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Heavy Metal Contamination and Associated Health Risks at the Halleluyah Dumpsite, Zuru, Kebbi State, Nigeria: Effects on Soil and Vegetables

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ABSTRACT

Background and Objective: Soil is an important natural resource essential for agricultural productivity. However, contamination from dumpsites can introduce toxic elements into the soil and plants, necessitating periodic assessments. The objective of this study is to investigate the extent of heavy metal contamination in soil and edible vegetables grown around the Halleluyah Dumpsite in Zuru, Kebbi State, Nigeria, and to evaluate the potential health risks posed to the local population through consumption and environmental exposure. **Materials and Methods:** This study evaluated the concentrations of lead (Pb), nickel (Ni), cadmium (Cd), manganese (Mn), and copper (Cu) in soil and three commonly consumed vegetables, *Solanum lycopersicum* (tomato), *Amaranthus viridis* (amaranthus), and *Lactuca sativa* (lettuce), collected from the vicinity of the Halleluyah Dumpsite in Zuru, Kebbi State, Nigeria. Soil samples were taken at depths of 5, 10, and 15 cm, and both soil and plant samples were analyzed. The study also calculated the average daily inhalation (ADI), average daily dermal exposure (ADDE), target hazard quotient (THQ), and health risk index (HRI) for the heavy metals. **Results:** The Pb and Cd exceeded World Health Organization (WHO) permissible limits in all three vegetables. The Mn and Cu exceeded the safe limits only in *S. lycopersicum*, while Ni remained within acceptable levels. The THQ values for heavy metals in the vegetables were within safe limits, but their HRI values were above the threshold ($\geq$1). In the soil, all heavy metals except Cd were within permissible limits. However, the ADI values for Cd, Mn, Ni, and Cu exceeded recommended safety thresholds, while Pb remained within limits. The ADDE values for heavy metals from soil exposure were within safe levels, but the THQ and HRI values exceeded the permissible threshold ($\geq$1). **Conclusion:** Based on these findings, consuming vegetables grown in the affected soil and direct exposure to the contaminated soil may pose significant health risks. Therefore, remediation of the soil around the dumpsite, along with regular monitoring, is necessary to mitigate potential environmental and health hazards.

KEYWORDS

Amaranthus viridis (amaranthus), average daily inhalation (ADI), dumpsite, lead (Pb), soil

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INTRODUCTION

Soil is a vital natural resource that supports food production systems and vegetation cultivation for feed, fiber, and fuel[1]. Nearly all the food consumed by humans originates from crops grown directly or indirectly in soil[2]. Additionally, soil serves as a crucial source of nutrients and functions as a natural filter, removing pollutants from water and food[3]. However, soil can also harbor heavy metals, chemical compounds, and microorganisms that pose health risks to humans through contaminated food crops, drinking water, or inhalation[4,5]. Heavy metals can enter the soil naturally through rock weathering or due to human activities such as mining, metal processing, automobile emissions, coal combustion, and the use of fertilizers, manure, and pesticides[6,7]. Furthermore, dumpsites containing solid waste, sewage sludge, and wastewater from treatment plants can release heavy metals into the soil, exacerbating contamination[8,9].

In urban areas, particularly in developing nations, poorly managed dumpsites are often major sources of heavy metal pollution[10]. Leachates from these sites may contain toxic compounds and microorganisms, which can alter soil properties such as acidity, alkalinity, cohesiveness, and compressibility[11]. These changes can reduce soil fertility and hinder plant growth. Additionally, heavy metals present in contaminated soil can accumulate in the human body through food consumption or environmental exposure, potentially causing neurological, cardiovascular, endocrine, and immunological disorders[12,13]. The severity of these health impacts depends on the concentration of heavy metals, the route of exposure, and individual susceptibility[14]. Given these risks, evaluating the safety of soil and plants cultivated near dumpsites is essential.

In Zuru, Kebbi State, Nigeria, open waste dumping and urban farming-especially vegetable cultivation are common practices. The Halleluyah Dumpsite is a notable waste disposal site in the town, where municipal, agricultural, and artisanal waste are frequently discarded. Among the most commonly grown vegetables in the area are *Solanum lycopersicum* (tomato), *Amaranthus viridis* (amaranthus), and *Lactuca sativa* (lettuce). Tomatoes, belonging to the Solanaceae family, are rich in bioactive compounds with antioxidant and anticancer properties[15]. Amaranthus consists of approximately 60 species, all highly nutritious and abundant in phytochemicals, vitamins, and minerals[16]. Lettuce is low in calories, fat, and sodium while possessing anti-inflammatory, sedative, and antioxidant properties[17]. These vegetables are widely consumed in Zuru and transported to neighboring communities in Kebbi State, other Nigerian States, and even countries such as Niger and Benin Republic. Despite their economic and nutritional significance, there is limited documentation on the impact of dumpsite contamination on soil quality and the plants grown in the area. Such information is crucial for preventing potential health hazards. Therefore, this study assessed the effects of the Halleluyah Dumpsite in Zuru, Kebbi State, Nigeria, on the surrounding soil and the cultivation of *Solanum lycopersicum*, *Amaranthus viridis*, and *Lactuca sativa*.

MATERIALS AND METHODS

Study area: This study was conducted around the Halleluyah Dumpsite in Zuru Town, Kebbi State, Nigeria, between October, 2023 and January, 2024 (Fig. 1). Zuru is situated in the Southeastern part of the state and is characterized by highlands to the West, while the Eastern region is relatively flat, featuring scattered granite formations and inselbergs. The town lies at approximately 11°26'6.79"N Latitude and 5°14'5.78"E Longitude. It covers an area of about 653 km^2 and has an elevation of approximately 350 m.a.s.l.[18].

