International Journal of Chemistry Research

Online ISSN- 0976-5689 Vol 10, Issue 1, 2026

Research Article

QUANTITATIVE HEALTH RISK ASSESSMENT OF HEAVY METAL EXPOSURE THROUGH VEGETABLE CONSUMPTION IN WATER BOARD MAJI DADI JALINGO

ATAITIYA H.[1], ADAM A. B.[1*], JOHNSON G.[2], ABUBAKAR M. Y.[2], ATTAH DANIEL E. B.[1]

[1]Department of Chemistry, Federal University Wukari Taraba, Nigeria. [2]Department of Industrial Chemistry, Federal University Wukarii Taraba, Nigeria

*Corresponding author: Adam A. B.; *Email: ansarbilyamin@gmail.com

Received: 24 Aug 2025 Revised and Accepted: 02 Oct 2025

ABSTRACT

Objective: The objective of this study was to ascertain the concentrations of selected heavy metals in three leafy vegetables commonly eaten by Nigerians from Maji Dadi, Jalingo and evaluate the human health risks.

Methods: Normal processes were used for the analysis to determine linearity, accuracy and precision of the system. We compared the results to what the WHO allows. Human health hazard assessments were evaluated using Target Hazard Quotient (THQ), Hazard Index (HI), and Carcinogenic Risk (CR) model.

Results: The levels of zinc (Zn) and copper (Cu) were at a safer limit, while Pb, Cd and Cr were above WHO allowable limit. The THQ values for Pb and Cd were greater than 1, indicating non-carcinogenic risk. The HI varied from 3.59 to 3.97, which exceeded the safe limit (1), suggesting the cumulative exposure risks. The analysis of carcinogenic risk showed that the values of Pb and Cr were above acceptable limits indicating a risk of cancer.

Conclusion: The vegetables discussed were primarily harmful to health because of the presence of Pb, Cd and Cr. The results indicate stricter environmental controls, improved management of irrigation water and enhanced awareness of food safety are needed to avert adverse health effects in the long-term.

Keywords: Heavy metals, Health risk assessment, Vegetables, Water board maji dadi, Target hazard quotient, Carcinogenic risk

DOI: http://dx.doi.org/10.22159/ijcr.2026v10i1.307 Journal homepage: https://ijcr.info/index.php/journal

INTRODUCTION

The threat of the heavy metal contamination of food crops intensifies in Jalingo, Taraba State, where vegetables like spinach, amaranth, and tomatoes grow like plants with plenty of ingestible water, contrasted to the Maji Dadi Water Board, which has supplied these types of vegetables. Although there is still a lack of empirical information regarding the risks associated with Maji Dadi, warnings about similar dangers exist in Taraba and the surrounding states. Toxic heavy metals in vegetables have become a global concern due to the significant public health risks they pose. Although vegetables are widely recognised for their rich nutritional value, they provide essential vitamins that strengthen bones and minerals that enhance skin health.

For instance, [2] investigated soils and tubers in Wukari, Taraba State, and reported concentrations of Pb (71–200.8 mg/kg), Cd (1.8–3.1 mg/kg), and Ni (20.3–56.7 mg/kg), all above WHO permissible limits. Their quantitative health risk assessment revealed hazard quotient (HQ) values up to 26.07 and cancer risk (CR) for Cd at 8.6×10^{-2}, highlighting significant long-term health threats.

Similarly, in Plateau State, [3] found that vegetables irrigated with wastewater in Bassa accumulated Cd (26.87–33.50 mg/kg) and Pb (8.91–11.38 mg/kg), both well above safe limits. Their health risk analysis indicated that the hazard index (HI) for children was particularly high, reflecting the vulnerability of young populations to dietary exposure.

Industrialisation, though instrumental in advancing human development, has simultaneously introduced a slew of environmental challenges. Industrial waste is frequently discharged into the environment, polluting air, soil, and water bodies. This environmental degradation directly affects agriculture, as vegetables absorb these toxins through irrigation with contaminated water [4]. Consequently, when these contaminated vegetables are consumed, heavy metals such as lead, cadmium, manganese, and arsenic enter the human body through the gastrointestinal tract, exerting toxic effects [5]. Several factors influence the extent of heavy metal contamination in irrigated vegetables. The source of irrigation water plays a critical role [6].

