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Hyperaccumulation and Translocation of Potentially Toxic Elements (PTEs) from Industrial Soil by a Tropical African Weed, *Senna tora*

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Abstract: Field samples of *Senna tora,* a stress tolerant tropical weed, growing in an industrial area with high anthropogenic activities were collected and separated into leaves, stems and roots to assess the accumulation and translocation of six Potentially Toxic Elements (PTEs) (Zn, Cu, Cd, Cr, Pb and Ni) from the soil media. Atomic Absorption Spectroscopy (AAS) was used to assess the concentrations. The bioaccumulation ion/transfer of metals from roots to shoots and from soil to roots were evaluated in terms of translocation and bioconcentration factor. TF values of 7.23, 6.43, 5.00, 3.00 2.62 and 2.05 for Cr, Cu, Cd, Ni, Zn and Pb respectively indicate that *Senna tora* was efficient in translocation of PTEs from roots to shoots and follows the trend Cr > Cu > Cd > Ni > Zn > Pb respectively. This is an indication that the plant is therefore suitable for phytoextraction of these elements in that order. BCF values of Cu (7.68), Cr (5.47), Pb (4.97), Zn (3.77), Cd (2.93) and Ni (1.49) follows the trend Cu > Cr > Pb > Zn > Cd > Ni. This show that *Senna tora* may be suitable a candidate for phytostabilization of Chromium and lead in contaminated soils as it retains high concentration of these elements in its roots. Based on the translocation factor (TF) and the bioconcentration factor (BCF) values, the study shows high potential for hyperaccumulation of Cr and Cu of this plant for both phytoextraction and Phytostabilization, thus throwing up this plant as a very important plant species to be considered for the remediation of multi-element polluted sites where this green technology is desired.

1. Introduction

Among pollutants found in the environment, potentially toxic elements (PTEs) represents a worrying concern because of their numerous sources, toxic nature, non-degradable characteristics, and potential for accumulation (Yazdanfar *et al*., 2024; Miyah *et al*., 2022). Soils earmarked for agricultural purposes are subject to pollution by these toxic elements at very rates due to anthropogenic activities globally (Zakari & Audu, 2021a). PTEs that surpass accepted standards can pose a high risk to ecosystems due to their ecological impacts (Onyegeme-okerenta & West, 2023). A number of methods have been suggested to prevent the entry of PTEs into the food chain through soil remediation. The green way is the best by the use of natural plants or natural phosphate or clay modified by Arabic gum (Errich *et al*., 2021; El Hammari *et al*., 2022). Soil remediation is the process of treating contaminated soil to recover its original state (Praveen & Nagalakshmi, 2022). Soil contaminated with metals can be remediated by using various measures which include chemical, physical and biological methods (Zakari & Audu, 2021b). However phytoremediation, a green chemistry approach which uses green plants to remove PTEs from soil, sediments and water, has gained prominence from researchers globally in recent years (Liu & Tran, 2021; Abdouni *et al.*, 2022; Aassim *et al.*, 2023). Phytoremediation has been considered one of the most meritorious remediation techniques when it has to do with PTEs removal from soil (Paes *et al.*, 2023). It has the advantage of the uptake abilities of plant roots systems, followed by the translocation, bioaccumulation and contaminant storage abilities of the entire plant body (Karim *et al.*, 2016; Elshamy *et al.*, 2019). Scholarly articles from literature have revealed some plant families such as Brassicaceae, Euphorbiaceae, Asteraceae, and Fabaceae as good hyperaccumulators of PTEs, of which many can be used to accumulate significant amounts of PTEs (Gavrilescu, 2021).

