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Heavy Metals Accumulation of Some Plant Species Grown on Mining Area at Mahad AD'Dahab, Saudi Arabia

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Abstract: Samples from different plants species, which grown around Mahad AD'Dahab Mine, have been selected to study their ability to accumulate these heavy metals. These plant species were: *Pergularia tomentosa*, *Calotropis procera*, *Acacia tortilis*, *Ochradenus baccatus*, *Salsola* sp., *Rhiza strica*, *Convolvalus* sp., *Euculeptus* sp., *Family graminaea* and *Prosopis juliflora*. Moreover, some of soil samples under each plant were collected. Plants and soils samples were analyzed for their contents of As, Cd, Cu, Pb and Zn. Two way ANOVA analysis without interaction was performed to examine the effect of plant species and heavy metals concentration in soil on their accumulation by plants. Although significant differences were not found at 0.01 levels among the plant species, it was found that *Pergularia tomentosa* was the highest to accumulate heavy metals. Considering the mean of accumulating heavy metals, plant species accumulated heavy metals by this order: *Pergularia tomentosa*, *Euculeptus* sp. *Convolvalus* sp. *Family graminaea*, *Rhiza strica*, *Acacia tortilis*, *Prosopis juliflora*, *Salsola* sp. *Calotropis procera*, *Ochradenus baccatus*. According to the mean of BAF's, heavy metals concentration of Cd was found to be significantly different than Cu, Pb and Zn. From above, these plants should be described as not-excluder and can be explored further for phytoremediation of metal polluted soils. On other hand, the practice of providing foliage and pods as fodder for live stock should be avoided in Mahad AD'Dahab area.

Key words: Heavy metals, cadmium, copper, lead, zinc, arsenic, pollution, mining activities, contamination, phytoremediation, Mahad AD'Dahab

INTRODUCTION

Because of industrialization and mining, soils, plants and water resources are at risk for contamination with heavy metals. Soil highly contaminated with metals may disrupt the physical, chemical and biological balance of the soil. The heavy metals most frequently encountered in include As, Cd, Cu, Pb and Zn, all of which cause risks for human health and the environment (Alloway *et al*., 1990). Therefore, the reclamation of polluted soils and evaluation of environmental risk necessitate a greater understanding about the remediation of contaminated soils.

Although heavy metals contaminated soils affect the growth of plants, many species of plants have adopted to tolerate high concentrations of heavy metals. Presence of plants in contaminated soils necessarily means that they are tolerant to high levels of heavy metals and able to accumulate or exclude them. Plants that accumulate metals in their above ground tissues are termed metal non-excluders. They could be divided to indicators and hyper accumulators. Indicators species should have levels of metals in their tissues reflected to their levels in soil. Several plant species are well known indicators of heavy metals pollution in soil (Wenzel and Jockwer, 1999). For example, honey mesquite (*Prosopis juliflora*), was studied as a possible bio-indicator of industrial smelter pollution in Arizona State (Gabriel and Patten, 1994). On other hand, the hyper accumulators can concentrate metals to concentrations far exceeding which in soil (Singh, 2005).

Remediation of contaminated soils using green plants, including grasses, forbs and woody species to remove heavy metals or to render them harmless is currently being studied through the world (Schnoor *et al*., 1995; Comis, 1996; Wu *et al*., 1999). This is often called phytoremediation. It is particularly challenging due to the low mobility and generally low bioavailability of heavy metals.

Thangavel *et al*. (2000) reported that using *P. juliflora*, for the bio-recovery of aluminium. Moreover, *P. juliflora* has accumulated Ni, Cr, Cu and Pb (Niverthitha *et al*., 2002; Senthilkumar *et al*., 2005). Most

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kinds of ragweed and *Thlapsi rotundifolum* can be used to remove lead while *Thlaspi caerulescens* can be used to remove zinc and cadmium (Comis, 1996). Indian mustard, are well known for removing Pb, S, Ni, Zn, Cu, Cd and Ch. To date, only a few of hyper accumulating plant species have been recognized to uptake more than one metal. Plants belonging to the *Brassicaceae family* (e.g., *Brassica* and *Thlapi* sp.) are the most hopeful ones considered for phytoremediation. Recently, plants of the genus *Pelargonium* were identified for remediation soils that were contaminated by heavy metals (Singh, 2005).

