

Full Length Research Paper

Determination of some selected heavy metals in vegetable samples in relation to health risk assessment from Gubi Dam Agricultural Area, Bauchi State, Nigeria

**Mohammed A. Shettima, Haruna B. Wayar, Zakari Mohammed,
Ayuba M. Jatau and Joseph C. Akan**

Department of Pure and Applied Chemistry, University of Maiduguri, P.M.B 1069, Maiduguri, Borno State, Nigeria.

Received 21 September, 2024; Accepted 21 March, 2025.

The levels of some heavy metals (Cr, Mn, Fe, Cu, Ni, Cd, Hg, As, Pb) were detected using Atomic Absorption Spectroscopy (AAS). Vegetable samples of tomatoes (*Solanum lycopersicum*), spinach (*Spinacia oleracea*), roselle (*Hibiscus sabdariffa*), onion (*Allium cepa*) and cucumber (*Cucumis sativus*) from five different agricultural locations (S₁ – S₅) around Gubi Dam, Bauchi State. The concentration of the selected heavy metals exceeded the maximum permissible limits as specified by FAO/WHO with exception the of Hg and As. Result on the average daily intake (ADI) were below the provisional tolerance daily intake for (Cr 0.5-0.2, Mn 20, Fe 0.048, Cu 3, Ni 1.4, Cd 0.0003, Hg 0.06, As 0.13 and Pb 0.214) mg/kg, in all the vegetable samples while the values of hazard quotient (HQ) were also lower than the threshold of 1 mg/kgd⁻¹. However, Cr concentration in spinach samples from point S₁ agricultural location recorded the highest value of 1.19E + 00 mg/kgd⁻¹ than the threshold of 1 mg/kgd⁻¹. Results from the hazard index (HI) shows that consumption of the vegetables from the study area might result to potential health risks with respect to Cd and Pb. The cancer risk (CR) assessment shows the probability of developing cancer-related illness with respect to the Cd, Ni and Cr. Based on the above results, the study concludes that the agricultural locations within Gubi Dam are exposed to potentially toxic heavy metals; thus, relevant agencies should be involved in monitoring the study environment.

Key words: Risk assessment, vegetables, heavy metals contamination, Gubi Dam, Nigeria.

INTRODUCTION

Vegetables are very important aspects in human life. Consumptions of crops cultivated on contaminated soil can indirectly affect human health. Heavy metals are elements with relatively high density and are poisonous even at low concentrations. On the other hand, they are regarded as essential minerals that are very important for

plant physiological functions (Zakari et al., 2022). However, the accumulation in higher concentrations than required can lead to serious health implications such as transferred from soil to plants and into food chain (Shittu et al., 2024).

The presence of heavy metals in the soil is a serious

*Corresponding author. E-mail: mashettima23@unimaid.edu.ng; Tel: +2348062822785, +2348021011886.

concern due to their absorption by plants which could expose human and animal consumers to a greater risk (Akan et al., 2021). Higher concentration of heavy metal is capable of causing harm to plants, animals and human. They are also regarded as important factor in soil quality degradation and reduction of the capacity of the soil to grow healthy plants (Mansur and Jazuli, 2007; Akan et al., 2021). Soil can be polluted from the accumulation of heavy metals through application of fertilizers, bio-solids (sewage sludge), animal manures, compost and pesticides (Uwumarongie-Ilori et al., 2012). Heavy metals exist in numerous forms in the soil but the forms that are available to plants are of greatest concern which includes the exchangeable, oxides and hydroxides, carbonate, and organic matter bonded metals (Calace et al., 2002; Akan et al., 2021). Due to the persistent nature and non-biodegradability of heavy metals, they continue to exist for several periods even when the source of pollutions ceases to exist or mitigated (Hu et al., 2021; Chen et al., 2024). The transfer of heavy metals especially into the human food chain through leafy vegetables and other pathways poses a significant threat to human health, affecting the normal functioning of human organs and potentially leading to other ailments (Järup, 2003; Zakari et al., 2022; Qi et al., 2023).

The health risks assessment was primarily aim to assess the carcinogenicity and non-carcinogenicity profile of heavy metals in a particular location through consumption of contaminated vegetables by the population. Non carcinogenic risk can be assessed based on hazard quotient (HQ) which is the ratio of calculated average daily intake (ADI) and established reference dose level (RfD) of each metal (USEPA, 2011). If $HQ > 1$, this has detrimental health effect on consumers (Wang et al., 2005). Higher HQ values of Cd, Cr, As, and Pb was reported by Liang et al. (2017). According to Wuana et al. (2016) and Lei et al. (2010), USEPA classified and considered heavy metals such as Cr, As, Pb, Cu and Cd as the most toxic metals. Hence bioaccumulation such metals in vegetables can lead to carcinogenic health related issues.

Vegetables can be contaminated by heavy metals if cultivated on polluted soil or are irrigated with polluted water. Due to the higher content of vitamin and minerals as well as antioxidant properties, vegetables are regarded as an important component of the human diet. Vegetable consumption is increasingly popular due to the extensive body of existing knowledge of their nutritional value, and one of the most common aspects of food quality is the trace amount of metal contamination (Sharma et al., 2009).

Gubi Dam is one of the numerous water reservoirs in the country, which hold runoff and release it during period of low runoff. The specific functions of the reservoir include serving as water body for fish production, source of irrigation and water supply to the state capital and its environs. The dam has its water source mainly coming

from three tributaries, namely the Gubi River, Tagwaye River linked with Shadawanka and Ran rivers (Abdullahi et al., 2014). Intense agricultural activities take place within the Gubi Dam coupled with the use of agrochemicals for crop production. Additionally, waste generated within the state and its environs flow into this dam. The water is used extensively for the irrigation of vegetables particularly at the agricultural locations of the dam. Hence, the use of water for irrigation of vegetables and agrochemicals might pose significant effect on the soil and vegetable crops thereby exposing consumers of the vegetable crops to accumulation of metals with time. This study therefore aims to determine the levels of heavy metals in vegetable and soil samples and to conduct risk assessment of heavy metals, using HQ, Hazard Index (HI) and cancer risk (CR) assessment.

METHODOLOGY

Study area and collection of samples

Vegetable samples were collected from five different agricultural areas around Gubi Dam (Figure 1), with the following coordinates:

1. Point S1: 10°24'12" N, 9°51'47" E
2. Point S2: 10°25'28" N, 9°52'40" E
3. Point S3: 10°24'50" N, 9°52'18" E
4. Point S4: 10°24'12" N, 9°51'47" E
5. Point S5: 10°23'56" N, 9°51'18" E

In each location, 20 g each of tomatoes (*Solanum lycopersicum*), spinach (*Spinacia oleracea*), roselle (*Hibiscus sabdariffa*), onion (*Allium cepa*) and cucumber (*Cucumis sativus*) vegetable samples were collected from three different points to provide replicate samples of each crop. The vegetable samples were collected in a clean polyethylene bag, and labelled appropriately. All the samples collected were transported to the Department of Chemistry Laboratory, University of Maiduguri and preserved in a refrigerator at 4°C until analysis (Figure 1).

Sample preparations

Digestion of dried vegetable samples

In an effort to achieved quality and accurate result, laboratory precautions were strictly observed to avoid contamination of samples; all the equipment and glass wears to be used were rinsed and cleaned using distilled water. Accurately 2 g of each of the dried vegetable samples, weighed into 250 cm³ conical flasks, 10 ml of mixture of Nitric acid and Hydrochloric acid of ratio 1:3 were added to each sample. The solutions were then heated on hot plate inside fume cupboard until white dense fume was observed. The solutions were then removed and allowed to cool to avoid over flow, followed by the addition of 3 cm³ of 30% H₂O₂. The solutions were later heated again until the volume reduced to 2 ml. The digests were allowed to cool, and then filtered into 100 ml volumetric flask. The content was diluted to 100 ml mark with distilled water.

