Introduction to the native plant species with phytoremediation potential growing in a high Fe and Zn contaminated site in the copper mine of Dehmadan, Iran

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Abstract

Mining activity is one main source of heavy metal pollution. In this study, Al, Ba, Be, Ca, Cd, Co, Ce, Cr, Cu, Fe, Ga, Gd, K, La, Li, Mg, Mn, Na, Nb, Nd, Ni, P, Pb, S, Sc, Si, Sr, Ti, V, Y, Zn and Zr were measured by ICP-OES analyzing of the soils taken in the Dehmadan mining area, Chaharmahal and Bakhtiari, Iran. Al, Fe, Cu, Si and Zn were the most frequent metals in the mining area. Phytoremediation is one of the eco-friendly methods to effectively remediate soils contaminated with heavy metals. Consequently, the wild plants were collected from the mining area and subjected to ICP-OES analysis to determine the elements concentrations. A reverse relation was observed between the metals concentrations and vegetation density in the mining area. Finally, the bioconcentration factor (BCF) of the root and shoot, and translocation factor (TF) were determined to assess phytoremediation potential of species. The shoot elements concentrations in combination with BCF and TF greater than 1 were assess to determine hyperaccumulators and plants with excluder potential. Overall, the results showed that BCF in parallel with TF and metals concentrations can advance the knowledge of recognizing hyperaccumulators for phytoremediation of polluted environment.

Introduction

The metals and minerals are natural components present in soils (Awa and Hadibarata 2020; Wang et al. 2018). Heavy metals are metalloids which are toxic at low concentrations (Awa and Hadibarata 2020; Ali et al. 2013; Sytar et al. 2019; Kour et al. 2021; Hajhashemi et al. 2019). They are classified into essential and non-essential elements. Essential heavy metals (e.g., copper (Cu), iron (Fe), magnesium (Mn) and zinc (Zn)) are needed by living organisms for physiological and biochemical performance. Non-essential heavy metals, such as arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb), are not involved in any physiological and biochemical functions in living organisms (Ali et al. 2013; Maiz et al. 2000; Hajhashemi et al. 2020). Minerals and metals mining is an important activity in the industrialized and developing countries (Rashed 2010). High degree of metal pollution in the environment has been arising from mining activities, which adversely affects the ecological safety and wild flora (Moreno-Jiménez et al. 2009; Ghosh and Maiti 2021). The extraction of metals such as gold (Au), silver (Ag), iron (Fe), copper (Cu), lead (Pb), zinc (Zn), chromium (Cr), mercury (Hg) and etc. happens for the economic or industrial development of societies, while the metals including Cd, selenium (Se), strontium (Sr) and As are often enriched in mineral deposits and recovered as by-products (Rashed 2010; Alaquouri et al. 2020; Zhong et al. 2020). The heavy metals contamination has become a worldwide concern as they can cause adverse impacts on plants, animals and humans through contaminated-soil (Awa and Hadibarata 2020; Song et al. 2014; Faseela et al. 2019). The soil-remediation technologies has been developing to manage deposit of toxic metals in the environment. Phytoremediation is one of the effective, eco-friendly and easy-applying remediation method, which has recently achieved enormous interest from the researchers for soil remediation (Awa and Hadibarata 2020; Sytar et al. 2019).

Phytoremediation is a treatment technique to utilize plants in purpose of removing the contaminants from environment (Awa and Hadibarata 2020; January et al. 2008). As the plants used to remove the contaminants are not affecting the topsoil, this technique is environment-friendly and does not disturb the ecosystem (Awa and Hadibarata 2020). The selection of the appropriate hyperaccumulators is the key to a successful plant-based heavy metal remediation of contaminated soils and mine tailings (Awa and Hadibarata 2020; Ghosh and Maiti 2021). However, it should be considered that mining sites are not favorable medium for vegetation cover because of low levels of organic matter and nutrients, high concentrations of harmful heavy metals, unfavorable pH and low water availability (Ghosh and Maiti 2021). Accordingly, recognition of wild plants in the mining site has a critical value to recognize suitable hyperaccumulators for phytoremediation activities. The mechanism of phytoremediation is affected by several factors such as the plant species, properties of medium, and bioavailability of metals (Awa and Hadibarata 2020). The form of heavy metals as free metal ions and soluble metal complexes is important in order of their bioavailability to let them be absorbed by the plant roots through phytoremediation (Awa and Hadibarata 2020). However, the solubility of the metals is an important issue for the bioavailability of heavy metals in soil, minor information is available about the correlation between extractable elements and phytoavailability, especially when wild plants are involved (Awa and Hadibarata 2020; Moreno-Jiménez et al. 2009).

