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Research Article

Detection and Phytoextraction of Heavy Metals by Selected Edible and Non-Edible Plants from Irrigated Sites in Kano Metropolis, Nigeria

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ABSTRACT

Heavy metal contamination in irrigated sites poses significant risks to human health and environment. The most persistent challenges are heavy metal pollution from untreated industrial effluents discharged into rivers and irrigation channels accumulates in soils and are readily transferred into crops through irrigation and root uptake. The study investigates the potential of heavy metal contamination in soils and irrigation waters across a rural-to-industrial gradient and evaluates metal uptake/partitioning in a native shrub (*Dodonaea viscosa*) and tomato in Kano. Laboratory analysis was carried out and CSV/Excel datasets were used to compute location-level indices (Contamination factor, Pollution Load Index, Bio concentration and Translocation factors), descriptive statistics, and between-site contrasts. Results of the findings showed the mean soil pollution load index (PLI) was highest (±8.15) at Challawa (severe multi-metal burden) and declined (±2.57) along the spatial gradient toward Dambatta and the control (±0.96). Tomato fruits from contaminated farms contained markedly elevated Lead (Pb) (2.3mg/kg) and modestly higher Cadmium (Cd) (0.6mg/kg) compared with the control (0.1mg/kg); *D. viscosa* preferentially retained Pb and Chromium (Cr) in roots with Pb and Cr showing low translocation (TF < 0.6), indicating retention within roots, while Zn, Cu, and Ni exhibited higher mobility (TF ≈ 0.7–0.8), and suggesting moderate phytoextraction capability Findings of the investigations had established a substantial heavy-metal pressure on wastewater-irrigated agriculture around Challawa. The shrub *D. viscosa* shows phytostabilization traits for Pb/Cr and moderate phytoaccumulation for Zn/Cu/Ni; however, food-crop safety is compromised, under- scoring the need for effluent control and phytoremediation.

Keywords: Bioconcentration; Contamination factor; *Dodonaea viscosa*; Mean soil Pollution; Pollution load index; Translocation factors

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INTRODUCTION

Industrialization and urban expansion across Northern Nigeria, particularly around Kano State, have introduced significant environmental pressures on agricultural lands. One of the most persistent challenges is heavy metal pollution from untreated industrial effluents discharged into rivers and irrigation channels. These pollutants, notably lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn), accumulate in soils and are readily transferred into crops through irrigation and root uptake (Ali *et al.*, 2013; Emamverdian *et al.*, 2015). Over time, this process compromises soil fertility, plant productivity, and food safety, posing severe risks to human and ecological health. In the Kano River Basin, widespread use of wastewater for irrigation has led to the build-up of heavy metals in farmlands adjoining industrial zones such as Challawa and Sharada, where tanneries, textile mills, and metal workshops release effluents with minimal or no treatment (Hamidu *et al.*, 2021). Studies have shown that vegetables and grains cultivated in these areas frequently contain Pb and Cd levels that exceed international food safety limits, threatening local food security (Akan *et al.*, 2009; Isiuku and Enyoh, 2020). Chronic exposure to such contaminants can result in neurological, renal, and carcinogenic effects in humans, while also altering plant metabolism, reducing chlorophyll synthesis, and impairing photosynthesis. The persistence of toxic metals in soils, even years after discharge cessation, underlines the inadequacy of conventional management approaches and the urgent need for sustainable, low-cost remediation. One such strategy is phytoremediation—the use of plants to extract, stabilize, or transform pollutants from the environment. Unlike mechanical or chemical soil treatments, phytoremediation is cost-effective, environ- mentally friendly, and suitable for developing regions Tabrez *et al*., 2022a). However, selecting the right plant species is critical. Edible crops such as tomato (*Solanum lycopersicum*) may absorb heavy metals into their edible tissues, creating health hazards rather than solutions. Conversely, non-edible, metal-tolerant plants like *Dodonaea viscosa*, an evergreen shrub native to tropical and subtropical regions, offer promising potential for phytostabilization and phytoextraction (Acosta-Núñez *et al*., 2024a; Castañeda-Espinoza *et al*., 2023). Its proven ability to withstand harsh, metal-rich environments and its palatability to livestock make it ideal for field-level applications around polluted farm land. Building upon these realities, the present study aims to quantify heavy metal contamination in soils and irrigation waters across a rural-to-industrial gradient in Kano and provides actionable insights into sustainable soil management in pollution- prone agricultural zones of northern Nigeria. Ultimately, the findings contribute to identifying safe cultivation zones, guiding effluent management policies, and supporting the adoption of native, non-edible species for eco-restoration in developing contexts.

