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Transfer and Accumulation of Some Heavy Metals in Native Vegetation Plants

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Authors' contributions

This study was carried out in collaboration among all authors. Authors AMG and MMA designed the study, performed the experimental process and wrote the first draft of the manuscript. Author NAB managed the analysis of the experiment and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Phytoremediation procedure can be defined as the use of selected plants in order to eliminate some heavy metals from the soil, or wastewater in a cost-effective method. This study aimed to investigate the concentrations of heavy metals such as Cd, Pb, Cu, Zn and Cr in soils and vegetation plants grown in Wadi Hanifa, Riyadh city, Kingdom of Saudi Arabia. Five sites have been chosen for collected plant samples (shoot and root) for one year, and five plant species have been chosen which distributed in the study area including *Ziziphus spina-christi*, *Prosopis juliflora, Rhazya stricta*, *Ochradenus baccatus* and *Conocarpus erectus*. Determination of Cd, Pb, Cu, Zn and Cr has been done with ICP. Accumulation coefficient (AC), and translocation factor (TF) have been calculated to evaluate the ability of selected plants to extract the heavy metals from soil. The results indicated that *Ziziphus spina-christi and Conocarpus erectus* showed the high ability to accumulate the Pb and Zn in its root and shoot compared with other plants. The trend of heavy metal translocation factors for different plants was in the order of Cd > Cr > Pb > Cu > Zn. The accumulation coefficient (AC) of the Cd, Pb, Zn, Cu and Cr in the roots/soil of *Ziziphus spina-christi*,

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Prosopis juliflora, *Rhazya stricta*, *Ochradenus baccatus* and *Conocarpus erectus* were varied from 0.80 to 3.60. The order of AC in the shoot as follows: Pb > Cu > Zn > Cr > Cd, while in roots of as follows: Cd > Cr > Pb > Cr > Zn.

Keywords: Heavy metals; transfer; accumulation; Ziziphus spina-christi; Prosopis juliflora; Rhazya stricta; Ochradenus baccatus and Conocarpus erectus.

1. INTRODUCTION

Heavy metals are becoming increasingly prevalent in soil environments as a result of wastewater irrigation, sludge application, solid waste disposal, automobiles exhaust and industrial wastewater discharge [1,2]. The release of heavy metals into the environment by industrial activities presents a serious environmental threat. Heavy metal contamination is considered as a dominant source of pollution and a potentially growing environmental and human health concern worldwide [3,4]. Copper (Cu), lead (Pb) and cadmium (Cd) can become a sanitary and ecological threat to drinking water resources, even at very low concentrations [5]. In addition, Cd and zinc (Zn) are common industrial pollutants [6,7]. Cadmium is harmful to plant at relatively low concentrations. Zinc is one of the eight essential micronutrients and it is needed by plants in small amounts, but yet crucial to plant development. In plants, Zn is a key constituent of many enzymes and proteins. It plays an important role in a wide range of processes, such as growth hormone production and internode elongation [8].

Some plants can potentially accumulate certain heavy metal ions in an order of magnitude greater than the surrounding medium [9]. Therefore, clean alternatives must be developed in order to remove heavy metals from effluents. Heavy metals can be removed from industrial wastewater and contained soil by a range of physicochemical remediation technologies such as precipitation, ion exchange, adsorption, electrochemical processes and membrane processes [10-12]. However, these technologies are expensive and energy-intensive, driving towards a search of cheaper alternatives [13].

Phytoremediation is a method of environmental treatment that makes use of the ability of some plant species to accumulate certain heavy metals in amounts exceeding the nutrients requirements of plants. Phytoextraction is one of the elements of phytoremediation in which heavy metals from the contaminated site are taken up by plants and then transported from roots to shoots and removed with crops from a specified area of nature [14]. Numerous processes exist for removing heavy metals, including ion exchange, precipitation, ultrafiltration, and adsorption. Among these methods, phytoremediation by natural plants is effective and cheap when compared to other methods. Phytoremediation is phytostablisation where plants are used to minimise some of heavy metals mobility in contaminated soils. Nowadays, then 500 plants are known as hyperaccumulation of heavy metals into their aboveground biomass including weeds, trees, grasses and vegetable crops [15, 16].

