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Assessment of Heavy Metal Contamination and Health Risks from Urban-Grown Vegetables in Kano State, Nigeria

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Abstract

*This study evaluates the concentrations and associated health risks of cadmium (Cd), nickel (Ni), lead (Pb), manganese (Mn), and chromium (Cr), in six commonly consumed vegetables (pepper, lettuce, carrot, beetroot, spinach, and onion) cultivated in three urban locations in Kano State, Nigeria namely: Wudil, Nomans-Land, and Sharada. Metal concentrations were quantified u*sing Microwave Plasma – Atomic Emission Spectroscopy (MP-AES), *and the results revealed spatial and crop-specific variability. The highest concentrations of Cd and Mn were observed in vegetables from Wudil, with Cd range of 0.19 to 0.36mg/kg and Mn of 0.67 to 9.29 mg/kg, particularly in carrot (0.36 mg/kg) and lettuce (0.27 mg/kg), while Cr of 0.41 mg/kg and Pb of 0.82 mg/kg levels were notably elevated in samples from Sharada. Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) were calculated to assess non-carcinogenic health risks. Cd consistently exhibited the highest THQ across all samples, with carrot (Nomans-Land) and lettuce (Sharada) exceeding the US EPA's safety threshold (HI > 1). Cr and Pb also significantly contributed to cumulative health risks. Root and leafy vegetables showed a higher propensity for metal accumulation, highlighting the influence of plant type and environmental exposure. The findings underscore the potential public health risks associated with the consumption of vegetables grown in contaminated urban and peri-urban environments. Routine monitoring and stricter control of anthropogenic pollution sources are recommended to safeguard food safety.*

Keywords: Vegetables, Cadmium, Carcinogenic, Heavy metals, Health risk, Risk.

Introduction

The quality of irrigation water is a critical factor in ensuring sustainable soil health, crop productivity, and food safety, especially in arid and semi-arid regions like Kano, Nigeria, where erratic rainfall and limited freshwater resources necessitate intensive irrigation practices [1, 2]. However, the increasing reliance on contaminated water sources for irrigation has raised significant environmental and public health concerns due to the potential accumulation of toxic substances, particularly heavy metals, in agricultural soils and crops [3, 4].

Heavy metals such as Cd, Ni, Pb, Mn, and Cr are non-biodegradable and persist in the environment, allowing for long-term accumulation in soils and bioavailability to crops [2, 5]. These metals originate from both geogenic sources such as the weathering of parent rock materials and anthropogenic activities, including industrial discharge, urban runoff, traffic emissions, the overuse of agrochemicals, and improper waste management [6, 7]. Their persistence in the soil and plant system not only reduces soil fertility and impairs plant growth but also poses significant risks to human health through dietary exposure [4].

In Kano State, a rapidly urbanizing and industrializing region of northern Nigeria, the main contributors to heavy metal pollution include untreated industrial effluents, leachates from open dumpsites, combustion emissions, and the excessive application of chemical fertilizers and pesticides[7, 8]. Moreover, the use of untreated wastewater and surface runoff for irrigation further intensifies the contamination of agricultural land and food crops, raising concerns about long-term environmental sustainability and the safety of food systems [1, 3].

Previous investigations have documented the presence of heavy metals in urban-grown vegetables in Kano State. For instance, Audu and Lawal [9] examined the accumulation of Pb, Cd, and Cr in lettuce and spinach cultivated around the Sharada Industrial Estate. Their findings indicated elevated concentrations of these metals, which were attributed to emissions from industrial activities and vehicular traffic. However, their study was limited in scope, focusing on a narrow range of metals and omitting critical health risk indices such as Estimated Daily Intake (EDI) and Hazard Index (HI), which are essential for comprehensive public health risk evaluation [9].

In a more recent study, Badamasi *et al.* [10] assessed levels of Cd, Ni, Pb, and Cr in vegetables irrigated with wastewater across selected sites in Kano. Although their analysis revealed concentrations exceeding WHO safety thresholds, the study lacked spatially explicit comparisons across different land-use types and did not evaluate manganese (Mn) a common soil and air contaminant in industrial zones known to bioaccumulate in leafy vegetables [10].

