

Assessment and Categorization of Metal-Accumulating Potentials of Two Tropical Weeds Cultivated on Asunle Dumpsite, Obafemi Awolowo University, Ile Ife.

Tolulope D. Ojewole^{1*}, Oluwatosin A. Adedeji¹ and Moses B. Adewole²

¹Department of Environmental Management and Toxicology, University of Ilesha, Ilesha, Osun State

²Institute of Ecology and Environmental Studies, Obafemi Awolowo University, Ile-Ife

Abstract

This study assessed and categorized the metal-accumulating potential of *Tithonia diversifolia* Mexican (Sunflower) and *Chromolaena odorata* (Siamweed) cultivated on Obafemi Awolowo University general dumpsite popularly called Asunle dumpsite in relation to the available heavy metals of interest, which are Pb, Cd, Cu and Hg. Viable seedlings of *T. diversifolia* and *C. odorata* were collected within the Obafemi Awolowo University (OAU), Ile-Ife and authenticated at IFE Herbarium. The experiment was laid in Randomized Complete Block Design (RCBD) in three replicates which involved three treatments namely; *T. diversifolia*, *C. odorata* and a control plot without weed plant. Growth parameters such as number of leaves, stem girth, plant height and leaf area were measured at two-week intervals for 12 weeks. After harvesting, the plant were separated into roots and shoots using clean razor blade and rinsed with distilled water and were oven-dried at 70 °C to constant weight. Heavy metal uptake in the root and shoot samples was determined using standard methods. Results were analysed using analysis of variance and means were separated by Duncan's Multiple Range Test at $p < 0.05$. Categorization of the test weeds into accumulators, hyperaccumulators or excluders were carried out by determining the Bio-accumulation and Translocation factors which were also used to determine the metal-accumulating potentials of the test weeds. The results from this research showed that Heavy metal uptake was generally higher in the root than the shoot for both test weeds. However, significantly higher values ($p < 0.05$) were observed for Cu (2.11 mg/kg) in the shoot of *T. diversifolia* and Pb (9.32 mg/kg) in the root of *C. odorata*. Transfer factors for Pb (0.92), Cd (0.83), Cu (1.68) and Hg (1.00) for *T. diversifolia*; and for Pb (0.68), Cd (2.17), Cu (0.67) and Hg (0.35) for *C. odorata* were obtained. The bioaccumulation factors of all the metals considered were less than one (1) for both weeds. The study concluded that high clay content and alkalinity of the dumpsite soil could be responsible for the unavailability of heavy metals in the study site. It was also concluded that *T. diversifolia* and *C. odorata* are more of excluders than accumulators of some of the heavy metals in the study area. The exceptions are Cu and Hg in *T. diversifolia* and Cd in *C. odorata* which were accumulated.

© NJEH 2024 Published by Living Science Foundation.

Keywords: Dumpsite, *Tithonia diversifolia*, *Chromolaena odorata*, and Bioaccumulation/ Translocation Factors, hyperaccumulators and excluders.

1. Introduction

Heavy metals are common pollutants in the soil environment, namely, cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), copper (Cu), zinc (Zn), nickel (Ni). This type of contamination is biologically toxic, widely distributed, and persists long-term in soil environment (Kumar *et al.*, 2022). With the rapid development of economy and society, a variety of heavy metals contaminated soil threatens the environment and public health (Zhao *et al.*, 2022).The world

Accepted 24th October, 2024.

DOI:10.5281/zenodo.14902888

*Corresponding author

Email address: tolulope_ojewole@unilesa.edu.ng (Ojewole T.D.)

is now undergoing a silent epidemic of environmental poisoning from the ever-increasing number of metals being introduced into the biosphere from dumpsites (Matheka, 2023). Pollution by heavy metals occurs mainly from industrial, domestic, and agricultural wastes as well as from combination of fuels from automobile.

Heavy metals are non-biodegradable substances that become hazardous and toxic when accumulated over time in higher concentration in the environment. Heavy metal contamination of agricultural soils is a major environmental problem (Rashid *et al.*, 2023). They are trace elements such as zinc (Zn), copper (Cu), manganese (Mn), nickel (Ni) and cobalt (Co), some of which are micro nutrients necessary for plant growth. Others have no known biological function such as cadmium (Cd), lead (Pb) and mercury (Hg) (Balali-Mood *et al.*, 2021). They cause various contamination of soils, sediments, surface and underground waters in the vicinity of dumpsite areas while some soil nutrients are also lost or unavailable for crop uptake (Awino *et al.*, 2020). Globally, notable awareness and efforts have been geared towards the use of specific plants to absorb heavy metals in contaminated soils (Hu *et al.*, 2024). One of the most promising ways of reclaiming contaminated soil is the phytoremediation which involves the use of some plants with special hyperaccumulating attributes (Hassan *et al.*, 2024; Yan *et al.*, 2020). According to Glišić *et al.*, (2024), the plants to be used must be able to produce large biomass and have ability to hyperaccumulate trace elements. One of such plants is *Tithonia diversifolia* whose effectiveness in remediation of lead has been reported by Shojaei *et al.*, (2021).

