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Phytoremediation: An Ecological Solution to Heavy-Metal-Polluted Soil and Evaluation of Plant Removal Ability

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Abstract: The concentrations of eight metals cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Nickel (Ni), Lead (Pb) and Zinc (Zn) in soils and different plant organs of seven native plant species (*Calotropis procera*, *Citrullus colocynthis*, *Rhazya stricta*, *Cassia italic*, *Phragmite australis*, *Cyperus laevigatus and Argemone Mexicana*) collected from industrial zone in Riyadh City were investigated. The aim was to define which species and which plant organs exhibit the greatest accumulation and evaluate whether these species could be usefully employed in biomonitoring studies and phytoremediation programs. The bioaccumulation and transfer of metals from soil to roots and from roots to shoots was evaluated in terms of bioaccumulation factor (BAF) and translocation factor (TF). Results showed that the concentrations of heavy metals in the soils have the sequence of (Fe > Zn >Cr >Cu > Pb > Ni > Co > Cd) while in plants the trend was (Fe > Zn >Cu >Cr > Ni > Co > Pb > Cd). Generally, leaves of the studied species accumulated less heavy metals than the corresponding roots except for Cd that could be accumulated in all plant organs (leaves, stems and roots). Based on BAFs and TFs values, most of the studied species have potential for phytostabilization and phytoextraction. *Calotropis procera* was suggested for phytostabiliation of Cu, Cd and Zn wheras *Rhazya stricta*, *Phragmite australis* and *Cyperus laevigatus* for Ni phytostabiliation. Among the plant species screened for Cd, Cu, Ni, Co, Pb and Zn, most of the species were efficient to take up and translocate more than one heavy metal from roots to shoots. In conclusion, according to accumulation capability of the investigated species for most metals, both *Phragmite australis* and *Cyperus laevigatus* were found to be the best candidates for biomonitoring and phytoremediation programs of polluted soils.

Key words: Heavy Metals · Pollution · Phytoremediation · Metal Accumulators

INTRODUCTION

Heavy metal concentrations in past few years have reached to a promising toxic level due to consequences of anthropogenic activities and urbanization. Nowadays it is well-known that cities suffer from considerable pollution due to a wide array of substances that contaminate the air, water and soil [1]. Metal persistence in soil for much longer periods than in other compartments of the biosphere is a matter of serious concern. According to Beyersmann and Hartwig [2] heavy metals like As, Cd, Cr, Ni, Pb, etc, have been classified to be carcinogenic to humans and wildlife.

Recently, numerous efforts have been undertaken to find cost-effective technologies for remediation of heavy metal-contaminated soil [3]. Therefore, plants can be used to ameliorate heavy metal pollutants from the soil. This cost effective approach is called phytoremediation which also referred as green solution [4]. Phytoremediation has recently become a subject of public and scientific interest and a topic of many researches [5-7]. For chemically polluted lands, vegetation plays an increasingly important ecological and sanitary roles [5]. Proper management of plants in such areas may significantly contribute to restoring the natural environment.

Plants growing in metalliferous soil can be grouped into the following three categories according to Baker [8]. a) excluders, in which metal concentrations in the shoots are maintained at low level up to a critical value across a wide range of soil concentrations; b) accumulators, in which metals are concentrated in above-ground plant parts from low to great soil concentrations; and c)

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indicators, in which the internal concentration reflects external levels. Moreover, the bioavailability of trace elements for plants is dependent on many environmental factors: concentrations in the environment, a biotic factors, exposure time, growth form of the plant, type of absorption mechanisms, affinity of trace elements for the adsorption sites and element speciation [9].

