


# Assessment of native plants for phytoremediation of heavy metals in artisanal gold mining areas in Mbeya Region, Tanzania

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## ABSTRACT

Artisanal and small-scale gold mining (ASGM) in Tanzania is an important sector, employing over 1.5 million people. Despite the profound benefits, the activity is associated with environmental contamination by the release of heavy metals, which affects soil quality and public health. Therefore, this study was conducted to assess the potential of locally adapted plants to remove heavy metals in contaminated soils around the Lupa Goldfield, Chunya District, in the Mbeya region. A total of 50 soil samples and 19 plant species were collected from mining tailings at depths of 0–200 m across five villages (Chokaa, Makongolosi, Itumbi, Matundasi, and Mbugani). Atomic absorption spectroscopy (AAS) was used to quantify the concentrations of Pb, Hg, Cd, As, and Zn in both soil and plant samples. Plant specimens were identified and deposited in the NM-AIST Herbarium for reference. Mean soil concentrations at the tailing heaps were  $40.73 \pm 0.5 \text{ mg kg}^{-1}$  for Pb,  $3.17 \pm 0.14 \text{ mg kg}^{-1}$  for Hg,  $4.36 \pm 0.25 \text{ mg kg}^{-1}$  for Cd,  $1.69 \pm 0.02 \text{ mg kg}^{-1}$  for As and  $24.9 \pm 0.54 \text{ mg kg}^{-1}$  for Zn declining sharply to  $17.48 \pm 0.64 \text{ mg kg}^{-1}$  (Pb),  $1.03 \pm 0.23 \text{ mg kg}^{-1}$  (Hg), and  $0.16 \pm 0.05 \text{ mg kg}^{-1}$  (Cd),  $0.27 \pm 0.01 \text{ mg kg}^{-1}$  (As) and  $5.99 \pm 0.54 \text{ mg kg}^{-1}$  (Zn) at 200 m ( $p < 0.05$ ), confirming significant point-source pollution. The highest concentrations of heavy metals were recorded in the following plant species: Pb =  $1.71 \text{ mg kg}^{-1}$  in *Urochloa mutica*, (Hg =  $1.38 \pm 0.2 \text{ mg kg}^{-1}$ ) in *Schonocleptus corymbosus*, (Cd =  $1.05 \pm 0.05 \text{ mg kg}^{-1}$ ) in *Bauhinia petersiana*, (As =  $0.9 \pm 0.01 \text{ mg kg}^{-1}$ ) in *U. mutica* and Zn =  $4.2 \pm 0.2 \text{ mg kg}^{-1}$  in *U. trichopus*. On remediation potential, *U. mutica*, *B. petersiana*, *Cyperus rotundus*, *Cariniana estrellensis* and *Cymbopogon giganteus* (BAF > 1 and TF > 1) were identified as potential remediators for As. while *B. petersiana*, *C. giganteus* and *Terminalia sambesiasca* (BAF > 1 and TF > 1) were found to be good remediators for Cd. *Schoenocleptus corymbosus* (BAF > 1 and TF > 1) was found to be a good remediator for Hg. These findings provide a quantitative basis for integrating the identified plant species into low-cost ecological restoration strategies in ASGM-impacted landscapes in the Lupa gold field.

**Keywords:** bioaccumulation factor, translocation factor, heavy metals, artisanal gold mining, native plants, accumulators, Tanzania.

## INTRODUCTION

Artisanal and small-scale gold mining (ASGM) is a significant economic activity practised worldwide. In Sub-Saharan Africa, this practice is widespread, leading to significant pollution of soils, water, and living things (Kahangwa et al., 2021). Chemical composition of the metal ore and chemical ore processing are the

principal sources of heavy metals concentration in the ASGM (Chen et al., 2023; Moulatlet et al., 2025). Accumulation of heavy metals in plants or water tends to induce risks to humans and the entire ecosystem due to their toxicity. Heavy metals commonly associated with ASGM activities include chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), cadmium (Cd), and manganese (Mn) (Nali, 2001; Nyakuwanika and Panicker, 2025). In East

Africa, there has been a complexity in implementing phytoremediation strategies because the distribution of heavy metals is not well mapped (Li et al., 2023; Xu et al., 2024).

According to Sharma et al. (2023), Wang et al. (2022), and Xu et al. (2024), various conventional methods for the remediation of heavy metals from the contaminated environment exist; these include but are not limited to solid fraction, chemical stabilization and washing. Nevertheless, these techniques are associated with limited effectiveness and safety to the environment. Majorly, physical remediation methods are typically expensive, require high expertise and equipment needs, while transporting contaminated soil raises secondary contamination risks and complicates the disposal of polluted materials (Wang et al., 2022).

For the remediation methods to be adopted in ASGM, they should consider the availability of resources (funds and expertise) and the call for environmental conservation (Sharma et al., 2023). Phytoremediation is a promising approach, where plants are employed in the removal of heavy metals from ASGM through mechanisms such as immobilization, stabilization and conversion of metals into harmless compounds in the environment (Kafle et al., 2022; Sharma et al., 2023; Khan et al., 2023). Plants are naturally adapted to heavy metal-polluted environments and offer remedies to climate assessors (Kafle et al., 2022). Several factors affect the effectiveness of phytoremediation, such as the capacity of the plant for accumulation, site of translocation (roots or shoots), survival rate, biomass yield and tolerance capacity (Sharma et al., 2023). When selecting suitable plants for remediation, exceptionally high-capacity plants to accumulate heavy metals and the ability to tolerate and survive under extreme conditions are selected (Abid et al., 2025). Another factor is consideration for plants with the capacity to ensure normal growth and physiological functionality while under contaminated environments (Hosman, 2017). Elevated levels of heavy metals in Tanzania have been revealed by several studies, with the highest concentration reported near the tailing sites from Geita, North Mara, and Golden Pride (Kahangwa et al., 2021; Mganga et al., 2014). Nevertheless, there is inadequate information on the phytoremediation potential of native plant species in Tanzania, and especially in the Lupa Goldfield, where such information is not published. (Kahangwa et al., 2021; Mganga et al., 2014).

