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ORIGINAL ARTICLE

Phytoremediation potential of native plants grown in the vicinity of Ahangaran lead–zinc mine (Hamedan, Iran)

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Abstract This study aims to assess the extent of metal accumulation by plants found in a mining area in Hamedan Province in the central west part of Iran. It also investigates to find suitable plants for phytoextraction and phytostabilization as two phytoremediation strategies. Plants with a high bioconcentration factor (BCF) and low translocation factor (TF) have the potential for phytostabilization while plants with both BCFs and TFs greater than one have the potential to be used for phytoextraction. In this study, shoots and roots of the 12 plant species and the associated soil samples were collected. The collected samples were then analyzed by measurement of total concentrations of trace elements (Pb, Zn, Mn and Fe) using atomic absorption spectrophotometer. Simultaneously, BCF and TF parameters were calculated for each element. Results showed that although samples suitable for phytoextraction of Pb, Zn, Mn and Fe and phytostabilization of Fe were not detected, *Scrophularia scoparia* was the most suitable for phytostabilization of Pb, *Centaurea virgata, Echinophora platyloba* and *Scariola orientalis* had the potential for phytostabilization of Zn and *Centaurea virgata* and *Cirsium congestum* were the most efficient in phytostabilization of Mn. Present study showed that native plant species growing on contaminated sites may have the potential for phytoremediation.

Keywords Phytoremediation · Lead–zinc mine · Heavy metals · Native plants · Translocation factor · Bioconcentration factor

Introduction

Waste released from mines causes major environmental problems all over the world. Heavy metals content in mine waste are much higher than in contaminated soils. They are harmful to humans and animals and tend to accumulate in the food chain (McDowell 1992; Nouri et al. 2008). Activities such as mining and smelting of metal ores, industrial emissions and applications of insecticides and fertilizers have all contributed to elevate levels of heavy metals in the environment (Alloway 1994; Atafar et al. 2008). Several technologies are available to remediate soils contaminated by heavy metals. However, many of these technologies are costly, e.g., excavation of contaminated material and chemical/physical treatment or do not achieve a long-term nor esthetic solution (Cao et al. 2002; Mulligan et al. 2001). Metal accumulation by plants is affected by many factors. In general, variations in plants species, the growth stage of the plants and element characteristics control absorption, accumulation and translocation of metals (Guilizzoni 1991; Samarghandi et al. 2007; Behbahaninia et al. 2009). Phytoremediation can provide a cost-effective, long-lasting and esthetic solution for remediation of contaminated sites (Ma et al. 2001). Phytoremediation is the process of application of green plants to remove or render environmental contaminants harmless (Cuningham and Berti 1993; Nouri et al. 2009). There is an evidence that plants such as *Sebera acuminate* and *Thlaspi caerulescens* can accumulate heavy metals in their tissues (Cuningham and Ow 1996), *Arabidopsis thaliana*

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(Delhaize 1996), *Typha latifolia* and *Phragmites australis* (Ye et al. 2001). *T. latifolia* and *P. australis* have been successfully used for phytoremediation of Pb/Zn mine (Ye et al. 1997a, b). Remediation of heavy metals by plant species can be divided into three groups: phytoextraction, metal accumulating plants are planted on contaminated soil and later harvested in order to remove metals from the soil; rhizofiltration, roots of metal accumulating plants absorb metals from polluted effluents and are later harvested to diminish the metals in the effluent; and phytostabilisation, metal-tolerant plants are used to reduce the mobility of metals, thus, the metals are stabilized in the substrate (Salt et al. 1995; Abdel-Ghani et al. 2007). Plants with both bioconcentration factors and translocation factors greater than one (TF and BCF > 1) have the potential to be used in phytoextraction. Besides, plants with bioconcentration factor greater than one and translocation factor less than one (BCF > 1 and TF < 1) have the potential for phytostabilization (Yoon et al. 2006). There has been a continuing interest in searching for native plants that are tolerant towards heavy metals (Shu et al. 2002 and Mcgrath and Zhao 2003).

