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Bioaccumulation and Translocation of Potentially Toxic Elements (PTEs) by *Khaya Senegalensis* at Challawa Industrial Estate, Kano, Nigeria

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Abstract

Field samples of *Khaya senegalensis,* an *African mahogany,* growing in an industrial area with high anthropogenic activities(Challawa) were collected and were 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. Atomic Absorption Spectroscopy (AAS) was used to assess the concentrations. The bioaccumulation/ transfer of metals from roots to shoots and from soil to roots were evaluated in terms of translocation and bioconcentration factor. TF values of 2.53, 2.86 , 2.38, and 1.78 for Zn **,** Cd , Cu and Ni respectively indicate that *Khaya senegalensis* was efficient in translocation of PTEs from roots to shoots and follows the trend Zn > Cd > Cu > Ni respectively. This is an indication that the plant is therefore suitable for phytoextraction of Zn**,** Cd, Cu and Ni. BCF shows values of Cu (1.65), Cd (5.65), Cr (7.26), Pb (1.82), Ni (2.08) and Zn(0.710) and follows the trend Cr > Cd > Cu > Pb > Ni > Zn This show that *Khaya senegalensis* may be suitable a candidate for phytostabilization of Chromium and lead in contaminated soils as it retains high concentration of these metals in its roots. Based on the translocation factor (TF) and the bio concentration factor (BCF) values, the study show the suitability of this plant for both phytoextraction of Zn**,** Cu, Cd and Ni and phytostabilization of Cr and Pb in the study area and where desired.

1. Introduction

Soil, an important sink of nutrients and pollutants, plays a vital role in environmental sustainability and security [1]. Regrettably, soil pollution has turned out to be a drawback of some kind in terms of development and wellbeing of humans in recent years as a result of heavy metal contamination due to industrial and agricultural activities [2, 3, 4 and 5]. Heavy metals, which are among the Potentially Toxic Elements (PTEs), are defined as metals or metalloids known to be harmful to living organisms if in sufficiently high concentrations in soil [6] and have become the focus of attention in recent years owing to the fact that they could be a threat to human health and biosphere at a trace level due to their universality, toxicity and tenacity [7].

Over the years various research have been conducted to mitigate this challenging scenario. Some physical, chemical and biological techniques have been advanced to remediate metal contaminated soils. Most of these techniques are conventional remediation technologies which has to do with physical, and chemical methods in order to bring contamination to adequate level [8]. However, phytoremediation has been recognized as cost effective method for remediation of metal contaminated soils [9]. It involves transformation by plants, each possessing a different approach to remediate soils contaminated with metals [10].One of such approach, phytoextraction uses plants ability to assimilate toxic metals from belowground parts and transfer them to other tissues of plants where they may accumulate [11]. Phytoextraction is a solar-driven technique which uses plant roots to translocate heavy metals from soil to other tissues of plants located above the ground [12].As for phytostabilization, it's a technology which utilizes the ability of plants to reduce the bioavailability and mobility of toxic metals and stabilize them below the ground in soils [13].

Despite the fact that traditional phytoremediation by using green plants to alleviate soil contamination seems a viable approach to tackle the Problem of Potentially toxic elements, it has not been applied successfully as a result of a number of limitations. Its main drawback is the later use of the contaminated biomass generated from the phytoremediation process [14]. Others are, the fact that it takes time to clean up the contaminated soil and very small concentrations of metals is bioavailable which varies with some soil properties like pH and organic matter [15]. *Khaya senegalensis* (Family: Meliaceae) was selected for this study. To the best of our knowledge, this is the first study examining *Khaya senegalensis* accumulation capacity relative to background metal concentration in this industrial area. The aim of the study is two pronged. Firstly, to assess the accumulation and translocation of six heavy metals in tissues of this plant growing naturally at Challawa Industrial Estate. Secondly, to look at the suitability of using this plant for phytoremediation and as potential bio-indicators for metal contamination of soils. A picture of the plant, *Khaya senegalensis* is shown in **Figure 9**.

2. Methodology

2.1 Preparation of reagents

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.