The hyperaccumulator plants extract, accumulate and tolerate high level of metals. They can accumulate heavy metals in their shoots and roots, by phytoextraction and phytostabilization, respectively. Phytoextraction is using of plants to remove/extract pollutants from contaminated soil, while in phytostabilization, the pollutants remain in the soil and are immobilized (Ghosh and Maiti 2021). Phytoextraction or phytoaccumulation is done by a plant when the roots can absorb, transport, and accumulate pollutants in the aboveground biomass such as shoots and leaves (Awa and Hadibarata 2020; Marrugo-Negrete et al. 2016). The plants with phytoextraction property should have high ability in producing high biomass or accumulating pollutants. The hyperaccumulator plants are desirable for performing phytoextraction because they have a high ability to accumulate pollutants. The effectiveness of the plant in phytoextraction of metals is determined through the ratio of metals concentrations in the soil and in the plant. However, the low metal bioavailability in soil and low metal absorption rate will limit the performance of phytoextraction (Awa and Hadibarata 2020; Usman et al. 2019). Besides, the metals phytoextraction effectiveness will also be lowered when they are held within the roots instead of being transported to shoots and leaves (Awa and Hadibarata 2020). In the phytostabilization process, the plants alter the soil chemistry and facilitate the absorption and precipitation processes of heavy metals in soil (Awa and Hadibarata 2020; Ali et al. 2013). The plants extract special redox enzymes during phytostabilization process and convert the heavy metals into a less toxic state in soil (Awa and Hadibarata 2020). However, phytostabilization is only a management strategy to inactivate and stabilize the heavy metals, but not removing pollutants from the environment (Awa and Hadibarata 2020; Sasmaz and Sasmaz 2009).

The difference in hyperaccumulator behavior toward heavy metals remains a concern to utilize the most appropriate hyperaccumulator to improve the phytoremediation efficiency. Due to the limitation of physical and chemical remediation techniques, phytoremediation becomes an important choice to remediate the heavy metal-contaminated soil. Both of phytostabilization and phytoextraction are the main phytoremediation mechanisms, which the selection of appropriate plant species is important to enhance the efficiency and success rate of phytoremediation technology. Recognition of the wild plant species that accumulate large amounts of heavy metals in their biomass and remain healthy is very important (Ali et al. 2013; Ali and Chaudhury 2016; Ghosh and Maiti 2021; Mertens et al. 2005; Marrugo-Negrete et al. 2016). Accordingly, this experiment was designed to collect and analyse the soils of the Dehmadan mining area to exactly determine the concentrations of metals and minerals and evaluate the plants to remediate metal-contaminated soils. Then, the wild

plants growing in the soil-polluted Dehmadan mining area were collected to recognize their species, analyse the minerals and metals in their shoots and roots, calculate the bioconcentration factor of shoots and root, and translocation factor, and introduce hyperaccumulators.

Materials And Methods

Description of the site investigated

Iran ranked 17th copper deposit in the world. In Iran, major sedimentary copper deposits are found in the Zagros fold belt and the Tabas block. The area of Mashayekh in Chaharmahal and Bakhtiari Province, Iran, is structurally located in the high Zagros belt. Mashayekh is characterized by two mining districts of Dehmadan and Darreh-Yas (Supplementary Fig. 1), which are approximately two kilometers apart. Dehmadan mining area is located in Dehmadan village in Mashayekh Rural District, Naghan District, Kiar County, Chaharmahal and Bakhtiari Province, Iran. Based on the nearest weather station reports in Naghan District, mean annual rainfall is 397.2 mm. The yearly minimum and maximum temperatures are -5 and 40°C , in winter and summer, respectively, were recorded from 2018 to 2021. The most mineralization in the Dehmadan deposit is associated with organic-bearing carbonate rocks. Lithologic units of the Dehmadan ore deposits are mainly included dolomite, quartz and minor feldspar. In addition, silty and clay minerals were also detected in the mineralogical composition of the sedimentary units of the area. The mineralography study in the area showed the primary minerals including chalcopyrite, pyrite, bornite, and secondary minerals of malachite, azorite, chalcocite, covellite, hematite and limonite. The second most important producer of copper after porphyry copper is sedimentary rock-hosted copper deposits. One deposits of sedimentary rock-hosted copper is recognized in Dehmadan ore (Zarasvandi et al. 2020; Aghili et al. 2018; Afzal et al. 2017; Pourkaseb et al. 2016).

