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Dietary Exposure and Health Risk Assessment of Heavy Metals in Leafy Vegetables from Afor-Ugbolu Market, Nigeria

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ABSTRACT

The safety of leafy vegetables is increasingly threatened by heavy metal contamination, particularly in developing regions where routine monitoring is limited. This study investigated the levels, dietary exposure, and potential health risks of selected heavy metals (Cu, Pb, Zn, and Cd) in three widely consumed leafy vegetables—Talinum triangulare, Vernonia amygdalina, and Telfairia occidentalis—purchased from Afor-Ugbolu Market, Nigeria. Samples collected from multiple vendors were processed and analyzed using atomic absorption spectrophotometry under validated analytical conditions. Human health risk was evaluated using estimated daily intake (EDI), target hazard quotient (THQ), hazard index (HI), carcinogenic risk (CR), and pollution load index (PLI). Metal concentrations ranged from 0.041–0.301 mg/kg for copper, 0.041–0.122 mg/kg for lead, 0.0039–0.0287 mg/kg for cadmium, and 0.052–0.091 mg/kg for zinc, with bitter leaf exhibiting the highest cadmium levels (0.0287 mg/kg) and pumpkin leaf showing the highest lead concentrations (0.122 mg/kg). All measured concentrations remained below the WHO/FAO permissible limits. Target hazard quotient (THQ) values for individual metals ranged from 0.009 to 0.172, with all vegetables displaying THQ values below unity. The combined hazard index (HI) values ranged from 0.114 to 0.241, with bitter leaf showing the highest value (0.241); however, all HI values remained below the acceptable threshold of unity, indicating negligible non-carcinogenic risk. Cadmium contributed most prominently to carcinogenic risk, particularly in bitter leaf (5.36×10^{-5}), approaching the upper acceptable threshold, while lead showed low carcinogenic risk across all vegetables. The pollution load index values for all vegetables were less than one (ranging from 0.020–0.031), indicating the absence of significant environmental contamination. These results suggest that the studied vegetables are safe for consumption in terms of immediate health effects. Nevertheless, the potential for long-term risks associated with cadmium exposure highlights the need for continuous monitoring, improved agricultural practices, and stricter environmental control measures to ensure food safety and protect public health.

Keywords: Heavy metals, Leafy vegetables, Dietary exposure, Risk assessment, Cadmium, Nigeria

INTRODUCTION

Leafy vegetables are vital components of human diets due to their high content of essential micronutrients, dietary fibre, and bioactive compounds that contribute to the prevention of chronic diseases and the maintenance of overall health (Hosen *et al*., 2024; Shetty *et al*., 2025). In many developing countries, including Nigeria, vegetables such as *Talinum triangulare* (water leaf), *Vernonia amygdalina* (bitter leaf), and *Telfairia occidentalis* (pumpkin leaf) are widely consumed because of their affordability, accessibility, and ethnomedicinal significance. However, the nutritional benefits of these vegetables may be compromised by contamination with heavy metals, which has become an increasing global food safety concern (Ali *et al*., 2025).

Heavy metals such as copper (Cu) and zinc (Zn) are essential trace elements required for various physiological and enzymatic processes, but they can become toxic when present in excessive concentrations. In contrast, lead (Pb) and cadmium (Cd) are non-essential elements with well-documented toxic effects even at low levels of exposure [Tchounwou *et al*., 2022; World Health Organization (WHO), 2021]. Chronic exposure to Pb has been associated with neurotoxicity, cognitive impairment, and cardiovascular dysfunction, while Cd exposure has been linked to renal damage, bone demineralisation, and carcinogenic outcomes (Jaishankar *et al*., 23; Habu *et al*., 2025). These risks are particularly significant in populations with high reliance on plant-based diets.

The contamination of vegetables by heavy metals is primarily driven by anthropogenic activities, including industrial emissions, vehicular exhaust, improper waste disposal, and the use of contaminated water for irrigation (Kaur *et al*., 2025). Additionally, agricultural practices such as the application of fertilizers and pesticides can introduce trace metals into soils, where they persist due to their non-biodegradable nature (Chmielewski *et al*., 2025). Once present in the soil, these metals can be taken up by plants through root absorption or deposited on leaf surfaces from the atmosphere. Leafy vegetables are particularly susceptible to metal accumulation because of their high transpiration rates and large surface areas, which enhance both uptake and deposition processes (Chmielewski *et al*., 2025).