There has been a worldwide desire for cost-effective and efficient solutions to address the issue of PTEs contamination in agricultural soils (Yeşilyurt, 2023). Unfortunately, with the clear advantages afforded by phytoremediation as a cheap green chemistry option to alleviate soil contamination, it has not been explored fully to remove PTEs in these parts of the world. *Senna tora* (Family: Fabaceae), a wild, stress tolerant and easily grown legume (Patra *et al.*, 2020) (Badamasi *et al.*, 2017) which grows well in wasteland as a rainy season weed (Pawar, 2015) was selected for this study. It was sighted growing well in the study area under investigation. To the best of our knowledge, literature on accumulation ability of *Senna tora* relative to background metal concentration in this industrial area are very scarce and few reports suggest its role as a hyper accumulator (Jena *et al.*, 2016; Ugwa et al., 2019). Therefore, the study was conceptualized to assess the accumulation and translocation of six PTEs in tissues of this plant which grows naturally at Challawa Industrial Estate. Furthermore, its suitability for phytoremediation and as potential bio-indicators for toxic metal pollution of soils was assessed by evaluating its translocation and bioconcentration factors.

2. Methodology

2.1 Preparation of reagents

In preparing reagents, analytical grade chemicals of high purity and deionized water were used in the analysis. Laboratory apparatus including glass wares and plastic vessels for reagents were soaked in nitric-acid and thoroughly washed with detergent solution, followed by rinsing with tap water, deionized water and finally with the analyte samples to be used.

2.2 Study area

The field study was carried out in the vicinity of Challawa Industrial area. The area is situated in Kumbotso local government of Kano state. Sampling was carried out at Yandanko village in Challawa Industrial area, located between latitudes 11°52´48.81” and along longitudes 8°28´17.25”. The Global Positioning System (GPS) was utilized in recording the coordinates and Geographical Information System (GIS) was employed to locate the map of the study area as shown below (Figure 1).

2.3 Field sampling of soil and plant species.

Senna tora was collected from both Challawa Industrial area and the control site (Langel village), which was approximately 17.5km away from Challawa Industrial area (Photo 1). The plant species were collected from these sites at almost similar stage of growth as that from the Challawa sample Industrial area and including the control site (Langel village). Identification of the collected plant species was done by a taxonomist at the Plant Biology Department of Bayero University Kano and a herbarium number *Senna tora (bukhan 0309)* was assigned to the plant. The sample was labeled, placed in polythene bags and transported to the University and air-dried. Three soil samples were also collected at each sampling point for the plant and composites samples were prepared to be used in the experiments. The soil samples were air dried and ground into fine powder and sieved through 2mm plastic mesh and stored in labeled polythene bags.