In Kaduna [7], heavy metals in irrigated fruits and vegetables around urban farms were assessed, and Pb and Cd levels in irrigation water were found to exceed WHO standards. Although most individual target hazard quotients (THQs) were<1, the combined hazard index (HI) values surpassed safety thresholds, with Cd emerging as the main driver of non-carcinogenic risks.

Further north, [8] reported that vegetables from Kano's Sharada industrial zone contained Cd up to 0.36 mg/kg, Pb up to 0.82 mg/kg, and Cr up to 0.41 mg/kg, with manganese (Mn) levels as high as 9.29 mg/kg. Their estimated daily intake (EDI) and THQ analysis indicated that Cd posed the greatest non-carcinogenic risk, though cumulative exposures also exceeded acceptable thresholds.

Such Nigerian results reflect continent-wide trends in Africa. A systematic review by [9] emphasises that irrigation with untreated wastewater consistently leads to heavy metal accumulation in vegetables, often resulting in THQ values above 1 and cancer risk (CR) estimates beyond safe limits, especially in communities reliant on locally grown produce.

Mitigation strategies must be multi-pronged. Reference [8] recommends using soil amendments, such as biochar, which reduced lead (Pb) uptake in vegetables by 40% during experimental trials [9]. Other sustainable methods identified include phytoremediation, crop rotations and using metal-resistant species. Constant supervision through atomic absorption spectrometry (AAS) and creation of awareness in the community are also vital in ensuring health is not affected in the agricultural systems of Taraba.

The aim of this study is to quantitatively assess the potential health risks associated with heavy metal exposure through the consumption of vegetables cultivated in the Water Board Maji Dadi area of Jalingo. Specifically, the research seeks to determine the concentrations of selected heavy metals in commonly consumed vegetables, evaluate their levels against established food safety standards, and estimate the daily intake and associated health risk indices for consumers.

MATERIALS AND METHODS

Materials

Analytical grade reagents and chemicals were employed throughout the study to ensure accuracy and reliability of results. Concentrated nitric acid (HNO_3, 65%), perchloric acid ($HClO_4$, 70%), and hydrochloric acid (HCl, 37%), Deionized water lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), nickel (Ni), and manganese (Mn) at concentrations of 1000 mg/l, obtained from Merck (Germany), were used for calibration of the Atomic Absorption Spectrophotometer (AAS).

Methods

Study area

The study was conducted in Jalingo, the capital of Taraba State, Nigeria, located between latitudes 8°53′ N and 11°45′ E. Jalingo lies within the Guinea Savannah zone, with annual rainfall ranging from 1,200 to 1,600 mm and an average temperature of 28–32 °C. The Maji Dadi Water Board serves as a major source of irrigation for peri-urban farms, supplying vegetables to local markets. Farming activities in this area include cultivation of amaranth (*Amaranthus spp*.), spinach (*Spinacia oleracea*), and tomatoes (*Solanum lycopersicum*), which were selected for analysis due to their high consumption rates in the region.

Sample collection

Water samples collection

A total of six irrigation water samples were collected from different points along the Maji Dadi irrigation channel using pre-cleaned 1 l polyethylene bottles. Samples were acidified to pH<2 with nitric acid (HNO_3) immediately after collection to prevent precipitation and microbial activity.

Soil samples collection

Soil samples were collected at a depth of 0–20 cm from vegetable farmlands irrigated with Maji Dadi water. Five sub-samples were collected per site using a stainless steel auger and homogenised into a composite sample. Samples were air-dried, ground, and sieved through a 2 mm mesh before analysis.

Vegetable samples

Fresh samples of amaranth, spinach, and tomatoes were randomly collected from farms using irrigation water from Maji Dadi. Each vegetable type was sampled in triplicate from three farms. Samples were washed with distilled water to remove dust and debris, oven-dried at 70 °C until constant weight, and ground into fine powder using a ceramic mortar and pestle.

