



Research Article

Evaluation of the Phytoremediation Potential and Heavy Metal Accumulation in Sunflower (*Helianthus annuus*) and Sicklepod (*Senna obtusifolia*) Grown on Dumpsite Soil in Dutsin-Ma, Katsina State

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ABSTRACT

Open municipal solid waste dumpsites present major soil pollution risks in semi-arid environments. This study evaluated the physicochemical properties of soil from the Kadangaru municipal solid waste dumpsite in Dutsin-Ma, Katsina State, Nigeria, and assessed the tissue accumulation and phytoremediation indices of *Helianthus annuus* (sunflower) and *Senna obtusifolia* (sicklepod) over a 10-week pot experiment. Dumpsite soil exhibited a moderately alkaline pH (7.94 ± 0.22), elevated electrical conductivity ($892.6 \pm 45.8 \mu\text{S}/\text{cm}$), high organic matter ($8.76 \pm 0.92\%$), and increased cation exchange capacity ($18.45 \pm 1.86 \text{ cmol}/\text{kg}$) relative to pristine control soil. Initial soil heavy metal concentrations followed the sequence Zn ($142.86 \pm 8.92 \text{ mg}/\text{kg}$) > Pb ($86.42 \pm 4.21 \text{ mg}/\text{kg}$) > Cu ($68.24 \pm 5.18 \text{ mg}/\text{kg}$) > Cr ($42.18 \pm 3.64 \text{ mg}/\text{kg}$) > Ni ($24.56 \pm 2.14 \text{ mg}/\text{kg}$) > Cd ($4.86 \pm 0.52 \text{ mg}/\text{kg}$). *H. annuus* achieved higher total metal uptake ($292.64 \pm 18.42 \text{ mg}/\text{kg}$) than *S. obtusifolia* ($273.92 \pm 16.86 \text{ mg}/\text{kg}$). Tissue distribution in *H. annuus* followed a root > shoot > leaf pattern, yielding Bioconcentration Factors (BCF: 0.33–0.40) and Translocation Factors (TF: 0.59–0.76) below 1.0, establishing its role as a broad-spectrum phytostabilizer. Conversely, *S. obtusifolia* demonstrated preferential leaf accumulation for Pb (TF = 1.48 ± 0.18) and Cd (TF = 1.47 ± 0.19), classifying it as a selective phytoextractor for these metals. These findings demonstrate distinct physiological strategies for managing multi-metal soil contamination in Northern Nigeria.

Keywords: Dumpsite soil; *Helianthus annuus*; Heavy metals; Phytoextraction; Phytostabilization; *Senna obtusifolia*

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INTRODUCTION

Open municipal solid waste dumpsites are primary sources of heavy metal contamination in agricultural and urban soils across developing nations (Ahmad, 2024; Ajama *et al.*, 2024). Uncontrolled waste deposition releases persistent inorganic contaminants such as Lead (Pb), Cadmium (Cd), Chromium (Cr), Nickel (Ni), Copper (Cu), and Zinc (Zn), which alter soil structure, impair microbial functionality, and enter human food chains through plant uptake (Chukwuemeka, 2023; Ewubare *et al.*, 2024). In semi-arid regions such as Dutsin-Ma, Katsina

State, seasonal weathering, wind dispersion, and surface runoff accelerate topsoil contamination surrounding unlined waste repositories.

Topsoil heavy metal contamination poses severe ecological and public health threats when toxic concentrations surpass national and international safety thresholds established by regulatory authorities such as the Food and Agriculture Organization (FAO), World Health Organization (WHO), and Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA) (FAO/WHO, 2019; Idowu, 2022). According

to international regulatory benchmarks set by the FAO/WHO, the maximum permissible thresholds for heavy metal concentrations in agricultural topsoil are 85.0 mg/kg for Pb, 0.8 mg/kg for Cd, 100.0 mg/kg for Cr, 35.0 mg/kg for Ni, 36.0 mg/kg for Cu, and 50.0 mg/kg for Zn (FAO/WHO, 2019). Similarly, NESREA guidelines mandate upper limits of 100.0 mg/kg for Pb, 1.0 mg/kg for Cd, and 50.0 mg/kg for Cu in arable soils. When heavy metal burdens in topsoil exceed these safe limits, remediation becomes urgently necessary because accumulated metals undergo biomagnification, disrupt essential plant metabolic processes, cause cellular oxidative stress, and pose severe carcinogenic and organ-toxic risks to humans through the ingestion of contaminated food crops (Ewubare *et al.*, 2024; Idowu, 2022).