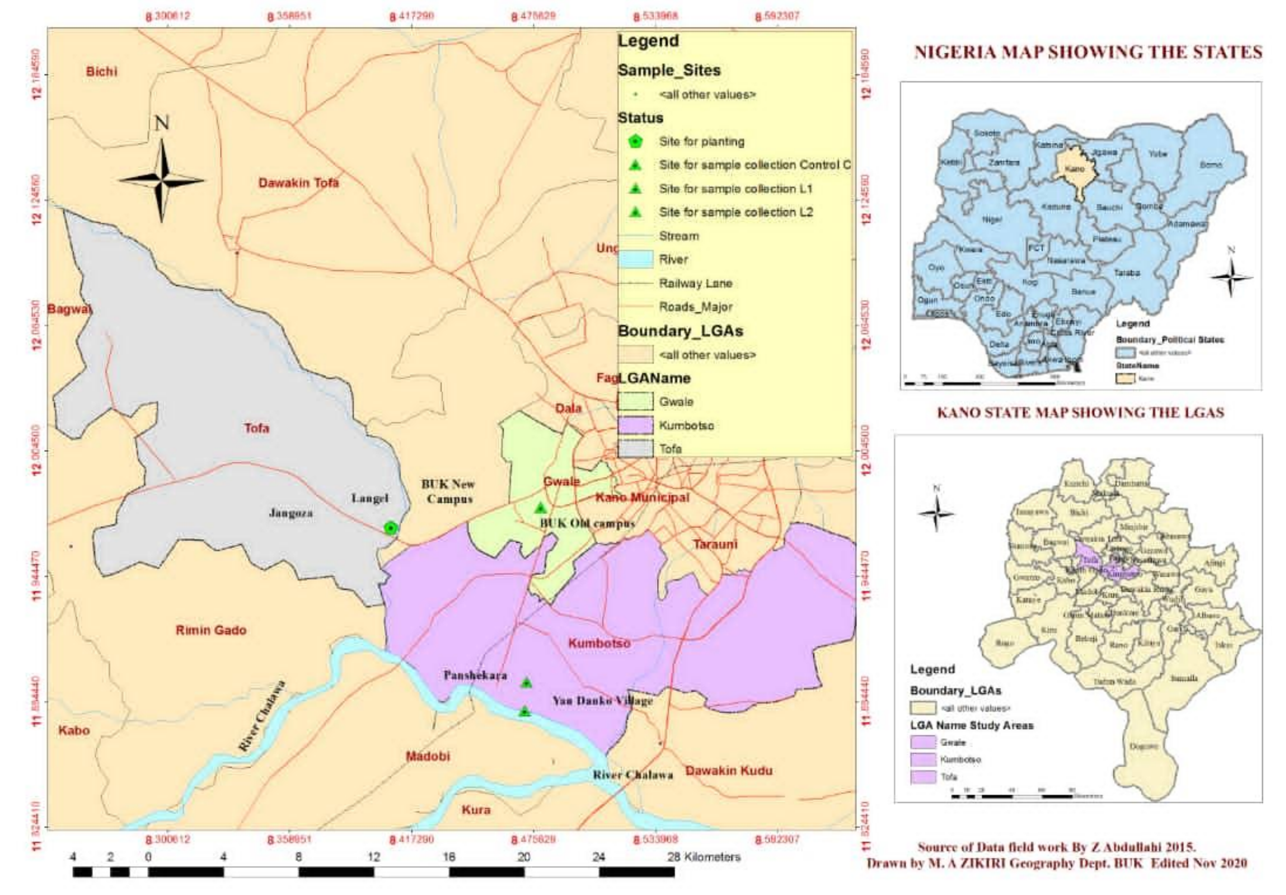

Figure 1: Map of Kumbotso and Tofa LGA Showing Sampling location

2.4 Experiments

Digestion of soil samples

1g of the soil sample from Yandanko, at Challawa was mixed with 20cm^3 of nitric acid (HNO_3) (70% w/v, S.G 1.42g/cm^3) and allowed to stand for 1hour. 15cm^3 of perchloric acid (H_3PO_4) (70% w/v, S.G 1.67g/cm^3) was then added and the mixture was placed in a sand bath and heated at 55˚C until dense white fumes were observed. It was allowed to cool and filtered into the 100cm^3 volumetric flask and made to the mark. The resulting solution was analyzed for metal concentrations using Atomic Absorption Spectrophotometer Buck scientific, Model-210VGP (Tanee and Amadi, 2016).

Plant tissue analysis

Prior to analyses root and shoot samples were subjected to thorough washing using distilled water to eliminate remaining soil particles adhered to the plant samples. Samples were subsequently oven dried to consistent weights at 105°C. Each dried sample was ground to a powdery form and 0.5 gram of each sample was used for analysis. The measured samples were placed in a crucible and placed into the muffle furnace and subjected to dry ashing at 550°C.The ash was then dissolved in 10ml 0.1M nitric acid, filtered and made up to the 100cm^3 mark and analyzed for metal concentrations using Atomic absorption spectroscopy (Inuwa and Mohammed, 2018).

Photo 1: A picture of *Senna tora* Plant

2.5 Statistical analysis

All data gathered were analyzed statistically using analysis of variance (ANOVA). When significant differences were detected between treatments, Tukey test (at $P < 0.05$) was calculated for each parameter and all graphs were plotted by employing Microsoft Excel.

3. Results and Discussion

3.1 Soil properties

The soil physico-chemical characteristics from the study area have been reported in our earlier works. Results revealed that the area is characterized by sandy texture (66.8%).As indicated from earlier report, the pH of soil was slightly acidic with a value of 6.0 while that of the control is 6.8 (Zakari and Audu, 2021c).