Soil And Plant Sampling And Analysis

Soils and plants were sampled in the surroundings of the Dehmadan mining area (location, $31^{\circ}41'51''\text{N}$ $50^{\circ}52'36''\text{E}$). The studied site extended about 100000 m^2 . Based on the difference in the density of wild vegetation in the mining area, the happened in a triangle form with three sampling points. The sampling area within the Dehmadan mining zone was dividing soils into three sites: (1) soils close to mining extraction tunnel, (2) soils at the southern side of mining tunnel by about 200 m distance from site 1, and (3) soils on the top of the mining tunnel by about 500 m distance from site 1. The soil sampling was performed from the topsoil (0-15 cm depth) directly nearby the plants. The soil samples of three sites were separately oven-dried at 70°C for 48 hours. Then, they were ground and passed through 0.15 mm mesh. In order to element and metal analysis, 0.5 g of fine powder of soils were digested with 10 ml of a mixture of HNO_3 / HClO_4 / HF (5:1:1,v:v:v) at $140-150^{\circ}\text{C}$ until a colorless solution obtained (Baker and Amacher 1983; Rashed 2010). Then, the solutions were diluted to 100 ml with HPLC quality water. An Inductively Coupled Plasma-Optical Emission Spectrometry was used for measurement of elements in the soil.

The growing season in the Dehmadan mining area is from March to July. The plants samples in the area were collected for three consecutive years, from March 2018 to July 2021. As some plants were just observed one year in the Dehmadan mining area, the investigation was only done on plants that were present in the area all of three years of study. At first, the plant species of plants were recognized. Then the shoots and roots of plants were carefully separated and washed with tap water. Then, they were rinsed with the HPLC quality water. The plants samples were oven-dried at 70°C for 48 hours and ground to achieve a fine powder. The fine powder of shoots and roots (0.1 g) were digested with a mixture of HNO_3 (3 ml) and H_2O_2 (30%; 1 ml) at $140-150^{\circ}\text{C}$ to achieve a colorless digested solution. The digests volume were made up to 10 ml with HPLC quality water. The Inductively Coupled Plasma-Optical Emission Spectrometry (Varian, 735 ICP-OES, Australia) was used to measure elements in the plant samples.

Phytoremediation Potential Of Plants

Two indices of the bioconcentration factor of the root (BCF_{root}) and shoot $\text{BCF}_{\text{shoot}}$, and translocation factor (TF) were calculated to assess phytoremediation potential of plants (Ali et al. 2013; Mertens et al. 2005; Wang et al. 2017). BCF_{root} and $\text{BCF}_{\text{shoot}}$ may be used to assess the accumulation capacity of the roots and shoots. BCF and TF were calculated using the following equation (Ali and Chaudhury 2016; Usman et al. 2019):

$$\text{BCF}_{\text{root}} = C_{\text{root}}/C_{\text{soil}}$$

$$\text{BCF}_{\text{shoot}} = C_{\text{shoot}}/C_{\text{soil}}$$

$$\text{TF} = C_{\text{shoot}}/C_{\text{root}}$$

Where C_{root} , C_{shoot} and C_{soil} are the elements concentrations in the roots, shoots and soils.

If BCF value is above 1.0, it indicates that the metal accumulation potential of plant, which can be used for phytoremediation purposes. If BCF value is below or equal to 1.0, the plant species is not suitable for phytoremediation. The plants with TF value higher than 1.0 can be used for phytoextraction purpose, while they are not applicable for phytostabilisation. If the TF value is less than 1.0, the plant species is suitable for phytostabilisation, but it cannot be used for phytoextraction purpose. (Ali et al. 2013; Ali and Chaudhury 2016; Sasmaz and Sasmaz 2009).

Results

The chemical analysis of the soils from three different sites 1 to 3 showed the presence of heavy metals in the Dehmadan mining area. The results of ICP-OES soils are presented in Table 1. The elements of Ag, Cr, Dy, Er, Eu, Ge, Te, Th, Tl, U and Yb were not detectable in the soils and plant samples. Different

concentrations of Al, Ba, Be, Ca, Cd, Co, Ce, Cr, Cu, Fe, Ga, Gd, K, La, Li, Mg, Mn, Na, Nb, Nd, Ni, P, Pb, S, Sc, Si, Sr, Ti, V, Y, Zn and Zr were detected in the soils of the Dehmadan mining area. The most frequent metals in the area were Al, Fe, Cu, Si and Zn, with the highest concentrations achieved in the site 2. The average elements concentrations in the soils of Dehmadan mining area were recorded about 6953, 8576 and 5705 mg/Kg in sites 1, 2 and 3, respectively. Accordingly, site 2 was the most polluted site among the investigated sites. The elements of Cd and Gd were only detected in site 2, while their contents in sites 1 and 3 was not detectable. It was also noticed that the highest levels of Be, Co, Cr, Na, Nb and Zr were achieved from site 3. The average Ca, K, Mg, Na, P and S minerals were about 150551, 161985 and 109508 mg/Kg in sites 1, 2 and 3, respectively, with the highest concentrations in site 2. The minerals of Ca, Mg, P and S presented at their highest concentrations in site 2. In reverse, the highest and lowest level of Na was measured in site 3 and 2, respectively.