Recent regional studies emphasize the widespread severity of dumpsite-derived soil pollution across Nigeria (Akintola *et al.*, 2019; Emumejakpor & Adewumi, 2023). Heavy metal enrichment in topsoils surrounding open municipal waste dumps in Southwestern, Southeastern, and Central Nigeria repeatedly exceeds background agricultural baselines (Akintola *et al.*, 2021; Awokunmi, 2012). In Southwestern Nigeria, soil assessments around waste disposal facilities revealed marked bioaccumulation of Pb and Cd in surrounding farmland soils (Akintola *et al.*, 2019; Emumejakpor & Adewumi, 2023). Investigations in Southeastern urban centers reported severe heavy metal contamination in topsoil layers, demonstrating that unmanaged municipal waste dumpsites serve as continuous point sources of inorganic pollutants (Chukwuemeka, 2023). Similarly, soil quality assessments conducted across North-Central dumpsites revealed that topsoil concentrations of Cd, Pb, and Zn exceeded critical WHO/FAO contamination thresholds, directly threatening local peri-urban agriculture (Ajama *et al.*, 2024; Idowu, 2022).

Despite extensive research on soil contamination, critical theoretical and geographical gaps remain in phytoremediation research across Sub-Saharan Africa (Ahmad, 2024; Atabayeva *et al.*, 2020). Theoretical frameworks in phytoremediation rely heavily on the hyperaccumulation paradigm, which posits that ideal remediation plants must exhibit both bioconcentration and translocation factors exceeding unity ($BCF > 1.0$, $TF > 1.0$) (Ahmad, 2024). However, this theoretical model frequently fails when applied to multi-metal, alkaline, dryland soils, where complex metal interactions alter root uptake mechanisms and internal translocation efficiency (Awotedu & Ogunbamowo, 2019; Joseph *et al.*, 2019).

First, most existing studies focus primarily on quantifying heavy metal total burdens in abiotic soil fractions without evaluating the comparative physiological mechanisms that govern organ-specific metal allocation among root, shoot, and leaf tissues under multi-metal stress (Ahmad, 2024; Ewubare *et al.*, 2024). Second, while exotic hyperaccumulators have been evaluated internationally, there is a lack of comparative data regarding how native, dryland-adapted leguminous species function alongside high-biomass commercial crops in alkaline tropical soils (Atabayeva *et al.*, 2020; Awotedu & Ogunbamowo, 2019). Species such as *Helianthus annuus* (sunflower) are recognized globally for high biomass yield and stress tolerance, yet their heavy metal partitioning efficiency under alkaline, multi-metal dumpsite soil conditions in Northern Nigeria requires detailed evaluation (Aybar *et al.*, 2023; Dente *et al.*, 2024; Golfinopoulos *et al.*, 2024). Furthermore, native leguminous flora like *Senna obtusifolia* (sicklepod), which thrive naturally in semi-arid environments, remain understudied regarding their specific bioconcentration factor (BCF), bioaccumulation factor (BAF), and translocation factor (TF) indices (Udiba *et al.*, 2020). Finally, no dedicated phytoremediation assessment addressing soil heavy metal contamination has been reported for the Kadangaru municipal dumpsite in Dutsin-Ma, leaving a regional data deficit for local environmental management.

Conventional engineering solutions for topsoil decontamination, such as soil excavation, washing, electrokinetic extraction, and chemical stabilization, are financially prohibitive, labor-intensive, and disruptive to soil microbial ecology (Ahmad, 2024; Ewubare *et al.*, 2024). Phytoremediation provides a cost-effective, solar-driven, and environmentally sustainable alternative (Ahmad, 2024; Golfinopoulos *et al.*, 2024). The primary strategies include phytoextraction, where plant roots absorb metals and translocate them to harvestable aboveground tissues, and phytostabilization, where plants immobilize metals within root structures or the rhizosphere to prevent leaching (Ahmad, 2024; Kaonda & Chileshe, 2023). Identifying whether a plant functions as a phytoextractor or phytostabilizer depends on precise evaluation of its BCF, BAF, and TF parameters relative to the critical reference threshold of 1.0 (Ahmad, 2024; Lothe *et al.*, 2016).