Dietary intake is a major pathway of human exposure to heavy metals, especially in regions where vegetables constitute a significant portion of daily food consumption. Unlike acute toxicity, which is relatively rare, chronic exposure through food consumption is more common and may lead to bioaccumulation of metals in human tissues over time, resulting in long-term health effects (Singh *et al*., 2020). Even when metal concentrations in individual food items fall within permissible limits, cumulative exposure from multiple dietary sources may pose substantial health risks, particularly for vulnerable populations such as children and pregnant women (FAO/WHO, 2019).

In Nigeria, the issue of heavy metal contamination in vegetables is exacerbated by rapid urbanization, inadequate environmental regulation, and limited routine monitoring of food safety (Falae *et al*., 2025). Vegetables sold in open markets are often sourced from diverse locations, including peri-urban and roadside farms that are exposed to various pollution sources. Consequently, consumers may unknowingly be exposed to contaminated food products. Recent studies across different Nigerian regions have reported detectable levels of heavy metals in commonly consumed vegetables, underscoring the need for continuous surveillance and risk assessment (Kola *et al.*, 2026).

Afor-Ugbolu Market serves as a major distribution hub for leafy vegetables consumed by a large population in Delta State and its surrounding areas. Despite its importance in the local food supply chain, there is limited empirical data on the levels of heavy metal contamination in vegetables sold in this market. Given the high consumption rate of water leaf, bitter leaf, and pumpkin leaf, it is essential to evaluate their safety with respect to heavy metal exposure.

Therefore, this study aims to (i) determine the concentrations of selected heavy metals (Cu, Pb, Zn, and Cd) in commonly consumed leafy vegetables obtained from Afor-Ugbolu Market, and (ii) assess the associated dietary exposure and potential non-carcinogenic and carcinogenic health risks. The findings will contribute to the existing body of knowledge on food safety and provide evidence-based insights for public health protection and policy formulation.

MATERIALS AND METHODS

Study Area

This study was conducted at Afor-Ugbolu Market, a prominent open market located in Ugbolu, Delta State, Nigeria (approximately 6.30844° N latitude and 6.68886° E longitude). The market serves as a major commercial hub, supplying a wide range of fresh vegetables sourced from surrounding rural and peri-urban farming communities. Due to its central role in the local food distribution network and high consumer patronage, the market provides a representative setting for assessing potential dietary exposure to heavy metals through vegetable consumption.

Sample Collection

Fresh samples of three commonly consumed leafy vegetables—water leaf (*Talinum triangulare*), bitter leaf (*Vernonia amygdalina*), and pumpkin leaf (*Telfairia occidentalis*)—were purchased from randomly selected vendors within Afor-Ugbolu Market. To ensure representativeness, samples were collected from multiple vendors across different sections of the market. Thirteen different samples of each vegetable type were collected, and the samples were pooled to form composite samples. The collected samples were placed in clean polyethylene bags, properly labelled, and transported to the laboratory for analysis.

Sample Preparation

In the laboratory, vegetable samples were thoroughly washed with tap water followed by distilled water to remove soil particles, dust, and surface contaminants. The edible portions were separated and air-dried at room temperature, followed by oven-drying at 60–70°C until a constant weight was achieved. The dried samples were ground into fine powder using a clean mortar and pestle and sieved to obtain uniform particle size. The powdered samples were stored in airtight containers prior to digestion and analysis.

Digestion of Samples

A wet digestion method was employed for the extraction of heavy metals. Approximately 1.0 g of the dried sample was weighed into a digestion flask. A mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a ratio of 3:1 was added. The mixture was heated on a hot plate under controlled conditions until a clear solution was obtained, indicating complete digestion. The digest was allowed to cool, filtered using Whatman filter paper, and diluted to a known volume (e.g., 50 mL) with deionised water.

