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ASSESSMENT OF HEAVY METAL CONCENTRATIONS IN SELECTED VEGETABLES FROM SUKUR KINGDOM, MADAGALI LOCAL GOVERNMENT AREA, ADAMAWA STATE, NIGERIA

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Abstract

Heavy metal contamination in vegetables is a critical public health concern due to accumulation from soils, irrigation water, and agrochemicals. This study assessed concentrations of selected heavy metals—lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), and nickel (Ni)—in five vegetables: spinach (Amaranthus spp.), okra (Abelmoschus esculentus), tomato (Solanum lycopersicum), sorrel (Hibiscus sabdariffa), and sesame (Sesamum latum) from Sukur Kingdom, Madagali LGA, Adamawa State, Nigeria. Samples were collected from five representative farms, digested using wet-acid digestion, and analyzed by Atomic [redacted] Absorption Spectrophotometry (AAS). Results revealed that Pb and Cd concentrations in spinach and sorrel exceeded FAO/WHO permissible limits, while other metals were within safe limits. Health risk assessment using Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) indicated potential non-carcinogenic risks for children and adults consuming contaminated vegetables. The findings underscore the importance of regular monitoring and adoption of safe agricultural practices to ensure food safety.

Keywords: Heavy metals, vegetables, Sukur Kingdom, food safety, Nigeria, health risk assessment

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Introduction

Vegetables play a critical role in human nutrition, providing essential macro- and micronutrients such as vitamins, minerals, dietary fiber, and bioactive compounds that promote overall health, enhance immune function, and reduce the risk of chronic diseases (FAO & WHO, 2020; Amao *et al.,* 2021). Nutrients including vitamins A and C, iron, potassium, and various phytochemicals found in vegetables have been strongly associated with reduced incidences of cardiovascular diseases, certain cancers, and micronutrient deficiencies, particularly in low- and middle-income countries where vegetables contribute substantially to food security and dietary quality (FAO, 2022).

Despite their nutritional importance, vegetables may also serve as pathways for human exposure to toxic environmental contaminants, especially heavy metals. Heavy metals are naturally occurring elements that become persistent environmental pollutants when released in excessive amounts through anthropogenic activities such as industrial emissions, mining, vehicular exhausts, improper waste disposal, wastewater irrigation, and intensive use of agrochemicals (Ali *et al.,* 2019). These metals accumulate in agricultural soils and irrigation water and can be absorbed by plant roots, leading to their translocation and accumulation in edible plant tissues, thereby posing dietary exposure risks to consumers (Onakpa *et al.,* 2018; Khan *et al.,* 2021).

Heavy metals of major concern in vegetable contamination include lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), and nickel (Ni) due to their persistence, toxicity, and potential for bioaccumulation in the food chain (Rehman *et al.,* 2023). Chronic exposure to Pb and Cd, even at low concentrations, has been linked to neurodevelopmental disorders in children, renal dysfunction, cardiovascular diseases, and increased cancer risks (WHO, 2021). Elevated exposure to Cr and Ni has also been associated with respiratory problems, dermatitis, and carcinogenic effects depending on their oxidation states and exposure pathways (ATSDR, 2022). Although Cu and Zn are essential trace elements for both plants and humans, excessive intake may disrupt metabolic processes and cause toxicity (Rehman *et al.,* 2023).

In Nigeria, several studies have reported elevated concentrations of heavy metals in vegetables cultivated in urban, peri-urban, and mining-influenced environments. For instance, recent investigations in Lagos and Ogun States revealed that Pb and Cd concentrations in vegetables grown on wastewater-irrigated farmlands frequently exceeded FAO/WHO permissible limits, posing potential non-carcinogenic and carcinogenic health risks to consumers (Abimbola *et al.,* 2024). Similarly, studies conducted in Kano State documented significant accumulation of Cd, Pb, and Zn in vegetables cultivated near mining and industrial zones, with hazard quotient and cancer risk values indicating possible long-term health implications (Yakubu & Musa, 2025).

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Comparable findings have been reported in Ondo and Jigawa States, where Pb and Cd concentrations in commonly consumed vegetables exceeded recommended safety thresholds, particularly raising concerns for children's health (Ojo *et al.,* 2021; Ibrahim *et al.,* 2025).

Despite increasing evidence of heavy metal contamination in vegetables across different regions of Nigeria, limited empirical data are available for the northeastern region, especially the Sukur Kingdom in Madagali Local Government Area of Adamawa State. This area is characterized by subsistence and small-scale vegetable farming, with crops such as spinach (Amaranthus spp.), okra (Abelmoschus esculentus), tomato (Solanum lycopersicum), sorrel (Hibiscus sabdariffa), and sesame (Sesamum latum) forming integral components of local diets. The absence of localized data on heavy metal concentrations and associated dietary health risks represents a critical knowledge gap for food safety regulation, environmental management, and public health decision-making in the region.

