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Original Article

# Assessment of Heavy Metal Accumulation Potential of Six Indigenous Herbaceous Plants from Waste Dumpsites in Lokoja, Kogi State

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## ABSTRACT

Heavy metal contamination from municipal solid waste poses significant environmental and health risks in urbanizing areas. This study evaluated the accumulation potential of six indigenous herbaceous plants (*Ageratum conyzoides*, *Axonopus compressus*, *Boerhavia diffusa*, *Cynodon dactylon*, *Digitaria ciliaris*, and *Setaria pumila*) growing on three major dumpsites in Lokoja, Kogi State, Nigeria. Soil and plant samples were collected from dumpsites and a control site and analyzed for Pb, Cd, Cr, Zn, Cu, and Ni using Flame Atomic Absorption Spectrophotometry. Bioaccumulation (BAF), translocation (TF), and enrichment coefficients (EC) were calculated, and statistical analyses assessed interspecies differences and soil–plant correlations. Results showed that dumpsite soils were highly contaminated with Zn ($412.50 \pm 18.70$ mg/kg), Cu ($198.30 \pm 9.10$ mg/kg), Pb ($185.20 \pm 9.40$ mg/kg), and Cd ($3.56 \pm 0.21$ mg/kg), exceeding WHO/FAO limits. Root tissues accumulated higher metal concentrations than shoots, indicating restricted translocation. However, *C. dactylon* and *S. pumila* exhibited higher BAF (1.067 and 0.983 for Cd), TF (0.717 and 0.709 for Zn), and EC (1.912 and 1.765 for Cd), reflecting strong phytoextraction potential. Strong positive correlations between soil and shoot metals, especially Zn ($r = 0.75$), Pb ($r = 0.71$), and Cu ($r = 0.68$), indicated that soil contamination drives plant accumulation. The study demonstrates that *C. dactylon* and *S. pumila* effectively accumulate heavy metals and are promising candidates for sustainable phytoremediation of contaminated soils in Lokoja.


**Keywords:** Bioaccumulation, Heavy metals, Herbaceous Plants, Phytoremediation, Translocation

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## INTRODUCTION

Rapid urbanization and industrialization in developing countries have led to increased municipal solid waste generation, resulting in numerous uncontrolled dumpsites. These sites are major sources of environmental contamination, particularly with heavy metals such as lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), chromium (Cr), and nickel (Ni) [1-3]. Heavy metals are persistent pollutants due to their non-biodegradable nature, bioaccumulation potential, and harmful effects on human and ecological health [4-6]. Once released into soils, they can enter the soil–plant–human continuum, posing long-term risks to ecosystems and public health [7-9].

In Nigeria and across Africa, solid waste management challenges have led to widespread soil contamination [10-12]. Several studies have documented high heavy metal concentrations in soils and vegetables near dumpsites [1,13,14], with Pb, Cu, and Zn often surpassing safety standards, indicating significant anthropogenic impact [15-17]. Metals like Cd and Pb are particularly mobile and toxic, even at low concentrations, highlighting the need for effective remediation strategies [18,19]. Phytoremediation offers an eco-friendly, cost-effective approach for managing heavy metal-contaminated soils [20-22]. Indigenous herbaceous plants are promising candidates due to their rapid growth, adaptability, and ability to accumulate metals [23-25]. Studies have shown species-specific differences in uptake, bioaccumulation, and translocation, emphasizing the importance of identifying efficient species for targeted remediation [26-28]. Moreover, correlations between soil contamination and plant tissue accumulation provide insights into metal transfer dynamics, guiding species selection to reduce soil metal load while minimizing human exposure risks [29-31]. Despite growing research on urban soil contamination in Nigeria, data on the efficiency of indigenous herbaceous plants in Lokoja remain limited. Considering the city's rapid expansion, rising population, and the proximity of dumpsites to residential areas, evaluating local plant capacity for metal accumulation and translocation is essential for sustainable environmental management [2,12,32]. This study, therefore, aimed to assess heavy metal contamination in municipal dumpsite soils in Lokoja and evaluate the bioaccumulation, translocation, and enrichment potential of six indigenous herbaceous plants to identify suitable candidates for phytoremediation.