Determination of Heavy Metals

The concentrations of copper (Cu), lead (Pb), zinc (Zn), and cadmium (Cd) in the digested samples were determined using Atomic Absorption Spectrophotometry (AAS) (Buck Scientific Model 210 VGP, USA). The instrument was operated under optimized conditions with element-specific hollow cathode lamps. Detection wavelengths (nm) were set as follows: Cu (324.8 nm), Pb (217.0 nm), Zn (213.9 nm), and Cd (228.8 nm). Calibration curves were prepared using standard solutions at concentrations of 0.0, 0.5, 1.0, 2.0, and 5.0 mg/L for each metal. The calibration curves demonstrated excellent linearity, with correlation coefficients (R^2) greater than 0.995 for all analyzed metals.
Quality assurance was maintained by analyzing reagent blanks, duplicate samples, and certified reference materials. The limits of detection (LOD) and limits of quantification (LOQ) were determined based on three and ten times the standard deviation of the blank signal, respectively. The limits of detection (LOD) and limits of quantification (LOQ) for each metal were determined based on the analytical performance of the Atomic Absorption Spectrophotometer. The LOD values were 0.01 mg/kg for Cu, 0.005 mg/kg for Pb, 0.001 mg/kg for Cd, and 0.005 mg/kg for Zn, while the corresponding LOQ values were 0.03 mg/kg, 0.015 mg/kg, 0.003 mg/kg, and 0.015 mg/kg, respectively. These values are consistent with typical detection capabilities of flame AAS under optimized operating conditions.

Recovery rates ranged from 90% to 110%, indicating high analytical accuracy and reliability. All measurements were conducted in triplicate, and the mean values were reported.

Quality Assurance and Quality Control (QA/QC)

To ensure reliability of the results, standard analytical procedures were followed. All glassware and equipment were thoroughly cleaned and rinsed with deionised water prior to use. Blank samples and standard reference materials were analysed alongside the samples to check for contamination and accuracy. Recovery studies were conducted to validate the digestion and analytical procedures, with acceptable recovery rates ranging between 90% and 110%.

Health Risk Assessment

To evaluate the potential health risks associated with the consumption of contaminated vegetables, the following indices were calculated:

Estimated Daily Intake (EDI)

The Estimated Daily Intake (EDI) of each metal was calculated using the equation below and the IR and BW values where according to FAO (2019).

$EDI = (C_{metal} \times IR) / BW$

Where:

C = concentration of the metal (mg/kg),

IR = ingestion rate of vegetable taken as 0.345 kg/day and

BW = average body weight (70 kg for adults).

Hazard Quotient of Metal to Human (HQ): The hazard quotient (HQ) was applied to assess the potential health risks linked to the intake of vegetables. HQ represents the ratio of exposure to the reference oral dosage (RFD). If the ratio is less than one (1), there will be no significant risk.

$HQ = \frac{DIM}{RFDM}$ (USEPA, 2017)

Where DIM = represents the average daily dose (mg/kg/d) of the metal, RFDM = is the reference dose of the metal (mg/kg/d), which is defined as the maximum tolerable daily intake of metal with no adverse effect. The RFDM used were 0.04, 0.0035, 0.001 and 0.30 or Copper, Lead, Cadmium and Zinc respectively (USEPA, 2010)

Hazard Index (HI)**:** The hazard index (HI) was calculated to determine the overall health risk of exposure to all the heavy metals via the ingestion of a RTE vegetables described by (USEPA, 2002). The hazard index (HI) was calculated as the summation of the hazard quotient (HQ) arising from all the metals examined. $HI = \sum HQ$

The hazard index value correlates with the toxicity level of the ingested vegetables. HI > 1 signifies that the anticipated exposure may present possible health hazards.

Pollution Load Index (PLI)

The pollution load index (PLI) was used to assess the overall level of heavy metal contamination in the analyzed vegetables. The PLI was calculated using the contamination factor (CF) of each metal according to standard procedures:

$CF = \frac{Cmetal}{Creference}$

$PLI = (CF_{CU} \times CF_{Pb} \times CF_{Cd} \times CF_{Zn})^{1/4}$

Where:

- C_{metal} is the measured concentration of the metal (mg/kg)
- $C_{reference}$ is the permissible limit recommended by the Food and Agriculture Organization and World Health Organization

The reference values used were: Cu (40 mg/kg), Pb (0.30 mg/kg), Cd (0.20 mg/kg), and Zn (60 mg/kg) (FOA, 2011)

PLI values were interpreted as follows:

- PLI < 1: no pollution
- PLI = 1: baseline level

- PLI > 1: polluted

Statistical Analysis
Data obtained were expressed as mean ± standard deviation. One-way Analysis of Variance (ANOVA) was used to determine significant differences in heavy metal concentrations among the vegetable samples. Differences were considered statistically significant at $p < 0.05$. Statistical analyses were performed using software such as SPSS version 25.

