

# Heavy Metal Contamination, Bioaccumulation and Potential Human Health Risks in Soils and Vegetables Irrigated Along River Delimi, Jos Metropolis, Nigeria

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**Abstract:** This study assessed the concentrations of six heavy metals (Pb, Cr, Cd, Cu, Zn, and Ni) in soils and vegetables (cabbage and lettuce) collected from selected Fadama farms in Jos Metropolis, namely Katako Bridge, Farin Gada Bridge, and Yelwa Langalanga. Soil and vegetable samples were analyzed using Atomic Absorption Spectrometry (AAS), and the data were subjected to descriptive and inferential statistical analyses. The results showed that Yelwa Langalanga recorded the highest mean concentrations of Cd (0.102 mg/kg) and Cr (0.106 mg/kg), both exceeding WHO threshold values, while Katako Bridge had the highest Pb concentration (0.092 mg/kg), close to the WHO permissible limit. Soil pH was highest at Katako Bridge, whereas Yelwa Langalanga had the highest organic matter and cation exchange capacity. Pb, Cr, Cd, and Cu were generally more abundant than Zn and Ni across the study sites. Significant differences were observed between heavy metal concentrations in soils and vegetables, and Pb, Cr, and Cd in cabbage and lettuce exceeded WHO limits. Chromium showed the highest bioaccumulation factor (0.27), and a strong soil–vegetable relationship was observed for Cu ( $R^2 = 0.86$ ), while relationships for other metals were weak. The study recommends that the application of chemical fertilizers be guided by professional advice and that other potential sources of contamination, particularly irrigation water, should be investigated further.

**Keywords:** Heavy Metals, Soil Contamination, Vegetables, Bioaccumulation Factor, Fadama Farming, Jos Metropolis.

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## I. INTRODUCTION

Heavy metal contamination of agricultural soils has become one of the most significant environmental challenges worldwide because of rapid urbanization, industrialization, mining activities, population growth, and unsustainable waste management practices. Unlike many organic pollutants, heavy metals are non-biodegradable, persistent, and capable of accumulating in soils over long periods, thereby posing serious ecological and public health concerns (Ali et al., 2023; Rehman et al., 2023). Urban agriculture, particularly vegetable cultivation around rivers and floodplains, is especially vulnerable because irrigation water often receives untreated municipal wastewater, industrial effluents, and stormwater runoff containing toxic metals.

Vegetables constitute an essential component of the human diet because they supply vitamins, minerals, dietary

fibre, and antioxidants required for healthy growth and disease prevention. However, leafy vegetables such as cabbage (*Brassica oleracea*) and lettuce (*Lactuca sativa*) are also efficient accumulators of heavy metals due to their shallow root systems, rapid growth rates, and extensive leaf surfaces that facilitate both root uptake and atmospheric deposition (Singh et al., 2020; Rahman et al., 2021). Consequently, vegetables cultivated on contaminated soils may serve as major pathways through which toxic metals enter the human food chain.

Among the heavy metals commonly detected in agricultural soils, lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn) are of particular environmental importance. Although copper and zinc are essential micronutrients for plants, excessive concentrations may become toxic to both plants and humans. Conversely, lead and cadmium have no known biological function and are

highly toxic even at relatively low concentrations, while chromium toxicity depends largely on its oxidation state. Long-term dietary exposure to these metals has been associated with neurological disorders, kidney dysfunction, liver damage, cardiovascular diseases, developmental abnormalities, and several forms of cancer (World Health Organization [WHO], 2021; Rai et al., 2019).

The accumulation of heavy metals in vegetables depends on several interacting factors, including total metal concentration in soil, soil pH, organic matter content, cation exchange capacity, irrigation water quality, plant species, and agricultural management practices (Liu et al., 2020; Zhao et al., 2024). Slightly acidic soils generally increase metal mobility and bioavailability, thereby enhancing their uptake by crops. Consequently, monitoring heavy metal concentrations in soils and edible vegetables is essential for evaluating food safety, protecting public health, and promoting sustainable agricultural production.

In Nigeria, urban agriculture has expanded considerably over the past two decades due to increasing food demand, unemployment, and rapid urban population growth. Around Jos Metropolis, floodplain farming along River Delimi supports year-round cultivation of vegetables that are widely distributed to local markets. However, the river receives runoff from residential settlements, automobile repair workshops, commercial activities, municipal wastes, and remnants of historical tin-mining operations. These activities represent potential sources of heavy metal contamination capable of affecting soil quality and vegetable safety.

Several studies conducted in different parts of Nigeria have reported heavy metal contamination of agricultural soils and vegetables irrigated with wastewater or cultivated near highways and industrial areas (Ayangbenro & Babalola, 2017; Islam et al., 2022). Nevertheless, relatively few recent investigations have comprehensively evaluated the distribution of heavy metals simultaneously in soils and vegetables around Farin Gada Bridge while also examining bioaccumulation patterns and the relationship between soil contamination and vegetable uptake. Moreover, continuous urban expansion and changing land-use practices may have altered contamination levels since earlier investigations, creating the need for updated environmental assessments.

Therefore, this study assessed the concentrations of selected heavy metals (Pb, Cd, Zn, Cu, Cr, and Ni) in soils and commonly consumed vegetables cultivated around Farin Gada Bridge, Jos Metropolis. Specifically, the study determined the spatial distribution of heavy metals in soils and vegetables, compared measured concentrations with international guideline values, evaluated bioaccumulation factors, and examined the relationships between soil and vegetable heavy metal concentrations. The findings provide important baseline information for environmental monitoring, food safety management, and the development of evidence-based policies aimed at protecting public health and promoting sustainable urban agriculture in Plateau State, Nigeria.

## II. MATERIALS AND METHODS

### ➤ Study Area

The study was conducted on irrigated fadama farmlands located along River Delimi in Jos Metropolis, Plateau State, north-central Nigeria. Three major vegetable-producing sites were purposively selected, namely Katako Bridge (KB), Farin Gada Bridge (FGB), and Yelwa Langalanga (YL). These locations were selected because they represent the major dry-season irrigation clusters along River Delimi and are subjected to varying degrees of anthropogenic influences, including municipal wastewater discharge, agricultural activities, urban runoff, automobile workshops, and commercial activities. The study area is characterized by a tropical highland climate with distinct wet and dry seasons and supports intensive cultivation of leafy vegetables throughout the dry season.