MATERIALS AND METHODS

Study Area and Site Selection

The study was carried out in Kano State, Northern Nigeria, within the Kano River Basin irrigation network. This region exhibits a semi-arid tropical climate with mean annual rainfall of 800–900 mm and temperatures ranging between 18–38 °C. Four sites were selected to represent a pollution gradient from industrial to rural settings: Challawa **(**Kumbotso**)**—a heavily industrialized area receiving effluents from tanneries, textile and metal-processing factories; Wudil **(**Fangale**)**—a peri-urban agricultural site receiving moderate urban runoff; Dambatta **(**Thomas Dam**)**—a rural irrigation site with minimal industrial influence; and a control site located upstream of industrial discharge, representing baseline metal levels. The soil type across all locations is predominantly loamy sand. Each site was geo-referenced using GPS and mapped relative to irrigation channels to capture hydrological connectivity.

Soil and Plant Sampling

Field sampling was conducted during the dry irrigation season (February–April) when wastewater usage peaks. At each site, two active farms were selected. From each farm, three composite soil samples (0–20 cm depth) were collected using a stainless-steel auger. Each composite consisted of five subsamples within a 10 m × 10 m grid. In total, 24 composite samples were obtained (6 per location). Samples were air-dried, gently crushed, and sieved through a 2 mm mesh before analysis. Plant sampling targeted two species: tomato (*Solanum lycopersicum*) and *Dodonaea viscosa*. Tomato plants were separated into roots, stems, leaves, and fruits, while *D. viscosa* samples (3–5 mature shrubs per site) were divided into roots and leaves. Plant parts were rinsed with distilled water, blotted dry, and stored in labelled paper bags.

Analysis of Samples

Soil pH was measured in a 1:2.5 soil–water suspension, and electrical conductivity (EC) determined from the supernatant. Organic matter (OM) content was analyzed using the Walkley–Black dichromate oxidation method. For metal quantification, 1.0 g of soil or plant tissue was digested using aqua regia (HCl: HNO_3 = 3:1) on a hot plate and filtered through Whatman No. 42 filter paper. Heavy metals (Pb, Cd, Cr, Ni, Cu, and Zn) were determined using Atomic Absorption Spectrophotometry (PerkinElmer Analyst 400). Standard reference materials and reagent blanks were analyzed concurrently for quality assurance.

Computation of Indices

Four major indices were calculated to evaluate soil contamination and plant uptake behavior: the Contamination Factor (CF), Pollution Load Index (PLI), Bioconcentration Factor (BCF), and Translocation Factor (TF).

Contamination Factor (CF): $= \frac{C}{Fi!} = \frac{Ci}{Cre/fi} \qquad (1)$

where C_i is the concentration of metal *i* in the sample and $C_{ref,i}$ is the concentration of the same metal in the control soil.

Pollution Load Index (PLI):

$PLI = (CF_1 \times CF_2 \times . . . \times CF_n)^{1/n} \qquad (2)$

A PLI value greater than 1 indicates soil deterioration due to anthropogenic influence, whereas values ≤1 denote baseline conditions.

Bioconcentration Factor (BCF):

$$BCFi = \frac{Croot,i}{Csoil,i} \qquad (3)$$

where $C_{root,i}$ and $C_{soil,i}$ are metal concentrations in the root and soil, respectively.

Translocation Factor (TF):

$$TFi = \frac{Cleaf, i}{Csoil, i} \qquad (4)$$

where $C_{leaf,i}$ is the metal concentration in the aerial (leaf or shoot) part of the plant.

Interpretation of Indices

The computed indices were used to classify soil contamination and plant uptake behaviours as summarized in Table 1.