### Study Area

This study was carried out in Lokoja metropolis, Kogi State, Nigeria, located at the confluence of the Niger and Benue Rivers (7°48′20″ N, 6°43′10″ E) [33]. The area has a tropical wet-and-dry climate with a rainy season from April to October, a dry season from November to March, annual rainfall of 1,000–1,500 mm, and mean temperatures of 25–32 °C [33,34]. Lokoja is a rapidly growing administrative and commercial city, with an estimated population of about 931,092 in 2025, indicating increasing urbanization and anthropogenic pressure (World Population Review, 2025). Geologically, the area lies within a transition zone between Precambrian Basement Complex rocks and Cretaceous sedimentary formations of the Bida Basin, resulting in predominantly sandy-loam to clay-loam soils that influence heavy-metal mobility and retention [33,34]. Three major municipal dumpsites: Adankolo, Felele, and Ganaja Village, were selected based on waste volume and proximity to residential areas; these sites contain mixed municipal wastes such as household refuse, plastics, food residues, metals, and spent batteries. A control site with minimal anthropogenic influence was established about 5 km from the dumpsites (7°46′12″ N, 6°40′55″ E) to provide baseline heavy-metal levels for comparison.

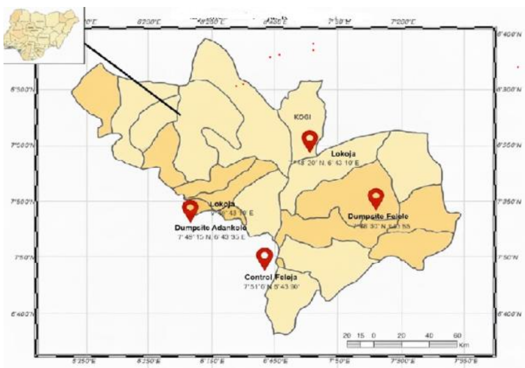


**Figure 1:** Location map of Nigeria showing Kogi State and the Lokoja study area with sampling locations.

## Sample Collection, Plant Identification, and Processing

Plant and soil samples were concurrently collected from three municipal dumpsites (Adankolo, Felele, and Ganaja Village) and a control site in Lokoja, Nigeria. Six abundant indigenous herbaceous species: *Ageratum conyzoides* L. (Asteraceae), *Axonopus compressus* (Sw.) P. Beauv. (Poaceae), *Boerhavia diffusa* L. (Nyctaginaceae), *Cynodon dactylon* (L.) Pers. (Poaceae), *Digitaria ciliaris* (Retz.) Koeler (Poaceae), and *Setaria pumila* (Poir.) Roem. & Schult. (Poaceae) (Figure 2), were selected based on their wide distribution and persistence at the sites, making them suitable indicators of metal contamination [23,27,30]. Plants were identified in the field using morphological features and verified with standard botanical databases. For each species at each site, ≥5 whole-plant replicates were randomly collected. In the laboratory, roots and shoots were separated, washed, oven-dried (80 °C), ground, and stored for analysis. Corresponding rhizosphere soils (0–15 cm) were collected, composited per site, air-dried, sieved (2 mm), and stored for heavy-metal determination.


**Figure 2:** Selected indigenous herbaceous plant species growing around municipal solid waste dumpsites in Lokoja, Kogi State, Nigeria.

