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Study on Using Green Plants to Remove Contaminants from Soil Through Phytoremediation

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ABSTRACT

Contamination of heavy metals represents one of the most pressing threats to water and soil resources, as well as human health. Phytoremediation can be used to remediate metal-contaminated sites. The aim of this study was to assess the accumulation of eight heavy metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in soils and shoots of four different native plant species collected from the industrial area of Riyadh, Saudi Arabia. The plants were *Cyperus laevigatus, Cassia italic, Rhazya stricta, Anabasis setifera*. The results showed that the mean values of concentrations of heavy metals in the soils followed the sequence Cd > Cu > Pb > Ni > Zn > Cr > Mn > Fe, while in plants the trend was Cd > Ni > Cr > Pb > Cu > Zn > Mn > Fe. The four local plant species in the industrial zone grew without apparent toxicity. High concentrations of Fe and Mn were found in plants and soils from which the plant species were taken. The investigated species could accumulate Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn, and this indicated that most native plant species were effective in uptake and transferring more than one element from soil to shoot. Consequently, the results showed that most plant species in the industrial area of Riyadh might be suitable for heavy-metal extraction of Fe and Mn from contaminated soils and to be candidates for phytoremediation.

INTRODUCTION

Environmental pollution with heavy metals has become a worldwide crisis, affecting agriculture and contributing to bioaccumulation and biomagnification in the food chain. Contamination of soil and groundwater from anthropogenic sources is a major concern in many developing countries including Saudi Arabia. Heavy metals are among the most important sorts of contaminants in contaminated soil. Soil contamination from industrial activities and mining factories is a widespread issue worldwide. As soil is the buffer zone between the atmosphere and groundwater, soil contamination poses a serious threat to the groundwater and to the environmental system (Shams et al. 2008). Environmental pollution with heavy metals is a global disaster that is related to human activities such as mining, smelting, electroplating, energy and fuel production, power transmission, intensive agriculture, sludge dumping, and smelting operations (Igwe & Abia 2006). The Food and Agriculture Organization of the United Nations has estimated that at a minimum 105 t of unwanted pesticides are in "storage" in developing countries, with at least 2×10^4 t in African countries (Chaudhry et al. 2002). Over the past fifteen years there has been tremendous growth in industries in Saudi Arabia, resulting in pollution of the environment from industrial activities in places that have industrial areas such as Riyadh, Gopal and Uabwa. The trend for the transport of heavy metals from soil to forage is so high that toxicity can be expected at any time of the year, because ruminants graze year round (Asia et al. 2011, Khadija et al. 2011).

The most common heavy metals at hazardous waste sites are cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) (Anon 1997). Use of natural resources for industrial raw materials has become an important part of human development in the twentieth century. Human demand for resources and for processing of raw materials has increased environmental and economic contradictions in industries (Sen & Chakraborty 2009). This widespread industrial development in urban areas has led to a significant reduction in land designated for waste disposal. The disposal of industrial and household waste in the environment affects the quality of soil and groundwater and makes the use of soil undesirable. This disposal has increased environmental pollution due to large concentrations of heavy metals, resulting in considerable efforts to remove these pollutants from the environment. Environmental contamination by trace and heavy metals through industrial wastes is one of the main health problems in industrial countries. Metal contaminants can easily enter into the food chain, if contaminated water, soils and/or plants are used for food production. Industrial effluents generally consist of organic compounds, inorganic complexes and other non-biodegradable substances (Huguet et al. 2009). Heavy metals can enter into plants directly by rain and dust thrown on the leaves, and they can be taken up from the soil solution through the roots (Jozic et al. 2009). Based on spatial analysis, it was determined that areas with high concentrations of metals were generally located in industrial and residential areas, roadsides, and crowded commercial districts (Cicchella et al. 2008).