The overall objectives of this research were: (1) to determine the concentrations of Pb, Zn, Mn and Fe in plant biomass growing on a contaminated site; (2) to compare metal concentrations in the aboveground biomass with those in roots and in soils, and (3) to assess the feasibility of using of these plants for phytoremediation purpose. Results of this study should provide insight for using native plants to remediate metal-contaminated sites.

Materials and methods

Site characterization

The plant and soil samples used in this study were collected from a known metal-contaminated site located in an urban area, called Ahangaran lead–zinc mine of Malayer city, southwest of Hamedan (Fig. 1). The site has been vacant, occupied approximately 1,600,000 m^2, and is covered mainly by grasses. Human activities such as mining have contributed to metal concentrations in this site. Contamination of heavy metals was mainly concentrated in the top 20 cm at the site.

Selected characteristics of the soil samples collected from this study are shown in Table 1.

Plant sampling and analysis

Twelve plant species and the associated soil samples were collected in the surrounding area of Ahangaran mine from May to June 2007. The studied species consisted of 11 genera and 8 families (Table 2), of which 4 species belonged to Asteraceae, forming the most dominant component in metal-polluted sites.

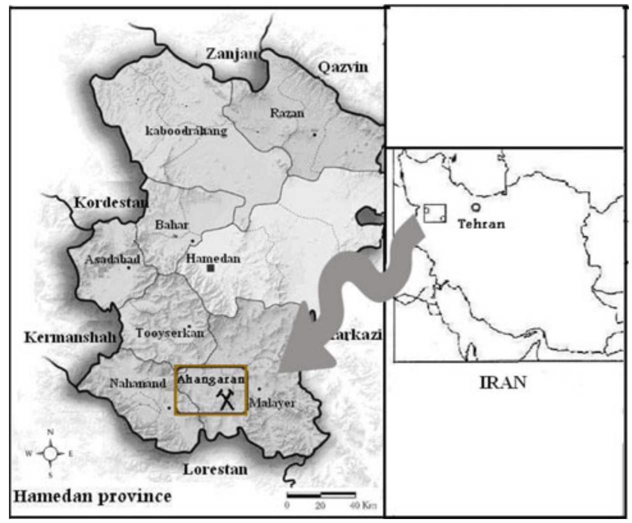

Fig. 1 Location of the study area

Plant samples were thoroughly washed with running tap water and rinsed with deionized water to remove any soil particles attached to the plant surfaces, then oven dried (70°C) to constant weight. The dried tissues were weighed and ground into powder for metal concentration analysis. Metal contents (Fe, Zn, Pb and Mn) of the plant samples were extracted by acid digestion followed by measurement of total concentrations of all elements of interest using atomic absorption spectrophotometer (GBC Avanta, Australia) (Ward et al. 1975).

Soil sampling and analysis

Soils were sampled from the same sites and location points as the plants. The top 20 cm soil from between the plant roots was collected, air-dried for 3 weeks, and then sieved through a 2-mm mesh. Samples were then analyzed for total metals (Fe, Zn, Pb and Mn). Total metal contents were extracted by acid digestion. Metal contents were measured by atomic absorption spectrophotometer (GBC Avanta, Australia), (Sposito 1989). Soil samples were also analyzed for pH, electrical conductivity (EC) and total P. The pH and EC values (solid:distilled water = 1:5) of soil samples were measured by a pH meter and an EC meter, respectively (Thomas 1996; Roades 1996). Total phosphorus was measured using the method of Olsen (Rowell 1994) and soil texture, was determined according to Tan (1995).

