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Assessment of Phytoremediation Potential of Indigenous Flora around the Steel Industries in Nigeria Ajaokuta Steel Company Limited, Ajaokuta, Kogi State, Nigeria

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Abstract

In recent years, with the development of the global industrialization, the content of heavy metals in the soil caused by industrial activities has gradually increased, resulting in environmental deterioration. There is a need to provide viable option that is economical, environmental friendly and sustainable for clean-up of environmental contamination such as phytoremediation. Series of studies conducted in the past on heavy metals content in soil around Ajaokuta Steel Company Limited (ASCL) without considering the remediation technologies of such contents. This study primarily assessed the phytoremedial potential of indigenous flora around Ajaokuta Steel Company Limited Ajaokuta, Kogi State, Nigeria. To achieve this, top and sub soil samples along with control were collected around the vicinity of ASCL for heavy metals analysis. Four different indigenous plants (*Imperata cylindrica* (Spear grass or cotton wool grass), *Sida acuta* (Wire weed), *Helianthus annuus* (Sunflower) and *Chromoleana odarata* (Siam weed) grown within the vicinity of the ASCL were randomly collected for heavy metals analysis. The samples were digested and analyzed using Atomic Absorption Spectrophotometer (AAS) (Perkin Elmer® Analyst 100 model). The data obtained were analyzed using SPSS 20 for descriptive and inferential statistics. The metal transfer factors were also determined. The results obtained revealed that the potential of remediating Lead by *C. odarata* was high compared to other plant species which uptake 10.33 mg/kg, 20.11 mg/kg, and 25.32 mg/kg in the leaves, stem and root respectively. The bioaccumulation level of Lead in *C. odarata* and *H. annus* were recorded to be 0.91 mg/kg and 0.71 mg/kg respectively which indicated highest bioaccumulation factor. Unlike the bioaccumulation factors, the translocation factors were high in all the heavy metals investigated. The study revealed that *C. odarata*, *I. cylindrica* and *S. acuta* are good accumulators of heavy metals and they should therefore be encouraged to be cultivated. The plant species may be regarded as hyperaccumulators, which is characterized by their ability to accumulate high quantities of metals in their tissues.

Keywords: Hyperaccumulators; Heavy metals; Phytoremediation; Indigenous flora

Introduction

Environmental contamination by heavy metals is a serious problem arising from the rapid industrialization and urbanization resulting in environmental degradation [1-3]. The global problem concerning contamination of the environment as an aftermath of anthropogenic activities is on the increase which has resulted in environmental build up of waste products of which heavy metals are of particular concern [4]. Soil is one of the natural resources that provide essential elements and interrelating functions which include as a store for biodiversity, natural habitat for living organisms, food and biomass production as well as a relatively stable reservoir for the whole ecosystem. However, it can easily deteriorate by both anthropogenic and natural changes [5,6]. The uptake of toxic heavy metals from contaminated soils by food and foliage plants comprises a prominent path for such elements to enter the food chain and finally be ingested by human. Ingestion and eventually accumulation of toxic heavy metals pose a threat to human health and should be minimized [7-9] (Figures 1 and 2).

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Many clean-up technologies have been developed for the treatment of contaminated soils in which few were effective in the removal of heavy metals from the contaminated soils [10]. The use of plants and associated microorganisms to remove or degrade harmful environmental contaminants and to revitalize contaminated sites is gaining more attention [11]. Plants have evolved potential mechanisms like detoxification of metals in the roots and tolerance to metal stress by preventing the accumulation at the sensitive sites [12]. Effective phytoremediation depends upon correct selection of local plant species, preferably with hyper-accumulator characteristics that can grow on land of marginal quality in terms of fertility, age; texture and structure of polluted soil and mixture of metals present [13,14].

Some plants are tolerant and are able to accumulate such metals in appreciable quantities due to their effective uptakes and translocations and are regarded as accumulators [15]. The uptake and transfer of heavy metals from soil to plants is a process of significant importance in determining the transfer factor (TF) and translocation index (Ti) of the plants. Plants take up or hyperaccumulate contaminants through their roots and store them in the tissues of the stem or leaves, though these contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. However, the metals can be recovered for reuse by phytomining [16].

Studies conducted have looked specifically at the contents of heavy metals around the ASCL, Kogi State, Nigeria without considering the remediation technologies of such contents [17]. In other to provide viable, more cost-effective, environmental friendly and sustainable clean-up technologies for environmental contaminants, this study assessed the potential of indigenous plant species for phytoremediation of heavy metals in soils around Ajaokuta Steel Company Limited, Kogi State, Nigeria.