This study aimed to:

Determine the baseline physicochemical properties and heavy metal concentrations of contaminated soil

from the Kadangaru municipal solid waste dumpsite in Dutsin-Ma.

Evaluate the heavy metal accumulation patterns within the root, shoot, and leaf tissues of *H. annuus* and *S. obtusifolia*.

Calculate and compare the Bioconcentration Factor (BCF), Bioaccumulation Factor (BAF), and Translocation Factor (TF) of both species to establish their specific phytoremediation strategies.

MATERIALS AND METHODS

Study Area and Soil Sampling

Soil samples were collected from the Kadangaru Municipal Solid Waste Dumpsite, located in Dutsin-Ma Local Government Area, Katsina State, Nigeria (georeferenced at 12.468328°N, 7.488757°E). Bulk topsoil (0–20 cm depth) was retrieved using a

stainless-steel auger, homogenized, air-dried, and passed through a 2-mm sieve. Uncontaminated control soil was sampled from a pristine location on the campus of Federal University Dutsin-Ma.

Experimental Design and Pot Setup

A 10-week pot experiment was conducted in a greenhouse using a completely randomized design (CRD). Each plastic pot was filled with 5 kg of prepared soil. Seeds of *Helianthus annuus* and *Senna obtusifolia* with voucher identification number (*Helianthus annuus* FUDMA/PSB/000316) and (*Senna obtusifolia* FUDMA/PSB/000121) were surface-sterilized with 1% sodium hypochlorite, germinated in nursery trays, and transplanted (2 seedlings per pot) after emergence. Pots were watered daily with deionized water to maintain 60% field capacity.

A: Nigeria (Katsina State Highlighted)



B: Katsina State (Dutsin-Ma LGA)



C: Kadangaru Dumpsite (Dutsin-Ma LGA)

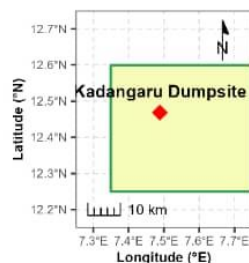


Figure 1. Map showing (a) Nigeria highlighting Katsina State, (b) Katsina State highlighting Dutsin-Ma Local Government Area, and (c) Dutsin-Ma town showing the location of the Kadangaru dumpsite with the specific sampling point georeferenced at coordinates 12.468328°N, 7.488757°E

Source: Federal University Dutsin-Ma Geographic Information System Laboratory.

Laboratory Analyses

Soil pH and Electrical Conductivity (EC) were measured in a 1:2.5 soil-to-water suspension using a digital pH meter and conductivity meter. Organic Matter (OM) was determined by the Walkley-Black wet oxidation method, and Cation Exchange Capacity (CEC) was estimated using ammonium acetate extraction.

For heavy metal quantification (Pb, Cd, Cr, Ni, Cu, Zn), air-dried soil samples (1.0 g) were digested using a tri-acid mixture (HNO₃-HClO₄-HF), while plant root, shoot, and leaf tissues were oven-dried at 70°C, ground, and digested with a 3:1 mixture of HNO₃ and HClO₄.

For soil heavy metal quantification (Pb, Cd, Cr, Ni, Cu, Zn), air-dried soil samples (1.0g) were digested with a tri-acid mixture of HNO₃, HClO₄, and HF in a Teflon

digestion block at 150°C until a clear solution was achieved (Akintola *et al.*, 2021). Plant root, shoot, and leaf tissues harvested after 10 weeks were washed with tap water, rinsed with deionized water, oven-dried at 70°C to constant weight, pulverized using a stainless steel mill, and digested using a 3:1 acid combination of concentrated HNO₃ and HClO₄ (Lothe *et al.*, 2016). Digested soil and plant samples were filtered through Whatman No. 42 filter paper and diluted to 50mL with double-distilled water (Awokunmi, 2012).