Zuru experiences a tropical climate with distinct wet and dry seasons. The dry season lasts from November to February, while the wet season extends from April to October. The region receives an average annual rainfall of 1,025-1,050 mm, with temperatures ranging from 31°C in January to 38°C in April[18].

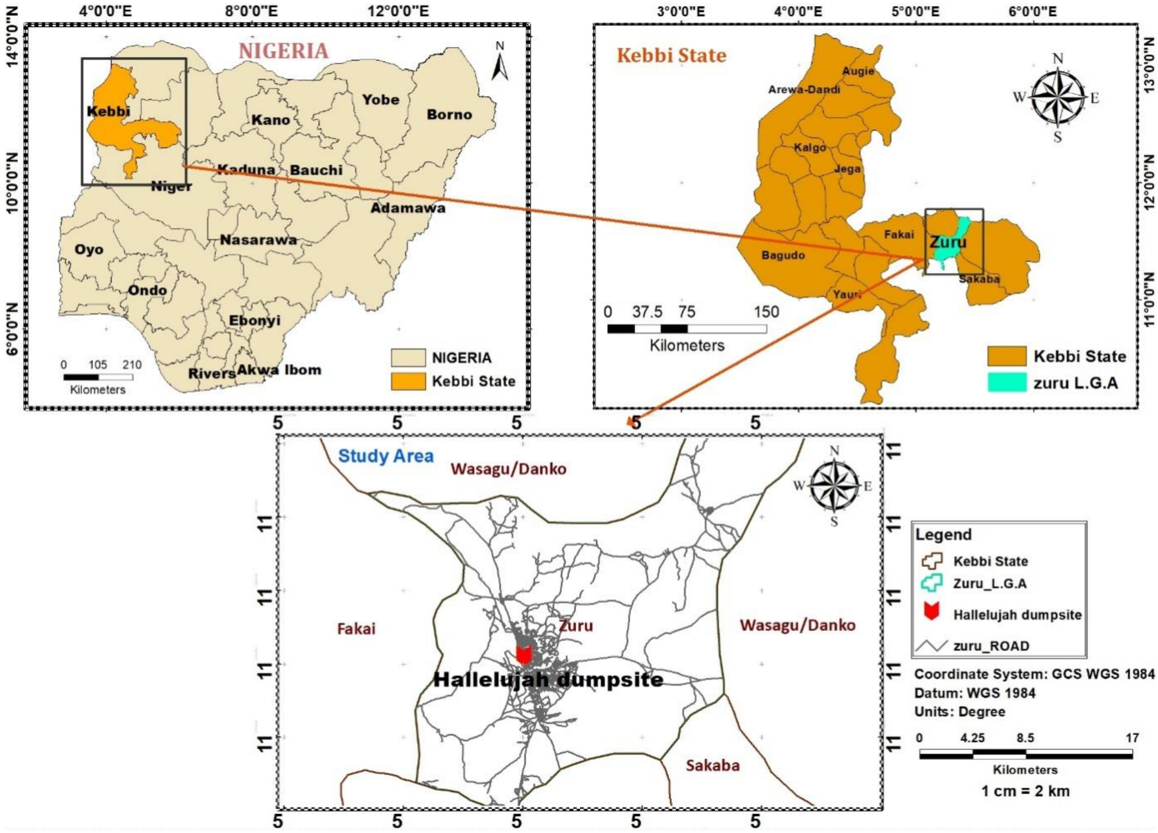

Fig. 1: Map of the study area

Plant and soil sample collection and preparation: Samples of *Solanum lycopersicum* (tomato), *Amaranthus viridis* (amaranthus), and *Lactuca sativa* (lettuce) were collected from a farm near the Halleluyah Dumpsite in Zuru, Kebbi State. The leaves were separated from the stems and thoroughly washed with tap water to remove surface contaminants. They were then air-dried at room temperature for two weeks. Once dried, the leaves were ground into a fine powder using a pestle and mortar, properly labeled, and stored in a desiccator until further analysis.

Soil samples were randomly collected from the farmland at depths of 5, 10, and 15 cm. The samples were placed in clean polyethylene bags, appropriately labeled, and transported to the laboratory. They were air-dried at room temperature (24°C) for six days before being oven-dried until a constant weight was achieved. The dried samples were then finely ground using a mortar and pestle and stored in a desiccator for subsequent analysis.

Heavy metal analysis: The heavy metal concentrations in the vegetable and soil samples were analyzed using atomic absorption spectroscopy (AAS), following the method described by Yahaya *et al.*[19]. To prepare the samples for analysis, 5 g of finely ground plant or soil material were placed into a clean beaker. A digestion mixture consisting of 10 mL of nitric acid (HNO_3), 10 mL of perchloric acid ($HClO_4$), and 1 mL of sulfuric acid (H_2SO_4) was added. The mixture was stirred continuously for a few minutes to ensure proper digestion, followed by the addition of 5 mL of distilled water. The solution was swirled again to achieve uniformity.

After digestion, the solution was filtered into a 50 mL volumetric flask, and distilled water was added to bring the volume up to the mark. The heavy metal concentrations, including cadmium (Cd), manganese (Mn), nickel (Ni), copper (Cu), and lead (Pb), were determined using a PG-990 atomic absorption spectrophotometer. Appropriate calibration standards and quality control measures were implemented to ensure the accuracy and reliability of the results.

Quality control and assurance: All glassware and plastic materials used in the analysis were thoroughly washed with a detergent solution and rinsed with deionized water. To eliminate any potential contamination, they were then sterilized using 10% nitric acid (HNO_3) and rinsed again with deionized water before use.

To ensure the accuracy and reliability of the results, background contamination in the soil and vegetable samples was carefully monitored. This was achieved by analyzing blank samples after every five sample analyses to detect any potential contamination. Additionally, each heavy metal was measured in triplicate to assess reproducibility, and the results were found to be highly consistent, with a 95% confidence level. The mean values of the triplicate measurements for each heavy metal were used for further analysis.