In the present study, 21 vascular plants were collected from different sites of the Dehmadan mining area. They belong to 9 families of Asteraceae (9 plants), Fabaceae (3 plants), Lamiaceae (2), Boraginaceae (2), Caryophyllaceae (1 plant), Gentianaceae (1 plant), Geraniaceae (1 plant), Papaveraceae (1 plant), and Rubicaceae (1) (Supplementary Fig. 2). The results of ICP-OES analysis of shoots and roots of all plants are presented in table 2. Based on the result of elements analysis, even though Be, Cd, Ce, Co, Ga, Gd, Nb, Nd, Sc, Y and Zr were observed in the Dehmadan mining area, none of those elements could be detected in the shoots and roots of plants collected in the area. Besides, the elements of Ce, Cr, La, Li, Mn, Ni, Th, Ti and V were only detected in a few plants species, while they were not detectable in lots of plants species. The element of Ce were measured only in the roots of *Callipeltis macrostegia* and *Silene*. The Cr element was detected in the roots of *Callipeltis macrostegia* and *Urospermum picroides*. La, Li and V were only observed in *Callipeltis macrostegia*. Mn was found in *Crepis pulchra*, *Crupina crupinastrum*, *Geranium rotundifolium* L., *Sonchus oleraceus* L., *Steptorrhampus persicus*, *Picris strigosa* and *Onosma elwendicum*, while no other plants in the area accumulated it. The plants species of *Acinus graveolens*, *Centaurea iberica*, *Medicago rigidula* and *Picris strigosa* showed the trace amount of Ni in their tissues. The element of Th was only detected in *Centaurea iberica* and *Onosma elwendicum*. The element of Ti was shown in *Anthemis odontostephana*, *Callipeltis macrostegia*, *Centaurea iberica*, *Crupina crupinastrum*, *Medicago rigidula*, *Medicago rodota*, *Roemeria refracta* and *Silene Sp*. The elements of Al, Ba, Ca, Cu, Fe, K, Mg, Na, P, S, Si, and Zn were widely detected in the roots and shoots of all plants species collected in the mining area, which their contents varied in the shoots and roots of different species (Table 2).

The results of BCF_{root} and BCF_{shoot} are presented in tables 3 and 4. The value of BCF_{root} for different metals in the plant species collected from the Dehmadan mining area were Al (0.013-0.262), Ba (0.0125-2.356), Ca (0.215-1.852), Cu (0.005-2.386), Fe (0.003-0.068), K (2.695-17.147), Mg (0.396-3.50), Mn (0.002-0.202), Na (0.200-1.979), Ni (1.706-2.890), P (7.458-47.187), S (0.462-3.661), Si (0.081-0.349), Sr (0.613-4.209), Ti ((0.018-7.088) and Zn (0.017-114.05). Also, the BCF_{shoot} calculated for metals in the different plant species from sites 1-3 were included Al (0.010-0.126), Ba (0.125-2.757), Ca (0.207-2.440), Cu (0.003-0.852), Fe (0.020-0.061), K (1.818-18.571), Mg (0.340-3.588), Mn (0.003-0.626), Na (0.145-1.598), Ni (2.389-4.046), P (13.672-94.374), S (0.791-3.642), Si (0.012-0.273), Sr (0.613-1.812), Ti (0.018-1.611) and Zn (0.012-33.740). In addition, the TF value was calculated for elements detected in different plant species in the Dehmadan mining area (Table 5). The TF value of different elements varied as described in follow: Al (0.1-7.6), Ba (0.4-5.6), Ca (0.2-3.9), Cu (0.1-3.0), Fe (0.4-7.2), K (0.4-2.9), Mg (0.1-7.1), Mn (1.1-3.1), Na (0.5-3.8), Ni (1.0-1.4), P (0.7-6.9), S (0.4-4.8), Si (0.1-1.5), Sr (0.2-1.8), Ti (0.2-1.6) and Zn (0.1-13.8).

Discussion

The Dehmadan mining area is introduced as one of the main sedimentary Cu deposits in Iran (Pourkaseb et al. 2016). Pourkaseb et al. (2016) detected Ag, Al, As, Ba, Ca, Co, Cu, Fe, Mg, Ni, S, Sc, Si, Sr, Th and V in the soil samples of Dehmadan using Inductively Coupled plasma Mass Spectroscopy (ICP-MS) analysis at the Lab West Analytical Laboratories in the Australia. These data confirms the results of present investigation based on the presence of Al, Ba, Ca, Cu, Fe, Mg, Ni, Sc, Si, Sr and V in the soils of Dehmadan, while in opposite to their report, we could not detect Ag, As, Co and Th in the collected soils from sites 1 to 3. Regardless Pourkaseb et al. (2016) report, the results of ICP-OES analysis of present study showed the presence of Be, Cd, Cr, Ga, Gd, K, La, Li, Mn, Na, Nb, Nd, P, Pb, Ti, Y, Zn and Zr in the soils of Dehmadan. The observed differences in the elements of our study and Pourkaseb et al. (2016) might be dependents on the sites of collecting soils, because we just collected soils from the sites with vegetation to study on the metals absorption and accumulation in the wild plant species.

