Accumulation coefficient and translocation factor of heavy metals through *Rhazya stricta* grown in the mining area of Mahad AD'Dahab, Saudi Arabia

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Abstract

Plant specie *Rhazya stricta*, which naturally grows around Mahad AD'Dahab Mine, has been selected in order to study its ability to absorb and accumulate heavy metals (Cd, Cu, Pb, Zn). Twenty four samples from roots, stems, and leaves of *Rhazya stricta* were collected at 0, 1, 2, 3, 4, 5, 6, and 7 km away from the landfill. Moreover, eight compost soil samples were collected from each plant site. Plant and soil samples were analyzed for total concentration of Cd, Cu, Pb, and Zn. The results showed soil contamination with respect to Cd, Cu, Pb and Zn. The concentration of those metals was very high near the landfill area (first and second locations) compared with the others. Therefore, the enrichment factor (EF) indicated very highly polluted ($20 < EF \leq 40$) with Cd (33) and Zn (22) at the first location, whereas EF was 8 and 10 for Cd and Zn, respectively, at 1km away from the first location, which means a significant contamination ($5 < EF \leq 20$). Furthermore, the results showed a reduction of the accumulation coefficient (AC) (<1) of heavy metals (Cd, Cu, Pb, Zn). Nevertheless, the high concentration of heavy metals in soil reflected positively on the absorption by *Rhazya stricta*. Therefore, *Rhazya stricta*, in the first and second locations, had higher concentrations of heavy metals in their roots, stems, and leaves. The study clarified that the accumulation factor for Cd, Pb, Cu and Zn was high in roots compared with stems or leaves of *Rhazya stricta*. The translocation factor (TF) of Cu from roots to stems was (0.76), while it was (0.63) for cadmium. However, based on (TF) from stems to leaves, heavy metals can be ordered as follows: Cd> Zn> Cu> Pb. These results indicated that *Rhazya stricta* might not be appropriate

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for extracting heavy metals in contaminated soil, but it could be used to stabilize soil and thus prevent soil erosion, which results in reducing pollution in the surrounding areas. In addition, *Rhazya stricts* could be used as an indicator to soil contamination with heavy metals (Cd, Cu, Pb, and Zn). On other hand, the practice of providing foliage and pods as fodder for live stock should be avoided in the Mahad AD'Dahab area.

Keywords: heavy metals, Rhazya stricts, Mahad AD'Dahab, Saudi Arabia, gold mining.

1 Introduction

The contamination of soils or plants with heavy metals is one of the most dangerous types of pollution [1]. High accumulation of heavy metals was found on the surface of the soil in the areas of mining and industrial activity [2], which leads to environmental problems, such as increasing the concentration of these metals to toxic levels to plants, animals and humans, which results in serious health problems [3].

There are a number of studies on the plant uptake of heavy elements. Kathleen et al. [4] found that some species of plants reduce the mercury in water by absorption through the roots and accumulation in plants. It was also proved that the six species that belong to *Thlaspi* sp (Brassicaceae) can accumulate 0.1% Cd, 3% Zn, and 0.5% Pb in their branches [5, 6]. The ability of plants to accumulate elements depends on the size of plant and the speed of its growth [7].

Thangavel et al. [8] mentioned that *P. juliflora* could be used in the remediation of soils contaminated with aluminium. Moreover, *P. juliflora* was found to absorb nickel, chromium and lead [9, 10]. In addition, many types of ragweed were used to remove lead, while *thlapsi rotundifolium* was used for removing zinc and cadmium [11]. These plants are good for Phytoremediation, but it becomes dangerous when they are within pastoral areas.

Chelates, such as EDTA and DTPA, have been used to try to evaluate the bioavailability of heavy metals. The DTPA has been widely used in calcareous soils [12]. However, Ortiz and Alcañiz [13] found that DTPA extraction gave a very low correlation coefficient of *Dactylis glomerata* leaf concentration with Pb, Ni, Cu, and Cd. Vandecasteele et al. [14] found that EDTA is stronger than DTPA in the extraction of Zn, Cd, Cu, Pb and Ni. Moreover, they concluded that DTPA does not give a good indication of the extraction for zinc absorption by the plant. In addition, DTPA was poorly correlated with lead and cadmium.

There are several mining projects in Saudi Arabia, including gold mining in the Mahad AD'Dahab area. Its production began in 1988. Many studies found that the soil surrounding the gold mine is contaminated with respect to cadmium, copper, lead, zinc and mercury, where 99% of the studied soil samples (139 samples) were contaminated with one or more of those heavy metals depending on the Enrichment Factor (EF) [15]. Moreover, another study found that the total concentrations of Zn, Pb, Cu, Cd, and As were 1482, 355, 479, 7 and 30 mg kg^{-1} respectively [16]. In addition, Ketata and Husain [17] reported that the average total concentration of (Cd, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn) is higher than the maximum concentration that could be found in uncontaminated soil.