Soil contaminated with metals pose a major environmental and human health problem that is still in need of an effective and affordable technological solution. Nonradioactive As, Cd, Cu, Hg, Pb and Zn, and radioactive Sr, Cs and U (referred to here as toxic metals) are the most environmentally important metallic pollutants. Several methods are already being used to clean up the soil from these kinds of contaminants, but most of them are costly and do not provide good performance. Phytoremediation, as a method to solve environmental contamination, has been growing rapidly in recent years. This green technology that involves "tolerant plants" has been utilized to clean up soil and ground water from heavy metals and other toxic organic compounds. Phytoremediation has become a subject of public and scientific interest and a topic of much research (Horsfall & Spiff 2005).

Heavy metals present in soils can be taken up by plants using phytoremediation, which is an economical way to remediate heavy-metal-contaminated environments. Phytoremediation is defined as the use of green plants to remove, contain, or make environmental contaminants harmless (Cunningham & Bertie 1993). Phytoremediation of heavy metals is divided into three groups: 1) phytoextraction-plants accumulate metals in contaminated soils and are later harvested to remove the metals from the soil; 2) rhizofiltration - roots absorb metals from contaminated effluents and are later harvested; and 3) phytostabilization-metals are stabilized in the substrate (Salt et al. 1995). One of the reasons for using phytoremediation is because it has a low cost and minimal maintenance requirements (Cunningham & Bertie 1993). Wong (2003) noticed that phytoremediation has been used to restore polluted soil in industrial areas, because these soils are sources of air and water pollution. According to the different capacities of metal absorption, some plant species are able to accumulate relatively high metal concentrations in the above ground tissues, and they can be good candidates for phytoremediation.

Moreover, phytoremediation is a promising method for reclamation of soils contaminated with heavy metals by using hyperaccumulator plants. A hyperaccumulator is a plant that absorbs toxins, such as heavy metals, to a greater concentration than that in the soil in which it is growing (Baker et al. 2000, Ghosh & Singh 2005).

More than 400 plant species belonging to 45 plant families have been identified and reported from temperate to tropical regions with the ability to tolerate and hyperaccumulate trace elements (Baker & Brooks 1989). These plants have been considered suitable for soil stabilization and extraction of heavy metals (Madejon et al. 2002). Plant species with slow growth of the shoot and root system and small biomass production are not generally preferred for phytoremediation. Yoon et al. (2006) showed that plant species with high translocation factor (TF) values were considered suitable for phytoextraction. It is desirable to have heavy metals easily translocated to harvestable plant parts, i.e., shoots. Once the plants have grown and absorbed the metal pollutants, they are harvested, and the heavy metal-contaminated biomass processed for further use (recycling) or disposed off safely. Some crops may be palatable and pose a risk to grazing of animals (Lasat 2000). High heavy metal accumulating ability in cereal crops, such as maize (*Zea mays* L.), has been found (Vijayarengan 2005). However, one challenge that needs to be met, and a pre-requisite for implementation of successful phytoremediation, is the selection and identification of available of plant species locally. It is important to use local plants for phytoremediation, because these native plants are often better in terms of survival, growth, and reproduction under environmental stress than plants introduced from another environment (Yoon et al. 2006, Antonsiewicz et al. 2008). Some authors found high concentrations of trace metals in plants grown in polluted areas. Ibrahim et al. (2013) assessed accumulation of toxic heavy metals (Cd, Zn, Cu, Ni, Pb) in the soil, shoots and roots of six plant species collected from an industrial zone of Riyadh, Saudi Arabia. Their results showed that *Phragmites australis* and *Lycium shawii*, together with *Malva parviflora* and *Rhazya stricta*, had a highly positive phytoextraction potential for Cd and Pb, whereas, *Datura stramonium* and *Citrullus colocynthis* were found to be suitable for phytostabilization of soils contaminated with Ni and Cu. Al-Qahtani (2012) studied heavy metal accumulation in native plant species grown in contaminated soils in an industrial area in Riyadh. Her results showed that the concentrations of heavy metals in the soils had 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; and leaves of the studied species accumulated a smaller amount of the heavy metals than the corresponding roots, except for Cd, which accumulated in all plant organs (leaves, stems and roots). And she found that both *Phragmites australis* and *Cyperus laevigatus* were the best candidates for biomonitoring and phytoremediation programs of polluted soils. Yoon et al. (2006) reported that native plant species growing on contaminated sites may have the potential for phytoremediation. Therefore, the search for native plants that are tolerant to heavy metals is of importance.