3.2 Potentially toxic elements (PTEs) in Senna tora

Data obtained from the field studies showed that the PTEs concentrations in the plant tissues varied among plant species. Fig 2 depicts the distribution of PTEs contents for the plant *Senna tora* where observed Zn concentrations (mg kg^{-1}) in *Senna tora* were noted. The Zn concentration in *Senna tora* tissues follows the decreasing order pattern as leaf > stem > `root. One-way Anova shows that there is significant difference between the Zn levels in the leaf, stem, root and soil at $P < 0.05$. The Post Hoc Tukey test however, showed that levels of Zn in the leaf portions of this plant is significantly higher than those obtained in the soil, root and stem. There is no significant difference between the levels of zinc in the root and the stem. However, results showed that roots of *Senna tora* were found to accumulate substantial amounts of zinc than leaf and stem as depicted by fig 2. This result agreed with the findings of Suleiman, (2014) who reported a higher Zn accumulation in the leaves of *Senna tora*. The main sources of Zn could be attributed to improper disposal of batteries, excessive use of agricultural fertilizers and soil treated with sludge sewage (Nardis *et al.*, 2018). Zn turns toxic to plants at high dose, however it is a crucial micronutrient typically absorbed in its ionic form (Zn^{2+}) by plants (Guo *et al.*, 2024). It is essential for protein synthesis, reproduction and seed development However, high levels of Zn retards the growth of plants, cause yellowing of the leaves and imbalance between reactive oxygen species (ROS) (Wei *et al.*, 2021).