Elemental analysis of the samples

Determination of Cr, Mn, Fe, Cu, Ni, Hg, Cd, As and Pb was made

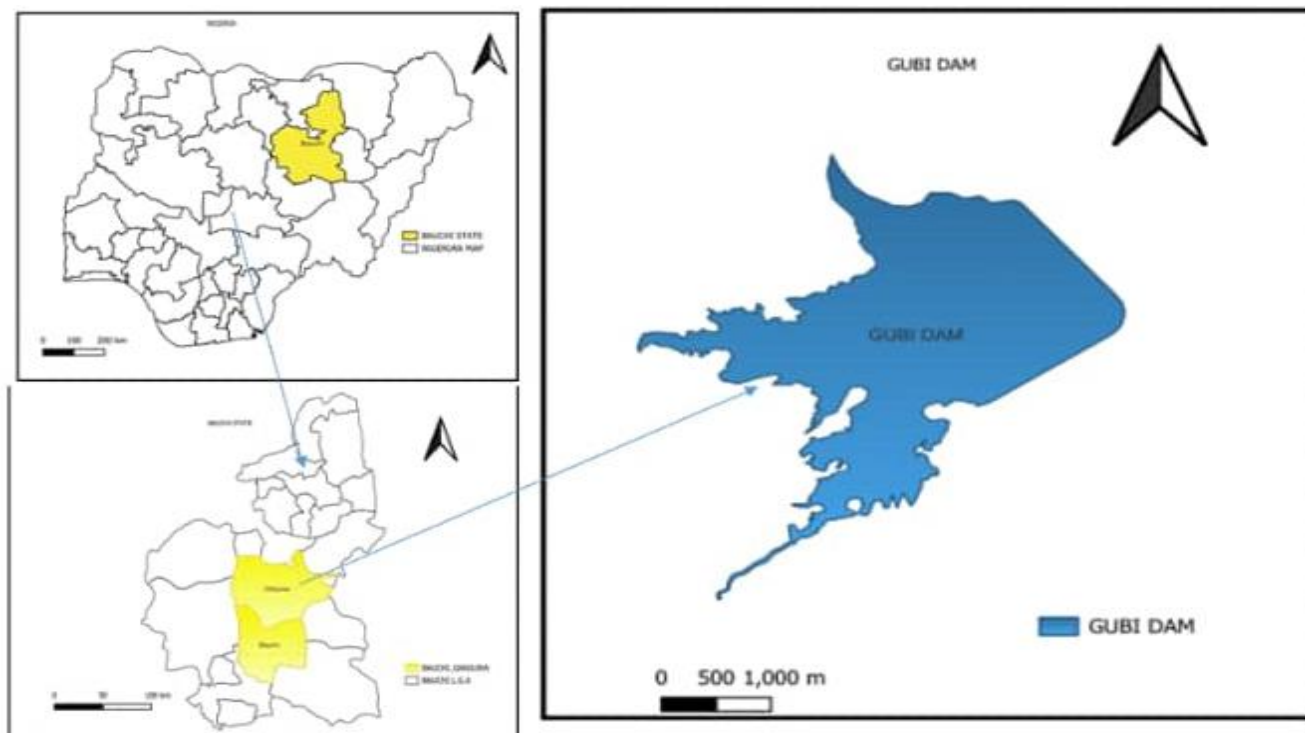


Figure 1. Study area and collection of samples.

directly on each final solution using Perkin-Elmer Analyst 300 Atomic Absorption Spectroscopy (AAS).

Calibration of solutions

Standard solution of each sample Cr, Mn, Fe, Cu, Ni, Hg, Cd, As and Pb were prepared according to the manufacturer procedure for Atomic absorption spectroscopy to be used. A known 1000 mg/l concentration of the metal solutions was prepared from their salts.

Statistical analysis

Values obtained were subjected to one-way analysis of variance (ANOVA) which was used to assess whether the parameters varied significantly across vegetable samples. Probability less than 0.05 ($p < 0.05$) was considered statistically significant. All statistical calculations were performed using SPSS 9.0 for windows.

Risk assessment

Average daily intake (ADI) values for consumptions of the metals

The assessments of daily environmental exposure of heavy metals in vegetable were done in the form of carcinogenic and non-carcinogenic health risk assessment. The assessment was carried out for adult with an average body weight of 70 kg and based on oral ingestion exposure pathways which result from intake of heavy metal through consumption of edible fruit without proper washing. The calculations for all the heavy metals were carried out based on the standard procedures by (USEPA, 1996; Isa et al., 2015). This process involves using tools of science and statistic to measure and

determine hazards and exposure pathways, and eventually used the calculated or estimated numerical values to ascertain potential risk (Lushenko, 2010) using Equation 1 (USEPA, 1996) Table 1:

$$ADI_{ing} = \frac{C \times InR \times EF \times ED}{BW \times AT} \quad (1)$$

Hazard quotient (HQ) and hazard index (HI)

HQ value of heavy metals were estimated based on quotient between concentration of metal, environmental exposure values and unique reference dose (RfD) established for each metal (Table 1). Hence HQ was regarded as an evaluation of health risk level due to exposure of heavy metals with respect to ADI. Hence the values of HQ were estimated using Equation 2 (USEPA, 2011):

$$HQ_{ing} = ADI \times \frac{CF}{RfD} \quad (2)$$

Similarly HI values which expressed as a total health risk value comprises of all the estimated exposure pathways (USEPA, 1989). Hence the (HI) values were calculated using summation of each heavy metal (HQ) through the exposure pathways (ingestion) using Equation 3 (USEPA, 2011):

$$HI = \sum HQ_{ing} \quad (3)$$

Carcinogenic health risk assessment

The carcinogenic health risk assessment is a way of assessing carcinogenic risk there by estimating the probabilities of individual to develop cancer due to exposure to a potential carcinogenic heavy metal over a lifetime. The CR values of each metals were

Table 1. Heavy metal exposure factors used.

Factor	Definition	Value	Unit
C	Soil metal conc.	-	mg/kg
ingR	Soil ingestion rate	100	mg/d
ED	Exposure duration	20	Years
BW	Body weight	70	kg
AT	Average time	$365 \times \text{ED}$	Days
CF	Conversion rate	$1.00\text{E-}06$	kg/mg
EF	Exposure frequency	350	Days/year
ABS	Absorption factor	0.03 For As, 0.01 for other metals	

Source: Shahir et al. (2021).

calculated using the estimated average daily dose converted by unique cancer slope factor (CSF) established for each potential carcinogenic heavy metals, which indicate a chance for average direct exposure of an individual to develop a cancer over a lifetime (UAEPA, 1989) (Supplementary Tables 1 to 8). The CR values of each metal were calculated using Equation 4:

$$\text{CRs} = \sum \text{ADD} \times \text{CSF} \quad (4)$$

RESULTS AND DISCUSSION

Chromium is one of the heavy metals in the environment whose concentration is steadily increasing due to industrial growth, particularly in the development of metals, chemicals and tanning industries (Adeleken and Abegunde, 2011). From the results of this study, the mean concentration of Cr in vegetable samples were observed to be higher in roselle samples obtained from S₅ agriculture location, with a value of 5.27 ± 0.15 mg/kg, while the lowest concentration was recorded in Cucumber obtained from S₃ with a value of 1.34 ± 0.08 mg/kg. However, the result of the study shows that the concentration of Cr was higher than the values of $0.33 \pm 0.049 - 0.02 \pm 0.004$ mg/kg reported by Barau et al. (2018) and $2.30 \pm 0.06 - 0.39 \pm 0.04$ mg/kg reported by Ullah et al. (2022). The level of Cr in this study were compared with the permissible limit of 0.1-0.2 mg/kg assigned by FAO/WHO (2013), which were found to be higher than the permissible limit. According to Agency for Toxic Substances and Disease Registry (1998), ingestion of high concentration of chromium by humans and animals may result in acute gastrointestinal issues, related to vomiting, abdominal pain, and hemorrhage.