The identification of metal hyperaccumulators, plants capable of accumulating extra- ordinary high metal levels, demonstrates that plants have the genetic potential to clean up contaminated soil. Hyperaccumulators are also characterized by a shoot-to-root metal concentration ratio (i-e. the translocation factor (TF) of more than 1, whereas non-hyperaccumulator plants usually have great metal concentrations in the roots than in the shoots. Several authors [10, 11] include the bioaccumulation factor (BAF) as an element for classification as a hyperaccumulator species. The BAF refers to the plant metal concentration in root and the soil metal concentration ratio. This ratio should be greater than one for inclusion into the hyperaccumulator category. Importance of hyperaccumulators has emphasized on further research in exploring the contaminated sites and finding new hyperaccumulator plants. Many plant species have become metal tolerant due to the adaptive responses of plant species to heavy metals, as these species are growing in contaminated sites from a long period. According to Antonsiewicz *et al.* [12] and Yoon *et al.* [13], 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. Therefore, the search for native plants that are tolerant to heavy metals is of particular importance. Few studies evaluated, under field conditions, the potential for phytoremediation of native plants [14]. With this idea and public concern over soil contamination by heavy metals in industrialized area in Riyadh City, Saudi Arabia, searching for plant species with the potential for phytoremediation is necessary because no metal-tolerant and metal hyperaccumulator plants with potential application to this area have been reported. Therefore, the aim of this study was to: 1) evaluate the concentrations of Cd, Co, Cr, Cu, Fe, Pb, Ni and Zn in soils and different plant organs (leaves, stems and roots) of seven native plant species (*Calotropis procera* (1), *Citrullus colocynthis* (2), *Rhazya stricta* (3), *Cassia italic* (4), *Phragmite australis* (5), *Cyperus laevigatus* (6) *and Argemone Mexicana* (7)), 2) define which species and which plant organ exhibit the greatest accumulation, 3) evaluate whether these species could be usefully employed in biomonitoring studies. Moreover, BAF and TF indices were determined to assess the tolerance categories developed by these species and to evaluate their potential for phytoremediation purposes.

MATERIALS AND METHODS

Site Description: The Second Industrial City that located 12 Km south of Riyadh City, capital of Saudi Arabia, was established in 1976. It has been developed on four stages of a total area more than 18 million square meters. It houses more than 1050 of different industrial units with 120 thousand workers. The most important industries in this area are: food industries, metal industries, electrical and control equipment industries and chemical industries. Plants growing in the nearby zone of industrial areas along various industrial units exhibiting increased concentrations of heavy metals, serving in many cases as biomonitors/ accumulators of pollution load. The area of collected plants and soils extended about 3 Km around metal and chemical industries. The climate in this area is continental with extremes of heat in summer and markedly cold in winter with low rainfall distributed mainly from December to March. The dried soil are similar to natural one, sandy clay, but with different metal concentration. Our observation showed that the vegetation was few and non-compact. Plant species collected were the most common/dominant species at the contaminated area. A total of seven plants and soils (at 0-20 cm depth from rhizosphere of each plant were taken from each site from where plant sample was rooted) were collected in August and September 2010 and their scientific names and characteristics were determined. The concentration of heavy metals was determined in the soil and in plant organs. The plants with high concentration of heavy metals were chosen as accumulators.

Sampling: Soils as well as seven abundant and dominating native plants (*Calotropis procera, Citrullus colocynthis, Rhazya stricta, Cassia italica, Phragmite australis, Cyperus laevigatus and Argemone mexicana*) were collected from the second industrial area, south of Riyadh City, Saudi Arabia. For each soil sample, pH, texture and heavy metals were measured. pH of soil was measured immediately after collection using suspension of soil and water at a ratio of 1:2.5; additionally, this suspension was stirred for 5 min. For plant sampling, at least three whole plants of each species of current year were collected. To remove only soils, roots and rhizomes were washed with tap water while leaves were not washed before analyses. Therefore, the element concentrations in the roots and rhizomes refer to their tissue and surficially adsorbed elements. The native plant species were identified according to Alfarhan and Thomas [15]. Leaves, rhizomes and roots of the collected plants were separated to identify the different accumulation capability and selectivity of each organ.

Analytical Techniques: Soil samples (a composite mixture) were wet-sieved through a 63-mm sieve, washed with de-ionised water, dried at 105°C and homogenized. A representative portion of the sample (About 20 g) was used for grain size analysis using the standard dry sieving and sedimentation techniques [16]. For heavy metals analysis, one gram of homogenized samples was digested using HNO_3-HF-H_3BO_4 acids according to Wade *et al.* [17]. Plant materials were oven-dried at 75°C and grounded to a fine powder. In this way, homogeneous samples were obtained for each plant organ. Approximately 0.2 gram of leaves, rhizomes and roots powder were weighed and digested according to method described by Allen [18]. Soil and plant samples were analyzed for heavy metals by inductively coupled plasma optical emission spectrometry (ICP-OES) using a perkin Elmer Model Optima 5300 DV spectrometer. All the analyses were carried out on three subsamples.