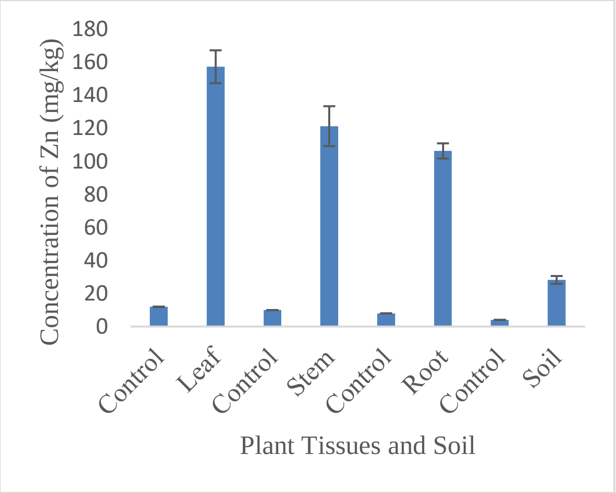

Fig 2: Concentration of Zinc in Tissues and Soil Samples of *Senna tora*

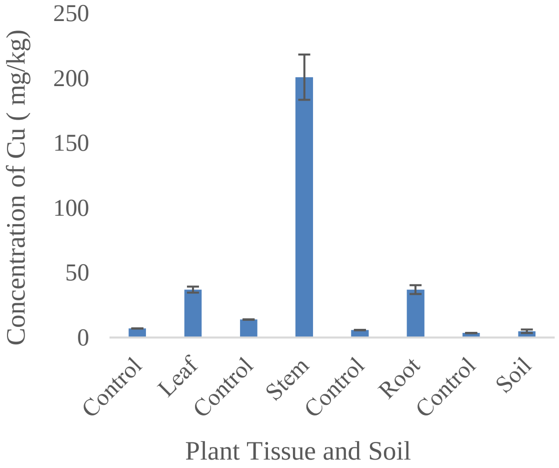

Fig 3: Concentration of Copper in Tissues and Soil Samples of *Senna tora*

The Cu concentration in Senna tora tissues follows the decreasing order pattern as stem > root > leaf. One way Anova shows that there is significant difference between the Cu levels in the leaf, stem, root and soil at $P < 0.05$. The Post Hoc Tukey test however, revealed that the Cu levels in the stem of this plant is significantly higher at $P < 0.05$ than those obtained in the leaf, root and soil. However, there is no significant difference between the levels of Cu in the leaf and root. In addition, the Cu levels in the soil is significantly lower than that of the tissues (leaf, stem and root. However, results showed that stem of Senna tora were found to accumulate considerable amounts of Cu than leaf and root as depicted by Fig 3. This result is consistent with that obtained by (Sharma *et al.*, 2020) for another plant, Chenopodium album (L) in a similar research. When copper is not available, plants develop specific deficiency symptoms, primarily affecting young leaves and reproductive organs (Wang *et al.*, 2024). Plants maintain copper levels in their cells by delivering copper ions into the vacuole when the high concentration of copper in the cytoplasm, and the stored Cu in vacuoles is released for incorporation into various redox proteins in different organelles to function (Wang *et al.*, 2024).

The Cd concentration in the Senna tora tissues follows the decreasing order pattern as leaf > stem>root. One way Anova shows that there is significant difference between the Cd levels in the leaf, stem, root and soil at $P < 0.05$. The Post Hoc Tukey test however, revealed that there are significant differences at $P < 0.05$ between the levels of Cd in soil, root, leaf and stem. However, the Cd levels in the leaf of this plant is significantly higher than those obtained in the stem, root and soil. In addition, it also shows that, the Cd levels in the root is significantly lower than that of the stem and leaf. However, results showed that leaves and stem of Senna tora were found to accumulate considerable amounts of Cd than roots as depicted by Figs 4 & 5. This result agreed with that obtained by Tang *et al.*, (2020) for another leguminous plant fava bean (Vicia fava) where the shoot concentration is high. Anthropogenic activities such as pesticides, sewage sludge and industrial activities are the major sources of Cd in soils (Ahmad *et al.*, 2022).

The Cr concentration in the Senna tora tissues follows the decreasing order pattern as leaf > stem > root. One way Anova shows that there is significant difference between the Cr levels in the leaf, stem, root and soil at $P < 0.05$. The Post Hoc Tukey test however, revealed that, there is significant difference at $P < 0.05$ between the levels of Cr in soil, root, stem and leaf. However, the Cr levels in the leaf of this plant is significantly higher than those obtained in the stem, root and soil. The same table also shows that, the Cr levels in the soil is significantly lower than that of the tissues (leaf, stem and root). In most plants, chromium is mainly present in the roots and is hardly transferred into above-ground parts (Han *et al.*, 2023). However, results showed that leaf of Senna tora were found to accumulate considerable amounts of Cr than the stem, root and soil as depicted by Fig 5. The result of this study show that this plant has the potential for the phytoextraction of Cr. Source of chromium could be attributed to organic fertilizers (like biosolids and phosphorus fertilizers) containing substantial amounts of Cr, which contributes to the Cr-contamination in agricultural soils (Ullah *et al.*, 2023).