Because of Mahad AD'Dahab Mine (Saudi Arabia), its soil was approved to be contaminated with As, Cd, Cu, Pb and Zn (Al-Farraj and Al-Wabel, 2006). The huge landfill of Mahad AD'Dahab Mine may lead to rapid accumulation of heavy metals in soils around mining area. Heavy metals contamination can be carried with soil particles swept away from the initial areas of pollution by wind and rain.

In the present research, some plants (wild or agricultural plant) grown in heavy metals contaminated soils around Mahad AD'Dahab Mine have been selected to assess their ability to accumulate heavy metals and their potential use in the reclamation of metal contaminated soils. Therefore, our goals in this research have focused on evaluate concentration of heavy metals in those plant species to identify the plant species best adapted for the uptake of specific metal. Furthermore, the possibility to use some plants as bio-indicator for heavy metals contamination is one of our objectives. Finally, the bioavailability of heavy metals (As, Cd, Cu, Pb, Zn) in soils of Mahad AD'Dahab Mine is one of our goals.

MATERIALS AND METHODS

Study area and collection of plant and soil samples: The plant and soil samples used for this research were collected in 2005 from the surrounding area of Mahad AD'Dahab Mine (23°30= N; 40°30= E). Sites of the samples were chosen because of its high contaminated with respect to heavy metals (Cd, Cu, Pb, Zn … etc) (Al-Farraj and Al-Wable, 2006). Plants and Soil samples were collected randomly from 21 different locations, where the depths of soil samples were 0-15, 15-30 and 30-45 cm. Samples for each location were mixed to ensure homogeneity, dried at room temperature and gently ground to pass through a 2 mm sieve. Plant species included *Pergularia tomentosa*, *Calotropis procera*, *Acacia tortilis*, *Ochradenus baccatus*, *Salsola* sp., *Rhiza strica*, *Convolvalus* sp., *Euculeptus* sp., *Family graminaea* and *Prosopis juliflora* were found at the twenty one selected locations. Deferent branches (leaves and stems) were collected from each plant. These branches were mixed, rinsed well in double distilled water (to incomplete removal of metals on the surface of leaves and stems) and dried at 60°C. The air-dried plant samples were powdered homogenously for further analysis.

Chemical and physical analysis: Soil pH and EC were measured in distilled water extracts after equilibration for 24 h. The ratio of soil and distilled water was 1:5 (Thomas, 1996; Rhoades, 1996). Cations and inions (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^{-}, $CO_3^{=}$, Cl^{-}, $SO_4^{=}$) were determined in those extracted soil solutions (Richards, 1954; Rainwater and Thatcher, 1979). Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1994). Content of $CaCO_3$ was determined by calcimeter method (Loeppert and Suarez, 1996). Soil organic matter of the soil samples were determined by digested them using concentrated H_2SO_4 (Nelson and Sommers, 1996).

Heavy metals analysis: Soil samples were digested with HNO_3-$HClO_4$-HF (Hossner, 1996). Dried and powdered plant samples were acid digested with HNO_3 and $HClO_4$ (Chapman and Pratt, 1966). Digested soil and plant sample 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.

Statistical analysis methodology: A two-way analysis of variance (ANOVA) was used to evaluate the effect of the different plant species and concentration of metal in plant over its concentration in soil (which named BAF's) on accumulation of heavy metals by plant. In addition to that, 0.01 significance level will be considered to conclude the differences. ANOVA was followed by LSD test when appropriate to compares all possible pairs of means after the f-test rejects the null hypothesis that groups do not differ. However, in the analysis of this paper and if the p-value of rejecting the effect of any if the independent variables is not too big, LSC test will be applied even if the f-test leads to acceptance of then null hypothesis.