All reagents used in the study were of analytical grade to minimize contamination and ensure the precision of the measurements.

Health risk assessment

Health risk assessment of the vegetables: The average daily intake (ADI), target hazard quotient (THQ), and health risk index (HRI) of heavy metals in the vegetable samples were assessed using standard risk assessment models, as described by Yahaya *et al.*[20]. These parameters were calculated using Eq. 1-3 to evaluate the potential health risks associated with consuming contaminated vegetables. The ADI was used to estimate the daily exposure to heavy metals through vegetable consumption, while the THQ assessed non-carcinogenic health risks. The HRI provided an overall risk evaluation by comparing metal concentrations with established safety limits:

$$ADI = \frac{HMC \times CF \times DVI}{ABW} \tag{1}$$

where, HMC refers to the heavy metal concentration in the edible parts of vegetables (mg/kg), CF represents the conversion factor for transforming vegetable weight from fresh to dry matter, DVI denotes the daily vegetable intake, and ABW corresponds to the average body weight of consumers. According to Yahaya *et al.*[20], the standard CF value for vegetables is 0.085, the DVI is 65 g/day, and the ABW is 65 kg. These standardized values were used to ensure consistency and accuracy in calculating the potential dietary exposure to heavy metals through vegetable consumption:

$$THQ = \frac{EF \times ED \times DVI \times HMC \times 10^{-3}}{RFD \times ABW \times AET} \tag{2}$$

where, EF represents exposure frequency, ED denotes exposure duration, and AET refers to the average exposure time for non-carcinogens. According to Yahaya *et al.*[20], the standard EF value is 356 days per year, while ED is 54 years, which corresponds to the average life expectancy in Nigeria. The AET is calculated as the product of ED and EF, representing the total exposure time over a lifetime.

The reference doses (RFD) for the assessed heavy metals are as follows: 0.0035 mg/kg/day for lead (Pb), 0.04 mg/kg/day for cadmium (Cd), 0.07 mg/kg/day for copper (Cu), 0.14 mg/kg/day for manganese (Mn), and 0.02 mg/kg/day for nickel (Ni). These values indicate the maximum permissible daily exposure levels that are not expected to cause adverse health effects over a lifetime of exposure.

A target hazard quotient (THQ) value greater than 1 suggests a potential health risk, indicating that exposure to the heavy metal may lead to significant adverse effects[20]. This threshold is crucial for assessing the safety of consuming vegetables grown in contaminated soils:

$$HRI = \Sigma THQ \text{ of individual heavy metals} \tag{3}$$

Health risk assessment of the soil: The average daily inhalation (ADI), average daily dermal exposure (ADDE), and hazard quotient (HQ) of heavy metals in the soil were assessed using established risk assessment models, as described by Yahaya *et al.*[21]. These parameters were calculated using Eq. 4-6 to evaluate potential health risks associated with exposure to contaminated soil. The ADI estimates the daily intake of heavy metals through inhalation of dust particles, while the ADDE quantifies exposure through skin contact. The HQ is used to assess non-carcinogenic health risks by comparing exposure levels with established safety thresholds:

$$\text{ADI} = \frac{\text{CoH} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{ABW} \times \text{AT}} \tag{4}$$

$$\text{ADDE} = \frac{\text{CoH} \times \text{ESSA} \times \text{AF} \times \text{DAF} \times \text{EF} \times \text{ED}}{\text{ABW} \times \text{AT}} \tag{5}$$

$$\text{HQ} = \frac{\text{ADI/ADDE}}{\text{RFD}} \tag{6}$$

where, CoH represents the heavy metal concentration in the soil (mg/kg); IR denotes the inhalation rate of soil particles, which is 7.6 m^3/day for children and 16 m^3/day for adults; EF represents the exposure frequency, set at 365 days per year to account for daily exposure; ED refers to the exposure duration, which is 6 years for children and 24 years for adults; ESSA stands for the exposed skin surface area, measured at 2800 cm^2 for children and 5700 cm^2 for adults; AF is the soil adherence factor, with a standard value of 0.07 kg/m^2/day; ABW denotes the average body weight, which is 29 kg for children and 65 kg for adults; AT represents the average exposure time (days), calculated as ED×365; DAF is the dermal absorption factor, which varies for different heavy metals: Cadmium (Cd)= 0.14, manganese (Mn)= 0.001, nickel (Ni)= 0.35, copper (Cu)= 0.1, and lead (Pb)= 0.006.

These standardized parameters are essential for assessing inhalation and dermal exposure risks associated with soil contamination. They help in estimating potential health hazards, particularly for vulnerable populations such as children.

Data analysis: Values were expressed as Mean±Standard Deviation (SD) and analyzed using Microsoft Excel. The software was also utilized to calculate the average daily intake (ADI), average daily dermal exposure (ADDE), hazard quotient (HQ), and health risk index (HRI) of the heavy metals. These statistical measures ensure accuracy and reliability in assessing the potential health risks associated with heavy metal exposure.

RESULTS AND DISCUSSION

Concentrations of heavy metals in the soil and health risks: Table 1 presents the concentrations of cadmium (Cd), manganese (Mn), lead (Pb), copper (Cu), and nickel (Ni) in soil samples collected at depths of 5, 10, and 15 cm around the Halleluyah Dumpsite in Zuru, Kebbi State, Nigeria. The analysis revealed elevated levels of these heavy metals; however, except for Cd, their concentrations remained within the permissible limits set by the World Health Organization (WHO) for soils. The results also showed a general trend of decreasing concentrations with increasing soil depth (5>10>15 cm). Among the heavy metals analyzed, Pb had the highest concentration, whereas Cd had the lowest.