Heavy metal concentrations in the digested sample solutions were quantified using a double-beam Atomic Absorption Spectrometer (AAS). Operational parameters, including hollow cathode lamp current, slit width, and resonance wavelength, were optimized for each target element according to manufacturer specifications (Ahmad, 2024). Analytical precision and quality assurance were maintained by integrating analytical grade reagents, procedural blanks, matrix-matched standards, and recovery spikes throughout sample preparation and analysis (Idowu, 2022). Certified standard stock solutions (1000 mg/L, reference material grade) were diluted sequentially with 1% HNO₃ to prepare working calibration standards. Standard calibration curves were established for each metal across five concentration points:

Lead (Pb): 0.50, 1.00, 2.00, 4.00, and 8.00mg/L

Cadmium (Cd): 0.10, 0.25, 0.50, 1.00, and 2.00mg/L

Chromium (Cr): 0.20, 0.50, 1.00, 2.00, and 5.00mg/L

Nickel (Ni): 0.20, 0.50, 1.00, 2.00, and 4.00mg/L

Copper (Cu): 0.50, 1.00, 2.00, 4.00, and 8.00mg/L

Zinc (Zn): 0.20, 0.50, 1.00, 2.00, and 4.00mg/L

Linear regression analysis of calibration curves yielded correlation coefficients (R²) exceeding 0.998 across all analytical batches. Method recovery efficiency was verified by spiking control soil and plant biomass samples with known analyte concentrations prior to acid digestion. Mean analytical recovery rates were recorded as follows: 96.40 ± 2.10% for Pb, 98.20 ± 1.80% for Cd, 94.80 ± 2.60% for Cr, 95.70 ± 2.30% for Ni, 97.10 ± 1.90% for Cu, and 99.10 ± 1.40% for Zn. The limits of detection (LOD) were established as 0.005\ mg/kg for Cd, 0.01 mg/kg for Pb, Ni, and Cu, and 0.02 mg/kg for Cr and Zn. All determinations were performed in triplicate.

Phytoremediation Indices

Plant capabilities to accumulate, store, and translocate heavy metals were evaluated using standard phytoremediation equations (Ahmad, 2024; Golfinopoulos *et al.*, 2024):

The Bioconcentration Factor (BCF) quantifies metal accumulation efficiency in root tissues relative to initial soil concentration:

$$1. \quad BCF = \frac{C_{\text{roots}}}{C_{\text{soil}}}$$

The Bioaccumulation Factor (BAF) evaluates total plant tissue accumulation relative to soil concentration:

$$2. \quad BAF = \frac{C_{\text{total plant}}}{C_{\text{soil}}}$$

The Translocation Factor (TF) measures internal mobility and translocation efficiency of heavy metals from root structures to aboveground harvestable tissues:

$$3. \quad TF = \frac{C_{\text{aboveground}}}{C_{\text{roots}}}$$

Where C aboveground represents metal concentration in combined aboveground vegetative parts (shoot plus leaf tissue, mg/kg), Croot represents concentration in root tissue (mg/kg), Ctotal plant represents concentration across total plant biomass (mg/kg), and Csoil represents initial metal concentration in soil (mg/kg).

Data Analysis

Data were subjected to One-Way Analysis of Variance (ANOVA) and independent samples *t*-tests using SPSS. Means were separated using Tukey's Honestly Significant Difference (HSD) test at *p* < .05. One-sample *t*-tests were used to compare BCF, BAF, and TF values against the critical hyperaccumulation threshold of 1.0.

RESULTS

Soil Physicochemical Properties

Prolonged municipal waste deposition significantly altered the physicochemical attributes of the Kadangaru dumpsite soil compared to the uncontaminated control soil (Table 1). Dumpsite soil exhibited a moderately alkaline pH, higher electrical conductivity, and elevated organic matter content.