RESULTS AND DISCUSSION

The basic physicochemical properties of studied soil samples are summarized in Table 1. Table 2 shows the concentration of heavy metals of soil samples that surrounding studied plant species compared to the average concentrations and the normal ranges in soils. There is no doubt, all soil samples are contaminated with respect to As, Cd, Cu, Pb and Zn. The whole soil samples

Table 1: Basic physicochemical properties of soil samples that surrounding plant species

Plant species	pH	EC dS m^{-1}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	$SO_4^=$	$CaCO_3^=$ %	OM g kg^{-1}	Texture
			(meq L^{-1})									
Acacia tortilis	8.0	0.5	2.9	0.3	1.2	0.3	2.3	1.7	1.5	3.7	3.6	Sandy loam
Calotropis procera	8.1	0.6	5.6	0.5	1.6	0.2	2.3	1.3	4.4	5.8	1.0	Silt loam
Convolvalus sp.	8.5	0.2	2.0	0.1	0.5	0.1	1.8	1.8	0.0	4.4	0.6	Silt loam
Euculeptus sp.	9.0	0.5	3.3	0.6	1.3	0.2	3.0	2.6	0.9	16.9	1.0	Silty clay loam
Family graminaea	7.8	0.9	1.5	0.4	1.9	0.5	3.1	1.6	0.5	8.2	2.4	Sandy clay loam
Ochradenus baccatus	8.0	1.0	5.6	0.6	2.6	0.1	2.3	0.8	5.9	4.4	11.7	Sandy loam
Pergularia tomentosa	7.7	3.1	26.3	2.6	8.6	0.5	2.8	13.3	22.8	8.7	1.9	Sandy loam
Prosopis juliflora	7.8	0.9	1.5	0.4	1.9	0.5	3.1	1.6	0.5	8.2	2.4	Sandy clay loam
Rhiza strica	8.2	0.3	1.7	0.1	0.5	0.1	2.6	1.4	0.0	4.1	1.0	Sandy loam
Salsola sp.	8.4	0.4	2.2	1.2	2.9	0.2	2.5	1.5	2.4	6.5	2.7	Sandy clay loam

Table 2: Total heavy metals concentration of soil samples that surrounding plant species studied, the average concentration and common range in soils (mg kg^{-1})

	Total concentration (mg kg^{-1})					Cm/Average. m*				
Plant species	As	Cd	Cu	Pb	Zn	As	Cd	Cu	Pb	Zn
Acacia tortilis	11.0	3.5	400	223	654	2.2	58	13	22	13
Calotropis procera	10.3	19.2	1443	1050	3363	2.1	320	48	105	67
Convolvalus sp.	15.9	0.4	43	21	92	3.2	7	1	2	2
Euculeptus sp.	9.3	1.5	143	86	300	1.9	25	5	9	6
Family graminaea	13.0	0.4	85	62	154	2.6	7	3	6	3
Ochradenus baccatus	12.0	13.3	1400	779	2247	2.4	222	47	78	45
Pergularia tomentosa	12.9	6.9	807	636	1321	2.6	115	27	64	26
Prosopis juliflora	13.0	0.4	85	62	154	2.6	7	3	6	3
Rhiza strica	10.7	0.5	95	67	155	2.1	8	3	7	3
Salsola sp.	7.6	30.0	1074	218	5444	1.5	500	36	22	109
Common range in soils[1]										
Max.	50	0.7	100	200	300					
Min.	1	0.01	2	2	10					
Average	5	0.06	30	10	50					

*Cm: concentration of heavy metals in studied soils; while Ave. m: The average concentration in soil as reported by Lindsay, 1979, [1]Lindsay, 1979