### ➤ Study Design and Reconnaissance Survey

A cross-sectional field survey was adopted for the study. Prior to sample collection, a reconnaissance survey was undertaken to identify accessible irrigation farms, assess prevailing farming practices, determine irrigation sources, and establish representative sampling points. Information obtained during the survey was used to develop the sampling framework and ensure adequate spatial coverage of the study sites.

### ➤ Sample Collection

Soil and vegetable samples were collected during the dry season (February–March), when irrigation farming is at its peak and before the onset of rainfall to minimize dilution effects.

#### • Soil Sampling

Surface soil samples (0–15 cm) were collected using a stainless-steel soil auger after removing surface debris. Twelve sampling points were established at each study location, giving a total of thirty-six (36) soil samples. At each sampling point, composite samples were prepared by combining several subsamples collected within a one-metre radius to minimize spatial variability. Samples were stored in labelled polyethylene bags and transported to the laboratory for analysis. In the laboratory, samples were air-dried at room temperature, gently crushed, homogenized, and sieved through a 2-mm mesh prior to analysis following standard soil preparation procedures (USEPA, 1996; APHA, 2017).

#### • Vegetable Sampling

Fresh edible leaves of cabbage (*Brassica oleracea*) and lettuce (*Lactuca sativa*) were collected from farms corresponding to the soil sampling points. Six vegetable samples were obtained from each study site, resulting in eighteen (18) samples. Samples were placed in sterile polyethylene bags and transported immediately to the laboratory. The vegetable samples were washed thoroughly with distilled water to remove adhered soil particles and atmospheric deposits, oven-dried at 70°C to constant weight, ground into fine powder using a porcelain mortar, and stored in clean airtight containers until chemical analysis (APHA, 2017).

### ➤ Determination of Heavy Metals

Prepared soil and vegetable samples were digested using nitric acid (HNO<sub>3</sub>), hydrochloric acid (HCl), and perchloric acid (HClO<sub>4</sub>) following the United States Environmental Protection Agency (USEPA) acid digestion protocol (Method 3050B). The digested solutions were filtered and diluted to appropriate volumes with deionized water before instrumental analysis. Heavy metal concentrations of lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), chromium (Cr), and nickel (Ni) were determined using Flame Atomic Absorption Spectrophotometry (AAS). Instrument calibration was performed using certified standard solutions, while reagent blanks and duplicate samples were included for quality assurance and quality control throughout the analytical process (USEPA, 1996; APHA, 2017).

### ➤ Determination of Soil Physicochemical Properties

Selected physicochemical properties of the soil were analysed to evaluate factors influencing heavy metal mobility and bioavailability. Soil pH was measured in calcium chloride (CaCl<sub>2</sub>) suspension using a calibrated digital pH meter. Organic matter content was determined using the Walkley–Black wet oxidation method, while cation exchange capacity (CEC) was determined using the ammonium acetate extraction method at pH 7.0 according to standard analytical procedures. These soil parameters are widely recognized as important controls on heavy metal adsorption, mobility, and plant uptake.

### ➤ Bioaccumulation Factor

The bioaccumulation factor (BAF) was calculated to evaluate the transfer of heavy metals from soil to vegetables using Equation (1):

$$BAF = C_v / C_s$$

Where:

- $C_v$  = concentration of heavy metal in vegetable (mg kg<sup>-1</sup>)
- $C_s$  = concentration of heavy metal in soil (mg kg<sup>-1</sup>)

A BAF greater than one indicates efficient accumulation of heavy metals by plants, whereas values below one indicate limited uptake from soil.

### ➤ Statistical Analysis

Data obtained from laboratory analyses were subjected to descriptive and inferential statistical analyses using IBM SPSS (Version 25.0). Descriptive statistics, including mean, standard deviation, coefficient of variation, minimum, and maximum values, were computed for all measured variables. One-way Analysis of Variance (ANOVA) was used to determine significant spatial differences in heavy metal concentrations among the three sampling locations. Independent sample *t*-tests were employed to compare heavy metal concentrations between soils and vegetables. Pearson correlation and simple linear regression analyses were further performed to evaluate relationships between heavy metal concentrations in soils and vegetables. Statistical significance was assessed at the 95% confidence level ( $p < 0.05$ ). The measured concentrations were compared with recommended guideline values established by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) to evaluate the contamination status of the study area.

## III. RESULTS

### ➤ Distribution of Heavy Metals in Soil

Heavy metal concentrations exhibited marked spatial variation among the three sampling locations (Table 1). Overall, chromium and cadmium were the dominant metals in the soils, whereas zinc and nickel occurred at comparatively lower concentrations. These differences indicate varying levels of anthropogenic influence across the River Delimi floodplain.

As illustrated in Figure 1, the three sampling locations are distributed along River Delimi and represent different sections of the urban agricultural corridor within Jos Metropolis. Although the sites share similar environmental conditions, they are exposed to varying degrees of anthropogenic activities such as vehicular traffic, municipal waste disposal, commercial activities, and urban runoff. These differences were reflected in the concentrations of heavy metals observed in the soil samples. The concentrations of heavy metals varied considerably among the three sampling locations: Farin Gada bridge, Katako bridge and Yelwa Langalanga.

Table 1 Distribution of Heavy Metals and Soil pH at the Study Locations

| Location                | Statistic | Pb    | Cd     | Zn    | Cu    | Cr    | Ni     | pH (CaCl <sub>2</sub> ) |
|-------------------------|-----------|-------|--------|-------|-------|-------|--------|-------------------------|
| Katako Bridge           | Mean      | 0.021 | 0.040  | 0.020 | 0.089 | 0.087 | 0.011  | 6.39                    |
|                         | SD        | 0.010 | 0.040  | 0.000 | 0.000 | 0.050 | 0.010  |                         |
|                         | CV (%)    | 10.86 | 99.68  | 12.81 | 28.60 | 57.47 | 100.00 |                         |
| Farin Gada Bridge       | Mean      | 0.092 | 0.040  | 0.020 | 0.010 | 0.080 | 0.030  | 6.37                    |
|                         | SD        | 0.090 | 0.060  | 0.010 | 0.000 | 0.050 | 0.030  |                         |
|                         | CV (%)    | 92.42 | 135.25 | 29.68 | 78.72 | 62.76 | 106.61 |                         |
| Yelwa Langalanga Bridge | Mean      | 0.039 | 0.102  | 0.003 | 0.008 | 0.106 | 0.007  | 6.35                    |
|                         | SD        | 0.020 | 0.060  | 0.000 | 0.000 | 0.090 | 0.000  |                         |
|                         | CV (%)    | 52.63 | 58.20  | 9.67  | 45.14 | 85.91 | 61.65  |                         |

Source: Field Analysis (2026).