Despite increasing awareness of the risks associated with contaminated urban agriculture in Kano State, few studies to date have employed a multi-metal approach integrated with detailed spatial variability and health risk assessment metrics. Furthermore, critical exposure pathways such as dietary intake and chronic toxicity remain understudied in the context of Kano's diverse agro-urban landscape. The present study addresses these gaps by quantifying Cd, Ni, Pb, Mn, and Cr in commonly consumed vegetables across industrial and non-industrial areas, and applying standardized health risk assessment models (EDI, THQ, and HI) to evaluate public health implications.

This study investigates the concentrations of selected heavy metals, in soils and commonly consumed vegetables (carrot, lettuce, pepper, and onion) cultivated in three agricultural zones within Kano: Wudil, Nomans-Land, and Sharada. The objectives are to evaluate the levels of contamination, identify potential sources, compare the findings against regulatory safety thresholds, and assess potential health risks. Ultimately, this research aims to inform policies on environmental monitoring, sustainable agricultural practices, and public health interventions.

Materials and Methods

Study Area

Kano City (11.7471° N, 8.5247° E) is the most populous urban centre in northern Nigeria and the second largest city in the country, with a population of approximately 4.49 million and an annual growth rate of 3.16% [11, 12]. The city is characterized by rapid urbanization, intense agricultural activity, and growing industrial development, all of which contribute to environmental pollution. The study was carried out in Kano State across three purposively selected location: Wudil, Nomans Land, and Sharada, (Figure 1) chosen for their diverse land-use types and anthropogenic influences. Wudil represents a peri-urban agricultural area, Nomans Land is a densely populated residential zone, and Sharada is an established industrial hub with a high concentration of manufacturing and processing facilities [7, 8].

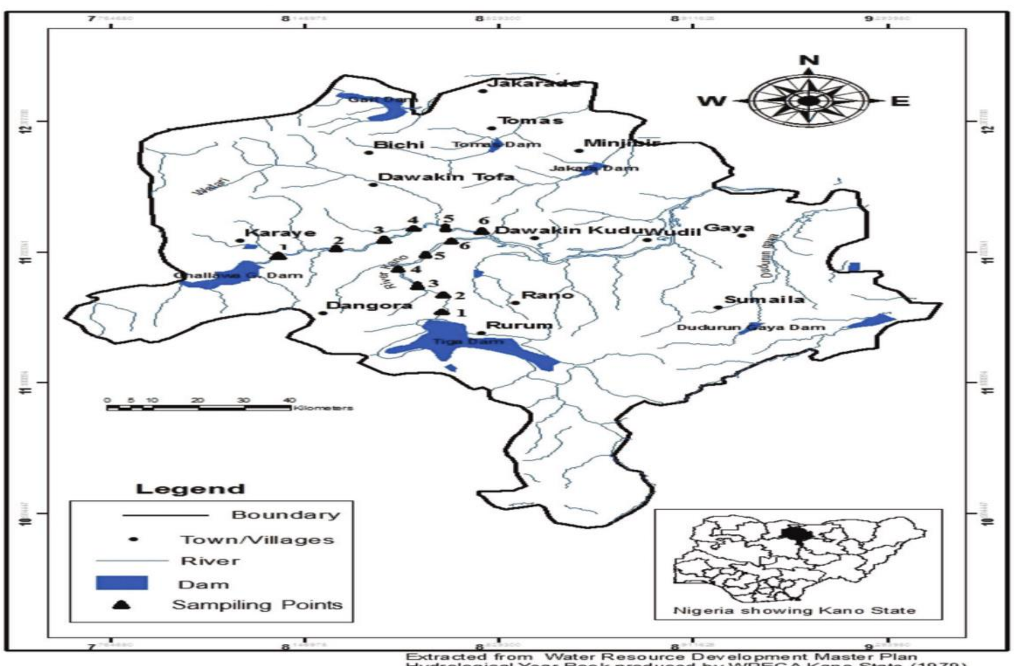

Figure 1: Map of Kano State showing Sample Sites

Sampling Design

The sampling campaign was carried out over a three-month period from January to March 2025, coinciding with the dry season when irrigation activity is most intensive. A total of 64 samples were collected from eight sites across the three locations. Samples included both soil and edible portions of vegetables (carrot, lettuce, pepper, and onion) and were taken twice daily—between 08:00–11:00 and 15:30–18:30, to account for possible diurnal variations in exposure or irrigation activity (Figure 1). Each site included four sampling points, spaced to capture spatial variability across roadside, residential, and commercial zones. The vegetable samples were selected based on their popularity in local diets and susceptibility to heavy metal uptake due to their morphology (root, leafy, and fruiting types).