Table 3: Concentrations of heavy metals of different species grown surrounding Mahad AD'Dahab Mine (mg kg^{-1})

	Plant					BAF's*				
Plant species	As	Cd	Cu	Pb	Zn	As	Cd	Cu	Pb	Zn
Acacia tortilis	10.9	0.4	21.2	8.4	63.0	0.99	0.13	0.05	0.04	0.10
Calotropis procera	10.2	0.0	34.4	15.3	83.3	0.99	0.00	0.02	0.01	0.02
*Convolvalus*sp.	12.7	1.4	12.6	4.4	40.4	0.80	3.43	0.29	0.21	0.44
Euculeptus sp.	10.5	0.3	65.7	3.0	44.8	1.13	0.17	0.46	0.03	0.15
Family graminaea	8.7	0.8	69.7	27.8	134.7	0.67	1.88	0.82	0.45	0.87
Ochradenus baccatus	8.7	1.3	23.7	11.7	73.6	0.73	0.09	0.02	0.02	0.03
Pergularia tomentosa	11.2	76.7	333.0	89.0	720.6	0.87	11.11	0.41	0.14	0.55
Prosopis juliflora	9.0	0.0	50.0	5.8	69.2	0.69	0.00	0.59	0.09	0.45
Rhiza strica	10.7	0.6	12.0	2.9	64.3	1.00	1.16	0.13	0.04	0.41
Salsola sp.	9.2	12.7	51.2	11.1	117.2	1.21	0.42	0.05	0.05	0.02
Max	12.7	76.7	333.0	89.0	720.6	1.21	11.11	0.82	0.45	0.87
Min	8.7	0.0	12.0	2.9	40.4	0.67	0.00	0.02	0.01	0.02
Average	10.2	9.4	67.3	17.9	141.1	0.91	1.84	0.28	0.11	0.30

*BAF's: Concentration of metal in plant over its concentration in soil

have concentrations more than the average in soils. Furthermore, most of soil samples have concentration extremely higher than maximum of Cd, Cu, Pb and Zn in soils (Lindsay, 1979).

Table 3 and Fig. 1 illustrate the concentrations of heavy metals in different species of plants. Results showed that *Convolvalus* sp. accumulated As more than others, while *Family graminaea* was the lowest. Except As, *Pergularia tomentosa* accumulated heavy metals extremely higher than other species. It accumulated 720, 333, 89, 76.7 and 11.2 mg kg^{-1} of Zn, Cu, Pb, Cd and As, respectively (Table 3). It is interesting to note that, the respective of their concentrations in the soil have an approximately similar order (Zn = 1321; Cu = 807; Pb = 636; As = 12.9 and Cd = 6.9) (Table 2).

Generally, the results showed that heavy metals concentrations were much lower in plant shoots compared to their total concentration in the soil (Table 3). There is an exception of As and Cd with some species. *Pergularia tomentosa*, *Convolvalus* sp., *Family sraminaea* and *Rhiza strica* concentrated Cd in their shoots to levels far exceeding those present in the soil. The calculated BAF's for these species were 11.11, 3.43, 1.88, 1.16, respectively. However, Cd was not detected in the samples of both