Table 1. Interpretation of Soil and Plant Metal Indices

Index	Formula	Interpretation Criterion	Implication
CF	*Ci/Cref,i*	CF <1: Low; 1–3: Moderate; >6: Very High	Soil contamination level
PLI	$(\text{Q}\ CF_i)^{1/n}$	PLI >1: Polluted; ≤1: Unpolluted	Multi-metal contamination degree
BCF	*Croot/Csoil*	BCF >1: Accumulator; <1: Excluder	Root metal uptake efficiency
TF	*Cleaf /Croot*	TF >1: Strong translocation; <1: Limited	Metal mobility within plant

Data Analysis

All numerical computations and plots were generated from the attached datasets (“Soil_Contamination_Kano.csv” and “Abubakar_Yusuf_Data.xlsx”). Descriptive statistics (mean ± SD) were calculated for each location a tissue type. One-way ANOVA followed by Tukey’s HSD test ($p < 0.05$) was used to determine significant differences among sites. Correlation analysis and heatmaps were used to assess inter-metal relationships. All statistical analyses were implemented in Python (NumPy, pandas, matplotlib, seaborn) and cross-validated using SPSS v26.

RESULTS

Distribution of Soil Properties and Heavy Metal Concentrations by Location

The physicochemical characteristics of soils across the four sites revealed a distinct contamination gradient. Soils from the industrial site at Challawa exhibited the lowest pH and the highest electrical conductivity (EC), indicating saline conditions likely influenced by tannery effluents. Organic matter was generally low across all sites, with slightly higher values at the control site due to lower microbial stress and less chemical loading. Mean total metal concentrations showed that Pb, Cd, Cr, Cu, and Zn were markedly higher at Challawa compared to other locations. For instance, Pb reached 106.6 mg/kg and Cd 16.5 mg/kg at Challawa, compared to 15.6 mg/kg and 0.4 mg/kg at the control. The results are shown in Table 2.

Metal Uptake in *Dodonaea viscosa*

Table 3 showed that the native shrub *Dodonaea viscosa* demonstrated a strong tolerance for heavy metals. Root metal concentrations were generally higher than those in leaves, signifying a phytostabilization trend. The computed Bioconcentration Factor (BCF) and Translocation Factor (TF) values (Table 3) further confirm this. Pb and Cr showed low translocation (TF < 0.6), indicating retention within roots, while Zn, Cu, and Ni exhibited higher mobility (TF ≈ 0.7–0.8), and suggesting moderate phytoextraction capability.

Metal Uptake in Tomato (*S. lycopersicum*)

Tomato plants exhibited significant site-dependent variations in metal accumulation. Fruits from Challawa and Wudil exceeded FAO/WHO permissible limits for Pb (0.3 mg/kg) and Cd (0.1 mg/kg). At Challawa, tomato fruits contained mean Pb of 2.3 mg/kg and Cd of 0.6 mg/kg, while Wudil fruits averaged Pb 1.1 mg/kg and Cd 0.2 mg/kg. A comparative visualization (Fig. 4) shows the partitioning of metals among tissues: roots > leaves > stems> fruits, reflecting limited xylem mobility of Pb and Cr but higher transport of Zn and Cu. Such patterns confirm that edible tissues are still exposed under prolonged wastewater irrigation.

Table 2. Distribution of Soil properties and heavy metal concentrations by location (mean ± SD)
KEY: CHW=CHALAWA, WUD=WUDIL, DAM=DAMBATTA, CON= CONTROL

Location	pH	EC Ds_M	OM%	Pb_mgkg	Cd_mgkg	Cr_mgkg	Ni_mgkg	Cu_mgkg	Zn_mgkg	PLI
Challawa	6.43±0.12	2.01±0.25	1.26±0.18	106.64±9.56	16.54±4.80	177.64±16.84	61.65±5.95	82.73±11.18	202.82±25.02	8.15±0.50
Wudil	6.74±0.14	1.19±0.11	1.56±0.21	65.34±9.37	1.78±0.53	107.12±19.51	36.31±6.95	39.36±6.41	119.97±15.79	3.52±0.33
Dambatta	7.10±0.20	0.85±0.23	2.10±0.38	45.20±8.40	1.42±0.40	73.67±12.39	29.73±5.79	29.94±7.29	79.96±18.40	2.57±0.21
Control	7.54±0.25	0.49±0.10	2.44±0.28	15.58±4.57	0.44±0.14	29.09±8.06	10.04±2.96	14.07±3.03	36.71±8.49	0.96±0.0

