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Phytoremediation Potentials of Heavy Metals in Contaminated Soils by The Selected Plant Species from Three Villages (Takuti, Gulu and Takalafiya) In Lapai, Niger State, Nigeria

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ABSTRACT: The objective of this paper was to evaluate the Phytoremediation potentials of heavy metals in contaminated soils by the selected plant species from three villages (Takuti, Gulu and Takalafiya) in Lapai, Niger State, Nigeria using standard procedures after nine (9) plant samples were exposed to contaminated soils and the heavy metals preliminary concentrations in the plant species, were measured before exposure and post-contamination exposure. The results showed Nickel (Ni) accumulation in plant to be in the decreasing order of *Eleusine indica* (5.65 ± 0.99) > *Cyperus odoratus* (5.55 ± 0.97) > *Juncus tenuis* (5.34 ± 0.94) > *Amorpha fruticosa* (5.15 ± 0.90) > *Senna obtusifolia* (5.02 ± 0.88) > *Ricinus communis* (4.96 ± 0.87) > *Pueraria montana* (4.76 ± 0.83) > *Cyperus rotundus* (3.24 ± 0.56) > *Amaranthus spinosus* (2.42 ± 0.42 mg/kg) while Cadmium (Cd) recorded *Juncus tenuis* (5.64 ± 0.99), *Eleusine indica* (5.53 ± 0.97), *Senna obtusifolia* (5.45 ± 0.95), *Cyperus rotundus* (5.18 ± 0.91), *Amaranthus spinosus* (4.83 ± 0.84), *Amorpha fruticosa* (4.55 ± 0.79), *Cyperus odoratus* (4.47 ± 0.78), *Ricinus communis* (4.08 ± 0.71) and *Pueraria montana* (4.05 ± 0.71 mg/kg) respectively. The Bioaccumulation Factor of all the plant species were below 1 for Ni and Cr while Cd recorded 0.41 to 4.89. The Translocation Factor for Ni ranges from 7.61 to 10.63, Cd ranges from 5.2 to 8.5 and Cr from 6.96 to 7.8 for the studies plant species. Thus, this study suggests that, the plant species can be used for the phytoremediation of soils contaminated with heavy metals.

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Heavy metals are natural components of the Earth's crust, but their concentrations have reached toxic levels in many ecosystems due to anthropogenic activities (Sarma, 2011). Fifty-three elements fall into

the category of heavy metals, defined as the group of elements whose densities are higher than 5g, and are recognized as ubiquitous environmental contaminants in industrialized societies (Anarado *et al.*, 2019). Soil

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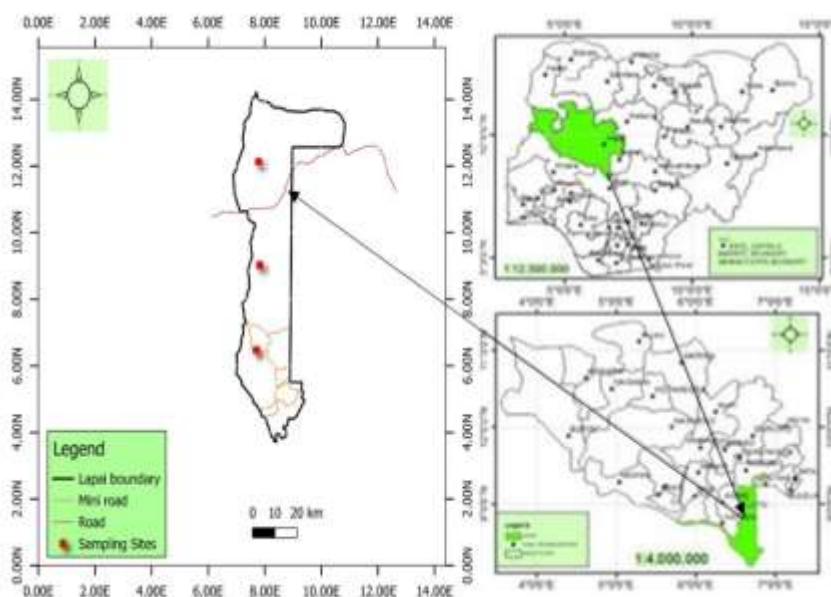
contamination by heavy metals has been occurring for centuries, but its extent has increased markedly since the last 50 years due to technological developments and increased use of materials containing these metals (Taneja *et al.*, 2022). Soils, being a critical component of ecosystems, play a vital role in supporting plant growth and filtering pollutants. However, soil contamination by heavy metals can have devastating effects on plant growth, animal health, and human well-being. The accumulation of heavy metals in soils can occur through various activities, including mining, dumping of heavy metal wastes, sewage sludge, paints, fertilizers, pesticides, wastewater irrigation, animal manure, coal combustion residues, atmospheric deposition, and spillage of chemicals (Alengebawy *et al.*, 2021).