## Chemical Digestion and Metal Analysis

Dried and homogenized plant (root and shoot) and soil samples were acid-digested prior to heavy-metal analysis following standard protocols [14]. Briefly, 1.0 g of plant material was digested with a mixed acid of $HNO_3$–$HClO_4$ (4:1, v/v), while 1.0 g of soil was digested using aqua regia (HCl:$HNO_3$, 3:1, v/v). Digests were filtered, diluted with deionized water, and analyzed for Pb, Cd, Cr, Zn, Cu, and Ni using Flame Atomic Absorption Spectrophotometry (Buck Scientific 210/211 VGP, USA). Analytical quality was ensured using blanks, duplicates, and standard calibrations, with recoveries of 90–110%. Results were expressed as mg/kg dry weight for subsequent analysis.

### Bioaccumulation Assessment

The bioaccumulation potential of heavy metals in the selected herbaceous plants was assessed using the bioaccumulation factor (BAF), which measures the plant's ability to uptake and retain metals from soil. BAF for each metal and species was calculated as the ratio of total metal concentration in plant tissues to the corresponding soil metal concentration.

$$\text{BAF} = \frac{\text{C}-root+\text{C}-shoot}{\text{C}-soil}$$

Where C-*root* and C-*shoot* are metal concentrations (mg/kg DW) in roots and shoots, and C-*soil* is the metal concentration in rhizosphere soil. BAF >1 indicates enhanced bioaccumulation, while BAF <1 suggests limited uptake relative to soil [35].

### Translocation Factor (TF)

The movement of metals from roots to shoots was assessed using the translocation factor (TF). It was calculated as the ratio of metal concentration in shoots to roots:

$$\text{TF} = \frac{\text{C}-shoot}{\text{C}-root}$$

Where C-*shoot* and C-*root* are metal concentrations (mg/kg DW) in shoots and roots, respectively. TF >1 indicates efficient translocation to shoots. TF <1 suggests metals are largely retained in roots [35].

### Enrichment Coefficient (EC)

Shoot enrichment relative to background soil was assessed using the enrichment coefficient (EC). It was calculated as the ratio of metal concentration in shoots to that in control soil, reflecting the plant's ability to accumulate metals above natural levels.

$$\text{EC} = \frac{\text{C}-shoot}{\text{C}-controlsoil}$$

Where C-*shoot* is the metal concentration (mg/kg DW) in shoots and C-control soil is the background soil metal concentration. EC >1 indicates significant enrichment and anthropogenic influence, while EC <1 suggests limited accumulation relative to background levels [35].

### Data Analysis

Data were analyzed using descriptive and inferential statistics. Means and standard deviations were calculated for metal concentrations and accumulation indices. Differences among species were assessed by one-way ANOVA with Tukey's HSD ($p < 0.05$). Pearson correlation evaluated relationships between soil and shoot metal concentrations, with significance at $p < 0.05$ and $p < 0.01$ and correlation strength interpreted using standard classifications [42].

## RESULTS AND DISCUSSION

The mean heavy metal concentrations in soils from the municipal dumpsites and control site in Lokoja are presented in Table 1. All analyzed metals were markedly higher in dumpsite soils than in control soils, indicating strong anthropogenic inputs from solid waste disposal. Zinc (Zn) showed the highest mean concentration (412.50 $\pm$ 18.70 mg/kg), followed by Cu (198.30 $\pm$ 9.10 mg/kg), Pb (185.20 $\pm$ 9.40 mg/kg), Cr (72.40 $\pm$ 4.00 mg/kg), Ni (45.80 $\pm$ 2.50 mg/kg), and Cd (3.56 $\pm$ 0.21 mg/kg). Soil pollution index (SPI) values identified Cd (5.20), Cu (5.40), and Pb (4.80) as the most critical contaminants relative to WHO/FAO limits. Significant differences ($p < 0.05$) between dumpsite and control soils were observed for all metals, confirming waste-induced enrichment.