Al-Farraj and Al-Wabel [18] studied the concentration of heavy metals in the branches of ten plants that were grown around Mahad AlD'Dahab Mine. They found that *Pergularia tomentosa* had the highest concentration of heavy metals, while *Rhazya stricta* had the lowest accumulation. Therefore, those plants could be described as tolerant of soil contaminated by heavy metals, but they have different mechanisms. Al-Farraj et al. [19] found that *Ochradenus baccatus* is not excluded from absorbing heavy metals. Based on the AC, heavy metals were ordered as follows: Cd> Zn> As> Cu> Pb for shoots and Cd> Zn> Cu> Pb> As for roots.

From above, it is very important to study the behaviour of those plants in the contaminated areas, which will help in the perception of the bio-remediation of soils contaminated with heavy metals, as well as avoiding grazing areas where there is a serious risk of transmission to humans. Nevertheless, there are only a few studies that have examined the levels of heavy metals in mining areas in Saudi Arabia, as well as their effects on the ecosystem (human, animal, plant). Therefore, the objective of the current research is mainly to study the accumulation of heavy metals (Cd, Cu, Pb, Zn) in *Rhazya stricta* grown in the gold mining area at Mahad AD'Dahab, Saudi Arabia. Dry *Rhazya stricta* is one of the plants that could feed cattle and birds.

2 Materials and methods

2.1 Study area and collection of plant and soil samples

The *Rhazya stricta* and soil samples used for this research were collected in 2007 from the surrounding area of Mahad AD'Dahab Mine (23º30 = N; 40º30 = E) at 0, 1, 2, 3, 4, 5, 6, and 7 km from the Mine landfill. Mahad AD'Dahab has the largest and oldest gold mine in Saudi Arabia. Twenty four samples from roots, stems, and leaves of *Rhazya stricta* were collected from eight plants. These samples (stems, leaves and roots) were mixed separately and dried at 60ºC. The air-dried plant samples were powdered homogenously for further analysis. In addition, eight representative surface soil samples (0-30cm) were collected from the same location.

2.2 Heavy metals analysis

Dried and powdered plant samples were acid digested with HNO_3 and $HClO_4$ [20]. Soil samples were digested with HNO_3-$HClO_4$-HF [21]. Moreover, the DTPA extractable fraction was obtained by mechanical shaking of the soil samples with DTPA, $CaCl_2$ and TEA (triethanolamine), and buffered at pH 7.3 for 2 h [22]. Soil analysis was done with two replicates. The plants and soil digested or extracted were analyzed for heavy metal concentration (As, Cd, Cu, Pb, Zn) using ICP-AES (Perkin Elemer, 4300 DV). Due care was taken to avoid metal contamination in the process of sampling, washing, drying and grinding. Moreover, all analyses of plant samples were done on three replicates

2.3 Coefficient and translocation factor of heavy metals

Plant–soil relationships were assessed for heavy metal accumulation in leaves, stems and roots. The accumulation coefficient (AC), defined as the plant/soil concentration quotient [23], was calculated as

$$AC= (C_{root,\ stem\ or\ leave}/C_{soil})$$

where $C_{root,\ stem\ or\ leave}$ = Concentration of heavy metal in *Rhazya stricta* aerial or root part (mg kg^{-1}) and C_{soil} = Concentration in soil (mg kg^{-1}). Moreover, the translocation factor (TF) was calculated to estimate the transfer of heavy metals from roots to stems or leaves of *Rhazya stricta* TF = ($C_{stem\ or\ leave}/C_{root}$) [24].

3 Results and discussions

3.1 Contamination of soil samples

The average basic physicochemical properties of the studied soil samples are summarized in table 1. Table 2 shows the concentration of heavy metals of Mahad AD'Dahab's soil compared to the average concentrations and the normal ranges in soils. The soil has concentrations more than the average in soils. Furthermore, the soil has concentrations much higher than the maximum levels of Cd, Cu, Pb and Zn according to Lindsay [25], particularly that from the landfill area (first and second locations). Therefore, soil from Mahad AD'Dahab could be described as contaminated soil with respect to Cd, Cu, Pb and Zn. This result agreed well with the results of Al-Farraj and Al-Wabel [15]. The high concentration of heavy metals in soil resulted in increasing the extraction of DTPA. The average concentration of heavy metals extracted by DTPA follows the order: Pb (4.3%); Cd (2.5%); Cu (2); Zn (0.9) (Fig. 1).