With the local concern about the contamination of soil with heavy metals in the industrial area of Riyadh and the lack of research in this area, it becomes necessary to search for local plant species with the potential for phytoremediation, which can reduce the pollution of the environment and its impact on health. Therefore, the aim of this study was to evaluate the concentrations of Cd, Co, Cr, Cu, Mn, Ni, Pb, Fe, and Zn in soil and native plant species that are in the industrial area of Riyadh.

MATERIAL AND METHODS

Site description and collection of samples: The area that was studied is an industrial city located south of Riyadh, the capital of Saudi Arabia, which is inhabited by approximately 18% of the population of Saudi Arabia. The studied area (Fig. 1) included more than 1,100 factories and more than 120,000 workers and employees. The plant and soil samples were collected from the same sites and location points at the same time of year. Nine sites were chosen for sample collection using a global position system (GPS). Three soil samples, taken from the 0-20 cm depth, were randomly collected at each location where a plant sample was taken. The three soil samples were thoroughly mixed to obtain a representative sample. Immediately after collection, the soils were air-dried at room temperature (25 ± 2 °C); soil samples were sieved and stored in polyethylene bottles prior to analyses. For plant sampling, the vegetation density around the industrial city was generally low, making comprehensive sampling impossible. However, only the abundant, existing plant species in the area were collected. The native plant species were identified according to Al Farhan & Thomas (1994). A total of 3-5 plants, including shoots of each species, were collected randomly from each site and mixed to form a composite sample; the samples were placed in labelled bags and transported to the laboratory. Plant samples were washed with tap water and deionized water to remove any surface dust and soil particles, then oven dried at 55°C and ground to a fine powder and stored in polyethylene bottles for further analysis.

Plant and soil analysis: Air-dried soil samples were used to determine pH (1:5 soil water extract), electrical conductivity (EC) (1:5 soil water extract), and particle size analysis using standard laboratory methods (Rayment & Higginson 1992). Cation exchange capacity was determined by the silver thiourea method (Rayment & Higginson 1992). Organic carbon was determined by the modified Walkley and Black method (McLeod 1973). Soil samples were digested according to USEPA Method 3050A (USEPA 1996) for the analysis of heavy metals. To estimate the total heavy metals in the plants, samples were digested according to Chapman & Pratt (1996). Final solutions for soil and plant samples were analysed for heavy metal concentration using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). The results were submitted to descriptive statistics (maximum, minimum, average, mean, and standard deviation) and analysed by ANOVA. Statistical significance was defined as $p < 0.05$.

RESULTS AND DISCUSSION

The main properties of the soils are shown in Table 1. The results indicated that soils taken from different sites in the industrial area south of Riyadh had small differences in texture and pH. In general, soil pH was alkaline in nature,

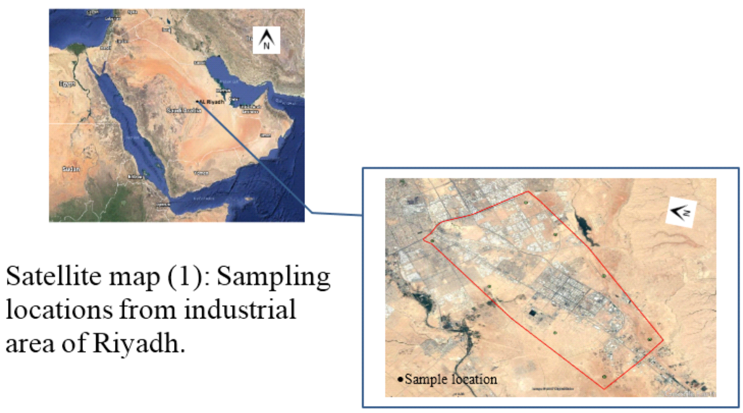

Fig. 1: Satellite map - sampling locations from industrial area of Riyadh.