Manganese is one of the essential trace mineral elements that play a critical role in various human physiological functions, but excessive exposure can lead to significant health issues. Highest concentration of Mn with a value of 23.12 ± 8.82 mg/kg was recorded in onion, while tomatoes recorded a lowest value of 1.09 ± 0.03 mg/kg from the same location. In a similar study carried out by Nanven et al. (2015) in North Central Nigeria, reported a higher mean concentration range of 220.65 ± 33.24 and 29.85 ± 8.35 mg/kg as compared to

the present study. Comparatively, the level of Mn in this study was also found to be significantly lower than the reported values of 129.32 ± 1.14 and 33.41 ± 0.49 mg/kg respectively by Ashraf et al. (2021). The concentrations of the Mn in this were further observed to be apparently higher than the maximum permissible limit of 0.3 mg/kg as specified by FAO/WHO (2013). Higher accumulation of Mn may result to cognitive impairment related issues emanated from long time sleepiness, weakness and loss of appetite as reported by NJ-Health (2012).

The concentration of Iron (Fe) reported in this study was observed to be dominant in onion samples obtained from S₁, and S₃ with a highest and lowest concentration values of 72.12 ± 3.87 and 21.23 ± 3.87 mg/kg respectively. Most et al. (2019) reported a higher concentration range of 2,362.56 to 1,436.34 mg/kg in vegetables than in the present study. Similarly, Alexander and Ubandoma (2014) in a similar study carried out on vegetables grown along River Yedzaram in the Uba area, Adamawa State reported a higher mean concentration range of 48.67 ± 0.1 to 31.72 ± 0.71 mg/kg, but lower than the concentrations reported in this study. Also, the concentrations of Fe in this study were further observed to be exorbitantly higher than the maximum limit of 0.3 mg/kg by FAO/WHO (2013).

Cu recorded a concentration of 8.23 ± 1.98 mg/kg in spinach obtained from point S₅, while point S₄ recorded the lowest concentration of 1.06 ± 0.06 mg/kg in spinach. Ashraf et al. (2021) reported higher values of Cu in vegetable samples ranging from $13.65 \pm 0.21 - 9.24 \pm 0.12$ mg/kg. Also, the concentrations of Cu in the present study were found to be higher than maximum limit of 0.1mg/kg as reported by FAO/WHO (2013). Though consequences of copper deficiencies are very rare, but it can result in several health implications such as anemia and some other neurological problems (Collins, 2014). Similarly, excessive intake of copper also has detrimental effect related to gastrointestinal distress, organ damage and even neurological symptoms such as anxiety and cognitive difficulties (ATSDR, 2024).

Ni also found to be dominant with a value of 4.22 ± 0.33 mg/kg in spinach obtained from point S₅, while tomatoes

obtained from point S₄ recorded the least concentration of 0.01 ± 0.01 mg/kg. Ullah et al. (2022) reported a lower range value of 0.39 ± 0.04 to 0.15 ± 0.03 mg/kg; while, Babandi et al. (2012) in a similar study reported a higher concentration range of 35.00 ± 17.00 to 9.00 ± 3.00 mg/kg.

However, the concentration of Ni in vegetable samples exceeded the maximum standard limit of 0.1 mg/kg recommended by FAO/WHO (2013). Acute exposure to nickel through ingestion could result in several toxicities that can result to nausea, vomiting, vertigo, and irritation which potentially lead to more severe symptoms such as chest stiffness, cough and visual impairments (Kusal et al., 2018).

The concentration of Cd in the vegetable sample was significantly ($p > 0.05$) higher in spinach obtained from point S₁ with a value of 1.32 ± 0.03 mg/kg, while the lowest concentration was recorded in onion obtained from S₂ with a value of 0.13 ± 0.01 mg/kg, which was similar to the concentration range of 1.81 ± 0.09 and 0.02 ± 0.01 mg/kg reported by Uwah et al. (2011). However, the concentrations of Cd in this study exceeded the standard permissible limit of 0.02 mg/kg reported by FAO/WHO (2013). According to WHO (2007, 2011), cadmium contained in soil can be taken up by certain crops and accumulate in the food chain. For non-smokers, food serves as major environmental source of cadmium in human. Higher concentrations of cadmium are mostly found in kidney and liver of mammals fed with elevated level of cadmium. When consumption is taken into account, vegetables, cereals/grains are considered major food categories that contribute to cadmium exposure in several countries.

This study revealed that cucumber harvested from point S₅ recorded the highest concentration of Hg with a value of 5.00×10^{-4} mg/kg, while Roselle from all locations except from point S₅ area recorded the lowest concentration of 1.00×10^{-4} mg/kg. Higher concentration of Hg 2.00×10^{-3} to 4.00×10^{-3} mg/kg in vegetables was reported in a similar study carried out by Otitoju et al. (2012). The concentrations of Hg in the present study were found to be lower than values of 0.05 mg/kg specified by FAO/WHO (1995).

In this present study, cucumber shows the highest concentration of As with a value of 0.03 ± 0.03 mg/kg from point S₅, while tomatoes from point S₂ shows the lowest value of 0.001 ± 0.001 mg/kg. Uwah et al. (2011) reported a higher concentration of 1.73 ± 0.20 to 0.15 ± 0.10 mg/kg and Akan et al. (2009) in a similar study carried out in Kano Nigeria reported a concentration ranging from 0.01 to $2.00 \mu\text{g g}^{-1}$. The concentrations of As in this study also exceeded the maximum permissible limits 0.1 mg/kg set by FAO/WHO (1995). Higher accumulation of Arsenic in human body may cause inhibition of several enzymes involved in vital biological processes, which eventually resulted to generate reactive oxygen species (ROS) leading to oxygen stress and DNA impairments that can give rise to carcinogenesis, immune dysfunctions and

inflammation (Chinthalapally et al., 2017).

Additionally, the concentration of Pb was significantly ($p > 0.05$) higher in onion obtained from S₃ with a value of 2.54 ± 0.11 mg/kg, while the lowest concentration was recorded in cucumber from point S₅ with a value of 0.22 ± 0.001 mg/kg. Babandi et al. (2012) in a similar study reported level of Pb in vegetables with values ranging from 17.14 ± 0.10 and 10.21 ± 0.20 mg/kg, the said values were observed to be lower than those reported in the present study. The concentration of Pb also compared with permissible level of 0.1 mg/kg (vegetables) as specified by FAO/WHO (2013). The levels of Pb in all the vegetable samples exceeded the above standard limit.

The present study further revealed that the concentrations Cr, Mn, Fe, Cu, Ni, Hg, As, Cd and Pb in all the vegetable samples exceeded the permissible limits of FAO/WHO (2013), except for Hg and As which recorded a concentrations below the permissible limit. This result is in agreement with the study carried out by Akan et al. (2013) which showed a higher concentration of heavy metals in vegetables as compared with FAO/WHO standard.

The observed higher concentrations of heavy metals in the studied vegetable samples as compared with the standard permissible limit could be attributed to the continuous absorption of the metals by plant for physiological functions, and as a result give rise to higher accumulations with time.