Table 1: Levels of heavy metals in soil samples collected around Halleluyah Dumpsite in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Mn	Ni	Cu	Pb
5	3.0±1.1	4.2±1.5	10.0±2.0	11.0±3.1	15.2±3.1
10	2.4±1.2	3.2±1.1	10.0±1.9	9.0±2.7	14.1±2.9
15	1.9±0.9	3.1±1.1	9.0±1.9	9.1±2.6	14.0±3.0
WHO limit[39]	0.8	6.61	35	36	85

Values were expressed as Mean±SD (n = 6) and mg/kg and WHO: World Health Organization

Table 2: Average daily inhalation (ADI) of heavy metals by adults in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Mn	Ni	Cu	Pb
5	0.74	1.03	2.46	2.71	3.74
10	0.59	0.79	2.46	2.22	3.74
15	0.47	0.76	2.22	2.24	3.45
WHO limit[39]	0.02	0.05	0.02	4.0	0.01

Values were expressed as Mean±SD and WHO: World Health Organization

Table 3: Average daily inhalation (ADI) of heavy metals by children in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Mn	Ni	Cu	Pb
5	0.79	1.10	2.62	2.88	3.98
10	0.63	0.84	2.62	2.36	3.70
15	0.50	0.81	2.36	2.38	3.67
WHO limit[39]	0.01	0.05	0.02	4.0	0.01

Values were expressed as Mean±SD and WHO: World Health Organization

Table 4: Average daily dermal exposure (ADDE) to heavy metals by adults in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Mn	Ni	Cu	Pb
5	0.003	0.00003	0.021	0.007	0.0006
10	0.002	0.00002	0.022	0.006	0.0005
15	0.002	0.00002	0.019	0.006	0.0005
WHO limit[39]	0.01	0.05	5.0	4.0	0.01

Values were expressed as Mean±SD and WHO: World Health Organization

Table 5: Average daily dermal exposure (ADDE) to heavy metals by children in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Mn	Ni	Cu	Pb
5	0.0028	0.000028	0.024	0.0074	0.0006
10	0.0023	0.000022	0.024	0.0061	0.00095
15	0.0018	0.000021	0.021	0.0062	0.00057
WHO limit[39]	0.01	0.05	5.0	4.0	0.01

These findings align with previous studies investigating heavy metal contamination in soils near dumpsites. For example, Oghenejoboh *et al.*[22] reported elevated levels of heavy metals in agricultural soils near a dumpsite in Oleh, Niger Delta, Nigeria. Similarly, Ibrahim *et al.*[23] found high concentrations of Cu, Pb, Cr, and Ni in and around a dumpsite in Potiskum, Yobe State, Nigeria. Furthermore, Nkop *et al.*[24] documented significant Cd contamination in soils near dumpsites in Akwa Ibom State, Nigeria. However, the concentrations observed in the present study were generally lower than those reported in the aforementioned studies. This discrepancy could be attributed to variations in the composition and management of the dumpsites, differences in waste disposal practices, and the age of the waste. Older waste tends to release higher concentrations of toxic metals over time[25]. The relatively lower heavy metal levels in the Halleluyah Dumpsite may be due to its comparatively better waste management and the predominance of domestic and agricultural waste, as Zuru is not an industrialized area.

Although most heavy metals in the soil were found within permissible limits, it is important to note that there are no truly “safe” levels for some heavy metals due to their persistence and bio-accumulative nature[26]. Heavy metals are non-biodegradable, meaning they can accumulate in the soil, plants, and animals, eventually reaching toxic levels.

Table 2 and 3 show the average daily intake (ADI) of Cd, Mn, Ni, and Cu through inhalation by adults and children. The ADI values exceeded the recommended safety limits, indicating a potential risk of heavy metal accumulation in the body due to prolonged exposure. However, the average daily dermal exposure (ADDE) values for the heavy metals remained within tolerable limits, suggesting that dermal absorption may not pose a significant health risk (Table 4 and 5).

Table 6: Target hazard quotient (THQ) and health risk index (HRI) of the heavy metals via inhalation by adults in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Target Mn	Hazard Ni	Quotient Cu	Pb	Health risk index
5	790	-	131	72	1063	2056
10	630	-	131	59	986	1806
15	500	-	118	60	985	1663

THQ and HRI above 1 is considered toxic

Table 7: Target hazard quotient (THQ) and health risk index (HRI) of the heavy metals via inhalation by children in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Target Mn	Hazard Ni	Quotient Cu	Pb	Health risk index
5	790	-	131	72	1063	2056
10	630	-	131	59	1051	12264
15	500	-	118	59	1043	9965

THQ and HRI above 1 is considered toxic

Table 8: Target hazard quotient (THQ) and health risk index (HRI) of the heavy metals via dermal ingestion by adults in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Target Mn	Hazard Ni	Quotient Cu	Pb	Health risk index
5	104	0.00019	26	0.57	1.07	132
10	84	0.00014	28	0.46	0.99	114
15	64	0.00014	24	0.47	0.99	90

THQ and HRI above 1 is considered toxic

Table 9: Target hazard quotient (THQ) and health risk index (HRI) of the heavy metals via dermal exposure by children in Zuru, Kebbi State, Nigeria

Soil depth (cm)	Cd	Target Mn	Hazard Ni	Quotient Cu	Pb	Health risk index
5	112	0.0002	30	0.62	1.18	144
10	92	0.00016	30	0.51	0.18	123
15	72	0.00015	27	0.52	1.09	101

THQ and HRI above 1 is considered toxic

Nevertheless, the target hazard quotient (THQ) and health risk index (HRI) values for heavy metal exposure via inhalation and dermal contact exceeded the recommended threshold (>1) for both adults and children (Table 6-9). This suggests that these heavy metals may interact synergistically, increasing the risk of adverse environmental and health effects.