Heavy metal accumulation in soils is of utmost importance in agricultural production due to its adverse effects on food safety, marketability and crop growth due to phytotoxicity and environmental health of soil organisms (Ayasa *et al.*, 2018). Plants growing in metal-polluted sites exhibit retarded metabolism, growth, biomass production and metal accumulation. Several physiological and biochemical processes in plants are affected by metals. A few metals like copper, manganese, cobalt and zinc are however essential to plant growth in trace amount. However, when metals bioaccumulate at excessive levels, they could become toxic to plants (Collin *et al.*, 2022). Heavy metals are kept under environmental pollutants category due to their detrimental effects on plants, animals and biological systems. Heavy metal contamination results from anthropogenic (mining, smelting operations and agriculture) and natural activities and this has caused the release of Cd, Co, Cr, Pb, and Ni in soil up to toxic levels. Heavy metals are persistent in nature, and thereby, bioaccumulate in soils and plants (Alengebawy *et al.*, 2021). Some plants on dumpsites regulate their metabolism in response to heavy metals and protect themselves against metal poisoning through the mechanism of detoxification and tolerance to heavy metal stress. Metal toxicity and tolerance in plants is a subject that has been broadly reviewed. Heavy metals, in soils of waste dumps, which are the main category of environmental pollutants, can remain in the soils for long periods; their accumulation is potentially hazardous to humans, animals and plants (Jayakumar *et al.*, 2021; Briffa *et al.*, 2020; Alengebawy *et al.*, 2021). For soils on dumpsites to be useful again for agricultural purposes, the heavy metal content must be greatly wiped off or removed. This can be achieved by the process called remediation or metal accumulation (Donald *et al.*, 2022).

Translocation factor, the ratio of shoot to root metals, indicates internal metal transportation. Plant species differ widely in their ability to accumulate heavy metals (Pasricha *et al.*, 2021). The transfer factor can also be defined as the ratio of the concentration of metals in plants to the total concentration in the soil. It was observed that the transfer factors for the same metal in the dumpsite were significantly different according to the type of plants and vegetables (Ekere *et al.*, 2020). The ability of a plant to accumulate metals from contaminated soils can be evaluated by a factor which is the bioaccumulation/bioconcentration factor (BAF/BCF). Proc *et al.* (2021) assumed that plants with BCF values > 1 are accumulators, while plants with BCF values < 1 are excluders. Additionally, plants could be classified as potential hyperaccumulators if the BCF values were > 10 (Hidayati and Rini, 2020). Generally, the higher metal accumulation in the above-ground components of a plant with BCF and TF values > 1 has been shown to be likely to explain the higher potential for metal extraction from contaminated sites (Eben *et al.*, 2024).

The aim of this research work is to assess the pathways of selected heavy metals, if any, in the weeds after harvest; which will determine the metal-accumulating potential of the weeds cultivated on the dumpsite and to categorize the test weeds into accumulator, hyperaccumulators or excluders in relation to the heavy metals of interest.

2. Research Materials And Methods

Sample collection and Preparation

A portion of the dumpsite of 10m × 13m plot of land was used for the experiment and the treatments were laid in Randomized Complete Block Design which included three treatments which are: T1 (Treatment 1, Seedlings of *Tithonia diversifolia*), T2 (Treatment 2, Seedlings of *Chromolaena odorata*) and T3 (control, no treatment). Each of these treatments was replicated thrice to make nine plots of 40cm × 60cm with 1m as intra and inter-row spacing. Thirty-six (36) seedlings of each treatment were transplanted on each plot. Viable seedlings of both *Tithonia diversifolia* and *Chromolaena odorata* were collected from an open field at the Institute of Ecology and Environmental Studies O.A.U,

where there is minimal traffic and authenticated at IFE Herbarium and were planted two seedlings per hole which were later thinned to one seedling per hole leaving 36 plant stands on each plot to grow. Weeding was carried out every two weeks to curb weed interference with the tested plants. The experiment was conducted for a period of 12 weeks.