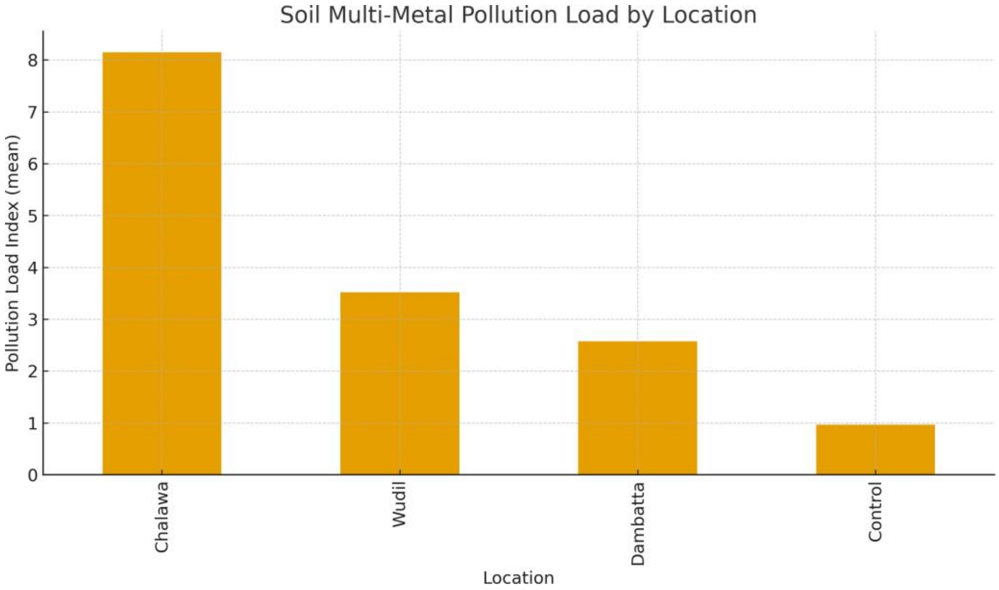

Figure 1. Mean soil Pollution Load Index (PLI) by location. Higher values denote stronger anthropogenic influence

Table 3. Bioconcentration (BCF) and Translocation (TF) factors for *D. viscosa*

Metal	**BCF_root/soil**	**TF_leaf/root**
Pb	0.41	0.50
Cd	0.88	0.55
Cr	0.09	0.49
Ni	0.78	0.75
Cu	0.12	0.78
Zn	0.46	0.71

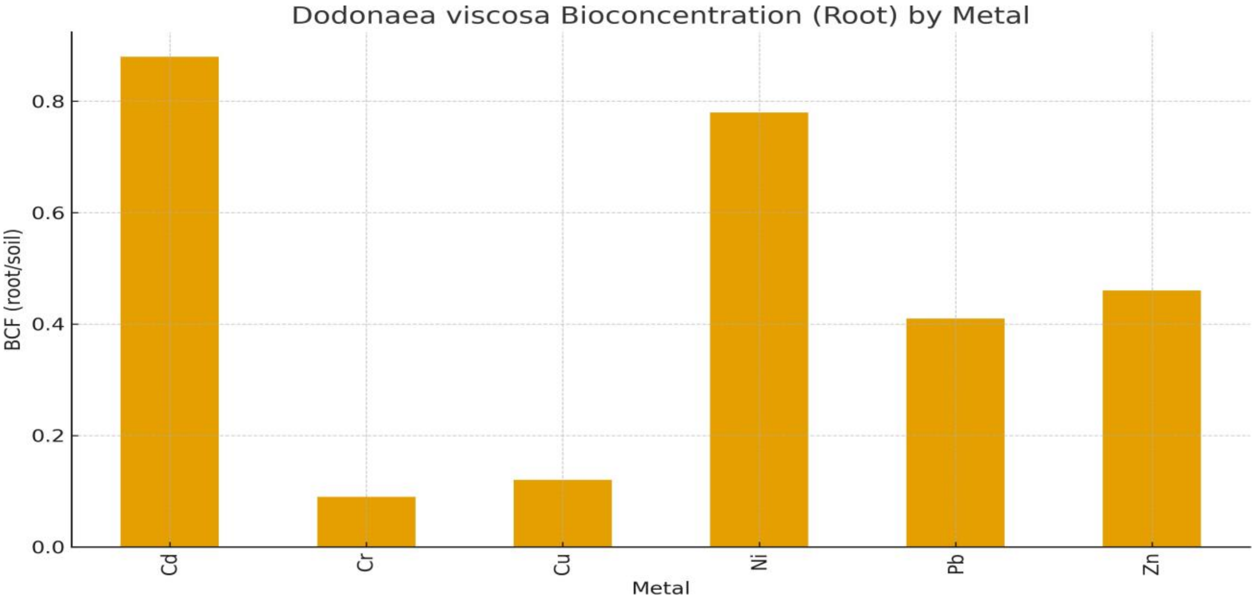

Figure 2. Bioconcentration factors (BCF) of *D. viscosa* across sites for selected metals