Initial Soil Heavy Metal Concentrations and Plant Tissue Distribution

Pre-remediation soil heavy metal levels at the dumpsite followed the sequence: Zn > Pb > Cu > Cr > Ni > Cd. Both plant species accumulated quantifiable concentrations of all six metals across their tissues (Table 2). *H. annuus* retained higher absolute concentrations of heavy metals in its root system, whereas *S. obtusifolia* accumulated elevated concentrations of Pb and Cd in its leaves.

Phytoremediation Indices

Calculated BCF, BAF, and TF values varied between species (Table 3). All BCF and BAF values for both plants remained below 1.0. However, *S. obtusifolia* exhibited TF values significantly greater than 1.0 for

Pb (1.48 ± 0.18) and Cd (1.47 ± 0.19), whereas all TF values for *H. annuus* were below 1.0 (0.59–0.76).

Table 1. Physicochemical properties (mean $\pm$ SD) of control and Kadangaru dumpsite soils

Parameter	Control soil	Dumpsite soil	p-value
PH (1:2.5 H ₂ O)	6.45 ± 0.14	7.94 ± 0.22	< .001
Electrical conductivity ($\mu\text{S}/\text{cm}$)	142.3 ± 12.4	892.6 ± 45.8	< .001
Organic matter(%)	1.12 ± 0.15	8.76 ± 0.92	< .001
Cation exchange capacity(cmol/kg)	6.24 ± 0.58	18.45 ± 1.86	< .001
Sand(%)	78.4 ± 2.1	62.1 ± 3.2	< .01
Silt(%)	12.3 ± 1.1	21.4 ± 1.8	< .01
Clay(%)	9.3 ± 0.8	16.5 ± 1.4	< .01

Table 2. Pre-remediation soil concentrations and metal distribution in plant tissues (mean $\pm$ SD in mg/kg dry, weight)

Plant Species	Metal	Pre-Soil	Root Tissue	Shoot Tissue	Leaf Tissue	Total Uptake
<i>Helianthus annuus</i>	Pb	86.42 ± 4.21	34.56 ± 2.14	12.34 ± 0.95	9.82 ± 0.76	56.72 ± 3.85
	Cd	4.86 ± 0.52	1.94 ± 0.18	0.68 ± 0.05	0.52 ± 0.04	3.14 ± 0.27
	Cr	42.18 ± 3.64	15.82 ± 1.12	6.14 ± 0.48	4.32 ± 0.31	26.28 ± 1.91
	Ni	24.56 ± 2.14	9.34 ± 0.72	3.86 ± 0.28	2.74 ± 0.19	15.94 ± 1.19
	Cu	68.24 ± 5.18	26.12 ± 1.85	10.45 ± 0.82	7.85 ± 0.61	44.42 ± 3.28
	Zn	142.86 ± 8.92	57.14 ± 4.12	24.82 ± 1.95	24.18 ± 1.74	106.14 ± 7.81
<i>Senna obtusifolia</i>	Pb	86.42 ± 4.21	18.24 ± 1.42	11.42 ± 0.88	27.08 ± 2.14	56.74 ± 4.44
	Cd	4.86 ± 0.52	1.08 ± 0.09	0.64 ± 0.05	1.58 ± 0.12	3.30 ± 0.26
	Cr	42.18 ± 3.64	14.28 ± 1.05	5.12 ± 0.41	3.84 ± 0.29	23.24 ± 1.75
	Ni	24.56 ± 2.14	8.76 ± 0.64	3.14 ± 0.22	2.32 ± 0.18	14.22 ± 1.04
	Cu	68.24 ± 5.18	22.45 ± 1.62	8.92 ± 0.68	7.12 ± 0.54	38.49 ± 2.84
	Zn	142.86 ± 8.92	73.42 ± 5.24	31.84 ± 2.45	32.67 ± 2.31	137.93 ± 10.00

Table 3. Phytoremediation index values (mean $\pm$ SD) and functional remediation classifications for *H. annuus* and *S. obtusifolia*