Laboratory Analysis of Soil Samples

Pre-planting and post-harvest test of the experimental soil was carried out at the Agronomy laboratory, University of Ibadan, Oyo State using laboratory procedures in the laboratory manual by IITA (1979) manual series No 1. They include: Determination of pH, particle size, organic carbon, organic matter, exchangeable cations, total nitrogen, available phosphorus, exchangeable acidity and heavy metals.

Plant Samples preparation for Analysis.

Twelve weeks after planting, when the experiment was concluded, plant samples were randomly collected per treatment from all the replicates using a clean knife, and the roots were carefully dug up with a hand-held hoe. The plant tissues were separated into root and shoot, thoroughly washed with distilled water, weighed, and oven-dried at 70°C for 48 hours at the Institute of Ecology and Environmental Studies, Obafemi Awolowo University, Nigeria.

Heavy metal determination in plant samples

The plant samples were oven dried and milled using a milling machine. From the dried fine samples, 0.5g was weighed into a beaker and between 5 and 10 ml of an acid mixture of nitric acid and perchloric acid in ratio 2: 1 was added and placed on a hot plate under a fume cupboard and allowed to undergo heating at 70°C for about 30 minutes. There was a colour change to colourless, the digest was allowed to cool and made up to 25 ml with distilled water. The digest was read on Buck Scientific Atomic Absorption Spectrophotometer model 210/21, VGP to determine Pb, Cd, Cu and Hg.

Bioaccumulation and Translocation Factors

The bioaccumulation and translocation factors of the tested plant species were obtained using the equations below:

$$\begin{aligned} \text{Shoot bioaccumulation factor} &= \frac{\text{Concentration of heavy metal in shoot}}{\text{Concentration of heavy metal in soil}} \\ \text{Root bioaccumulation factor} &= \frac{\text{Concentration of heavy metal in root}}{\text{Concentration of heavy metal in soil}} \\ \text{Whole plant accumulation factor} &= \frac{\text{Concentration of heavy metal in plant}}{\text{Concentration of heavy metal in soil}} \\ \text{Transfer factor} &= \frac{\text{Concentration of heavy metal in shoot}}{\text{Concentration of heavy metal in root}} \end{aligned}$$

(Gupta *et al.*, 2021 and Edogbo *et al.*, 2020).

Statistical Analysis

Data collected were subjected to descriptive and inferential analysis (t-test and ANOVA) according to the general model procedure of the Statistical Analysis System (SAS) statistical package. Means were separated using Duncan's Multiple Range Test ($p < 0.05$).

3. Results

Determination of the Root-Shoot Partitioning of the Heavy Metals.

The root- shoot partitioning of the heavy metals in the test weeds are graphically presented in figure 1 and 2. From figure 1, which is for (treatment A), it could be observed that lead (Pb) was absorbed by the weed more than other heavy metals followed by Cu, then by Hg and lastly Cd in this order: $Pb > Cu > Hg > Cd$ with the values of 11.32, 2.11, 1.11 and 0.18 kg^{-1} in the root and 10.44, 0.54, 1.09 and 0.15 $g\ kg^{-1}$ in the shoot for lead, cadmium, copper and mercury respectively. For Pb, there was a considerable amount that was translocated to the shoot from the root. For Cu, the amount in the shoot was more than the amount in the root which means that more of its quantity was translocated to the shoot. There was no significant difference between the amount of Hg and Cd observed both in the shoot and root, though, Hg was more absorbed than Cd. Likewise for *C. odorata* (treatment B), figure 2, it could be observed generally that the concentration of the selected heavy metals were concentrated more in the roots than in the shoots with lead (Pb) having the highest concentration (9.32 $g\ kg^{-1}$) while cadmium (Cd) had the lowest concentration with 9.32, 2.00, 1.16 $g\ kg^{-1}$ and 0.07 kg^{-1} in the root; and 6.37, 1.33 and 0.41 and 0.13 $g\ kg^{-1}$ in shoots for lead, copper, mercury and cadmium respectively.

The descending order of which the heavy metals are absorbed in the weeds was $Pb > Cu > Hg > Cd$., which depicted that Pb is the most absorbed from the soil followed by Cu, this followed by Hg and the least was Cd. The root – shootpartitioning for most of the heavy metals followed the same pattern, that is, more in the root than in the shoot.