Exposure to Pb is known to cause neurological, respiratory, urinary, and cardiovascular disorders through immune suppression, oxidative stress, and inflammatory responses[27]. The Cd is classified as a human carcinogen and has been associated with kidney damage, bone demineralization, and lung cancer[28]. Excessive Cu exposure can lead to gastrointestinal distress, including nausea, vomiting, and abdominal pain[29]. The Mn toxicity has been linked to neurological impairments such as dystonia, bradykinesia, rigidity, reproductive issues, Parkinson's disease, and tremors[30].

In addition to human health risks, heavy metal contamination can have severe ecological consequences. The Cu and Cd accumulation in soil can reduce microbial biomass and activity, thereby disrupting nutrient cycling and decreasing soil fertility[31]. The Pb toxicity in plants leads to reduced photosynthesis, stunted growth, chlorosis, mineral deficiencies, water imbalances, enzyme dysfunction, and cell death[32]. The Ni contamination negatively impacts soil fertility and plant growth[33]. The Cu exposure can inhibit seed germination, cause root and shoot stunting, and reduce crop yields[34]. The Mn accumulation suppresses stomatal opening and leaf anatomical development by inducing indole acetic acid deficiency, thereby impairing carbon dioxide assimilation and slowing plant growth[35].

In addition to agricultural and domestic sources, other potential contributors to heavy metal contamination at the Halleluyah Dumpsite include artisanal activities, traffic emissions, and urban runoff. The people of Zuru engage in metal smelting, which is a known source of heavy metal deposition in the soil. Haider *et al.*[36] reported that mining, smelting, metal scraps, and metal-containing products such as paints, cosmetics, and synthetic fertilizers are among the primary sources of heavy metal pollution in the environment. Another potential source of heavy metal contamination is the disposal of herbal medicines, which are widely consumed in Zuru, as in many other Nigerian Towns. Herbal medicines often contain heavy metals, and their indiscriminate disposal could contribute to the heavy metal load in the dumpsite[37]. Similarly, pharmaceutical waste, frequently discarded in dumpsites, serves as another potential source of heavy metal pollution[37]. Beyond these anthropogenic sources, natural processes may also contribute to the presence of heavy metals in the dumpsite. Geological weathering, leaching of minerals, and atmospheric deposition are known to introduce heavy metals into the environment over time[38]. Therefore, while human activities significantly influence heavy metal accumulation, natural geochemical processes may also play a role in the observed contamination levels.

Concentrations of heavy metals in the vegetables and health risks: Table 10 presents the concentrations of cadmium (Cd), manganese (Mn), lead (Pb), copper (Cu), and nickel (Ni) in *Solanum lycopersicum* (tomato), *Amaranthus viridis* (amaranthus), and *Lactuca sativa* (lettuce) collected from farmland near the Halleluyah Dumpsite. The results indicate that Pb and Cd exceeded the World Health Organization (WHO)[39] permissible limits in all three vegetables. Additionally, Mn and Cu were found above safe limits in *S. lycopersicum*, whereas Ni remained within permissible levels across all the vegetables. These findings suggest that *S. lycopersicum* was the most contaminated among the sampled vegetables.

Among the detected heavy metals, Cu exhibited the highest concentrations, while Cd had the lowest. These results align with the studies of Akintola and Bodede[40], Holcomb *et al.*[41], and Akintola *et al.*[42], who reported excessive levels of heavy metals in edible plants grown on dumpsite soil. However, the findings contradict those of Opaluwa *et al.*[43] and Palanivel *et al.*[44], who reported permissible levels of certain heavy metals in vegetables cultivated near dumpsites. These discrepancies may arise from variations in waste management practices, the type and age of dumped materials, as well as differences in the metal-accumulating properties of plant species. The ability of plants to absorb heavy metals is influenced by multiple factors, including soil characteristics, plant species, fertilizer application, organic and inorganic matter content, and soil age[45]. Generally, vegetables are known to accumulate significant amounts of heavy metals[45].

The potential health risks associated with heavy metal contamination in these vegetables were assessed in Table 11. The results indicate that the average daily intake (ADI) of Cd and Pb through the consumption of the three vegetables exceeded recommended safety limits, while the ADI of Ni was above the permissible threshold in *L. sativa*. However, the ADI of Cu and Mn remained within acceptable limits. Although the target hazard quotient (THQ) for individual heavy metals in the vegetables was within safe levels, the health risk index (HRI) exceeded the permissible threshold (>1) (Table 12). The HRI represents the sum of the THQ values for multiple heavy metals in a substance, indicating that the heavy metals in these vegetables can interact additively, potentially increasing health risks for consumers. Heavy metals are known to interact synergistically, amplifying their toxic effects. According to Chu and Chow[46], Cu can combine with various heavy metals to enhance overall toxicity. For example, Cu and Cd, as well as a combination of Cu, Cd, and Cr, have been shown to increase the toxicity of substances. Experimental studies on rats have demonstrated that Cd and Pb synergistically elevate toxicity levels[47]. Cedergreen[48] also reported synergistic interactions between heavy metals such as Cd and Zn, Cu and Zn, and Cu and Cd, which can disrupt cellular functions in humans.

