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Evaluation of Potentially Toxic Elements Uptake and Translocation in *Senna occidentalis* from Industrially Contaminated Soil

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ABSTRACT

Field samples of *Senna occidentalis,* a shrub, growing in an industrial area with high anthropogenic activities were collected and separated into shoots, roots and associated ground soil to evaluate the accumulation and translocation of Potentially Toxic Elements (PTEs) (Zn, Cu, Cd, Cr, Pb and Ni) from the soil. Atomic absorption spectroscopy (AAS) was used to assess their levels. The bioaccumulation/ transfer of PTEs from roots to shoots, and from soil to roots were evaluated in terms of translocation (TF) and bioconcentration factors (BCF). TF values of 2.51, 2.31, 31.10, 1.32 and 1.41 for Zn, Cu**,** Cd, Pb and Ni respectively showing that *Senna occidentalis* was efficient in translocation of PTEs from roots to shoots, and follows the trend Cd > Zn > Cu > Ni > Pb respectively. This depicts the plant as a likely candidate for phytoextraction of these elements. BCF values of Cr (0.99) and Cd (0.19) were noted. The BCF value is a pointer that the plant specie may be suitable for phytostabilization of Cr and possibly Cd in the contaminated soils as it retains high concentration of these elements in its roots in the area under study.

Keywords: PTEs, *Senna occidentalis*, translocation, phytoextraction, accumulation and phytostabilization.

INTRODUCTION

Anthropogenic activities and industrialization, coupled with burning of fossil fuels and municipal garbage dumping has led to increasing levels of pollution around the world [1-4]. Since metals build up in food crops, prolonged pollution of soil lowers its fertility and microbial biodiversity, leading to a major impact on agricultural yield and quality of human health. Pollution from

Potentially toxic elements damages soils, upsets ecosystems, and harms human health [5]. PTEs are non-biodegradable and persist in the environmental bodies for a long time expanding the negative effect on the environment and ecosystem [6]. PTEs that surpass accepted standards can pose a high risk to ecosystems due to their ecological impacts. A number of methods have been suggested to prevent the entry of PTEs into the food chain through soil remediation. Soil remediation is the process of treating contaminated soil to recover its original state [7]. Over the years, many techniques were developed to treat or remediate sites polluted with metals some of which include chemical, physical and biological methods [8-10] land filling, soil washing, flushing and excavation [11]. However, phytoremediation, a green technology which uses green plants to remove PTEs from soil and other environmental media, offers a promising approach to mitigating environmental pollution in our ecosystem [12-14]. Phytoremediation has been considered one of the most meritorious remediation techniques when it has to do with PTEs removal from soil [15]. 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 [16]. There has been a worldwide desire for cost-effective and efficient solutions to address the issue of PTEs contamination in agricultural soils [1]. Unfortunately, the advantages afforded by phytoremediation as a cheap green chemistry option to alleviate soil contamination has not been explored fully to remove PTEs in these parts of the world.

Senna occidentalis or S. occidentalis (Family: Fabaceae), a shrub that grows on wasteland, was sighted growing well in the study area under investigation and was therefore selected for this study. A number of scholarly articles from literature have shown some plant families such as Fabaceae (legumes) as proven hyperaccumulators of PTEs, of which many can be used to accumulate significant amounts of PTEs [17-21]. According to other earlier reports by Antonsiewicz, Yoon and their co-workers [22], native plants should be preferred for phytoremediation because these plants are often better in terms of survival, growth and reproduction under environmental stress than plants introduced from other environment. Few studies evaluated, under field conditions, the potential of *S. occidentalis* as a native plant which grows naturally at the study site, Challawa Industrial Estate, Kano Nigeria.

To the best of our knowledge, literature regarding accumulation capacity in different tissue portion of this plant is very limited or not even reported, hence this research could be regarded as the first study investigating the accumulation potential of *S. occidentalis* relative to background metal concentration in this Industrial area. With this idea and public concern of metal contamination, this study was designed to assess the potential for accumulation and translocation of PTEs of interest in tissues of this plant.