The objectives of this research were to determine the concentration of some heavy metals in some native plant species growing on a contaminated soil which located in the Wadi Hanifa, Riyadh city, Kingdom of Saudi Arabia and to assessment and evaluation of heavy metals pollution.

2. MATERIALS AND METHODS

2.1 Experimental Sit Description and Soil Chemical Analysis

Wadi Hanifa (24°14'27.0" N 47°00'00.0" E) is a valley in the Najd region, Riyadh province, in central Saudi Arabia. The valley runs for a length of 120 km from northwest to southeast, cutting through the city of Riyadh, the capital of Saudi Arabia. Temperatures in summer reach an average of 43.9°C and precipitation averages only 62 mm per year in the driest places Rain falls with great intensity for short periods, causing flash floods. The nature of the dry, warm climate leads to a high percentage of the scarce rainfall being instantly evaporated [17,18]. Represented soil samples were collected from the surface layer (0-20 cm depth) by 20x20 m. The soil samples were air-dried at room temperature for two weeks and then sieved by 2-mm stainless steel sieve. The pH and EC of samples were measured (using 1:5 ratio of w/v with deionised distilled water) by pH-meter and the electrical conductivity (EC) meter respectively. Complex metric EDTA titration was employed for determining Ca^{++} and Mg^{++} simultaneously and individually [19]. Sodium and potassium were determined using flame photometer (Corning

400). Carbonate and bicarbonate were determined by titration with H_2SO_4 while silver nitrate was used to determine chloride [19]. Sulphate was determined by turbidity method as described by Lindsay [20]. Particle size distribution was analysed according to Gee and Bauder [21]. Calcium Carbonate content was determined using the Calcimeter [22]. Some selected soil physical and chemical properties are presented in Table (1). The total content of heavy metals (Cd, Pb, Zn, Cu, Cr and Zn) in the soil samples were determined after digestion with HNO_3-$HClO_4$-HF as described by Hossner [23], then total heavy metals content were determined using ICP (Perkin Elmer, Model 4300DV).

2.2 Plant Sample Collection and Plant Analysis

Five plant native plant species (*Ziziphus spina-christi*, *Prosopis juliflora, Rhazya stricta*, *Ochradenus baccatus* and *Conocarpus erectus*) based on their coverage at the Wady Henifia, Riyadh city, Saudi Arabia were collected in acid-washed polythene bags according to the sampling procedures of Australian National Botanic Garden [23,24]. Table 2 shows the botanical and vernacular names of plants species collected from the study area. The collected plant samples were separated into shoot and root, washed gently with deionised water for approximately 5 minutes to remove soil particles adhered to the plant roots, then, air-dried at 60°and finally ground and powdered using a Wiley mill. The plant samples were acid digested with HNO_3-$HClO_4$ mixture according to Chapman and Pratt, (1996). After digestion, the cooled samples were diluted to 50 mL with distilled water and filtered into plastic bottles pre-washed with acid. The concentrations of heavy metals mainly (Cd, Pb, Zn, Cu, Cr and Fe) were measured using ICP (Perkin Elmer, Model 4300 DV). Reagent blanks and standards were used where appropriate to ensure accuracy and precision in heavy metals analysis.

2.3 Estimation of Heavy Metals between Soil and Plant

2.3.1 Accumulation coefficient

Accumulation coefficient was used for evaluation of heavy metals accumulation in the plant according to Tony [25] as flows:

$$Ac = \frac{C_{root,\ stem,\ leaves}}{C_{soil}}$$

Ac = concentration of heavy metal in plant shoot (mg kg^{-1})/ concentration of heavy metal in background soil (mg kg^{-1}).