2.2 Study Area

The field study was carried out in the vicinity of Challawa Industrial area. The area is located in Kumbotso local government of Kano state. 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 below in **Figure 1.**

2.3 Field sampling of soil and plant specie (Yan danko challawa and Langel village).

Nine sampling points from three locations were systematically established after every 100m. *Khaya senegalensis* was collected for analysis with at least three species per sampling point including the control site (Langel village), which was far away from Challawa Industrial area. The plant specie was collected from these sites at almost similar stage of growth as that from the Challawa sample and were used as the control. Identification of the collected plant specie was done at the Plant Biology Department of Bayero University Kano and a herbarium number *Khaya senegalensis (bukhan 0116)* 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 obtained. The composite soil samples were air dried and ground into fine powder using pestle and mortar and sieved through 2mm plastic mesh and stored in labeled polythene bags.

2.4 Experiments

Details of soil digestion are as described in previous reports [16]. Plant tissue analysis are as described in previous reports [17].

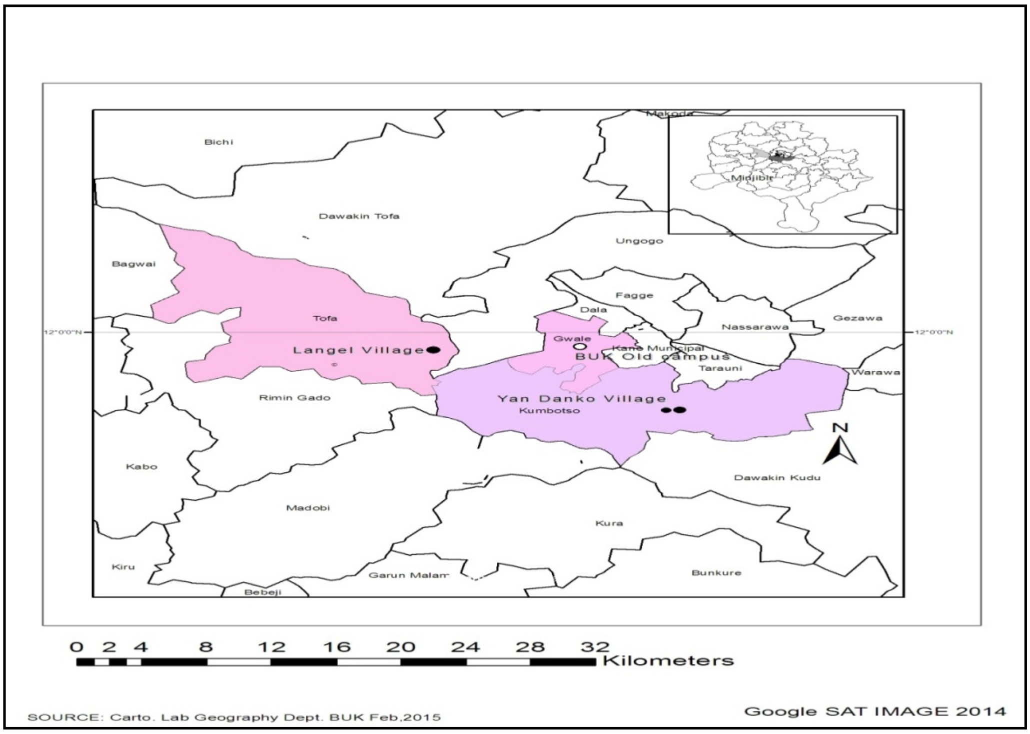

Figure 1. **Map of Kumbotso and Tofa LGA showing sampling location**

3. Results and Discussion

3.1 Soil properties

The soil physico-chemical characteristics from the study area under investigation are presented in **Table 1.** Results revealed that the area is characterized by sandy texture (66.8%). As a result the pH of the soil was slightly acidic with a value of 6.0 while that of the control is 6.8. Lower pH values in soil leads to higher heavy metal solubility [18].