This study sought to bridge the existing knowledge gap by investigating the potential of native plant species for phytoremediation of heavy metal pollution in ASGM, using Chunya District as a case study.

## METHODOLOGY

### Study area

The study was carried out in Lupa Goldfield, located in Chunya District, Mbeya region, lying on coordinates 8° 43' 5.65" S, 33° 16' 57.91" E. The site is located in the south-west of Tanzania; it has a historical record of ASGM, which is associated with heavy metals environmental pollution and degradation. The sites were specifically selected from the active and abandoned artisanal mining tailings and the neighbouring environment. The site is experiencing a semi-arid climate with seasonal rainfall and vegetation, especially the miombo woodland, maize and grassland, together with native plant species embanked in shrubs. The location map for the case study area, with specific selected locations, is shown in Figure 1.

### Soil and native plant species sampling

Soil sampling followed the USEPA (1996) protocol, combining cluster and simple random sampling. Five villages, Chokaa, Matundasi, Makongolosi, Itumbi, and Mbuga served as clusters. Within each village, two sites were selected by simple random sampling. At each site, soil samples were collected along a transect at the following distances from the tailing heap: 0 m (at the heap), 50 m, 100 m, 150 m, and 200 m. For each point, a 20 × 20 cm plot was established, and six subsamples were taken from the 0–30 cm depth using a soil auger; these subsamples were combined to form a single composite sample. This process produced five composite samples per site. In each plot, at least three representative native plant species were also collected. Additionally, a negative control point located 6 km from the tailing heap was sampled for both soil and plants to provide a baseline for comparison.

### Soil and plant sample preparation

Soil samples preparation: Initially, soil air drying was done at room temperature for 72

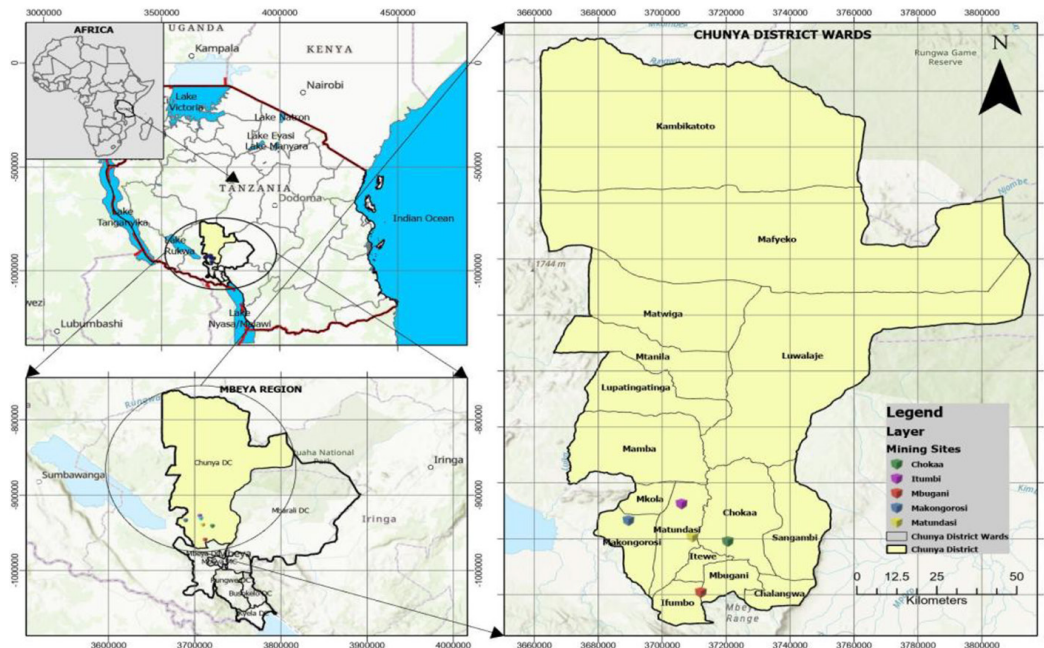


Figure 1. A map showing the location of the case study area

hours to eliminate their natural moisture while preserving their natural properties. A mortar and pestle were used to dry the dried samples to achieve a uniform texture, then sieved through a 2 mm mesh filter to ensure consistency (Tan, 2005). The samples that were processed were subsequently stored in pre-cleaned, acid-washed polyethene containers until the digestion phase. Plant samples were thoroughly rinsed with distilled water to remove surface contaminants. The samples were then air-dried before being oven-dried at a temperature of 60 °C to remove any remaining moisture while retaining volatile compounds in the plant samples (Anawar et al., 2011). Once fully dried, the samples were ground into a fine powder using a mechanical grinder to ensure homogeneity (Gong et al., 2020).

#### Determination of soil pH and electrical conductivity

Soil pH and EC were determined using the Bruckner (2012) protocol, in which a 1:2.5 ratio of air-dried soil to de-ionised water was added to a 50 mL beaker and shaken for 30 minutes. After the suspension was left to settle, an EC meter and a pH meter were used to quantify EC and pH, respectively. After every 25 EC and pH readings, the electrode was rinsed using distilled water to maximize the accuracy.

#### Heavy metal quantification in soils and in plant species from the study site

The soil and plant samples were digested using acids in accordance with the protocol by the US EPA (1996). For each sample, 10 g was added to a 250 mL conical flask, then 10 mL concentrated  $\text{HNO}_3$  were added, and then the mixture was heated for 15 minutes at 100 °C, then cooled. The addition of 5 ml of concentrated HCL was done, followed by 30 minutes of reheating until brown fumes ceased. When the mixture cooled, 3 ml of  $\text{H}_2\text{O}_2$  was added to oxidize remaining organics (an extra 1 ml of  $\text{H}_2\text{O}_2$  was used if effervescence continued). Finally, the addition of 10 mL of ml concentrated HCl was done before heating the mixture for 5 minutes. The digest was filtered, then water was added to make up 100 ml, which was then stored in an acid-washed apparatus. An Atomic Absorption Spectrophotometer (AAS) was then used to quantify the heavy metal concentrations in the soil and plant samples.