Irrigation Context

Kano State faces significant water management challenges due to its arid climate, limited surface water resources, and heavy dependence on irrigation to support year-round agriculture. Common irrigation sources in the study area include rivers, shallow groundwater, untreated domestic wastewater, and industrial effluents. While wastewater irrigation can improve crop nutrient availability and yield, it also introduces toxic contaminants, particularly heavy metals that pose risks to food safety, soil health, and human health [7, 8].

Site selection reflected the diverse sources of irrigation water and the heterogeneity in land use across Kano metropolis. These sources were identified through field observation and interviews with local farmers and residents.

Sample Collection

All samples were collected in a clean labeled polyethylene bags and transported to the laboratory in cool conditions to prevent degradation plastic container and immediately transported to the laboratory for digestion and heavy metal analysis. In the laboratory, soil samples were air-dried, sieved through a 2 mm mesh, and digested. Crop samples were washed, dried, and ashed before digestion for heavy metal analysis.

Sample Preparation

Using Advanced Microwave Digestion System (Model: ETHOS EASY, Milestone Srl, Italy). Sample preparation was conducted in accordance with the equipment's programmed protocol. Specifically: Two hundred milligram (200 mg) of ground samples and 50 milliliters of liquid samples were weighed and transferred into 90 ml microwave digestion vessels. To each vessel, 10 ml of a mixed acid solution (15.9N trace metal grade nitric acid, hydrogen peroxide, and perchloric acid in a 7:2:1 ratio) was added. The vessels were left to stand for one hour before digestion. Ramp temperature from ambient to 200°C over 20 minutes, and maintained at 200°C for an additional 20 minutes. Post-transferred into a 50 ml volumetric flask, brought to volume with deionized water, and then filtered in preparation for instrumental analysis [13].

Experimental Procedure

All measurements were performed using the Agilent 4210 MP-AES system. The sample introduction system consisted of PVC peristaltic pump tubing (white/white and blue/blue). A single-pass cyclonic spray chamber and a oneNeb nebuliser. Analytical processing was managed using the Agilent MP Expert software, which, automatically subtracted background signals from analytical readings. Recorded and 0sample. The software was also used to optimized the nebulization pressure and viewing position for each wavelength selected to enhance sensitivity. All analytes were measured sequentially under optimized conditions, as configured using a standard reference solution to streamline parameter calibration [13].

Potential Health Risk Assessment

Health risk assessment is a critical tool for evaluating the potential adverse effects of human exposure to environmental contaminants, particularly toxic elements such as heavy metals [14]. In this study, the non-carcinogenic health risks associated with the consumption of heavy metal-contaminated vegetables were assessed using the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) methodologies. The assessment framework followed guidelines provided by the United States Environmental Protection Agency[15] [16].

Estimated Daily Intake (EDI)

The EDI quantifies the amount of a specific heavy metal ingested daily through vegetable consumption and is expressed in mg/kg body weight/day. The EDI reflects both the contamination level in vegetables and the average daily intake by consumers. It is calculated using Equation 1:

$$\mathrm{EDI} = \frac{\mathrm{C_m \times IR}}{\mathrm{BW}} \qquad \textbf{Equation 1}$$

Where: $\mathrm{C_m}$ = Concentration of the heavy metal in the vegetable (mg/kg)

IR = Ingestion rate of the vegetable (kg/day)

BW = Average body weight (assumed to be 60 kg for adults or 70 kg in some studies) is typically assumed [17]

Target Hazard Quotient (THQ)

The THQ is a dimensionless ratio that compares the estimated daily intake of a contaminant with its reference oral dose ($\mathrm{RfD_o}$), as shown below in Equation 2:

$$\mathrm{THQ} = \frac{\mathrm{EDI}}{\mathrm{RfD_o}} \qquad \textbf{Equation 2}$$

Where: RfD_o = Reference dose for oral exposure to the contaminant (mg/kg/day), obtained from established toxicological data [18].