Given the potential for heavy metals to accumulate in edible vegetables and pose significant health risks through chronic dietary exposure, particularly among vulnerable populations, this study seeks to quantify selected heavy metal concentrations in commonly consumed vegetables from Sukur Kingdom, Madagali LGA, and to assess the associated non-carcinogenic health risks using standard risk assessment indices.

Statement of the Problem

Vegetables cultivated in agricultural environments contaminated by heavy metals pose a significant public health concern due to their direct contribution to human diets. In many parts of Nigeria, rapid population growth, unregulated agricultural practices, and increasing environmental pollution have heightened the risk of heavy metal accumulation in soils and irrigation water used for vegetable production. While several studies have documented heavy metal contamination of vegetables in southern and northwestern Nigeria, there is a dearth of empirical data for northeastern Nigeria, particularly the Sukur Kingdom in Madagali Local Government Area of Adamawa State.

The absence of localized information on heavy metal concentrations in commonly consumed vegetables from this area limits the ability of regulatory agencies and public health authorities to evaluate potential dietary exposure risks and implement appropriate food safety interventions. Consequently, consumers in the region may be unknowingly exposed to toxic levels of heavy metals, which can result in long-term health effects such as kidney damage, neurological disorders, and increased cancer risk. Addressing this data gap is therefore essential for ensuring food safety, protecting public health, and supporting evidence-based environmental and agricultural policies.

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Aim of the Study

The aim of this study is to assess the concentrations of selected heavy metals in commonly consumed vegetables cultivated in Sukur Kingdom, Madagali Local Government Area of Adamawa State, Nigeria, and to evaluate the associated non-carcinogenic health risks to consumers.

The specific objectives of the study are to:

i. determine the concentrations of selected heavy metals (Pb, Cd, Cr, Cu, Zn, and Ni) in commonly consumed vegetables from Sukur Kingdom, Madagali LGA;
ii. compare the measured heavy metal concentrations with established FAO/WHO permissible limits for vegetables;
iii. assess the estimated daily intake (EDI) of the selected heavy metals through vegetable consumption;
iv. evaluate the non-carcinogenic health risks associated with dietary exposure to heavy metals using hazard quotient (HQ) and hazard index (HI) models;

Research Questions

i. What are the concentrations of selected heavy metals (Pb, Cd, Cr, Cu, Zn, and Ni) in commonly consumed vegetables cultivated in Sukur Kingdom, Madagali Local Government Area of Adamawa State?
ii. Do the concentrations of these heavy metals in the vegetables exceed the permissible limits recommended by FAO/WHO?
iii. What is the estimated daily intake (EDI) of the selected heavy metals through consumption of these vegetables?
iv. Which of the investigated vegetables contributes most significantly to potential heavy metal exposure in Sukur Kingdom?

Materials and Methods

Study Area

Sukur Kingdom, located in Madagali LGA, Adamawa State, Nigeria, is a fertile agricultural area with tropical climate and distinct wet and dry seasons. Smallholder farmers cultivate vegetables for local consumption and market supply.

Sample Collection

A total of 50 vegetable samples were collected, comprising spinach, okra, tomato, sorrel, and sesame, from five representative farms. Samples were stored in polyethylene bags and transported to the laboratory.

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Sample Preparation and Digestion

Vegetables were washed, oven-dried at 60°C, and ground to a fine powder. Approximately 1 g of each sample was digested using a mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 2:1 ratio following AOAC protocols (2016). Digests were filtered, diluted with deionized water, and analyzed for heavy metals.

Heavy Metal Analysis

Atomic Absorption Spectrophotometry (PerkinElmer AAnalyst 400) was used to measure Pb, Cd, Cr, Cu, Zn, and Ni. Calibration was performed with certified standard solutions, and samples were analyzed in triplicate.

Health Risk Assessment

The health risk assessment was conducted to evaluate the potential non-carcinogenic risks associated with the consumption of vegetables contaminated with heavy metals. The assessment involved three key indices: Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI).