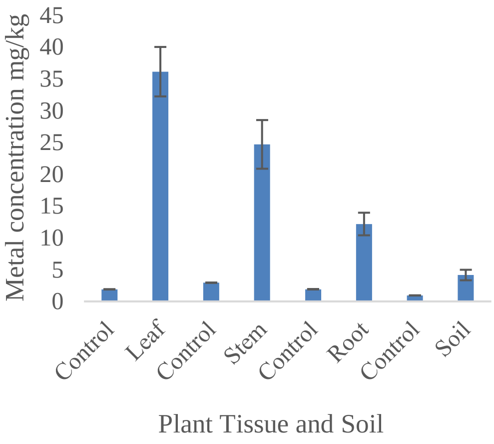

Fig 4: Concentration of Cadmium in Tissues and Soil Samples of *Senna tora*

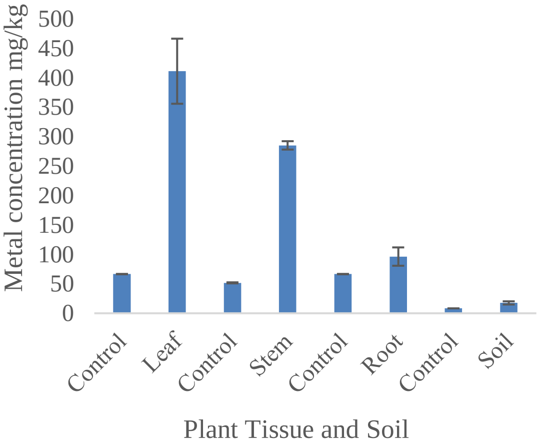

Fig 5: Concentration of Chromium in Tissues and Soil Samples of *Senna tora*

The Pb concentration in the Senna tora tissues follows the decreasing order pattern as root > stem > leaf. One way Anova shows that there is significant difference between the Pb levels in the leaf, stem, root and soil at $P < 0.05$. In a similar study, Badamasi *et al*, (2017), reported more accumulation in roots than shoots for the same plant. This agreed with the result of this study. The Post Hoc Tukey test however, revealed that the Pb levels in the soil is significantly lower than those obtained in the stem, root and leaf. However, there is no significant difference between the levels of Pb in stem, root and leaf. However, results showed that all tissue parts (i.e. stem, root and leaf) of *Senna tora* were found to accumulate substantial proportions of Pb as depicted by fig 6. This agreed with the report by (Zhang *et al.*, 2024) who reported that Pb ions are absorbed by plant roots, they do not only accumulate within root cells but these ions travel through the whole plant system and finally accumulate in the leaf vesicles. The result also agreed with the findings of Udiba *et al.*, (2020) who reported a similar result of high Pb concentration in roots with another similar plant *Senna obstusifolia*. The Ni concentration in the *Senna tora* tissues follows the decreasing order pattern as leaf > stem > root. One way Anova shows that there is significant difference between the Ni levels in the leaf, stem, root and soil at $P < 0.05$. The Post Hoc Tukey test revealed that Ni levels in the leaf of this plant is significantly higher than those obtained in the stem, root and soil. However, there is no significant difference between the levels of Ni in soil and root, root and stem, stem and leaf. However, results showed that leaf of *Senna tora* were found to accumulate quite substantial amounts of Ni than the root as depicted by fig 7. This results agreed with the findings of (Heidari *et al.*, 2020) for another plant *Calendula tripterocarpa* where shoot accumulation is more in the shoots than roots. Sources of Nickel are from anthropogenic activities in the air, water, sediments, and soil. Chemical and physical processes and biological transport mechanisms found in living species introduce Ni into the environment and distribute it across the ecosystem (Mustafa et al., 2023).

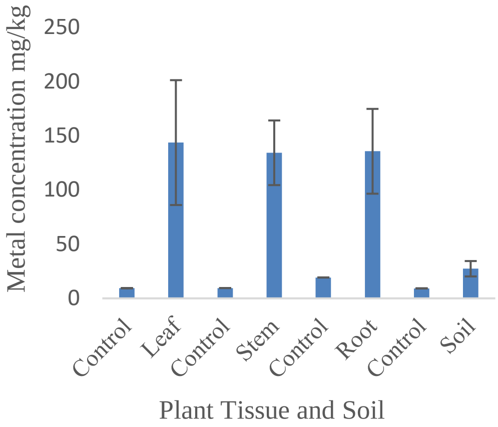

Fig 6: Concentration of Lead in Tissues and Soil Samples of *Senna tora*

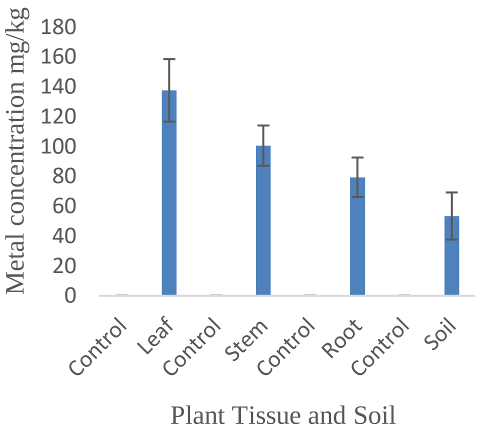

Fig 7: Concentration of Nickel in Tissues and Soil Samples of *Senna tora*

3.3 Bioaccumulation and translocation in Senna tora

The Translocation and Bioaccumulation in *Senna tora* is as shown in Fig 8.