MATERIALS AND METHODS

;Study area

The field study was carried out in the vicinity of Challawa Industrial area. The area is located in Kumbotso Local Government area of Kano state, Nigeria. Sampling was done 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 used in recording the coordinates and Geographical Information System (GIS) was used to locate the map of the study area as shown in Figure 1.

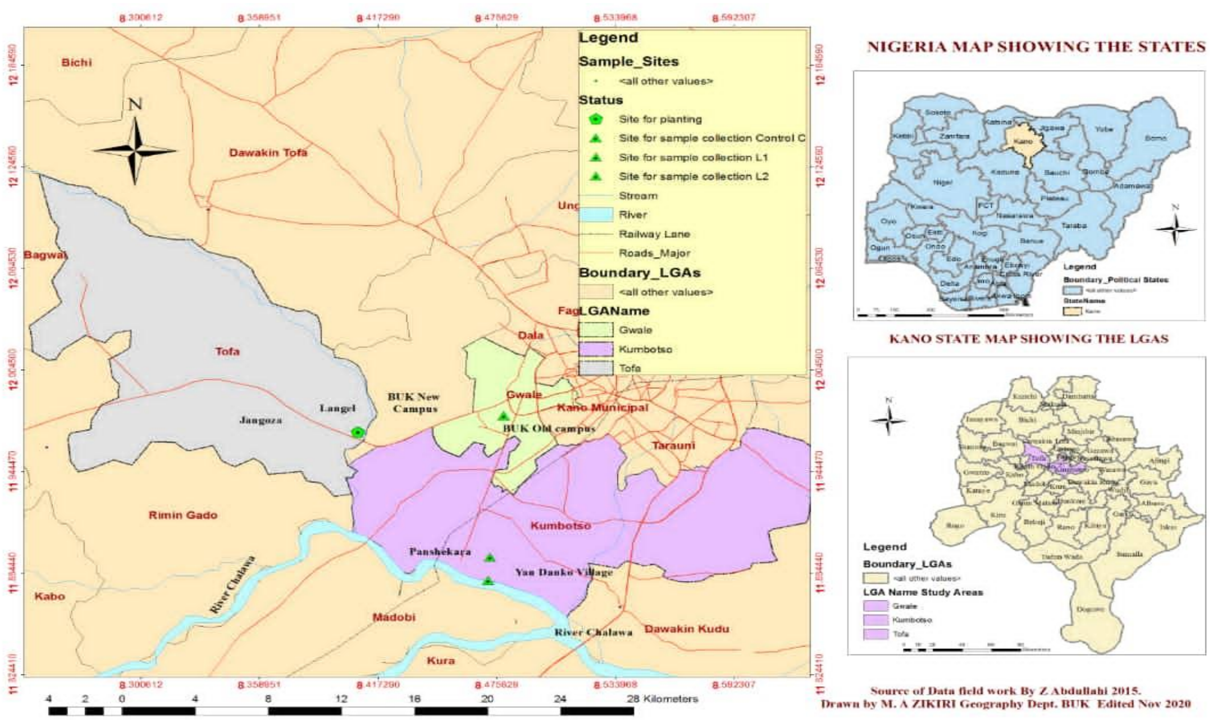

Figure 1: Map of Kumbotso and Tofa LGA Showing Sampling location

Materials

In the preparation of reagents, chemicals of analytical grade purity and deionized water were used throughout the analysis. All the laboratory apparatus (glass wares and the plastic containers) were first soaked in nitric-acid and thoroughly washed with detergent solution, followed by several rinses with tap water, deionized water and finally with the analyte samples.

The plant, *S. occidentalis* was collected from both Challawa Industrial area, Kumbotso LGA of Kano State, Nigeria, and a Control site (Langel village). The plant specie was collected from these sites at almost similar stage of growth. The plant specie collected was identified at the herbarium number of Plant Biology Department of Bayero University Kano and a voucher number *S. occidentalis* (bukhan 0073) was assigned to the plant. The sample was labeled, placed in polythene bags and transported to the University and air-dried.