Interpretation of THQ: THQ < 1: No significant non-carcinogenic risk and THQ > 1: Potential for adverse non-carcinogenic health effects

Hazard Index (HI)

The HI is the cumulative measure of non-carcinogenic risk due to exposure to multiple heavy metals in a given vegetable sample and is computed as the sum of individual THQ:

$$\mathrm{HI} = \sum \mathrm{THQ_i} \qquad \textbf{Equation 3}$$

Where $\mathrm{THQ_i}$ represents the target hazard quotient for each heavy metal present. An HI value greater than (>)1.0 indicates a potential health risk due to combined exposure [18, 19].

This approach provides a comprehensive understanding of the overall risk posed by multi-metal contamination in edible crops, thereby guiding public health interventions and environmental regulation.

Statistical Analyses

One-way analysis of variance (ANOVA) was used to evaluate the significant variation in heavy metal concentrations in samples from different locations. A p - value < 0.05 was considered statistically significant. All data was transformed into the mean standard deviation of three replicates.

Results and Discussion

Spatial Variation in Heavy Metal Concentrations in Vegetables

The concentrations of Cd, Ni, Pb, Mn, and Cr were quantified in vegetable samples, including pepper, lettuce, carrot, beetroot, spinach, and onion, collected from three urban locations: Wudil, Nomans-Land, and Sharada (Table 1). The results reveal distinct spatial and crop-specific patterns in heavy metal accumulation, influenced by both anthropogenic activities and local environmental conditions.

Vegetables from Wudil generally exhibited the highest concentrations of Cd and Mn lettuce recorded and Mn levels of 0.27 mg/kg and 9.28 mg/kg respectively, while pepper contained 0.19 mg/kg Cd and 4.87 mg/kg Mn. The highest Cd concentration overall was recorded in carrot (0.36 mg/kg), a root crop known for its high potential to absorb metals from soil, corroborating earlier findings from India and China [18-20]. These elevated levels may reflect contamination from agricultural runoff, irrigation with untreated wastewater, or vehicular emissions [1]. Elevated Mn concentrations in leafy vegetables align with known physiological traits, such as higher transpiration rates and foliar surface area, [9] that facilitate Mn accumulation. In contrast, Ni and Pb levels in Wudil vegetables were moderate and remained within the ranges commonly reported for vegetables grown in urban areas.

In Nomans-Land, vegetables such as beetroot, pepper, and spinach showed moderate levels of Cd (0.22–0.31 mg/kg) and Pb (0.10–0.13 mg/kg). Notably, spinach recorded the highest Cr concentration in the study (0.42 mg/kg), likely indicating atmospheric deposition from industrial emissions or traffic-related pollution. The relatively consistent metal concentrations across vegetables from this location suggest uniform contamination of agricultural soils or similar cultivation and irrigation practices. Mn concentrations were comparatively lower than those observed in Wudil, ranging from 0.78–1.72 mg/kg.

Vegetables sampled from Sharada, particularly onion and lettuce, exhibited the highest concentrations of Pb (0.15 mg/kg) and Cr (0.40–0.41 mg/kg). These elevated values are likely attributed to the area's industrial profile, potentially including proximity to metal processing facilities and waste discharge points. In contrast, Ni values were negative or near-zero (–0.01 mg/kg) in Sharada vegetables, possibly reflecting values below detection limits or analytical uncertainty.

These patterns are consistent with previous findings of Audu and Lawal, (2006) with elevated Ni and Pb in urban vegetables [9] as well as data reporting similar or higher concentrations for Mn and Cr in leafy vegetables [20, 21]. Badamasi *et al*. (2023) reported comparable Cd and Ni levels but reported higher concentrations of Pb and Cr, and lower levels of Mn, further confirming the existence of spatial variability in metal accumulation across urban Kano.[10]

The spatial distribution shows Cd was highest in Wudil carrot (0.36 mg/kg), indicating significant root uptake. Elevated Cd levels were detected across all locations. Ni was generally low, with values at or below detection limits in Sharada vegetables [10]. Pb levels peaked in Sharada vegetables, suggesting possible environmental pollution from lead-containing sources [9]. Mn reached the highest value in Wudil lettuce (9.28 mg/kg), in line with known foliar uptake characteristics. Cr concentrations were notably high in Nomans-Land spinach (0.42 mg/kg) and Sharada vegetables, likely linked to industrial activities [21].