Plants, in particular, are susceptible to heavy metal contamination, as they can absorb these metals through their roots and accumulate them in their

tissues. Terrestrial invasive plants, including non-native species that grow in non-aquatic habitats, can play a significant role in phytoremediation, the process of using plants to remove pollutants from the environment (Holt, 2011). Consequently, the objective of this paper was to evaluate the Phytoremediation potentials of heavy metals in contaminated soils by the selected plant species from three villages (Takuti, Gulu and Takalafiya) in Lapai, Niger State, Nigeria,

MATERIALS AND METHODS

Study Area: This study was carried out in Lapai, Niger State which lies on Latitude 8° To $11^{\circ}30'$ North and Longitude $03^{\circ}30'$ To $07^{\circ}40'$ East. The State is bordered to the North by Zamfara State, West by Kebbi State, South by Kogi State, South West by Kwara State, North-East by Kaduna State, and South East by FCT.



The study area was stratified into three distinct sites (Site A, Site B, and Site C) based on their proximity to abandoned mining activities, soil type, and vegetation cover. This stratification aimed to capture the variability in heavy metal contamination and plant species distribution across the area. Three plant samples were collected from each site, resulting in a total of nine samples. The selection of three samples per site was based on the assumption that this number would provide a representative snapshot of the plant species composition and heavy metal accumulation patterns at each site. Furthermore, collecting multiple samples from each site allowed for the calculation of

mean values and standard deviations, providing a more robust dataset for analysis.

Collection and Identification of Plant Samples: This study involved a preliminary survey of the study area to identify potential sampling sites and plant species. Subsequent visits were made to the selected sites for plant sample collection. Plant sampling was conducted using a randomized quadrat method, where three quadrats (1m x 1m) were randomly placed at each of the three sites (Site A, Site B, and Site C). Within each quadrat, three plant species were randomly selected and harvested, resulting in a total

of nine plant samples. Plant samples were collected in clean, sterile bags and transported to the laboratory for identification and analysis. Plant identification was conducted using a combination of morphological characteristics, such as leaf shape, flower color, and stem texture, and botanical keys specific to the region. The identified plant species were then verified using relevant literature and expert consultation in the school biological laboratory of Ibrahim Badamasi Babangida University Lapai, Niger State.

Collection of Soil Samples and Preparation for Analysis: Soil samples were collected from the three sites (Site A, Site B, and Site C) using a handheld soil auger (10 cm diameter). Sampling was conducted at two depths: 0-15 cm (surface soil) and 15-30 cm (subsurface soil). Three replicate samples were collected from each site at each depth, and these were bulked to form a single composite sample per site per depth. All the soil samples collected were air-dried for 2 to 4 days and mixed thoroughly to achieve homogeneity.

Soil Sampling and Characterization: Soil samples were collected from three distinct areas in Lapai, Niger State, Nigeria. The sampling areas were selected based on their potential for heavy metal contamination.

Soil 1 (Refuse Dump Sites): Soil samples were collected from refuse dump sites in Lapai, where municipal waste is disposed of. Sampling was conducted at five different locations within the dump sites.

Soil 2 (Abandoned Mining Sites): Soil samples were collected from abandoned mining sites in Lapai, where mining activities had previously taken place. Sampling was conducted at five different locations within the mining sites.

Soil 3 (Anthropogenic Areas): Soil samples were collected from areas with high anthropogenic activity, including agricultural fields, construction sites, and areas with high vehicle traffic. Sampling was conducted at five different locations within these areas. The composite soil samples were air-dried, ground, and passed through a 2-mm sieve to remove rocks and un-decomposed organic materials. The particle size of the soil samples was further reduced to less than 5g for analytical experiments using a laboratory sieve. The soil samples were then analyzed for various edaphic properties, including soil texture, pH, electrical conductivity (EC), and organic matter content, using standard methods

(Tesfaye *et al.*, 2015; Haque *et al.*, 2021; Xiangzheng *et al.*, 2021). The distribution of potentially toxic elements (PTEs) in the soil samples was determined using a simplified sequential extraction procedure based on the first two fractions (exchangeable and carbonate-bound) of the Tessier method (Kabirinejad *et al.*, 2014).

Preparation and Digestion of Samples for Heavy Metals Analysis: The plant samples collected were separated into roots, stems, and leaves and then cut into smaller pieces and carefully washed with tap and deionized water to remove any surface soil or dust deposits, as reported by Aliyu *et al.* (2022). The parts of plants were placed on cardboard paper to dry in an open air in the laboratory for two weeks (Audu *et al.*, 2022). The dried samples were ground into fine powder using a ceramic pestle and mortar and stored in white polythene bags. For the analysis of metal accumulation, the method described by Aliyu *et al.* (2022) was employed for this analysis. Specifically, 1g of the solid sample was weighed, and 15ml of freshly prepared acid HNO₃ was added, followed by 5ml of HCl. The mixture was then boiled gently over a water bath (95°C) for 4-5 hours (or until the sample had completely dissolved). The dissolved sample was filtered using Whatman filter paper, and the final solution (i.e., the filtrate) was made to 50cm³ with deionized water.