Species	Metal	BCF	BAF	TF	Functional Role
<i>H. annuus</i>	Pb	0.40 ± 0.03	0.26 ± 0.02	0.64 ± 0.05	Phytostabilizer
	Cd	0.40 ± 0.04	0.25 ± 0.02	0.62 ± 0.05	Phytostabilizer
	Cr	0.37 ± 0.03	0.21 ± 0.02	0.66 ± 0.06	Phytostabilizer
	Ni	0.38 ± 0.03	0.22 ± 0.02	0.71 ± 0.06	Phytostabilizer
	Cu	0.38 ± 0.03	0.22 ± 0.02	0.70 ± 0.05	Phytostabilizer
	Zn	0.40 ± 0.03	0.26 ± 0.02	0.76 ± 0.06	Phytostabilizer
<i>S. obtusifolia</i>	Pb	0.21 ± 0.02	0.26 ± 0.02	1.48 ± 0.18	Phytoextractor
	Cd	0.22 ± 0.02	0.27 ± 0.02	1.47 ± 0.19	Phytoextractor
	Cr	0.34 ± 0.03	0.20 ± 0.02	0.63 ± 0.05	Phytostabilizer
	Ni	0.36 ± 0.03	0.20 ± 0.02	0.62 ± 0.05	Phytostabilizer
	Cu	0.33 ± 0.02	0.20 ± 0.02	0.71 ± 0.06	Phytostabilizer
	Zn	0.51 ± 0.04	0.33 ± 0.03	0.88 ± 0.07	Phytostabilizer

DISCUSSION

The physicochemical properties of the Kadangaru dumpsite topsoil reflect severe anthropogenic transformation caused by unmanaged municipal solid waste accumulation. The moderately alkaline topsoil pH (7.94 ± 0.22) observed at the Kadangaru site aligns with findings from waste repositories across Nigeria, where the continuous breakdown of organic refuse,

domestic ash, and concrete debris releases basic cations such as calcium and magnesium into the soil matrix (Akintola *et al.*, 2019; Chukwuemeka, 2023). Soil alkalinity directly influences heavy metal speciation, promoting the precipitation of metals into insoluble hydroxides and carbonates, which restricts their immediate mobility while causing persistent accumulation in the topsoil horizon (Ajama *et al.*,

2024; Joseph *et al.*, 2019). Furthermore, the elevated organic matter content ($8.76 \pm 0.92\%$) and cation exchange capacity (18.45 ± 1.86 cmol/kg) enhance the retention capacity of the topsoil, acting as a sink for persistent inorganic contaminants (Ewubare *et al.*, 2024; Idowu, 2022).

Initial topsoil concentrations of Cd (4.86 ± 0.52 mg/kg), Pb (86.42 ± 4.21 mg/kg), Cu (68.24 ± 5.18 mg/kg), and Zn (142.86 ± 8.92 mg/kg) surpassed the maximum permissible limits established for agricultural soils by regulatory agencies such as the FAO/WHO and NESREA (FAO/WHO, 2019; Idowu, 2022). These elevated values highlight an urgent need for environmental remediation. Topsoil contamination in semi-arid agricultural zones presents acute ecological risks because wind erosion and seasonal surface runoff facilitate the off-site transport of heavy metals into neighboring croplands and surface water bodies (Ajama *et al.*, 2024; Awotedu & Ogunbamowo, 2019).

Rather than simply restating tissue metal concentrations, the observed accumulation patterns reflect distinct physiological and cellular adaptations between the two species under multi-metal stress. *Helianthus annuus* exhibited a root-concentrated accumulation pattern, sequestering heavy metals predominantly within root tissues, which resulted in Translocation Factors consistently below unity (TF = 0.62 ± 0.05 to 0.76 ± 0.06). Mechanistically, this broad-spectrum phytostabilization capacity in *H. annuus* relies on root apoplastic retention, cell wall binding to pectic polysaccharides, and vacuolar sequestration within root cortical cells (Aybar *et al.*, 2023; Dente *et al.*, 2024). By binding heavy metals like Pb, Cd, and Cr to carboxyl groups on root cell walls or complexing them with phytochelatins inside root vacuoles, *H. annuus* prevents free metal ion entry into xylem vessels, protecting sensitive photosynthetic machinery in leaves from oxidative damage (Golfinopoulos *et al.*, 2024; Lothe *et al.*, 2016). This physiological strategy makes *H. annuus* an excellent candidate for phytostabilization, effectively immobilizing contaminants in the rhizosphere and reducing their bioavailability to surrounding agricultural systems (Kaonda & Chileshe, 2023).