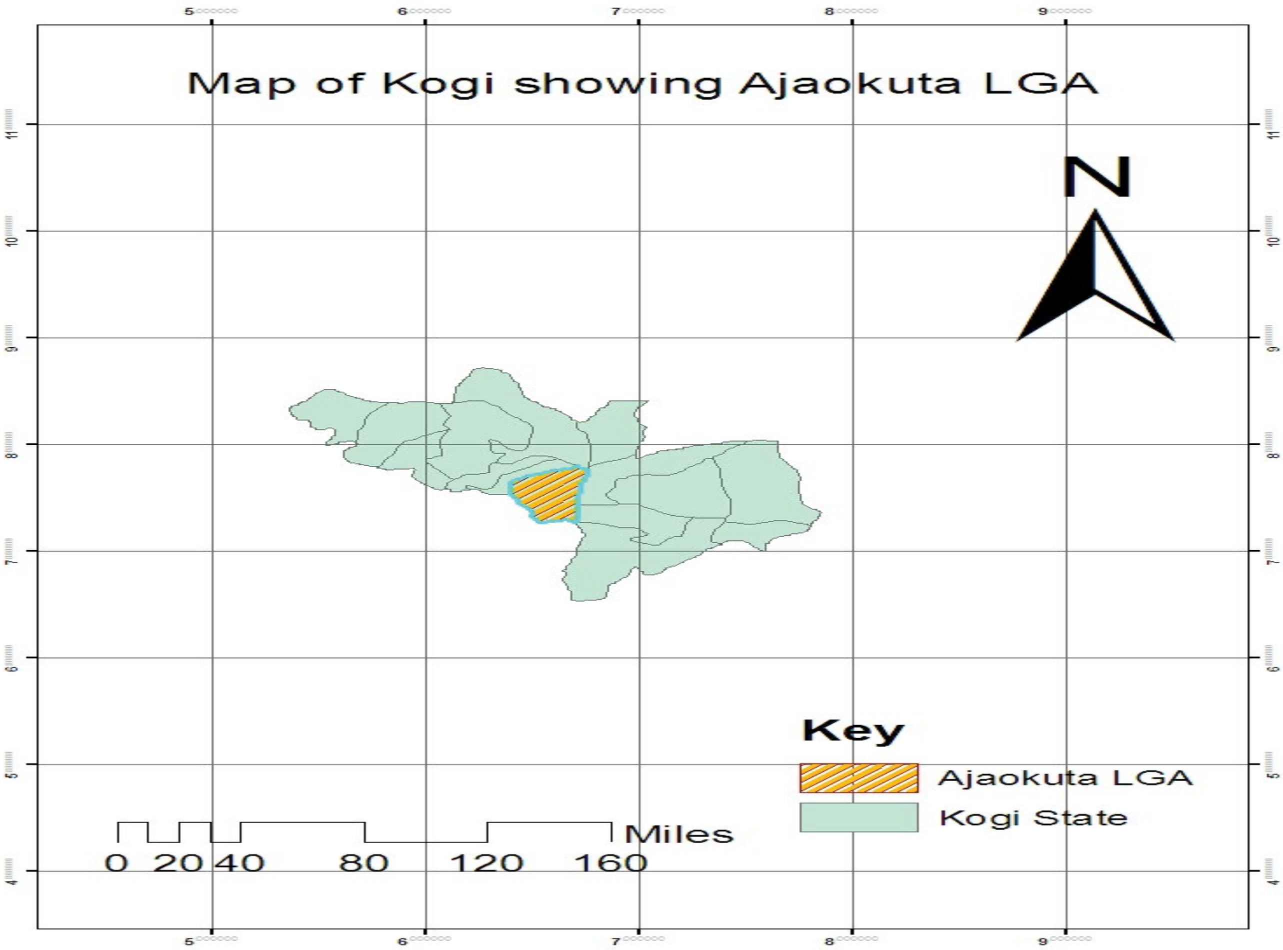

Figure 1. Map of Kogi State showing Ajaokuta, LGA Kogi State, Nigeria.