Average daily intake, hazard quotient and hazard index as well as cancer risk assessment of heavy metals upon consumptions of vegetable

Estimation of the level of exposure and the routes through which contaminants entered target living beings are of great importance for understanding the underlying health risks. An essential pathway of human exposure to substantial metals is natural food chain. In adult, the ADI values were estimated based on the average vegetables consumed on daily basis. The ADI from different vegetables in adult is shown in this study. The ADI values revealed that the vegetable samples are free of risks, as the results shows the concentrations of the heavy metals were below the provisional tolerable daily intakes (PTDIs) for Cr 0.05-0.2, Mn 20 mg, Fe 0.048 mg, Cu 3 mg, Ni 1.4 mg, Hg 0.0003 mg, Cd 0.06 mg, As 0.13 mg, Pb 0.214 mg by FAO/WHO (2011), which had set based on body weight for an average adult (70 kg). The present result is in agreement with the study carried out in Bangladesh by Shaheen et al. (2016) and Lagos Nigeria by Adedokun et al. (2016), both reported an ADI values of heavy metals in vegetable lower than PTDI.

However, the higher HQ value of Cd observed in this study indicates a potential health risk of the metal through consumptions of vegetable. Hence spinach from S₁ might pose a significant health risk when consumed. According

to Arise et al. (2015), heavy metals like Cd, Cr, Pb, Ni and As have no biological and nutritional importance in human physiology and can be toxic even at low concentrations. The HI value expresses the combined non-carcinogenic effects of multiple elements for consumption of selected vegetable, the value of HI in this study shows that (Cr, Mn, Fe, Cu, Ni, Hg, As) were below the accepted value of 1 mg/kgd^{-1} , except for Cd and Pb. The hazard Index ($HI > 1$) was observed in Cd and Pb from S₁ and S₃, S₄ and S₅ and finally Pb from S₂. Similarly, higher HI value of Cd and Pb in vegetables was reported by Gebreyohannes and Gebrekidan (2018). Inferentially, the heavy metals from the sampling locations in this study with $HI < 1$ except for Cd and Pb indicate that these metals may have no carcinogenic potential health effect (Yisa et al., 2024). Additionally, CR assessment is another marker for determining carcinogenic effect that may arise from the intake of heavy metals. Total CR above the range of $1.00\text{E}-06 - 1.00\text{E}-04$ is considered unacceptable (USEPA, 2015). From this present study, the CRs for As and Pb in the vegetables were found to be lower than the accepted value, this implies that the vegetables within the study areas consumed by consumers at these values may possibly not be associated with As and Pb-induced cancer but rather much more with Cd, As, Pb, Ni, Cr related cancer since their concentrations were above the permissible level. Liang et al. (2017) also reported higher CRs value for Ni, Cd and Cr in vegetable grown in Guangdong, China. Many types of cancers are known to be highly related to chronic exposures to low concentrations of toxic heavy metals (Yisa et al., 2024). Hence, the population and the consumers that depend on the vegetables grown within the study area are possibly at a higher verge of health risk.

Conclusion

The study detected parameters in the soil and vegetables analyzed. The use of agrochemicals in the study area may contribute to the presence heavy metals in the vegetables. Result from HQ and HI indicates that, consuming vegetables from the study area may pose potential health risk particularly concerning cadmium (Cd) and lead (Pb). The CR assessment suggests a probability of developing cancer-related illness due to cadmium (Cd), nickel (Ni) and chromium (Cr). This research further demonstrates that the agricultural location within the Gubi Dam is exposed to potentially toxic heavy metals. Based on the above result, relevant agencies should be involved to monitoring the study environment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Abdullahi I, Bayang F, Garba H, Haladu S, Ndububa OI, Tsoho, U (2014). Gubi Water Treatment Plant as a Source of Water Supply in Bauchi Township. *American Journal of Engineering Research* 3(6):107-119.
- Adedokun AH, Njoku KL, Akinola MO, Adesuyi AA, Jolaoso AO (2016). Potential Human Health Risk Assessment of Heavy Metals Intake via Consumption of some Leafy Vegetables obtained from Four Market in Lagos Metropolis, Nigeria. *Journal of Applied Science and Environmental Management* 20(3):530-539.
- Adeleken BA, Abegunde KD (2011). Heavy Metals Contamination of Soil and Groundwater at Automobile Mechanic Villages in Ibadan Nigeria. *International Journal of Physical Science* 6(5):1045-1058.
- Agency for Toxic Substances and Disease Registry (1998). Toxicological Profile for Chromium. U.S. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA.
- Agency for Toxic Substances and Disease Registry (ATSDR) (2024). Toxicological Profile for Copper. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. <https://www.atsdr.cdc.gov/toxprofiles/tp132.pdf>
- Akan JC, Abdulrahman FI, Ogugbuaja VO, Ayodele JT (2009). Heavy Metals and Anion Levels in Some Samples of Vegetable Grown Within the Vicinity of Challawa Industrial Area Kano State Nigeria. *American Journal of Applied Sciences* 6(3):534-542.
- Akan JC, Kolo BG, Yikala BS, Ogugbuaja VO (2013). Determination of Some Heavy Metals in Vegetable Samples from Biu Local Government Area Borno State North Eastern Nigeria. *International Journal of Environmental Monitoring and Analysis* 1(2):40-46.
- Akan JC, Zakari M, Ayuba M J, Wayar HB, Shettima MA (2021). Levels and Health Risk Assessment of Heavy Metal Contamination in Soil and Different Varieties of Rice from Jere Agricultural Locations Borno State Northeastern Nigeria. *Journal of Chemistry Letters* 2:96-113.
- Alexander P, Ubandoma WH (2014). Determination of Some Heavy Metals in Selected Edible Vegetables Grown along River Yedzaram in Uba area Adamawa State Nigeria. *African Journal of Pure and Applied Chemistry* 8(4):78-82.
- Arise RO, Idowu OA, Farohunbi ST, Abubakar FA (2015). Levels of Some Metals and Earthworm Phosphatase Activities in the Soil around Odo-Efo River, Ilorin, Kwara State. *Centre Point Journal (Science Edition)* 21(1):88-105.
- Ashraf I, Ahmad SA, Raza AA, Teng H (2021). Heavy metals assessment in water soil vegetables and their associated health risks via consumption of vegetables District Kasur Pakistan. *SN Applied Sciences* 3:552.
- Babandi A, Atiku MK, Alhassan AJ, Ibrahim A, Shehu D (2012). Level of heavy metals in soil and some vegetables irrigated with industrial waste water around Sharada Industrial area Kano Nigeria. *Chemsearch Journal* 3(2):34-38.
- Barau BW, Abdulhameed A, Ezra AG, Muhammad M, Kyari EM, Bawa U, Yuguda AU (2018). Heavy Metal Contamination of Some Vegetables from Pesticides and the Potential Health Risk in Bauchi Northern Nigeria. *AFRREV STECH: An International Journal of Science and Technology* 7(1):1-11.
- Calace N, Petronio BM, Picciolo M, Pietroletti M (2002). Heavy metal uptake by barley growing in polluted soils: relationship with heavy metal speciation in soils. *Communications in Soil Science and Plant Analysis* 33(1-2):103-115.
- Chen Y, Zhao J, Chen X, Zheng L (2024). Analysis of the Source Apportionment and Pathways of Heavy Metals in Soil in a Coal Mining Area Based on Machine Learning and an APCS-MLR Model. *Minerals* 14(1):54.
- Chinthalapally VR, Sanya P, Altaf M, Mudassir F, Mark PD, Adam SA, Hiroshi YY (2017). Biological effects and epidemiological consequences of arsenic exposure, and reagents that can ameliorate arsenic damage in vivo. *Oncotarget* 8(34):57605-57621.
- Collins JF (2014). Copper. In: Ross AC, Caballero B, Cousins RJ, Tucker KL, Ziegler TR, eds. *Modern Nutrition in Health and Disease*. 11th ed. Baltimore, MD: Lippincott Williams and Wilkins. pp. 206-216. Available at: <https://cloud.uobasrah.edu.iq/uploads/2023/07/11/6043%20D8%A7%D9%85%D8%B1%D8%B6%20D8%AA%D8%BA%D8%B0%D9>