2.3.2 Translocation factor

Translocation factor (TF) describes the amount of heavy metal transferred from the soil to the plant under equilibrium conditions [26]. Heavy metals from the soil are consumed by plant roots and then distributed in various plant tissues. Transfer of this heavy metal from soil to plant tissues is measured using the TF indicator, which measures the ratio of the concentration of a specific metal in plant tissue to the concentration of the same metal in soil. If the TF values are ≥ 1.0 it shows a higher uptake of metal from the soil by the plant, while lower values mean less absorption of the metal from the soil, and the plant can be used for consumption [27].

Translocation Factor (TF) was calculated as follows:

$$TF = \frac{Metal_{shoot}}{Metal_{roots}}$$

3. RESULTS AND DISCUSSION

3.1 Soil Characteristics

Selected physical and chemical properties of soil collected from the Wadi Hanifa are listed in Table 1. The soil texture was sandy; the soil pH was 7.80 with EC 4.50 dS m-1in. In addition, results indicated that the percentage of CaCO3 was 19.2%. Also, a wide range of soil heavy metals concentration was observed of soil at the start of collecting the plant samples. The total content of Cu 20±0.10 mg kg-1; Zn 35±1.20 mg kg-1; Pb 15±0.70 mg kg-1; Cd 0.20±0.01 mg kg-1 and Cr 30±1.15 mg kg-1. According to Lindsay, [28] who reported that 35 mg kg-1 Zn 40 mg kg-1 Pb, 10 mg kg-1 Cd, 0.05 mg kg-1 and Cr 95 mg kg-1 the average of heavy metals concentrations in common soils. The results indicated that the total concentration of Cr, Pb, Zn and Cu were within the normal range of common soils expect the Cd. Wastewater samples were collected from different locations in the Wadi Hanifa. The results indicated that the water quality was characterised by high pH and contains high concentrations of Fe, Mn, Zn, Cd, Ni, Pb, and Mo compared with

Table 1. Soil physical and chemical properties of Wadi Hanifa, Riyadh city, Kingdom of Saudi Arabia

pH	Cations (meq L^{-1})				Anions (meq L^{-1})				*EC dS m^{-1}	Particles size distribution %			$CaCO_3$%
	K^+	Na^+	Mg^{2+}	Ca^{2+}	Cl^-	HCO_3^-	$SO_4^=$	$CO_3^=$		Clay	Silt	Sand	
7.80	5.00	0.90	0.50	0.90	4.50	0.80	0.08	0.00	4.30	10.0	8.00	82.0	19.2

**EC: Electrical conductivity. Results of soil properties expressed as the average of three replicates*

Table 2. Description (botanical and vernacular names) of plants species grown in the study area

Name of plants	Common names	Latin name	Binomial name	Family name	Order name
Ziziphus spina-christi	Ziziphus, crown of thorns, sidr	*Ziziphus spina-christi*(L.) Desf.	*Ziziphus jujuba*	Rhamnaceae	Rosales
Prosopis juliflora	Prosopis	*Prosopis juliflora* (Sw.) DC	*Prosopis juliflora*	Mimosaceae	Fabaceae
Rhazya stricta	Harmal	*Rhazya stricta* Decne	*Rhazya stricta*	Zygophyllaceae	Apocynaceae
Ochradenus baccatus	Pearl plant, qardi, Qurdi, Taily Weed	*Ochradenus baccatus* Delile	*Ochradenus baccatus*	Resedaceae	Resedaceae
Conocarpus erectus	Buttonwood, button mangrove	*Conocarpus acutifolius Willd.* ex Schult.	*Conocarpus erectus*	Combretaceae	Myrtales

the Kingdom of Saudi Arabia. The higher content of some heavy in the study site could be a result of irrigation using wastewater, sewage sludge, solid waste disposal, automobiles exhaust and industrial activities. Heavy metals are highly toxic elements that can concentrate and accumulate in live tissues. Lead, Cu and especially Cd can become a sanitary and ecological threat to drinking water resources, even at very low concentrations. Also, Cd and Zn elements are common industrial pollutants [6].