Table 1. **Physico-chemical properties for soil from the sampling locations**

Parameter	Study Area	Control	*RVAS[19]
pH	6	6.8	6-7.8
EC(µs/cm)	41.6	13.66	
Total organic carbon (%)	0.1596	0.0399	0.8-1.2
Total N (%)	0.07	0.07	0.05-0.3
Sand (%)	66.8	58.8	variable
Silt (%)	14	32	variable
Clay (%)	19.2	9.2	variable
Zn(mg/kg)	87.04±0.5	35.09±0.03	
Cd(mg/kg)	11.38±0.281	9.43±0.28	
Cu(mg/kg)	19.83±0.86	15.71±0.6	
Cr(mg/kg)	39.00±5.20	8.33±0.00	
Pb(mg/kg)	28.57±0.00	7.93±2.75	
Ni(mg/kg)	34.92±2.75	17.46±5.49	

**(RVAS) = Recommended values for agricultural soil* [19]

3.2 Concentration of potentially toxic elements (PTEs) in tissues

The data from the field studies show that the PTEs levels in the plant tissues varied among plant species, which reflected the edaphic metal conditions in the area. Metal levels in plant tissues differed among species at the same location indicating their different capacities for metal uptake. Normal concentrations of Pb, Cu, Zn and Cd in mg kg^{-1} were reported as 5–10 for Pb, 20–30 for Cu, and 27–150 for Zn 0.05–0.2 for Cd, 0.01–0.05 for Cr and 0.1–5 for Ni while excessive levels (mg kg^{-1}) for Pb, Cu, Zn, Cd, Cr and Ni were 30–300, 20–100, 30–300, 5–30, 5–30, 10–100 respectively [20]. In *K. senegalensis*, depicted by **Figure 2**, the Zn concentration in the tissues follows the decreasing order pattern as stem > root > leaf. One-way Anova (Zhu et al., 2020) [11] 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, revealed that the Zn levels in the stem of *Khaya senegalensis* plant is significantly higher than those obtained in the leaf and root. Results showed that stem of *Khaya senegalensis* were found to accumulate considerable amounts of zinc than leaf and root of *K. senegalensis* as depicted by **Figure 2**. This result agree to the findings of [4] with another woody species *Salix psammophila* which showed a higher concentration of Zn in its shoots (stem plus leaf).

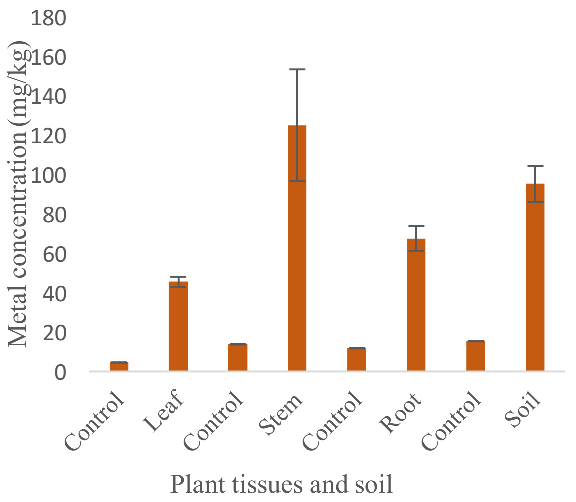

Figure 2. Distribution of Levels of Zinc in Tissues and Soil Samples of *Khaya senegalensis*

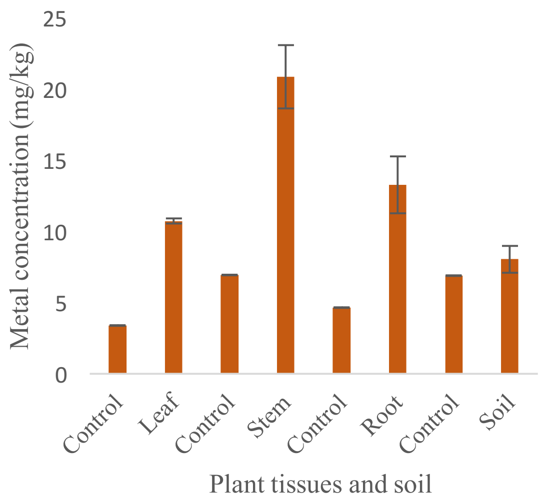

Figure 3. Distribution of Levels of Copper in Tissues and Soil Samples of *Khaya senegalensis*