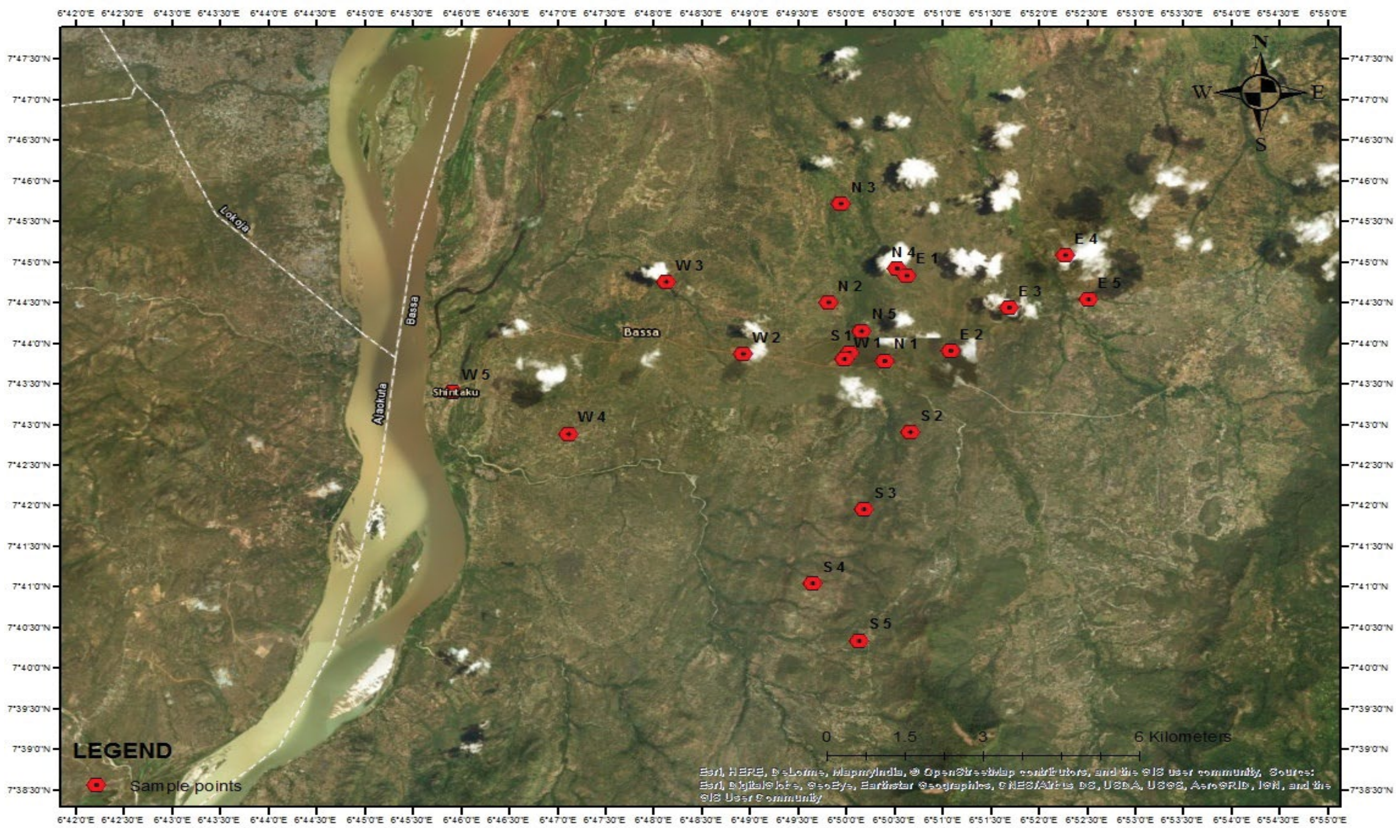

Figure 2. Geo-reference of plants and soils sampling points around the ASCL, Kogi State, Nigeria.

Materials and Methods

Study area

Ajaokuta Steel Company Limited is located in Ajaokuta Local Government Area of Kogi State, along the bank of lower river Niger region in North Central Nigeria, with Latitude 70 33` 44.24``N and Longitude 60 39` 17.89``E and altitude range 74-187 metres with an area of 1,362 km² and a population of 122,321 at the 2006 census [18].

Collection of samples

Plant species: Vegetation study was carried out based on the predominant native flora and four different indigenous plants grown within the four cardinal points (vicinity) of the ASCL were randomly collected with a stainless steel trowel and knife. The plants were *Imperata cylindrica* (Spear grass or cotton wool grass), *Sida acuta* (Wire weed), *Helianthus annuus* (Sunflower) and *Chromoleana odarata* (Siam weed). The plant species was properly labeled and packed in polyethylene bags. The plant species were identified and classified taxonomically with the help of taxonomists. Samples of the same plant species were also collected as control from the farms which are away from the sampling site. Each plant sample was separated into leaves, stem and root and the components were cut into pieces. The samples were rinsed with distilled water and dried to a constant weight in an oven at temperature of 70°C for 48 hours so as to deactivate the enzymatic activities. Thereafter, each part of the samples was mechanically grounded into fine powdery using an agate mortar and was further dried to obtain a constant weight.

Soil samples: Five sampling spots at a distance of 50 m from each other were mapped out for each top and sub soil samples collection within the sampling site, using a clean stainless trowel from 0-15 cm depth. A soil sample which served as control was also collected. The soil samples were manually sorted to remove coarse materials and air-dried under ambient conditions in the laboratory for 72 hours. The samples were thoroughly mixed in a clean plastic bucket to obtain composite samples (top and sub) and sieved with 2 mm mesh size [19].

Sample treatment

Five grams (5 g) of prepared soil samples were digested with 15 ml nitric acid, 20 ml perchloric acid and 15 ml hydrochloric acid and placed on a hot plate for 3 minutes. On cooling, the digest was filtered into a 100 ml volumetric flask and made up to the mark with distilled water [19]. One gram (1 g) of the dry plant sample was placed in a test tube, treated with 5ml of a 5:1 mixture of Aqua regia (HNO_3-HCl) and perchloric acid ($HClO_4$) [20]. The digested samples were analyzed for the selected heavy metals (Cd, Cu, Zn and Pb) using Atomic Absorption Spectrophotometer (AAS) (Perkin Elmer® Analyst 100 model). In addition to metal concentration, the pH, percentage of organic matter and percentages of sand, silt, and clay of the soil were determined using Orion 920 A pH meter; Walkley and Black method and Hydrometer method respectively as described by White [21].