Table 1 Soil characteristics of the surrounding area of Ahangaran mine (mean ± SE)

Parameters	EC (μs/m)	pH	P (mg/kg)	$CaCO_3$ (mg/kg)	Clay (%)	Silt (%)	Sand (%)
Value	385 ± 14	7.8 ± 0.02	56 ± 12	18 ± 3.7	9 ± 0.5	20 ± 2.6	71 ± 7.1

Table 2 Species composition in surrounding area of Ahangaran mine

Species no.	Scientific name	Family
1	*Euphorbia macroclada* Boiss.	*Euphorbiaceae*
2	*Centaurea virgata* Lam.	*Asteraceae*
3	*Reseda lutea* L.	*Resedaceae*
4	*Echinophora platyloba* DC.	*Gramineae*
5	*Cichorium intybus* L.	*Asteraceae*
6	*Tamarix ramosissima* Ledeb.	*Tamaricaceae*
7	*Cirsium congestum* Fisch. and C. A.	*Asteraceae*
8	*Scrophularia scoparia* Pennell	*Scrophulariaceae*
9	*Chaerophyllum macropodum* Boiss.	*Umbelliferae*
10	*Cardaria draba* (L.) Desv.	*Cruciferae*
11	*Scariola orientalis* (Boiss.) Sojak.	*Asteraceae*
12	*Reseda alba* L.	*Resedaceae*

Table 3 Pb concentrations in soil and plant samples (mg/kg)

Scientific name	Roots	Shoots	Soil
Euphorbia macroclada Boiss.	3,809	8,095	9,451
Centaurea virgata Lam.	1,180	1,927	8,446
Reseda lutea L.	98	1,774	7,367
Echinophora platyloba DC.	1,421	10,121	10,426
Cichorium intybus L.	ND	15	12,140
Tamarix ramosissima Ledeb.	130	2,010	10,401
Cirsium congestum Fisch. and C. A.	6,750	2,934	7,389
Scrophularia scoparia Pennell	577	6,270	6,847
Chaerophyllum macropodum Boiss.	3,421	149	6,895
Cardaria draba (L.) Desv.	676	3,171	3,847
Scariola orientalis (Boiss.) Sojak.	1,204	9,017	9,140
Reseda alba L.	1,743	703	9,535

ND not detected

Calculation of TF and BCF

The ability of plants to tolerate and accumulate heavy metals is useful for phytoextraction and phytostabilization purpose measured using translocation factor (TF) and bioconcentration factor (BCF) defined as the ratio of metal concentration in plant shoots to roots ($[Metal]_{Shoot}/[Metal]_{Root}$) and the ratio of metal concentration in plant roots to soils ($[Metal]_{Root}/[Metal]_{Soil}$), respectively (Yoon et al. 2006).

Results and discussion

Soil characteristics and metal concentrations

As shown in Table 1, soils in the surrounding area of mine were slightly alkaline; with an average pH of approximately 7.8. The pH conditions were suitable for plant growth. The average of EC, total P concentration and $CaCO_3$ were 385 μs/m, 56 mg/kg and 18 mg/kg, respectively. Also, texture of soil was loam-sandy in the soil collected from the surrounding area of mine.

The present study shows that some plants can colonize sites with a wide range of metal concentrations in the soils. According to Kabata-Pendias and Pendias (1984), 2–200 mg/kg Pb, 70–400 mg/kg Zn and 300–500 mg/kg Mn and insignificant data for Fe would be considered toxic to plants based on total fractions in soil. The metal (Fe, Zn, Pb and Mn) contents in the surrounding area of mine greatly exceed these ranges (Tables 3, 4, 5, 6); therefore, the 12 plant species grown in these contaminated sites have exhibited high metal tolerance.