The Cu concentration in the *Khaya senegalensis* tissues follows the decreasing order pattern as stem > root > leaf. One-way Anova [10] shows that there is significant difference between the Cu levels in the leaf, stem, root and soil at $P < 0.05$. However, the Cu levels in the stem of *Khaya senegalensis* plant is significantly higher than those obtained in the root, leaf and soil. Results showed that the stem portion of *Khaya senegalensis* were found to accumulate high amounts of Cu than leaf and root as depicted by **Figure 3**. This result differs with the findings of [10] with the woody specie willow, *Salix spp* which accumulated in high quantities of Cu in the shoots. Copper is typically found in concentrations of about <10 mg kg^{-1} in plants [6], but in this study it exceeded this value in the roots and shoots of the plant.

The Cd concentration in the *Khaya senegalensis* tissues follows the decreasing order pattern as leaf > stem> root. One-way Anova [21] 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 the Cd levels in the leaf of *Khaya senegalensis* plant is significantly higher than those obtained in the stem, soil and root. However, results showed that leaf portion of *Khaya senegalensis* was found to accumulate considerable amounts of Cd than the stem and root as depicted by **Figure 4.** This result agrees with the findings of [22] for the same plant which had higher Cd levels in the leaf tissues than the root. Higher concentrations of cd has been shown to minimize cell and whole plant growth [23].

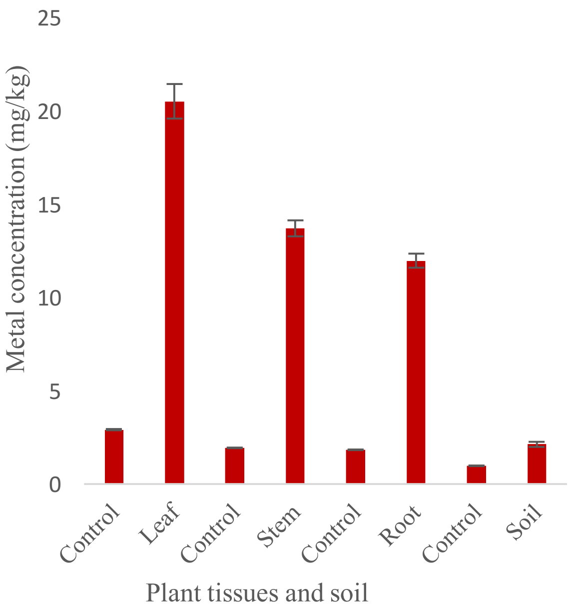

Figure 4. Distribution of Levels of Cadmium in Tissues and Soil Samples of *Khaya senegalensis*

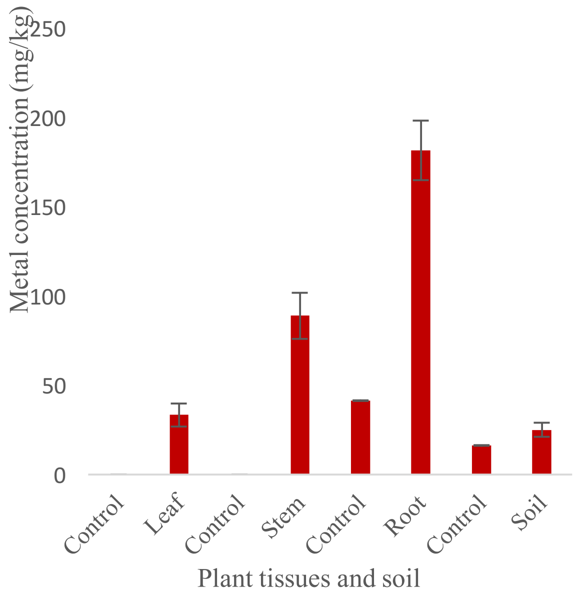

Figure 5. Distribution of Levels of Chromium in Tissues and Soil Samples of *Khaya senegalensis*

The Cr concentration in the *Khaya senegalensis* tissues follows the decreasing order pattern as root > stem > leaf. One-way Anova [10] 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 the Cr levels in the root of *Khaya senegalensis* plant is significantly higher than those obtained in the stem, leaf, and soil at $P < 0.05$. However, results showed that roots of *Khaya senegalensis* were found to accumulate considerable amounts of Cr than leaf and stem of as depicted by **Figure 5**. Previous research reports on heavy metal accumulation by terrestrial plants have shown that roots have higher metal deposition than other parts of plants [24]. This is consistent with the findings of our study.