Metal transfer factor

Bioaccumulation Factor (BAF): Plant ability to take up heavy metals from the soil was evaluated by determining the ratio of element concentration in plants to element concentration in soil, i.e., the plants with a high BAF >1, (i.e., metal concentration ratio of plant roots to soil) are suitable for phytoextraction.

Translocation Factor (TF): By determining the ratio of element concentration in plant shoots to element concentration in roots, i.e., Plant with low TF <1, i.e., metal concentration ratio of plant shoots to roots has the potential for phyto-stabilization.

Pollution Index (PI): Is the ratio of concentration of heavy metal in the soil to concentration of metals in the permissible standards as described by Cheraghi et al. [22].

Statistical analysis

The data obtained were analyzed using SPSS 20 for descriptive and inferential statistics. One way analysis of variance (ANOVA) was used to determine the level of significance at $p<0.05$.

Results

The average pH of the soil sample was 6.50 which are within the WHO permissible limit of 6.5-8.5. The sample has very low percentage of organic matter (1.34 ± 0.5) which may be absent in the ammonium, nitrate and organic forms (Table 1).

Table 2 showed that all the heavy metals from the top and sub soil around ASCL do not exceed the limits with their pollution index (PI). *H. annuus* has no potential of remediating Cadmium as the levels in leaves, stem and root showed appreciably low values of 0.001 mg/kg, 0.002 mg/kg and 0.003 mg/kg respectively. This indicates that *H. annuus* is a poor phyto-extractor of Cadmium. Unlike the *C. odarata* which uptake the Cadmium both on their leaves, stems and roots as 0.03 mg/kg, 0.04 mg/kg and 0.06 mg/kg. *C. odarata* and *I. cylidrica* are hyper-accumulators of Cadmium (Figure 3). The levels of Copper uptake in leaves, stems and roots were high in all the plant species especially the *C. odarata* (8.45 mg/kg, 10.00 mg/kg, 12.55 mg/kg) (Figure 4). The potential of remediating Lead by *C. odarata* was high compared to other plant species which uptake (10.33 mg/kg, 20.11 mg/kg, and 25.32 mg/kg) in the leaves, stem and root respectively (Figure 5). The selected plant species have the ability to remediate the Zinc except the *H. annus* which low values (4.11 mg/kg, 6.21 mg/kg and 9.23 mg/kg) in their phyto-remediative parts (Figure 6). In general, the phyto-remediation potential of the selected plant species for heavy metals was high in the roots as depicted in Figures 7 and 8. The percentages of heavy metals content in the roots vary averagely at 4.5% while that of the stems is at 3.2% and the leaves vary at 2.3% in all the plants. The bioaccumulation level of Lead in *C. odarata* and *H. annus* are 0.91 mg/kg and 0.71 mg/kg respectively. Cadmium also had a little bit high bioaccumulation factors in *C. odarata* and *I. cylindrica* which were 0.72 mg/kg and 0.66 mg/kg respectively. However, Lead has the highest BAF as shown

Table 1. Properties of soil from ASCL.

Properties	Values (%)
pH	6.50 ± 0.3
Sand	61.28 ± 5.2
Silt	7.12 ± 0.8
Clay	31.60 ± 2.6
Organic matter	1.34 ± 0.5

Table 2. Mean concentrations of heavy metals in soil around ASCL and their pollution indices.

Metal (mg/kg)	Topsoil	Subsoil	PI (Topsoil)	PI (Subsoil)	EU, (2002) (mg/kg)
Cadmium (Cd)	0.13 ± 0.2	0.05 ± 0.02	0.04	0.02	140
Copper (Cu)	40.80 ± 5.8	29.01 ± 1.2	0.29	0.21	300
Lead (Pb)	36.30 ± 3.1	25.20 ± 2.01	0.12	0.08	300
Zinc (Zn)	60.80 ± 11.9	55.41 ± 5.01	0.20	0.18	3