Metal concentrations in plants

Metal concentrations in plants vary with plant species (Alloway et al. 1990). Plant uptake of heavy metals from soil occurs either passively with the mass flow of water into the roots, or through active transport crosses of the plasma membrane of root epidermal cells. Under normal growing conditions, plants can potentially accumulate certain metal ions an order of magnitude greater than the surrounding medium (Kim et al. 2003). Concentrations of Pb, Mn, Zn and Fe in collected plant species are provided in Tables 3, 4, 5, 6. Toxic concentrations of heavy metals for various plant species are 10–100, 400–1,000, 100–400 and 80–1,450 mg/kg for Pb, Mn, Zn and Fe, respectively (Kabata-Pendias and Pendias 1984). According to Tables 3, 4, 5, 6, in the most (62.5%) of the plant samples, heavy metal contents were higher than toxic levels. Total Pb concentrations in the plant roots ranged from non-detectable to as high as 6,750 mg/kg and plant shoots from 15 to as high as 9,017 mg/kg, with the maximum level in the roots of *Cirsium congestum* and shoots of *Scariola orientalis*. Total Zn concentrations in the plant roots ranged from non-detectable to 2,938 mg/kg and plant shoots from non-detectable to 3,538 mg/kg, with the maximum level in the roots of *Reseda lutea* and shoots of *Scariola orientalis*. Total concentrations of Mn in the plant roots ranged from

Table 4 Zn concentrations in soil and plant samples (mg/kg)

Scientific name	Roots	Shoots	Soil
Euphorbia macroclada Boiss.	81	967	1,645
Centaurea virgata Lam.	762	3,155	1,825
Reseda lutea L.	2,938	313	2,593
Echinophora platyloba DC.	1,925	2,150	2,016
Cichorium intybus L.	ND	32	1,389
Tamarix ramosissima Ledeb.	351	2,624	3,967
Cirsium congestum Fisch. and C. A.	1,751	590	1,916
Scrophularia scoparia Pennell	341	68	3,638
Chaerophyllum macropodum Boiss.	1,425	356	4,205
Cardaria draba (L.) Desv.	1,757	860	3,909
Scariola orientalis (Boiss.) Sojak.	1,429	3,538	2,119
Reseda alba L.	73	ND	2,845

ND not detected

Table 5 Mn concentrations in soil and plant samples (mg/kg)

Scientific name	Roots	Shoots	Soil
Euphorbia macroclada Boiss.	57	149	843
Centaurea virgata Lam.	156	1,220	963
Reseda lutea L.	29	116	975
Echinophora platyloba DC.	1,283	303	1,361
Cichorium intybus L.	235	62	962
Tamarix ramosissima Ledeb.	76	15	909
Cirsium congestum Fisch. and C. A.	459	538	512
Scrophularia scoparia Pennell	36	386	751
Chaerophyllum macropodum Boiss.	342	177	596
Cardaria draba (L.) Desv.	128	261	609
Scariola orientalis (Boiss.) Sojak.	105	626	751
Reseda alba L.	325	17	695

ND not detected

Table 6 Fe concentrations in soil and plant samples (mg/kg)

Scientific name	Roots	Shoots	Soil
Euphorbia macroclada Boiss.	57	149	843
Centaurea virgata Lam.	156	1,220	963
Reseda lutea L.	1,611	3,617	12,433
Echinophora platyloba DC.	4,045	10,764	12,168
Cichorium intybus L.	2,752	10,819	13,889
Tamarix ramosissima Ledeb.	7,808	4,311	11,881
Cirsium congestum Fisch. and C. A.	53	117	10,315
Scrophularia scoparia Pennell	ND	215	9,198
Chaerophyllum macropodum Boiss.	3,652	9,709	10,617
Cardaria draba (L.) Desv.	1,306	2,557	10,515
Scariola orientalis (Boiss.) Sojak.	1,645	1,370	9,201
Reseda alba L.	1,637	1,938	9,574

ND not detected

29 to as high as 1,283 mg/kg and plant shoots from 15 to as high as 1,220 mg/kg, with the maximum being in the roots of *Echinophora platyloba* and shoots of *Centaurea virgata*. Fe concentrations in plant roots differed among species at the polluted site from non-detectable to 7,808 mg/kg and in shoots from 117 to 10,819 mg/kg, with the maximum content in the roots of *Tamarix ramosissima* and shoots of *Cichorium intybus*.