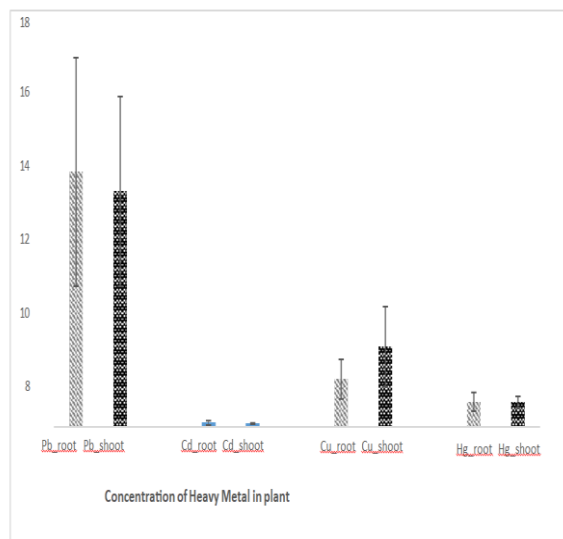


Figure 1: Concentration of Heavy Metals in *T. diversifolia*
(Bars indicate standard error.

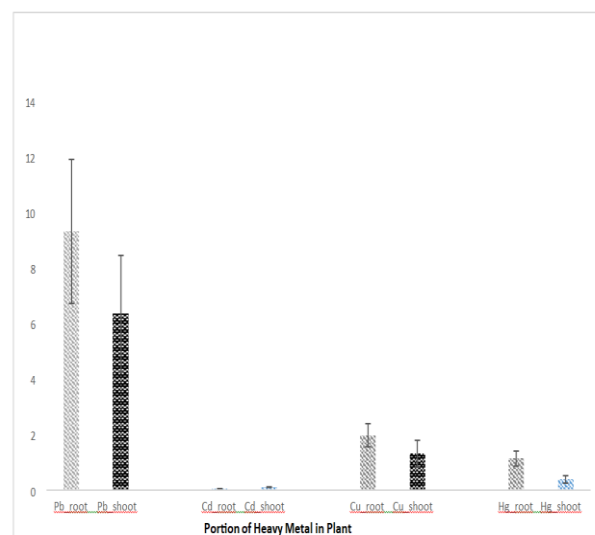


Figure 2: Portion of heavy Metals in the *C. odorata*
Bars indicate standard error

From table 1a, it could be observed that there was no significant difference at $p < 0.05$ for the translocation of the selected heavy metals from the root to the shoot of *T. diversifolia* (with the p-values of 0.902, 0.768, 0.521 and 0.970 for lead, cadmium, copper and mercury respectively). The same condition went for *C. odorata* (Table 1b) except for Cd in which there was a significant difference between the amounts translocated from the root to the shoot at $p < 0.05$ (with p-values of 0.425, 0.04, 0.355 and 0.09 for lead, cadmium, copper and mercury respectively).

Table 1a: The Root and Shoot Concentration of the Heavy Metals in *T. diversifolia*

Metal	Root (g kg ⁻¹)	Shoot (g kg ⁻¹)	T-value	p-value
Pb	11.34	10.44	0.131	0.902
Cd	0.18	0.15	0.338	0.768
Cu	2.11	3.54	0.725	0.521
Hg	1.11	1.09	0.041	0.970

Table 1b: The Root and Shoot Concentration of the Heavy Metals in *C. Odorata*

Metal	Root (g kg ⁻¹)	Shoot (g kg ⁻¹)	T-value	p-value
Pb	9.32	6.37	0.887	0.425
Cd	0.07	0.13	3.258	0.047
Cu	2.00	1.33	1.045	0.355
Hg	1.16	0.41	2.468	0.090

Means significant at $p < 0.05$ **Transfer Factor (TF) and Bio-accumulation Factor (BAF)**