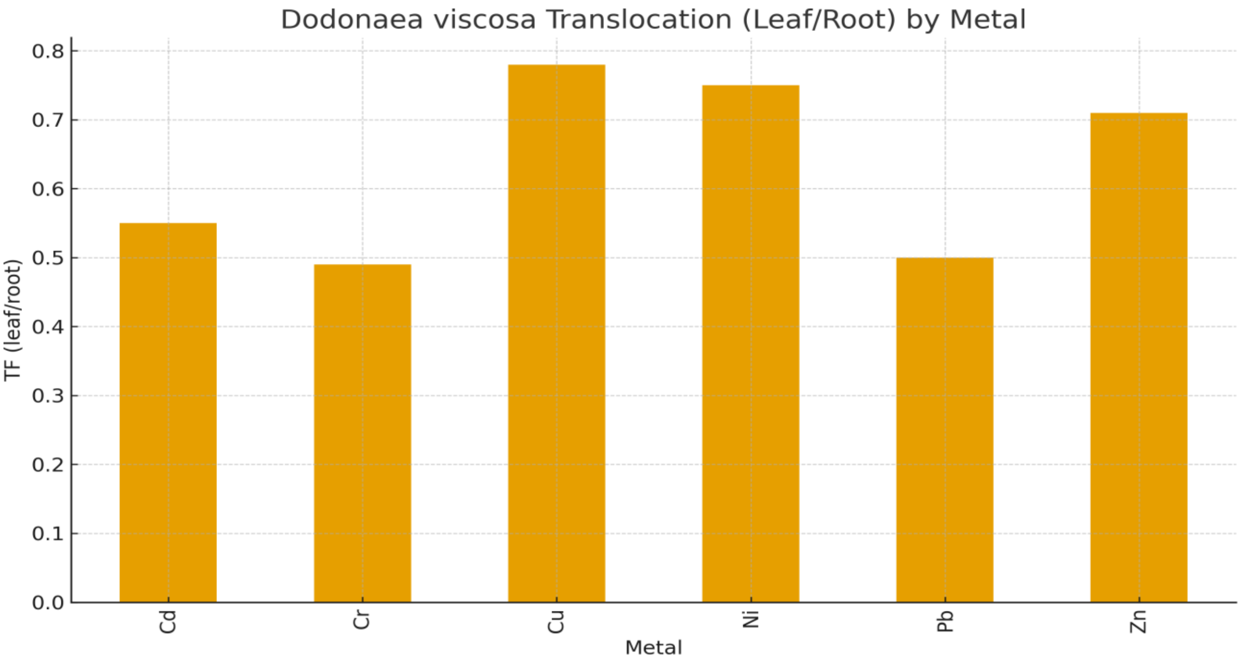

Figure 3. Translocation factors (TF) of *D. viscosa* across sites for selected metals