Elevated Pb and Cu levels are consistent with previous reports from dumpsites and industrial areas in Kogi State [1,2] and other Nigerian cities [13,8]. Similarly, high Pb and Zn concentrations reported in Yobe State [16] support the widespread nature of dumpsite-related metal accumulation. The Zn concentration exceeded the WHO/FAO guideline (300 mg/kg), in agreement with findings by Abd-Elhalim *et al*. [24]. Chromium levels were comparable to those reported in Nasarawa and Niger States [10] but lower than values from industrial regions in China [31], likely reflecting differences in industrial intensity and geochemical background. Cadmium slightly exceeded permissible limits, consistent with reports from Ondo Town [3,15], and is commonly associated with discarded batteries and electronic waste [8,18]. Nickel levels were below guideline limits but may still pose long-term risks due to persistence and bioaccumulation [6,9]. The significant enrichment of Pb, Cu, and Zn poses risks to soil quality, groundwater, and food safety, underscoring the need for regulatory control and continuous environmental monitoring.

**Table 1:** Mean heavy metal concentrations (mg/kg) in soil from municipal solid waste dumpsites and control sites in Lokoja, Kogi State

| Heavy Metal | Dumpsite Soil | Control Soil | Soil Pollution Index (SPI)* | WHO/FAO Limit (mg/kg) |
|---|---|---|---|---|
| Pb | $185.20 \pm 9.40^a$ | $38.60 \pm 2.10^b$ | 4.80 | 100 |
| Cd | $3.56 \pm 0.21^a$ | $0.68 \pm 0.04^b$ | 5.20 | 3 |
| Cr | $72.40 \pm 4.00^a$ | $22.10 \pm 1.20^b$ | 3.30 | 100 |
| Zn | $412.50 \pm 18.70^a$ | $95.20 \pm 4.30^b$ | 4.30 | 300 |
| Cu | $198.30 \pm 9.10^a$ | $36.80 \pm 2.00^b$ | 5.40 | 100 |
| Ni | $45.80 \pm 2.50^a$ | $13.00 \pm 0.80^b$ | 3.50 | 50 |

*Different superscripts within rows indicate significant differences ($p < 0.05$). *Soil Pollution Index (SPI) determined as ratio dumpsite soil concentration ÷ control soil concentration.*

The mean heavy-metal concentrations in plant roots are shown in Table 2. Across all species, metal levels were consistently higher in roots than in other plant organs, indicating that roots act as the primary sink for metal accumulation. Lead (Pb) and zinc (Zn) dominated root tissues, reflecting their high abundance and persistence in dumpsite-impacted soils, in line with previous reports identifying Pb and Zn as major contaminants from mixed urban wastes [27,39]. *Cynodon dactylon* exhibited the highest root concentrations of all analyzed metals (Pb 78.50 mg/kg, Cd 2.50 mg/kg, Cr 37.00 mg/kg, Zn 156.20 mg/kg, Cu 68.50 mg/kg, and Ni 22.10 mg/kg). This agrees with studies showing that metals are preferentially retained in roots due to limited translocation and strong rhizosphere adsorption [36]. Similar findings by Santoyo-Martínez *et al.* [20] and Mussali-Galante *et al.* [23] attributed high root accumulation to sequestration within cell walls and vacuoles as a detoxification strategy. In contrast, the lower metal levels in *B. diffusa* suggest reduced uptake or more effective exclusion mechanisms, likely related to species-specific differences in rhizosphere chemistry, root exudation, and metal-binding capacity [19,37].