#### Data analysis

Heavy metal concentration in both soil and plant samples was determined by analysing using R software, and the mean concentrations were separated using Tukey's Test. The criterion by Baker et al. (2000), which uses the bioaccumulation factor (BAF), was used to categorize the accumulator plants. Bioaccumulation factor means

the quantity of heavy metals that is bioaccumulated in tissues in proportion to the amount present in the soil. Therefore, this study determined the BAF based on the ratio of metal concentration in native plant species tissue (shoot and root) to the concentrations of metal in soil (Eq. 1). Bioaccumulation Factor can also indicate the plant’s ability to accumulate toxic elements.

$$BAF = \frac{\text{Concentration of metal in plant}}{\text{Concentration of metal in soil}} \quad (1)$$

The translocation factor is used to assess the transfer of heavy metals from the roots to the above-ground parts, thereby accounting for their removal from soils. The TF is calculated as the ratio of heavy metal concentration in the plant shoot to that in the root (Usman et al. 2012), as shown in (Eq. 2).

$$TF = \frac{\text{Concentration of metal in shoot}}{\text{Concentration of metal in root}} \quad (2)$$

## RESULTS AND DISCUSSION

### Soil pH and electrical conductivity

A considerable reduction in soil pH and EC with an increase in the spatial distance from the tailing source to 200 m was recorded for all

villages and sites. i.e. Soil pH for the study area ranged from Alkaline (above 7.5) at the tailing sources to strongly acidic (5.5–4.5) at 200 m. While the soil EC ranged from Saline soils (above 2 dS/m) at the tailing source to non-saline (below 2 dS/m) at 200 m from the tailing source (Table 1).

Soil chemical properties varied with distance from tailings and between sites: pH 5.2–8.3 (strongly acidic to alkaline) and EC 1–2850  $\mu\text{S cm}^{-1}$ . pH was highest at tailing points (0 m), notably Chokaa 8.3, Matundasi 8.2, Makongolosi 8.0, Mbugani 8.0, then declined toward neutral/acidic values with distance, approaching the negative-control pH 5.2. For example, Itumbi fell from pH 7.8 at 0 m to 6.4 at 200 m (Site 1) and from 6.1 to 5.7 (Site 2). Higher pH near tailings suggests alkaline influence from mining residues; the influence weakens with distance.

Soil pH strongly affects heavy-metal mobility, solubility, and bioavailability: alkaline soils tend to reduce solubility (e.g., Pb may precipitate or adsorb), while acidic soils increase solubility and plant uptake. Thus, metals are likely less mobile near tailings and more available in slightly acidic soils further away, consistent with other studies.

EC showed the same spatial pattern, highest at 0 m, especially Makongolosi (2801 and 2850

**Table 1.** Soil pH and soil EC

Parameter	Distance	Site 1				Site 2			
	(m)	Soil pH	Rating	EC ( $\mu\text{Scm}^{-1}$ )	Rating	Soil pH	Rating	EC ( $\mu\text{Scm}^{-1}$ )	Rating
Itumbi	0	7.8±0.6	Alkaline	930±51	NS	6.1±0.6	Acidic	950±1	NS
	100	6.9±0.5	Neutral	31±1	NS	6.0±0.5	Acidic	34±1	NS
	200	6.4±0.5	Acidic	24±1	NS	5.7±0.5	Acidic	25±1	NS
	-Ve control	5.2±0.6	Strongly Acidic	1±0.5	NS	5.2±0.6	Strongly acidic	1±0.5	NS
Makongolosi	0	8.0±0.5	Alkaline	2801±1	S	7.6±0.5	Alkaline	2850±1	S
	100	6.4±0.5	Acidic	20±1	NS	6.7±1.0	Neutral	28±1	NS
	200	6.0±0.5	Acidic	2±1	NS	5.9±1.0	Acidic	3.5±1	NS
	-Ve control	5.2±0.6	Strongly Acidic	1±0.5	NS	5.2±0.6	Strongly acidic	1±0.5	NS
Mbugani	0	8.0±0.5	Alkaline	140±1	S	7.5±0.5	Alkaline	300±0.1	NS
	100	7.0±0.5	Neutral	3±1	NS	6.6±0.5	Neutral	7±1.0	NS
	200	6.0±0.5	Acidic	3±1	NS	6.0±0.5	Acidic	6±1.0	NS
	-Ve control	5.2±0.6	Strongly Acidic	1±0.5	NS	5.2±0.6	Strongly acidic	1±0.5	NS
Chokaa	0	8.3±0.5	Alkaline	1056±1	NS	7.4±0.5	Alkaline	1200±1	NS
	100	6.8±0.5	Neutral	41±1	NS	6.6±0.5	Neutral	39±1	NS
	200	6.5±0.5	Acidic	28±1	NS	6.0±0.5	Acidic	26±1	NS
	-Ve control	5.2±0.6	Strongly Acidic	1±0.5	NS	5.2±0.6	Strongly acidic	1±0.5	NS
Matundasi	0	8.2±0.5	Alkaline	77±1	NS	7.4±0.5	Neutral	130±1	NS
	100	8.0±0.5	Alkaline	36±1	NS	6.6±0.5	Neutral	47±1	NS
	200	6.0±0.5	Acidic	25±1	NS	6.0±0.5	Acidic	22±1	NS
	-Ve control	5.2±0.6	Strongly Acidic	1±0.5	NS	5.2±0.57	Strongly acidic	1±0.5	NS

**Note:** pH – power of hydrogen ions in soil, EC – electrical conductivity, S – saline, NS – non-saline. Parameters are rated according to Landon (2014).

$\mu\text{S cm}^{-1}$  at Sites 1 and 2), indicating accumulation of soluble salts from mining residues and declining toward background values ( $\approx 1 \mu\text{S cm}^{-1}$ ) by 200 m. In Itumbi, EC dropped from 930  $\mu\text{S cm}^{-1}$  at 0 m to 24  $\mu\text{S cm}^{-1}$  at 200 m, confirming mining impacts are localised. Elevated EC from dissolved minerals increases salinity, alters soil structure, and affects ionic interactions that influence metal mobility and plant uptake.

