher risks compared to adults. This increased risk can be attributed to children's higher relative intake of these vegetables and their smaller body size, which results in greater exposure to potential contaminants per unit of body weight. Additionally, children's bodies may accumulate contaminants more quickly and are more susceptible to their effects due to ongoing development.

Conversely, cress presented a different scenario, with adults experiencing a higher risk compared to children. This discrepancy may be due to different contamination patterns or accumulation rates specific to cress, which could affect adults more than children.

CONCLUSION

According to the study, Pb concentrations in vegetable samples surpass the Maximum Allowable Concentrations (MAC), even though the mean amounts of heavy metals are normally within acceptable levels. Low noncarcinogenic health risks are indicated by the Target Hazard Quotient (THQ) and Hazard Index (HRI) levels for both adults and children. Furthermore, the carcinogenic heavy metals' Incremental lifelong Cancer Risk (ILCR) values are within tolerable ranges, yet lifelong exposure may raise concerns. The aforementioned results highlighted the significance of ongoing surveillance, enhanced farming methods, and public health alerts in reducing the possible long-term hazards linked to heavy metal exposure resulting from vegetable consumption.

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