**Table 2:** Heavy metal concentrations (mg/kg dry weight) in roots of six indigenous herbaceous plants growing around municipal solid waste dumpsites in Lokoja, Kogi State

| Metal | *A. conyzoides* | *A. compressus* | *B. diffusa* | *C. dactylon* | *D. ciliaris* | *S. pumila* |
|---|---|---|---|---|---|---|
| Pb | $63.40 \pm 3.20^{a}$ | $70.10 \pm 3.50^{b}$ | $58.20 \pm 2.80^{a}$ | $78.50 \pm 4.00^{c}$ | $66.30 \pm 3.40^{b}$ | $72.40 \pm 3.80^{b}$ |
| Cd | $1.80 \pm 0.08^{a}$ | $2.10 \pm 0.09^{b}$ | $1.70 \pm 0.07^{a}$ | $2.50 \pm 0.11^{c}$ | $2.00 \pm 0.09^{b}$ | $2.30 \pm 0.10^{c}$ |
| Cr | $28.60 \pm 1.50^{a}$ | $32.20 \pm 1.70^{b}$ | $26.10 \pm 1.30^{a}$ | $37.00 \pm 2.00^{c}$ | $31.00 \pm 1.60^{b}$ | $34.10 \pm 1.80^{bc}$ |
| Zn | $128.40 \pm 6.20^{a}$ | $142.30 \pm 7.10^{b}$ | $118.60 \pm 5.90^{c}$ | $156.20 \pm 7.80^{d}$ | $133.70 \pm 6.50^{ab}$ | $148.10 \pm 7.00^{d}$ |
| Cu | $54.00 \pm 2.80^{a}$ | $60.20 \pm 3.10^{b}$ | $50.30 \pm 2.50^{a}$ | $68.50 \pm 3.40^{c}$ | $57.20 \pm 2.90^{ab}$ | $63.80 \pm 3.20^{bc}$ |
| Ni | $17.20 \pm 0.80^{a}$ | $19.50 \pm 0.90^{b}$ | $16.30 \pm 0.70^{a}$ | $22.10 \pm 1.10^{c}$ | $18.70 \pm 0.90^{b}$ | $20.50 \pm 1.00^{c}$ |

*Different superscripts within rows indicate significant differences ($p < 0.05$).*

The mean heavy-metal concentrations in shoots (Table 3) were consistently lower than in roots across all species, indicating restricted upward translocation of metals. This suggests that most absorbed metals were retained in roots, thereby protecting photosynthetically active tissues. Similar root-retention mechanisms have been widely reported in contaminated environments [19,36,38]. Despite this general trend, *C. dactylon* recorded relatively higher shoot concentrations, especially of Zn (112.00 mg/kg) and Pb (48.00 mg/kg), indicating greater tolerance and translocation capacity. This agrees with findings by Sabir *et al.* [39] for tolerant herbs on dumpsites. Consistent with earlier reports [26,40], essential metals (Zn and Cu) showed higher shoot mobility than non-essential toxic metals (Pb and Cd) due to their physiological roles. Lower shoot metal levels in *B. diffusa* and *A. conyzoides* suggest effective detoxification and restricted xylem loading, reflecting species-specific differences in transport, chelation, sequestration, and micronutrient demand in aerial tissues [5].

**Table 3**: Heavy metal concentrations (mg/kg dry weight) in shoots of six indigenous herbaceous plants growing around municipal solid waste dumpsites in Lokoja, Kogi State

| Metal | *A. conyzoides* | *A. compressus* | *B. diffusa* | *C. dactylon* | *D. ciliaris* | *S. pumila* |
|---|---|---|---|---|---|---|
| Pb | $35.60 \pm 1.90^{a}$ | $41.20 \pm 2.10^{b}$ | $31.50 \pm 1.60^{a}$ | $48.00 \pm 2.50^{c}$ | $38.20 \pm 2.00^{b}$ | $44.10 \pm 2.30^{bc}$ |
| Cd | $0.90 \pm 0.04^{a}$ | $1.10 \pm 0.05^{b}$ | $0.85 \pm 0.04^{a}$ | $1.30 \pm 0.06^{c}$ | $1.05 \pm 0.05^{b}$ | $1.20 \pm 0.06^{c}$ |
| Cr | $15.20 \pm 0.80^{a}$ | $18.00 \pm 0.90^{b}$ | $13.80 \pm 0.70^{a}$ | $22.10 \pm 1.10^{c}$ | $17.10 \pm 0.80^{b}$ | $19.50 \pm 0.90^{bc}$ |
| Zn | $87.00 \pm 4.20^{a}$ | $98.50 \pm 4.80^{b}$ | $78.40 \pm 3.90^{c}$ | $112.00 \pm 5.60^{d}$ | $92.60 \pm 4.50^{b}$ | $105.00 \pm 5.20^{d}$ |
| Cu | $29.00 \pm 1.50^{a}$ | $33.10 \pm 1.70^{b}$ | $25.40 \pm 1.30^{a}$ | $40.10 \pm 2.00^{c}$ | $31.00 \pm 1.60^{b}$ | $36.80 \pm 1.80^{bc}$ |
| Ni | $9.50 \pm 0.50^{a}$ | $11.20 \pm 0.60^{b}$ | $8.70 \pm 0.40^{a}$ | $13.80 \pm 0.70^{c}$ | $10.70 \pm 0.50^{b}$ | $12.40 \pm 0.60^{c}$ |