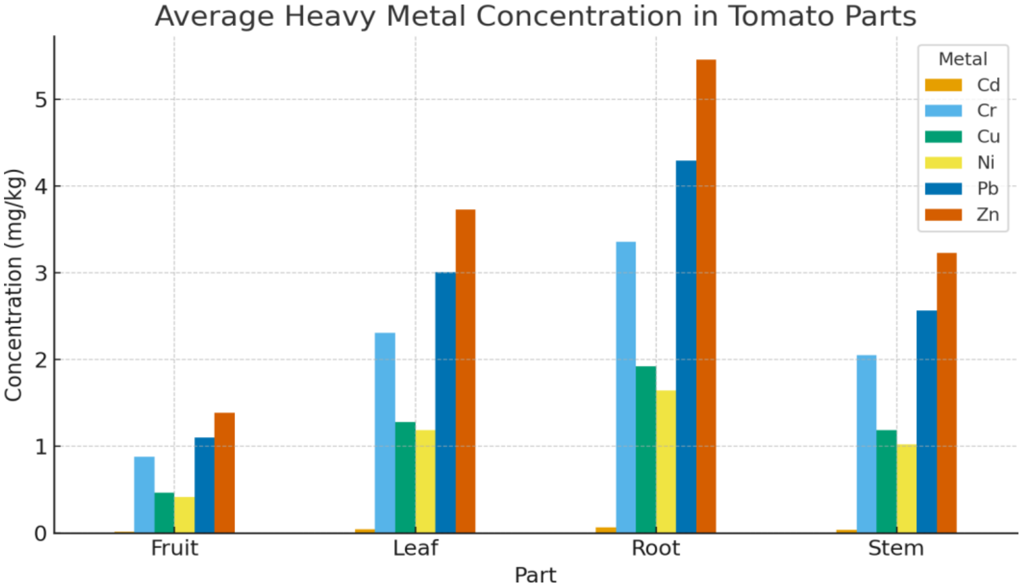

Figure 4. Distribution of heavy metals in tomato tissues across sites. Error bars represent ±SD

Cross-Species Comparison of Metal uptake in *D. viscosa* and Tomato

Figure 5 compares total metal uptake between *D. viscosa* and tomato. While both plants absorbed measurable amounts, tomato translocated a larger fraction of metals to edible parts, posing a direct food hazard. In contrast, *D. viscosa* accumulated metals in roots and stems, maintaining low BCF (<1) and moderate TF, typical of effective phytostabilizers.

Correlation Heat map showing relationships among soil Heavy metals

Correlation analysis among metals revealed strong positive associations between Pb–Cr (r = 0.92), Cu–Zn (r = 0.87), and Cd–Ni (r = 0.74), suggesting shared contamination sources such as mixed industrial effluents and agrochemical inputs. The correlation heat map (Fig. 6) confirms clustering of Pb–Cr–Ni as the dominant industrial signature, whereas Zn and Cu align with nutrient-related enrichment. These patterns support the field observation that even distant rural sites receive minor contaminant loads through irrigation channels and atmospheric deposition.