The study area is located along River Delimi in Jos Metropolis, Plateau State, Nigeria. Figure 1 illustrates the course of the river and the locations of the three sampling sites

(Katako Bridge, Farin Gada Bridge, and Yelwa Langalanga Bridge), which represent major vegetable cultivation areas within the River Delimi floodplain.

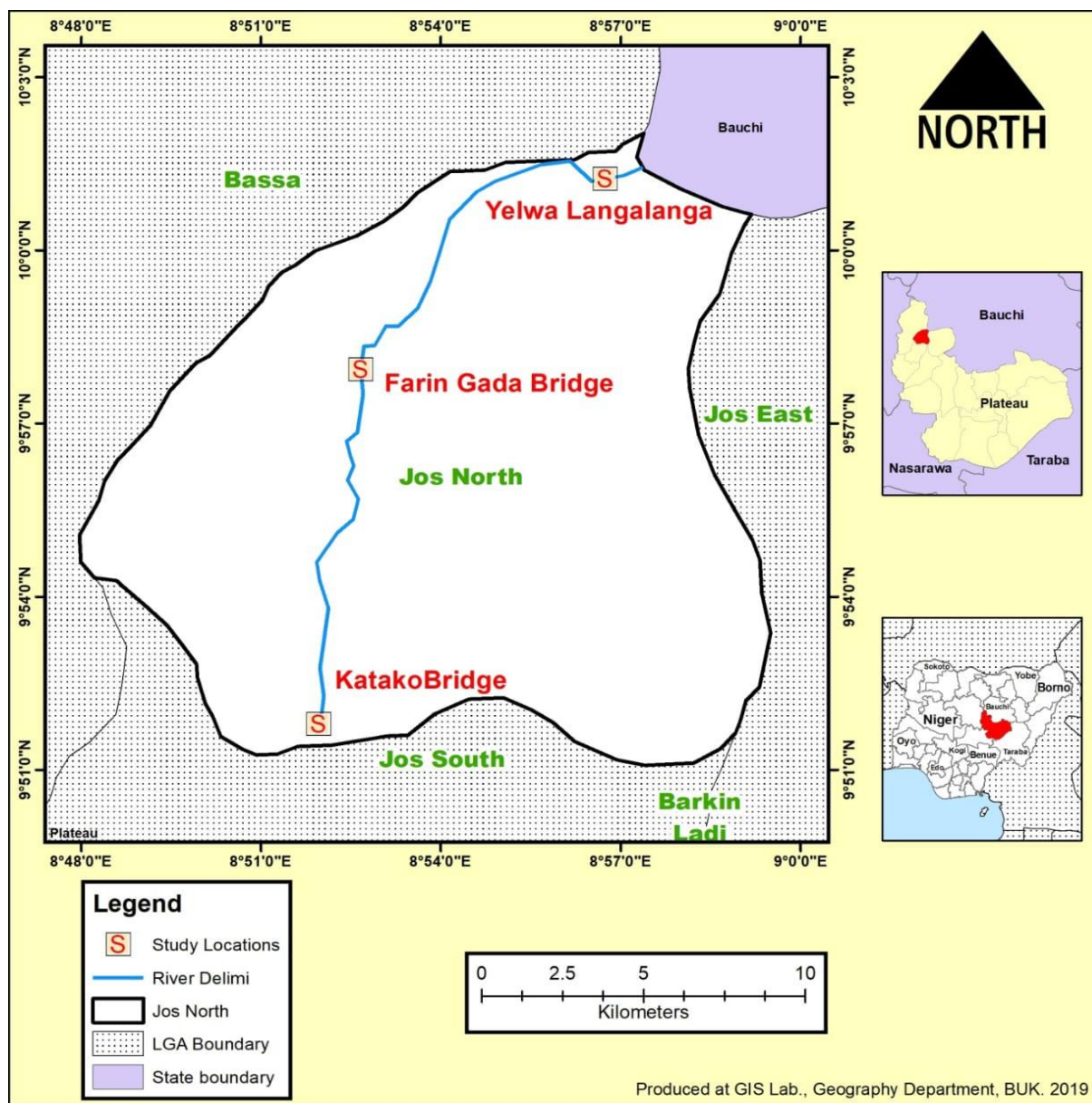


Fig 1 Map of River Delimi Showing the Study Area and Sampling Locations  
Source: Authors' GIS Compilation (2026).

Figure 1. Map of River Delimi showing the study area and sampling locations whereas lead (0.021 mg/kg) and zinc (0.020 mg/kg) recorded the lowest values. Cadmium and chromium also displayed relatively high variability, while nickel showed the highest coefficient of variation (100%), indicating substantial spatial variation within the sampling area. The average soil pH was 6.39, indicating slightly acidic soil conditions.

At Farin Gada Bridge, lead recorded the highest mean concentration (0.092 mg/kg), followed by chromium (0.080 mg/kg), whereas copper (0.010 mg/kg) and zinc (0.020 mg/kg) were the least abundant metals. The order of abundance was: Pb > Cr > Cd > Ni > Zn > Cu.

Cadmium exhibited the greatest variability (CV = 135.25%), followed by nickel (106.61%), suggesting considerable heterogeneity in their distribution across the farmland. The mean soil pH was 6.37, indicating slightly acidic conditions comparable to those observed at Katako Bridge.

At Yelwa Langalanga Bridge, chromium (0.106 mg/kg) and cadmium (0.102 mg/kg) were the predominant heavy metals, whereas nickel (0.007 mg/kg) and zinc (0.003 mg/kg) occurred at the lowest concentrations. The order of abundance was: Cr > Cd > Pb > Cu > Ni > Zn.