*Different superscripts within rows indicate significant differences ($p < 0.05$).*

The bioaccumulation factor (BAF) results (Table 4) revealed species-specific accumulation patterns. Most metals had BAF values below 1, indicating generally limited uptake. Notably, Cd in *C. dactylon* showed a BAF >1 (1.067), suggesting moderate bioaccumulation. This aligns with Huang *et al.* [28], who reported that Cd exhibits higher mobility and weak binding to soil particles, making it more available for plant uptake. Elevated BAFs in *C. dactylon* and *S. pumila* indicate superior uptake and adaptability to metal-polluted soils. Similar observations have been reported by Mulenga *et al.* [25], who highlighted the resilience and accumulation efficiency of certain herbaceous species in contaminated environments. In contrast, the persistently low BAFs in *B. diffusa* reflect its limited capacity for phyto extraction, consistent with the findings of Enetimi and Tariwari [41]. These inter-specific differences likely arise from a combination of soil factors, such as pH, organic matter and metal speciation, and species-specific physiological traits that regulate root uptake and metal translocation [28,37].

**Table 4:** Bioaccumulation factors (BAF) of heavy metals in six indigenous herbaceous plants growing around municipal solid waste dumpsites in Lokoja, Kogi State

| *Metal* | *A. conyzoides* | *A. compressus* | *B. diffusa* | *C. dactylon* | *D. ciliaris* | *S. pumila* |
|---|---|---|---|---|---|---|
| **Pb** | $0.535^{c}$ | $0.601^{b}$ | $0.484^{e}$ | $0.683^{a}$ | $0.564^{d}$ | $0.629^{b}$ |
| **Cd** | $0.758^{d}$ | $0.899^{b}$ | $0.716^{e}$ | $1.067^{a}$ | $0.857^{c}$ | $0.983^{b}$ |
| **Cr** | $0.605^{d}$ | $0.693^{c}$ | $0.551^{e}$ | $0.816^{a}$ | $0.664^{c}$ | $0.740^{b}$ |
| **Zn** | $0.522^{d}$ | $0.584^{c}$ | $0.478^{e}$ | $0.650^{a}$ | $0.549^{c}$ | $0.614^{b}$ |
| **Cu** | $0.419^{d}$ | $0.471^{c}$ | $0.382^{e}$ | $0.548^{a}$ | $0.445^{d}$ | $0.507^{b}$ |
| **Ni** | $0.583^{d}$ | $0.670^{c}$ | $0.546^{e}$ | $0.784^{a}$ | $0.642^{c}$ | $0.718^{b}$ |

*Values with different superscripts within rows indicate significant differences ($p < 0.05$).*