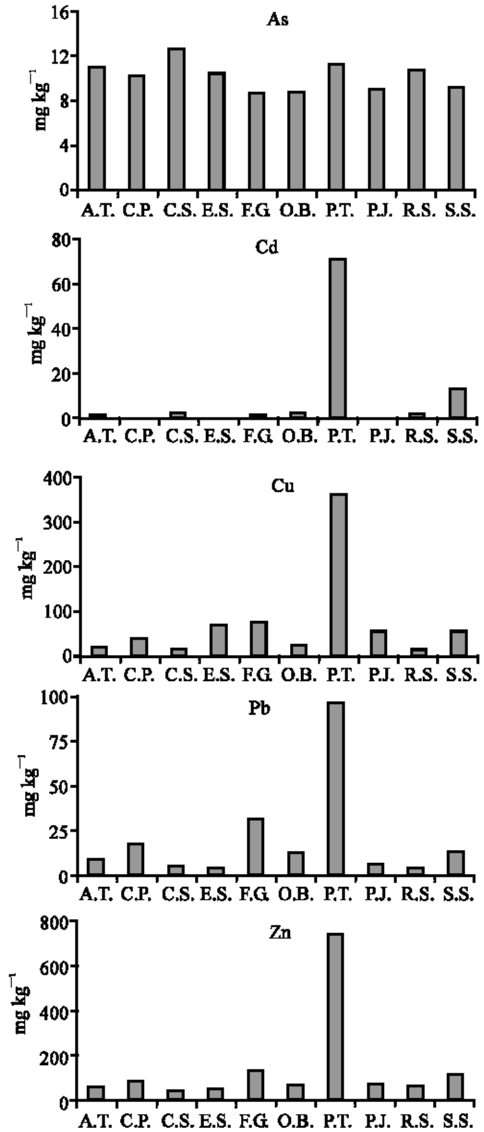

Fig. 1: Heavy metals concentration (As, Cd, Cu, Pb, Zn) of plant species grown surrounding Mahad AD'Dahab Mine (A.T.: *Acacia tortili* C.P.: *Calotropis procer;* C.S.: *Convolvalus*sp.; E.S.: *Euculeptus* sp., F.G.: *Family graminae*; O.B.: *Ochradenus baccatus;* P.T.: *Pergularia tomentosa;* P.J.:*: Prosopis juliflora*; R.S. *Rhiza strica;* S.S.: *Salsola* sp.)

Calotropis procera and *Prosopis juliflora*. In contrast, Senthilkumar *et al.* (2005) reported accumulation of heavy metals including Cd by *Prosopis juliflora.* That could be explained because of differences of physical and chemical soil properties which can affect the accumulation of metals by plants (Senthilkumar *et al.*, 2005). Moreover, roots of *Prosopis juliflora* were very deep whereas depth of soil samples < 45 cm. The As concentration of most of species of plant were close to the concentration in their soils (Table 3). The average of BAF's was 0.91 which close to one. *Acacia tortilis, Calotropis procera*, *Euculeptus* sp., *Rhiza strica* and *Salsola* sp. had concentration of As equal to or higher than its level in the soil. From above, it is clear to recognize that the total heavy metal concentration in soil is the poor indicator of metal availability for plant uptake.

According to the average of BAF's, the order of heavy metals accumulation by plants was Cd> As> Zn> Cu> Pb. The average was 1.84, 0.91, 0.3, 0.28 and 0.11, respectively (Table 3). In the present study, Cd and As were found to be particularly mobile in the soil-plant systems. Both are widespread contaminants in urban environments, however, Cd is a much more zootoxic metal and of more concern to human health and to food chains (Dickinson and Pulford, 2005). On the other hand, Pb, Cu and Zn were low and insufficiently mobile in soil-plant in this research. Other researchers have reported low uptake of As and Pb (French *et al.*, 2006). While, others found that woody biomass may have relevance to clean-up soils contaminated by Zn (Rosselli *et al.*, 2003). The elevated accumulation of Cd agreed with it's high mobility. Whereas, Pb has low mobility, so the lowest accumulated is reasonable.