Table 1: Selected properties of the soils in the industrial city south of Riyadh.

Properties	Mean	Minimum	Maximum	SD
pH (H_2O)	7.7	7.9	8.4	0.2
EC (dS m^{-1})	1.53	0.8	4	1.5
HCO_3^-	0.09	0.5	1.2	0.2
OM g kg^{-1}	0.6	0.2	1.4	0.4
CEC (cmol(+) kg^{-1})	2.1	0.2	0.2	5.7
$CaCO_3$ %	16.25	10.3	31	6.5
Sand %	85	79	94.5	6.2
Clay %	5.1	1.6	8	2.1
Silt %	9.8	3.7	17	4.8

Table 2: Total heavy metal concentrations in the soil in the industrial city south of Riyadh (mg kg^{-1}).

Heavy metal	Maximum	Minimum	Mean	SD
Cd	1.78	0.00	0.56	0.67
Cr	97.86	12.79	28.46	27.07
Cu	13.18	3.64	6.25	2.87
Fe	6182.30	4368.88	5203.37	636.22
Mn	121.30	63.81	96.42	17.65
Ni	17.27	8.73	13.61	2.94
Pb	21.17	6.15	10.03	4.62
Zn	55.02	14.08	22.45	12.65

SD: standard deviation

and the pH of the soil from which the plants were sampled throughout the studied area ranged from 7.7 to 8.4. This has been reported by other authors working in the same industrial area (Al-Qahtani 2012, Adel et al. 2014). The high pH of the samples is due to a high content of calcium carbonate, and the total calcium carbonate content for samples was 16.25% on average. EC ranged from 0.8 to 4 dS m^{-1} within an average 1.53 dS m^{-1}. The soil samples contained various soil textures; clay ranged from 1.6 to 8%; silt ranged from 3.7 to 17%; and sand ranged from 79 to 94.5% (Table 1). The results showed that all sites had a sandy texture and a high content of sand. The content of the OM was low due to the fact that the soil was sandy under the semi-dry arid areas.

The study conducted in this industrial city showed a group of local plants that constitute the dominant vegetation in the contaminated area. They were *Cyperus laevigatus, Cassia italica, Rhazya stricta* and *Anabasis setifera.* To assess their ability to accumulate Cd, Co, Cr, Cu, Mn, Ni, Pb, Fe and Zn, elements in the soil and plant samples were determined.

The concentrations of the elements in soil taken from the industrial area and in the shoots of plants are presented in Fig. 2. Table 3 shows the exact values of the concentration of the heavy metals in the shoots of plants. Heavy metal concentrations in the soil followed the order of Fe > Mn > Cr > Zn > Ni > Pb > Cu > Cd, while in plants the trend was Fe > Zn > Mn > Cu > Pb > Cr > Ni > Cd for *Anabasis setifera*; Fe > Mn > Zn > Cu > Cr > Pb > Ni > Cd for *Cassia italica*, Fe > Mn > Zn > Cu > Cr > Cd > Ni > Pb for *Cyperus laevigatus*; and Fe > Mn > Zn > Pb ≥ Cu > Cr > Ni > Cd for *Rhazya stricta.* The data showed that the heavy metal concentrations in the plant tissues differed among species at the polluted site, indicating the plants' different capacities for metal uptake. Plant species able to accumulate relatively high metal concentrations in the aboveground tissues are good candidates for phytoremediation.