Study on the wild vegetation of mining area is important to introduce tolerate and survival plants in the heavy metals-polluted environment (Awa and Hadibarata 2020; Hesami et al. 2018; Marrugo-Negrete et al. 2016). For the purpose of investigation on the vegetation of Dehmadan, the study site in the mining area was divided into three types of vegetation including: site 1, around the mining extraction tunnel, with a dense plants species belong to Asteraceae, Boraginaceae, Fabaceae, Gentianaceae, Geraniaceae and Laminaceae families; site 2, along the southern side of mining tunnel, with the plants from Asteraceae, Laminaceae and Papveraceae families; and site 3, in the upper-site of the mining tunnel, with plants species from the families of Asteraceae, Caryophyllaceae, Fabaceae and Rubicaceae. Accordingly, Asteraceae was the most abundant plant family in the mining area (Fig. 2), which was common between three studying sites. Based on the results of present study, 12, 3 and 6 plant species were collected from sites 1, 2 and 3, respectively. Accordingly, the highest and less vegetation density and species were observed in the sites 1 and 2, respectively, which might be due to the concentrations of trace metals. The highest levels of Cd, Cu, Fe, Ga, Gd, Li, Mn, Ni, Pb, Sc, V, Y and Zn were registered in site 2. Site 3 was more polluted than site 2, with higher concentrations of Ba, Be, Co, Cr, Cu, Fe, Ga, Mn, Nb, Nd, Ni, Pb, Y, Zn and Zr, compared to site 1. The flora is usually reduced in extremely metals polluted areas (Mleczeek et al. 2017), which is in according to the results of present study.

Metallophytes are plant species that are specifically adapted to and thrive in the metal-rich soils, which mining activities have been changing and destroying their niche. Metallophytes are divided into three categories: (a) metal excluders, which accumulate heavy metals into their roots but restrict their transport to the above ground parts, (b) metal indicators, which accumulate heavy metals in their aerial parts and reflect heavy metal concentrations in the substrate, (c) hyperaccumulators, which concentrate heavy metals in their aerial tissues to levels far exceeding those present in the soils (Ali et al. 2013; Marrugo-Negrete et al. 2016). Hyperaccumulators are the desirable plants species to perform phytoextraction as they have a high ability to absorb and accumulate the pollutants (Ali et al. 2013; Awa and Hadibarata 2020). The concentrations of different elements at their highest and lowest values in the roots and shoots are shown in table 4 to better know the hyperaccumulators. Even though the standard for hyperaccumulators has not been introduced scientifically, some authors have defined special metal concentration higher than a specific value per g dry mass (Ali et al. 2013). Van der Ent et al. (2013) recommend the following

concentration criteria for metals and metalloids in dried foliage with plant species growing in their natural habitats: 100 mg kg⁻¹ for Cd, Se and Tl; 300 mg kg⁻¹ for Co, Cu and Cr; 1000 mg kg⁻¹ for Ni, Pb and As; 3000 mg kg⁻¹ for Zn; and 10000 mg kg⁻¹ for Mn. In general, hyperaccumulators achieve 100-fold higher shoot metals concentrations compared to non-accumulator plants (Chaney et al. 2007; Lasat 2002). Besides, TF is a useful measure in supporting other evidence of hyperaccumulation, which in hyperaccumulators achieve the value of greater than 1 (Van der Ent et al. 2013; Ali et al. 2013). The results of present study has shown the TF value more than 1 for Al in 7 plants, Ba in 10 plants, Fe in 13 plants, Ca in 17 plants, K in 15 plants, Mg in 11 plants, Mn, in 2 plants, Na in 10 plants, P in 15 plants, Si in 12 plants and Zn in 10 plants. Among the trace metals, the highest TF value was observed for Zn in *Geranium rotundifolium*. Comparing the trace metals, the most number of plants with the TF value greater than one was also achieved for Fe. Accordingly, the hyperaccumulators of metals in the Dehmadan mining area were defined as shown in table 5.