3.2 Concentration of Heavy Metal in Plant Species

Table 3 shows the heavy metals content in shoot and roots of selected plant species. In general, the concentration of Cd, Pb, Zn, Cu and Cr in roots of *Ziziphus spina-christi*, *prosopis juliflora*, *Rhazya stricta*, *Ochradenus baccatus* and *Conocarpus erectus* plant species was higher than that in shoots. The concentration of heavy metals in shoots and roots varied with heavy metals type and plant species. Plant *Ziziphus spina-christi and Conocarpus erectus* showed the high ability to accumulate the Pb and Zn in its root and shoot compared with the other plants. All the studied plant species showed the ability to accumulate the Pb, Zn, Cu, Cr expect Cd. The results were in agreement with reported by Al-Wahaibi [29], Al-Otabi and Al-Farraj [30]. Some of the heavy metal from soil occurs either passively with the mass flow of water and accumulated plant roots [9,31]. Some plants can accumulate certain metal ions in higher concentration than the surrounding soil [32]. The study of heavy metal accumulation in second industrial wastewater of Riyadh city, Ghoneim et al [7] reported that the concentrations of Cr, Ni, Cu, Zn, and Pb in *Fagonia indica* and *Cenchrus ciliaris* plants were markedly higher than *Rhazya stricta* plant. According to the State Environmental Protection Administration and China, the average concentration of Cr, Ni, Cu and Cd elements were 0.50, 9.0, 20 and 0.20 mg kg^{-1} on a dry weight basis, respectively. In the current study, the concentration of Cr, Ni and Zn concentrations in roots and shoot of *Ziziphus spina-christi*, *Prosopis juliflora*, *Rhazya stricta*, *Ochradenus baccatus* and *Conocarpus erectus* have exceeded the concentration limits. The heavy metals enter the environment from both natural processes which included weathering, parent material rock erosions and atmospheric deposition and from anthropogenic activities such as using chemicals, sewage sludge disposal, mining [33-35]. The heavy metal accumulated could contaminate the soil and vegetables at high concentrations.

3.3 Accumulation Coefficient (AC)

The accumulation coefficient (AC) of the Cd, Pb, Zn, Cu and Cr in the roots/soil of *Ziziphus spina-christi*, *prosopis juliflora*, *Rhazya stricta*, *Ochradenus baccatus* and *Conocarpus erectus* were varied from 0.80 to 3.60 (Table 4). The results indicated that the AC values depend on the heavy metal type and plant species. Regardless the AC values were 0.02-4.0, 0.02-3.40, 0.70-3.60, 0.71-3.90 and 0.46-5.60 for *Ziziphus spina-christi*, *Prosopis juliflora*, *Rhazya stricta*, *Ochradenus baccatus* and *Conocarpus erectus*, respectively. The order of AC in the shoot were as follows: Pb>Cu>Zn>Cr>Cd, while in roots it followed the trend of: Cd>Cr>Pb>Cr> Zn. The calculated range of AC values of the heavy metals in the roots of *Fagonia indica* and *Cenchrus ciliaris* were 0.31-2.30 [2,36]. The higher AC values of the studied plant indicated that these plant species could be accumulated heavy metals and also can be used for heavy metal phytoextraction from contaminated soil.

3.4 Translocation Factor (TF)

The calculated (TF) values of transfer the heavy metals from soil to different plant spices are presented in (Table 5). The TF values varied among the plant species and highest TF for Cd in *Prosopis juliflora*, *Ochradenus baccatus* followed by Cr in *Rhazya stricta*, *Ochradenus baccatus* and *prosopis juliflora* plant, while the lowest TF for Zn and Cu was recorded in all studied plants. The high TF for Cd, Cr and Pb heavy metals from soil to plant indicated that a strong accumulation of those metals. The calculated TF values for heavy metals were found in the order: Cd>Cr>Pb>Zn>Cu. The results indicated that the plant species have a different ability to accumulate heavy metals. The results show clearly that the plant species differ to use its ability to accumulate the heavy from the soil (Fig. 1). For example, the ability of the *Ochradenus baccatus* and *prosopis juliflora* plant for the accumulation of Cd was higher than other plant species, while *Rhazya stricta* had the ability to accumulate Cr. The higher the value of TF means that the more heavy metal could be accumulated by plants parts. Cadmium, Cr and Pb were the highest TF values, which agreed with Yang et al., [37]. By comparing TF values, for *Ziziphus spina- christi*, *Prosopis juliflora*, *Rhazya stricta*, *Ochradenus baccatus* and