These pH–EC gradients have implications for phytoremediation: species selection must match local soil conditions because metal bioavailability varies with pH and EC; indigenous species adapted to local soils are preferable. Chemical reagents used in gold processing and ore composition contribute to high pH and EC on tailings (Nordstrom et al., 2015). Under high pH and EC, dissolved salts facilitate ion exchange and desorption, allowing metals such as Hg, Zn, Cd, and Pb to dissolve into water (Nungula et al., 2024). Conversely, at low pH, metals are adsorbed on soil particles, limiting mobility (Ngugi et al., 2022). For example, Pb declined from 36  $\text{mg kg}^{-1}$  at pH 8 and EC  $\sim 2800 \mu\text{S cm}^{-1}$  to 24  $\text{mg kg}^{-1}$  at 200 m, where pH  $\approx 6$  and EC  $\approx 2 \mu\text{S cm}^{-1}$  in Makongolosi Site 1, showing that downfield metal migration is impeded by immobilization. Water percolation and leaching reduce EC to  $< 40 \mu\text{S cm}^{-1}$  at 200 m while pH falls to  $\sim 5.5$ – $6.5$ ; under these conditions, metals adsorb onto clay and Fe/Mn oxides, lowering dissolved concentrations. Therefore, the observed decrease in heavy metals with distance from tailings is explained by immobilization and reduced mobility due to changing pH and EC.

### Spatial distribution of heavy metal concentrations in soils around the gold mining tailings

A decreased concentration of heavy metals was recorded with an increasing distance from the tailing source. The results indicate that, across all sites, contamination levels decreased with increasing distance from the tailing source (Figure 2–4). Phytoremediation by indigenous plants and dilution by soil layers may be factors contributing to decreasing metal concentrations. The concentration of Pb peaked at the tailing source (0 m), 40.73  $\text{mg kg}^{-1}$  and significantly declined to 17.48  $\text{mg kg}^{-1}$  (Mbugani village at 200 m). Similarly, the highest concentration of Hg was recorded at the tailing source (0 m) in Chokaa and Makongolosi village, which declined to

1.02  $\text{mg kg}^{-1}$  at 200 m from the tailing source. This inverse relationship between heavy metal concentration and distance was consistent across all metals analysed, indicating a strong point-source pollution origin from the mining tailings sites. The decrease of contamination level from the tailing source follows a specific pattern with a steep concentration gradient within the initial 100 m. For example, this study recorded a sharp decrease from the 50 m to the 100 m mark across all locations. The highest concentration of Pb, Hg and Zn was recorded among the sites Chokaa and Makongolosi, identifying them as the epicentres of contamination. While moderate levels of the similar metals were recorded from Itumbi and Matundasi sites where as the lowest concentration for all tested metals was recorded in Mbugani sites. Therefore, this study serves as evidence that ASGM activities are the primary contributor heavy metals contamination, the higher concentrations being within 0–100 m from the tailing source or mining sites which gradually decrease up 200 m and declined with distance, dropping by 4–50% at 200 m ( $p < 0.05$ ).

There is a distinct point source contamination profile where heavy metals decrease with distance from the tailing sources. This study was able to reveal a special pattern of heavy metal distribution on soils around ASGM sites. The high concentration of heavy metals within 0–100 m indicates higher deposition of metal-laden particulates from mineral ore processing sites, where this has been evidenced from other ASGM in Ghana, Kenya, and Ethiopia (Akele et al., 2016). The exceptionally high levels of Pb and Hg at proximal sites in Chokaa and Makongolosi (35  $\text{mg/kg}$  and 3  $\text{mg/kg}$ , respectively) reflect previously reported concentrations from Tanzanian and South Indian gold belts, where amalgamation and tailings disposal were the dominant contamination pathways (Adimalla and Qian, 2019). Heavy metal concentration can decline up 80% beyond 500 m, which can be attributed to dilution, adsorption and sedimentation activities (Kabata-Pendias and Pendias, 2001). Pb and Zn have strong sorption to clay and organic matter, thus tend to remain concentrated near the tailing source. According to Bose-O'Reilly et al. (2010), UNEP (2019), mercury depicted a small decline with increasing distance, due to its high mobility in the atmosphere and is deposited near amalgam-burning zones.

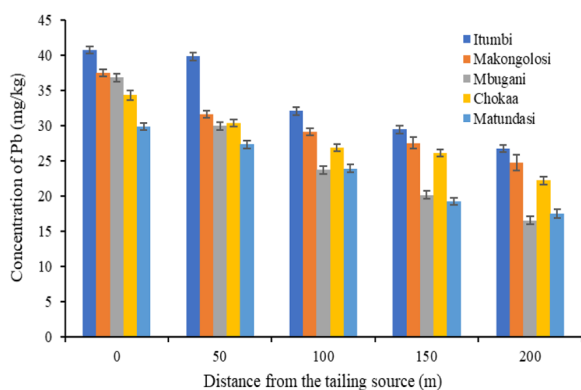


Figure 2. Silver (Pb) concentration distributed across the distance of the sites

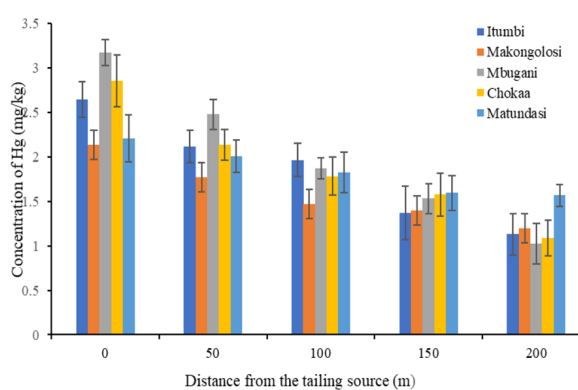


Figure 3. Mercury (Hg) concentration distributed across the distance of sites

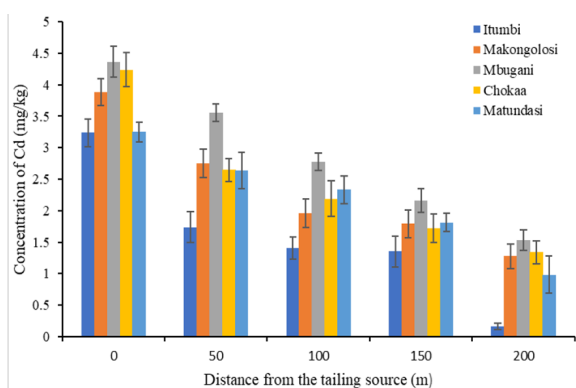


Figure 4. Cadmium (Cd) concentration distributed across the distance of the sites