The results of the present investigation show that *P. tomentosa* has ability to accumulate all heavy metals (As, Cd, Cu, Pb, Zn) (Fig. 1). That could be explained because of soil of *P. tomentosa* had relatively higher salinity (3.1 dS m^{-1}), higher soluble $SO_4^{=}$ (22.8 meq L^{-1}) and relatively lower pH (7.7). These parameters were observed to increase the solubility of heavy metals (Helal *et al.*, 1996; Alloway *et al.*, 1980; Gabriella and Anton, 2005). Furthermore, *P. tomentosa* could not be described hyperaccumulator because of less accumulation of heavy metals. Actually, parts of plants which were analyzed for heavy metals didn't include roots. In hyper-accumulator species, heavy metals accumulate both in the shoot and the root (Singh, 2005). Vandecasteele *et al.* (2005) found that elevated wood, park and foliar concentrations for Cd and Zn, while Cr, Cu, Ni and Pb were less easily accumulated in aboveground biomass compartments. Anyway, *P. tomentosa* could be used to remediate heavy metal polluted soil at Mahad AD'Dahab Mine and other similar due to its ability to accumulate various heavy metals.

Table 4 shows the result of ANOVA analysis, where it shows a significant differences among the averages of heavy metals ($F_{4, 136}$ = 2.085, p = 0.086). However, no significance differences have been found among the groups of plant species ($F_{9, 136}$ = 0.871, p = 0.553).

For the plant species variable, based on the averages of accumulation, the plants can be ordered as follows: *Pergularia tomentosa*> *Euculeptus* sp.>

Table 4: Two-way ANOVA table of heavy

Sources	df	Sum square III	Mean square	f-value	p-value
Plant species	9	54.371	6.041	0.871	0.553
Heavy Metal	4	57.837	14.459	2.085	0.086
Error	136	943.044	6.934		
Total	149	1055.253			

Table 5: Matrix results (Mean difference and corresponding p-values) of LSD test for the plant species variable

Plant species	A.T.	C.P.	C.S.	E.S.	F.G.	O.B.	P.J.	P.T.	R.S.	S.S.
A.T.										
C.P.	0.154									
	(0.907)									
C.S.	-0.593	0.747								
	(0.653)	-(0.655)								
E.S.	-1.157	-1.311	-0.564							
	(0.081)	(0.282)	(0.643)							
F.G.	-0.531	-0.685	0.0621	0.625						
	(0.688)	(0.682)	(0.970)	(0.607)						
O.B.	0.189	0.0353	0.782	1.346	-0.720					
	(0.886)	(0.983)	(0.639)	(0.269)	(0.666)					
P.J.	0.0015	-0.153	0.594	1.158	-0.188	0.188				
	(0.999)	(0.927)	(0.722)	(0.342)	(0.910)	(0.910)				
P.T.	-2.265	-2.419	-1.672	-1.108	-2.454	-2.266	2.266			
	(0.088)	(0.149)	(0.317)	(0.363)	(0.143)	(0.176)	(0.176)			
R.S.	-0.246	-0.400	0.347	0.911	-0.435	-0.247	2.019	-2.019		
	(0.785)	(0.769)	(0.799)	(0.221)	(0.749)	(0.856)	(0.140)	(0.140)		
S.S.	0.0144	-0.140	0.607	1.171	-0.175	0.0128	2.279	0.260	-0.260	
	(0.991)	(0.933)	(0.716)	(0.336)	(0.916)	(0.994)	(0.173)	(0.849)	(0.849)	

A.T. *Acacia tortili* C.P. *Calotropis procer* C.S. *Convolvalus* sp. E.S. *Euculeptus* sp. F.G. *Family graminae* O.B. *Ochradenus baccatus* P.T. *Pergularia tomentosa* P.J. *Prosopis juliflora* R.S. *Rhiza strica* S.S. *Salsola* sp.