Cadmium (Cd): Fig. 2 shows Cd concentrations of the four plant species. Significant differences among the studied plants in Cd concentrations and the pattern of Cd concentrations in the plants were observed. The highest uptake of Cd was attained by *Cyperus laevigatus.* The total Cd concentrations in the shoot of *Cyperus laevigatus* and *Anabasis setifera* were 4.59 mg kg^{-1} and 1.06 mg kg^{-1}, respectively. The results indicated that *Cyperus laevigatus* could be regarded as a Cd accumulator plant. The distribution of Cd within plant organs was variable and the data illustrated translocation from roots to shoots (Kabata et al. 2001).

Chromium (Cr): Chromium is a non-essential mineral for plant growth. It may be possible that plants do not have any specific mechanism for transfer of Cr (Shanker et al. 2005).

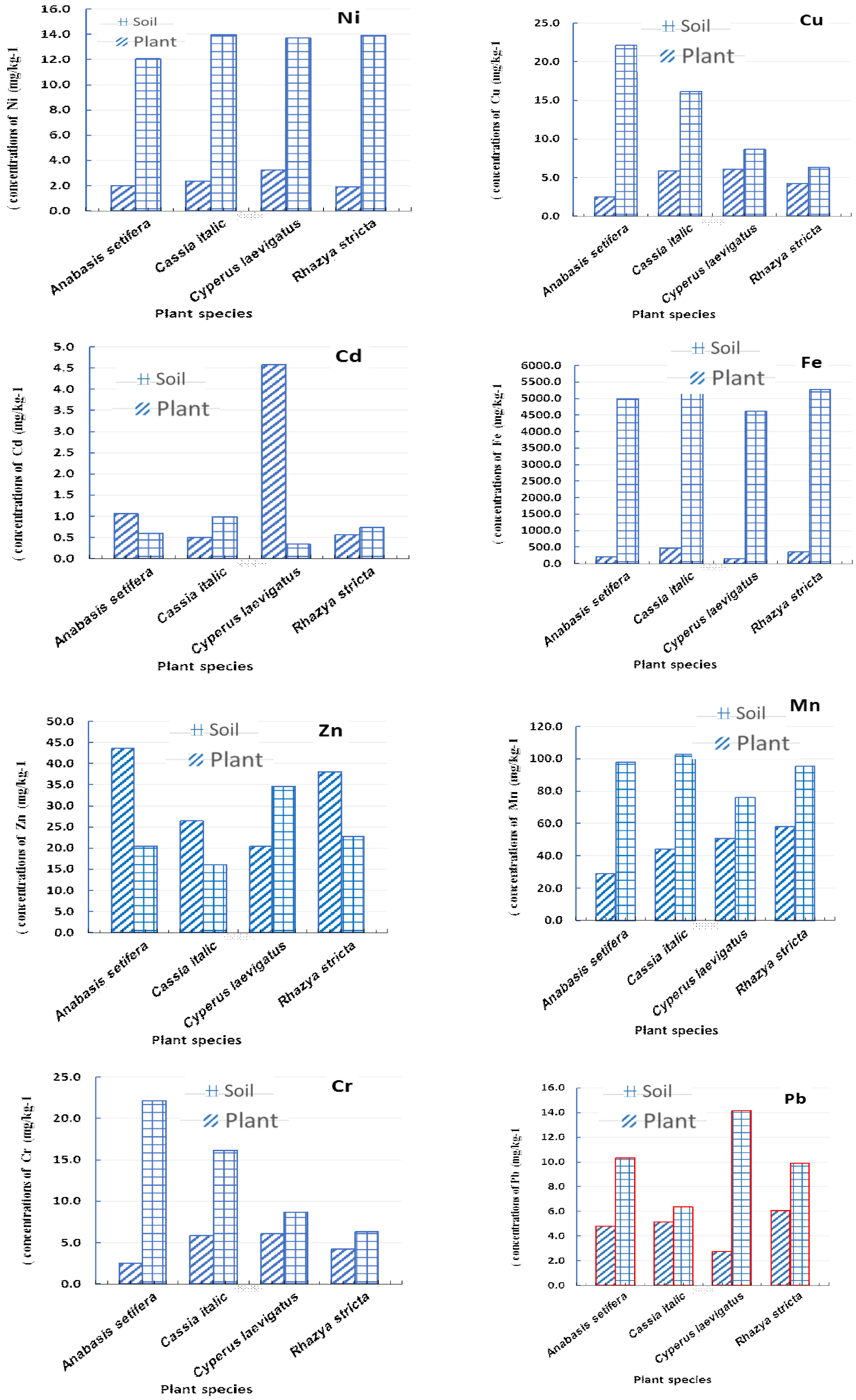

Fig. 2: Average Cd, Cr, Cu, Fe, Pb, Ni, Zn and Pb concentrations (mg kg^{-1}) in shoots and soil associated with *Cyperus laevigatus, Cassia italic, Rhazya stricta* and *Anabasis setifera.*

Table 3: The mean of heavy metal values (mg kg^{-1}) in shoots of four plant species.

Plant Species	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Anabasis setifera	1.1	2.5	5.8	207.5	29.1	2.0	4.8	43.6
Cassia italica	0.5	5.9	8.6	464.7	44.4	2.3	5.1	26.6
Cyperus laevigatus	4.6	6.1	15.5	148.1	50.7	3.3	2.7	20.4
Rhazya stricta	0.6	4.2	6.0	354.7	158.1	1.9	6.0	38.1
Mean	1.7	4.7	8.9	293.8	70.6	2.4	4.7	32.1

The mean values for Cr in *Anabasis setifera, Cassia italica, Cyperus laevigatus* and *Rhazya stricta* were 2.53, 5.87, 6.05 and 4.23 mg kg^{-1}, respectively. There were no significant differences among the plants in Cr concentrations. Soils of all selected sites in the area