Standard Reference Material (SRM) of National Institute and Technology (NIST, 2709 San Joaquin Soil and 1547Peach leaves) and internal reference materials were used for precision, quality assurance and control (QA/QC) for selected metal measurements. Average values of three replicates were taken for each determination. The precision of analytical procedures was expressed as Relative Standard Deviation (RSD) which ranged from 5-10% and was calculated from the standard deviation divided by the mean. The recovery rates of studied metals were within 90±10%. Chemicals, stock solutions and reagents were obtained from Merck and was of analytical grade. All glassware before use were washed with distilled water, soaked in nitric acid (30%) overnight, rinsed in deionized water and air-dried.

Biological Concentration Factor (BCF) was calculated as metal concentration ratio of plant roots to soil given in equation 1 [14]. Translocation Factor (TF) was described as ratio of heavy metals in plant shoot to that in plant root given in equation 2 [19-20].

$$BAC = [Metals]\ root/[Metals]soil \quad (1)$$

$$TF = [Metals]\ shoot/\ [Metals]\ root \quad (2)$$

RESULTS AND DISCUSSION

Soil Properties: The topsoil from the different sampling sites, in the area under investigation, had small differences in texture and pH (Table 1). Results revealed that all sites are characterized by sandy texture (88%-93%) except soil collected in the area located with *Phragmite australis* whereas mud percentage reaches 76% as this area affected by direct outfall of industrial wastes. The uniform grain size distribution obtained along the area indicated a stable depositional environment for a long period of time.

As indicated from Table 1, the pH of soil was alkaline in nature throughout the studied area and varies from 6.7-7.6.

Plant and Soil Metal Composition: Heavy metals contamination of arable soil showed several problems, including phytotoxic effects of certain elements such as Cd, Pb, Zn and Cu, which are well known as micronutrients and cause several phytotoxicities if critical endogenous levels are exceeded [21-22]. Another and even a more serious problem is posed by the up taking of potentially noxious elements through food or forage plant species and their being transferred to the food chain and, finally, to humans [23]. All heavy metals at high concentrations have strong toxic effects and are regarded as environmental pollutants [23]. The use of plants for environmental restoration is an emerging technology. In this approach, plants capable of accumulating high levels of metals are grown in contaminated soils [24]. Interest in phytoextraction has significantly grown following the identification of metal accumulator plants.

According to the results of this study, the native plants and soil can well present further information about the metal content of their environment. plant and soil analyses revealed that the accumulation is considerably the consequence of a kind of elements [25]. The concentrations of the investigated heavy metals in soil possess the sequence of (Fe > Zn >Cr >Cu > Pb > Ni > Co > Cd) while in plants the trend was (Fe > Zn >Cu >Cr > Ni > Co > Pb > Cd). However, the investigated native plants exhibited different element concentrations, depending on plant organ and the sampling site.

Cadmium (Cd) is a toxic element and exists along with Zn in nature. Average Cd concentrations of the seven plants and soils are given in Fig. 1. Generally, The Cd concentration in the soils was relatively low (1 $\mu g.g^{-1}$ d.w). The highest Cd concentration was recorded in association with *Argemone Mexicana* (Site 7) and

Table 1: Characteristics of soils from studied sites

	Soil sites						
Soil properties	1	2	3	4	5	6	7
pH	6.7±0.05	6.9±0.06	7.3±0.07	7.3±0.07	7.6±0.06	7.1±0.04	7.5±0.08
Sand %	90.1	92.5	88.6	93.2	33.2	90.7	86.5
Mud %	9.9	7.5	11.4	6.8	76.8	9.3	13.5