The transfer factor and bio-accumulation factor for each of the heavy metals to different plant parts are presented in the Tables 2 to 4. The heavy metals had varied TF values for each plant. For *T. diversifolia* (treatment A), for all the heavy metals, the least TF value was 0.83 for Cd and the highest was 1.68 for Cu in the order of $0.83 < 0.92 < 1 < 1.68$ for Cd, Pb, Hg and Cu respectively. For *C. odorata* (treatment B), the TF values were relatively low compared to that of *T. diversifolia*. The highest TF was found in Cd with 2.17 and the lowest was in Hg with 0.35. The order is $0.35 < 0.67 < 0.68 < 2.17$ for Hg, Cu, Pb and Cd respectively. The shoot and root bio-accumulation factors by the two test weeds are presented in Tables 3 and 4. It was observed in treatment A that Pb has the highest BAF value of 0.19, followed by 0.06 for Cu, 0.04 for Hg and finally 0.03 for Cd. For treatment B, Pb also had the highest value with 0.08, followed by Cd with 0.03 but Cu and Hg had the same value which was 0.02. The Root BAF, Table 4. Treatment A has Pb with the highest value followed by Cd and Hg with the same Value, 0.04 and Cu the lowest with 0.03 while for treatment B, Pb still has the highest BAF value of 0.12, followed by Hg with 0.05, followed by Cu with 0.03 and Cd with the least value of 0.01. Comparing the shoot BAF and the root BAF to consider the root- shoot partitioning for each heavy metal in the two test weeds. For Pb in treatment A, it was observed that a considerable amount absorbed by the root (0.19) was translocated to the shoot (0.18). The same condition went for Cd, 0.04 in the root and 0.03 in the shoot, while Cu had a larger amount translocated to the shoot (0.06) whereas 0.03 was left in the root, while Hg has equal amount both in the root and in the shoot. Also, for treatment B, *C. odorata*, the root BAF value for Pb (0.12) was more than the amount found in the shoot (0.08). This also went for Cu and Hg but for Cd, the root BAF was less than the shoot BAF. Indicating that more of Cd was translocated to the aerial part of *C. odorata*. Generally speaking, considering the root - shoot partitioning of the heavy metals, it was observed that more of the heavy metals were retained at the root zone of the test weeds, indicating that they are not translocated to the shoot as they are supposed to.

Table 2: Transfer factor (TF) of the selected heavy metals in the two test plants.

Treatment	Pb	Cd	Cu	Hg
A	0.92	0.83	1.68	1.00
B	0.68	2.17	0.67	0.35

Table 3: Bioaccumulation factor of the selected metals in the root of the plants

Treatment	Pb	Cd	Cu	Hg
A	0.19	0.04	0.03	0.04
B	0.12	0.01	0.03	0.05

Table 4: Bioaccumulation factor of the selected metals in the shoot of the plants

Treatment	Pb	Cd	Cu	Hg
A	0.18	0.03	0.06	0.04
B	0.08	0.03	0.02	0.02

Legend: Treatment A - *Tithonia diversifolia* Treatment B - *Chromolaena odorata*

Pre-crop and Post- harvest heavy metal content in the soil of the Dumpsite

Copper (Cu) levels showed the greatest reduction from 99.88 mg/kg in pre-crop soil to 71.83 mg/kg in soil with *Chromolaena odorata*, 62.08 mg/kg in soil with *Tithonia diversifolia* and 55.83 mg/kg in control soil. Mercury (Hg) decreased from 37.82 mg/kg in pre-crop soil to 28.97 mg/kg in control soil, 26.94 mg/kg in soil with *Tithonia diversifolia* and 21.33 mg/kg in soil with *Chromolaena odorata*. Lead (Pb) levels dropped from 188.52 mg/kg in pre-crop soil to 78.33 mg/kg in soil with *Chromolaena odorata*, 58.17 mg/kg in soil with *Tithonia diversifolia* and 44.53 mg/kg in control soil, though no significant differences were noted. Cadmium (Cd) levels showed minimal reduction, from 1.85 mg/kg in pre-crop soil to 1.67 mg/kg in soil with *Tithonia diversifolia*, 1.46 mg/kg in soil with *Chromolaena odorata* and 1.35 mg/kg in control soil, with no significant differences observed.

Table 5: The Pre-crop and Post- harvest heavy metal content in the soil of the Dumpsite

Property	Treatment (mgkg ⁻¹)			
	A	B	C	D
Cu	99.88 ^a	55.83 ^b	62.08 ^b	71.83 ^{ab}
Pb	188.52 ^a	44.53 ^a	58.17 ^a	78.33 ^a
Cd	1.85 ^a	1.35 ^a	1.67 ^a	1.46 ^a
Hg	37.82 ^a	28.97 ^a	26.94 ^{ab}	21.33 ^b

Legend

A: Pre-crop soil

B: Control Soil

C: soil with *Tithonia diversifolia*

D: Soil with *Chromolaena odorata*

Different superscripts across roll suggests significant difference at p<0.05

4. Discussion

Chromolaena odorata (Siam weed) and *Tithonia diversifolia* (Sunflower) were selected for this study on the basis of their invasiveness and survival in extreme harsh conditions in almost all soils as well as their seemingly non-vegetative use in the Nigerian environment, to evaluate their prowess to accumulate heavy metals into their body system. The highest value of heavy metals (Cd, Pb, Hg and Cu) in the root and shoot was found in *T. diversifolia* (Adesodun et al, 2010). Concentrations of the selected heavy metals were higher in the roots than in the shoots in the test weeds and this was also established by Ashraf and Ali (2007) except for Cu that translocated greater portion of its concentration to the shoot in *T. diversifolia*. It could be observed that the two test plants have the capacity to mob or absorb Lead from lead – contaminated soil because of the drastic reduction in the amount of Pb when comparing the pre and control soils with the two plants.