Soil samples (3) were also collected at each sampling point for the plant and composites samples were prepared and used in the experiments. The soil samples were air dried and ground into fine powder and sieved through 2 mm plastic mesh and stored in labeled polythene bags.
Plate 1 shows the picture of *Senna occidentalis* plant.

Plate 1: A picture *Senna Occidentalis* plant at the screen house

Digestion of Soil Samples

About 1 g of the soil sample from Yandanko, at Challawa was mixed with 20 cm^3 of nitric acid (HNO_3) (70% w/v, S.G 1.42 g/cm^3) and allowed to stand for 1 hour. Approximately, 15 cm^3 of perchloric acid (H_3PO_4) (70% w/v, S.G 1.67 g/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 100 cm^3 volumetric flask and made to the mark. The resultant solution was analyzed for elemental concentrations using Atomic absorption spectrophotometer (Buck scientific, Model-210VGP) [23].

Plant Tissue Analysis

Prior to the analyses root and shoot samples were thoroughly washed using distilled water to remove all adhering soil particles. Samples were then oven dried to constant weights at 105°C. Each dried sample was ground to powder and 0.5 gram of each sample was used for analysis. These samples were placed in a crucible and transferred to the muffle furnace and ashed at 550 ˚C. The ash is then dissolved in 10 ml 0.1 M nitric acid, filtered and made up to the 100 cm^3 mark and analyzed for PTEs content using Atomic Absorption spectrophotometer [24].

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.

RESULTS AND DISCUSSION

Soil properties

The soil physico-chemical characteristics from the study area have been reported in our earlier works. Results indicates 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 [18].

Accumulation of Potentially Toxic Elements in Tissues Portions and Associated Soil of *Senna occidentalis*

The chart showing the distribution of Zn content in *Senna occidentalis* is illustrated in Figure 2**.** The Zn concentration in the 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 $P < 0.05$. This result agreed with that obtained by Sharma et al [25] for *A. philoxeroide* (L.) in a similar research. The Post Hoc Tukey test however, revealed that there is no significant difference at $P < 0.05$ between the levels of zinc in the root, stem and leaf. However, the Zn levels in the soil is significantly lower than that of the tissues.

However, results showed that all three tissue portions (root, stem, leaf) of this plant were found to accumulate high amounts of zinc from the soil as depicted in Figure 2. All results are much higher than the control.

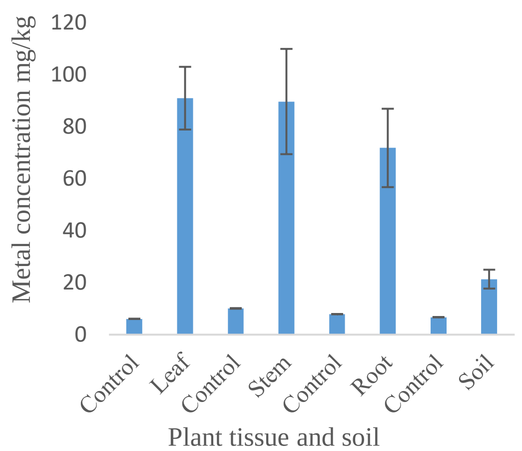

Figure 2: Concentration of zinc in tissues and soil samples of *S. occidentalis*

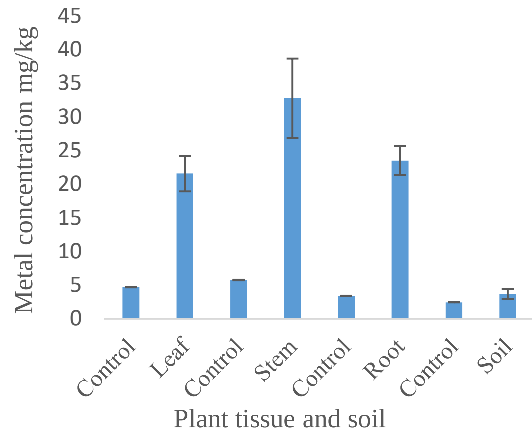

Figure 3: Concentration of copper in tissues and soil samples of *S. occidentalis*

The Cu concentration in the 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 Tukey test however, revealed that the Cu levels in the stem is significantly higher at $P < 0.05$ than those obtained in the root, leaf and soil. However, there is no significant difference between the levels of Cu in the leaf and the root. Also, the Cu levels in the soil is significantly lower than that of the stem, root and leaf. However, results showed that stem was found to accumulate high amounts of Cu than the leaf and root as depicted in Figure 3. This result agreed with that obtained by Sharma et al [25] for *A. philoxeroide* (L.) and *Eclipta alba* with both plants having shoot concentrations higher than the root concentrations.