For suggesting a candidate species for phytoextraction, the evaluation and selection of plants cannot entirely depend on the shoot metals concentrations. Both BCF and TF are important in screening hyperaccumulators for phytoextraction of heavy metals (Ali et al. 2013; Marrugo-Negrete et al. 2016). The effectiveness of the plant species in phytoextraction is determined through the ratio of element concentrations in the soil and the plant (Awa and Hadibarata 2020). The phytoextraction efficiency can be quantified by calculating BCF and TF. Therefore, the BCF value was calculated for both roots and shoots of plant species collected from Dehmadan. Yoon et al. (2006) recommended that only plants with both BCF and TF greater than 1 have the potential to be used for phytoextraction. However, high metal concentrations in soil could result in a BCF < 1. For example, in the Dehmadan mining area, the plants with high concentrations of Fe and Al showed BCF < 1. It is recommended by Van der Ent et al. (2013) that BCF has little advantage over simple comparisons of foliar metal concentrations and might have use for comparisons of growing plants in homogenized soil or in hydroponic cultures. Among the macronutrients, P showed the highest BCF value in the roots and shoots, which refers to low concentrations of P in the soils of Dehmadan, compared with other elements of Na, Mg, K and Si. Accordingly, the BCF value for P can also confirm Van der Ent et al. (2013) suggestion that BCF is not a completely reliable feature for quantifying the relative difference in the bioavailability of heavy metals to plants. However, the BCF value of roots and shoots for Zn in lots of plant species collected in the Dehmadan mining area were greater than 1. Based on the amounts of BCF_{shoots} and TF greater than 1, *Anthemis odontostephana*, *Astragalus Sp.*, *Callipeltis macrostegia*, *Centaureum pulchellum*, *Crepis pulchra*, *Crepis Sancata*, *Crupina crupinastrum*, *Geranium rotundifolium*, *Heliotropium europaeum*, *Medicago rigidula*, *Medicago rodota*, *Onosma elwendicum*, *Urospermum picroides*, *Roemeria refracta*, *Silene Sp.*, *Sonchus oleraceus L.*, *Steptorrhampus persicus*, and *Ziziphora tenuior* have the potential to be used for Zn phytoextraction. It should be pointed that the highest level of BCF_{shoots} was obtained in *Geranium rotundifolium*, which is almost 8-11 folds greater than *Urospermum picroides*, *Roemeria refracta* and *Ziziphora tenuior*. *Geranium rotundifolium* was collected from site 1 with 65.5 mg kg⁻¹ Zn in soils, while *Urospermum picroides*, *Roemeria refracta* and *Ziziphora tenuior* were collected from site 2 with 6421 mg kg⁻¹ Zn in soils. The Zn value in site 2 was about 100 folds greater than site 1, while BCF_{shoots} for *Geranium rotundifolium* from site 1 was almost 10 folds greater than plants of site 2. It is one another reason that BCF in parallel with TF and the metals concentrations in aboveground parts can be used for suggesting hyperaccumulators, while by itself is not a convenient way for quantifying hyperaccumulators (Van der Ent et al. 2013; Ali et al. 2013).

Based on the table 6, the highest levels of elements concentrations in shoots, BCF_{shoot} and TF were achieved for Al in *Acinus graveolens*, Cu in *Anthemis odontostephana*, Mn in *Steptorrhampus persicus*, Ni in *Medicago rigidula*, and P and Zn in *Geranium rotundifolium* at the same time. The greatest elements concentrations in shoots and BCF_{shoot} were observed for Ba and Si in *Onosma elwendicum*, K in *Centaurea iberica*, and S in *Crepis Sancata*, while the highest level of TF was registered for Ba in *Roemeria refracta*, K in *Astragalus Sp.*, S in *Ziziphora tenuior* and Si in *Anthemis odontostephana*. The highest elements concentrations in shoots and TF were measured for Ca and Mg in *Heliotropium europaeum*, Na in *Centaureum pulchellum*, Sr in *Onosma elwendicum* and Ti in *Acinus graveolens*, whereas the highest BCF_{shoot} was achieved for Ca in *Medicago rodota* (2.4), Mg in *Silene Sp.* (3.5), Na in *Roemeria refracta* (1.6), Sr in *Roemeria refracta* (1.8) and Ti in *Callipeltis macrostegia* (1.6). Regarding Fe, the highest levels of elements concentrations in shoots, BCF_{shoot} and TF were achieved in three different plants of *Urospermum picroides*, *Medicago rigidula* and *Crepis pulchra*, respectively, whereas the BCF value in all of them was less than 1. Overall, table 6 has shown that determination of hyperaccumulators can be more accurate if the evaluation of some parameters happens together. Even though, the BCF_{shoot} value for Al, Cu and Mn in *Acinus graveolens*, *Anthemis odontostephana* and *Anthemis odontostephana*, respectively, were less than 1, they were the highest levels, in parallel with the elements concentrations in shoots and TF. Accordingly, they can be suggested as hyperaccumulators. In summary, the plants shown in table 5 has the potential to absorb and accumulate high levels of elements.