Heavy Metal Analysis of the Samples: Atomic Absorption Spectroscopy (AAS) was employed to determine the heavy metal concentrations in the samples. The process commenced with sample preparation, involving drying, grinding, and digestion of the samples using a digestion reagent to release the heavy metals. The digested samples were then filtered to remove solid particles. The AAS instrument was set up with the appropriate lamp and wavelength selected for the target heavy metal. The digested sample was aspirated into the nebulizer, converting it into a fine aerosol, which was then introduced into a flame or graphite furnace for atomization. The absorbance of the atomized heavy metals was measured at the selected wavelength, and the signal detected using a photomultiplier tube or charge-coupled device. Calibration was performed using standards of known heavy metal concentrations, and the sample absorbance values were analyzed against the calibration curve to determine the heavy metal concentrations. Quality control checks, including blank and spiked sample analysis, were conducted to ensure accuracy and precision. The AAS instrument provided a quantitative measurement of the heavy metal

concentration in the samples, expressed in milligrams per kilogram (mg/kg) or micrograms per liter ($\mu\text{g/L}$).

Preliminary and Post-Processing of Heavy Metals: The plant species were analyzed after collection from the study area for heavy metal concentrations before exposure to contaminated soils (preliminary concentration). The plants were then grown in contaminated soils for three months, after which they were re-analyzed for heavy metal concentrations (post-processing). The soils of the study area were also analyzed after collection from the study sites for heavy metal concentrations before subjecting the plants to them (preliminary concentration). The soils were then re-analyzed for heavy metal concentrations after the plants had been harvested for heavy metal concentrations (post-processing).

Bioaccumulation Factor: Bioaccumulation factor (BAF) is the ratio of heavy metals in root to that in the soil. The accumulation of Metals in plant tissues was examined as according to (Mohanty and Kumar, 2017). With BAF values > 1 indicating the accumulation of a particular PTE in roots. The mobility ratio

$$BAF = \frac{Cr}{Cs} \quad (1)$$

Where; Cs = concentration in soil, Cr = Concentration in root

Translocation Factor: Translocation factor (TF) is the ratio of PTE in plant shoot to that in plant root. It was evaluated using the following equation:

$$TF = \frac{Cs}{Cr} \quad (2)$$

Where; Cs = concentration in shoot, Cr = Concentration in root

With TF values > 1 indicating that the plants translocate metals effectively from roots to aerial parts. Plants with a Bioaccumulation Factor and Translocation Factor above 1 are appropriate for phytoextraction purposes, whereas when only the BCF exceeds 1 they show phytostabilization potential (Nazli *et al.*, 2020; Pandey *et al.*, 2021; Wahsha *et al.*, 2012).

Statistical Analysis: Data on heavy metals concentrations in the samples were analyzed using Analysis of Variance (ANOVA). Similarly, a post hoc tu key test was also carried out to compare metal concentrations of different plants species.

Floristic Diversity of Plants in all three Villages: Tables 1, 2, and 3 Present the floristic diversity of terrestrial plants found in the selected villages (Takuti, Gulu and Takalafiya) in Lapai, Niger State, with 9 plant species consisting of 6 families. The floristic diversity of plants identified in this study were, Fabaceae (*Amorpha fruticose*, *Pueraria montana*, *Senna obtusifolia*), Cyperaceae (*Cyperus odoratus* and *Cyperus rotundus*), Amaranthaceae (*Amaranthus spinosus*), Euphorbiaceae (*Ricinus communis*), Juncaceae (*Juncus tenuis*) and Poaceae (*Eleusine Indica*).

Table 1: Plant species collected from Takuti

S/N	VOUCHER NO.	FAMILY NAME	SPECIES NAME	COMMON NAME	LOCAL NAME
1	IBBU210555	Cyperaceae	<i>Cyperus rotundus</i>	Purple nutsedge	Ayàà àyàà
2	IBBU2105189	Fabaceae	<i>Amorpha fruticose</i>	Desert false Indigo	Umdaka Wenkangala
3	IBBU2105271	Fabaceae	<i>Senna obtusifolia</i>	Sicklepod	Gayà ebá

Table 2: Plant species collected from Gulu

S/N	VOUCHER NO.	FAMILY NAME	SPECIES NAME	COMMON NAME	LOCAL NAME
1	IBBU2105272	Poaceae	<i>Eleusine Indica</i>	Goosegrass	Cincere
2	IBBU2105241	Fabaceae	<i>Pueraria montana</i>	Kudzu	Ikhambi Lenkangala
3	IBBU21056	Cyperaceae	<i>Cyperus odoratus</i>	Fragrant flatsedge	Umbiza Enephunga

Table 3: Plant species collected from Takalafiya

S/N	VOUCHER NO.	FAMILY NAME	SPECIES NAME	COMMON NAME	LOCAL NAME
1	IBBU210582	Euphorbiaceae	<i>Ricinus communis</i>	Castor bean	Zurma nasara
2	IBBU210592	Juncaceae	<i>Juncus tenuis</i>	Poverty rush	Umhlanga Wompofu
3	IBBU210595	Amaranthaceae	<i>Amaranthus spinosus</i>	Spiny amaranth	Eka Shanshangí

Preliminary Concentration of Heavy Metals in the Plants of the Study Area: Figure 1 The preliminary data of heavy metals in the plants of the study area was determined through laboratory analysis of plant samples collected from the three villages (Takuti,