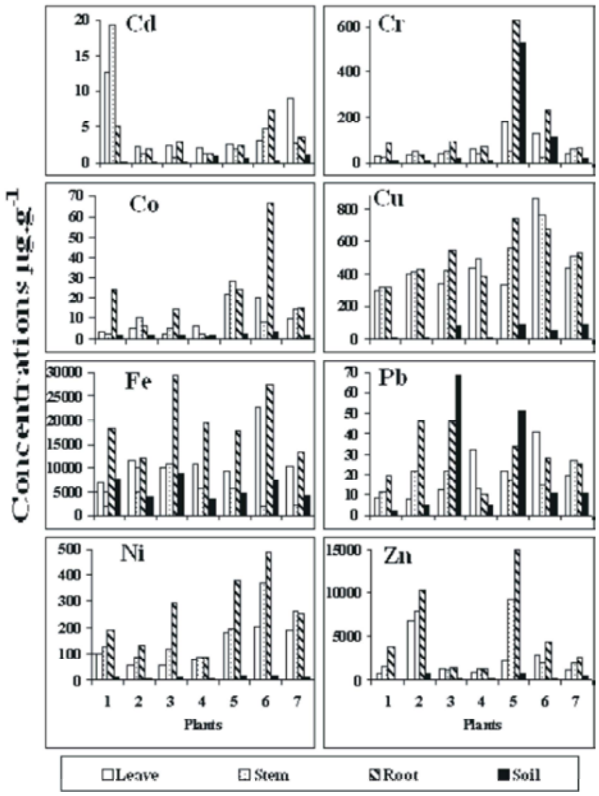

Fig. 1: Average Cd, Cr, Co, Cu, Fe, Pb, Ni and Zn concentrations (ug.g^{-1} dry weight) in leaves, stems and roots as well as soil associated with *Calotropis procera* (1), *Citrullus colocynthis* (2), *Rhazya stricta* (3), *Cassia italic* (4), *Phragmite australis* (5), *Cyperus laevigatus* (6) *and Argemone mexicana* (7)

Cassia italic (Site 4). This is may be attributed to the relatively high pH value (Table 1) which enhance Cd precipitation at this sites [26]. Results indicated that Cd could be accumulated in all plant organs (leaves, stems and roots). The distribution of Cd within plant organs is quite variable and clearly illustrates its rapid translocation from roots to shoots [27]. The highest uptake of Cd was attained by *Calotropis procera* stem followed by *Argemone Mexicana*.

Chromium (Cr) is one of the toxic metals widely distributed in nature. It has two forms found in the environment, trivalent and hexavalent. The latter form is considered to be the greatest threat because of its strong oxidizing ability as well as high solubility and availability to penetrate cell membranes [28]. Chromium (Cr) is a non-essential metal to plant growth and may be possible that plants do not have any specific mechanism and transport of Cr [29]. Generally, soils of all selected sites in the area under investigation acquired low concentrations of Cr except in site associated with *Phragmite australis* (Fig. 1), with the highest value recorded (528 ug.g^{-1} d.w.). This is due to its location in place of highly polluted drain affected by industrial discharges. Results from the present study showed that roots of all plants attained higher Cr concentrations than other organs, with the highest value of 628.8 528 ug.g^{-1} d.w attained by *Phragmite australis* root. This could be because Cr is immobilized in the vacuoles of the root cells and showed less translocation, thus rendering it less toxic. This may be a neutral toxicity response of the plants [30]. According to Macnicol and Beckett, [30], the toxic levels of Cr in plants range from 1 to 10 µg.g^{-1} dry weight.

Copper (Cu) is an essential element for plants and animals. However, excessive concentrations of this metal are considered to be highly toxic. The distribution pattern of Cu in the soil of studied sites (Fig. 1) indicated that sites 3, 5 and 7 were enriched with this element (> 80 μg.g-1 d.w) compared with other sites. The average concentrations of Cu in all examined species are comparable (Fig. 1). Generally, roots of most plants attained higher Cu concentrations than other organs, with maximum value of 741 $\mu g.g^{-1}$ d.w attained by *Phragmite australis* root. However, leaves and stems of both *Cassia italica* and *Cyperus Laevigatus* were found to accumulate considerable amounts of Cu (Fig. 1). Cu concentrations in plants above 10-30 $\mu g.g^{-1}$ d.w are regarded as poisonous [30]. Within roots, Cu is associated mainly with cell walls and is largely immobile. However, higher concentrations of Cu in shoots (leaves and stems) are always in phases of intensive growth and at the luxury Cu supply level [31]. High concentrations of Cu in the roots of. *Phragmite australis* with relatively high pH values in soil (Table 1) may be attributed to the presence of plaque, a metal-rich rhizo-concentrations composed of iron hydroxides and other metals that are mobilized and precipitated on the root surface [32]. This is in agreement with the finding of Weis and Weis [33] who reported that at higher pH conditions (> 7.0) the presence of plaque enhanced Cu uptake into roots.