According to Department of Petroleum Resources, DPR (2002), Cu content of the soils was above the intervention and target values while Cd content fall within the two values according to DPR and also Hg. Pb value was far above the target

value but within the intervention value. For Cd and Cu, their levels in the soil of the dumpsite were more than the values in natural soil but within the tolerable level while lead's concentration after planting falls within the average natural soil values but far more than it before planting. Though, some of these heavy metal content falls below the critical permissible levels, their persistence in the soil of the dumpsite may lead to increase uptake by plants if farmers continue to use the dumpsites for agricultural purposes (Klock *et al.*, 1984). He also reported that the plants can accumulate relatively large amount of these metals by foliar absorption.

For a plant to be an efficient tool for metal-accumulation on a polluted soil, the bioaccumulation factor and transfer factor must be taken into consideration (Wahsha *et al.*, 2012). Transfer Factor (TF) (Yoon *et al.*, 2006), is defined as the ratio of the metal concentration in the shoots to that in the roots. Plants with TF values > 1 are classified as high- efficiency plants for metal translocation from the roots to shoots (Ma and Komar *et al.*, 2001). Yoon *et al.*, (2006) suggested that plant species with TF values > 1 actively take up metals from the soil and accumulate them in their above-ground parts; therefore, they could be good hyperaccumulators. The highest transfer factor in shoot was recorded in *C. odorata* for Cd because much of the heavy metal absorbed by the plant root was translocated to the shoot. This implies that *C. odorata* is an accumulator of Cd on a dumpsite. This also is applicable to Cu and Hg which had TF greater than one in *T. diversifolia* which make the plant an accumulator of both heavy metals.

The ability of the test plants to accumulate metals from contaminated soils was also evaluated by the bioaccumulation factor (BAF). Baker (1981) assumed that plants with BCF values greater than one are accumulators, while plants with BCF values less than one are excluders.

Additionally, plants were classified as potential hyperaccumulators if the BCF values were greater than ten (Aransiola *et al.*, 2013). The results in this study showed that *T. diversifolia* and *C. odorata* that have BAF values less than one for Pb, Hg, Cu and Cd indicating that the plant has the potential to be used as an excluder of these heavy metals, while the low BAF values for all the metals may be due to high Pb concentration in the soil (Bååth *et al.*, 2005). The success of the metal-accumulation process depends on heavy metal removal by the shoots (Usman and Mohamed, 2009).

The reduction in heavy metal concentrations across different soil treatments indicates varying levels of metal uptake or stabilization by *Chromolaena odorata* and *Tithonia diversifolia*. Copper showed the greatest reduction, with *Tithonia diversifolia* demonstrating higher effectiveness than *Chromolaena odorata*, although the control soil exhibited the lowest Cu levels, this may be as a result of other influencing factors. Mercury levels decreased most significantly in soil with *Chromolaena odorata*, this suggests that the weed has potential for Hg remediation. Lead levels also declined, but with no significant differences among treatments, this may be as a result of natural processes or microbial activity. Cadmium showed only minimal reductions, with no significant variation between treatments, indicating its persistence in soil and limited phytoremediation potential by the tested plants. These findings suggest that while both plant species contribute to metal reduction, their effectiveness varies by metal type, with *Chromolaena odorata* being more effective for Hg and *Tithonia diversifolia* showing greater potential for Cu and Pb.

5. Categorization of the test weeds

It could be inferred from this research work that the two test weeds are majorly excluders of the heavy metals of interest, though, not in all. The table 6 below shows the categories to which the weeds fall considering each metal.

Table 6: Categorization of the test weeds

Treatment	Pb	Cd	Cu	Hg
1	Excluder	Excluder	Accumulator	Accumulator
2	Excluder	Accumulator	Excluder	Excluder

Legend: 1: *Tithonia diversifolia*

2: *Chromolaena odorata*

6. Conclusion

As it is in most cases, dumpsite soils are highly polluted with toxic substances; heavy metals inclusive, due to indiscriminate dumping of unsorted wastes on it. The fate of the soils to be remediated by weeds depends largely on the weeds' heavy metal accumulating potentials. It was observed from numerous research works that some are excluders, some accumulators, while others are hyperaccumulators. From this study, the heavy metals were bioaccumulated in both plants, but *T. diversifolia* exhibited higher bioaccumulation. However, the bioaccumulation factors for nearly all metals were below 1, indicating that the weeds function more as excluders rather than accumulators of heavy metals. The concentration of heavy metals accumulated by the weeds were not really transferred to the aerial parts in both test weeds. This is evident in *T. diversifolia* for Cu and Hg *C. odorata* for Cd as they have transfer factors ≥ 1 .