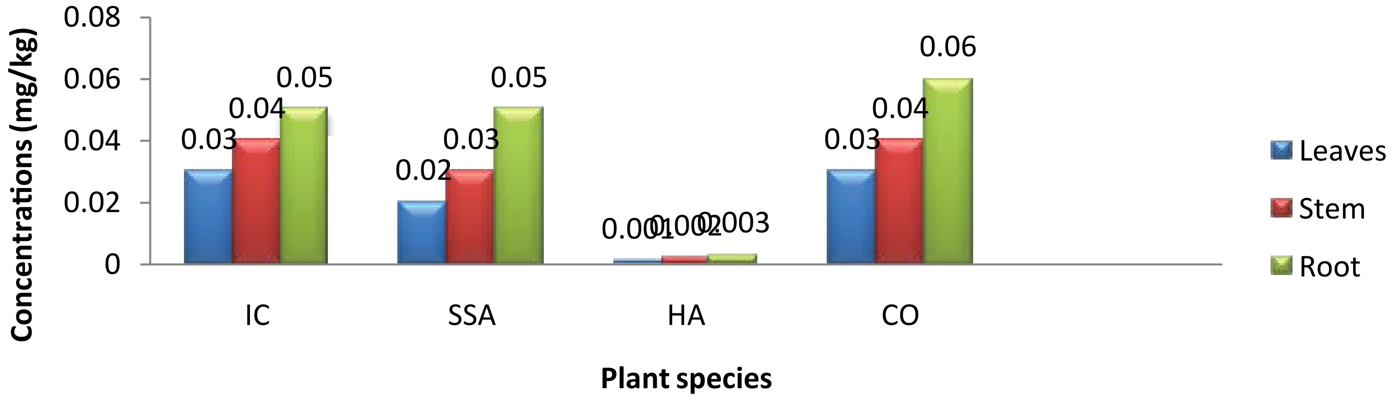

Figure 3. Level of Cadmium concentrations in plant species. IC: = *Imperata cylindrica*, SA: = *Sida acuta,* HA: = *Helianthus annuus*, CO: = *Chromolaena odarata.*

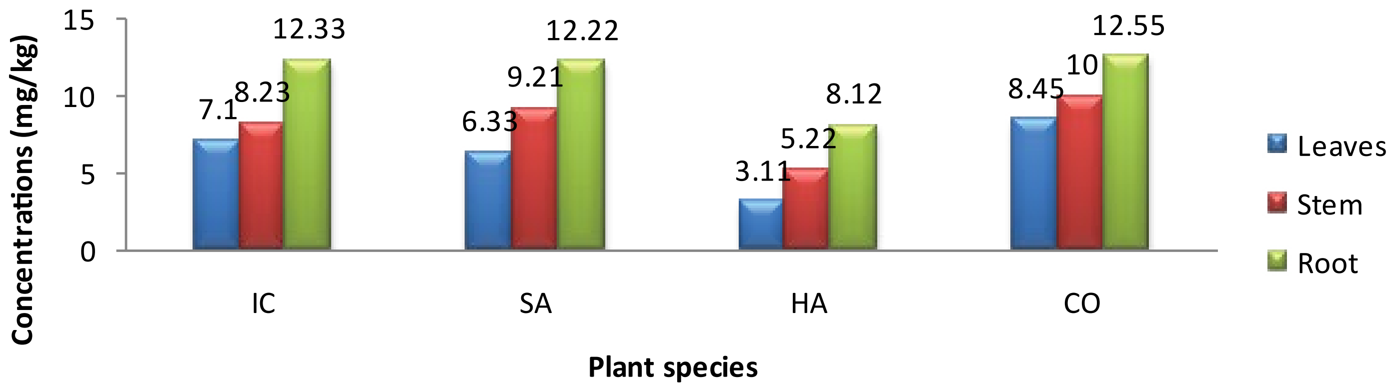

Figure 4. Level of Copper concentrations in plant species.

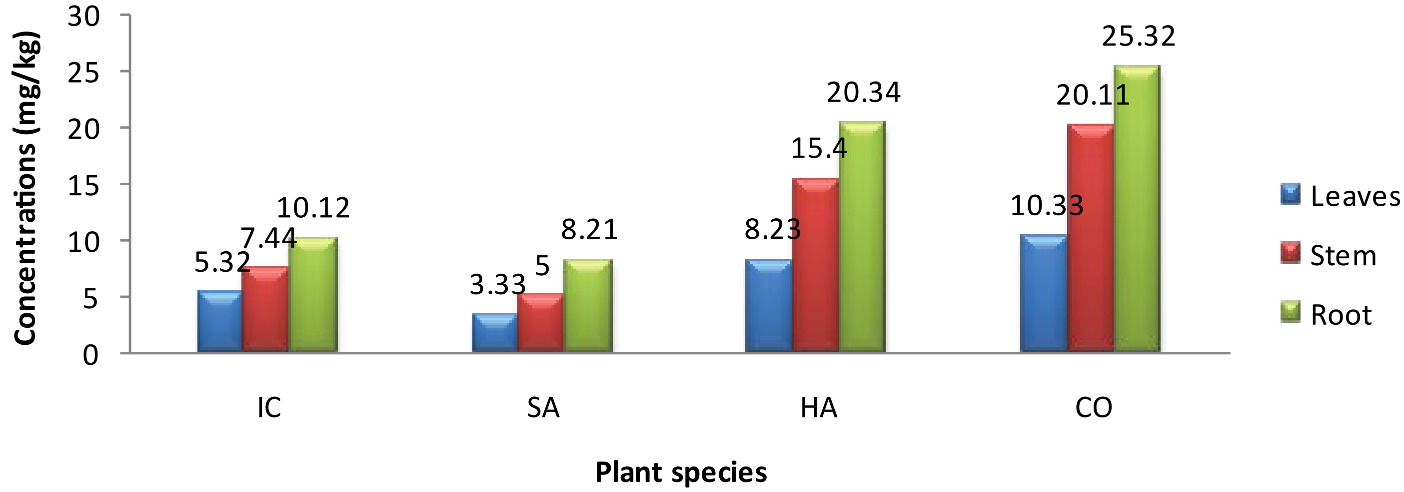

Figure 5. Level of Lead concentrations in plant species.