The Cd concentration in the tissues follows the decreasing order pattern as stem > leaf >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 Tukey test however, revealed that significant differences exist at $P < 0.05$ between the levels of Cd in root, soil, leaf and stem. Moreover, the Cd levels in the root is significantly lower than that of the stem. However, the Cd levels in the stem is significantly higher than those obtained in the root, soil and leaf. Generally, results showed that the stem and leaf were found to accumulate considerable amounts of Cd than root depicted in Figure 4. This result agreed with the findings of Zhu, et al. [26] who obtained high concentrations of Cd in *Festuca arundinacea S* and Indian mustard (*Brassica juncea* L.). This is a sign of great potential for phytoextraction for Cd. Cadmium can be readily taken up by roots and translocated to shoots [27]. The higher Cd content observed in the leaves of this plant could be attributed to the fact that Cd is transported with sap flow hence a greater content in the leaves is observed [28].

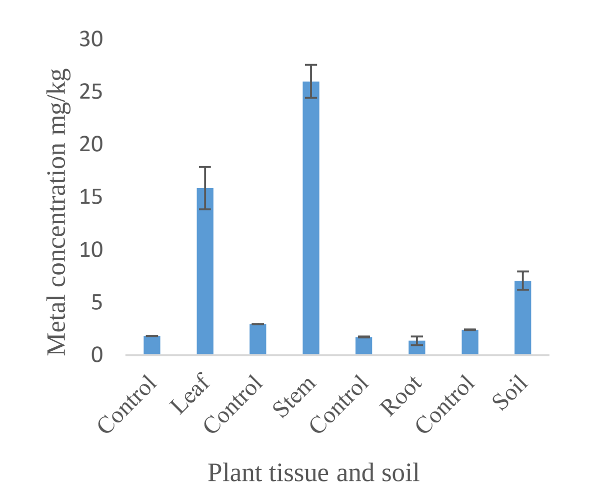

Figure 4: Concentration of cadmium in tissues and Soil Samples of *S. occidentalis*

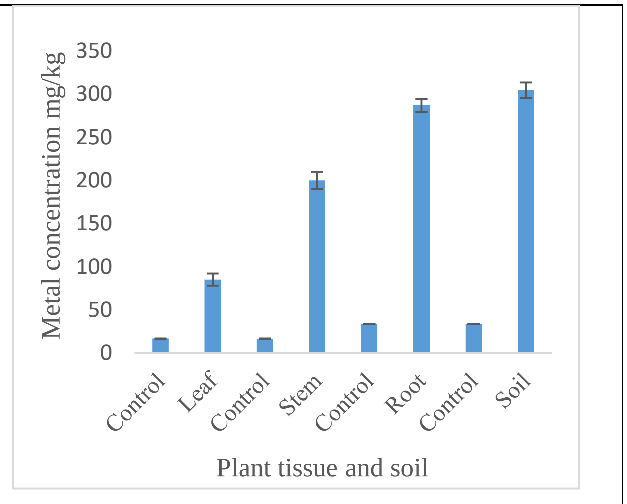

Figure 5: Concentration of chromium in tissues and Soil Samples of *S. occidentalis*

The Cr concentration in the tissues follows the decreasing order pattern as root > stem > leaf. 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 Tukey test revealed that, a significant difference at $P < 0.05$ exist between the levels of Cr in soil, leaf, stem and root. It further shows that, Cr levels in the root and soil are not significantly different from each other. In addition, the Cr levels in the root is significantly higher than those obtained in the stem and leaf. However, results showed that roots were found to accumulate considerable amounts of Cr than leaf and stem as depicted in Figure 5. This result agreed with the findings of Zhang et al [29] who obtained a similar result for high Cr in roots of *Brassica campestris* than the shoots. Mohanty et al. [30] recorded a similar result of high levels of Cr in the roots over the shoots of *Diectomis fastigiata*.