Iron (Fe) is an essential micronutrient for plants and animals [34]. However, excessive Fe uptake can produce toxic effects. Fe is the most abundant metal in the studied area. The highest Fe concentration (Fig. 1) was determined in the soil of site 3, affected by industrial discharges from a nearby industrial complex. Results obtained from plant analysis asserted that roots of all seven plants are found to be highly capable of Fe accumulation (Fig. 1). The highest concentrations were recorded in roots of *Rhazia stricta* (29160 $\mu g.g^{-1}$ d.w) followed by *Cyperus laevigatus* (27398 $\mu g.g^{-1}$ d.w). According to Allen [18], Fe concentrations above 40-500 $\mu g.g^{-1}$ d.w are considered as toxic to plants. As indicated by Tiffin [31], roots tend to absorb Fe^{+2} cation more than Fe^{+3}. The ability of roots to reduce Fe^{+3} to Fe^{+2} is believed to be fundamental in the absorption of this cation by most plants [35]. Moreover, some bacteria species (e.g. *Metallogenium* sp.) are involved in Fe reduction and are known to accumulate this metal on the surface of living cells [36]. Higher concentrations of Fe in the roots of the investigated species could be due to its precipitation in iron- plaque on the root surface [37, 38].

Lead (Pb) is the least mobile among the heavy metals. It is not essential but toxic to plants. The highest Pb concentration in soils was detected at sites 3 and 5. As regards to Pb accumulation in plants, Pb is believed to be the metal of least bioavailability and the most highly accumulated metal in root tissue while Pb shoot accumulation is much lower in most plant species [27]. This is in agreement with results obtained from plant analysis in our study. The highest Pb concentration was detected in roots of all studied plants (Fig. 1) except in case of *Cassia italic* and *Cyperus laevigatus* whereas leaves exhibited more concentrations than roots. Recent results of Pb translocation and uptake studies showed that Pb is mobile within the plant under certain conditions [39]. Also Blaylock and Huang [40] indicated that shoot Pb concentrations reached a value similar to the concentration found in intact roots of the same species, when it is immersed in a nutrient solution containing Pb. Generally, Pb concentrations in all seven plants were notably higher at sites 2, 3 and 6. This is could be related to airborne Pb deposition emitted from a heavily traffic high way affected the open area under investigation. Airborn Pb is readily taken up by plants through foliage [41]. As such, it may be suggested that the habitually occurrence of *Cassia italic* and *Cyperus laevigatus* in an open desert area make it capable of receiving higher amounts of airborn Pb (32 and 40.8 $\mu g.g^{-1}$ d.w, respectively). According to Ross [42], 30-300 $\mu g.g^{-1}$ Pb concentrations are considered toxic to plants. Plants with higher Pb translocation will yield a higher shoot Pb concentration. These plants are considered promising for Pb phytoremediation programs because only shoots should be harvested in Pb phytoextraction which highlights the importance of the selected species as Pb accumulators [43].

Although Zn is essential trace element, high levels can cause harmful health effects. Toxicity of high level Zn concentrations in man is well known, [44]. Zn concentrations in soils in the studied area attained highest values of 820 and 680 μg/g d.w at sites 5 and 2, respectively (Fig. 1). According to Kloke [23], toxicity level of this element is around 300 μg. g -1d.w.

The upper toxic levels of Zn in various plants range from 100 to 500 μg/g d.w [45]. Results demonstrated that roots often contain more Zn than shoots. The highest Zn root concentration,15060 $\mu g.\ g^{-1}$, was attained by *Phragmite australis*. Roots are thought to be important for zinc uptake [46]. It was noted that the highest zinc concentrations in roots of *Phragmite australis* and *Citrullus colocynthis* were associated with high concentrations in soils at the same place. Previous studies on the accumulation of various metal ions by native plants have shown that the deposition of most metals was higher in roots than the other parts of plants [47, 48]. This was in line with the findings of the present study. *Phragmite australis* was tested for concurrent removal of Zn. This plant has removed the metal successfully without production of toxicity.

The mean concentration in normal plants (aboveground tissues) is 66 µg/g [49] and the toxic level is up to 230 µg/g [50-51]. The ranges of Zn in plants presented here were generally higher than the levels reported for other plants [52]. Results obtained by Aboulroos *et al*. [53] indicated that Zn content of plant increased with increasing levels of Zn in the soils. The research done by Kandil *et al*. [54] found highly significant correlations between the soil content of macro, micro-nutrients and heavy metals and its accumulation in roots of plants.