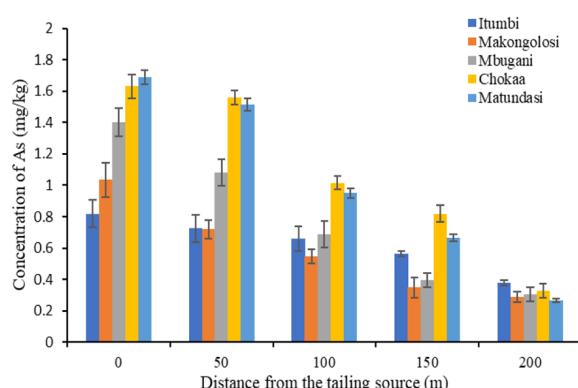


Figure 5. Arsenic (As) concentration distributed across the distance of the sites

### Accumulation of selected heavy metals in native plants from the Artisanal mining sites in Chunya District

#### Bioaccumulation of Pb in native plants

The variation in bioaccumulation factor of Pb recorded by the studied plant species revealed their differences in their ability to uptake and accumulate Pb from contaminated soils (Figure 7). The highest concentration of Pb was recorded in *Urochloa mutica*, *A. heptaphylla*, and *M. obstusifolia* (Figure 12). *Urochloa mutica*, *A. heptaphylla*, and *M. obstusifolia* demonstrate greater potential for Pb uptake from the environment and can be recommended as good candidates for phytoextraction in phytoremediation programs for Pb in mining sectors to reduce lead in contaminated soil. All the tested native plant species appear to have high Pb bioaccumulation potential, as their mean concentrations exceeded  $0.3 \text{ mg kg}^{-1}$ , which is the recommended phytotoxic threshold established by the WHO/FAO Codex Alimentarius (2001; 2007) and the USEPA Soil Screening Guidance (1996). The lowest Pb concentrations were observed in

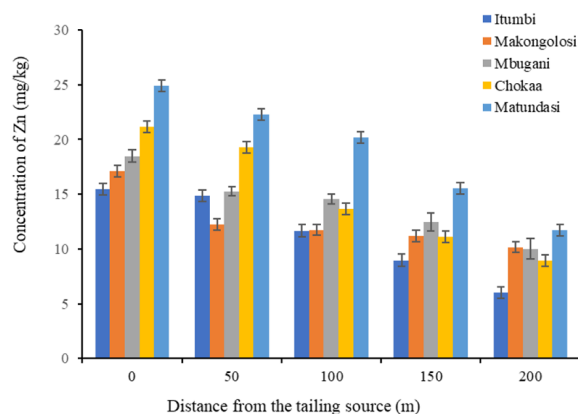


Figure 6. Zinc (Zn) concentration distributed across the distance of the sites

*Justicia flava* and *Entada abyssinica*, with values of approximately  $0.4\text{--}0.5 \text{ mg kg}^{-1}$ . These native plants seem to have poor Pb accumulation ability, which may indicate metal exclusion mechanisms that prevent heavy metal uptake.

#### Accumulation of mercury in native plants

The results indicate that mercury accumulation among plant species varies considerably,

demonstrating differences in the bioaccumulation potential (Figure 8). The highest Hg concentration was observed in *S. corymbosus*, with approximately 1.35–1.40 mg kg<sup>-1</sup>, indicating a significantly higher Hg accumulation compared to other species. The lowest concentration of Hg was recorded by *T. sambesiaca* (0.3 mg/kg), indicating that this plant species may possess metal exclusion mechanisms that limit Hg uptake from the soils (Figure 8).

**Accumulation of Cd in native plants**

The results reveal that *B. petersiana* recorded the highest cadmium concentration (Figure 9), indicating that the Cd concentration in this native plant species is significantly higher compared with all the other plant species analyzed in this study (Figure 9). This suggests that *B. petersiana* has a relatively strong ability to bioaccumulate Cd

from the environment (Figure 9). *Dichrostachys cinerea*, *S.corymbosus*, *M. obsitufolia*, *A. heptaphylla*, *C. molle*, *C. rotundus*, *C. glutinosum*, *D. altissima*, *E. abyssinica*, *B. disticha*, *U. mutica*, *V. depanorobium*, *J. flava* and *C. giganteus* recorded the lowest Cd concentration. In general, the results show that Cd accumulation differed significantly among the native plant species, with *B. petersiana* showing the highest accumulation potential, while most other species showed relatively similar Cd accumulation.

**Accumulation of As in native plant species**

The results indicate that *U. mutica* recorded significantly higher As concentration compared with all other native plant species in the study, suggesting that this species has exceptionally good potential to uptake As from the environment compared to the other native plant species. It was