The translocation factor (TF) values (Table 5) were generally below 1 for all metals, indicating restricted movement from roots to shoots. This highlights the roots as the main site for metal sequestration, protecting photosynthetically active tissues from toxicity. Zn, however, showed relatively higher TFs, especially in *C. dactylon* (0.717) and *S. pumila* (0.709), reflecting its mobility within plant tissues due to essential roles in enzymatic activity, protein synthesis, and overall metabolism. This agrees with Rahman *et al*. [19], who reported Zn's efficient translocation linked to its physiological importance. In contrast, TFs for Pb and Cd remained low across all species, indicating strong root sequestration. This aligns with Okorosaye-Orubite and Igwe [38] and Ohiagu *et al.* [14], who noted limited translocation of these toxic metals as a strategy to prevent oxidative stress and metabolic disruption in shoots. Species-dependent TF variations were evident. These variations likely resulted from differences in metal transporter activity, xylem loading, and detoxification. *C. dactylon* efficiently translocated essential metals like Zn and Ni while restricting non-essential metals, reflecting species-specific metal regulation strategies [5].

**Table 5:** Translocation Factors (TF) of heavy metals in six indigenous herbaceous plants growing around municipal solid waste dumpsites in Lokoja, Kogi State

| Metal | *A. conyzoides* | *A. compressus* | *B. diffusa* | *C. dactylon* | *D. ciliaris* | *S. pumila* |
|---|---|---|---|---|---|---|
| Pb | $0.561^{c}$ | $0.588^{b}$ | $0.541^{e}$ | $0.612^{a}$ | $0.576^{c}$ | $0.609^{a}$ |
| Cd | $0.500^{d}$ | $0.524^{b}$ | $0.500^{d}$ | $0.520^{c}$ | $0.525^{b}$ | $0.522^{c}$ |
| Cr | $0.532^{d}$ | $0.559^{c}$ | $0.529^{d}$ | $0.597^{a}$ | $0.552^{c}$ | $0.572^{b}$ |
| Zn | $0.678^{c}$ | $0.692^{b}$ | $0.661^{d}$ | $0.717^{a}$ | $0.693^{b}$ | $0.709^{a}$ |
| Cu | $0.537^{d}$ | $0.550^{c}$ | $0.505^{e}$ | $0.586^{a}$ | $0.542^{c}$ | $0.577^{b}$ |
| Ni | $0.552^{c}$ | $0.574^{b}$ | $0.534^{e}$ | $0.624^{a}$ | $0.572^{c}$ | $0.604^{a}$ |

*Values with different superscripts within rows indicate significant differences ($p < 0.05$)*

The enrichment coefficient (EC) results (Table 6) further provide insight into shoot metal accumulation. EC values for Cd exceeded 1 in all species, with *C. dactylon* showing the highest value (1.912), indicating strong Cd enrichment in shoots. This agrees with Sabir *et al*. (2022), who reported enhanced Cd accumulation in plants on municipal dumpsites, and with Abd-Elhalim *et al.* [24], who noted that waste-amended soils promote Cd uptake and shoot enrichment. On the other hand, EC values for Pb and Cr were generally below 1, suggesting limited shoot enrichment. This indicates that these non-essential toxic metals were mostly retained in roots, supporting similar findings by Ohiagu *et al.* [14] and

Okorosaye-Orubite and Igwe [38]. Species differences in EC likely reflected soil metal speciation, nutrient demand, and metal competition during uptake and translocation, as reported by Huang *et al.* [28] and Mulenga *et al.* [29].

The correlation analysis (Table 7) showed mostly moderate to strong positive relationships between soil metal concentrations and their accumulation in shoots of herbaceous plants around Lokoja dumpsites. Strong significant correlations were observed for Zn ($r = 0.75, p < 0.01$), Pb ($r = 0.71, p < 0.01$), Cu ($r = 0.68, p < 0.01$), and Ni ($r = 0.65, p < 0.05$), indicating that higher soil metal levels closely corresponded with increased plant uptake.