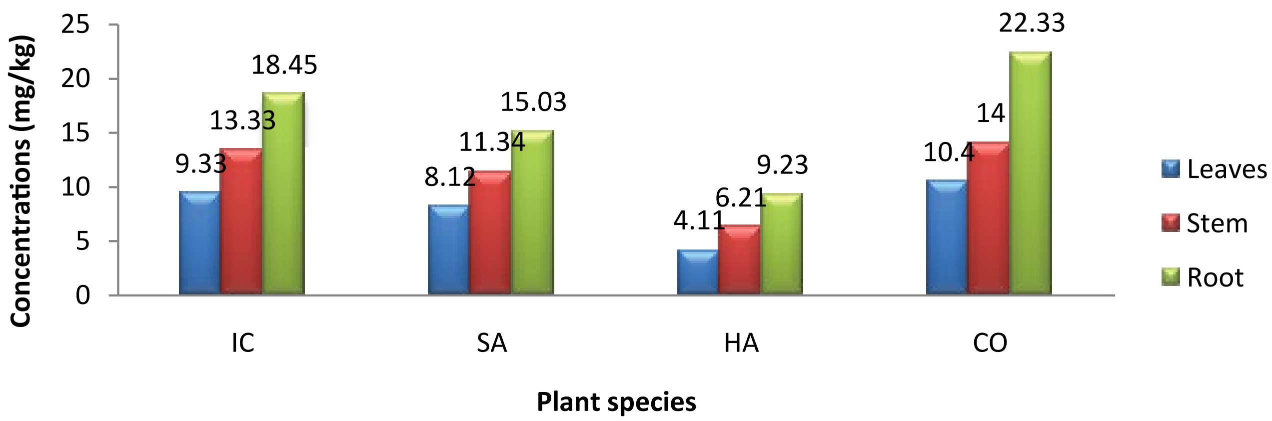

Figure 6. Level of Zinc concentrations in plant species.

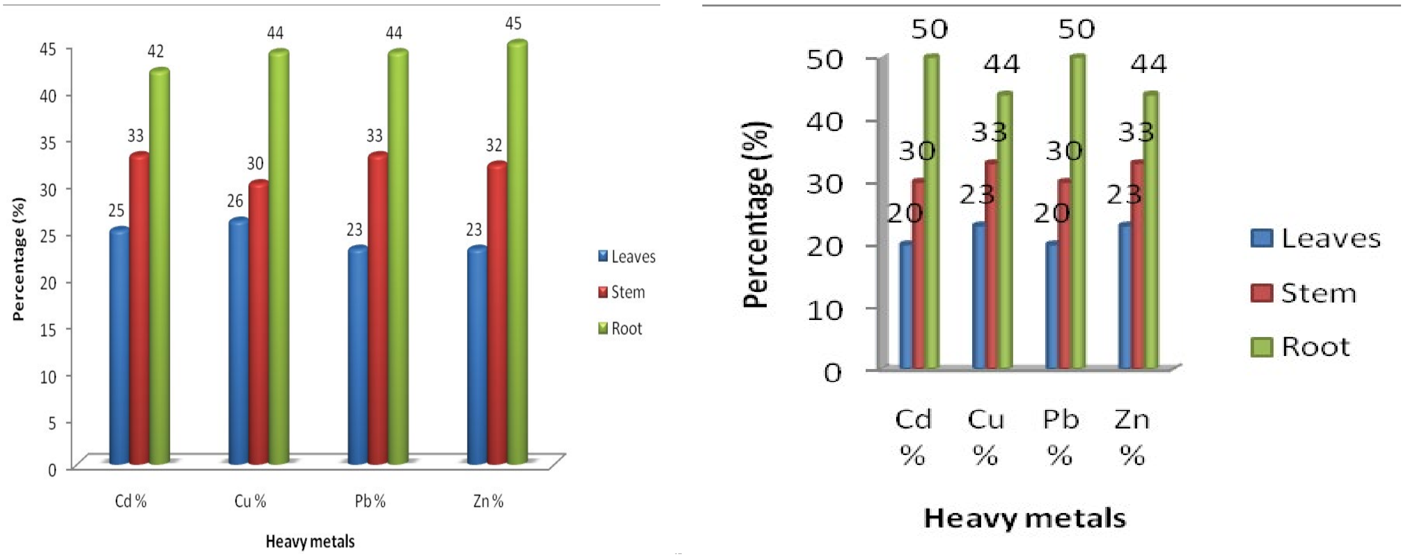

Figure 7. Percentage of heavy metals in *Imperata cylindrica* and *S. acuta* in the plant respectively.