- %8A%D8%A9.pdf
- FAO/WHO (1995). Evaluation of certain food Additives and Contaminants. Geneva World Health Organization Joint FAO/WHO Expert Committee on Food Additives. World Health Organization Technical Report Series 859:29–35.
- FAO/WHO (2011). Food Standard Programme Codex Committee on Contaminants Food Fifth Session. The Hague Netherlands.
- FAO/WHO (2013). Guidelines for the safe use of Wastewater and Food Stuff Wastewater use in Agriculture. Report by WHO Switzerland, Geneva P. 988.
- Gebreyohannes F, Gebrekidan A (2018). Health Risk Assessment of Heavy Metals via Consumption of Spinach Vegetable Grown in Elalla River. *Bulletin of the Chemical Society of Ethiopia* 32(1):65-75.
- Hu Y, You M, Liu G, Dong Z (2021). Characteristics and potential ecological risks of heavy metal pollution in surface soil around coal-fired power plant. *Environmental Earth Sciences* 80(17):566.
- Järup L (2003). Hazards of heavy metal contamination. *British Medical Bulletin* 68(1):167-182.
- Kusal KD, Chandramouli RR, Ishwar BB, Swastika D, Shrilaxmi B, Lata M, Jyoti PK, Biradar MS (2018). Primary concept of nickel toxicity – an overview. *Journal of Basic and Clinical Physiology and Pharmacology* 30(2):141-152.
- Lei M, Zhang Y, Khan S, Qin PF, Liao BH (2010). Pollution fractionation, and mobility of Pb, Cd, Cu and Zn in garden and peddy soils from a Pb/Zn mining area. *Environmental Monitoring and Assessment* 168:215-222.
- Liang Y, Xiaoyun Y, Zhi D, Qin W, Houmei L, Jie T (2017). Heavy Metal Contamination and Health Risk Assessment in the Vicinity of a Tailing Pond in Guangdong China. *International Journal of Environmental Resources and Public Health* 14(1557):1-17.
- Lushenko MA (2010). A risk assessment for ingestion of toxic chemicals in fish from Imperial beach, California. Doctoral dissertation, San Diego State University.
- Mansur UD, Jazuli A (2007). Irrigation and Heavy Metals Pollution in Soils under Urban and Peri-Urban Agricultural Systems. *International Journal of Pure and Applied Sciences* 1(3):37-42.
- Most LB, Umme HBN, Razib H, Ashiqur R (2019). Levels of Heavy Metals in Soil and Vegetables and Health Risk Assessment. *International Journal of Scientific and Technology Research* 8(7):770-775.
- Nanven ND, Egila JN, Lohdip YN (2015). Heavy Metal Concentrations in Some Vegetables Grown in a Farm Treated with Urban Solid Waste in Kuru Jantar Nigeria. *British Journal of Applied Science and Technology* 8(2):139-147.
- New Jersey Health of Department (NJ-Health) (2012). Right to know Hazardous Substance Fact Sheet. New Jersey. <https://web.doh.nj.gov/rthksfs/indexfs.aspx>
- Ottitoju O, Akpanabiatu MI, Ottitoju GTO, Ndem JI, Uwah AF, Akpanyung EO, Ekanem JT (2012). Heavy Metal Contamination of Green Leafy Vegetable Gardens in Itam Road Construction Site in Uyo, Nigeria. *Research Journal of Environmental and Earth Sciences* 4(4):371-375.
- Qi M, Wu Y, Zhang S, Li G, An T (2023). Pollution Profiles Source Identification and Health Risk Assessment of Heavy Metals in Soil near a Non-Ferrous Metal Smelting Plant. *International Journal of Environmental Resources Public Health* 20:1004.
- Shaheen N, Irfan NMD, Khan IN, Saiful-Islam MD, Ahmed K (2016). Presence of Heavy Metals in Fruits and Vegetables: Health risk implications in Bangladesh. *Chemosphere* 152:431-438.
- Sharma RK, Agrawal M, Marshall FM (2009). Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. *Food Chemical Toxicology* 47(3):583–591.
- Shittu AM, Ansar BA, Shamsu AI, Abubakar A, Abdullahi JA, Nasiru AM (2024). Determination of heavy Metals in Soil of Farin Gada Vegetable Farm Jos North Local Government Plateau State Nigeria. *International Research Journal of Chemistry* 1:7-12.
- Ullah N, Ur Rehman M, Ahmad B, Ali I, Younas M, Aslam MS, Atta-ur Rahman Ensiyeh T, Ali F, Mashallah R (2022). Assessment of heavy metals accumulation in agricultural soil vegetables and associated health risks. *PLoS ONE* 17(6):1-14.
- US Environmental Protection Agency (USEPA) (1989). Risk-assessment guidance for superfund. Volume 1. Human health evaluation manual. Office of Solid Waste and Emergency Response Washington, DC (USA). https://www.epa.gov/sites/default/files/2015-09/documents/rags_a.pdf
- US Environmental Protection Agency (USEPA) (1996). United State Environmental Protection Agency. Quantitative uncertainty analysis of superfund Residential Risk pathway model for soil and ground water: white paper. Office of Health and Environmental Assessment, Oak Ridge TN USA.
- US Environmental Protection Agency (USEPA) (2011). United State Environmental Protection Agency. Regional Screening Level (RSL) summary table. Washinton, DC
- US Environmental Protection Agency (USEPA) (2015). Risk Based Screening Composite Table. Human Health Evaluation Manual Part A: Table 0615. Washington DC USA.
- Uwah EI, Ndahi NP, Abdulrahman FI, Ogugbuaja VO (2011). Heavy Metal Levels in Spinach (*Amaranthus caudatus*) and Lettuce (*Lactuca sativa*) grown in Maiduguri Nigeria. *Journal of Environmental Chemistry and Ecotoxicology* 3(10):264-271.
- Uwumarongie-Ilori EG, Aisueni NO, Sulaiman-Ilobu BB, Ekhatior F Eneje RC, Efezie-Osiele A (2012). Immobilization effect of cow dung on lead and chromium in soil cultivated with oil palm. *Bulletin of Environment Pharmacology and Life Sciences* 1(9):74-80.
- Wang XT, Sato Xing B, Tao S (2005). Health Risk of Heavy Metals to the General Public in Tianjin China via Consumption of Vegetables and Fish. *Science of Total Environment Publication* 350(1-3):28-37.
- WHO (2007). Health risks of heavy metals from long-range transboundary air pollution. In *Health risks of heavy metals from long-range transboundary air pollution* <https://iris.who.int/handle/10665/107872>
- WHO (2011). Safety evaluation of certain food additives and contaminants in food. Prepared by the Seventy-third meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA), Nutrition and Food Safety (NFS), Standards & Scientific Advice on Food Nutrition (SSA) 543p. <https://www.who.int/publications/i/item/9789241660648>
- Wuana RA, Eneji IS, Naku JU (2016). Single and mixed chelants – assisted phytoextraction of heavy metals in municipal waste dump soil by castor. *Advance Environmental Resources* 5:19-35.
- Yisa AG, Oziamo AS, Chukwu MN, Aletan UI, Oniye SJ, Adams AE, Adaora O, Saliu OA, Blessingb E, Stephen O, Ayodeji IO (2024). Health risk assessment of lead and cadmium in roadside roasted corn from selected areas of Bwari Local Government Area, FCT, Nigeria. *UMYU Journal of Microbiology Research* 9(1):84-92.
- Zakari M, Shettima MA, Wayar HB, Ayuba MM, Akan JC (2022). Determination of some heavy metals in soil and vegetable samples from Gonglung agricultural location of Jere Local Government Area of Borno State, Nigeria. *Journal of Chemistry Letters* 3(4):174-180.