Gulu, and Takalafiya). The plant samples were digested using a mixture of nitric acid and perchloric acid, and the resulting solutions were analyzed for heavy metal concentrations using Inductively Coupled Plasma Mass Spectrometry (ICP-MS),

distinct patterns emerged regarding the heavy metal concentrations in each plant species. For Nickel (Ni), the plant species with the highest concentration varies across regions. In Takuti, *Juncus tenuis* exhibits the highest Ni concentration (1.7 ± 0.31 mg/kg), followed by *Senna obtusifolia* (6.2 ± 1.12 mg/kg) in Gulu and *Cyperus odoratus* (0.43 ± 0.09 mg/kg) in Takalafiya. Conversely, the plant species with the lowest Ni concentration also varies: *Cyperus rotundus* (0.1 ± 0.05 mg/kg) in Takuti, *Cyperus rotundus* (0.1 ± 0.05 mg/kg) in Gulu, and *Pueraria montana* (0.1 ± 0.05 mg/kg) in Takalafiya. Similarly, for Cadmium (Cd) and Chromium (Cr), different plant species show varying concentrations across the regions, indicating the regional specificity of heavy

metal accumulation in plant species. For Cd, *Cyperus rotundus* (0.7 ± 0.09 mg/kg) and *Pueraria montana* (0.7 ± 0.013 mg/kg) in Takalafiya exhibits the highest concentration, while *Juncus tenuis* (0.1 ± 0.05 mg/kg) in Takuti shows the lowest. In terms of Cr concentration, *Amaranthus spinosus* (0.43 ± 0.09 mg/kg) in Takalafiya records the highest, while *Ricinus communis* (0.08 ± 0.05 mg/kg) in Takuti and *Amaranthus spinosus* in Gulu (0.08 ± 0.05 mg/kg) exhibits the lowest concentration. Overall, the results suggest a complex interplay between plant species and regional environmental factors influencing heavy metal accumulation.

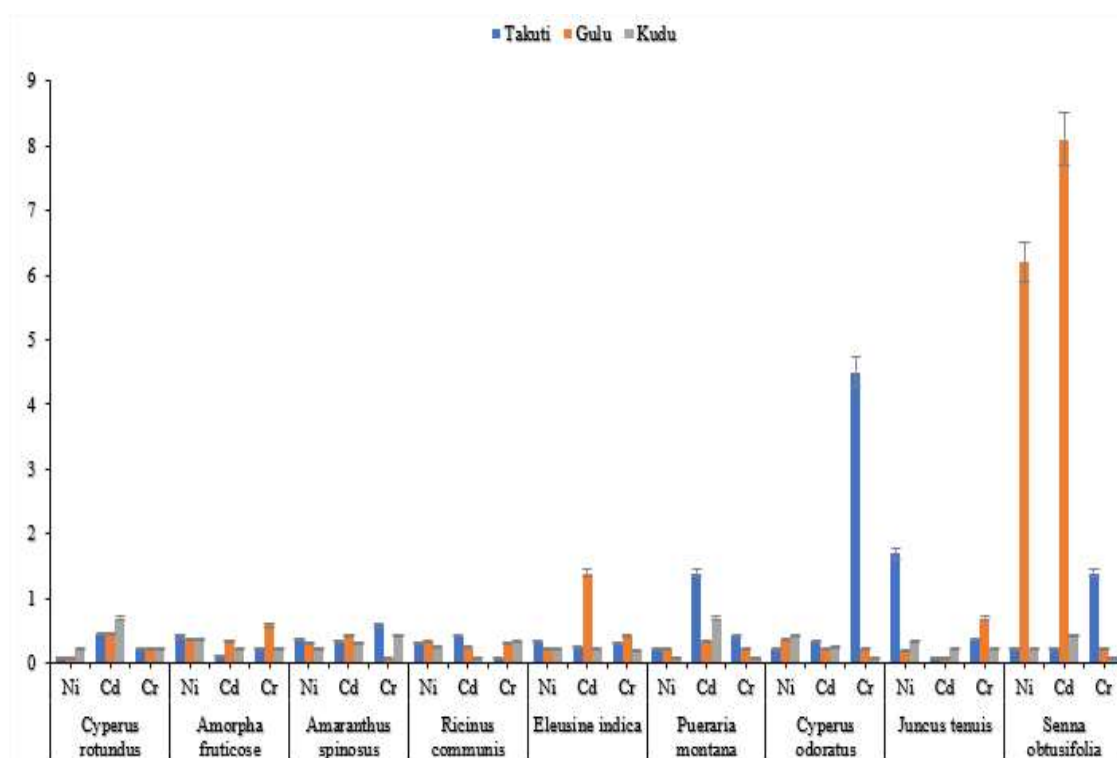


Fig. 1: preliminary concentration of heavy metals in the selected plants of the study area.