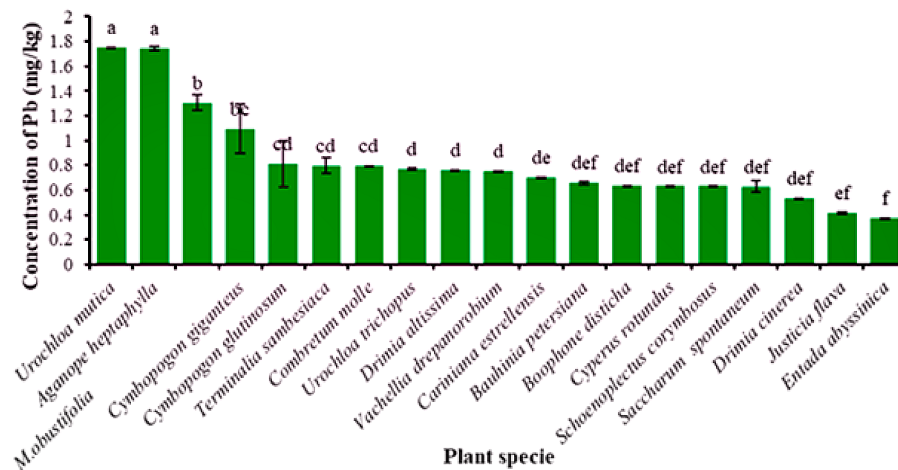


Figure 7. Concentration of Pb in the collected native species

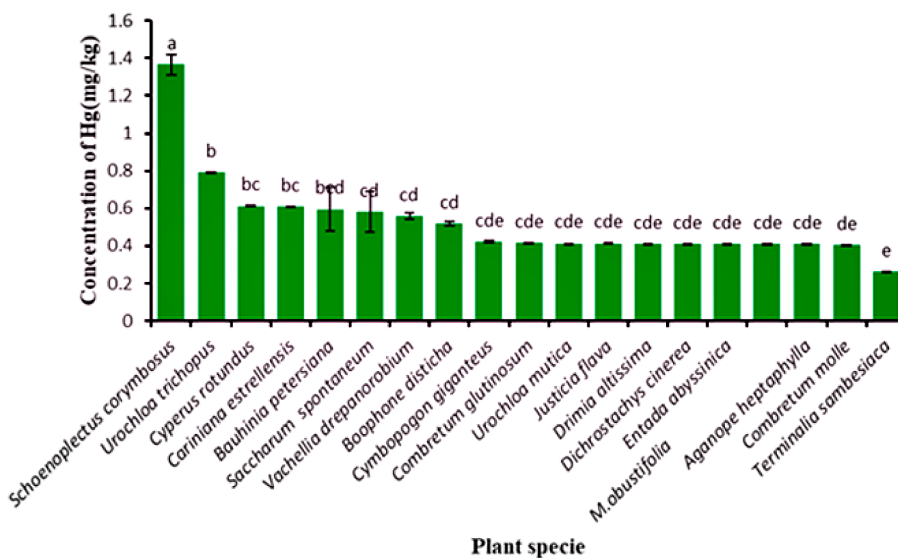


Figure 8. Concentration of Hg in collected native plant species

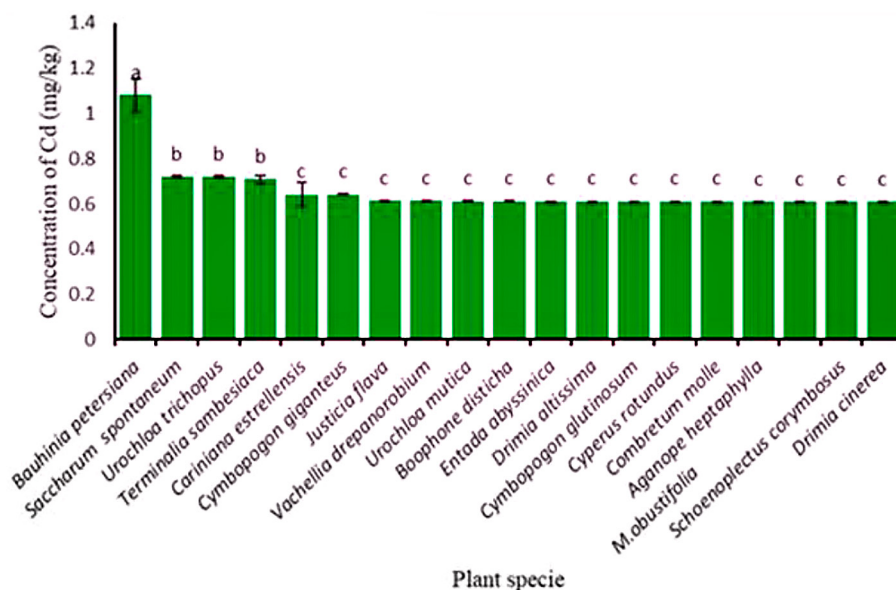


Figure 9. Concentration of Cd in collected native plant species

followed by *B. petersiana*, indicating that its concentration is significantly lower than that of *U. mutica* but still higher than most of the remaining species. Overall, the results show that As accumulation varies significantly among plant species.

#### Accumulation of Zn in native plants

*Urochloa trichopus* and *S. spontaneum* recorded the highest Zn concentrations, approximately 4.1–4.2 mg/kg, indicating that these native plant species accumulated significantly higher levels of Zn compared with most of the other species in this study. The lowest Zn concentrations (2.0 mg/kg) were observed in species such as *D. cinerea*, *C. molle*, *M. obsitufolia*, *A. heptaphylla*,

*C. glutinosum*, *B. disticha*, *E. abyssinica*, and *D. altissima* (Figure 11).

#### Bioaccumulation factor and translocation factor

The results of the bioaccumulation factor (BAF) are summarised in Table 2. *Schoenoplectus corymbosus* recorded  $BAF > 1$  for Hg, which implies the plant species is a good accumulator. Furthermore, *U. mutica* and *T. sambesiaca* recorded  $BAF > 1$  for Cd, and thus were categorized as accumulators. Unlike other heavy metals, As was found to be highly bioaccumulative by several plant species, as they recorded  $BAF > 1$ .