Table 10: Levels of heavy metals in *S. lycopersicum*, *A. viridis*, and *L. sativa* collected around Halleluyah Dumpsite in Zuru, Kebbi State, Nigeria

Plant	Cd	Mn	Ni	Cu	Pb
S. lycopersicum	0.6±0.02	3.0±0.07	4.0±0.9	0.62	1.18
A. viridis	0.3±0.01	1.6±0.01	6.3±0.2	0.51	0.18
L. sativa	0.3±0.01	1.0±0.01	4.2±0.8	0.52	1.09
WHO limit[39]	0.02	2.0	10.0	10.0	0.3

Values were expressed as Mean±SD (n = 6) and mg/kg and WHO: World Health Organization

Table 11: Average daily intake (mg/person/day) of heavy metals in *S. lycopersicum*, *A. viridis*, and *L. sativa* collected around Halleluya Dumpsite in Zuru, Kebbi State, Nigeria

Plant	Cd	Mn	Ni	Cu	Pb
S. lycopersicum	0.051	0.255	0.340	0.884	0.077
A. viridis	0.026	0.136	0.536	0.765	0.060
L. sativa	0.026	0.085	0.357	0.255	0.068
Recommended	0.000	-	0.500	10.0	0.3

Table 12: Target hazard quotient (THQ) and Health risk index (HRI) of heavy metals in *S. lycopersicum*, *A. viridis*, and *L. sativa* collected around Halleluyah Dumpsite in Zuru, Kebbi State, Nigeria

Plant	Cd	Target Mn	Hazard Ni	Quotient Cu	Pb	Health risk index
S. lycopersicum	0.6	0.02	0.20	0.26	0.26	1.34
A. viridis	0.3	0.01	0.32	0.23	0.20	1.06
L. sativa	0.3	0.01	0.21	0.01	0.23	0.76

THQ and HRI above 1 is considered toxic

The findings of this study are consistent with those of Ekere *et al.*[49], who reported non-permissible THQ values for Cd in plants grown on dumpsites in Enugu, Nigeria. Similarly, Obas *et al.*[50] documented excessive THQ levels for nearly all evaluated heavy metals in plants cultivated near a dumpsite in Ebonyi State, Nigeria. These results highlight the potential health risks associated with consuming vegetables grown in contaminated environments and underscore the need for stringent monitoring and remediation efforts to mitigate heavy metal exposure in food crops.

CONCLUSION

Soil samples collected from the Halleluyah Dumpsite in Zuru, Kebbi State, Nigeria, exhibited elevated concentrations of cadmium (Cd), manganese (Mn), lead (Pb), copper (Cu), and nickel (Ni). However, only Cd exceeded permissible safety limits. The average daily inhalation (ADI) of these heavy metals surpassed recommended thresholds, whereas the average daily dermal exposure (ADDE) remained within safe limits. The target hazard quotient (THQ) and health risk index (HRI) for both inhalation and dermal exposure exceeded the acceptable threshold (>1), indicating potential health risks. Additionally, *Solanum lycopersicum* (tomato), *Amaranthus viridis* (amaranthus), and *Lactuca sativa* (lettuce) cultivated in the contaminated soil contained at least two heavy metals at concentrations above WHO-permissible limits. Furthermore, the HRI values for heavy metal exposure through vegetable consumption were also above the allowable threshold (>1), suggesting an increased risk of adverse health effects. These findings highlight significant environmental and health concerns associated with both direct exposure to the soil and consumption of crops grown in the area. To mitigate potential health risks, cultivation and consumption of crops from the dumpsite should be discouraged until appropriate soil remediation measures are implemented.

SIGNIFICANCE STATEMENT

Improper waste management at open dumpsites poses serious environmental and public health risks, especially in developing regions. This study assessed heavy metal contamination in soil and vegetables from the Halleluyah Dumpsite in Zuru, Nigeria, revealing elevated levels of cadmium, lead, manganese, copper, and nickel, with associated non-carcinogenic health risks. The findings highlight significant exposure through inhalation, dermal contact, and vegetable consumption. This research emphasizes the urgent need for remediation efforts and stricter waste management practices. Broadly, it underscores the environmental and food safety challenges posed by unregulated dumpsites, offering critical insights for policymakers and public health interventions globally.

REFERENCES

1. Sharma, P., P. Sharma and N. Thakur, 2024. Sustainable farming practices and soil health: A pathway to achieving SDGs and future prospects. Discover Sustainability, Vol. 5. 10.1007/s43621-024-00447-4.
2. Silver, W.L., T. Perez, A. Mayer and A.R. Jones, 2021. The role of soil in the contribution of food and feed. Phil. Trans. R. Soc. B Biol. Sci., Vol. 376. 10.1098/rstb.2020.0181.
3. Brevik, E.C., L. Slaughter, B.R. Singh, J.J. Steffan, D. Collier, P. Barnhart and P. Pereira, 2020. Soil and human health: Current status and future needs. Air Soil Water Res., Vol. 13. 10.1177/1178622120934441.
4. Hu, X., J. Wang, Y. Lv, X. Liu and J. Zhong *et al*., 2021. Effects of heavy metals/metalloids and soil properties on microbial communities in farmland in the vicinity of a metals smelter. Front. Microbiol., Vol. 12. doi.org/10.3389/fmicb.2021.707786.
5. Abdur Rashid, B.J. Schutte, A. Ulery, M.K. Deyholos, S. Sanogo, E.A. Lehnhoff and L. Beck, 2023. Heavy metal contamination in agricultural soil: Environmental pollutants affecting crop health. Agronomy, Vol. 13. 10.3390/agronomy13061521.
6. Laniyan, T.A. and O.M. Morakinyo, 2021. Environmental sustainability and prevention of heavy metal pollution of some geo-materials within a city in Southwestern Nigeria. Heliyon, Vol. 7. 10.1016/j.heliyon.2021.e06796.
7. Angon, P.B., M. Shafiul Islam, K.C. Shreejana, A. Das, N. Anjum, A. Poudel and S.A. Suchi, 2024. Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain. Heliyon, Vol. 10. 10.1016/j.heliyon.2024.e28357.
8. Briffa, J., E. Sinagra and R. Blundell, 2020. Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon, Vol. 6. 10.1016/j.heliyon.2020.e04691.
9. Yahaya, T., Y. Abdulganiyu, B.H. Gulumbe, E. Oladele, D. Anyebe and U. Shemishere, 2022. Heavy metals and microorganisms in borehole water around the Olusosun Dumpsite in Lagos, Nigeria: Occurrence and health risk assessment. Avicenna J. Environ. Health Eng., 9: 69-74.
10. Ibor, O.R., A.B. Andem, G. Eni, G.A. Arong, A.O. Adeougn and A. Arukwe, 2020. Contaminant levels and endocrine disruptive effects in *Clarias gariepinus* exposed to simulated leachate from a solid waste dumpsite in Calabar, Nigeria. Aquat. Toxicol., Vol. 219. 10.1016/j.aquatox.2019.105375.
11. Zamani, N., M. Merzouki, F.Z. Talbi, M. Najy and A. Janati-Iddrissi, 2025. Risk assessment of groundwater and surface water contamination by waste leachate from the Guercif open dump, Morocco. Int. J. Environ. Stud., 82: 201-222.
12. Zaynab, M., R. Al-Yahyai, A. Ameen, Y. Sharif and L. Ali *et al*., 2022. Health and environmental effects of heavy metals. J. King Saud Univ. Sci., Vol. 34. 10.1016/j.jksus.2021.101653.
13. K. Jomova, S.Y. Alomar, E. Nepovimova, K. Kuca and M. Valko, 2025. Heavy metals: Toxicity and human health effects. Arch. Toxicol., 99: 153-209.
14. Afzal, A. and N. Mahreen, 2024. Emerging insights into the impacts of heavy metals exposure on health, reproductive and productive performance of livestock. Front. Pharmacol., Vol. 15. 10.3389/fphar.2024.1375137.
15. Kumar, M., M. Tomar, D.J. huyan, S. Punia and S. Grasso *et al*., 2021. Tomato (*Solanum lycopersicum* L.) seed: A review on bioactives and biomedical activities. Biomed. Pharmacother., Vol. 142. 10.1016/j.biopha.2021.112018.
16. Sattar, M., F. Saeed, M. Afzaal, A. Rasheed and A. Asif *et al*., 2024. An overview of the nutritional and therapeutic properties of Amaranth. Int. J. Food Prop., 27: 263-272.