Chromium exhibited the highest coefficient of variation (85.91%), whereas zinc showed the least variability (9.67%). The mean soil pH was 6.35, indicating that soils across all study locations were consistently slightly acidic.

Overall, chromium and cadmium consistently recorded comparatively higher concentrations across the three locations, while zinc and nickel generally occurred at relatively lower concentrations. Soil pH ranged from 6.35 to

6.39, reflecting moderately acidic to slightly acidic conditions that may enhance the mobility and availability of heavy metals within the soil.

#### ➤ Distribution of Heavy Metals in Vegetables

The concentrations of heavy metals in cabbage (*Brassica oleracea*) and lettuce (*Lactuca sativa*) cultivated at the three study locations are presented in Table 2.

Table 2 Mean Concentration (mg/kg), Standard Deviation and Coefficient of Variation of Heavy Metals in Vegetables

| Location          | Vegetable | Pb    | Cd    | Zn    | Cu    | Cr    | Ni    |
|-------------------|-----------|-------|-------|-------|-------|-------|-------|
| Katako Bridge     | Cabbage   | 0.938 | 0.145 | 0.223 | 0.382 | 0.188 | 0.343 |
| Farin Gada Bridge | Cabbage   | 0.837 | 0.146 | 0.261 | 0.372 | 0.194 | 0.365 |
| Yelwa Langalanga  | Cabbage   | 0.403 | 0.181 | 0.401 | 0.682 | 0.167 | 0.237 |
| Katako Bridge     | Lettuce   | 0.860 | 0.141 | 0.205 | 0.330 | 0.185 | 0.467 |
| Farin Gada Bridge | Lettuce   | 0.775 | 0.198 | 0.274 | 0.340 | 0.267 | 0.303 |
| Yelwa Langalanga  | Lettuce   | 0.380 | 0.176 | 0.420 | 0.569 | 0.165 | 0.199 |

Source: Field Analysis (2026).

Heavy metals were detected in both cabbage and lettuce collected from all sampling locations, indicating uptake of metals from the surrounding agricultural soils.

Among the cabbage samples, lead recorded the highest mean concentration at Katako Bridge (0.938 mg/kg) and Farin Gada Bridge (0.837 mg/kg), whereas copper was highest at Yelwa Langalanga Bridge (0.682 mg/kg). Cadmium concentrations varied only slightly among the three locations, ranging from 0.145 to 0.181 mg/kg. Zinc concentrations were highest at Yelwa Langalanga (0.401 mg/kg), while chromium concentrations remained relatively uniform across all sites (0.167–0.194 mg/kg).

The order of heavy metal accumulation in cabbage was: Katako Bridge: Pb > Cu > Ni > Zn > Cr > Cd, Farin Gada Bridge: Pb > Ni > Cu > Zn > Cr > Cd and Yelwa Langalanga Bridge: Cu > Zn > Pb > Ni > Cd > Cr

The coefficients of variation showed considerable spatial variability, particularly for lead and copper, suggesting heterogeneous distribution of these metals within the cultivated fields.

Similarly, heavy metals were detected in all lettuce samples. Lead recorded the highest concentration at Katako Bridge (0.860 mg/kg), while zinc (0.420 mg/kg) and copper (0.569 mg/kg) were highest at Yelwa Langalanga Bridge. Chromium concentrations ranged from 0.165 to 0.267 mg/kg, with the highest value occurring at Farin Gada Bridge.

The order of heavy metal accumulation in lettuce was: Katako Bridge: Pb > Ni > Cu > Zn > Cr > Cd, Farin Gada Bridge: Pb > Cu > Ni > Zn > Cr > Cd and Yelwa Langalanga Bridge: Cu > Zn > Pb > Ni > Cd > Cr

Across all locations, lead and copper generally occurred at higher concentrations than the other investigated metals, whereas cadmium consistently exhibited comparatively lower concentrations. The widespread occurrence of heavy metals in both vegetable species indicates their ability to absorb and accumulate metals from the cultivated soils.

#### ➤ Comparison of Heavy Metal Concentrations in Soil and Vegetables

An independent samples *t*-test was conducted to determine whether significant differences existed between the concentrations of heavy metals in soil and those accumulated in cabbage and lettuce. The results are presented in Table 3.

Table 3 Independent Samples T-Test Comparing Heavy Metal Concentrations in Soil and Vegetables

(a) Soil vs. Cabbage

| Heavy Metal | Standard Error | t-value | df | p-value                | t-critical | Significance | Effect Size (r) |
|-------------|----------------|---------|----|------------------------|------------|--------------|-----------------|
| Pb          | 0.0765         | 8.728   | 68 | $5.24 \times 10^{-13}$ | 1.668      | Significant  | 0.727           |
| Cd          | 0.0131         | 7.312   | 68 | $1.94 \times 10^{-10}$ | 1.668      | Significant  | 0.663           |
| Zn          | 0.0394         | 6.805   | 68 | $1.59 \times 10^{-9}$  | 1.668      | Significant  | 0.636           |
| Cu          | 0.0559         | 8.653   | 68 | $7.15 \times 10^{-13}$ | 1.668      | Significant  | 0.724           |
| Cr          | 0.0252         | 4.445   | 68 | $1.66 \times 10^{-5}$  | 1.668      | Significant  | 0.475           |
| Ni          | 0.0340         | 8.516   | 68 | $1.27 \times 10^{-12}$ | 1.668      | Significant  | 0.718           |

(b) Soil vs. Lettuce

| Heavy Metal | Standard Error | t-value | df | p-value                | t-critical | Significance | Effect Size (r) |
|-------------|----------------|---------|----|------------------------|------------|--------------|-----------------|
| Pb          | 0.0767         | 7.987   | 68 | $1.16 \times 10^{-11}$ | 1.668      | Significant  | 0.696           |
| Cd          | 0.0248         | 4.451   | 68 | $1.63 \times 10^{-5}$  | 1.668      | Significant  | 0.475           |

|           |        |       |    |                        |       |             |       |
|-----------|--------|-------|----|------------------------|-------|-------------|-------|
| <b>Zn</b> | 0.0411 | 6.656 | 68 | $2.94 \times 10^{-9}$  | 1.668 | Significant | 0.628 |
| <b>Cu</b> | 0.0559 | 8.653 | 68 | $7.15 \times 10^{-13}$ | 1.668 | Significant | 0.724 |
| <b>Cr</b> | 0.0252 | 4.445 | 68 | $1.66 \times 10^{-5}$  | 1.668 | Significant | 0.475 |
| <b>Ni</b> | 0.0398 | 7.546 | 68 | $7.31 \times 10^{-11}$ | 1.668 | Significant | 0.675 |

Source: Field Analysis (2026).