Plants can also immobilize heavy metals in the soils through absorption by roots, precipitation, metal valence reduction in rhizosphere or complexation (Awa and Hadibarata 2020; Ali et al. 2013). Phytostabilization minimizes the heavy metals accumulation in biota and leaching into underground waters, through limiting their movement. Actually, phytostabilization is a management strategy for stabilizing toxic contaminants, and is not a permanent solution, because heavy metals remain in the soil (Ali et al. 2013; Awa and Hadibarata 2020). The plants species of *Silene Sp.* (Al), *Astragalus Sp.* (Ca), *Ziziphora tenuior*

(Cu), *Callipeltis macrostegia* (Fe), *Crepis pulchra* (K), *Anthemis odontostephana* (Mg), *Astragalus Sp.* (Mn), *Urospermum picroides* (Na), *Callipeltis macrostegia* (S), *Silene Sp.* (Si), *Callipeltis macrostegia* (Sr), *Crupina crupinastrum* (Ti) and *Callipeltis macrostegia* (Zn) accumulated the highest levels of elements in their roots, while the TF value in them was less than 1.0. Regardless, *Onosma elwendicum* (Ba), *Medicago rigidula* (Ni) and *Silene Sp.* (P) with the highest elements in their roots showed the TF value equal or higher than 1 (Table 7). Based on the table 7, it was noticed that no correlation exists between the highest level of elements in the roots, BCF_{root} and TF. As it is shown in table 5, some plants in Dehmadan mining area absorbed and accumulated metals in their roots, while they did not transfer them to their shoots. For example, *Astragalus Sp.* with high levels of Cu in the roots and BCF_{roots} greater than 1 (about 2.4) and no Cu transfer to shoots (TF=0) can be suggested as Cu excluder. Even though, no scientific value has been presented for the value of metals in the roots to exactly determine metal excluder, the plants with the highest concentrations of elements in their roots in combination with the BCF_{root} value higher than 1 may have the potential of metal excluder (table 7). The metal excluder plants with a low potential for metal extraction may be efficient for phytostabilization purposes (Ali et al. 2013). Besides, the effectiveness of phytoextraction will also be lowered when the metals are held within the roots instead of being transported to the aboveground parts.

Conclusion

The evaluation of wild vegetation in the Dehmadan mining area with high concentration of metals such as Al, Ba, Ca, Cd, Ce, Cr, Cu, Fe, Ga, Gd, K, La, Li, Mg, Mn, Na, Nb, Nd, Ni, P, Pb, S, Sc, Si, Sr, Ti, V, Y, Zn and Zr has shown the potential of some of species in absorption and accumulation of metals and minerals in their tissues. The results of present study showed that even though some plants showed the BCF_{shoot} value less than 1, they could effectively absorb, transferred and accumulate the elements to the aboveground parts. Accordingly, it can be suggested that the value of BCF_{shoot} in companion with the concentration of metals in the shoots and TF can be used for suggesting hyperaccumulators, while making decision based on every single of them maybe not accurate. In addition, some plants in the Dehmadan mining area could absorb and accumulate metals in the roots without transferring to the shoots. Even though, these plants cannot be suggested for phytoremediation, they can apply mechanism to tolerate high levels of pollutants. It can be suggested that plants with high concentrations of metals in the roots in companion with BCF_{root} greater than 1.0 have the potential of metal excluder. Furthered study on physiological, biochemical and molecular mechanism in the wild plants in the mining area is a promise to produce hyperaccumulator plants by biotechnology to remove pollutants in an eco-friendly way.

Declarations

Ethics approval and consent to participate:

Not applicable.

Consent for publication:

Not applicable.

Availability of data and materials:

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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The authors declare that they have no competing interests.

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Authors' contributions:

Shokoofeh Hajhashemi, Shakiba Rajabpoor, Marian Brestic: Conceptualization, project administration, and data curation. **Shokoofeh Hajhashemi, Shakiba Rajabpoor:** Data curation, methodology, formal analysis. **Shokoofeh Hajhashemi, Marian Brestic:** project administration. Shokoofeh Hajhashemi: formal analysis. **Shokoofeh Hajhashemi, Shakiba Rajabpoor, Marian Brestic:** original draft, writing – review and editing. All authors were involved in review and editing.

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Tables

Table 1 The concentrations of elements (mg Kg⁻¹) in soils of 3 sampling sites in the Dehmadan mining area in Chaharmahal and Bakhtiari, Iran.

Table 1

Element	Ag	AL	Ba	Be	Ca	Cd	Ce	Co	Cr	Cu	Dy	Er	Eu	Fe
Site														
1	<0.05	58700	399	1.85	51300	<0.05	48.1	13.8	<0.05	176	<0.05	<0.05	<0.05	35700
2	<0.05	58900	276	1.99	55800	18.9	48.3	165	<0.05	16600	<0.05	<0.05	<0.05	55800
3	<0.05	52000	395	2.01	20700	<0.05	44.8	83.6	19.0	2343	<0.05	<0.05	<0.05	40300

Continue table 1

Element	Ga	Gd	Ge	K	La	Li	Mg	Mn	Na	Nb	Nd	Ni	P	Pb
Site														
1	15.4	<0.05	<0.05	30800	22.2	43.5	28000	495	0.98	18.6	24.6	17.3	551	<0.05
2	17.6	5.46	<0.05	30800	21.2	44.9	35600	946	0.47	20.6	21.2	34.8	885	70.2
3	17.0	<0.05	<0.05	31200	20.6	39.6	25700	697	1.01	20.9	24.3	29.3	828	23.5