17. Assefa, A.D., O.S. Hur, B.S. Hahn, B. Kim, N.Y. Ro and J.H. Rhee, 2021. Nutritional metabolites of red pigmented lettuce (*Lactuca sativa*) germplasm and correlations with selected phenotypic characters. Foods, Vol. 10. 10.3390/foods10102504.
18. Agan, P.N., J.Y. Alhassan, S.S. Vintenaba and M.A. Muhammad, 2019. Impacts of climate change on rural-urban migration and agricultural productivity in Southern Region of Kebbi State, Nigeria. J. Earth Sci. Environ. Stud., 4: 714-720.
19. Yahaya, T., L.N. Aisha, A.S. Kalgo, N. Muhammad, M.J. Abubakar and M.U. Faruk, 2024. Contamination and risk assessment of heavy metals in water and fish obtained in Bunza River in Kebbi State, Nigeria. Environ. Health Eng. Manage. J., 11: 191-199.
20. Yahaya, T.O., O.A. Ogundipe, A. Abdulazeez, B. Usman and J. Danjuma, 2020. Bioaccumulation and health risk assessment of heavy metals in three vegetables consumed in Lagos, South-West Nigeria. Trop. J. Nat. Prod. Res., 4: 14-20.
21. Yahayaa, T.O., E.O. Oladele, B. Chibs, A. Abdulazeez and K. Nnochiri *et al*., 2020. Level and health risk evaluation of heavy metals and microorganisms in urban soils of Lagos, Southwest Nigeria. Algerian J. Biosci., 1: 51-60.
22. Oghenejoboh, K.M., P.W. Igbagara and U.M. Oghenejoboh, 2017. Contamination of agricultural soils by selected heavy metals from municipal solid waste dumpsites-A case study of Oleh Town in Nigeria's Niger Delta. Niger. J. Technol. Res., 12: 1-7.
23. Ibrahim, G.D., E.O. Nwaichi and G.O. Abu, 2020. Heavy metals contents of municipal solid waste dumpsites in Potiskum, Yobe State Nigeria. J. Environ. Prot., 11: 709-717.
24. Nkop, E.J., A.M. Ogunmolasuyi, K.O. Osezua and N.O. Wahab, 2016. Comparative study of heavy metals in the soil around waste dump sites within University of Uyo. Arch. Appl. Sci. Res., 8: 11-15.
25. Abiriga, D., L.S. Vestgarden and H. Klempe, 2020. Groundwater contamination from a municipal landfill: Effect of age, landfill closure, and season on groundwater chemistry. Sci. Total Environ., Vol. 737. 10.1016/j.scitotenv.2020.140307.
26. Yahaya, T.O., E.O. Oladele, O.R. Abiola, O. Ologe and A. Abdulazeez, 2021. Carcinogenic and non-carcinogenic risks of heavy metals in *Clarias gariepinus* (African catfish) obtained from Bariga section of Lagos Lagoon, Nigeria. Iran. J. Energy Environ., 12: 61-67.
27. Balali-Mood, M., K. Naseri, Z. Tahergorabi, M.R. Khazdair and M. Sadeghi, 2021. Toxic mechanisms of five heavy metals: Mercury, lead, chromium, cadmium, and arsenic. Front. Pharmacol., Vol. 12. 10.3389/fphar.2021.643972.
28. Kim, T.H., J.H. Kim, M.D.L. Kim, W.D. Suh and J.E. Kim *et al*., 2020. Exposure assessment and safe intake guidelines for heavy metals in consumed fishery products in the Republic of Korea. Environ. Sci. Pollut. Res., 27: 33042-33051.
29. Rahimzadeh, M.R., M.R. Rahimzadeh, S. Kazemi and A.A. Moghadamnia, 2024. Copper poisoning with emphasis on its clinical manifestations and treatment of intoxication. Adv. Public Health., Vol. 2024. 10.1155/2024/6001014.
30. Lucchini, R. and K. Tieu, 2023. Manganese-induced parkinsonism: Evidence from epidemiological and experimental studies. Biomolecules, Vol. 13. 10.3390/biom13081190.
31. Guo, Y., S. Cheng, H. Fang, J. Geng and Y. Li *et al*., 2024. Copper and cadmium co-contamination increases the risk of nitrogen loss in red paddy soils. J. Hazard. Mater., Vol. 479. 10.1016/j.jhazmat.2024.135626.
32. Shafeeq Ur Rahman, A. Qin, M. Zain, Z. Mushtaq and F. Mehmood *et al*., 2024. Pb uptake, accumulation, and translocation in plants: Plant physiological, biochemical, and molecular response: A review. Heliyon, Vol. 10. 10.1016/j.heliyon.2024.e27724.
33. Prematuri, R., M. Turjaman, T. Sato and K. Tawaraya, 2020. The impact of nickel mining on soil properties and growth of two fast-growing tropical trees species. Int. J. For. Res., Vol. 2020. 10.1155/2020/8837590.