Table 3. Heavy metal concentration (mg kg^{-1} dry weight) in the shoot and root tissues of some native plants

Plant type	Plant part	Cd	Pb	Zn	Cu	Cr
		Concentration (mg kg^{-1})				
Ochradenus baccatus	Shoot	0.20±0.01	0.50±0.03	20.1±1.10	6.20±0.10	20.1±1.50
	Root	0.10±0.01	30.5±2.50	25.1±2.00	18.1±1.02	10.5±0.80
Rhazya stricta	Shoot	0.01±0.01	0.50±0.03	4.10±0.04	0.50±0.01	15.0±1.20
	Root	0.30±0.01	18.2±1.10	29.1±1.20	15.1±0.30	7.50±0.80
Conocarpus erectus	Shoot	0.25±0.10	34.0±2.50	25.0±1.30	8.50±0.06	13.0±0.90
	Root	0.20±0.01	42.1±2.70	44.8±2.30	16.0±1.20	16.1±1.30
Ziziphus spina-christi	Shoot	0.23±0.01	45.0±2.90	46.0±2.40	14.0±1.30	12.0±0.90
	Root	0.19±0.01	45.1±2.90	55.2±2.90	22.1±1.5	29.1±2.20
Prosopis juliflora	Shoot	0.55±0.10	47.0±2.60	30.1±2.66	15.0±0.80	19.0±1.50
	Root	0.17±0.02	45.1±2.55	55.1±2.75	25.1±0.75	15.1±1.20

Results of heavy metals are expressed as the average ± standard deviation of the three replicates

Table 4. Heavy metals Accumulation Factors (AC) on a dry weight basis for some native plants grown in Wadi Hanifa

Heavy Metal	Accumulation Factor (AF)	*Ochradenus baccatus*	*Rhazya stricta*	*Conocarpus erectus*	*Ziziphus spina-christi*	*Prosopis juliflora*
Cd	Shoot/Soil	1.00	0.00	1.25	1.15	2.75
	Roots/Soil	0.50	1.50	1.00	1.00	0.90
Pb	Shoot/Soil	0.02	0.02	1.40	1.86	1.94
	Roots/Soil	1.30	0.80	1.70	1.90	1.90
Zn	Shoot/Soil	0.31	0.06	0.38	0.71	0.46
	Roots/Soil	0.40	0.40	0.70	0.80	0.80
Cu	Shoot/Soil	1.38	0.11	1.89	3.11	3.33
	Roots/Soil	4.00	3.40	3.60	3.90	3.60
Cr	Shoot/Soil	0.87	0.65	0.56	0.52	0.82
	Roots/Soil	0.50	0.30	0.70	1.30	0.70

native plants grown in Wadi Hanifa

Table 5. Heavy metals Translocation Factors (TF) on a dry weight basis for some native plants grown in Wadi Hanifa

Plant type	Translocation Factor (TF)				
	Cd	**Pb**	**Zn**	**Cu**	**Cr**
Ochradenus baccatus	2.00	0.02	0.80	0.34	1.90
Rhazya stricta	0.01	0.03	0.14	0.03	2.00
Conocarpus erectus	1.25	0.81	0.56	0.53	0.81
Ziziphus spina-christi	1.21	1.00	0.83	0.63	0.41
Prosopis juliflora	3.23	1.04	0.55	0.59	1.26