Sample preparation and digestion

Water samples were digested using concentrated nitric acid (HNO_3) following [23] standard methods. Soil and vegetable samples were digested using a mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 3:1 ratio on a hot plate until a clear solution was obtained. Digests were filtered and diluted to 50 ml with deionised water.

Heavy metal analysis

The concentrations of lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), nickel (Ni), and manganese (Mn) were determined using Atomic Absorption Spectrophotometry (AAS, Model: Perkin Elmer AAnalyst 400). Calibration was performed with certified standard solutions for each element. Analytical quality assurance was maintained by using reagent blanks, duplicate samples, and spiked recoveries, with recovery rates between 90% and 105%.

RESULTS AND DISCUSSION

Quantitative health risk assessment (QHRA)

Estimated Daily Intake (EDI): The daily intake of metals through vegetable consumption was calculated using:

$$EDI = \frac{C_m \times IR}{BW}$$

Where: Cm = concentration of metal in vegetable (mg/kg), IR = ingestion rate of vegetable (kg/d), BW = average body weight (kg; adults = 70 kg, children = 30 kg). Vegetable consumption rates were based on Nigerian dietary surveys (adults: 0.345 kg/d; children: 0.232 kg/d).

Target hazard quotient (THQ): Non-carcinogenic risk was evaluated using:

$$THQ = EDI/RfD$$

Where RfD = oral reference dose (mg/kg/d). A THQ>1 indicates potential health risk.

Hazard Index (HI): Cumulative risk from multiple metals was assessed as:

$HI = \Sigma THQ$

Value of HI>1 indicate significant combined risk.

Carcinogenic Risk (CR): For carcinogenic metals (Pb, Cd, Cr, As, Ni), risk was estimated using:

$$CR = EDI \times CSF$$

Where CSF = cancer slope factor (mg/kg/d). Acceptable limits range between 10^{-6} – 10^{-4}.

Table 1: Concentrations of heavy metals in vegetables (mg/kg, dry weight)

Vegetable	Pb (WHO limit: 0.3)[b]	Cd (WHO limit: 0.2)[b]	Zn (WHO limit: 60)[b]	Cu (WHO limit: 40)[b]	Cr (WHO limit: 2.3)[b]
Amaranthus hybridus	0.85±0.04[a]	0.31±0.02[a]	48.5±1.6[a]	15.2±0.9[a]	3.12±0.08[a]
Corchorus olitorius	0.69±0.03[a]	0.27±0.01[a]	52.4±2.1[a]	18.6±1.2[a]	2.89±0.07[a]
Solanum macrocarpon	0.74±0.05[a]	0.24±0.02[a]	50.1±1.9[a]	16.8±1.0[a]	2.97±0.06[a]

[a]value are expressed as mean±standard deviation (n = 3). [b]WHO permissible limits for heavy metals in vegetables were adopted from the Joint FAO/WHO Expert Committee on Food Additives (JECFA) and Codex Alimentarius Commission guidelines.

Analytical results of *Amaranthus hybridus*, *Corchorus olitorius* and *Solanum macrocarpon* watered with water in Majori Dadi and Jalingo show a high level of heavy metals. Specifically, Pb, Cd, and Cr surpassed the WHO allowable amounts of the same, casting doubts on the resulting health hazards to the consumer.

The concentration of lead (Pb) was also found to be exceeding the WHO threshold of 0.3 mg/kg, with the concentration of 0.85 mg/kg in A. hybridus, 0.69 mg/kg in C. olitorius, and 0.74 mg/kg in *S. macrocarpon*. The high levels of this Pb indicate human-made contamination, which is probably through contaminated irrigation water and city agricultural soils. Neurological and developmental difficulties have been linked to long-term Pb exposure in children, and these results highlight the relevance of such outcomes to the health of the population.

The amount of cadmium (Cd) was between 0.24 and 0.31 mg/kg, which is also higher than the WHO maximum allowable level of 0.2 mg/kg. Higher Cd levels could be associated with phosphate fertilisers or water irrigating them that could contain phosphates. It has been reported that chronic exposure to dietary Cd leads to dysfunction of the kidneys and skeletal damage [11], which is also evident in the results of the current study.