RESULTS
The concentrations of selected heavy metals (Cu, Pb, Cd, and Zn) in the analyzed leafy vegetables are presented in Table 1 as mean ± standard deviation. The results showed variability in metal accumulation among the vegetables. Copper concentrations ranged from 0.208 to 0.301 mg/kg, with bitter leaf exhibiting the highest mean value, while water leaf recorded the lowest. Lead concentrations were highest in pumpkin leaf (0.122 mg/kg) and lowest in bitter leaf (0.044 mg/kg). Cadmium levels were markedly elevated in bitter leaf (0.0287 mg/kg) compared to pumpkin and water leaves. Zinc concentrations varied moderately, with pumpkin and water leaves showing relatively higher values than bitter leaf. Statistical differences were observed for Pb and Cd ($p < 0.05$), while Cu and Zn showed no significant variation across the vegetables.

Table 1: Concentration of Heavy Metals in Selected Leafy Vegetables (mg/kg, Mean ± SD) and Comparison with Permissible Limits

Vegetable	Cu (mg/kg)	Pb (mg/kg)	Cd (mg/kg)	Zn (mg/kg)
Pumpkin leaf (*Telfairia occidentalis*)	0.278 ± 0.090^{ab}	0.122 ± 0.090^{a}	0.0039 ± 0.0040^{b}	0.091 ± 0.070^{a}
Bitter leaf (*Vernonia amygdalina*)	0.301 ± 0.090^{a}	0.044 ± 0.036^{b}	0.0287 ± 0.070^{a}	0.052 ± 0.050^{b}
Water leaf (*Talinum triangulare*)	0.208 ± 0.160^{b}	0.041 ± 0.033^{b}	0.0059 ± 0.0090^{b}	0.079 ± 0.100^{a}

Values are expressed as mean ± standard deviation ($n = 13$). Means within the same column followed by different superscripts are significantly different at $p < 0.05$.

The estimated daily intake (EDI) values Table 2 or all metals were generally low across the vegetables. Copper contributed the highest intake values, whereas cadmium showed the lowest intake in most cases. These values suggest limited daily exposure to heavy metals through the consumption of the studied vegetables.

Table 2: Estimated Daily Intake (EDI) of selected heavy metals through consumption of leafy vegetables from Afor-Ugbolu Market

Vegetable	Cu	Pb	Cd	Zn
Pumpkin leaf	0.00137	0.000601	1.92×10^{-5}	0.000448
Bitter leaf	0.00148	0.000217	1.41×10^{-4}	0.000256
Water leaf	0.00103	0.000202	2.91×10^{-5}	0.000389

The non-carcinogenic risk assessment, expressed as target hazard quotient (THQ) (Table 3), indicated that all individual metal values were below 1. Lead and cadmium contributed relatively higher THQ values compared to copper and zinc, particularly in pumpkin and bitter leaves, respectively. The combined hazard index (HI) values (Table 4) ranged from 0.114 to 0.241, with bitter leaf showing the highest value. However, all HI values remained below unity, indicating that the consumption of these vegetables does not pose significant non-carcinogenic health risks.

Table 3: Target Hazard Quotient (THQ) for selected heavy metals in leafy vegetables indicating non-carcinogenic health risk

Vegetable	Cu	Pb	Cd	Zn
Pumpkin leaf	0.034	0.172	0.019	0.0015
Bitter leaf	0.037	0.062	0.141	0.0009
Water leaf	0.026	0.058	0.029	0.0013

Table 4: Hazard Index (HI) of combined heavy metal exposure from consumption of selected leafy vegetables

Vegetable	HI
Pumpkin leaf	0.227
Bitter leaf	0.241
Water leaf	0.114

The carcinogenic risk (CR) values for lead and cadmium are presented in Table 5. Lead exhibited low carcinogenic risk values across all vegetables, falling within the acceptable range. In contrast, cadmium showed comparatively higher CR values, particularly in bitter leaf, where the risk was notably elevated relative to other vegetables. Although the values generally remained within permissible limits, the higher contribution of cadmium suggests a potential concern for long-term exposure.