Preliminary Concentration of Heavy Metals in the Soil of the Study Area: Figure 2 presents the data of heavy metals in the soil of the study area which was determined through laboratory analysis of soil samples collected from the three villages (Takuti, Gulu, and Takalafiya) in Lapai, Niger State, Nigeria. The soil samples were collected from the three different sites in each village, representing refuse dump sites (Soil 1), abandoned mining sites (Soil 2), and anthropogenic areas (Soil 3). The preliminary concentration of heavy metals in the soil samples collected from the three regions (Takuti, Gulu, and Takalafiya). The concentrations of Ni, Cd, and Cr are provided for each region. The results show that

Takuti village consistently exhibits the highest concentrations of Ni, Cd, and Cr across all soil samples. Specifically, the refuse dump sites in Takuti village show high concentrations of Cd (0.34 ± 0.03 mg/kg), while the abandoned mining sites show high concentrations of Ni (27.3 ± 0.6 mg/kg) and Cr (15.9 ± 0.5 mg/kg). The anthropogenic areas in Takuti village also exhibit relatively high concentrations of these heavy metals. In contrast, Gulu village consistently shows the lowest concentrations of Ni, Cd, and Cr. The refuse dump sites in Gulu village show low concentrations of Cr (10.2 ± 0.3 mg/kg), while the abandoned mining sites show low concentrations of Cd (0.18 ± 0.02 mg/kg). The

anthropogenic areas in Gulu village also exhibit relatively low concentrations of these heavy metals. Takalafiya village exhibits intermediate

concentrations of Ni, Cd, and Cr, falling between the values recorded for Takuti and Gulu villages.

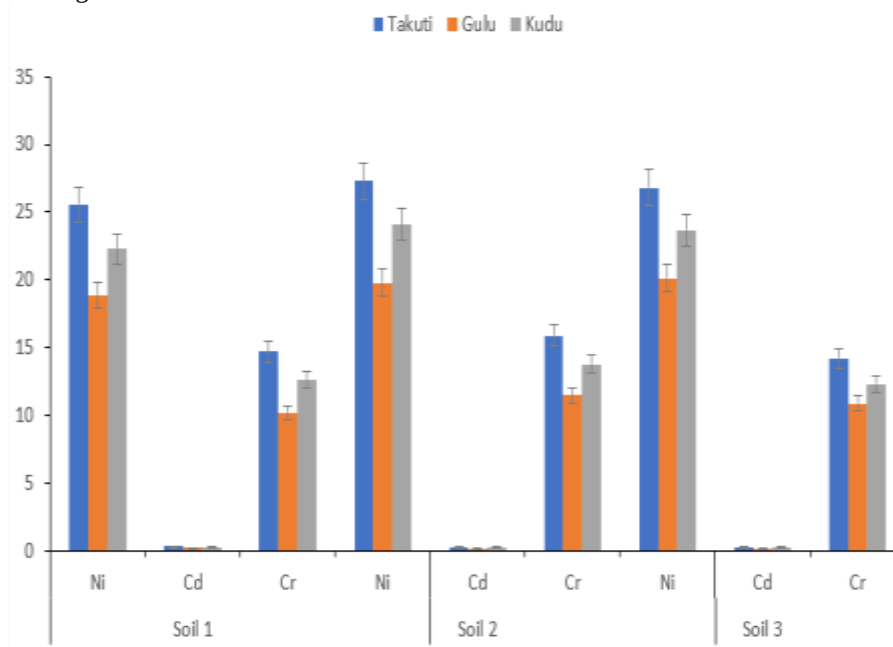


Fig. 2: Preliminary concentration of heavy metals in the soil of the study area

Assessment of Heavy Metals in the Selected Plants Post-Processing: Figure 3 represents the Assessment of Heavy Metals in the Selected Plants Post-Processing across the three regions, noticeable variations in heavy metal concentrations among different plant species and regions are observed. For Nickel (Ni), *Eleusine indica* exhibits the highest concentration in Takuti with (5.65 ± 0.99 mg/kg), *Cyperus odoratus* with 5.55 ± 0.97 mg/kg in Gulu, and *Juncus tenuis* with 5.34 ± 0.94 mg/kg in Takalafiya. Conversely, *Pueraria montana* records the lowest Ni concentration with 0.43 ± 0.08 mg/kg in Takuti, *Juncus tenuis* with 0.23 ± 0.04 mg/kg in Gulu, and 1.84 ± 0.32 mg/kg for *Ricinus communis* in Takalafiya. Similar trends are observed for Cadmium (Cd) and Chromium (Cr) concentrations. In Takuti, *Pueraria montana* records the highest Cd concentration (5.45 ± 0.95 mg/kg), while *Amorpha fruticosa* exhibits the lowest (1.46 ± 0.26 mg/kg). In Gulu, *Amaranthus spinosus* shows the highest Cd concentration (5.39 ± 0.94 mg/kg), while *Pueraria montana* has the lowest (1.49 ± 0.26 mg/kg). In Takalafiya, *Ricinus communis* exhibits the highest Cd concentration (5.44 ± 0.95 mg/kg), while *Cyperus rotundus* shows the lowest (0.68 ± 0.12 mg/kg). For Cr, *Juncus tenuis* records the highest concentration in Takuti with (5.64 ± 0.99 mg/kg), while *Ricinus communis* exhibits the lowest with concentration of (1.65 ± 0.29 mg/kg). *Cyperus rotundus* (5.18 ± 0.91 mg/kg) records the highest Cr in Gulu while

Amaranthus spinosus shows the lowest with (0.52 ± 0.09 mg/kg) concentration, while in Takalafiya, *Eleusine indica* has the highest concentration of Cr with (5.53 ± 0.97 mg/kg) while the lowest concentration was observed in *Pueraria montana* (0.95 ± 0.17 mg/kg). These findings suggest differential accumulation of heavy metals in plant species across various regions, highlighting the need for region-specific phytoremediation strategies.