Table 6: Matrix results (Mean differences and corresponding p-values) of LSD test for the metal variable

Metals	As	Cd	Cu	Pb	Zn
As					
Cd	-0.778 (0.255)				
Cu	0.469 (0.491)	1.247 (0.069)			
Pb	1.065 (0.119)	1.843 (0.008)	0.596 (0.382)		
Zn	0.562 (0.410)	1.339 (0.051)	0.092 (0.892)	0.504 (0.460)	

Convolvalus sp.> *Family graminaea*> *Rhiza strica*> *Acacia tortilis*> *Prosopis juliflora*> *Salsola* sp.> *Calotropis procera*> *Ochradenus baccatus*. Although, significance differences were not found among those types of plants, LSD test results in Table 5 shows differences among *Acacia tortilis* versus *Euculeptus* sp. and *Pergularia tomentosa*. That would happened due that the standard error of estimating the difference of the mean differences is too large comparing to its average.

For the heavy metals concentration, the mean of the BAF's for he As, Cd, Cu, Pb and Zn were found 1.073, 1.851, 0.604, 0.0077 and 0.511, respectively where the differences are significant. The LSD test showed that the mean of mean of BAF's at Cd differs significantly than the means of Cu ($p = 0.069$), Pb ($p = 0.008$), Zn ($p = 0.051$) (Table 6). No other significant differences were found between the other pairs of heavy metals concentration. In soils with pH = 5.5, as soils of Mahad AD'Dahab Mine, Pb solubility is controlled by phosphate and carbonate precipitates (Blaylock *et al*., 1997), so its relatively low bioavailability is reasonable.

CONCLUSIONS

The main reservation of our recommendation is that, these plants should be described as not-excluder, so they could be divided to indicators and hyper accumulators. Furthermore, they can be explored further for phytoremediation of metal polluted soils. According to the nature of soil properties, plant and kind of heavy metals, some of these plants species could be successfully used as an efficient and safety method for remediation of Mahad AD'Dahab soil. Moreover, since the area is open to be used for livestock, in view of heavy metals accumulation, a practice should be avoided.

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REFERENCES

Al-Farraj, A.S. and M.I. Al-Wable, 2006. Evaluation of Soil Pollution Around Mahad AD'Dahab Mine. Research Center of Food Sciences and Agricultural College, No. 21.

Alloway, B., 1990. Introduction. In: Heavy Metals in Soils. B.J. Alloway (Ed.). John Wiley and Sons, Inc. New York, pp: 3-6.

Alloway, B., J.I. Stroehlein, E.A. Hanlon and F. Turner, 1980. Quality of irrigation water and effects of sulphuric acid and gypsum on soil properties and Sudan grass yields. Soil Sci., 129: 315-320.

Blaylock, M.J., D.E. Salt, D.E. Dushenkov, S. Zakharova and O. Gussman *et al.*, 1997. Enhanced accumulation of Pb in Indian Mustard by soil applied chelating agents. Environ. Sci. Technol., 31: 860-865.

Chapman, H.D. and P.F. Pratt, 1966. Methods of Analysis for Soils, Plants and Water. Univ. California, Berkely, CA. USA.

Comis, D., 1996. Green remediation. J. Soil and Water Conser., 51: 184-187.

Dickinson, N.M. and I.D. Pulford, 2005. Cadmium phytoextraction using hortrotation coppice Salix: The vidence trail. Environ. Int., 31: 609-613.

French, C.J., N.M. Dickinson and P.D. Putwain, 2006. Woody biomass phytoremediation of contaminated brown field land. Environ. Pollut., 141: 387-395.

Gabriel, I.E. and D.T. Patten, 1994 Changes in the inorganic element concentration spectrum of mesquite foliage during operational and non-operational periods of a copper smelter. Water, Air, and Soil Pollut., 81: 207-217.

Gabriella, M.G. and A. Anton, 2005. Phytoremediation study; factors influencing heavy metal uptake of plants. Acta Biologica, 49: 69-70.

Gee, G.W. and J.W. Bauder, 1994. Particle-size Analysis. 377-382. In: Methods of Soil Analysis. Part 1, 3rd Edn. Physical and Mineralogical Methods. Klute, A. (Ed.), SSSA and ASA, Madison, WI.