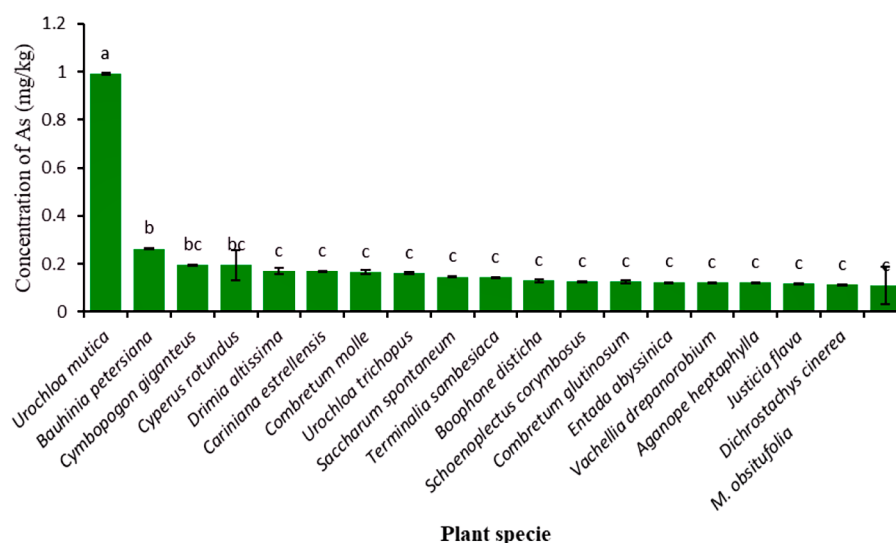


Figure 10. Concentration of As in the collected native plant species

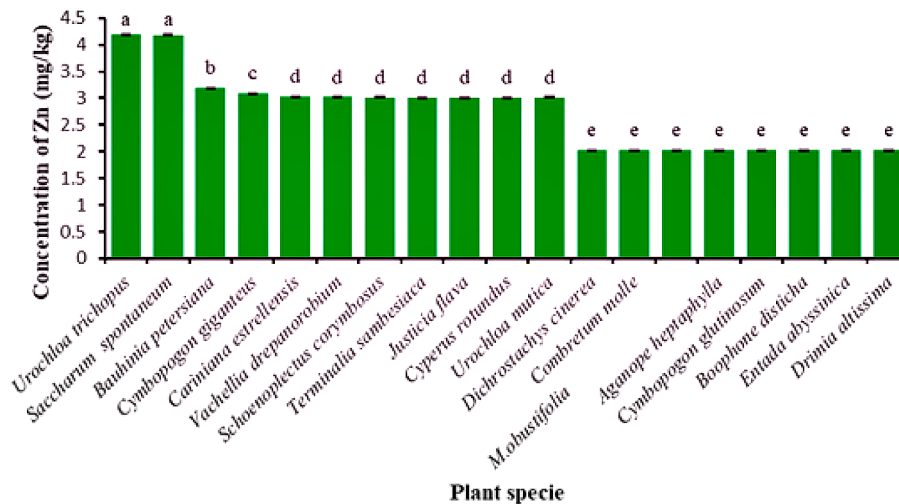


Figure 11. Concentration of Zn in collected native species

These were *U. mutica* (BAF=3.0), *S. spontaneum* (BAF=1.0), *C. giganteus* (BAF=1.3), *C. rotundus* (BAF=1.3), *C. molle* (BAF=1.1), *C. estrellensis* (BAF=1.1) and *D. altissima* (BAF=1.1), while *U. trichopus* was recorded (BAF=1.0). Furthermore, there was no individual native plant species that recorded BAF >1, indicating that the tested species maintain a low and relatively constant metal concentration in their shoots over a wide range of soil concentrations, primarily restricting metal uptake to their roots.

The same results indicated that only *U. mutica* recorded TF>1 for Pb. *Bauhinia petersiana*, *S. spontaneum*, *M. obsitufolia*, *V. drepanorobium*, *C. molle*, *U. trichopus*, *S. corymbosus* recorded TF>1 for Hg. *Bauhinia petersiana*, *M. obsitufolia*, *C. giganteus*, *T. sambesiaca*, *V. drepanorobium*, *C. molle*, *U. trichopus*, *B. disticha*, *E. abyssinica*, *S. corymbosus* and *C. glutinosum* recorded TF>1. *Urochloa mutica*, *B. petersiana*, *A. heptaphylla*, *S. sponteum*, *M. obsitufolia*, *C. giganteus*, *C. rotundus*, *C. molle*, *C. estrellensis*, *U. trichopus*, *D. altissima*, *B. disticha*, *E. abyssinica*, *S. corymbosus*, and *C. glutinosum* recorded TF>1. *Urochloa Mutica*, *S. sponteum*, *C. giganteus* recorded TF>1 for Zn (Table 2).

### Values greater than 1 are in bold font

Phytoremediation generally involves bioaccumulation of metals, which are then translocated to the harvestable plant parts. In this study, the heavy metals investigated included lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), and zinc (Zn). Among these heavy metals, Cd and As were detected in higher amounts in most of the

plant species, including *U. mutica*, *B. petersiana*, *C. rotundus*, *C. estrellensis*, *S. corymbosus* (for As), *C. giganteus*, and *B. petersiana* (for Cd). When heavy metals are concentrated in the tissues of the plants, it is confirmation that bioaccumulation and translocation have taken place.

*Urochloa mutica* was found to be an effective accumulator and translocator for arsenic (BAF >1 and TF>1). While other studies have the species as an accumulator for Pb, Cd and As (Ullah et al., 2020). The presence of nonspecific metal transporters: nodulin 26-like intrinsic proteins (NIPs), facilitates the uptake of arsenic, while phosphate transporters (PHTs) uptake As(V) due to phosphate structural similarity (Sandhu et al., 2025).

Another species recorded by this study for Cd and As accumulation and translocation (BAF > 1 and TF>1) was *B. petersiana*. According to Nofal et al. (2017) and Bha et al. (2022), the species uses two mechanisms for remediation, which are phytoextraction and phytostabilisation.

The lemon grass (*C. giganteus*) was also found to be a good candidate for remediation of Cd and As (BAF > 1 and TF>1), and it has also been recommended by other studies where its suitability is assessed using indices like the tolerance index (TI), transport index (Ti), bioaccumulation factor (BAF) (Gautam et al., 2017; Sharma et al., 2023).

The study identified *C. rotundus* as a potential accumulator of arsenic (BAF > 1 and TF>1). Its effectiveness in the removal of arsenic has been reported, depending on the sampled part of the plant, like roots, leaves, and also on the site conditions. Rohmanna et al. (2025) also revealed that the species is considered a sustainable remediator in mining-impacted sites.