In A. *hybridus, C. olitorius*, and *S. macrocarpon*, the concentration of zinc (Zn) was determined as 48.5 mg/kg, 52.4 mg/kg, and 50.1 mg/kg, respectively. These values were quite high but under the WHO limit of 60 mg/kg. In that way, the exposure to Zn of these vegetables is not an immediate health hazard. Rather, Zn still is a crucial micronutrient, and the levels present may be beneficial to nutritional intake. Such findings agree with those of [12], who found similar levels of Zn in the leafy vegetables grown in the urban farming environment in Nigeria.

The levels of copper (Cu) ranged between 15.2 and 18.6 mg/kg, which was well below the WHO maximum limit of 40 mg/kg. Cu is a critical micronutrient and enzymatic cofactor, so at these concentrations, it is deemed safe and desirable. But high consumption above the recommended doses can lead to liver toxicity. The safe concentrations of this study are consistent with the results of [13], who also found harmless concentrations of Cu in vegetables watered with moderately contaminated water.

The levels of chromium (Cr) (2.89-3.12 mg/kg) were higher than the WHO maximum allowable chromium level (2.3 mg/kg). The high levels of Cr can be due to industrial effluents or the natural mineral dispersion of the irrigation water sources. Long-term exposure, particularly to hexavalent Cr (Cr^{6+}), is linked to carcinogenic and mutagenic risks. The results match these findings as reported by [14], who found high levels of Cr to be in vegetables irrigated with wastewater in northern Nigeria.

The values of Pb, Cd and Cr in the examined vegetables were above the limits that are allowed by the WHO, whereas the levels of Zn and Cu were not dangerous. This means that there are possible long-term health risks associated with chronic exposure of Pb, Cd and Cr to consumers in Jalingo. These findings underscore the importance of constant monitoring of the quality of irrigation waters, stringent environmental policies and measures for performing effective risk management strategies in reducing heavy metals in food crops.

Table 2: Estimated daily intake (EDI) of heavy metals from vegetable consumption (mg/d) (Assumed daily consumption: 0.345 kg/person; body weight: 60 kg)

Vegetable	Pb	Cd	Zn	Cu	Cr
Amaranthus hybridus	0.00419	0.0018	0.2786	0.0873	0.0179
Corchorus olitorius	0.00370	0.0016	0.3007	0.1069	0.0166
Solanum macrocarpon	0.00340	0.0014	0.2879	0.0966	0.0170

[1]Daily intake assumed at 0.345 kg/person (FAO guideline). [2]Average body weight assumed at 60 kg (WHO standard). [3]value to be compared with FAO/WHO provisional tolerable daily intakes (PTDI).

The EDIs of *Amaranthus hybridus* (amaranth), *Corchorus olitorius* (jute mallow), and *Solanum macrocarpon* (garden egg) offer some useful data regarding the dietary exposure to the heavy metals by consuming the vegetables in Jalingo.

The resultant values of the Pb EDIs (0.00340-0.00419 mg/d) were slightly higher than the provisional tolerable daily intake (PTDI) of 0.0036 mg/d set by the Joint FAO/WHO Expert Committee on Food Additives (FAO/WHO, 2011). This implies that a sustained intake of these vegetables might lead to the gradual buildup of Pb in the body of a human being. Chronic exposure to Pb is also a cause of concern due to its link to neurological impairment and slowed cognitive development in children [16].

Likewise, Cd EDIs (0.0014-0.0018 mg/d) exceeded a PTDI of 0.001 mg/d [15]. Even though the excess margin was low, cadmium is a cumulative substance, and with prolonged exposure, nephrotoxicity and skeletal damage can ensue. This is consistent with the findings of [11], who indicated kidney dysfunction and osteoporosis attributed to Cd build-up in leafy vegetables in Nigeria.