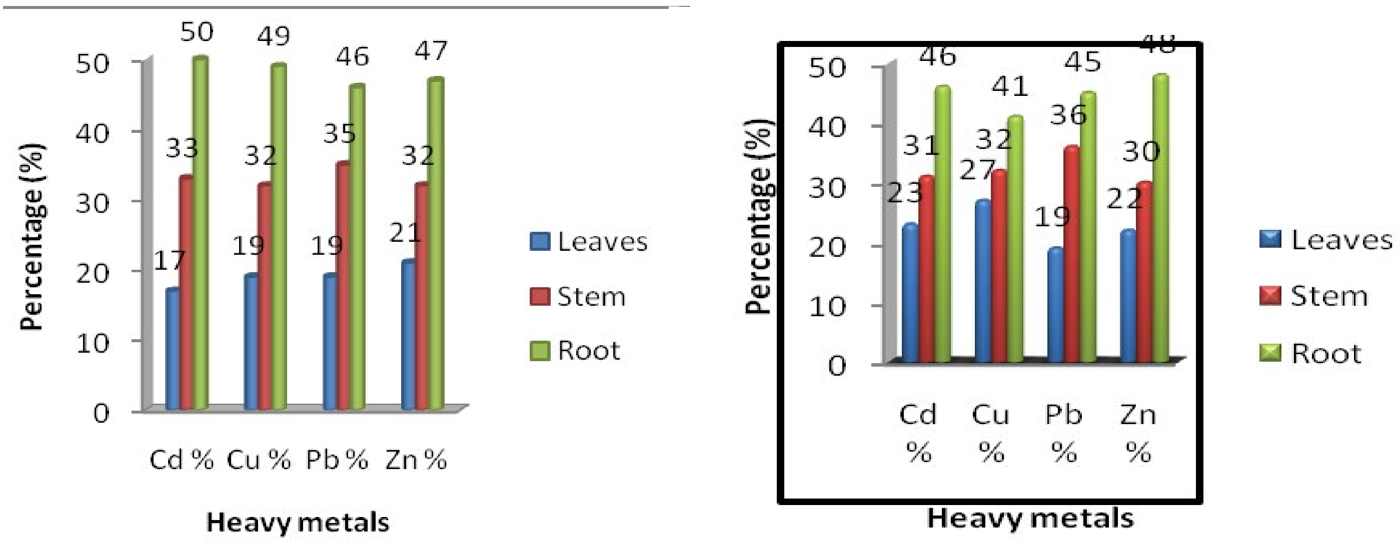

Figure 8. Percentage of heavy metals in *H. annus* and *C. odarata* in the plant respectively.

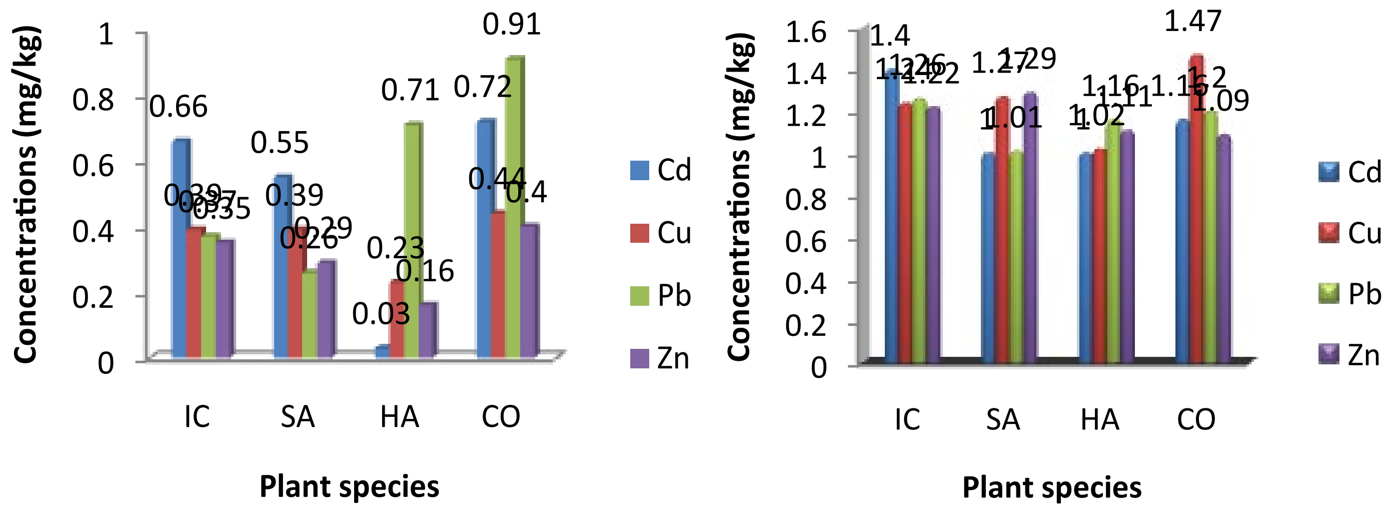

Figure 9. Bioaccumulation and translocation factors of the plant species respectively.

in Figure 5. Unlike the bioaccumulation factors, the translocation factors were high in all the heavy metals investigated (Figure 9).