Both, cobalt and nickel are used in the metallurgical industry, for the production of high quality iron-based alloys. They are also, used extensively as catalysts in the chemical and food industry, as prime materials for the reduction of paints and batteries and in the electroplating industry [55]. The highest Co and Ni concentrations in soils were detected at sites 6 and 5. As regards to Co and Ni accumulation in plants, they are believed to be highly accumulated in root tissues of *Cyperus laevigatus* (24.4 and 66.36 ug.g^{-1} for Co and Ni, respectively) and *Phragmite australis,*(378.6 and 489 ug.g^{-1} for Co and Ni, respectively). According to Kabata-Pendias and Pendias [56], the normal Ni content of terrestrial plants growing in uncontaminated soils was found to be in range of 0.1-3.7 ug.g^{-1}. Our results showed that concentrations of Ni in the investigated species were higher than the normal plant and this shows that these plants had a strong ability to tolerate this element. Heavy metal concentrations in roots of *Cyperus laevigatus* and *Phragmite australis* increased in the following pattern: Cu > Cr > Ni > Co. This is may indicate that all four metals come from similar sources of contamination. Moreover, increased concentrations of four metals in roots system were due to the presence of plaque, [32] with high pH conditions (> 7.0) which enhanced metals uptake into roots [33].

Bioaccumulation and Translocation in Plants: Accumulation of selected metals varied greatly among plants species and uptake of an element by a plant is primarily dependent on the plant species, its inherent controls and the soil quality [57]. Large number of factors control metal accumulation and bioavailability associated with soil and climatic conditions, plant genotype and agronomic management, including: active/passive transfer processes, sequestration and speciation, redox states, the type of plant root system and the response of plants to elements in relation to seasonal cycles [56]. Structure of the sediment has also been considered very important that affect the extent of the metals taken up by the plants. Clay particles also play an important role in availability of the metals. Metal solubility in soils is predominantly controlled by pH and oxidation state of the system [58]. Results indicated that soils of study area were sandy texture and were neutral in nature with pH greater than 6.7. Neutral and high soil pH can stabilize soil toxic elements, resulting in decreased leaching effects of the soils toxic elements. Moreover, toxic elements may also become stabilized due to slightly basic soil pH which may result in less element concentrations in the soil solution. This may restrain the absorbability of the elements from the soil solution and translocation into plant tissues [59]. Phytostabilisation is a process which depends on roots ability to limit the contaminant mobility and bio-availability in the soils which occurs through the sorption, precipitation, complexation or metal valance reduction [58]. Most of plant species under investigation had BAF >1, although the concentration of heavy metals remained below 1000 ug. g^{-1} (except for Fe and Zn). In general, BAF values of Cd, Cu, Ni and Zn were highest as compared to other metals (Table 2). The BAF values of *Calotropis procera, Citrullus colocynthis* and *Cassia italica* were highest for Cu (49.0, 58.9 and 55.9) and *Calotropis procera* for Cd (41.5). *Rhazya stricta*, *Phragmite australis* and *Cyperus laevigatus* had highest BAF for Ni while *Calotropis procera* and *Cyperus laevigatus* had highest BAF for Zn (191.0 and 27.6, respectively). Heavy metals tolerant species with high BAF can be used for phytostabilisation of contaminated soils as these species retains metals in their roots and limit metal mobility from roots to shoots once absorbed by roots of plants [19].

The translocation factors (TF) generally showed the movement of metal from soil to root and shoot, indicating the efficiency to uptake the bio-available metals from the system. TF gives an idea whether the native plant is an accumulator, excluder or indicator. Among the plant species screened for Cd, Cu, Ni, Co, Pb and Zn, most of the species were efficient to take up and translocate more than one heavy metal from roots to shoots (Table 3) with a noticeable variations between TF values. The highest