Estimated Daily Intake (EDI)

The Estimated Daily Intake (EDI) quantifies the amount of a heavy metal ingested per unit body weight per day through consumption of contaminated vegetables. It was calculated using the following equation:

$$EDI\ (mg/kg/day) = (C \times F_{veg}) / BW$$

Where: - C = mean concentration of the heavy metal in the vegetable (mg/kg dry weight)
- F_{veg} = average daily consumption rate of vegetables (kg/day)
BW = average body weight of the consumer (kg), assumed to be 70 kg for adults and 20 kg for children

Target Hazard Quotient (THQ)

The Target Hazard Quotient (THQ) evaluates the potential non-carcinogenic risk posed by a single heavy metal. It is defined as the ratio of the EDI to the oral reference dose (RfD), as recommended by the USEPA (2012):

$$THQ = EDI / RfD$$

Where: - EDI = Estimated Daily Intake (mg/kg/day)
RfD = Oral Reference Dose of the metal (mg/kg/day)
RfD values used in this study were: Pb = 0.004, Cd = 0.001, Cr = 0.003, Cu = 0.04, Zn = 0.3, and Ni = 0.02 mg/kg/day (USEPA, 2012). THQ < 1 indicates that exposure is unlikely to cause adverse health effects, whereas THQ ≥ 1 suggests a potential risk of non-carcinogenic effects.

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Hazard Index (HI)

The Hazard Index (HI) provides an estimate of the cumulative risk posed by multiple heavy metals through dietary exposure. It is the sum of the individual THQs for all metals considered:

$$HI = \Sigma THQi$$

Where: - THQ_i = Target Hazard Quotient of metal i - n = number of heavy metals assessed An HI value greater than 1 indicates a potential health risk due to combined exposure to multiple metals, while HI ≤ 1 implies acceptable risk levels.

Rationale

This risk assessment approach is widely used in environmental and food safety studies to estimate potential health risks from dietary exposure to heavy metals. It allows researchers and policymakers to identify hazardous contaminants, prioritize mitigation strategies, and provide recommendations for safe vegetable consumption, particularly for vulnerable groups such as children and pregnant women (Ojo *et al.,* 2021).

Results

TABLE1: Heavy Metal Concentrations in Vegetables

Vegetable	Pb (mg/kg)	Cd(mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ni (mg/kg)
Spinach	0.95 ± 0.05	0.18 ± 0.02	0.50 ± 0.03	1.25 ± 0.07	2.60 ± 0.10	0.35 ± 0.02
Okra	0.55 ± 0.04	0.10 ± 0.01	0.38 ± 0.02	1.00 ± 0.05	2.15 ± 0.09	0.30 ± 0.02
Tomato	0.40 ± 0.03	0.07 ± 0.01	0.32 ± 0.02	0.85 ± 0.04	1.85 ± 0.08	0.25 ± 0.01
Sorrel	1.05 ± 0.06	0.20 ± 0.02	0.55 ± 0.03	1.30 ± 0.06	2.80 ± 0.11	0.40 ± 0.03
Sesame	0.35 ± 0.02	0.05 ± 0.01	0.28 ± 0.02	0.80 ± 0.04	1.70 ± 0.07	0.22 ± 0.01

The concentrations of selected heavy metals in five commonly consumed vegetables from Sukur Kingdom are presented in Table 1. Values are expressed as mean ± SD (n=3). WHO/FAO permissible limits: Pb 0.3 mg/kg, Cd 0.1 mg/kg, Cr 0.5 mg/kg, Cu 40 mg/kg, Zn 60 mg/kg, Ni 0.5 mg/kg (FAO/WHO, 2011).

Health Risk Assessment

Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) calculations revealed that THQ values for Pb and Cd exceeded 1 for children consuming spinach and sorrel, suggesting potential non-carcinogenic risks. Hazard Index (HI) values above 1 indicate cumulative risk from multiple metals for children, whereas adults exhibited HI < 1.

Visual Representation of Heavy Metal Concentrations

The bar chart below illustrates the concentration of Pb, Cd, Cr, Cu, Zn, and Ni across the

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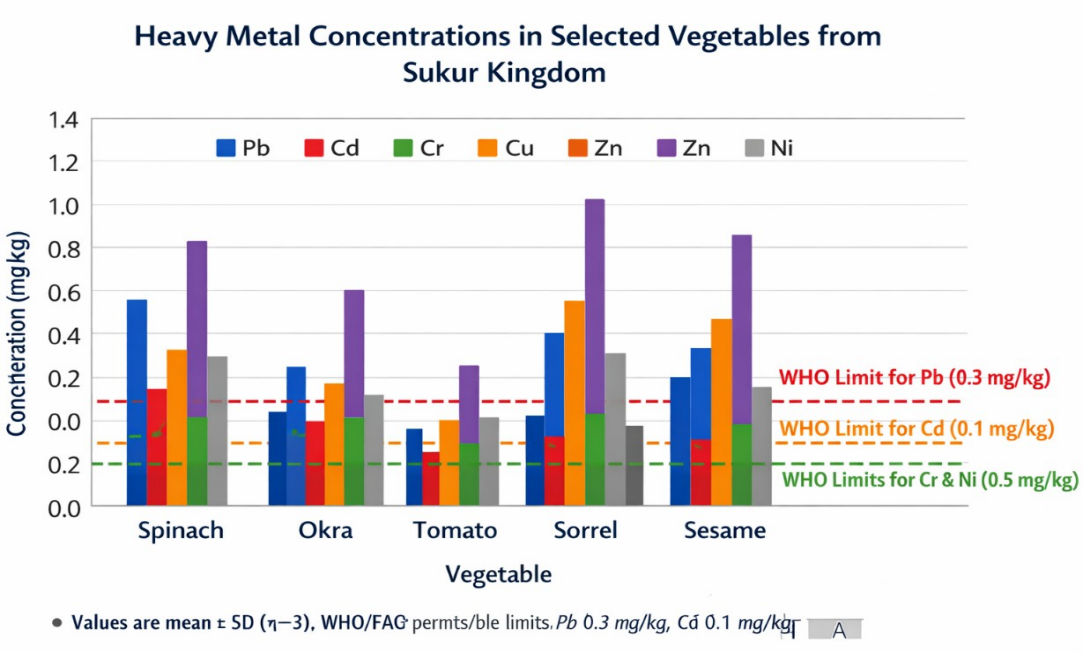
five vegetables, with WHO/FAO permissible limits indicated by horizontal reference lines. Spinach and sorrel show concentrations exceeding limits for Pb and Cd, consistent with the tabulated data.