Table 5: Carcinogenic Risk (CR) of Pb and Cd from consumption of selected leafy vegetables

Vegetable	Pb (CR)	Cd (CR)
Pumpkin leaf	5.11×10^{-6}	7.30×10^{-6}
Bitter leaf	1.85×10^{-6}	5.36×10^{-5}
Water leaf	1.72×10^{-6}	1.11×10^{-5}

The concentrations of all analyzed heavy metals were below the permissible limits established by the World Health Organization and Food and Agriculture Organization (Tables 6 and 7). However, lead exhibited relatively higher proximity to the permissible threshold, particularly in pumpkin leaf (40.7% of the limit), while cadmium showed notable elevation in bitter leaf (14.35% of the limit).

Table 6: **Comparison of heavy metal concentrations (mg/kg) in leafy vegetables with WHO/FAO permissible limits**

Metal	WHO/FAO Limit (mg/kg)	Pumpkin Leaf	Bitter Leaf	Water Leaf	Status
Cu	40.0	0.278 ± 0.090	0.301 ± 0.090	0.208 ± 0.160	Within limit
Zn	60.0	0.091 ± 0.070	0.052 ± 0.050	0.079 ± 0.100	Within limit
Pb	0.30	0.122 ± 0.090	0.044 ± 0.036	0.041 ± 0.033	Within limit
Cd	0.20	0.0039 ± 0.0040	0.0287 ± 0.070	0.0059 ± 0.0090	Within limit

Table 7: Percentage contribution of heavy metal concentrations in leafy vegetables relative to WHO/FAO permissible limits

Metal	Pumpkin Leaf (%)	Bitter Leaf (%)	Water Leaf (%)
Cu	0.70%	0.75%	0.52%
Zn	0.15%	0.09%	0.13%
Pb	40.7%	14.7%	13.7%
Cd	1.95%	14.35%	2.95%

The contamination factor (CF) and pollution load index (PLI) values for the analyzed vegetables are presented in Table 8 the CF values for all metals were less than 1, indicating low levels of contamination relative to international permissible limits. The PLI values ranged from 0.020 to 0.031 across the vegetables. Pumpkin leaf recorded the highest PLI value (0.031), followed by bitter leaf (0.026) and water leaf (0.020). However, all values were below unity, indicating that the vegetables are not polluted with respect to heavy metal contamination.

Table 8: Contamination Factor (CF) and Pollution Load Index (PLI) of Heavy Metals in Leafy Vegetables

Vegetable	CF (Cu)	CF (Pb)	CF (Cd)	CF (Zn)	PLI	Interpretation
Pumpkin leaf	0.0070	0.407	0.0195	0.00152	0.031	No pollution
Bitter leaf	0.0075	0.147	0.1435	0.00087	0.026	No pollution
Water leaf	0.0052	0.137	0.0295	0.00132	0.020	No pollution

The distribution pattern of heavy metals across the analyzed vegetables is further illustrated using a heatmap (Figure 1). The heatmap provides a visual representation of relative metal concentrations, highlighting variability among the vegetable types. Copper exhibited relatively consistent distribution across all samples, while lead showed higher intensity in pumpkin leaf compared to bitter and water leaves. Cadmium displayed a pronounced concentration in bitter leaf, consistent with the quantitative results, whereas zinc showed moderate distribution with slightly higher levels in pumpkin and water leaves. Overall, the heatmap corroborates the numerical data and emphasizes the differential accumulation patterns of heavy metals among the studied vegetables.