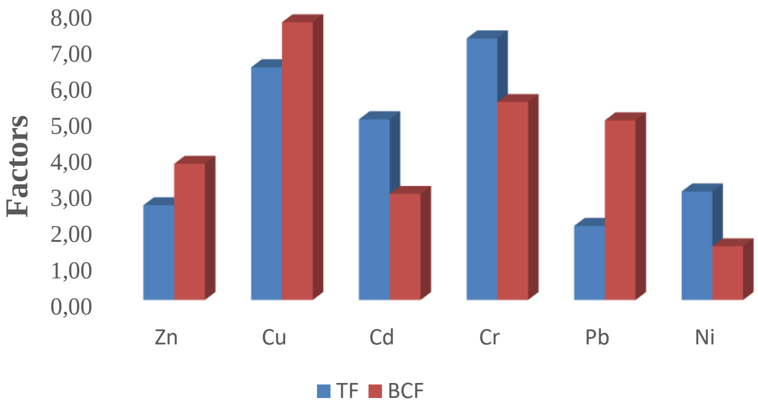

Fig 8: Translocation and Bioconcentration Factor for *Senna tora*

The translocation factor (TF) generally determines a plant capacity in PTEs translocation from the root to shoot, showing the efficiency to uptake the bio-available PTEs from the system. TF gives an idea whether the native plant is an accumulator, excluder or indicator. A plant is considered efficient in metal translocation from root to shoot when TF > 1; indicating an efficient metal transport system. Also TF < 1, suggest an ineffective metal transfer indicating that such plant species accumulate metals within the roots and rhizomes than in the shoot or leaves portions of plants. Bioconcentration factor (BCF) on the other hand, can be used to evaluate a plant's phytoremediation potential. A BCF value > 1 indicate that a plant is a hyperaccumulator whereas, a value less than one is indicative of an excluder. *Senna tora* was screened for Zn, Cu, Cd, Cr, Pb, and Ni. Results show that it has the ability to take up and translocate more than one heavy metal from roots to shoots as shown in figs 8 with noticeable variations between TF and BCF. It is easy for plants species with TF > 1 to translocate metals from roots to shoots than those which restrict PTEs in their roots.

Fig 8 show that *Senna tora* was efficient in translocation of all PTEs from roots to shoots with TF values of 2.62, 6.43, 5.00, 7.23 2.05 and 3.00 for Zn**,** Cu, Cd, Cr, Pb and Ni respectively. This is an indication that the plant is therefore suitable for phytoextraction of these elements. The same Fig 8 which illustrates the BCF values for *Senna tora* with the values of BCF > 1 for all the elements studied viz; Zn (3.77), Cu (7.68), Cd (2.93), Cr (5.47), Pb (4.97) and Ni (1.49). BCF values from this study show the hyperaccumulation of *Senna tora* for these elements in contaminated soils as it had a BCF > 1 and retains high concentration of these metals in its roots which gives it the extra option of being considered for phytostabilization.

Conclusion

Hyperaccumulation and translocation of potentially toxic elements (PTEs) from contaminated industrial soil by *Senna tora* was studied. This study, revealed this plant as a metal resistant specie capable of accumulating high amounts of Zn, Cr, Cd, Cu, Ni and Pb in its tissues. Translocation factor (TF) and Bioconcentration factor (BCF) values obtained from this study show the suitability of this plant for both phytoextraction and phytostabilization. For phytoextraction Cu and Cr are the highest accumulated element of the studied elements in the study area. A similar observation was made for phytostabilization, where these same elements Cu and Cr represented the highest accumulated element, thus throwing up this plant as a very important plant species to be considered for the remediation of multi-element polluted sites where this green technology is desired.

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