The independent samples *t*-test revealed statistically significant differences between heavy metal concentrations in soil and both vegetable species ( $p < 0.05$ ) for all investigated metals. For cabbage, the highest *t*-values were observed for lead ( $t = 8.728$ ), copper ( $t = 8.653$ ), and nickel ( $t = 8.516$ ), indicating substantial differences between soil and plant concentrations. Chromium recorded the lowest *t*-value ( $t = 4.445$ ), although the difference remained statistically significant. Similarly, lettuce exhibited significant differences for all metals. Copper showed the highest *t*-value ( $t = 8.653$ ), followed by lead ( $t = 7.987$ ) and nickel ( $t = 7.546$ ). Effect sizes ranged from moderate to strong (0.475–0.724),

suggesting that soil heavy metal concentrations exerted a considerable influence on the accumulation of metals in both cabbage and lettuce.

#### ➤ Comparison of Heavy Metal Concentrations with WHO Permissible Limits

To evaluate the contamination status of the study area, the mean concentrations of heavy metals in soils and vegetables were compared with the World Health Organization (WHO) permissible limits. The results are presented in Tables 4 and 5.

Table 4 Comparison of Mean Heavy Metal Concentrations in Soil with WHO Permissible Limits

| Heavy Metal | Mean (mg/kg) | WHO Limit (mg/kg) | Status       |
|-------------|--------------|-------------------|--------------|
| <b>Pb</b>   | 0.029        | 0.10              | Within limit |
| <b>Cd</b>   | 0.003        | 0.01              | Within limit |
| <b>Zn</b>   | 0.0022       | 15.00             | Within limit |
| <b>Cu</b>   | 0.007        | 1.50              | Within limit |
| <b>Cr</b>   | 0.053        | 0.05              | Above limit  |
| <b>Ni</b>   | 0.008        | 6.50              | Within limit |

Source: Field Analysis (2026).

The comparison indicates that the mean concentrations of lead, cadmium, zinc, copper, and nickel in soil were below the WHO permissible limits. Chromium, however, recorded

a mean concentration of 0.053 mg/kg, marginally exceeding the recommended limit of 0.050 mg/kg, suggesting localized chromium contamination within the study area.

Table 5 Comparison of Heavy Metal Concentrations in Vegetables with WHO Permissible Limits

| Heavy Metal | Cabbage (mg/kg) | Lettuce (mg/kg) | WHO Limit (mg/kg) | Status                 |
|-------------|-----------------|-----------------|-------------------|------------------------|
| <b>Pb</b>   | 0.99            | 1.05            | 0.30              | Above limit            |
| <b>Cd</b>   | 0.14            | 0.44            | 0.20              | Above limit in lettuce |
| <b>Zn</b>   | 0.20            | 0.22            | 99.40             | Within limit           |
| <b>Cu</b>   | 0.26            | 0.32            | 1.21              | Within limit           |
| <b>Cr</b>   | 0.20            | 0.21            | 0.13              | Above limit            |
| <b>Ni</b>   | 0.43            | 0.30            | 1.00              | Within limit           |

Source: Field Analysis (2026); WHO (2002).

The comparison revealed that lead concentrations in both cabbage and lettuce substantially exceeded the WHO permissible limit of 0.30 mg/kg. Chromium concentrations in both vegetables also exceeded the recommended limit of 0.13 mg/kg, while cadmium exceeded the permissible level only in lettuce. In contrast, zinc, copper, and nickel remained below the recommended international limits in both vegetable species.

These findings indicate that although soil contamination was generally low, the vegetables accumulated appreciable quantities of lead, chromium, and cadmium, suggesting efficient uptake of these metals and a potential risk to consumers through regular dietary exposure.

#### ➤ Physicochemical Properties of the Soil

The physicochemical characteristics of the soils collected from the three study locations are summarized in Table 6.

Table 6 Mean Physicochemical Properties of Soils at the Study Locations

| Parameter                                     | Katako Bridge | Farin Gada Bridge | Yelwa Langalanga Bridge |
|-----------------------------------------------|---------------|-------------------|-------------------------|
| <b>pH</b>                                     | 6.39          | 6.37              | 6.35                    |
| <b>Organic Matter (%)</b>                     | 1.35          | 1.41              | 1.50                    |
| <b>Cation Exchange Capacity (mmol/100 kg)</b> | 3.34          | 3.29              | 3.36                    |

Source: Field Analysis (2026).

The soils across all study locations were slightly acidic, with pH values ranging from 6.35 to 6.39. Katako Bridge recorded the highest pH (6.39), whereas Yelwa Langalanga exhibited the lowest (6.35). Organic matter content ranged from 1.35% to 1.50%, with the highest value observed at Yelwa Langalanga. Similarly, cation exchange capacity (CEC) varied only slightly among the study sites, ranging from 3.29 to 3.36 mmol/100 kg, indicating relatively low nutrient retention capacity.

Overall, the slight acidity and relatively low CEC values suggest soil conditions that may enhance the mobility and

bioavailability of certain heavy metals, thereby facilitating their uptake by vegetables cultivated within the study area.

#### ➤ *Bioaccumulation of Heavy Metals in Vegetables*

The transfer of heavy metals from soil to vegetables was evaluated using the Bioaccumulation Factor (BAF), which represents the ratio of heavy metal concentration in the edible portion of the vegetable to that in the corresponding soil. The BAF values for cabbage and lettuce are presented in Tables 7 and 8.

Table 7 Bioaccumulation Factor (BAF) of Heavy Metals in Cabbage

| Heavy Metal | Soil Concentration (X) | Cabbage Concentration (Y) | BAF  |
|-------------|------------------------|---------------------------|------|
| <b>Pb</b>   | 0.03                   | 1.05                      | 0.03 |
| <b>Cd</b>   | 0.00                   | 0.43                      | 0.01 |
| <b>Zn</b>   | 0.00                   | 0.21                      | 0.01 |
| <b>Cu</b>   | 0.01                   | 0.31                      | 0.02 |
| <b>Cr</b>   | 0.05                   | 0.20                      | 0.27 |
| <b>Ni</b>   | 0.01                   | 0.30                      | 0.03 |

Source: Field Analysis (2026).