**Table 2.** Bioaccumulation factor and translocation factor for the collected plant species

Plant species	Heavy metals	BAF	TF
<i>Urochloa mutica</i>	Pb	0.1	1.0
	Hg	0.4	0.9
	Cd	0.6	1.0
	As	3.0	3.6
	Zn	0.5	1.7
<i>Bauhinia petersiana</i>	Pb	0.0	0.8
	Hg	0.6	0.9
	Cd	1.3	1.4
	As	1.7	2.0
	Zn	0.5	0.7
<i>Aganope heptaphylla</i>	Pb	0.1	1.0
	Hg	0.4	0.9
	Cd	0.6	1.0
	As	0.8	1.6
	Zn	0.3	1.0
<i>Saccharum sponteum</i>	Pb	0.0	0.5
	Hg	0.6	1.4
	Cd	0.7	0.9
	As	1.0	1.1
	Zn	0.7	1.3
<i>Marhakamia obsitufolia</i>	Pb	0.0	0.6
	Hg	0.4	1.2
	Cd	0.6	1.3
	As	0.7	1.1
	Zn	0.3	0.6
<i>Cymbopogon giganteus</i>	Pb	0.0	0.8
	Hg	0.4	1.0
	Cd	1.7	1.8
	As	1.3	1.4
	Zn	0.5	1.1
<i>Cyperus rotundus</i>	Pb	0.0	0.4
	Hg	0.6	0.8
	Cd	0.6	0.9
	As	1.3	1.5
	Zn	0.3	1.0
<i>Terminalia sambesiaca</i>	Pb	0.1	1.0
	Hg	0.2	1.0
	Cd	1.4	1.6
	As	0.9	1.0
	Zn	0.5	1.0
<i>Vachellia drepanorobium</i>	Pb	0.0	0.5
	Hg	0.6	1.4
	Cd	0.6	1.4
	As	0.8	1.0
	Zn	0.5	0.8
<i>Dichrostachys cinerea</i>	Pb	0.0	0.6
	Hg	0.4	0.5
	Cd	0.6	0.6
<i>Dichrostachys cinerea</i>	As	0.8	1.0
	Zn	0.3	0.9
<i>Combretum molle</i>	Pb	0.1	1.0
	Hg	0.4	0.8
	Cd	0.6	1.1
	As	1.0	1.1
<i>Cariniana estrellensis</i>	Zn	0.3	0.7
	Pb	0.1	0.5
	Hg	0.6	0.8
	Cd	0.7	0.8
<i>Urochloa trichopus</i>	As	1.1	1.3
	Zn	0.5	1.0
	Pb	0.1	1.0
	Hg	0.8	1.2
<i>Drimia altissima</i>	Cd	0.8	1.1
	As	1.0	1.2
	Zn	0.7	1.0
	Pb	0.0	0.5
<i>Boophone disticha</i>	Hg	0.4	0.6
	Cd	0.6	1.0
	As	1.1	1.4
	Zn	0.3	0.6
<i>Justicia flava</i>	Pb	0.0	0.2
	Hg	0.5	1.0
	Cd	0.6	1.3
	As	0.9	1.7
<i>Entada abyssinica</i>	Zn	0.3	0.5
	Pb	0.0	0.1
	Hg	0.4	0.5
	Cd	0.6	1.0
<i>Schoenoplectus corymbosus</i>	As	0.8	1.0
	Zn	0.5	0.7
	Pb	0.0	0.3
	Hg	0.4	0.6
<i>Combretum glutinosum</i>	Cd	0.6	1.1
	As	0.8	1.2
	Zn	0.3	0.6
	Pb	0.1	0.2
<i>Combretum glutinosum</i>	Hg	1.3	1.7
	Cd	0.6	1.2
	As	0.9	1.1
	Zn	0.5	0.8
<i>Combretum glutinosum</i>	Pb	0.0	0.2
	Hg	0.4	0.5
	Cd	0.6	1.2
	As	0.8	1.3
<i>Combretum glutinosum</i>	Zn	0.3	0.6

*Cariniana estrellensis* was also recorded as a good candidate species for accumulation and translocation ( $BAF > 1$  and  $TF > 1$ ) for As. The species uses phytostabilization as a phytoremediation mechanism to retain metals in the roots, metallothioneins, phytochelatins, which are via metal-binding molecules and vacuolar sequestration, which reduces translocation and prevents erosion and leaching (Lan et al., 2020).

The study also revealed *Schoenoplectus corymbosus* as a potential accumulator and translocator ( $BAF = 1$  and  $TF > 1$ ) for mercury. *Schoenoplectus corymbosus* is a microphyte that is characterized by the production of high biomass and an extensive root system. Gettys et al. (2014) report that the species is very suitable for rhizofiltration in wetlands and variable/saline conditions. Because of these metals' high phytotoxicity, the complex physiological and genetic mechanisms required for uptake and detoxification, and plant defence responses that restrict uptake/translocation, the study did not reveal any remediating plants for Pb, Hg, or Zn, as also previously described by (Mehes-Smith et al., 2013; Emamverdian et al., 2015).

Metal accumulation is also characterized by effective metal transfer from roots to shoots, as measured by a translocation factor larger than one ( $TF > 1$ ). Therefore, all species that recorded  $TF > 1$  in this study were classified as good phyto translocators. For instance, *C. molle*, *B. disticha*, *E. abyssinica*, *S. corymbosus*, and *C. glutinosum* ( $TF > 1$ ) were all classified as good translocators for Cd and As, whereas *S. spontenium* and *M. obsitufolia*, *V. drepanorobium*, *U. trichpous* were classified as good translocators for Hg. But also, *C. giganteus* was classified as a translocator for Zn.

## CONCLUSIONS

Cadmium and Mercury levels within 0–200 m lateral distance from the tailing heaps were found to be higher than the permissible limits, while Zn, As and Pb were within the acceptable ranges. But also, the decline of concentration of these metals with increasing distance from the tailing source due to dispersion was recorded. Heavy metal dispersion was found to be affected by soil pH and EC, where higher pH and EC were found to be associated with higher concentrations of metals and vice versa. The elevated concentration poses risks to humans and the ecosystem, where mercury is

exceptionally detrimental to human health, and Cd is carcinogenic. This study revealed the presence of some native plant species with potential capacity to remove these metals (phytoremediation), where some species showed remediation potential to a single heavy metal, while a few showed potentials to more than one metal. The results indicate that the identified species employ either bioaccumulation or phytostabilization or both, for the removal of a given heavy metal.

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