under investigation had no differences in concentrations of Cr, except in the site associated with *Cyperus laevigatus* (Table 2), with the mean value recorded of 55.87 mg kg^{-1}. This is due to its location near a highly polluted drain with industrial discharge.

Copper (Cu): Copper is an essential element for plants. Fig. 2 illustrates that the highest concentration of Cu was in *Cyperus laevigatus* (15.48 mg kg^{-1}). However, shoots of *Anabasis setifera, Cassia italic* and *Rhazya stricta* were also found to accumulate reasonable amounts of Cu (5.7, 8.6 and 6.0 mg kg^{-1}, respectively). However, toxic effects can occur when shoots or leaves accumulate Cu in exceedingly high levels. Macnicol & Beckett (1985) reported that Cu concentrations in plants above 10-30 mg kg^{-1} are poisonous. Most Cu values in this study were not high.

Iron (Fe): Iron is a basic micronutrient for almost all living organisms, because it plays a crucial role in metabolic processes such as DNA synthesis, respiration and photosynthesis (Rout & Sahoo 2015). All the four plants accumulated Fe (Fig. 2). The concentrations of Fe were in the following order: *Cassia italica, Rhazya stricta*, *Anabasis setifera* and *Cyperus laevigatus* (464.7, 354.7, 207.5 and 148.1 mg kg^{-1}, respectively) (Table 3). Iron uptake by plants is fastest when iron is present in the ferrous form (Chaney et al. 1972). Increased levels of mineral contaminants due to human processes lead to a rapid accumulation of metals in soil and water. Thus, these minerals are likely to increase in concentration in plants, especially where plants grow in industrial areas and near large sources of emissions. In this way, the metal enters the food chain (Munnz & Tester 2008).