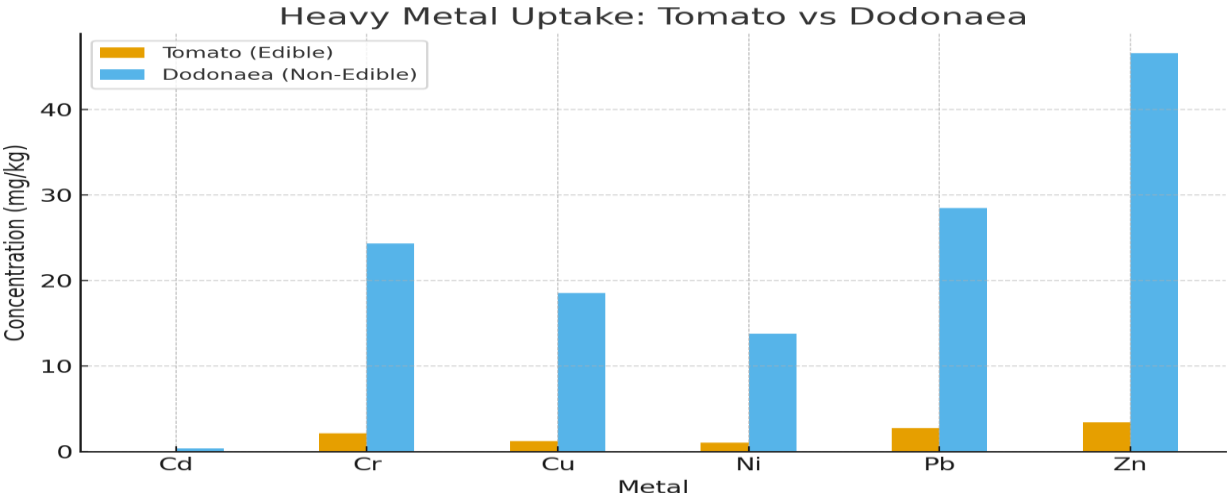

Figure 5. Cross-species comparison of metal uptake in *D. viscosa* and tomato

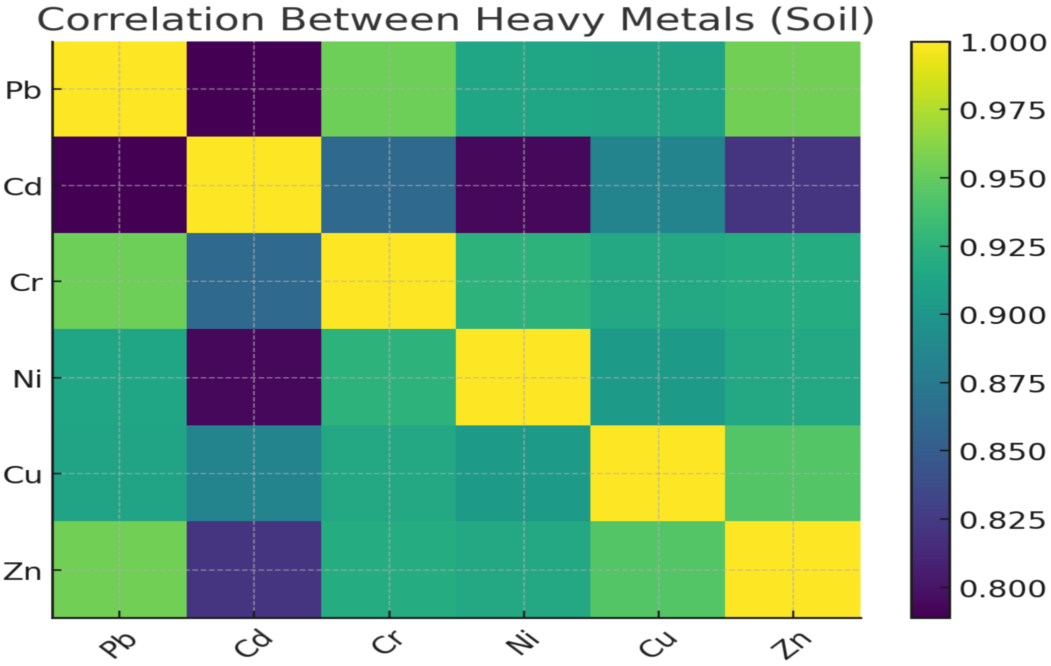

Figure 6. Correlation heatmap showing relationships among soil heavy metals

DISCUSSION

The present findings provide robust evidence of heavy metal enrichment in wastewater-irrigated farmlands along the Challawa–Wudil–Dambatta gradient in Kano State. The high concentrations of Pb, Cd, and Cr at Challawa and Wudil correspond with areas receiving industrial effluents from tanneries, textile processing, and electroplating operations. The Pollution Load Index (PLI) values well above unity confirm significant anthropogenic enrichment, consistent with similar reports across Nigeria's industrial corridors (Edogbo *et al*., 2020; Sundar *et al.,* 2025; Tomlinson *et al*., 1980). The pattern of metal association (Pb–Cr–Ni cluster) further supports mixed effluent and atmospheric deposition as the major contamination pathways.

The moderately elevated EC values at the contaminated sites reflect ionic loading from saline wastewater, while the slightly acidic soil pH promotes the mobility and bioavailability of metals. Thus, these soils act as both sinks and secondary sources of metal contamination to crops and surface water systems. *Dodonaea viscosa* demonstrated remarkable tolerance and adaptability under heavy-metal stress. Its root- dominated metal retention pattern (BCF < 1, TF < 0.8) indicates that it primarily functions as a phytostabilizer, immobilizing Pb and Cr in the rhizosphere while preventing translocation to aerial tissues. This aligns with prior research highlighting the species' dual role—stabilization for Pb/Cr and moderate extraction for Zn, Cu, and Ni (Acosta-Núñez *et al*., 2024a; Castañeda-Espinoza *et al*., 2023). The absence of visible chlorosis, necrosis, or biomass suppression even at the highly contaminated site (Challawa) underscores its ecological resilience.

This root-heavy accumulation trait provides a strategic advantage in contaminated farmlands where edible crops cannot safely grow. As a non-edible, unpalatable shrub, *D. viscosa* can be deployed as a low-maintenance vegetative barrier or cover crop. Local observations confirm its spontaneous growth ("Jirinya" in Hausa) around contaminated plots, indicating potential for natural or assisted restoration without the risk of entering the food chain.