Supplementary Tables

Supplementary Table 1. Concentrations of some heavy metals in vegetable samples from S₁ - S₅ agricultural location.

Location	Sample	Concentrations (mg/kg)								
		Cr	Mn	Fe	Cu	Ni	Cd	Hg	As	Pb
S ₁	Tomatoes	2.98 ^a ±0.22	17.23 ^a ±0.44	32.43 ^a ±3.24	2.74 ^a ±0.23	0.11 ^a ±0.05	0.54 ^a ±0.01	3.00E-04	0.004 ^a ±0.001	1.01 ^a ±0.03
	Spinach	1.87 ^b ±0.23	12.03 ^b ±0.12	22.65 ^b ±4.76	8.23 ^b ±1.98	0.23 ^b ±0.01	1.32 ^b ±0.03	1.00E-04	0.005 ^b ±0.001	1.82 ^b ±0.01
	Roselle	2.76 ^c ±0.11	11.02 ^c ±1.43	65.34 ^c ±7.23	2.11 ^c ±0.54	0.65 ^c ±0.03	1.09 ^c ±0.04	1.00E-04	0.017 ^c ±0.002	0.87 ^c ±0.05
	Onion	1.34 ^d ±0.32	4.09 ^d ±0.34	72.12 ^d ±4.87	3.12 ^d ±0.87	2.11 ^d ±0.07	0.22 ^d ±0.01	2.00E-04	0.003 ^d ±0.001	1.43 ^d ±0.03
	Cucumber	1.87 ^b ±0.43	2.34 ^e ±0.43	34.09 ^e ±8.23	1.93 ^e ±0.21	2.21 ^e ±0.07	0.43 ^e ±0.02	1.00E-04	0.005 ^b ±0.001	0.65 ^e ±0.04
S ₂	Tomatoes	3.29 ^a ±0.03	14.22 ^a ±1.43	22.23 ^a ±6.34	6.32 ^a ±1.02	3.65 ^a ±0.22	0.21 ^a ±0.02	3.00E-04	0.001 ^a ±0.001	2.04 ^a ±0.02
	Spinach	2.98 ^b ±0.05	2.09 ^b ±0.34	44.23 ^b ±3.98	2.64 ^b ±0.04	1.00 ^b ±0.01	0.18 ^b ±0.04	1.00E-04	0.014 ^b ±0.002	1.04 ^b ±0.05
	Roselle	4.23 ^c ±0.12	4.87 ^c ±0.62	53.12 ^c ±9.23	3.83 ^c ±0.08	0.65 ^c ±0.04	0.17 ^b ±0.01	1.00E-04	0.002 ^c ±0.001	0.54 ^c ±0.03
	Onion	1.93 ^d ±0.01	5.32 ^d ±1.23	65.22 ^d ±5.34	2.14 ^d ±0.04	1.34 ^d ±0.01	0.32 ^c ±0.06	1.00E-04	0.004 ^d ±0.001	0.77 ^d ±0.01
	Cucumber	3.28 ^b ±0.07	6.94 ^e ±0.65	21.34 ^e ±6.23	6.23 ^a ±0.21	0.22 ^e ±0.01	0.13 ^d ±0.01	4.00E-04	0.002 ^c ±0.001	2.04 ^a ±0.02
S ₃	Tomatoes	4.23 ^a ±0.23	3.65 ^a ±0.11	22.54 ^a ±3.29	1.09 ^a ±0.03	0.45 ^a ±0.02	0.14 ^a ±0.03	1.00E-04	0.005 ^a ±0.002	1.07 ^a ±0.04
	Spinach	1.87 ^b ±0.13	8.93 ^b ±0.41	41.23 ^b ±4.87	3.23 ^b ±0.01	1.00 ^b ±0.12	0.43 ^b ±0.07	4.00E-04	0.008 ^b ±0.001	2.22 ^b ±0.21
	Roselle	2.11 ^c ±0.16	4.21 ^c ±0.22	53.09 ^c ±1.93	5.23 ^c ±0.27	0.22 ^c ±0.05	0.14 ^a ±0.01	1.00E-04	0.011 ^c ±0.002	1.76 ^c ±0.04
	Onion	2.87 ^d ±0.52	6.87 ^d ±1.98	21.23 ^d ±3.87	1.23 ^d ±0.17	0.22 ^c ±0.02	0.73 ^c ±0.03	2.00E-04	0.016 ^d ±0.003	2.54 ^d ±0.11
	Cucumber	1.34 ^e ±0.08	4.56 ^e ±0.06	72.09 ^e ±8.09	4.12 ^e ±0.12	0.45 ^d ±0.16	0.25 ^d ±0.02	1.00E-04	0.005 ^a ±0.001	0.77 ^e ±0.13
S ₄	Tomatoes	2.16 ^a ±0.14	1.09 ^a ±0.03	45.87 ^a ±7.83	5.11 ^a ±0.14	0.01 ^a ±0.01	0.22 ^a ±0.01	1.00E-04	0.011 ^a ±0.001	0.56 ^a ±0.06
	Spinach	4.13 ^b ±0.41	5.34 ^b ±0.22	44.23 ^b ±9.34	1.06 ^b ±0.06	0.34 ^b ±0.02	0.16 ^b ±0.02	2.00E-04	0.015 ^b ±0.003	1.45 ^b ±0.02
	Roselle	3.18 ^c ±0.04	18.93 ^c ±6.63	58.23 ^c ±5.73	1.32 ^c ±0.02	1.00 ^c ±0.22	0.25 ^c ±0.01	1.00E-04	0.012 ^a ±0.005	0.72 ^c ±0.01
	Onion	3.64 ^d ±0.52	23.12 ^d ±8.82	47.96 ^d ±6.38	2.13 ^d ±0.11	0.11 ^d ±0.01	0.55 ^d ±0.03	1.00E-04	0.003 ^c ±0.001	2.13 ^d ±0.15
	Cucumber	2.98 ^e ±0.02	16.83 ^e ±3.72	25.34 ^e ±4.72	2.76 ^e ±0.03	2.04 ^e ±0.04	0.43 ^e ±0.01	3.00E-04	0.006 ^d ±0.002	0.87 ^e ±0.04
S ₅	Tomatoes	1.67 ^a ±0.03	12.32 ^a ±1.08	33.98 ^a ±4.32	1.32 ^a ±0.13	1.32 ^a ±0.03	0.18 ^a ±0.01	1.00E-04	0.002 ^a ±0.001	1.55 ^a ±0.01
	Spinach	3.23 ^b ±0.02	15.23 ^b ±1.92	51.23 ^b ±7.21	4.12 ^b ±0.32	4.22 ^b ±0.33	0.73 ^b ±0.07	3.00E-04	0.013 ^b ±0.003	2.01 ^b ±0.11
	Roselle	5.27 ^c ±0.15	9.12 ^c ±0.43	42.67 ^c ±5.33	3.24 ^c ±0.22	0.97 ^c ±0.05	0.37 ^c ±0.03	2.00E-04	0.021 ^c ±0.005	0.76 ^c ±0.02
	Onion	4.23 ^d ±0.11	10.98 ^d ±1.03	37.98 ^d ±3.28	1.87 ^d ±0.17	0.75 ^d ±0.11	0.17 ^a ±0.01	1.00E-04	0.011 ^d ±0.001	1.33 ^d ±0.33
	Cucumber	1.87 ^e ±0.06	8.93 ^e ±0.54	29.83 ^e ±1.87	2.43 ^e ±0.87	0.23 ^e ±0.02	0.53 ^d ±0.05	5.00E-04	0.031 ^e ±0.003	0.22 ^e ±0.01

Within columns of each sampling locations (S₁ – S₅). Mean with different letters are statistically different, P<0.05.