Assessment of heavy metals in the selected plants post-processing, Assessment of Heavy Metal Concentrations in Soil Post-Processing: Fig. 3 and Figure 4 represent the assessment of heavy metals in soil samples post-processing collected from the three regions: Takuti, Gulu, and Takalafiya. The results reveal distinct regional patterns in heavy metal concentrations. Takuti exhibits consistently higher concentrations of Nickel (Ni), Cadmium (Cd), and Chromium (Cr) compared to Takalafiya and Gulu. Ni concentrations varied across regions, with abandoned mining sites showing the highest values in Takuti (25.2 ± 0.4 mg/kg) and Takalafiya (23.0 ± 0.4 mg/kg), while anthropogenic areas had the highest concentration in Gulu (19.2 ± 0.3 mg/kg). Cd concentrations were highest in Takuti's refuse dump sites (0.31 ± 0.02 mg/kg) and Takalafiya's abandoned mining sites (0.30 ± 0.02 mg/kg). Cr concentrations were highest in abandoned mining sites across all regions, with Takuti showing the highest value (15.2

± 0.3 mg/kg). In contrast, Gulu consistently showed lower concentrations of Cr, with refuse dump sites having the lowest value (10.1 ± 0.3 mg/kg). These

regional variations suggest differences in soil quality and environmental pollution levels across the studied regions.

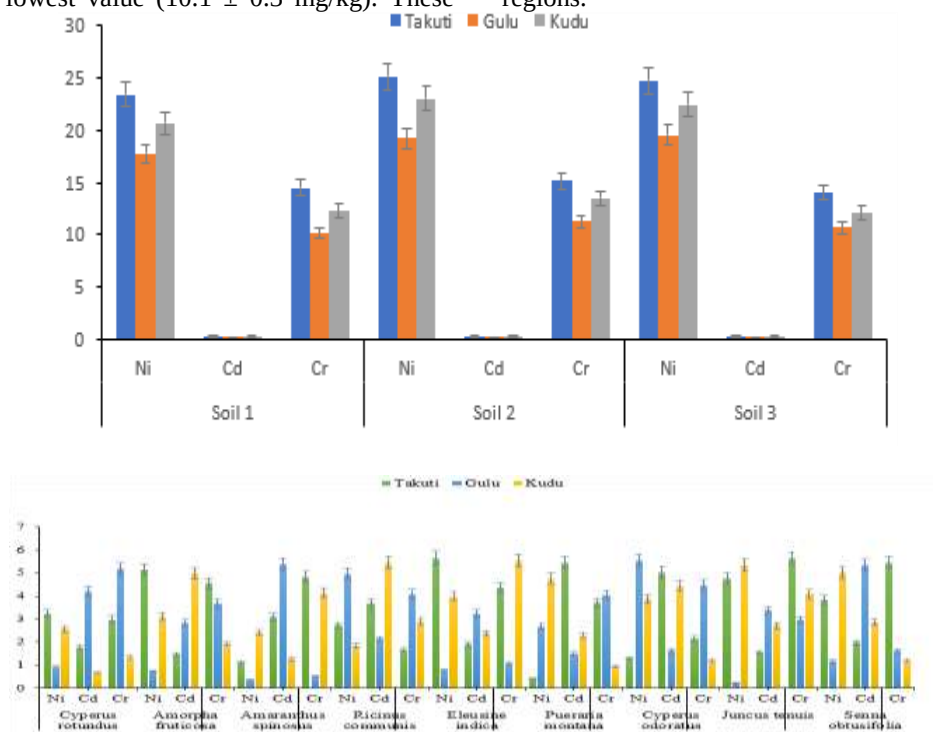


Fig. 4: assessment of heavy metal concentrations in soil post-processing

Table 4: Bioaccumulation and translocation factors of the selected plant species in the study area.

S/N	Plant Species	Heavy Metal (mg/kg)	Bioaccumulation Factor (BAF)	Translocation Factor (TF)
1	<i>Cyperus rotundus</i>	Ni	0.08	5.3
		Cd	0.41	5.69
		Cr	0.17	6.7
2	<i>Amorpha fruticosa</i>	Ni	0.11	7.25
		Cd	2.51	6.96
		Cr	0.17	6.48
3	<i>Amaranthus spinosus</i>	Ni	0.05	4.37
		Cd	2.69	8.31
		Cr	0.15	6.93
4	<i>Ricinus communis</i>	Ni	0.08	10.63
		Cd	1.39	8
		Cr	0.13	7.11
5	<i>Eleusine indica</i>	Ni	0.1	7.16
		Cd	1.22	8.14
		Cr	1.19	6.97
6	<i>Pueraria montana</i>	Ni	0.28	4.9
		Cd	2.58	5.57
		Cr	0.17	6.3
7	<i>Cyperus odoratus</i>	Ni	0.29	6.07
		Cd	2.47	6.81
		Cr	0.25	7.8
8	<i>Juncus tenuis</i>	Ni	0.09	9.11
		Cd	2.91	5.2
		Cr	0.26	8.25
9	<i>Senna obtusifolia</i>	Ni	0.12	7.87
		Cd	4.87	8.5
		Cr	0.11	6.96