3.2 Accumulation coefficient

Accumulation coefficients (ACs) of heavy metals in *Rhazya stricta* Decne ranged between <0.01 and 0.28, where the highest AC was for Cd followed by Cu then Zn, and finally Pb (Table 3). It is noted that the AC in roots was higher than that in the stems and leaves of *Rhazya stricta* for Cd and Cu, whereas the AC was proximate for Zn and Pb.

Table 1: The basic properties of Mahad AD'Dahab's soil.

pH	Cations mmol L^{-1}				Anions mmol L^{-1}				SAR	Textural Class	$CaCO_3$ %	OM %	CEC Cmol kg^{-1}
	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4					
8.1	3.5	0.3	3.8	0.6	nd	1.6	6.5	3.0	7.2	SL	5.3	0.14	8.3

Table 2: Total heavy metal concentrations of Mahad AD'Dahab's soil comparison with the common range in soils (mg kg^{-1}).

Element	Total Concentration at studied locations mg kg^{-1}								Common range in soils[1] mg kg^{-1}		
	1	2	3	4	5	6	7	8	Max.	Min.	Average
Cd	7.9	2.0	0.4	0.6	nd	0.3	nd	nd	0.7	0.01	0.06
Cu	944	612	97	180	114	183	92	137	100	2	30
Fe*	61	65	40	50	49	54	47	56	55	7	38
Pb	337	206	46	107	52	95	35	45	200	2	10
Zn	2112	1027	134	263	165	239	124	191	300	10	50

[1]Lindsay [25].
*number multiply by1000.

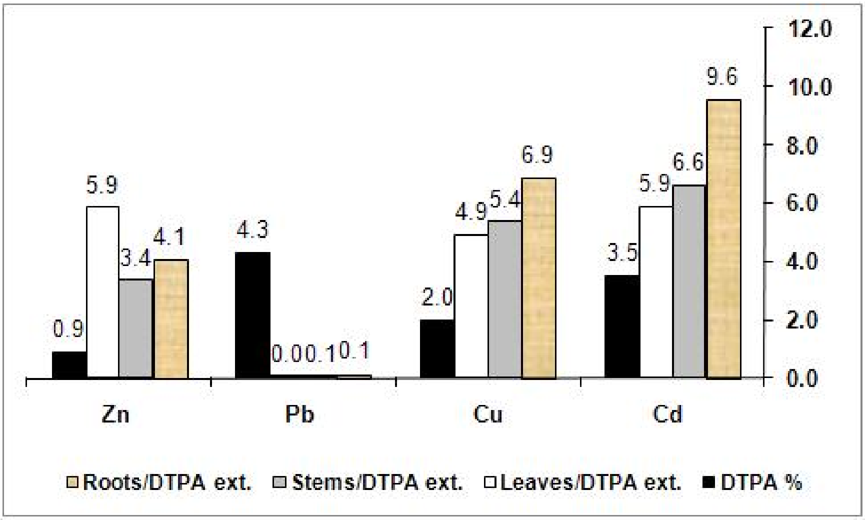

Figure 1: The percentage of heavy metals (%) extracted by DTPA compared with the ratio of their concentrations in roots, stems and leaves.

The AC of all studied heavy metals in *Rhazya stricta* was lower compared with *Ochradenus baccatus* [19]. The AC of Cd in the roots of *Ochradenus baccatus* was 0.58, while it was almost a half (0.28) in *Rhazya stricta*. While the AC was low for Cu (0.11) *Rhazya stricta* compared with *Ochradenus baccatus* (0.24), as well as for lead and zinc. The order of the accumulation coefficient of heavy metals in the roots of *Rhazya stricta* was as follows: Cd> Cu> Zn> Pb; this result agreed with that found in the previous study [19] for Cd and Pb.

Moreover, the results agreed with several previous studies [26–29]. Liu et al. [26] found the bioaccumulation coefficient as follows: Cd> Zn> Cu> Pb> As. In another study, the accumulation coefficient was 0.004-0.38 for *Zygophyllum fabago*, 0.003-0.063 of Pb in *Helichrysum decumbens*, and 0.014-0.119 of Cu in *Tamarix* sp [30].

Table 3: The average concentration of heavy metals in the roots, stems and leaves of *Rhazya stricta*, and the accumulation coefficient (AC) and translocation factor (TF).