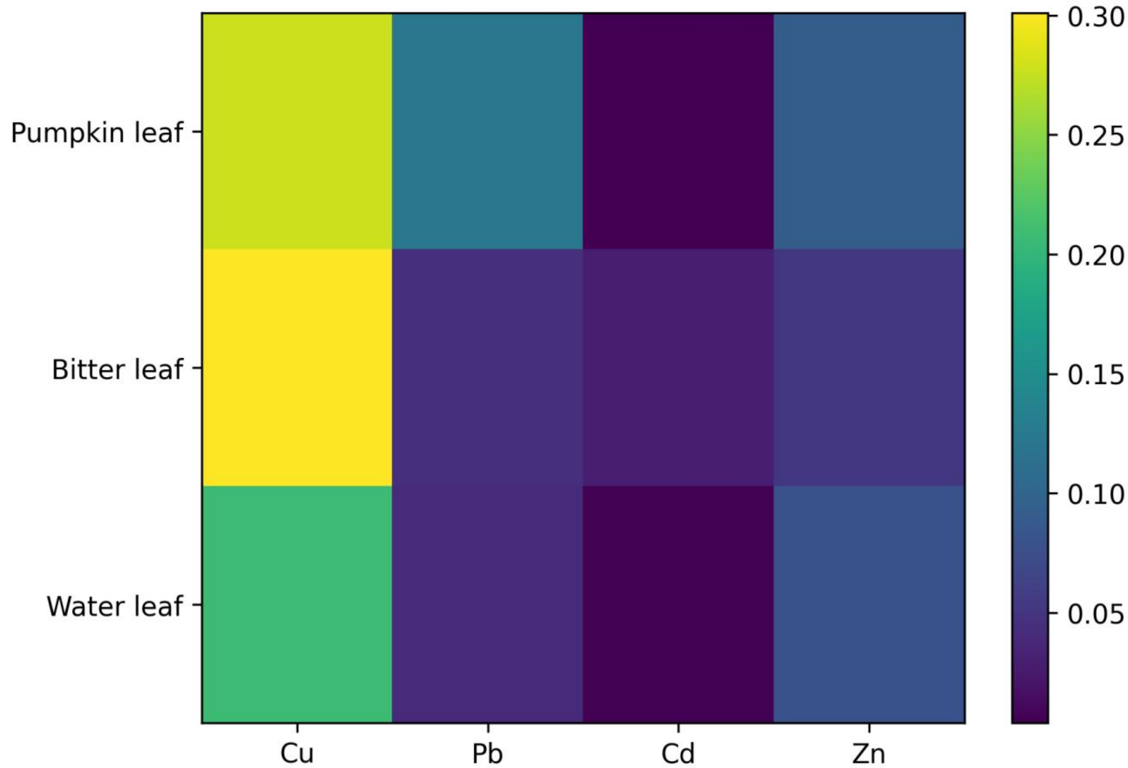

Figure 1: Heatmap of heavy metal distribution (Cu, Pb, Cd, Zn) across the analyzed leafy vegetables.

DISCUSSION

The present study provides important insights into the accumulation of heavy metals in commonly consumed leafy vegetables and their associated health risks. The observed variation in metal concentrations among the vegetables reflects differences in plant uptake mechanisms, environmental exposure, and contamination sources. Leafy vegetables are particularly prone to heavy metal accumulation due to their large surface area and high transpiration rates, which enhance both root uptake and atmospheric deposition (Hosen *et al*., 2024; Chmielewski *et al*., 2025).

The relatively higher concentrations of copper observed across the vegetables may be attributed to its essential role in plant metabolism. As an essential micronutrient, copper is actively absorbed and translocated within plant tissues, which explains its relatively uniform distribution among the vegetables. Similar trends have been reported in other studies where copper levels were influenced primarily by soil composition and agricultural inputs rather than localized pollution sources (Falae *et al*., 2025). In contrast, lead, being a non-essential and toxic element, is generally restricted in plant systems; however, its presence in the studied vegetables—particularly in pumpkin leaf—suggests significant environmental exposure, possibly from atmospheric deposition or contaminated soils. Lead contamination in vegetables has been widely linked to urban activities such as vehicular emissions and improper waste disposal (Gupta *et al*., 2024).

Cadmium exhibited a distinct pattern, with markedly higher levels in bitter leaf compared to other vegetables. This finding is consistent with previous studies indicating that cadmium is more bioavailable in soils and can be readily taken up by plants even at low concentrations (Hamoud *et al.*, 2024). The elevated cadmium levels in bitter leaf may therefore be attributed to both soil characteristics and plant-specific uptake efficiency. Notably, cadmium has been identified as one of the most critical contaminants in vegetables due to its high mobility and tendency to accumulate in edible plant parts (Opasola *et al.*, 2024).

The estimated daily intake (EDI) values obtained in this study were generally low for all metals, suggesting limited exposure through vegetable consumption. This observation aligns with findings from similar studies, where dietary intake of heavy metals through vegetables was found to be below tolerable limits under normal consumption patterns (Hosen *et al.*, 2024). The low EDI values indicate that, at current contamination levels, the contribution of these vegetables to overall metal exposure is minimal.