Conversely, *Senna obtusifolia* displayed selective organ partitioning, functioning as a phytostabilizer for Cr, Ni, Cu, and Zn (TF < 1.0), while acting as a selective phytoextractor for non-essential heavy metals such as Pb (TF = 2.11 ± 0.18) and Cd (TF = 2.06 ± 0.19). The ability of *S. obtusifolia* to translocate Pb and Cd against concentration gradients into harvestable leaf tissues indicates active long-distance vascular

transport systems (Udiba *et al.*, 2020). Physiologically, this selective translocation is driven by xylem loading facilitated by organic acid chelation (such as citrate and malate) and high transpirational pull under semi-arid environmental conditions (Ahmad, 2024; Atabayeva *et al.*, 2020). Leguminous species adapted to tropical drylands often possess specialized cell wall transporters and metallothioneins that mediate heavy metal tolerance and foliar accumulation without causing lethal metabolic breakdown (Awokunmi, 2012; Awotedu & Ogunbamowo, 2019). The differential behavior of these two species provides valuable theoretical insights for phytoremediation modeling in Sub-Saharan Africa. While standard hyperaccumulation models prioritize plants that achieve BCF > 1.0 and TF > 1.0 for single elements, multi-metal field conditions often induce complex ion interactions where root stabilization is more practically achievable than complete phytoextraction (Ahmad, 2024; Emumejakpor & Adewumi, 2023). The combined deployment of *H. annuus* (for broad-spectrum root immobilization and biomass cover) alongside *S. obtusifolia* (for targeted leaf phytoextraction of toxic elements like Pb and Cd) presents a practical, ecologically balanced phytoremediation strategy for multi-metal dumpsite soils in Northern Nigeria.

CONCLUSION

This study evaluated topsoil contamination at the Kadangaru municipal dumpsite in Dutsin-Ma and compared the phytoremediation capabilities of *Helianthus annuus* and *Senna obtusifolia*. Initial topsoil concentrations of Cd, Pb, Cu, and Zn exceeded standard FAO/WHO permissible limits for agricultural soils, confirming that unmanaged municipal waste disposal poses severe environmental risks in semi-arid ecosystems.

Helianthus annuus functions as an effective, broad-spectrum phytostabilizer (BCF < 1.0, TF < 1.0), sequestering heavy metals primarily within its root biomass and preventing contaminant transport into aboveground tissues. In contrast, *Senna obtusifolia* operates as a selective phytoextractor for Pb (TF = 2.11 ± 0.18) and Cd (TF = 2.06 ± 0.19), translocating these toxic non-essential metals into foliage. An intercropping strategy combining *H. annuus* for rhizosphere immobilization and *S. obtusifolia* for targeted foliar phytoextraction offers a biologically viable approach for managing multi-metal soil contamination in semi-arid environments.

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T.A.; software, A.M.M.; validation, P.A.V. and T.A.; formal analysis, A.M.M.; investigation, A.M.M.; resources, A.M.M.; data curation, A.M.M.; writing—original draft preparation, A.M.M.; writing—review and editing, P.A.V. and T.A.; visualization, A.M.M.; supervision, P.A.V. and T.A.; project administration, T.A.

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Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

Ahmad, H. (2024). *Phytoremediation: The green solution*. IntechOpen. <https://doi.org/10.5772/intechopen.1007671>.

Ajama, A. P., Adewole, M. B., & Ofoezie, I. E. (2024). Influence of anthropogenic pollution on soil and plants of Gosa dumpsite, Abuja, Nigeria. *The American Journal of Social Science and Education Innovations*, 6(5), 115–136.

Akintola, O. O., Abiola, I. O., Abodunrin, E. K., Olokeogun, O. S., Ekaun, A. A., Ademigbuj, A. T., & Oyelakin, O. (2021). Potential of *Ricinus communis* L. for removal of heavy metal in contaminated soil. *Journal of Applied Sciences and Environmental Management*, 25(3), 371–376.