The Pb concentration in the *Khaya senegalensis* tissues follows the decreasing order pattern as root > leaf > stem. One-way Anova [25] shows that there is significant difference between the Pb levels in the leaf, stem, root and soil at $P < 0.05$. The Post Hoc Tukey test however, revealed that the Pb levels in the root of *Khaya senegalensis* plant is significantly higher than those obtained in the stem, soil and leaf. Also, the Pb levels in the stem is significantly lower than that of the root. However, results showed that roots of *Khaya senegalensis* were found to accumulate considerable amounts of Pb than leaf and stem of *Khaya senegalensis* as depicted by **Figure 6**. Our results is similar to the findings of [26] who reported high levels of Pb in the roots of *Eclipta alba (L)*.

The Ni concentration in the *Khaya senegalensis* tissues follows the decreasing order pattern as root > stem > leaf. One-way Anova [5] 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 the Ni levels in the soil is significantly lower than the levels in the leaf, stem and root. However, there is no significant difference between the levels of Ni in the leaf, stem and root. However, results showed that the leaf, stem and root of *Khaya senegalensis* were found to accumulate large amounts of Ni as depicted by **Figure 7**. This is an indication that Ni can be accumulated in all organs of this plant. This results agrees with the findings of [22] who reported high accumulation for the roots of the same plant. A similar observation was made for another plant *Medicago lupulina L* where nickel concentration is high in the roots [27].

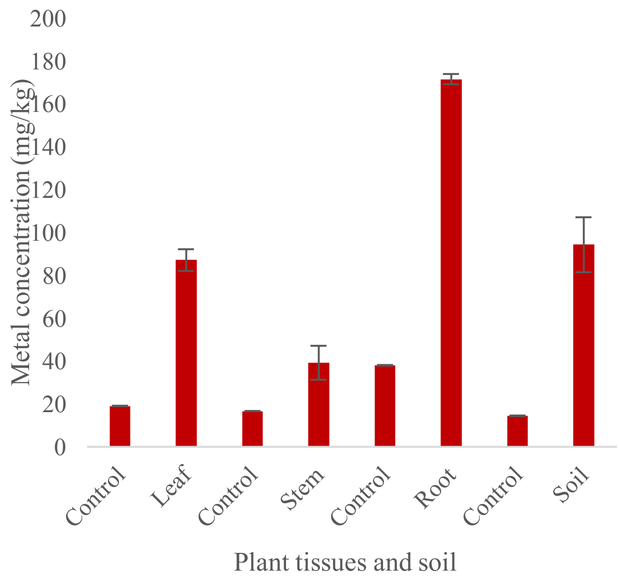

Figure 6. Distribution of Levels of Lead in Tissues and Soil Samples of *Khaya senegalensis*

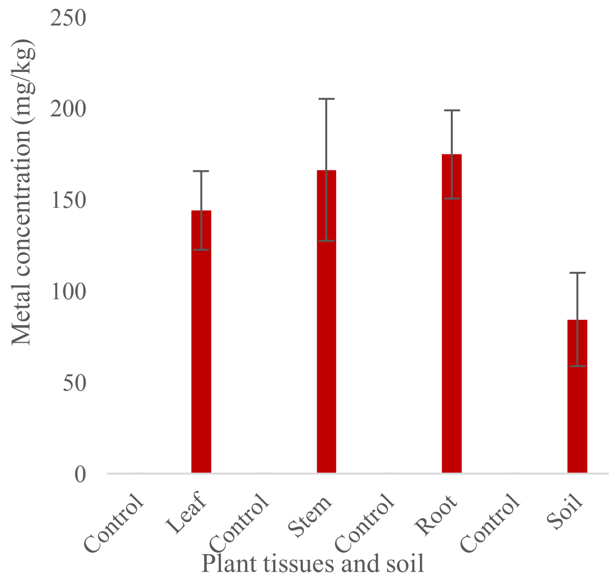

Figure 7. Distribution of Levels of Nickel in Tissues and Soil Samples of *Khaya senegalensis*

3.4 Bioaccumulation and translocation in Khaya senegalensis

The Translocation and Bioaccumulation in *Khaya senegalensis* is as shown in **Figure 8a-b** respectively. The translocation factors (TF) generally determine a plant capacity in heavy metals translocation from the root to shoot, demonstrating 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.