7. Recommendation

Based on the findings of this study, the following recommendations are made:

1. Prioritize the use of accumulator and/or hyperaccumulator plants for effective phytoremediation.
2. Efforts should be focused on reducing soil acidity during the remediation process by increasing the pH, which can be achieved through the application of agricultural lime, wood ash, bone meal, or crushed oyster shells, while avoiding ammonium-based fertilizers and considering the use of alkaline irrigation water.

References

- Adesodun, J. K., Atayese, M. O., Agbaje, T. A., Osadiaye, B. A., Mafe, O. F., & Soretire, A. A. (2010). Phytoremediation Potentials of Sunflowers (*Tithonia diversifolia* and *Helianthus annuus*) for Metals in Soils Contaminated with Zinc and Lead Nitrates. *Water, Air, and Soil Pollution*, 207(1-4), 195–201. doi:10.1007/s11270-009-0128-3
- Alengebaw, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M. Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. *Toxics*, 9(3), 42.
- Aransiola, S. A., Josiah, U. J., & Abioye, O. P. (2013). Phytoremediation of lead polluted soil by *Glycine max* L. *Applied and Environmental Soil Science*, 2013, Article ID 631619. https://doi.org/10.1155/2013/631619
- Awino, F. B., Maher, W. A., Krikowa, F., & Lynch, A. J. J. (2020). Occurrence of trace metals in food crops grown on the Mbale dumpsite, Uganda, and human health risks. *Integrated environmental assessment and management*, 16(3), 362-377.
- Ayesa, S. A., Chukwukab, K. S., & Odeyemi, O. O. (2018). Tolerance of *Tithonia diversifolia* and *C. odorata* in heavy metal simulated-polluted soils and three selected dumpsites. *Toxicology Reports*, 5, 1134-1139. https://doi.org/10.1016/j.toxrep.2018.11.007
- Bååth, E., Diaz-Ravina, M., & Bakken, L. R. (2005). Microbial biomass, community structure and metal tolerance of a naturally Pb-enriched forest soil. *Microbial Ecology*, 50, 496-505.
- Baker, A. J. (1981). Accumulators and excluders-strategies in the response of plants to heavy metals. *Journal of plant nutrition*, 3(1-4), 643-654.
- Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R., & Sadeghi, M. (2021). Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. *Frontiers in pharmacology*, 12, 643972.
- Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, 6(9).
- Collin, S., Baskar, A., Geevarghese, D. M., Ali, M. N. V. S., Bahubali, P., Choudhary, R., ... & Swamiappan, S. (2022). Bioaccumulation of lead (Pb) and its effects in plants: A review. *Journal of Hazardous Materials Letters*, 3, 100064.
- Donald, A. N., Raphael, P. B., Olumide, O. J., & Amarachukwu, O. F. (2022). Environmental Heavy Metal Pollution: Physicochemical Remediation Strategies to The Rescue. *Journal Of Environment Pollution And Human Health*, 10(2), 31-45.
- Eben, P., Mohri, M., Pauleit, S., Duthweiler, S., & Helmreich, B. (2024). Phytoextraction potential of herbaceous plant species and the influence of environmental factors—A meta-analytical approach. *Ecological Engineering*, 199, 107169.
- Edogbo, B., Okolocha, E., Maikai, B., Aluwong, T., & Uchendu, C. (2020). Risk analysis of heavy metal contamination in soil, vegetables and fish around Challawa area in Kano State, Nigeria. *Scientific African*, 7, e00281.
- Ekere, N. R., Ugbor, M. C. J., Ihedioha, J. N., Ukwueze, N. N., & Abugu, H. O. (2020). Ecological and potential health risk assessment of heavy metals in soils and food crops grown in abandoned urban open waste dumpsite. *Journal of Environmental Health Science and Engineering*, 18, 711-721.
- Glišić, R. M., Brković, D. L., Grbović, F. J., Mladenović, J. D., Rajičić, V. R., Marin, M. A., & Branković, S. R. (2024). Metal bioaccumulation and translocation potential of three herbal plant species at mine tailings. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 52(3), 13140-13140.