Table 1: Heavy metal concentrations (mg/kg) in vegetables from Wudil, Nomans-Land, and Sharada

Vegetable	**Location**	**Cd**	**Ni**	**Pb**	**Mn**	**Cr**
Pepper	Wudil	0.19	0.04	0.06	4.87	0.13
Lettuce	Wudil	0.27	0.06	0.02	9.28	0.10
Carrot	Wudil	0.36	0.03	0.12	0.97	0.12
Onion	Wudil	0.33	0.02	0.08	0.67	0.14
Beetroot	Nomans-Land	0.22	0.03	0.10	0.78	0.10
Pepper	Nomans-Land	0.25	0.03	0.10	0.79	0.10
Spinach	Nomans-Land	0.31	0.03	0.13	1.72	0.42
Onion	Sharada	0.23	-0.01	0.15	0.82	0.41
Lettuce	Sharada	0.28	-0.01	0.15	0.82	0.40

In comparison to WHO/FAO permissible limits, Sharada samples exceeded safe thresholds for Pb, Mn, and Cr, while samples from Wudil and Nomans-Land exceeded limits primarily for Cd and Mn. Ni concentrations remained below threshold levels at all sites [22].

Overall, these results highlight that vegetables cultivated in urban and peri-urban environments can accumulate significant quantities of heavy metals. The location-specific patterns observed underscore the importance of environmental and anthropogenic drivers, such as industrialization, traffic emissions, and agricultural practices in influencing heavy metal uptake. Wudil poses heightened risk for Cd and Mn exposure, Sharada for Pb and Cr, while Nomans-Land exhibits moderate but widespread contamination across multiple heavy metals.

Table 2: The mean and standard deviation (SD) values for heavy metals in **soil** and **vegetables** collected from Wudil, Nomans-Land, and Sharada

	Soil	**Vegetable**
Metal	Mean and Std Dev. (mg/kg)	Mean and Std Dev. (mg/kg)
Cd	0.29 ± 0.70	0.21 ± 0.02
Ni	-0.15 ± 0.04	0.02 ± 0.03.
Pb	1.41 ± 1.58	0.10 ± 0.05
Mn	6.12 ± 4.001	2.16 ± 2.4
Cr	0.57 ± 0.30	0.21 ± 0.17

Comparative Assessment of Heavy Metal Concentrations in Soil and Vegetables

As presented in Table 2, soils exhibited significantly higher mean concentrations of Mn and Pb compared to vegetable samples, accompanied by relatively large standard deviation values. This suggests substantial spatial heterogeneity in soil contamination levels across the study locations. In contrast, heavy metal concentrations in vegetables were generally lower for all metals, with Mn exhibiting the highest average concentration among the metals analyzed.

The observed standard deviations further reveal that the variability of metal concentrations is greater in soil than in vegetable matrices, particularly for Cd, Pb, and Mn. This pattern likely reflects the complex interactions between metal bioavailability in soil, plant uptake mechanisms [23]. This disparity may reflect complex interactions between the total concentration of metals in soils and their bioavailable fractions, which are influenced by soil pH, organic matter content, and competing ions. Furthermore, physiological and morphological traits of plants can regulate the translocation of metals from soil to edible tissues, thereby moderating extreme variations observed in the soil [24]. Thus, while soils may act as reservoirs of contamination, plant uptake processes appear to buffer some of this variability.

Table 3: The Estimated Daily Intake (EDI) (mg/kg/day), for heavy metals in each vegetable