Discussion

The soil pH was within the limits for agricultural use and poses no threat to the receiving environment. The importance of pH in metal uptake is important as it influences heavy metal adsorption, retention and mobility. Organic matter is another important soil component that influences metal mobility. It has a nutritional function by serving as a source of Nitrogen, Phosphorus and Sulphur and has a high binding capacity for cations and organic contaminants. The metals are accumulated in surface organic layers in agricultural and urban soils [23]. The levels of heavy metals in soil environment around the ASCL were low and within the European Economic Community maximum acceptable concentration limits for agricultural soils. Also, the levels were the WHO permissible limits of heavy metals in plants [24] which stipulated the Pb (2 mg/kg); Cd (0.02 mg/kg); Cu (10 mg/kg) and Zn (20 mg/kg). These findings agreed with the work of Olatunde and Osibanjo, [17] who reported that the heavy metals are heterogeneously distributed in soils around ASCL at appreciable concentrations. Therefore, the soil environment are not negatively impacted by heavy metals, hence could be regarded as pristine. Dieckmanni et al. [7] stated that the uptake of toxic metals from contaminated soils by food and foliage plants to enter the food chain and finally ingested by human, pose a threat to human health and should therefore be minimized. Heavy metal can be very toxic even in low concentration and are not easily degraded or destroyed. It is generally harmful to humans and other living organisms as heavy metals can easily bio-accumulate and cause food chain contamination.

Metal concentrations were found to be higher in the root than in the stems and leaves reason being that the roots has the first contact with the soil where the heavy metals are stored before translocation. The concentrations of metals at the roots of the plants were also higher than that of the shoots. The findings agreed with the work of Fulekar [16] who showed higher accumulation of all metals (Cd, Pb and Zn) in the roots than in the shoots. Ali et al. [25] and Sinha et al. [26] affirmed that the tropical grasses are fast growing plants with good tolerance for growth under a wide range of soil, rainfall and temperature conditions. Due to its good adaptation to environmental stress, high biomass production and fast growth rate; grasses are often used to be the preferable choice for phytoremediation compared to shrubs and trees [9].

C. odorata was hyperaccumulator of Pb which is in agreement with the work of Tanhan et al. [27] who reported that *C. odorata* collection accumulated 1377 mg/kg and 4236 mg/kg of Pb in their shoots and roots, respectively, and could tolerate soil Pb concentrations up to 100,000 mg/kg with a translocation factor of 7.62. They further investigated that the percentage uptakes of Pb, Cd, and Zn by *C. odorata* increased with increasing metal concentrations. Also *H. annuus* recorded high uptake of Lead which were 8.23 mg/kg, 15.40 mg/kg and 20.34 mg/kg in their leaves, stem and root respectively. These findings confirmed the work of Encheva et al. [28], who identified the sunflower (*H. annuus* L.) as one of the target species that has great potential as a phyto-extractor due to the fact that it produces large amounts of biomass, capable of hyper accumulating heavy metals in its harvestable parts (stems, leaves and roots) and it grows quickly. Apart from industrial applications of dry sunflower biomass, growing sunflowers have shown the potential to absorb various metal contaminants [14].

In general, the phytoremediation potential of the selected plants was high in the roots. This affirmed the fact that the roots accumulate the heavy metals from the soil as the first contact before transferring it to the stems and the leaves respectively. Delia [29] affirmed that uptake of contaminants in plants occurs primarily through the root system, which provides an enormous surface area that absorbs and accumulates the water and nutrients essential for growth. Hence, the use of trees (rather than smaller plants) in treating deeper contamination because tree roots penetrate more deeply into the ground and more effective.

Low bioaccumulation factors (BAF<1) were generally observed for all the selected heavy metals. Bioaccumulation factor is known to decrease with increasing metal concentrations in the soil [30]. Unlike the bioaccumulation factors, the translocation factors were high (TF>1) in all the heavy metals investigated. Smical et al. [31] reported that the use of plants to remove and translocate metals to their harvestable parts reduce the concentration of metals in contaminated soils to regulatory levels within a specific time frame. Some plant species have developed tolerance towards metals and are characterized by their ability to accumulate high quantities of metals in their tissues. A key trait of metal hyperaccumulators is the efficient metal transport from roots to shoots being, characterized by the TF>1 [32].

According to D'Souza et al. [33], who stated that all plants with phyto-remedial potentials are not alike; some maybe metal-specific while others may perform well for metals in combination. Phytoremedial potential of plants is influenced by the mobility and availability of heavy metals in soil and plants. Hyperaccumulators are plants that possess a plant-to-soil metal-concentration ratio (bioaccumulation factor) and shoot-to-root metal-concentration ratio (translocation factor) greater than one. The accumulation of these metals varies from plant to plant and soil to soil. The availability of metals for uptakes in plants depends on total concentration of metals in the soil, the forms in which they occur, pH, organic carbon, cation-exchange capacity, stage of growth of plants, and microorganisms around the root zone [34].

Conclusion

Heavy metals uptake, by plants using phytoremediation technology, seems to be a prosperous way to remediate heavy-metals-contaminated environment. Several factors must be considered in order to accomplish a high performance of remediation result. The most important factor is a suitable plant species which can be used to uptake the contaminants. From the study, *Chromolaena odarata*, *Imperata cylindrica* and *Sida acuta* are good accumulators of heavy metals and they should therefore be encouraged to be cultivated. The plant species have developed tolerance towards metals and they are hyperaccumulators, which is characterized by their ability to accumulate high quantities of metals in their tissues.

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