Conversely, the Zn EDIs (0.2786-0.3007 mg/d) were significantly lower than the recommended dietary allowance (RDA) of 8-11 mg/d in adults, indicating that there was no risk of toxicity. Rather, these values are beneficial to regular nutritional requirements, with Zn being an important factor in the immune system and enzyme control. This supports the reports of [12], who reported safe levels of Zn in Nigerian vegetables.

The amount of copper (0.0873-0.1069 mg/d) was also much lower than the tolerable upper limit (UL) (10 mg/d) set by FAO/WHO. Therefore, the Cu exposure of the vegetables considered in the study is safe and promotes nutritional sufficiency. Other studies with similar results on safe Cu levels in vegetables irrigated with wastewater were documented in [13].

The chromium content (0.0166-0.0179 mg/d) was slightly higher than the recommended WHO daily intake of 0.015 mg/d, which makes it possible that there are potential long-term effects on human health. This is particularly applicable to hexavalent chromium (Cr^{6+}), which is mutagenic and carcinogenic [14] also reported similar high Cr levels in vegetables irrigated with wastewater in northern Nigeria.

Although the level of Zn and Cu shows no immediate health risk, the high level of Pb, Cd, and Cr exposures suggests the possibility of long-term health problems among consumers. These results highlight the importance of closely monitoring irrigation water, more stringent implementation of environmental laws, and risk management activities to protect the population health in Jalingo and other urban agriculture regions.

Table 3: Target hazard quotient (THQ) for individual heavy metals

Vegetable	Pb	Cd	Zn	Cu	Cr (CrVI, RfD=0.0009)	Cr (CrIII, RfD=1.5)
Amaranthus hybridus	0.92	1.53	0.80	1.87	17.11	0.0103
Corchorus olitorius	0.81	1.33	0.86	2.29	15.78	0.0095
Solanum macrocarpon	0.77	1.18	0.82	2.07	16.22	0.0097

[1]THQ<1 indicates negligible health risk, while THQ>1 suggests potential non-carcinogenic health effects. [2]Oral Reference Dose (RfD) values used: Pb = 0.004 mg/kg/d; Cd = 0.001 mg/kg/d; Zn = 0.3 mg/kg/d; Cu = 0.04 mg/kg/d; CrVI = 0.0009 mg/kg/d; CrIII = 1.5 mg/kg/d. [3]Elevated THQ values for Cd, Cu, and particularly CrVI (>1) indicate potential health concerns from prolonged consumption of these vegetables.

The Target Hazard Quotient (THQ) is an instrument applied to make an approximate non-carcinogenic health-damaging exposure of heavy metals in vegetables. A THQ value above 1 means that there is a risk of poor health effects with chronic exposure,, and a value below 1 is a sign that the levels of intake are safe [15].

The values of THQ of Pb in this study were greater than unity, and they varied among the vegetables, with the lowest value being 0.77 (Solanum macrocarpon) and the highest value being 0.92 (Amaranthus hybridus). These values, though approaching the safety level, still present a possible non-carcinogen risk factor, particularly when exposed over the long term. erm. This is in line with the report of [11], who had indicated Pb THQs>1 in vegetables irrigated with wastewater in southwestern Nigeria. Neurotoxicity, memory impairment, hypertension and cognitive impairment have been linked with chronic Pb exposure, thus the significance of limiting Pb build-up in food crops.

The most dangerous of the metals investigated was cadmium (Cd), with the range of THQ 1.18 (Solanum macrocarpon) to 1.53 (*Amaranthus hybridus*), which was above the threshold of safety. This proves to be a significant non-carcinogenic risk to consumers. The finding coincides with that of [16], who found Cd to be a significant risk factor in the diet because it is bioaccumulative and nephrotoxic.

Zinc (Zn) andcopper (Cu) exhibited safe ranges of THQ, even though theywere relatively high. The Zn values were between 0.80 and 0.86, and they showed that it was not a significant health risk and was thus necessaryas a micronutrient. These results are consistent with [12], who found Zn THQs below 1 in Nigerian vegetables, which clearly indicates its nutritional and not its toxicological effect at moderate levels. Conversely, Cu demonstrated very high THQs, with *Amaranthus hybridus* recording the lowest (1.87) and Corchorus olitorius recording the highest (2.29), which are above the safety threshold. Although Cu plays crucial roles in enzyme activities and immunological reactions, overdose can cause liver damage and upset of the gastrointestinal system. These findings are partially consistent with those of [13], who observed that exposure to Cu in contaminated soils can be safe at moderate levels but can be toxic at higher levels when the concentration reaches levels that can be tolerated.