Bioaccumulation and Translocation Factors of the selected plant species in the study area: The table presents the bioaccumulation factor (BAF) and translocation factor (TF) of the selected plant species in the study area for Nickel (Ni), Cadmium (Cd), and Chromium (Cr). Among the plant species studied, *Senna obtusifolia* exhibits the highest bioaccumulation factor for Cd at 4.87 mg/kg, indicating its strong ability to accumulate Cd in its tissues while *Cyperus rotundus* exhibits the lowest bioaccumulation factor at 0.41 mg/kg. For Ni, *Cyperus odoratus* shows the highest bioaccumulation factor at 0.29 mg/kg while *Amaranthus spinosus* shows the lowest with 0.05 mg/kg. Regarding Cr, *Eleusine indica* displays the highest bioaccumulation factor at 1.19 mg/kg while *Senna obtusifolia* displays the lowest with 0.11 mg/kg. In terms of translocation factor, *Ricinus communis* demonstrates the highest translocation factor for Ni at 10.63 mg/kg, indicating its capacity to translocate Ni from roots to above-ground tissues efficiently while *Amaranthus spinosus* demonstrates the lowest with 4.37 mg/kg. For Cd, *Senna obtusifolia* displays the highest translocation factor at 8.5 mg/kg while *Juncus tenuis* displays the lowest at 5.2 mg/kg. *Juncus tenuis* exhibits the highest translocation factor for Cr at 8.25 mg/kg while *Pueraria montana* displays the lowest at 6.3 mg/kg. These factors provide insights into the ability of different plant species to uptake and translocate heavy metals, which is crucial for understanding their role in phytoremediation and environmental management strategies. The extent of heavy metals accumulation in the shoots and roots varied with the type of heavy metals and plant species. The concentrations of Ni and Cr in plant shoots, roots and soils except for Cd in *Cyperus rotundus* in Takalafiya were higher than the standard references (Stewart, 1989). Heavy metals in plants vary with the plant species (Mganga *et al.*, 2011; Nkansah and Belford, 2017), and their accumulations depend on the climatic conditions and soil characteristics (Bankole *et al.*, 2024; Mganga, 2014). The levels of heavy metals for most plant species in the present study exceeded the optima for Ni, Cd and Cr (Stewart, 1989). These findings provide an indication that consumption of plants or parts of plants with higher levels of Ni, Cd, and Cr by the primary consumers (herbivores) for a long period could lead to exposure through bioaccumulation/biomagnification in omnivores and carnivores such as humans which may pose health risks. These findings corroborated with those of Conesa *et al.* (2006) who found that total concentrations of Pb, Cu and Zn in mine tailings were above the threshold. Wong (2003) argued that the presence of higher concentration of Pb in the metalliferous soils may restrict the growth of all but

the most tolerant plant species. Generally, based on the results presented in this study the extent of heavy metal accumulation in the shoots and roots varied with the type of heavy metals and plant species (Mganga *et al.*, 2011; Nkansah and Belford, 2017). Their accumulations depend on the climatic conditions and soil characteristics (Bankole *et al.*, 2024; Mganga, 2014). Some plants accumulate heavy metals and others exclude heavy metals. Based on the criteria for accumulating heavy metals in the above ground part, in Takuti, Ni was highly accumulated by *Cyperus rotundus*, *Amorpha fruticose*, *Eleusine indica*, *Juncus tenuis*. The accumulation of Cd was higher in *Cyperus rotundus*, *Amorpha fruticose*, *Amaranthus spinosus*, *Ricinus communis*, *Eleusine indica*, *Pueraria montana*, *Cyperus odoratus*, *Juncus tenuis* and *Senna obtusifolia* than the standard threshold while Cr was higher accumulated by *Cyperus rotundus*, *Amorpha fruticose*, *Amaranthus spinosus*, *Ricinus communis*, *Eleusine indica*, *Pueraria montana*, *Cyperus odoratus*, *Juncus tenuis* and *Senna obtusifolia* compared to the preliminary study carried out on them likewise that of Gulu and Takalafiya respectively. The process of removing heavy metals from soils and accumulating them in the plant generally requires the bioaccumulation and translocation of heavy metals to easily harvestable plant parts. The studied heavy metals i.e., Ni, Cd and Cr recorded both BAF and TF > 1 in some species including *Amorpha fruticose* (Cd), *Amaranthus spinosus* (Cd), *Ricinus communis* (Cd), *Eleusine indica* (Cd and Cr), *Pueraria montana* (Cd), *Cyperus odoratus* (Cd), *Juncus tenuis* (Cd) and *Senna obtusifolia* (Cd). This implies that these species effectively accumulated and transferred heavy metals from the soil to the above ground parts. The higher BAF implies that anthropogenic activities in mining areas play a substantial role in the dynamics of heavy metals (Dolezalova *et al.*, 2015). Metal accumulation is characterized by effective metal transfer from roots to shoots, as measured by a translocation factor larger than one (TF > 1). Plant species with TF > 1 are regarded as good phytotranslocators. *Ricinus communis* is the best phytotranslocator for Ni, while *Senna obtusifolia* and *Juncus tenuis* are the best phytotranslocators for Cd and Cr among others. According to Nkansah and Belford (2017), plants with a BAF value greater than one (BAF>1) are suitable for phytoextraction or phytoaccumulation. *Senna obtusifolia* is the best phytoaccumulator of Cd while *Eleusine indica* for Cr into the roots and restricts their transport to the aerial portions. Further, the overall observation is that *Amorpha fruticose*, *Amaranthus spinosus*, *Ricinus communis*, *Eleusine indica*, *Pueraria montana*, *Cyperus odoratus*, *Juncus tenuis* and *Senna obtusifolia* are efficient