Element		Concentration (mg kg^{-1})			Accumulation Coefficient		
		Leaves	Stems	Roots	Leaves/Soil	Stems/Soil	Roots/Soil
Cd	1	0.31	0.31	1.13	0.04	0.04	0.14
	2	0.50	0.06	0.22	0.25	0.03	0.11
	3	0.09	0,12	0.22	0.23	0.32	0.60
	4	0.08	0.09	0.35	0.12	0.15	0.56
	5	0.05	0.10	0.20	--	--	--
	6	0.18	0.15	0.21	0.72	0.62	0.83
	7	0.14	0.26	0.34	--	--	--
	8	0.03	0.14	0.09	--	--	--
		Average			0.17	0.15	0.28
Cu	1	18.37	9.84	63.23	0.02	0.01	0.07
	2	25.83	24.17	23.45	0.04	0.04	0.04
	3	9.56	11.89	16.05	0.10	0.12	0.17
	4	4.52	5.56	21.29	0.03	0.03	0.12
	5	6.21	7.40	14.04	0.05	0.07	0.12
	6	10.60	20.19	13.11	0.06	0.11	0.07
	7	6.15	14.68	16.50	0.07	0.16	0.18
	8	5.83	9.83	10.14	0.04	0.07	0.07
		Average			0.05	0.08	0.11
Pb	1	0.31	0.58	4.11	<0.01	<0.01	0.01
	2	0.21	0.04	0.64	<0.01	<0.01	<0.01
	3	nd	0.06	0.22	--	<0.01	<0.01
	4	0.04	nd	0.13	<0.01	--	<0.01
	5	nd	nd	0.15	--	--	<0.01
	6	0.02	0.05	0.15	<0.01	<0.01	<0.01
	7	0.02	nd	0.34	<0.01	--	0.01
	8	nd	0.47	0.12	--	0.01	<0.01
		Average			<0.01	<0.01	<0.01
Zn	1	11.04	8.48	40.21	<0.01	<0.01	0.02
	2	8.61	5.28	6.47	<0.01	<0.01	<0.01
	3	7.72	6.86	5.19	0.06	0.05	0.04
	4	8.88	4.27	3.24	0.03	0.02	0.01
	5	7.97	4.10	4.88	0.05	0.03	0.03
	6	6.48	4.51	6.73	0.03	0.02	0.03
	7	3.96	4.35	9.67	0.03	0.04	0.08
	8	9.97	6.57	4.83	0.05	0.03	0.03
		Average			0.03	0.02	0.03

In general, the average of the AC of heavy metals in roots, stems and leaves of *Rhazya stricta* was low (<0.28). This result could be explained by the deep roots of the *Rhazya stricta* plants that were collected. Therefore, the collected roots were far from the contaminated surface soil [31]. In addition, another possibility is that *Rhazya stricta*'s absorption of heavy metals from contaminate soil is weak. Nevertheless, the high concentration of heavy metals in the soil resulted in an increased concentration in the roots, stems and leaves of *Rhazya stricta*. So sites 1 and 2, which were near landfills of the mine, had the highest concentration of heavy metals (Table 2). From the above, researchers could suggest the possibility of using *Rhazya stricta* as an indicator of soil contamination with respect to heavy metals (Cd, Cu, Pb, Zn). Moreover, *Rhazya stricta* could be used to prevent erosion and therefore reduce the spread of contamination to the surrounding areas. The AC of roots, stems and leaves shows that there was more contamination with Cd than other metals. This observation could be due to the nature of Cd, since it is recognized to be less retained by the soil than the others [32].

The AC of the heavy metals ranged between <0.01-0.17 in the roots, <0.01-0.15 in the stems, and <0.01-0.28 in the leaves. At the first location, the concentrations of the studied heavy metals in the roots of *Rhazya stricta* were three to nine times higher than their concentrations in stems or leaves. At other locations, Pb and Cd have low concentrations in roots but higher than concentrations in leaves and stems, except at the last location. Those results show that Cd, Cu, Pb, Zn tend to accumulate in the roots compared with stems and leaves, particularly in contaminated soils.

The order of the AC of heavy metals in roots, stems and leaves was as follows: Cd> Cu> Zn> Pb, except for Zn, which came second in roots before Cu. These results agreed with several previous studies [19, 26–29]. In Al-Farraj et al.'s study [19], the order of the AC of heavy metals in the roots and shoots of *Ochradenus baccatus* was Cd> Zn> Cu> Pb. Moreover, in Maria et al.'s study [29] the AC of Pb and As was low in leaves (<0.03) for a number of wood trees, while Cu was higher than that (0.2), and in contrast Zn was 0.9 and Cd 2.0.