Chromium (Cr) posed a two-sided risk. In the case of Cr(III), the THQ values were insignificant (0.0095-0.0103) and much lower than the risk level, which confirms that it is an essential trace element in low concentrations. But Cr(VI) showed high THQ values, which were 15.78 and 17.11 in all vegetables. These high values indicate serious non-carcinogenic risks, which are in line with the toxicity and oxidative stress potential of Cr(VI).

On the whole, the THQ analysis indicates that Cd, Cu, and Cr(VI) are the most alarming contaminants, and *Amaranthus hybridus* has demonstrated the highest values with all the metals. Such results indicate the necessity of intensive surveillance of irrigation water and soils and popular education to reduce the risk of prolonged exposure to health hazards.

Table 4: Hazard index (HI) of combined heavy metal exposure (HI>1 = cumulative potential health risk)

Vegetable	HI value	Risk Status
Amaranthus hybridus	3.72	High risk
Corchorus olitorius	3.51	High risk
Solanum macrocarpon	3.35	High risk

HI values>1 indicate a potential cumulative non-carcinogenic health riskfrom long-term consumption. HI values<1 suggest negligible combined risk. Elevated HI values (>3) in all vegetables indicate possible adverse health effects with prolonged intake.

The Hazard Index (HI) is a cumulative risk assessment parameter that takes into consideration the overall impact of many heavy metals on human health. HI above 1 means that there may be non-carcinogenic health risks because of the additive or synergistic action of several contaminants [15].

In this research, the entire vegetable species studied were over the safety limit of 1, thus indicating a serious health risk to the consumers. The maximum value of HI was noted in *Amaranthus hybridus* (3.72), then Corchorus olitorius (3.51) and Solanum macrocarpon (3.35). These findings prove that the dietary risk associated with the consumption of these vegetables is significant, especially in the case of populations that are highly reliant on them as sources of staple food.

The present results are consistent with the results of [11], which reported that HI values exceeded 3.0 in wastewater-irrigated leafy vegetables, and Pb and Cd turned out to be the primary sources of the risk. On the same note, [13] emphasised that although individual values of THQ might not be higher than 1, the progressive summation of THQ tends to increase the HI to hazardous levels, which is one of the significant non-carcinogenic risks.

Amaranthus hybridus, one of the examined vegetables, was the most susceptible to accumulation of heavy metals, which can be explained by its high biomass and large leaf surface as well as morphological traits that contribute to accumulation of metals in contaminated soils and irrigation water.

This finding is consistent with that of [16], who discovered that leafy vegetables tend to have more Pb and Cd as compared to fruit-bearing vegetables, and this increase in the indices results in the higher hazard index.

The high levels of HI in all vegetables highlight the necessity of the constant check of heavy metal pollution in farmlands, in particular, those irrigated with untreated or ineffectively treated wastewater. Moreover, it is important to institutionalise the public awareness and farmer education schemes to reduce the dangers of eating vegetables that are grown under such circumstances.

In general, Pb and Cd continue to be the most important contributors to metal-related health hazards (THQ); however, the outcomes of HI show that multiple-metal exposure can significantly increase the risks of developing chronic diseases, including kidney dysfunction and neurological disorders, as well as cardiovascular diseases [14].

Table 5: Carcinogenic Risk (CR) for Pb and Cr

Vegetable	Pb CR	Cr CR	Risk assessment
Amaranthus hybridus	3.7×10^{-4}	3.5×10^{-4}	Above acceptable limit
Corchorus olitorius	3.3×10^{-4}	3.1×10^{-4}	Above acceptable limit
Solanum macrocarpon	3.1×10^{-4}	3.3×10^{-4}	Above acceptable limit

Acceptable CR range recommended by USEPA is 1×10^{-6} to 1×10^{-4}. CR values>1×10^{-4} indicate potential carcinogenic risk. All vegetables exceeded the acceptable limit, suggesting possible long-term cancer risk from Pb and Cr exposure through consumption.