The bioaccumulation assessment showed that all investigated heavy metals were transferred from soil into cabbage, although the extent of accumulation differed among the metals. Chromium exhibited the highest bioaccumulation factor (0.27), indicating the greatest transfer efficiency from soil to cabbage. Lead and nickel recorded BAF values of 0.03, while copper had a value of 0.02. Cadmium and zinc showed

the lowest bioaccumulation factors (0.01 each), suggesting comparatively lower transfer into cabbage tissues. Although all BAF values were below one, indicating limited accumulation relative to the soil concentration, the detection of these metals in edible plant tissues demonstrates that cabbage cultivated within the study area is capable of absorbing heavy metals from contaminated soils.

Table 8 Bioaccumulation Factor (BAF) of Heavy Metals in Lettuce

| Heavy Metal | Soil Concentration (X) | Lettuce Concentration (Y) | BAF  |
|-------------|------------------------|---------------------------|------|
| <b>Pb</b>   | 0.03                   | 0.99                      | 0.03 |
| <b>Cd</b>   | 0.00                   | 0.13                      | 0.02 |
| <b>Zn</b>   | 0.00                   | 0.20                      | 0.01 |
| <b>Cu</b>   | 0.01                   | 0.25                      | 0.03 |
| <b>Cr</b>   | 0.05                   | 0.20                      | 0.27 |
| <b>Ni</b>   | 0.01                   | 0.43                      | 0.02 |

Source: Field Analysis (2026).

Similarly, lettuce accumulated all six heavy metals detected in the soil. Chromium recorded the highest bioaccumulation factor (0.27), followed by lead and copper (0.03 each). Cadmium and nickel exhibited BAF values of 0.02, while zinc recorded the lowest value (0.01). These findings indicate that lettuce, like cabbage, absorbed heavy metals from the surrounding soil, although the accumulation efficiencies varied among the investigated metals. Overall, chromium demonstrated the greatest tendency for transfer

from soil to vegetables, whereas zinc consistently exhibited the lowest transfer efficiency.

#### ➤ *Relationship between Heavy Metals in Soil and Vegetables*

Pearson's correlation analysis was performed to determine the relationship between heavy metal concentrations in soil and those accumulated in cabbage and lettuce. The results are presented in Tables 9 and 10.

Table 9 Correlation Between Heavy Metals in Soil and Cabbage

| Heavy Metal | Correlation Coefficient (R <sup>2</sup> ) | p-value                |
|-------------|-------------------------------------------|------------------------|
| <b>Pb</b>   | 0.160                                     | $1.86 \times 10^{-7}$  |
| <b>Cd</b>   | 0.280                                     | $1.19 \times 10^{-13}$ |
| <b>Zn</b>   | 0.253                                     | 0.902                  |
| <b>Cu</b>   | 0.002                                     | 0.0009                 |
| <b>Cr</b>   | 0.027                                     | 1.961                  |
| <b>Ni</b>   | 0.109                                     | 1.210                  |

Source: Field Analysis (2026).

The correlation analysis indicated generally weak relationships between heavy metal concentrations in soil and cabbage. Cadmium ( $R^2 = 0.280$ ) and zinc ( $R^2 = 0.253$ ) showed comparatively stronger positive relationships than

the remaining metals, whereas copper exhibited an almost negligible association ( $R^2 = 0.002$ ). These findings suggest that variations in soil metal concentrations only weakly influenced heavy metal accumulation in cabbage.

Table 10 Correlation Between Heavy Metals in Soil and Lettuce

| Heavy Metal | Correlation Coefficient ( $R^2$ ) | p-value               |
|-------------|-----------------------------------|-----------------------|
| <b>Pb</b>   | 0.174                             | $1.07 \times 10^{-6}$ |
| <b>Cd</b>   | 0.239                             | 0.00017               |
| <b>Zn</b>   | 0.004                             | 0.310                 |
| <b>Cu</b>   | 0.878                             | 0.00848               |
| <b>Cr</b>   | 0.176                             | 0.00015               |
| <b>Ni</b>   | 0.561                             | 0.00042               |

Source: Field Analysis (2026).

In contrast to cabbage, lettuce demonstrated stronger relationships for some heavy metals. Copper exhibited a very strong positive relationship with soil concentration ( $R^2 = 0.878$ ), followed by nickel ( $R^2 = 0.561$ ). Lead, cadmium, chromium, and zinc showed relatively weak relationships, indicating that factors other than soil concentration may also influence their uptake by lettuce.

#### ➤ Coefficient of Determination (Regression Analysis)

Regression analysis was performed to determine the extent to which heavy metal concentrations in soil explained the variation in heavy metal concentrations in cabbage and lettuce.

Table 11 Coefficient of Determination ( $R^2$ ) Between Soil and Cabbage

| Heavy Metal | $R^2$ | Adjusted $R^2$ | Standard Error |
|-------------|-------|----------------|----------------|
| <b>Pb</b>   | 0.026 | -0.003         | 0.449          |
| <b>Cd</b>   | 0.078 | 0.051          | 0.048          |
| <b>Zn</b>   | 0.064 | 0.003          | 0.228          |
| <b>Cu</b>   | 0.086 | -0.030         | 0.330          |
| <b>Cr</b>   | 0.000 | -0.029         | 0.050          |
| <b>Ni</b>   | 0.011 | -0.018         | 0.202          |

Source: Field Analysis (2026).

The regression results revealed generally low coefficients of determination for cabbage, indicating that soil heavy metal concentrations explained only a small proportion of the variability observed in cabbage. Copper recorded the

highest coefficient of determination ( $R^2 = 0.086$ ), while chromium exhibited virtually no explanatory relationship ( $R^2 = 0.000$ ).