Table 2: Bioaccumulation factor (BAF) of native plant species of selected metals

	Heavy metal concentrations							
Species	Cd	Cr	Co	Cu	Fe	Ni	Pb	Zn
Calotropis procera	41.5	7.8	12.7	49.0	2.4	21.3	8.8	191.0
Citrullus colocynthis	18.0	4.9	4.1	58.9	3.1	20.2	9.6	15.0
Rhazya stricta	27.3	5.8	8.4	6.8	3.3	31.8	0.7	11.2
Cassia italica	1.7	7.8	0.6	55.9	4.0	20.5	2.1	12.8
Phragmite australis	5.3	1.2	11.2	8.2	3.8	29.9	0.7	18.4
Cyperus laevigatus	20.1	2.1	19.3	13.4	3.8	30.6	2.5	27.6
Argemone mexicana	3.7	4.7	9.8	6.2	3.2	29.3	2.3	7.22

Table 3: Translocation factor (TF) of native plant species of selected metals

	Heavy metal concentrations							
Species	Cd	Cr	Co	Cu	Fe	Ni	Pb	Zn
Calotropis procera	6.38	0.54	0.27	1.90	0.48	1.23	1.02	0.60
Citrullus colocynthis	1.90	2.46	2.26	1.90	0.93	1.10	0.64	1.40
Rhazya stricta	1.10	0.96	0.50	1.40	0.70	0.60	0.74	1.70
Cassia italica	2.50	1.43	7.20	2.40	0.84	1.78	4.43	1.57
Phragmite australis	1.85	0.37	2.10	1.20	0.84	1.00	1.12	0.76
Cyperus laevigatus	1.08	0.67	0.43	2.40	0.90	1.16	1.98	1.16
Argemone mexicana	3.30	1.54	1.60	1.80	0.93	1.77	1.86	1.20

TF value (6.38) was found for Cd by *Calotropis procera*. Moreover. *Cassia italica* was efficient in translocation Co and Pb from roots to shoots with TF values of 7.2 and 4.43, respectively. According to Ghosh and Singh [58], high root to shoot translocation of heavy metals indicated that these plants have vital characteristics to be used in phytoextraction of these metals. It is easy for plants species with TF > 1 to translocate metals from roots to shoots than those which restrict metals in their roots.

High metal accumulation may be attributed to well develop detoxification mechanism based on sequestration of heavy metal ions in vacuoles, by binding them on appropriate ligands such as organic acids, proteins and peptides in the presence of enzymes that can function at high level of metalicions [19] and metal exclusion strategies of plant species [58]. Plant species with high TF values were considered suitable for phytoextraction generally requires translocation of heavy metals in easily harvestable plant parts i.e. shoots [13]. According to Ghosh and Singh [58] phyto-extraction is a process to remove the contamination from soil without destroying soil structure and fertility.

Results of the present study highlighted that all plants had relatively low BAF (2.4- 4.0) and TF < 1 for Fe in comparison to other metals. The elevated concentration of Fe in roots of plants under investigation and low translocation in above ground parts indicated their suitability for phytostabilisation of this element in the study area.

CONCLUSION

In the course of this study, we have concluded that: 1) all seven plants are resistant species containing in their tissues amounts of heavy metals that were much higher than those considered toxic for plants; 2) The concentrations of heavy metals in soils have the sequence of (Fe > Zn >Cr >Cu > Pb > Ni > Co > Cd) while in plants the trend was (Fe > Zn >Cu >Cr > Ni > Co > Pb > Cd; 3) Roots of all seven plants with the highest concentrations of all studied metals, except Cd, are the best biomonitors for heavy metals contamination in the studied area; 4) Generally, the bioaccumulation factor (BAF) values of Cd, Cu, Ni and Zn were highest as compared to other metals; 5) According to translocation factor (TF), the highest value was found for Cd by *Calotropis procera*.. *Cassia italic* was efficient in translocation of Co and Pb from roots to shoots. Those species could be considered as hyper accumulators and suitable for phytoextraction; 6) All plants had relatively low BAF and TF < 1 for Fe in comparison to other metals. The elevated concentration of Fe in roots of studied plants and low translocation in above ground parts indicated their suitability for phytostabilisation of this element in the study area; 7) Although all studied plant species could not reach the standard of a hypperaccumulator, they accumulated significant amount of selected metals in their tissues. The present study shows that some plant species can be suitable option for phytoextraction and phytostabilization. There is a need for field trial experiments, which have become more realistic and helps to incorporate the knowledge on metal uptake, transfer and distribution. Growing factors important to phytoremediation can provide a basis for genetic modification of plants for improved performance. Biotechnological and genetic engineering based approaches can be used to enhance the naturally occurring plants to detoxify hazardous compounds.

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