3.3 Translocation factor

The metal concentration ratio for the stems/roots, leaves/roots and leaves/stems was calculated for each metal. This quotient shows the TF of heavy metals from the roots to the stems and leaves. Table 4 shows the TF of heavy metals. Zinc has the highest TF (0.87, 1.49 and 1.36) compared with the others, while Pb has the lowest TF (0.59, 0.71 and 0.11). In general, the TF, from roots to stems or leaves was less than 1 for metals, except Zn, in leaves. Al-Farraj et al. [19] found the TF to be less than 1 for Cd, Zn, Cu, and Pb through *Ochradenus baccatus*. Those results stood in agreement with Gupta and Sinha [33], who found that the accumulation of heavy metals (Fe, Zn, Cr, Mn, Cu, Pb, Ni, Cd) was greater in roots in comparison with shoots of *Sesamum indicum*. Furthermore, Vandecateele et al. [34] found a strong correlation between Cd and Zn

Table 4: The translocation factor (TF) of heavy metals in *Rhazya stricta*.

Element		Translocation Factor		
		Stems/Roots	Leaves/Stems	Leaves/Roots
Cd	1	0.27	1.00	0.27
	2	0.28	8.29	2.32
	3	0.54	0.71	0.38
	4	0.27	0.82	0.22
	5	0.52	0.50	0.26
	6	0.75	1.17	0.88
	7	0.77	0.53	0.41
	8	1.60	0.25	0.40
Average		0.63	1.66	0.64
Cu	1	0.16	1.87	0.29
	2	1.03	1.07	1.10
	3	0.74	0.80	0.60
	4	0.26	0.81	0.21
	5	0.53	0.84	0.44
	6	1.54	0.52	0.81
	7	0.89	0.42	0.37
	8	0.97	0.59	0.58
Average		0.76	0.87	0.55
Pb	1	0.14	0.54	0.08
	2	0.07	4.80	0.32
	3	0.27	nd	nd
	4	nd	--	0.33
	5	nd	--	nd
	6	0.33	0.33	0.11
	7	nd	--	0.05
	8	3.93	nd	nd
Average		0.59	0.71	0.11
Zn	1	0.21	1.30	0.27
	2	0.82	1.63	1.33
	3	1.32	1.13	1.49
	4	1.32	2.08	2.74
	5	0.84	1.94	1.63
	6	0.67	1.44	0.96
	7	0.45	0.91	0.41
	8	1.36	1.52	2.06
Average		0.87	1.49	1.36

concentrations in leaves of two species of *Salix* and their concentration in soil. In addition, they found that the greatest accumulation of Cu, Cr, Pb, Fe, Mn and Ni was in the roots.

3.4 DTPA extractable

DTPA extract was proposed to extract available forms of micro-elements and heavy metals in calcareous soils. The present study did not find any relation between heavy metal concentrations in *Rhazya stricta* and DTPA extract. Figure 1 shows that the efficiency of DTPA was extracted as follows: Pb> Cd> Cu> Zn. Zinc extraction was the highest (4.3%), but it was the lowest absorbed by *Rhazya stricta* (≤0.1) (Fig. 1).

The result suggests that DTPA efficiency to extract metals does not mean efficiency in assessing the available form. Many of the previous studies have agreed with this suggestion. Gupta and Sinha [33] found a better relationship between Zn extracted by the DTPA, EDTA, NH_4NO_3 and that absorbed by the plant *Sesamum indicum*, but they were not linked with Ni, Cu and Pb. In addition, Ortiz and Alcañiz [13] found a relationship between the total concentration of Zn and that extracted by DTPA, Cr and the concentration in the leaves of the plant *Dactylis glomerata*. On the other hand, they did not find DTPA to be suitable for extracting Ni, Cu and Cd; while not finding the relationship between the concentration of those metals in the roots and their total concentrations in the soil or DTPA extracted. In another study, researchers found that the DTPA was less efficient than the EDTA for extracting heavy metals of the plant, despite the recent decline in pH [33]. From the above, we can say that although DTPA is considered to be suitable for calcareous soils, our results agree with the observation of McLaughlin et al. [35] that DTPA may over-estimate plant-available metals.

4 Conclusion

The studied soil of Mahad AD'Dahab is considered to be contaminated with heavy metals (cadmium, copper, lead, zinc). Moreover, heavy metals (Cd, Cu, Pb, and Zn) tend to be accumulated in the roots of *Rhazya stricta* compared to the stems and leaves. Therefore, it can be recommended that *Rhazya stricta* should be described as an indicator and a non-excluder.

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