Accumulation and translocation of metals in plants

The plant's ability to accumulate metals from soils and to translocate metals from the roots to the shoots can be estimated using the BCF and plant's ability is measured using the TF, respectively. Enrichment occurs when a contaminant taken up by a plant is not degraded rapidly, resulting in an accumulation in the plant. The process of phytoextraction generally requires the translocation of heavy metals to the easily harvestable plant parts, i.e., shoots (Yoon et al. 2006). Plant species which have strong ability to reduce metal translocation from roots to shoots are suitable as phytostabilizers for metal-contaminated soils such as mine tailing (Deng et al. 2004). By comparing BCF and TF, the ability of different plants in taking up metals from soils and translocating them to the shoots can be compared. Plants exhibiting TF and particularly BCF values greater than one are suitable for phytoextraction and plants with BCF greater than one and TF less than one have the potential for phytostabilization (Yoon et al. 2006).

As shown in Table 7, among the sampled plants, none of them were suitable for phytoextraction of Pb, Zn, Mn and Fe, and phytostabilization of Fe but *Scrophularia scoparia* was most suitable for phytostabilization of Pb (BCF = 1.43 and TF = 0.09), *Centaurea virgata, Echinophora platyloba* and *Scariola orientalis* had the potential for phytostabilization of Zn (BCF = 1.73, 1.07 and 1.67, and TF = 0.24, 0.89 and 0.40, respectively) and *Centaurea virgata* and *Cirsium congestum* were the most efficient in phytostabilization of Mn (BCF = 1.27, 1.07 And TF = 0.13 and 0.85, respectively).

Conclusion

This study was conducted to screen plants growing on a contaminated site to determine their potential for metal accumulation. Based on among the 12 sampled plant species, metal translocation into shoots appears to be very restricted in the most plant species so that harvesting plants will not be an effective source of metal removal in this site. However, in the view of toxicology, this could be a desirable property, as metals would not pass into the food chain via herbivores, and thus avoid potential risk to the

Table 7 Accumulation and translocation of Pb, Zn, Mn and Fe in the selected plants

Scientific name	Bioconcentration factor (BCF)				Translocation factor (TF)			
	Pb	Zn	Mn	Fe	Pb	Zn	Mn	Fe
Euphorbia macroclada Boiss.	0.86	0.59	–	0.30	0.47	0.08	0.38	0.44
Centaurea virgata Lam.	0.23	1.73	1.27	0.88	0.61	0.24	0.13	0.37
Reseda lutea L.	0.24	0.12	0.12	0.78	0.05	9.39	0.25	0.25
Echinophora platyloba DC.	0.97	1.07	0.22	0.36	0.14	0.89	4.20	1.81
Cichorium intybus L.	0.00	0.02	0.06	0.01	–	–	3.80	0.45
Tamarix ramosissima Ledeb.	0.19	0.67	0.02	0.02	0.06	0.13	5.06	–
Cirsium congestum Fisch. and C. A.	0.40	0.31	1.05	0.91	0.23	2.97	0.85	0.38
Scrophularia scoparia Pennell	1.43	0.02	0.51	0.24	0.09	5.01	0.09	0.51
Chaerophyllum macropodum Boiss.	0.02	0.08	0.30	0.15	22.96	4.00	1.93	1.20
Cardaria draba (L.) Desv.	0.93	0.22	0.43	0.20	0.21	2.04	0.49	0.84
Scariola orientalis (Boiss.) Sojak.	0.99	1.67	0.86	0.23	0.13	0.40	0.16	1.11
Reseda alba L.	0.07	–	0.02	0.02	2.48	–	19.12	15.76

BCF metal concentration ratio of plant roots to soil, *TF* metal concentration ratio of plant shoots to roots

environment. Therefore, plants with low shoot accumulation should be used in order to stabilize the metals and reduce the metal dispersion through grazing animals or at leaf senescence. In general, sampled plants are almost exclusively annual and perennial herbaceous species and produce relatively large biomass; therefore, their utility for phytoremediation is possible.

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