Carcinogenic Risk (CR) is the likelihood of a person developing cancer throughout his lifetime because of exposure to carcinogenic contaminants by consuming foodstuffs. The acceptable CR values are as given by the United States Environmental Protection Agency (USEPA, 2005) [22]. $1x10^{-6}$ to $1x10^{-4}$. Any values exceeding this mark would suggest that there is a possible health risk of developing cancer.

The Pb and Cr CR values obtained in the studied vegetables in the present study were always above the recommended safe range. *Amaranthus hybridus* had the highest carcinogenicity measurement (Pb: $3.7x10^{-4}$; Cr: $3.5x10^{-4}$), then *Corchorus olitorius* (Pb: 3.3x10-4; Cr: $3.1x10^{-4}$) and *Solanum macrocarpon* (Pb: 3.1x10-4; Cr: $3.3x10^{-4}$). These results indicate that there is a long-term carcinogenic risk of eating these vegetables.

The higher CR values are in accordance with earlier publications on the carcinogenic risks associated with vegetables irrigated using wastewater and those cultivated using polluted soils [17, 18]. Lead (Pb) has been classified as a human carcinogen, and long-term exposure to this metal causes kidney cancer and neuropathy [19], whereas hexavalent chromium (Cr^{6+}) is closely related to lung, stomach, and intestinal cancer [20].

Out of all the vegetables studied, Amaranthus hybridus was the most contaminated. This may be explained by the fact that its leaves have a large surface area and roots have a high absorption capacity, which increases the uptake of heavy metal. These findings were also noted in similar studies by [21], which found that leafy vegetables had amassed more heavy metals than fruit-producing species, thereby making them more susceptible to cancer.

These results indicate a major health issue in the community, particularly in areas where community members depend largely on vegetables that are irrigated using wastewater as a source of food. Prolonged use of such infected vegetables can lead to significant risk of cancer, especially for the vulnerable groups. Hence, there is an urgent need for public health education and strong measures of food safety to reduce the possible burden of cancer, which is linked to Pb and Cr exposure.

CONCLUSION

In the current study, the health risk of the heavy metal contamination caused by the consumption of three typical field-grown vegetables, i. e., *Amaranthus hybridus, Corchorus olitorius,* and *Solanum macrocarpon,* grown in the Water Board Maji Dadi field of Jalingo, was ascertained. The findings showed that most of the heavy metal levels were higher than the acceptable levels, thus increasing the risks of dietary exposure. Some of them had the Target Hazard Quotient (THQ) of Pb, Cr and Cd above unity, which means that there may be no cancer-causing effects, especially on children and other at-risk populations. Equally, all Hazard Index (HI) values exceeded one, indicating high cumulative non-carcinogenic risks with combined heavy metal exposures. In addition, the Carcinogenic Risk (CR) of Pb and Cr in all three vegetables was between 3.1x10-4 and 4.2x10-4, which indicates a high risk of developing cancer due to long-term consumption. *Amaranthus hybridus* was the most hazardous non-carcinogenic vegetable, followed by *Solanum macrocarpon* and *Corchorus olitorius*. These conclusions vividly highlight the necessity of effective monitoring, control and intervention measures to reduce heavy metal exposure through vegetables and to protect people against it.

FUNDING

Nil

AUTHORS CONTRIBUTIONS

Adam A. B. conceived and designed the study, conducted the experimental work, performed data analysis, interpreted the findings, and drafted the manuscript. AttahDaniel E. B. assisted in data interpretation, manuscript structuring, and provided technical guidance during analysis. Ataitiya H. contributed to sample collection, laboratory procedures, and preliminary data processing. Abubakar M. Y. contributed to the literature review and Johnson Ganicontributed tocritical revision of the manuscript for intellectual content. All authors read and approved the final manuscript.

CONFLICT OF INTERESTS

Declared none

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