Table 12 Coefficient of Determination ( $R^2$ ) Between Soil and Lettuce

| Heavy Metal | $R^2$ | Adjusted $R^2$ | Standard Error |
|-------------|-------|----------------|----------------|
| <b>Pb</b>   | 0.030 | 0.001          | 0.449          |
| <b>Cd</b>   | 0.057 | 0.028          | 0.131          |
| <b>Zn</b>   | 0.001 | -0.028         | 0.246          |
| <b>Cu</b>   | 0.007 | -0.022         | 0.321          |
| <b>Cr</b>   | 0.031 | 0.001          | 0.133          |
| <b>Ni</b>   | 0.314 | 0.293          | 0.197          |

Source: Field Analysis (2026).

For lettuce, nickel recorded the highest coefficient of determination ( $R^2 = 0.314$ ), indicating that approximately 31.4% of the variation in nickel concentration in lettuce could be explained by its concentration in the soil. Cadmium showed a relatively weak relationship ( $R^2 = 0.057$ ), while lead, zinc, copper, and chromium exhibited very low coefficients of determination. These findings suggest that, for most metals, soil concentration alone was insufficient to explain their accumulation in lettuce, and that other factors such as soil properties, plant physiology, and metal bioavailability may have contributed to the observed variability.

#### ➤ Summary of Findings

The results demonstrated spatial variation in heavy metal concentrations across the three study locations. Chromium and cadmium were the dominant contaminants in the soils, while lead and copper generally occurred at higher concentrations in vegetables. Independent sample *t*-tests confirmed significant differences between heavy metal concentrations in soils and vegetables ( $p < 0.05$ ). Comparison with WHO permissible limits showed that chromium exceeded the recommended limit in soil, whereas lead and chromium exceeded permissible limits in both cabbage and lettuce. Bioaccumulation analysis confirmed the transfer of

heavy metals from soil to vegetables, with chromium exhibiting the highest transfer efficiency. Correlation and regression analyses further indicated that the relationship between soil and vegetable heavy metal concentrations varied among the investigated metals, with stronger associations observed for copper and nickel in lettuce than in cabbage.

#### IV. DISCUSSION

##### ➤ *Heavy Metal Concentrations in Soil*

This study revealed considerable spatial variation in the concentrations of heavy metals across the three study locations. Chromium and cadmium recorded comparatively higher concentrations than the other investigated metals, whereas zinc and nickel generally occurred at lower concentrations. The elevated concentrations of chromium observed at Yelwa Langalanga and Katako Bridge may be associated with anthropogenic activities such as automobile emissions, indiscriminate waste disposal, runoff from urban settlements, and historical mining activities that characterize the Jos metropolis. Similar observations have been reported in urban agricultural soils where heavy metal enrichment was attributed to prolonged human activities and wastewater irrigation (Adimalla et al., 2019; Rehman et al., 2023).

The relatively high cadmium concentrations observed in some sampling locations may be associated with the continuous use of phosphate fertilizers, domestic wastes, discarded batteries, paints, and municipal refuse. Cadmium is regarded as one of the most mobile and toxic heavy metals because of its persistence in soils and its ability to accumulate in edible crops even at relatively low soil concentrations (Li et al., 2021). Similar findings have been reported for urban agricultural soils in Nigeria and other developing countries where cadmium accumulation has been linked to intensive farming and poor waste management practices (Ayangbenro & Babalola, 2017).

Although lead concentrations varied among the three study locations, the highest concentration occurred at Farin Gada Bridge. This finding may reflect the influence of traffic emissions, roadside activities, mechanical workshops, and urban runoff within the study area. Several studies have demonstrated that agricultural lands located near highways and densely populated urban centres often accumulate appreciable concentrations of lead because of continuous deposition from anthropogenic sources (Chowdhury et al., 2016; Islam et al., 2022).

The soil pH ranged from 6.35 to 6.39, indicating slightly acidic conditions across the study area. Slightly acidic soils generally enhance the solubility and mobility of heavy metals, thereby increasing their availability for plant uptake. This finding agrees with recent studies which reported that soil acidity is one of the major factors controlling heavy metal mobility and bioavailability in agricultural soils (Zhang et al., 2020; Ali et al., 2023).

The elevated chromium concentration observed at Yelwa Langalanga is likely associated with cumulative urban runoff, historical mining residues and waste disposal

activities within the catchment. Chromium is relatively persistent in soils and tends to accumulate in areas receiving repeated anthropogenic inputs, particularly where slightly acidic soil conditions increase its mobility.

##### ➤ *Heavy Metal Concentrations in Vegetables*

Heavy metals were detected in both cabbage and lettuce collected from all sampling locations, demonstrating that vegetables cultivated along the River Delimi floodplain accumulated metals from the surrounding soils. Lead recorded the highest concentrations in cabbage, while copper predominated in vegetables collected from Yelwa Langalanga. Chromium concentrations remained relatively consistent across the study sites, suggesting widespread contamination of agricultural soils.

The occurrence of lead in both cabbage and lettuce is of particular public health concern because lead has no known biological function in humans and may cause neurological disorders, kidney dysfunction, cardiovascular diseases, and developmental abnormalities following long-term exposure (World Health Organization [WHO], 2021). Similar studies conducted in urban agricultural systems across Africa have reported elevated lead concentrations in leafy vegetables cultivated with wastewater or grown close to major roads (Gebeyehu & Bayissa, 2020; Khan et al., 2022).

The relatively high concentrations of copper recorded in vegetables may reflect its essential role as a plant micronutrient. However, excessive copper accumulation may become toxic to plants and humans when concentrations exceed physiological requirements. Previous studies have similarly reported higher copper concentrations in leafy vegetables cultivated on urban soils because copper is readily absorbed by rapidly growing vegetable species (Rahman et al., 2021).

Leafy vegetables such as cabbage and lettuce generally accumulate higher concentrations of heavy metals because of their shallow rooting systems, rapid growth, and large leaf surface area that facilitates atmospheric deposition. Consequently, these vegetables are widely regarded as effective bioindicators of environmental contamination (Singh et al., 2020).

##### ➤ *Comparison with WHO Permissible Limits*

Comparison with WHO guideline values demonstrated that chromium slightly exceeded the recommended limit in soil, whereas lead and chromium exceeded the permissible limits in both cabbage and lettuce. Cadmium also exceeded the permissible concentration in lettuce.

The exceedance of chromium standards suggests that prolonged cultivation may gradually increase environmental contamination and reduce soil quality. Elevated chromium concentrations have been associated with reduced seed germination, inhibition of root development, and decreased crop productivity (Rai et al., 2019).