Helal, H.M., S.A. Haque, A.B. Ramadan and E. Schnug, 1996. Salinity-heavy metal interactions as evaluated by soil extraction and plant analysis. Commun. Soil Sci. Plant Anal., 27: 1355-1361.

Hossner, L.R., 1996. Dissolution for Total Elemental Analysis. In: Methods of Soil Analysis. Part 3. Chemical Methodes. Edited by Sparks *et al.* (Ed.),SSSA and ASA, Madison, WI., pp: 46-64.

Lindsay, W., 1979. Chemical Equilibrai in Soils. 1st Edn. A Wiley-Interscience Publication. John Wiley and Sons, New York.

Loeppert, R.H. and D. Suarez, 1996. Carbonate and Gypsum. In: Methods of Soil Analysis. Part 3. Chemical Methods. Sparks *et al.* (Ed.). SSSA and ASA, Madison, WI., pp: 437-474.

Nelson, D.W. and L.E. Sommers, 1996. Total Carbon, Organic Carbon and Organic Matter. In: Methods of Soil Analysis. Part 3. Chemical Methods. Sparks *et al.* (Ed.). SSSA and ASA, Madison, WI., pp: 961-1010.

Niverthitha, P., P. Thangavel, W.SPM. Prince and V. Subburam, 2002. Identification of heavy metal accumulating plants and their use in reclamation of soil contaminated with heavy metals. Eco. Environ. Cons., 8: 249-251.

Rainwater, F.H. and L.L. Thatcher, 1979. Methods of collection and analysis of water samples. Geological Survey Water-Supply, Washington, pp: 1454

Rhoades, J.D., 1996. Salinity: Electrical Conductivity and Total Dissolved Solids. In: Methods of Soil Analysis, Part 3. Chemical Methods. Sparks *et al.* (Ed.). Soil Science Society of America, Madison, WI, USA., pp: 417-435.

Richards, L.A., 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook No. 60, Indian Edition, Published by Prinlar for Oxford and IBH publishing Co. 66, Janpath New Delhi, India.

Rosselli, W., C. Keller and K. Boschi, 2003. Phytoextraction capacity of trees growing on a metal contaminated soil. Plant Soil, 256: 265-272.

Schnoor, J.L., L.A. Licht, S.C. McCutcheon, N.L. Wolfe and L.H. Carreira, 1995. Phytoremediation of organic and nutrient contaminants. Environ. Sci. Technol., 29: 318-323.

Senthilkumar, P., W.SPM. Prince, S. Sivakumar and C.V. Subbhuraam, 2005. Prosopis Juliflora a green solution to decontaminate heavy metal (Cu and Cd) contaminated soils. Chemosphere, 60: 1493-1496.

Singh, V.P., 2005. Toxic Metals and Environmental Issues. Sarup and Sons. New Delhi, pp: 362.

Thangavel, P., V. Subburam, P. Shanmughavel and T. Muthukumar, 2000. *Prosopis juliflora* a metallophyte for the biorecovery of aluminium from urban industrial enclaves. XII IUFRO World Congress, Kula Lumpur, Malaysia.

Thomas, G.W., 1996. Soil pH and Soil Acidity. pp: 475-490. In: Methods of Soil Analysis, Part 3. Chemical Methods. Sparks *et al.* (Ed.). Soil Science Society of America, Madison, WI, USA.

Vandecasteele, B., E. Meers, P. Vervaeke, B.D. Vos, P. Quataert and F.M. Tack, 2005. Growth and trace metal accumulation of two *Salix* clones on sediment-derived soils with increasing contamination levels. Chemosphere, 58: 995-1002.

Wenzel, W.W. and F. Jockwer, 1999. Accumulation of heavy metals in plants grown on mineralized soils of the Austrian Alps. Environ. Pollut., 104: 145-155.

Wu, J., D.A. Laird and M.L. Thompson, 1999. Sorption and desorption of copper on soil clay components. J. Environ. Qual., 28: 334-338.