Supplementary Table 2. Average daily intake (mg/kgd⁻¹) of some heavy metals in vegetable samples from S₁ – S₅ agricultural location.

Location	Sample	Cr	Mn	Fe	Cu	Ni	Cd	Hg	As	Pb
S ₁	Tomatoes	2.68E-03	1.55E-02	2.92E-02	2.47E-03	9.90E-05	4.86E-04	2.70E-07	3.60E-06	9.09E-04
	Spinach	1.68E-03	1.08E-02	2.04E-02	7.41E-03	2.07E-04	1.19E-03	9.00E-08	4.50E-06	1.64E-03
	Roselle	2.48E-03	9.92E-03	5.88E-02	1.90E-03	5.85E-04	9.81E-04	9.00E-08	1.53E-05	7.83E-04
	Onion	1.21E-03	3.68E-03	6.49E-02	2.81E-03	1.90E-03	1.98E-04	1.80E-07	2.70E-06	1.29E-03
	Cucumber	1.68E-03	2.11E-03	3.07E-02	1.74E-03	1.99E-03	3.87E-04	9.00E-08	4.50E-06	5.85E-04
	Total	9.74E-03	4.20E-02	2.04E-01	1.63E-02	4.78E-03	3.24E-03	7.20E-07	3.06E-05	5.20E-03
S ₂	Tomatoes	2.96E-03	1.28E-02	2.00E-02	5.69E-03	3.29E-03	1.89E-04	2.70E-07	9.00E-07	1.84E-03
	Spinach	2.68E-03	1.88E-03	3.98E-02	2.38E-03	9.00E-04	1.62E-04	9.00E-08	1.26E-05	9.36E-04
	Roselle	3.81E-03	4.38E-03	4.78E-02	3.45E-03	5.85E-04	1.53E-04	9.00E-08	1.80E-06	4.86E-04
	Onion	1.74E-03	4.79E-03	5.87E-02	1.93E-03	1.21E-03	2.88E-04	9.00E-08	3.60E-06	6.93E-04
	Cucumber	2.95E-03	6.25E-03	1.92E-02	5.61E-03	1.98E-04	1.17E-04	3.60E-07	1.80E-06	1.84E-03
	Total	1.41E-02	3.01E-02	1.86E-01	1.90E-02	6.17E-03	9.09E-04	9.00E-07	2.07E-05	5.79E-03
S ₃	Tomatoes	3.81E-03	3.29E-03	2.03E-02	9.81E-04	4.05E-04	1.26E-04	9.00E-08	4.50E-06	9.63E-04
	Spinach	1.68E-03	8.04E-03	3.71E-02	2.91E-03	9.00E-04	3.87E-04	3.60E-07	7.20E-06	2.00E-03
	Roselle	1.90E-03	3.79E-03	4.78E-02	4.71E-03	1.98E-04	1.26E-04	9.00E-08	9.90E-06	1.58E-03
	Onion	2.58E-03	6.18E-03	1.91E-02	1.11E-03	1.98E-04	6.57E-04	1.80E-07	1.44E-05	2.29E-03
	Cucumber	1.21E-03	4.11E-03	6.49E-02	3.71E-03	4.05E-04	2.25E-04	9.00E-08	4.50E-06	6.93E-04
	Total	1.12E-02	2.54E-02	1.89E-01	1.34E-02	2.11E-03	1.52E-03	8.10E-07	4.05E-05	7.52E-03
S ₄	Tomatoes	1.94E-03	9.84E-04	4.13E-02	4.60E-03	9.00E-06	1.98E-04	9.00E-08	9.90E-06	5.04E-04
	Spinach	3.72E-03	4.81E-03	3.98E-02	9.54E-04	3.06E-04	1.44E-04	1.80E-07	1.35E-05	1.31E-03
	Roselle	2.86E-03	1.70E-02	5.24E-02	1.19E-03	9.00E-04	2.25E-04	9.00E-08	1.08E-05	6.48E-04
	Onion	3.28E-03	2.08E-02	4.32E-02	1.92E-03	9.90E-05	4.95E-04	9.00E-08	2.70E-06	1.92E-03
	Cucumber	2.68E-03	1.51E-02	2.28E-02	2.48E-03	1.84E-03	3.87E-04	2.70E-07	5.40E-06	7.83E-04
	Total	1.45E-02	5.88E-02	1.99E-01	1.11E-02	3.15E-03	1.45E-03	7.20E-07	4.23E-05	5.16E-03
S ₅	Tomatoes	1.50E-03	1.11E-02	3.06E-02	1.19E-03	1.19E-03	1.62E-04	9.00E-08	1.80E-06	1.40E-03
	Spinach	2.91E-03	1.37E-02	4.61E-02	3.71E-03	3.80E-03	6.57E-04	2.70E-07	1.17E-05	1.81E-03
	Roselle	4.74E-03	8.21E-03	3.84E-02	2.92E-03	8.73E-04	3.33E-04	1.80E-07	1.89E-05	6.84E-04
	Onion	3.81E-03	9.88E-03	3.42E-02	1.68E-03	6.75E-04	1.53E-04	9.00E-08	9.90E-06	1.20E-03
	Cucumber	1.68E-03	8.04E-03	2.68E-02	2.19E-03	2.07E-04	4.77E-04	4.50E-07	2.79E-05	1.98E-04
	Total	1.46E-02	5.09E-02	1.76E-01	1.17E-02	6.74E-03	1.78E-03	1.08E-06	7.02E-05	5.28E-03

Supplementary Table 3. Hazard quotient and hazard index of some heavy metals in vegetable samples from S₁ – S₅ agricultural location.