Lead (Pb): Plant species living in polluted areas were exposed to lead (Table 2). But the concentration of Pb in the soils was very low, reaching up to 14.18 mg kg^{-1}. Mean concentrations of Pb in shoots were 5.13, 6.05, 4.79 and 2.73 mg kg^{-1} in *Cassia italica*, *Rhazya stricta*, *Anabasis setifera* and *Cyperus laevigatus*, respectively. DelRio et al. (2002) showed that the concentration of lead in plant buds that are grown in soil containing up to 1000 mg of lead/kg ranged from 5-50 mg/kg. Kabata-Pendias & Pendias (2001) reported that Pb shoot accumulation is low in most plant species, because it occurs in water-insoluble chemical forms in the soil. This agrees with the results obtained from the plant analysis in this study. Moreover, Pb is the least mobile among the heavy metals, and it is not essential, but toxic, to plants.

Manganese (Mn): Manganese is an essential trace element for life tissues; however, exposure to excessive Mn can cause toxic effects on plants and people. Concentration of Mn in the soil and plant samples was at low levels. The average concentrations of Mn in soil were 98.09, 102.81, 76.02 and 95.53 mg kg^{-1} for sites with *Anabasis setifera*, *Cassia italica*, *Cyperus laevigatus* and *Rhazya stricta*, respectively. However, the concentration of Mn in their shoots was not high. Mean values were 29.13 mg kg^{-1} for *Anabasis setifera*, 44.37 mg kg^{-1} for *Cassia italica*, 50.66 mg kg^{-1} for *Cyperus laevigatus* and 158.06 mg kg^{-1} for *Rhazya stricta*. When comparing the Mn concentrations in soils and shoots, it was observed that the concentrations of Mn in shoots were maintained at low levels (Fig. 2). Manganese is thermodynamically unstable in anaerobic conditions (Tokalioglu et al. 2000). It is associated with the carbonate fraction in soils and might be co-precipitated with $CaCO_3$ (Kersten 1988). Because of the high concentration of Mn in *Rhazya stricta*, this native plant might be considered as a Mn hyperaccumulator and it might be used for phytoremediation of Mn-contaminated sites.

Other elements (Zn, Ni): The concentrations of the other studied elements (Zn, Ni) in soil and plants are shown in Tables 2 and 3 and Fig. 2. The mean concentration of Zn was in the order *Anabasis setifera* > *Rhazya stricta* > *Cassia italica* > *Cyperus laevigatus*. The highest mean Zn concentration occurred in the shoots of *Anabasis setifera* (43.57 mg kg^{-1}). The concentration of Ni in *Anabasis setifera, Cassia italica, Cyperus laevigatus* and *Rhazya stricta* were 2.0, 2.3, 3.3 and 1.9 mg kg^{-1}, respectively (Table 3). According to Kabata-Pendias & Pendias (2001), the normal Ni concentration of plants growing in uncontaminated soils is in range of 0.1-3.7 µg g^{-1} (0.1-3.7 mg kg^{-1}) for Ni. The results of this study showed that Ni concentrations in native plant species were not higher than normal plants.

CONCLUSION

This study was conducted to determine the potential for heavy metal accumulation of four native plant species, *Anabasis setifera*, *Rhazya stricta*, *Cassia italica* and *Cyperus laevigatus*, growing in an industrial city south of Riyadh. The results showed that the mean concentrations of heavy metals in the soils followed the order of Fe > Mn > Cr > Zn > Ni > Pb > Cu > Cd, while, in plants, they differed among species at the polluted site, which indicated their different capacities for metal uptake. The trend was Fe > Zn > Mn > Cu > Pb > Cr > Ni > Cd for *Anabasis Setifera*; Fe > Mn > Zn > Cu > Cr > Pb > Ni > Cd for *Cassia italica*; Fe > Mn > Zn> Cu > Cr > Cd > Ni > Pb for *Cyperus laevigatus*; and Fe > Mn > Zn > Pb > Cu > Cr > Ni > Cd for *Rhazya stricta*. Furthermore, the plant species examined in this study grew well under low nutrient conditions, which would be an advantage in phytoremediation, because cost would be reduced without fertilizer. The study showed that some plant species might be suitable for use in phytoremediation.

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