Non-carcinogenic risk assessment corroborates these findings. All target hazard quotient (THQ) values remained below unity across individual metals, while hazard index (HI) values consistently stayed below the threshold of 1 for all vegetables studied, demonstrating that neither individual metal exposures nor their combined effects pose significant health risks. These findings are consistent with previous reports where THQ and HI values below 1 were interpreted as indicative of acceptable risk levels (Hamoud *et al.*, 2024; Falae *et al.*, 2025). However, it is important to note that Pb and Cd contributed relatively higher proportions to the overall risk, suggesting that these metals remain the primary drivers of potential health concerns.

Despite the absence of significant non-carcinogenic risk, the carcinogenic risk assessment revealed a more nuanced picture. Lead exhibited low carcinogenic risk values across all vegetables, remaining within the acceptable range. In contrast, cadmium showed comparatively higher carcinogenic risk values, particularly in bitter leaf. This observation is consistent with the well-documented carcinogenic nature of cadmium, which has been associated with increased risks of lung, kidney, and prostate cancers (Laoye *et al.*, 2025). The higher carcinogenic contribution of cadmium, even at relatively low concentrations, underscores its high toxicity and long biological half-life.

Mechanistically, cadmium induces toxicity through oxidative stress, DNA damage, and disruption of cellular signaling pathways, which can lead to carcinogenesis over prolonged exposure periods. In contrast, lead, although toxic, tends to contribute more to non-carcinogenic effects such as neurological and cardiovascular disorders rather than cancer risk (Gupta *et al.*, 2024). This explains why cadmium, despite its lower concentration relative to some metals, emerged as the dominant contributor to carcinogenic risk in this study.

The findings of this study highlight the importance of considering both concentration levels and toxicological properties when evaluating food safety. While the concentrations of most metals were within permissible limits, the cumulative and long-term effects of exposure—particularly to cadmium—cannot be overlooked. Similar studies have emphasized that even low-level, chronic exposure to heavy metals through diet can lead to bioaccumulation and increased lifetime health risks (Chmielewski *et al.*, 2025).

Furthermore, the variability observed among vegetable types indicates that plant species significantly influence heavy metal accumulation. Differences in uptake and translocation mechanisms account for this variation (Peralta-Videa *et al.*, 2009; Chojnacka *et al.*, 2005). Bitter leaf (*Vernonia amygdalina*) showed a higher tendency for cadmium accumulation, suggesting that some vegetables can act as bioindicators of environmental contamination. Similar species-dependent accumulation patterns have been reported in Nigerian studies (John *et al.*, 2025; Nenman, 2025). This has important implications for food safety monitoring and risk management.

These results indicate that while the studied vegetables do not pose immediate non-carcinogenic health risks, there is a potential long-term concern associated with cadmium exposure. Continuous monitoring of heavy metal levels in vegetables, along with improved agricultural practices and environmental control measures, is essential to minimize contamination and protect public health.

CONCLUSION

This study assessed the concentrations, dietary exposure, and health risks of selected heavy metals (Cu, Pb, Zn, and Cd) in commonly consumed leafy vegetables from Afor-Ugbolu Market, Nigeria. The results revealed that metal concentrations varied among the vegetables, with bitter leaf showing relatively higher levels of cadmium, while pumpkin leaf exhibited higher lead concentrations. Despite these variations, most of the measured values were within internationally accepted permissible limits.

The estimated daily intake values for all metals were low, indicating minimal exposure through vegetable consumption. Furthermore, the target hazard quotient (THQ) and hazard index (HI) values were below unity for all vegetables, suggesting that their consumption does not pose significant non-carcinogenic health risks under current conditions.

However, the carcinogenic risk assessment highlighted cadmium as the major contributor to potential long-term health risks, particularly in bitter leaf, where values approached or exceeded acceptable thresholds. This finding underscores the importance of considering not only concentration levels but also the toxicological characteristics of individual metals.

While the studied vegetables can be considered relatively safe for consumption in the short term, the potential for cumulative and long-term effects especially due to cadmium exposure cannot be overlooked. Continuous monitoring of heavy metal contamination, adoption of safer agricultural practices, and stricter environmental regulation are recommended to ensure food safety and protect public health.

CONFLICTS OF INTREST

The authors declare no conflicts of interest

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