The Pb concentration in the 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 $P < 0.05$. The Tukey test however, revealed that the Pb levels in the root is significantly higher at $P < 0.05$ than those obtained in the stem, soil and leaf. However, there is no significant difference between the levels of Pb in the leaf and the stem. However, results showed that roots were found to accumulate considerable amounts of Pb than leaf and stem as illustrated in Figure 6. This result is consistent with the findings of Madanan et al [31] in a similar research with *Tagetes erecta L* which showed low translocation to aerial shoot portion and greater retention in the roots.

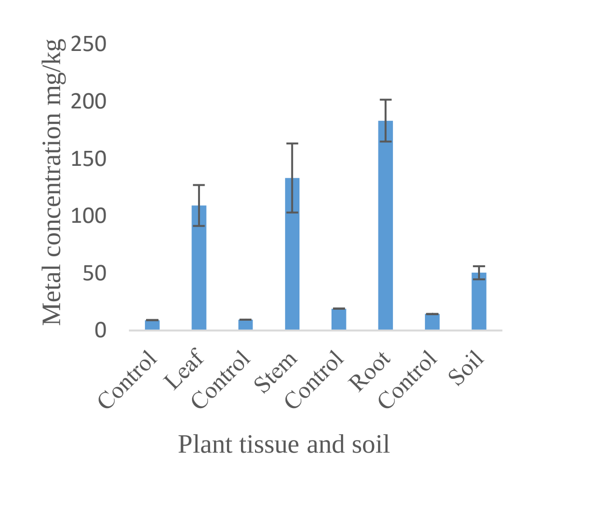

Figure 6: Concentration of Lead in Tissues and Soil Samples of *S. occidentalis*

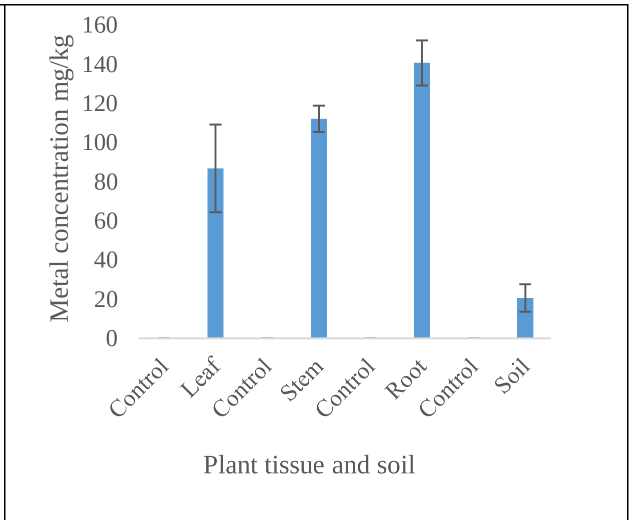

Figure 7: Concentration of Nickel in Tissues and Soil Samples of *S. occidentalis*

The Ni concentration in the SO tissues follows the decreasing order pattern as root > stem > leaf. 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 Tukey test however, revealed that there is no significant difference at $P < 0.05$ between the levels of Ni in leaf and stem. Moreover, the Ni levels in the soil is significantly lower than that of the tissues (leaf, stem and root). However, results showed that the combined shoot portion (leaf+stem) were found to contain fairly large amounts of Ni than the root portion as depicted in Figure 7. This result agrees with the findings of Kumar et al [32] in Ni accumulation for castor bean (*Ricinus communis*).

Bioaccumulation and Translocation of PTEs in *S. occidentalis*.

The Translocation and Bioaccumulation of PTEs in *S. occidentalis* is as shown in Figure 8. The Bioconcentration factor was determined as previously described for in-situ phytoextraction potential in native hyperaccumulator plants [33]. While the translocation factor was evaluated by calculating the ratio of metal concentration in plant shoot and metal concentration in plant root [33, 34].