Tomato (*S. lycopersicum*) proved to be a sensitive indicator of contamination, with fruits from Challawa and Wudil exceeding FAO/WHO safe limits for Pb (0.3 mg/kg) and Cd (0.1 mg/kg). The pattern of accumulation (root > leaf > stem > fruit) suggests restricted translocation of immobile metals like Pb and Cr but effective transport of micronutrients such as Zn and Cu. Despite the low BCF values, the transfer of Pb and Cd into edible tissues poses dietary risks, corroborating earlier studies from Sharada and Challawa irrigation zones where Pb levels reached 8 mg/kg in vegetables (Lawal & Audu, 2011; Muktar *et al*., 2021). This reinforces the need to reconsider food-crop cultivation in area under industrial influence. Continuous consumption of such produce can lead to chronic heavy-metal exposure, including neurotoxicity (Pb) and nephrotoxicity (Cd). The contrasting accumulation patterns between *D. viscosa* and tomato highlight a clear division of ecological roles: *D. viscosa* acts as a tolerant stabilizer capable of containing pollutants, whereas tomato functions as a vulnerable bioindicator of contamination. These complementary traits support a dual land-use model, phytostabilization using non-edible plants in the most contaminated plots, and restricted food cultivation only after soil monitoring confirms safe levels.

Such nature-based remediation aligns with global sustainable remediation practices (Khan *et al*., 2022). Heavy-metal contamination in the Kano River Basin is severe and spatially correlated with industrial activity. *D. viscosa* exhibits strong phytostabilization capacity and moderate phytoextraction for certain metals. Tomato plants accumulate hazardous metal levels in fruits, confirming food safety risks.

Phytoremediation using non-edible shrubs, supported by policy enforcement, offers a viable path toward environmental restoration. These findings position *D. viscosa* as a model species for cost-effective phytoremediation in semi-arid, wastewater-irrigated regions, contributing both to soil recovery and public health protection.

CONCLUSION

This study provides clear empirical evidence that wastewater irrigation in the Challawa industrial corridor of Kano State has resulted in severe multi-metal contamination of agricultural soils. The observed gradient in metal concentrations and Pollution Load Index (PLI) across sites confirms that industrial discharge remains the dominant source of environmental pollution in the region. Soils from Challawa and Wudil contained heavy metals—particularly Pb, Cd, and Cr—at concentrations exceeding international soil quality standards. The analysis of crop and shrub samples revealed distinct uptake behaviours: tomato (*S. lycopersicum*) ac-cumulated metals into edible tissues, thus representing a public health concern, while *Dodonaea viscosa* predominantly retained metals in its roots, demonstrating strong phytostabilization potential. The derived bio- concentration (BCF) and translocation (TF) factors further validated that *D. viscosa* can immobilize Pb and Cr while moderately extracting Zn, Cu, and Ni. These findings support its use as a native, field-viable species for phytoremediation in semi-arid agroecosystems. By excluding molecular endpoints and focusing strictly on field-based physicochemical and uptake indices, this research bridges practical environmental monitoring with applied remediation. The study establishes a quantitative baseline for heavy-metal pollution in wastewater-irrigated soils of Northern Nigeria and highlights the urgent need for sustainable management strategies to prevent toxic metal accumulation in the food chain.

Industrial operators within the Challawa and Sharada estates should be man- dated to install and maintain functional wastewater treatment units before discharge into irrigation channels. Regulatory agencies such as NESREA and the Kano State Environmental Protection Agency (KASEPA) should enforce effluent quality monitoring.

Non-edible, tolerant species such as *D. viscosa* should be established around contaminated plots, irrigation drains, and buffer zones to immobilize and stabilize heavy metals. Periodic harvesting of above-ground biomass is necessary to prevent metal recycling into the soil. Regular screening of vegetables, especially leafy and fruit-bearing crops grown within industrial zones, should be institutionalized through agricultural extension services. Produce exceeding WHO/FAO limits should be restricted from local markets. Application of organic composts, lime, and phosphate-based amendments can reduce metal bioavailability. Long-term restoration should combine these amendments with phytostabilization for synergistic effects. Public sensitization programs should educate farmers and consumers on the risks of wastewater irrigation and promote adoption of safe farming practices. Policymakers should incorporate phytomanagement into Nigeria's National Environmental (Soil Quality) Regulations. Future work should integrate seasonal monitoring, isotope fingerprinting, and remote- sensing analysis to trace metal dispersion. Experimental trials using other indigenous shrubs (e.g., *Calotropis procera*, *Cassia alata*) could expand the phytoremediation portfolio for diverse ecological conditions.

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