Location	Sample	Cr	Mn	Fe	Cu	Ni	Cd	Hg	As	Pb
S ₁	Tomatoes	1.79E-03	1.11E-01	4.17E-02	6.17E-02	4.95E-03	4.86E-01	2.70E-03	1.20E-02	2.27E-01
	Spinach	1.12E-03	7.73E-02	2.91E-02	1.85E-01	1.04E-02	1.19E+00	9.00E-04	1.50E-02	4.10E-01
	Roselle	1.66E-03	7.08E-02	8.40E-02	4.75E-02	2.93E-02	9.81E-01	9.00E-04	5.10E-02	1.96E-01
	Onion	8.04E-04	2.63E-02	9.27E-02	7.02E-02	9.50E-02	1.98E-01	1.80E-03	9.00E-03	3.22E-01
	Cucumber	1.12E-03	1.50E-02	4.38E-02	4.34E-02	9.95E-02	3.87E-01	9.00E-04	1.50E-02	1.46E-01
	Hazard Index	6.49E-03	3.00E-01	2.91E-01	4.08E-01	2.39E-01	3.24E+00	7.20E-03	1.02E-01	1.30E+00
S ₂	Tomatoes	1.97E-03	9.14E-02	2.86E-02	1.42E-01	1.64E-01	1.89E-01	2.70E-03	3.00E-03	4.59E-01
	Spinach	1.79E-03	1.34E-02	5.69E-02	5.94E-02	4.50E-02	1.62E-01	9.00E-04	4.20E-02	2.34E-01
	Roselle	2.54E-03	3.13E-02	6.83E-02	8.62E-02	2.93E-02	1.53E-01	9.00E-04	6.00E-03	1.22E-01
	Onion	1.16E-03	3.42E-02	8.39E-02	4.82E-02	6.03E-02	2.88E-01	9.00E-04	1.20E-02	1.73E-01
	Cucumber	1.97E-03	4.46E-02	2.74E-02	1.40E-01	9.90E-03	1.17E-01	3.60E-03	6.00E-03	4.59E-01
	Hazard Index	9.43E-03	2.15E-01	2.65E-01	4.76E-01	3.09E-01	9.09E-01	9.00E-03	6.90E-02	1.45E+00
S ₃	Tomatoes	2.54E-03	2.35E-02	2.90E-02	2.45E-02	2.03E-02	1.26E-01	9.00E-04	1.50E-02	2.41E-01
	Spinach	1.12E-03	5.74E-02	5.30E-02	7.27E-02	4.50E-02	3.87E-01	3.60E-03	2.40E-02	5.00E-01
	Roselle	1.27E-03	2.71E-02	6.83E-02	1.18E-01	9.90E-03	1.26E-01	9.00E-04	3.30E-02	3.96E-01
	Onion	1.72E-03	4.42E-02	2.73E-02	2.77E-02	9.90E-03	6.57E-01	1.80E-03	4.80E-02	5.72E-01
	Cucumber	8.04E-04	2.93E-02	9.27E-02	9.27E-02	2.03E-02	2.25E-01	9.00E-04	1.50E-02	1.73E-01
	Hazard Index	7.45E-03	1.81E-01	2.70E-01	3.35E-01	1.05E-01	1.52E+00	8.10E-03	1.35E-01	1.88E+00
S ₄	Tomatoes	1.30E-03	7.03E-03	5.90E-02	1.15E-01	4.50E-04	1.98E-01	9.00E-04	3.30E-02	1.26E-01
	Spinach	2.48E-03	3.43E-02	5.69E-02	2.39E-02	1.53E-02	1.44E-01	1.80E-03	4.50E-02	3.26E-01
	Roselle	1.91E-03	1.22E-01	7.49E-02	2.97E-02	4.50E-02	2.25E-01	9.00E-04	3.60E-02	1.62E-01
	Onion	2.18E-03	1.49E-01	6.17E-02	4.79E-02	4.95E-03	4.95E-01	9.00E-04	9.00E-03	4.79E-01
	Cucumber	1.79E-03	1.08E-01	3.26E-02	6.21E-02	9.18E-02	3.87E-01	2.70E-03	1.80E-02	1.96E-01
	Hazard Index	9.65E-03	4.20E-01	2.85E-01	2.79E-01	1.58E-01	1.45E+00	7.20E-03	1.41E-01	1.29E+00
S ₅	Tomatoes	1.00E-03	7.92E-02	4.37E-02	2.97E-02	5.94E-02	1.62E-01	9.00E-04	6.00E-03	3.49E-01
	Spinach	1.94E-03	9.79E-02	6.59E-02	9.27E-02	1.90E-01	6.57E-01	2.70E-03	3.90E-02	4.52E-01
	Roselle	3.16E-03	5.86E-02	5.49E-02	7.29E-02	4.37E-02	3.33E-01	1.80E-03	6.30E-02	1.71E-01
	Onion	2.54E-03	7.06E-02	4.88E-02	4.21E-02	3.38E-02	1.53E-01	9.00E-04	3.30E-02	2.99E-01
	Cucumber	1.12E-03	5.74E-02	3.84E-02	5.47E-02	1.04E-02	4.77E-01	4.50E-03	9.30E-02	4.95E-02
	Hazard Index	9.76E-03	3.64E-01	2.52E-01	2.92E-01	3.37E-01	1.78E+00	1.08E-02	2.34E-01	1.32E+00

Supplementary Table 4. Carcinogenic risk assessment values of heavy metals in vegetable samples from S₁ agricultural location.

Sample	Cancer risk values mg/kgd ⁻¹				Cr
	Cd	As	Pb	Ni	
Tomatoes	3.06E-03	5.40E-06	7.73E-06	1.68E-04	1.34E-03
Spinach	7.48E-03	6.75E-06	1.39E-05	3.52E-04	8.42E-04
Roselle	6.18E-03	2.30E-05	6.66E-06	9.95E-04	1.24E-03
Onion	1.25E-03	4.05E-06	1.09E-05	3.23E-03	6.03E-04
Cucumber	2.44E-03	6.75E-06	4.97E-06	3.38E-03	8.42E-04
ILCR	2.04E-02	4.59E-05	4.42E-05	8.12E-03	4.87E-03

ILCR: Incremental lifetime cancer risk.

Supplementary Table 5. Carcinogenic risk assessment values of heavy metals in vegetable samples from S₂ agricultural location.

Sample	Cancer risk values mg/kgd ⁻¹				Cr
	Cd	As	Pb	Ni	
Tomatoes	1.19E-03	1.35E-06	1.56E-05	5.58E-03	1.48E-03
Spinach	1.02E-03	1.89E-05	7.96E-06	1.53E-03	1.34E-03
Roselle	9.64E-04	2.70E-06	4.13E-06	9.95E-04	1.90E-03
Onion	1.81E-03	5.40E-06	5.89E-06	2.05E-03	8.69E-04
Cucumber	7.37E-04	2.70E-06	1.56E-05	3.37E-04	1.48E-03
ILCR	5.73E-03	3.11E-05	4.92E-05	1.05E-02	7.07E-03

ILCR: Incremental lifetime cancer risk.

Supplementary Table 6. Carcinogenic risk assessment values of heavy metals in vegetable samples from S₃ agricultural location.

Sample	Cancer risk values mg/kgd ⁻¹				Cr
	Cd	As	Pb	Ni	
Tomatoes	7.94E-04	6.75E-06	8.19E-06	6.89E-04	1.90E-03
Spinach	2.44E-03	1.08E-05	1.70E-05	1.53E-03	8.42E-04
Roselle	7.94E-04	1.49E-05	1.35E-05	3.37E-04	9.50E-04
Onion	4.14E-03	2.16E-05	1.94E-05	3.37E-04	1.29E-03
Cucumber	1.42E-03	6.75E-06	5.89E-06	6.89E-04	6.03E-04
ILCR	9.58E-03	6.08E-05	6.40E-05	3.58E-03	5.59E-03

ILCR: Incremental lifetime cancer risk.

Supplementary Table 7. Carcinogenic risk assessment values of heavy metals in vegetable samples from S₄ agricultural location.

Sample	Cancer risk values mg/kgd ⁻¹				Cr
	Cd	As	Pb	Ni	
Tomatoes	1.25E-03	1.49E-05	4.28E-06	1.53E-05	9.72E-04
Spinach	9.07E-04	2.03E-05	1.11E-05	5.20E-04	1.86E-03
Roselle	1.42E-03	1.62E-05	5.51E-06	1.53E-03	1.43E-03
Onion	3.12E-03	4.05E-06	1.63E-05	1.68E-04	1.64E-03
Cucumber	2.44E-03	8.10E-06	6.66E-06	3.12E-03	1.34E-03
ILCR	9.13E-03	6.35E-05	4.38E-05	5.36E-03	7.24E-03

ILCR: Incremental lifetime cancer risk.

Supplementary Table 8. Carcinogenic risk assessment values of heavy metals in vegetable samples from S₅ agricultural location.

Sample	Cancer risk values mg/kgd ⁻¹				Cr
	Cd	As	Pb	Ni	
Tomatoes	1.02E-03	2.70E-06	1.19E-05	2.02E-03	7.52E-04
Spinach	4.14E-03	1.76E-05	1.54E-05	6.46E-03	1.45E-03
Roselle	2.10E-03	2.84E-05	5.81E-06	1.48E-03	2.37E-03
Onion	9.64E-04	1.49E-05	1.02E-05	1.15E-03	1.90E-03
Cucumber	3.01E-03	4.19E-05	1.68E-06	3.52E-04	8.42E-04
ILCR	1.12E-02	1.05E-04	4.49E-05	1.15E-02	7.32E-03

ILCR: Incremental lifetime cancer risk.