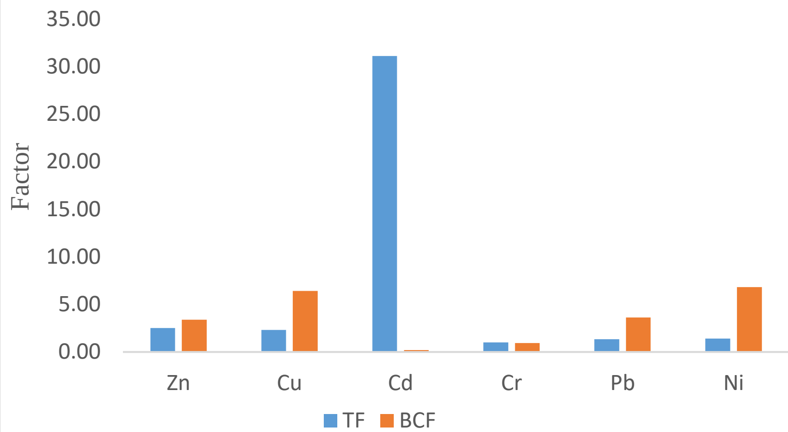

Fig 8: Translocation and Bioaccumulation factor in *Senna occidentalis*

The translocation factors express the ability of a plant to translocate heavy metals from the root to shoot in the soil-plant system [35]. TF determines plant efficiency in heavy metals translocation from the roots to the shoots. It shows whether the native plant can be classified as an accumulator, excluder or indicator. A plant is considered efficient in metal translocation from root to shoot when TF > 1; the reason being an efficient metal transport system TF < 1, suggest an ineffective metal transfer indicating that such plant species accumulate metals mostly or substantially in the roots and rhizomes than in the shoot portions or the leaves of plants [36] Bioconcentration factor 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 [36]. Both BCF and TF have to be considered for evaluating whether a plant is a metal hyperaccumulator. A hyperaccumulator plant should have BCF >1 or TF > 1 [33]. *S. occidentalis* was screened for Zn, Cu, Cd, Cr, Pb, and Ni. Results showed that it has the ability to take up and translocate more than one heavy metal from roots to shoots as shown in fig 8 with observed variations between TF and BCF.

The chat represented in Figure 8 showed that *S. occidentalis* was able to translocate PTEs from roots to shoots with TF values of 2.51, 2.31, 31.10, 1.32 and 1.41 for Zn**,** Cu, Cd, Pb and Ni respectively. This indicates that the plant may be considered for phytoextraction of Zn**,** Cu, Cd Pb and Ni. The exception being Cr with a TF value of 0.99. The same Fig 8 illustrates BCF > 1 for the elements Zn (3.37), Cu (6.42), Pb (3.63), and Ni (6.82) with the exception of Cd (0.19) and Cr (0.94) which had a BCF < 1. Therefore, Cr with a TF value of 0.99 on the one hand and BCF value of 0.94 on the other hand shows that this plant accumulates this metal more in the roots than in the shoots indicating ineffective transfer. A similar observation was made for BCF value of Cd which is less than unity. In general, BCF values from this study show that *S. occidentalis* may be suitable a candidate for phytostabilization of Cr and possibly Cd in soil as it still retains high concentration of these metals in its roots.

CONCLUSION

The potential for phytoremediation through bioaccumulation of *S. occidentalis* against six PTEs (Zn, Cr, Cd, Cu, Ni and Pb) was studied. From this study, we can reasonably conclude that the plant is a resistant species containing in its tissues amounts of PTEs that were much higher than those considered toxic for normal plants. Based on the translocation factor and the bio concentration factor (BCF) values, the study showed the suitability of this plant for both phytoextraction of Zn**,** Cu, Cr and Ni and phytostabilization of Cd and Pb in the study area and where desired.

Author's contributions: Dr Abdullahi Zakari conducted the research, Drs Dahiru Wakili Habib and Isah Balan contributed valuable insights on soils while Prof A.A Audu supervised the research.

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