Vegetable	Cd	Ni	Pb	Mn	Cr
			Wudil		
Pepper	1.09 x 10^{-3}	2.00 x 10^{-4}	3.45 x 10^{-4}	2.80 x 10^{-2}	7.48 x 10^{-4}
Lettuce	1.55 x 10^{-3}	3.45 x 10^{-4}	1.15 x 10^{-4}	5.33 x 10^{-2}	5.75 x 10^{-4}
Carrot	2.07 x 10^{-3}	1.72 x 10^{-4}	6.90 x 10^{-4}	5.58 x 10^{-3}	6.90 x 10^{-4}
Onion	1.90 x 10^{-3}	1.15 x 10^{-4}	4.60 x 10^{-4}	3.85 x 10^{-3}	8.05 x 10^{-4}
			Sharada		
Onion	1.32 x 10^{-3}	0.00	8.62 x 10^{-4}	4.72 x 10^{-3}	2.31 x 10^{-3}
Lettuce	1.61 x 10^{-3}	0.00	8.62 x 10^{-4}	4.72 x 10^{-3}	2.30 x 10^{-3}
			Noman's Land		
Beetroot	1.27 x 10^{-3}	1.72 x 10^{-4}	5.75 x 10^{-4}	4.49 x 10^{-3}	5.75 x 10^{-4}
Pepper	1.43 x 10^{-3}	1.72 x 10^{-4}	5.75 x 10^{-4}	4.54 x 10^{-3}	5.75 x 10^{-4}
Spinach	1.78 x 10^{-3}	1.73 x 10^{-4}	7.48 x 10^{-4}	9.90 x 10^{-3}	2.42 x 10^{-3}
Carrot	2.24 x 10^{-3}	1.15 x 10^{-3}	7.48 x 10^{-4}	9.95 x 10^{-3}	2.42 x 10^{-3}

Estimated Daily Intake (EDI) of Heavy Metals from Vegetable Consumption

The Estimated Daily Intake (EDI) values for Cd, Ni, Pb, Mn, and Cr were calculated to assess dietary exposure to heavy metals through vegetable consumption (Table 3). EDI values, expressed in mg/kg body weight/day, reflect both the concentration of each metal in the edible portion of the vegetables and the average daily consumption rate, thereby providing a realistic estimate of potential human exposure [15]

Among the metals assessed, Cd consistently exhibited the highest EDI values across all vegetable types. Notably elevated levels were recorded in carrot (root vegetable) samples from Nomans-Land (2.43x 10^{-3}mg/kg/day) and Wudil (2.07 x 10^{-3}mg/kg/day). This observation underscores the strong tendency of root vegetables, particularly carrots, to accumulate cadmium due to their direct and prolonged contact with contaminated soils [18, 19],. These values approach or exceed internationally recommended safety thresholds, raising concern regarding chronic dietary exposure and potential adverse health effects associated with Cd set by Joint WHO/FAO

Expert Committee on Food Additives (JECFA) at 8.30 x 10^{-4} mg/kg/day [25].

Cr also demonstrated elevated EDI values, especially in onion (Sharada) (2.31 x 10^{-3} mg/kg/day), lettuce (Sharada) (2.30x 10^{-3}mg/kg/day), and carrot (Nomans-Land) (2.42 x 10^{-3} mg/kg/day). These elevated intake levels may be attributed to higher Cr concentrations in soils from industrially active areas such as Sharada, potentially linked to improper disposal of untreated industrial effluents and poor waste management practices [1, 9].

For Mn, the highest EDI was observed in lettuce from Wudil (5.34 x 10^{-2}mg/kg/day), followed by pepper from the same location (2.80 x 10^{-2}mg/kg/day). This pattern is consistent with the known physiological characteristics of leafy vegetables, which tend to accumulate Mn more readily due to their large surface area, higher transpiration rates, and exposure to atmospheric deposition [26].

Pb exposure ranged from 1.15 to 8.62 x 10^{-4} mg/kg/day, with the highest values detected in onion and lettuce from Sharada. These findings suggest potential Pb contamination from vehicular emissions or industrial sources common to urban environments [20, 21]. Although Pb levels were lower than those of Cd and Mn, the toxicological significance of Pb remains considerable due to its cumulative effects and lack of a safe exposure threshold [15]

Ni recorded the lowest EDI values overall, ranging from non-detectable levels to 3.45 x 10^{-4} mg/kg/day, indicating a comparatively low health risk associated with Ni from vegetable consumption in the study area.

Cumulatively, carrot and lettuce exhibited the highest total EDI values for multiple metals, indicating a greater potential health risk associated with their consumption. Among the five metals analyzed, Cd and Cr were the most significant contributors to total EDI. Mn intake was notably high in leafy vegetables, reinforcing their role in heavy metal accumulation. While Ni posed the least concern, Pb remains a critical contaminant due to its chronic toxicity and widespread environmental persistence.