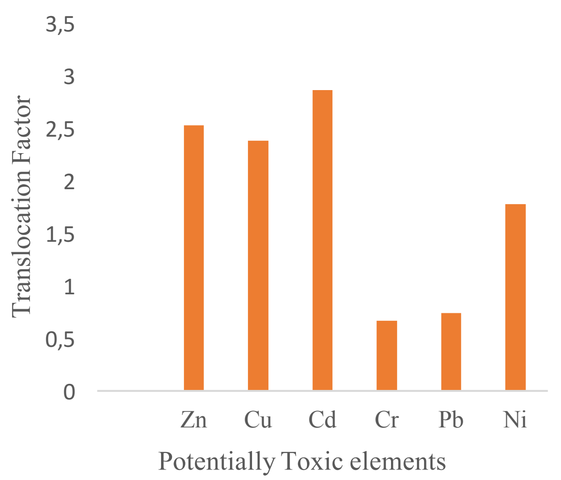

Figure 8a: Translocation factor of the six potentially toxic elements in *Khaya senegalensis*

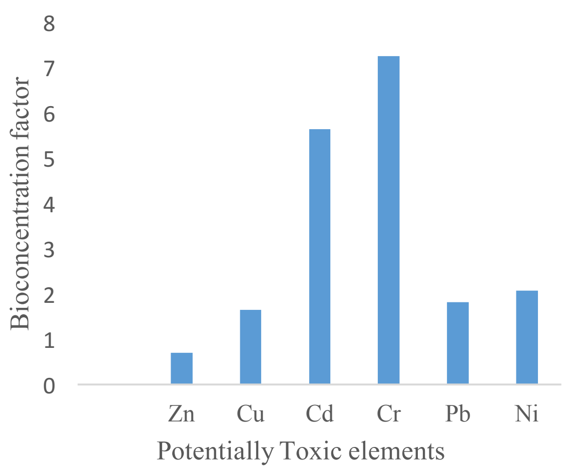

Figure 8b: Translocation factor of the six potentially toxic elements *in Khaya senegalensis*

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. 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. *Khaya senegalensis* 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 **Figure 8a-b** 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.

Figure 8a show that *Khaya senegalensis* was efficient in translocation of PTEs from roots to shoots with TF values of 2.53, 2.38, 2.86 and 1.78 for Zn**,** Cu, Cd and Ni respectively. This is an indication that the plant is therefore suitable for phytoextraction of Zn**,** Cu, Cd and Ni. The exception being Cr and Pb with a TF value of 0.67 and 0.74. In **Figure 8b**, which illustrates the BCF values for *Khaya senegalensis*, BCF > 1 were observed for the elements Cu (1.65), Cd (5.65), Cr (7.26), Pb (1.82), and Ni (2.08), with the exception of Zn (0.71) which had a BCF < 1. In general, BCF values from this study show that *Khaya senegalensis* may be suitable a candidate for phytostabilization of Chromium and lead in contaminated soils as it retains high concentration of these metals in its roots as seen with the low TF value of Cr (0.67) and Pb (0.74) and high BCF of Cr (7.26) and Pb (1.82).This limit their mobility from roots to shoots once absorbed by roots of the plant.

Figure 9 *:(A picture of Khaya senegalensis tree(African Mahogany)*

Conclusion

The potential for phytoremediation through bioaccumulation of *Khaya senegalensis* against six PTEs (Zn, Cr, Cd, Cu, Ni and Pb) was studied. In the course of 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 (TF) and the bio concentration factor (BCF) values, the study show the suitability of this plant for both phytoextraction of Zn**,** Cu, Cd and Ni and phytostabilization of Cr and Pb in the study area and where desired.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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