More importantly, the concentrations of lead observed in cabbage and lettuce were substantially above the WHO

permissible limit for vegetables. Regular consumption of vegetables containing elevated lead concentrations may increase the risk of chronic toxicity, especially among children and pregnant women. Recent epidemiological studies have continued to identify dietary intake of contaminated vegetables as an important pathway for human exposure to toxic metals in developing countries (WHO, 2021; FAO & WHO, 2022).

In contrast, zinc, copper, and nickel remained below the recommended international limits. These findings indicate that although the study area is not extensively contaminated by all investigated metals, lead, chromium, and cadmium require particular attention because of their toxicological significance.

#### ➤ *Bioaccumulation of Heavy Metals*

The bioaccumulation assessment showed that chromium exhibited the highest transfer factor in both cabbage and lettuce, whereas zinc recorded the lowest transfer efficiency. Although all bioaccumulation factors were below unity, indicating relatively limited transfer efficiency, the presence of heavy metals in edible vegetables confirms that soil remains an important source of contamination.

Plant uptake of heavy metals depends not only on total soil concentration but also on soil pH, organic matter content, cation exchange capacity, plant species, root morphology, and metal speciation. Previous investigations have demonstrated that leafy vegetables generally accumulate higher concentrations of chromium and lead than fruiting vegetables because of their physiological characteristics (Liu et al., 2020; Abbas et al., 2023).

#### ➤ *Relationship Between Heavy Metals in Soil and Vegetables*

The correlation and regression analyses revealed generally weak relationships between heavy metal concentrations in soil and cabbage, whereas stronger relationships were observed between soil and lettuce for copper and nickel. These findings suggest that heavy metal accumulation is influenced by multiple environmental and biological factors rather than soil concentration alone.

The relatively strong relationship between soil copper and lettuce indicates that lettuce responded more readily to changes in soil copper concentration than cabbage. Conversely, the weak relationships observed for most heavy metals indicate that soil physicochemical properties, irrigation water quality, plant physiology, and atmospheric deposition may have contributed significantly to heavy metal accumulation.

Recent studies have similarly reported that heavy metal uptake by vegetables is controlled by a combination of environmental conditions and plant-specific characteristics rather than total soil concentration alone (Shahid et al., 2020; Zhao et al., 2024).

#### ➤ *Implications for Environmental Quality and Public Health*

The findings of this study demonstrate that vegetables cultivated around Farin Gada Bridge have the potential to accumulate toxic heavy metals from contaminated agricultural soils. Although most soil concentrations remained within international guideline values, the elevated concentrations of lead, chromium, and cadmium in vegetables indicate potential food safety concerns.

Continuous consumption of contaminated vegetables may result in gradual accumulation of toxic metals within the human body, thereby increasing the risk of chronic diseases including kidney damage, neurological impairment, reproductive disorders, and certain cancers. These findings highlight the need for regular environmental monitoring, effective wastewater management, public awareness campaigns, and enforcement of environmental regulations to safeguard public health and ensure sustainable urban agriculture within Jos Metropolis.

### V. CONCLUSION

This study assessed the concentrations of selected heavy metals (Pb, Cd, Zn, Cu, Cr, and Ni) in soils and commonly consumed leafy vegetables (cabbage and lettuce) cultivated around Farin Gada Bridge, Jos Metropolis, Plateau State, Nigeria. The results demonstrated spatial variations in heavy metal concentrations across the study locations, indicating differences in the degree of environmental contamination associated with anthropogenic activities.

Chromium and cadmium were the predominant heavy metals detected in the soils, while lead and copper generally recorded the highest concentrations in vegetable samples. Comparison with World Health Organization (WHO) guideline values showed that chromium slightly exceeded the permissible limit in soil, whereas lead and chromium exceeded the recommended limits in both cabbage and lettuce. Cadmium also exceeded the permissible limit in lettuce. These findings indicate that although the soils were only moderately contaminated, leafy vegetables cultivated within the study area accumulated toxic metals to levels that may constitute a potential health risk to consumers.

The bioaccumulation analysis confirmed that all investigated heavy metals were transferred from soil into edible vegetable tissues, with chromium exhibiting the highest bioaccumulation factor. Correlation and regression analyses further revealed that while the relationships between soil and vegetable heavy metal concentrations varied among the investigated metals, soil remains an important source of contamination. However, other factors, including soil physicochemical properties, plant species, irrigation practices, and environmental conditions, also influence heavy metal uptake by vegetables.

The findings underscore the importance of continuous environmental surveillance in rapidly urbanizing agricultural landscapes where wastewater irrigation is practiced. Implementing sustainable irrigation practices, strengthening

environmental regulation, and promoting routine monitoring of heavy metals in soils and vegetables will be essential for safeguarding food safety and protecting public health in Jos Metropolis.

### RECOMMENDATIONS

➤ *Based on the Findings of this Study, the Following Recommendations are Proposed:*

- Routine monitoring of heavy metal concentrations in agricultural soils, irrigation water, and vegetables should be conducted by relevant environmental and public health agencies to ensure compliance with national and international food safety standards.
- Farmers should avoid the use of untreated wastewater and contaminated surface water for irrigation. Where wastewater irrigation is unavoidable, appropriate treatment should be carried out before agricultural use.
- Environmental protection agencies should strengthen the regulation of indiscriminate disposal of municipal wastes, industrial effluents, used batteries, automobile wastes, and other potential sources of heavy metal contamination within the River Delimi catchment.
- Public awareness programmes should be organized to educate farmers, vegetable vendors, and consumers on the health risks associated with heavy metal contamination and the importance of adopting environmentally sustainable farming practices.
- Soil management practices such as the application of organic amendments, biochar, compost, and liming materials should be encouraged to reduce heavy metal mobility and bioavailability in agricultural soils.
- Future studies should include seasonal assessment of heavy metal contamination, determination of human health risk indices such as Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and Lifetime Cancer Risk (LCR), as well as the evaluation of irrigation water quality to provide a more comprehensive assessment of environmental and public health risks.
- Government agencies should establish regular environmental surveillance programmes for urban agricultural lands within Jos Metropolis to ensure the long-term sustainability of vegetable production and the protection of public health.

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