Table 4: Target Hazard Quotient (THQ), and Hazard Index (HI) (mg/kg/day) for heavy metals in each vegetable

Vegetable	Cd	Ni	Pb	Mn	Cr	HI
Wudil						
Pepper	1.092	0.011	0.099	0.200	0.249	**1.652**
Lettuce	1.552	0.017	0.033	0.381	0.192	**2.175**
Carrot	2.070	0.009	0.197	0.040	0.230	**2.546**
Onion	1.897	0.006	0.131	0.028	0.268	**2.331**
Sharada						
Onion	1.323	0.000	0.246	0.034	0.786	**2.388**
Lettuce	1.610	0.000	0.246	0.034	0.767	**2.657**
Noman's Land						
Carrot	2.243	0.006	0.214	0.071	0.805	**3.338**
Pepper	1.438	0.009	0.164	0.032	0.192	**1.835**
Vegetable	1.782	0.009	0.214	0.071	0.805	**2.880**

Non-Carcinogenic Risk Assessment Using Target Hazard Quotient and Hazard Index

The non-carcinogenic health risks associated with the consumption of vegetables contaminated by heavy metals were assessed using the Target Hazard Quotient (THQ) and the cumulative Hazard Index (HI), as detailed in Table 4. The THQ assesses the potential health risk of a single metal, while the HI represents the combine risk from multiple metals. According to the United States Environmental Protection Agency (USEPA), a THQ or HI value exceeding 1.0 suggests a potential for adverse health effects from chronic exposure [15].

Among the metals analyzed, Cd exhibited the highest THQ values across all vegetable types, ranging from 1.092 in pepper (Wudil) to 2.243 in carrot (Nomans-Land), clearly indicating that Cd is the principal contributor to non-carcinogenic risk in the study area. The highest cumulative HI value was observed in carrot from Nomans-Land (3.338), followed by lettuce from Sharada (2.657) and carrot from Wudil (2.546). These values all exceed the US Environmental Protection Agency's (US EPA) acceptable threshold of HI = 1.0, indicating potential health risks from prolonged exposure [18].

Cr and Pb also contributed substantially to the cumulative risk profile. THQ values for Cr exceeded 0.75 in several vegetables, including onion from Sharada and carrot from Nomans-Land, suggesting possible localised industrial contamination, potentially linked to effluent discharge and metal processing activities [9]. Pb exhibited moderate THQ values, particularly in onion and lettuce from Sharada, likely reflecting contributions from traffic emissions or urban pollution sources such as vehicular emissions, atmospheric deposition, and deteriorating infrastructure [20, 21] .

Ni, in contrast, consistently recorded the lowest THQ values in all vegetable samples, suggesting a minimal risk of non-carcinogenic effects via dietary exposure. These observations align with previous findings reported in similar urban agricultural contexts [1].

Overall, the elevated HI values, particularly in root and leafy vegetables highlight the potential health hazards associated with multi-metal exposure. Although individual THQ values for some metals remained below the threshold of concern, the cumulative HI values emphasize the potential for chronic health effects, with Cd and Cr representing the most significant contributors to risk.

Conclusion

This study demonstrates that vegetables cultivated in urban and peri-urban areas of Kano, Nigeria, are contaminated with varying levels of heavy metals, particularly Cd, manganese Mn, Pb, and Cr. The concentrations and associated health risks were found to be both location- and crop-dependent, with root and leafy vegetables (such as carrot and lettuce) exhibiting the highest levels of metal accumulation. Health risk assessments using EDI), THQ, and HI revealed that Cd is the primary contributor to non-carcinogenic risk, with several vegetable samples exceeding the recommended safety thresholds. Although Ni posed relatively low risk, the cumulative effect of multi-metal exposure presents a significant public health concern, particularly for vulnerable populations with high vegetable consumption rates.

The findings underscore the urgent need for routine monitoring of heavy metals in food crops, improved agricultural practices, and the regulation of industrial emissions and wastewater discharges. Strengthening environmental policies and promoting safer irrigation and soil management strategies will be essential to minimize human exposure to toxic metals through dietary intake. Future studies should explore the bioavailability of metals, long-term health outcomes, and effective remediation approaches for contaminated urban farmlands.

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