**Table 6:** Enrichment coefficients (EC) of heavy metals in shoots of six indigenous herbaceous plants growing around municipal solid waste dumpsites in Lokoja, Kogi State

| Metal | *A. conyzoides* | *A. compressus* | *B. diffusa* | *C. dactylon* | *D. ciliaris* | *S. pumila* |
|---|---|---|---|---|---|---|
| Pb | $0.922^{c}$ | $1.067^{b}$ | $0.816^{e}$ | $1.244^{a}$ | $0.990^{c}$ | $1.142^{b}$ |
| Cd | $1.324^{c}$ | $1.618^{b}$ | $1.250^{d}$ | $1.912^{a}$ | $1.544^{c}$ | $1.765^{b}$ |
| Cr | $0.688^{d}$ | $0.814^{c}$ | $0.624^{e}$ | $1.000^{a}$ | $0.774^{c}$ | $0.882^{b}$ |
| Zn | $0.914^{c}$ | $1.035^{b}$ | $0.824^{d}$ | $1.176^{a}$ | $0.973^{c}$ | $1.103^{b}$ |
| Cu | $0.788^{c}$ | $0.899^{b}$ | $0.690^{d}$ | $1.090^{a}$ | $0.842^{c}$ | $1.000^{b}$ |
| Ni | $0.731^{c}$ | $0.862^{b}$ | $0.669^{d}$ | $1.062^{a}$ | $0.823^{c}$ | $0.954^{b}$ |

*Values with different superscripts within rows indicate significant differences ($p < 0.05$).*

These results suggest that soil metal availability is a key factor controlling accumulation. This agrees with Ebbu *et al.* [4], who reported strong soil–plant metal relationships in landfill environments. Similar patterns were observed by Tanee and Eshalomi-Mario [30] and Andráš *et al.* [37], emphasizing direct soil–plant transfer as a major pathway for metal uptake. Moderate correlations for Cd and Cr ($r = 0.48–0.60, p < 0.05$) suggest that other factors, such as selective uptake, sequestration, and toxicity avoidance, may also influence their accumulation in shoots.

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**Table 7:** Correlation between soil heavy metal concentrations and accumulation *of the indigenous herbaceous plants growing around waste dumpsites in Lokoja, Kogi State.*

| Metal | Pb | Cd | Cr | Zn | Cu | Ni |
|---|---|---|---|---|---|---|
| Pb | 1.00 | | | | | |
| Cd | 0.62* | 1.00 | | | | |
| Cr | 0.58* | 0.50* | 1.00 | | | |
| Zn | 0.75** | 0.55* | 0.60* | 1.00 | | |
| Cu | 0.71** | 0.48* | 0.57* | 0.68** | 1.00 | |
| Ni | 0.65* | 0.52* | 0.59* | 0.62* | 0.63* | 1.00 |

*Correlation strength was interpreted as: very weak ($r < 0.20$), weak (0.20–0.39), moderate (0.40–0.59), strong (0.60–0.79), and very strong (≥ 0.80). *Correlation is significant at $p < 0.05$; **Correlation is significant at $p < 0.01$.*

## CONCLUSION

Soils from municipal dumpsites in Lokoja were substantially contaminated with Pb, Cu, Zn, and Cd, and this poses ecological and health risks. The indigenous herbaceous plants showed species-specific metal accumulation, with *C. dactylon* and *S. pumila* exhibiting the highest uptake and translocation. The strong correlations between soil and shoot metal concentrations indicate that soil contamination drives plant accumulation. The species with high metal uptake, such as *C. dactylon* and *S. pumila*, are recommended for phytoremediation of contaminated dumpsites.

**Authors Contribution**
BOO and GIO conceptualized and designed the study. BOO, MI, and JMM conducted field sampling and data collection. BOO and ROO performed laboratory analyses and data analysis. BOO, JMM, and GIO interpreted the results. BOO drafted the manuscript, which was critically reviewed and revised by GIO, JMM, and ROO. All authors approved the final version for submission.

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