bioaccumulators of Cd. In this study, *Amorpha fruticose*, *Amaranthus spinosus*, *Ricinus communis*, *Pueraria montana*, *Cyperus odoratus*, *Juncus tenuis* and *Senna obtusifolia* was classified as a bioaccumulator for Cd. In Nigeria, Bankole *et al.*, (2024) reported that *Sporobolus pyramidalis* is one of the species showing a high level of metal tolerance to Cd and Ni. Similarly, in Australia, Nirola *et al.* (2015) suggested that *Sporobolus pyramidalis* can decontaminate soils polluted with Cd and Ni metals. A study conducted by Mkumbo and Gunno (2014) found the highest TF (4) of *Sporobolus pyramidalis* for Cd and indicated it to be a good plant for phytoremediation of Cd contaminated soils. Mkumbo and Gunno (2014) stretched that *Sporobolus pyramidalis* is a bioaccumulator of Cd. The findings of the present study contradict with those of Petelka *et al.* (2019) and Mganga (2014), that *Sporobolus pyramidalis* had a smaller bioaccumulation index for Cd and Cr hence is not preferred for phytoremediating soils contaminated with these metals. Sangu (2014) reported that *Sporobolus pyramidalis* is a bioaccumulator of Cd in the metalliferous soils, thus can be used to phytoremediate Cd contaminated soils. The present study also classified *Eleusine indica* as a potential plant for bioaccumulating Cr hence can potentially be used for phytoremediation of the soils contaminated with Cr. The findings are in line with those of a study conducted by Leteinteinturier *et al.* (2001) in the Central Province of Zambia, who identified *Melinis repens* to be one of the 39 species recommended for phytoremediation of heavy metal contaminated soils. In this study, *Ricinus communis* accumulated higher quantities of Ni hence this plant species is potential for phytoremediation of soils contaminated with Ni. This is supported by the study of Midhat *et al.*, (2019) who found that *Leucaena leucocephala* recorded a bioaccumulation factor greater than one for Cr, Mn and Ni. The study conducted by Freitas *et al.* (2004) indicated that the use of legumes in mine restoration could enrich soil nutrients, and the combined use of perennials and annuals can provide substantial inputs in terms of organic matter and nutrient recycling. Moreover, *Amaranthus spinosus* can be used to extract Cd contaminated soil hence a bio accumulator of Cd.

Conclusion: The findings of our study indicated that the studied plants are bio accumulators as evidenced from the levels of heavy metals, BAF and TF values. In this case, *Amorpha fruticose*, *Amaranthus spinosus*, *Ricinus communis*, *Eleusine indica*, *Pueraria montana*, *Cyperus odoratus*, *Juncus tenuis* and *Senna obtusifolia* are bioaccumulators of Cd while *Eleusine indica* is a bioaccumulator of Cr. This

study also provides an insight of plant species that are excluders of some heavy metals, Ni excluder was *Amaranthus spinosus*, *Pueraria montana*, and *Cyperus odoratus*. Cd excluders were *Juncus tenuis* and *Senna obtusifolia*, and Cr excluder was *Cyperus odoratus*. This study findings suggests a need for urgent attention to extend solutions to the problems of exposed contaminated sites. This needs to be accompanied with regular inspections and monitoring of heavy metals in soils and plant tissues to prevent excessive build-up of these metals in the food chain.

DECLARATIONS

Ethical Approval: This study did not involve human participants or animal experimentation and therefore did not require formal ethical approval. All procedures involving data handling and analysis were conducted responsibly and in accordance with standard academic and institutional guidelines.

Disclaimer (Artificial Intelligence): Author(s) hereby declare that no generative Artificial Intelligence (AI) technologies such as Large Language Models (ChatGPT, COPILOT, XLNet, Ernie 3.0 Titan etc) and text- to-image generators have been used during writing or editing of this manuscript.

Declaration of Conflict of Interest: The authors declare that no known conflict of interest or personal relationships that have influence the work reported in this paper.

Declaration of Data Availability: Data are available upon request from the corresponding Author.

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