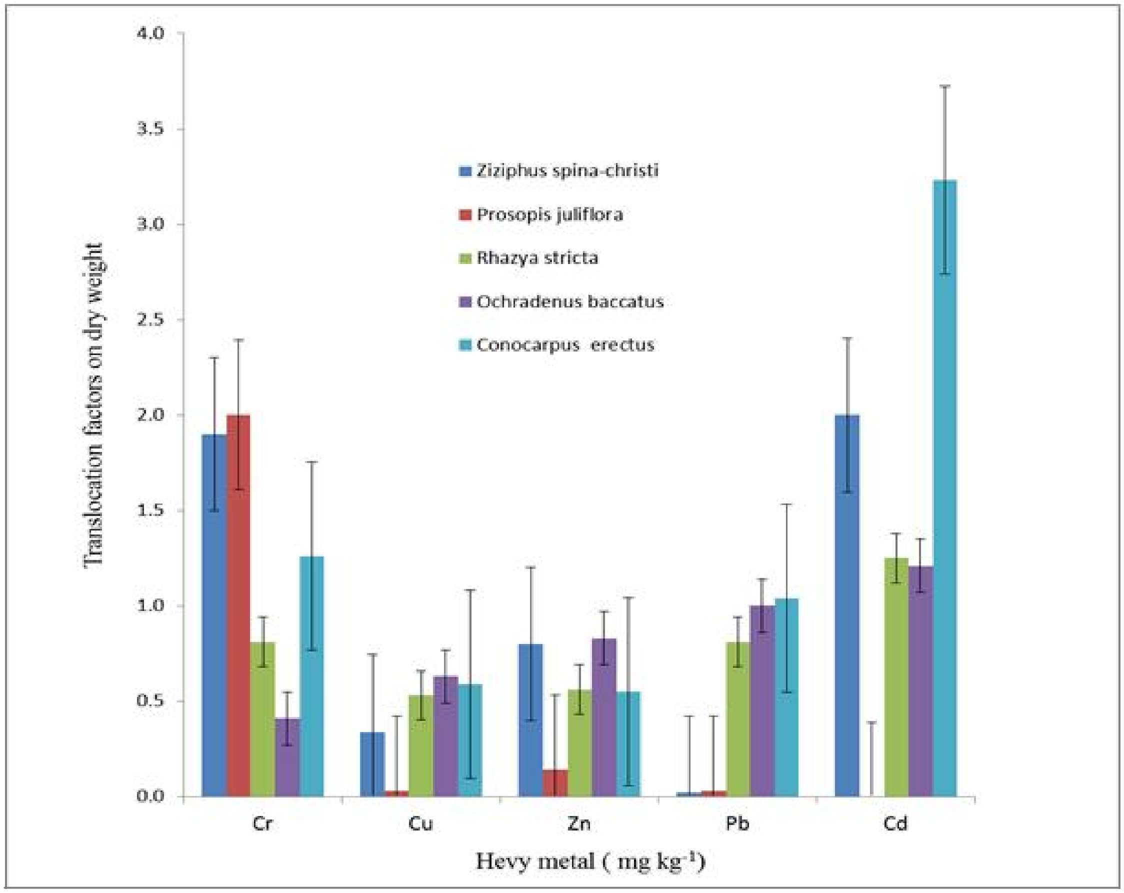

Fig. 1. Heavy metals translocation factors on dry weigh basis for native plants grown in Wadi Hanifa. Error bar represents ± standard error

Conocarpus erectus it could be compared with the ability of these plant species for the accumulation of heavy metals from the contaminated soil and translocations them in the plant canopy. Plants showing TF values less than one are unsuitable for photo extraction of some heavy metals [38] and but can be used as an indicator for soil contamination with some heavy metals.

4. CONCLUSION

This study was conducted to screen *Ziziphus spina-christi*, *Prosopis juliflora*, *Rhazya stricta*, *Ochradenus baccatus* and *Conocarpus erectus* plant species growing on Wadi Hanifa, Riyadh city, Kingdom of Saudi Arabia for their potential for removal of some heavy metal. The study confirmed that there were differences in the heavy element contents among plant species. The results showed that the existence Cd, Pb and Cr in the shoot and roots of *Prosopis juliflora*, *Ochradenus baccatus* and *Prosopis juliflora* plant species. The current study showed clearly that the plant species differed to use its ability to accumulate the heavy from the soil and wastewater and the recommendation that those species, with a high concentration in heavy elements.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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