34. Fortunato, G., I. Vaz-Moreira, O.C. Nunes and C.M. Manaia, 2021. Effect of copper and zinc as sulfate or nitrate salts on soil microbiome dynamics and bla_{VIM}-positive *Pseudomonas aeruginosa* survival. J. Hazard. Mater., Vol. 415. 10.1016/j.jhazmat.2021.125631.
35. Takagi, D., K. Ishiyama, M. Suganami, T. Ushijima and T. Fujii *et al*., 2021. Manganese toxicity disrupts indole acetic acid homeostasis and suppresses the CO_2 assimilation reaction in rice leaves. Sci. Rep., Vol. 11. 10.1038/s41598-021-00370-y.
36. Haider, F.U., C. Liqun, J.A. Coulter, S.A. Cheema and J. Wu *et al*., 2021. Cadmium toxicity in plants: Impacts and remediation strategies. Ecotoxicol. Environ. Saf., Vol. 211. 10.1016/j.ecoenv.2020.111887.
37. Akanchise, T., S. Boakye, L.S. Borquaye, M. Dodd and G. Darko, 2020. Distribution of heavy metals in soils from abandoned dump sites in Kumasi, Ghana. Sci. Afr., Vol. 10. 10.1016/j.sciaf.2020.e00614.
38. Vareda, J.P., A.J.M. Valente and L. Durães, 2019. Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. J. Environ. Manag., 246: 101-118.
39. WHO, 2017. Guidelines for Drinking-Water Quality, 4th Edition, Incorporating the 1st Addendum. 4th Edn., World Health Organization, Geneva, Switzerland, ISBN: 978-92-4-154995-0, Pages: 631.
40. Akintola, O.O. and I.A. Bodede, 2019. Distribution and accumulation of heavy metals in red cedar (*Cedrela odorata*) wood seedling grown in dumpsite soil. J. Appl. Sci. Environ. Manage., 23: 811-817.
41. Holcomb, D.A., J. Knee, T. Sumner, Z. Adriano and E. de Bruijn *et al*., 2020. Human fecal contamination of water, soil, and surfaces in households sharing poor-quality sanitation facilities in Maputo, Mozambique. Int. J. Hyg. Environ. Health., Vol. 226. 10.1016/j.ijheh.2020.113496.
42. Akintola, O.O., I.O. Abiola, E.K. Abodunrin, O.S. Olokeogun, A.A. Ekaun, A.T. Ademigbuji and K.O. Babatunde, 2021. Potential of *Ricinus communis* L. for removal of heavy metal in contaminated soil. J. Appl. Sci. Environ. Manage., 25: 371-376.
43. Opaluwa, O.D., M.O. Aremu, L.O. Ogbo, K.A. Abiola, I.E. Odiba, M.M. Abubakar and N.O. Nweze, 2012. Heavy metal concentrations in soils, plant leaves and crops grown around dump sites in Lafia Metropolis, Nasarawa State, Nigeria. Adv. Appl. Sci. Res., 3: 780-784.
44. Palanivel, T.M., B. Pracejus and R. Victor, 2020. Phytoremediation potential of castor (*Ricinus communis* L.) in the soils of the abandoned copper mine in Northern Oman: Implications for arid regions. Environ. Sci. Pollut. Res., 27: 17359-17369.
45. Zwolak, A., M. Sarzyńska, E. Szpyrka and K. Stawarczyk, 2019. Sources of soil pollution by heavy metals and their accumulation in vegetables: A review. Water Air Soil Pollut., Vol. 230. 10.1007/s11270-019-4221-y.
46. Chu, K.W. and K.L. Chow, 2002. Synergistic toxicity of multiple heavy metals is revealed by a biological assay using a nematode and its transgenic derivative. Aquat. Toxicol., 61: 53-64.
47. Andjelkovic, M., A.B. Djordjevic, E. Antonijevic, B. Antonijevic and M. Stanic *et al*., 2019. Toxic effect of acute cadmium and lead exposure in rat blood, liver, and kidney. Int. J. Environ. Res. Public Health, Vol. 16. 10.3390/ijerph16020274.
48. Cedergreen, N., 2014. Quantifying synergy: A systematic review of mixture toxicity Studies within environmental toxicology. PLoS ONE, Vol. 9. 10.1371/journal.pone.0096580.
49. Ekere, N.R., M.C.J. Ugbor, J.N. Ihedioha, N.N. Ukwueze and H.O. Abugu, 2020. Ecological and potential health risk assessment of heavy metals in soils and food crops grown in abandoned urban open waste dumpsite. J. Environ. Health Sci. Eng., 18: 711-721.
50. Obas, N.A., S.E. Obasi, G.A. Obianuju and E.O. Nnac, 2017. Health risk assessment of selected dumpsites in amata-akpoha community using cultivated edible plants. Res. J. Environ. Toxicol., 11: 62-71.