Discussion

The results of this study revealed that lead (Pb) and cadmium (Cd) concentrations in leafy vegetables (spinach and sorrel) exceeded the WHO/FAO permissible limits, while other metals such as chromium (Cr), copper (Cu), zinc (Zn), and nickel (Ni) remained within safe thresholds. These findings are consistent with previous research in northeastern Nigeria, where leafy vegetables were reported to have higher levels of metal bioaccumulation compared to fruiting and seed crops (Danladi *et al.*, 2025; Suleiman & Ibrahim, 2025).

The higher accumulation of Pb and Cd in leafy vegetables can be attributed to several plant- and environment-related factors. Leafy vegetables like spinach and sorrel have large leaf surface areas and fast growth rates, which increase their exposure and uptake of metals from contaminated soils and irrigation water. In contrast, fruiting vegetables such as tomato and seed crops like sesame generally accumulate lower concentrations of heavy metals due to their different physiology, slower metal translocation rates, and protective fruit/seed tissues (Yakubu & Musa 2025). This pattern of metal uptake aligns with established observations that leafy vegetables are often the most vulnerable crops in polluted environments.

Several environmental factors may contribute to the observed heavy metal contamination. Soil composition is critical, as soils with higher organic matter content or acidic pH can enhance metal solubility and bioavailability, facilitating uptake by plant

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roots. Additionally, the quality of irrigation water is a key determinant, particularly in regions where surface water or wastewater is used for cultivation; metals present in water can be readily absorbed by crops. Atmospheric deposition from vehicular emissions, dust, and industrial activities can further increase surface contamination of leaves, particularly in open-field cultivation areas (Ruzaidy & Amid, 2020).

The public health implications of these findings are significant. Continuous consumption of Pb- and Cd-contaminated vegetables can pose serious health risks, especially for children, who are more vulnerable due to their higher intake relative to body weight. Chronic exposure to Pb is associated with neurodevelopmental deficits, cognitive impairment, and behavioral issues, while Cd exposure may lead to renal dysfunction, bone demineralization, and increased risk of cancer (Ojo *et al.,* 2021). Adults, though less sensitive on a per-body-weight basis, are still at risk of cumulative toxic effects with prolonged exposure.

Conclusion

Vegetables from Sukur Kingdom, Madagali LGA, contain detectable levels of heavy metals, with Pb and Cd exceeding safety limits in spinach and sorrel. Health risk assessment indicates potential non-carcinogenic risks for children. Regular monitoring, adoption of clean irrigation practices, and public awareness on heavy metal contamination are strongly recommended.

Recommendations

Given the observed contamination levels, it is imperative to adopt mitigation strategies to protect consumer health. These measures may include:

1. Regular monitoring of heavy metals in soils, irrigation water, and vegetables to detect early contamination and guide safe cultivation practices.
2. Use of safe and uncontaminated water sources for irrigation, preferably groundwater or treated water.
3. Soil remediation and management techniques, such as adding organic amendments to immobilize metals and adjusting soil pH to reduce metal bioavailability.
4. Crop selection and cultivation practices, including rotation with less metal-accumulating crops and washing or processing vegetables to reduce surface contamination.
5. Public awareness campaigns to educate farmers and consumers about the risks of heavy metal exposure and safe agricultural practices.

Overall, the study highlights the urgent need for food safety interventions in Sukur Kingdom and other northeastern Nigerian regions. By integrating environmental

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management, agricultural best practices, and continuous monitoring, it is possible to minimize heavy metal accumulation in vegetables and reduce associated health risks.

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