- Gupta, N., Yadav, K. K., Kumar, V., Krishnan, S., Kumar, S., Nejad, Z. D., ... & Alam, J. (2021). Evaluating heavy metals contamination in soil and vegetables in the region of North India: Levels, transfer and potential human health risk analysis. *Environmental toxicology and pharmacology*, 82, 103563.
- Hassan, S., Bhadwal, S. S., Khan, M., Nissa, K. U., Shah, R. A., Bhat, H. M., ... & Ganai, B. A. (2024). Revitalizing contaminated lands: A state-of-the-art review on the remediation of mine-tailings using phytoremediation and genomic approaches. *Chemosphere*, 141889.
- Hidayati, N., & Rini, D. S. (2020). Evaluation of wild plants as lead (Pb) and cadmium (Cd) accumulators for phytoremediation of contaminated rice fields. *Biodiversitas Journal of Biological Diversity*, 21(5).
- Hu, Y., Wang, J., Yang, Y., Li, S., Wu, Q., Nepovimova, E., Zhang, X. & Kuca, K. (2024). Revolutionizing soil heavy metal remediation: Cutting-edge innovations in plant disposal technology. *Science of The Total Environment*, 170577.
- International Institute for Tropical Agriculture (IITA) (1979). Selected methods for soil analysis. Manual series. No.1. Revised edition. IITA, Ibadan, Nigeria 70pp.
- Jayakumar, M., Surendran, U., Raja, P., Kumar, A., & Senapathi, V. (2021). A review of heavy metals accumulation pathways, sources and management in soils. *Arabian Journal of Geosciences*, 14(20), 2156.
- Klock, E. G & Friedlova C.A. (1984). The influence of heavy metals on soil biological and chemical properties. *Soil and Water Research*, 5(1), 21-27.
- Kumar, R., Ivy, N., Bhattacharya, S., Dey, A., & Sharma, P. (2022). Coupled effects of microplastics and heavy metals on plants: Uptake, bioaccumulation, and environmental health perspectives. *Science of the Total Environment*, 836, 155619.
- Ma, L. Q., Komar, K. M., Tu, C., Zhang, W., Cai, Y., & Kennelley, E. D. (2001). A fern that hyperaccumulates arsenic. *Nature*, 409(6820), 579-579.
- Matheka, V. K. (2023). *Environmental effects and health risks associated with the location of Kalundu dumpsite, Kitui county to local residents* (Doctoral dissertation).
- Pasricha, S., Mathur, V., Garg, A., Lenka, S., Verma, K., & Agarwal, S. (2021). Molecular mechanisms underlying heavy metal uptake, translocation and tolerance in hyperaccumulators-an analysis: Heavy metal tolerance in hyperaccumulators. *Environmental Challenges*, 4, 100197.
- Proc, K., Bulak, P., Kaczor, M., & Bieganski, A. (2021). A new approach to quantifying bioaccumulation of elements in biological processes. *Biology*, 10(4), 345.
- Rashid, A., Schutte, B. J., Ulery, A., Deyholos, M. K., Sanogo, S., Lehnhoff, E. A., & Beck, L. (2023). Heavy metal contamination in agricultural soil: environmental pollutants affecting crop health. *Agronomy*, 13(6), 1521.
- Shojaei, S., Jafarpour, A., Shojai, S., Gyasi-Agyei, Y., & Rodrigo-Comino, J. (2021). Heavy metal uptake by plants from wastewater of different pulp concentrations and contaminated soils. *Journal of Cleaner Production*, 296, 126345.
- Usman, A. R. A., & Mohamed, H. M. (2009). Effect of microbial inoculation and EDTA on the uptake and translocation of heavy metal by corn and sunflower. *Chemosphere*, 76(7), 893-899.
- Wahsha, M., Bini, C., Argese, E., Minello, F., Fontana, S., & Wahsheh, H. (2012). Heavy metals accumulation in willows growing on Spolic Technosols from the abandoned Imperina Valley mine in Italy. *Journal of Geochemical Exploration*, 123, 19-24.
- Yan, A., Wang, Y., Tan, S. N., Mohd Yusof, M. L., Ghosh, S., & Chen, Z. (2020). Phytoremediation: a promising approach for revegetation of heavy metal-polluted land. *Frontiers in plant science*, 11, 359.
- Yoon, J., Cao, X., Zhou, Q., & Ma, L. Q. (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. *Science of the Total Environment*, 368(2-3), 456-464.
- Zhao, H., Wu, Y., Lan, X., Yang, Y., Wu, X., & Du, L. (2022). Comprehensive assessment of harmful heavy metals in contaminated soil in order to score pollution level. *Scientific Reports*, 12(1), 3552.