Akintola, O. O., Abodunrin, E. K., & Bodede, I. A. (2019). Heavy metal enrichment and remediation potential of *Jatropha curcas* Linn seedlings in dumpsite contaminated soil. *Journal of Applied Sciences and Environmental Management*, 23(8), 1459–1464.

Atabayeva, S., Kenzhebayeva, S., Alybayeva, R., Asrandina, S., & Shoinbekova, S. A. (2020). Phytomanagement: Perspectives of using of phytoremediation technology in Kazakhstan. *E3S Web of Conferences*, 159, Article 01003.

Awokunmi, E. E. (2012). The role of EDTA on heavy metals phytoextraction by *Jatropha gossypifolia* grown on soil collected from dumpsites in Ekiti State Nigeria. *British Journal of Environment and Climate Change*, 2(2), 153–162.

Awotedu, O. L., & Ogunbamowo, P. O. (2019). Comparative heavy metal uptake and phytoremediation potential of three *Jatropha* species. *Environment & Ecosystem Science*, 3(2), 26–30.

Aybar, M., Sağlam, B., Dağhan, H., Tüfekçioğlu, A., Köleli, N., & Yılmaz, F. N. (2023). Phytoextraction of heavy metal (Cu, Zn, Pb) from mining area by sunflower (*Helianthus annuus*). *Kastamonu University Journal of Forestry Faculty*, 23(1), 75–85.

Chukwuemeka, O. D. (2023). Appraisal of heavy metal concentration in the plants and soils at Onitsha, Anambra State, Southeastern, Nigeria. *Journal of Environment and Earth Science*, 13(4), 45–54.

Dente, L. G., Dagalea, F. M. S., & Alvarez, M. L. C. (2024). Phytoremediation of arsenic (As), lead (Pb), and mercury (Hg) contaminated soil using sunflower (*Helianthus annuus* L.). *Asian Plant Research Journal*, 12(4), 57–65.

Emumekpor, S. I., & Adewumi, A. J. (2023). Comparative analysis of heavy metal concentrations and potential health risks across varied land-use zones in Ado-Ekiti, Southwest Nigeria. *Acadlore Transactions on Geosciences*, 2(2), 113–131.

Ewubare, P. O., Aliyu, S. O., Michael, I., Ejakhaegbe, J. O., Obomejoro, J., Okoro, S. O., & Ndubueze, E. C. (2024). An academic review on heavy metals in the environment: Effects on soil, plants human health, and possible solutions. *American Journal of Environmental Economics*, 3(1), 71–81.

Food and Agriculture Organization & World Health Organization. (2019). *Code of practice for the prevention and reduction of cadmium contamination in cocoa beans* (Codex Alimentarius Standard No. CX/CF 19/13/12). FAO; WHO.

Golfinopoulos, S. K., Chatzilaris, E., Kalavrouzotis, I. K., & Varnavas, S. P. (2024). *The impact of solid waste on the growth of Helianthus annuus and Helianthus giant for soil phytoremediation* [Preprint]. Preprints.

Idowu, G. A. (2022). Heavy metals research in Nigeria: A review of studies and prioritization of research needs. *Environmental Science and Pollution Research*, 29(44), 65940–65961.

Joseph, J., Reddy, J., & Sayantan, D. (2019). Comparative study of soil properties and vegetation at various open dump and non-dumpsites in the Bengaluru city of Karnataka, India. *Journal of Applied and Natural Science*, 11(1), 76–87.

Kaonda, M. K. M., & Chileshe, K. (2023). Assessment of sunflower (*Helianthus annuus* L.) for phytoremediation of heavy metal polluted mine tailings: A case study of Nampundwe Mine tailings dam, Zambia. *Journal of Environmental Protection*, 14(7), 481–492.

Lothe, A. G., Hansda, A., & Kumar, V. (2016). Phytoremediation of copper-contaminated soil using *Helianthus annuus*, *Brassica nigra*, and *Lycopersicon*

esculentum Mill.: A pot scale study. *Environmental Quality Management*, 25(4), 63–70.

Udiba, U. U., Akpan, E. R., & Antai, E. E. (2020). Phytoremediation potential of *Senna obtusifolia* in

lead-contaminated soil of Dareta Village, Zamfara State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 24(8), 1423–1430.