Continue table 1

Element	Sc	Si	Sr	Te	Th	Ti	Tl	U	V	Y	Yb	Zn	Zr	
S														
Site														
1	30100	11.2	15000	81.6	<0.05	<0.05	2640	<0.05	<0.05	82.4	18	<0.05	65.5	76.1
2	34200	12	22000	60.7	<0.05	<0.05	2811	<0.05	<0.05	92.4	19.7	<0.05	6421	102
3	20980	9.38	10400	68.9	<0.05	<0.05	31.04	<0.05	<0.05	89.9	16.9	<0.05	513	104

Table 2 Element concentrations (mg Kg⁻¹) in roots and shoots of plants collected from the Dehmadan mining area in Chaharmahal and Bakhtiari, Iran.

Elements	Family	Site		Ag	Al	Ba	Be	Ca	Cd	Ce	Co	Cr	Cu	Fe	
Plant species															
<i>Acinus graveolens</i>	Laminaceae	1	leaf	<0.05	7400	110	<0.05	27200	<0.05	<0.05	<0.05	<0.05	<0.05	1070	7
			root	<0.05	980	60	<0.05	30200	<0.05	<0.05	<0.05	<0.05	60	2420	7
<i>Anthemis odontostephana</i>	Asteraceae	1	leaf	<0.05	1600	<0.05	<0.05	35600	<0.05	<0.05	<0.05	<0.05	150	2110	3
			Root	<0.05	1420	<0.05	<0.05	18800	<0.05	<0.05	<0.05	<0.05	50	1260	2
<i>Astragalus</i> Sp.	Fabaceae	1	leaf	<0.05	850	<0.05	<0.05	36700	<0.05	<0.05	<0.05	<0.05	<0.05	880	2
			root	<0.05	1620	50	<0.05	95000	<0.05	<0.05	<0.05	<0.05	420	1150	8
<i>Callipeltis macrostegia</i>	Rubicaceae	3	leaf	<0.05	1750	100	<0.05	41700	<0.05	<0.05	<0.05	<0.05	<0.05	1110	2
			root	<0.05	9140	140	<0.05	37500	<0.05	350	<0.05	70	70	2610	2
<i>Centaurea iberica</i>	Asteraceae	1	leaf	<0.05	2000	150	<0.05	47600	<0.05	<0.05	<0.05	<0.05	60	2110	1
			root	<0.05	4970	140	<0.05	20600	<0.05	<0.05	<0.05	<0.05	<0.05	690	2
<i>Centaurium pulchellum</i>	Gentianaceae	1	leaf	<0.05	4310	<0.05	<0.05	31000	<0.05	<0.05	<0.05	<0.05	<0.05	1510	2
			root	<0.05	2250	80	<0.05	17400	<0.05	<0.05	<0.05	<0.05	50	1210	7
<i>Crepis pulchra</i>	Asteraceae	3	leaf	<0.05	860	<0.05	<0.05	40000	<0.05	<0.05	<0.05	<0.05	150	1230	4
			root	<0.05	1120	50	<0.05	15400	<0.05	<0.05	<0.05	<0.05	720	170	1
<i>Crepis Sancata</i>	Asteraceae	3	leaf	<0.05	3500	70	<0.05	44400	<0.05	<0.05	<0.05	<0.05	90	1820	4
			root	<0.05	1070	60	<0.05	16100	<0.05	<0.05	<0.05	<0.05	220	1530	3
<i>Crupina crupinastrum</i>	Asteraceae	1	leaf	<0.05	1250	<0.05	<0.05	44100	<0.05	<0.05	<0.05	<0.05	<0.05	1360	7
			root	<0.05	2250	<0.05	<0.05	19700	<0.05	<0.05	<0.05	<0.05	50	1630	2
<i>Geranium rotundifolium</i> L.	Geraniaceae	1	leaf	<0.05	1720	270	<0.05	42200	<0.05	<0.05	<0.05	<0.05	<0.05	1460	7
			root	<0.05	840	370	<0.05	17800	<0.05	<0.05	<0.05	<0.05	<0.05	1130	3
<i>Heliotropium europaeum</i>	Boraginaceae	1	leaf	<0.05	710	<0.05	<0.05	74100	<0.05	<0.05	<0.05	<0.05	<0.05	1840	1
			root	<0.05	1000	100	<0.05	19100	<0.05	<0.05	<0.05	<0.05	<0.05	2020	6
<i>Medicago rigidula</i>	Fabaceae	1	leaf	<0.05	690	<0.05	<0.05	44800	<0.05	<0.05	<0.05	<0.05	50	2190	7
			root	<0.05	1800	80	<0.05	18400	<0.05	<0.05	<0.05	<0.05	80	710	2
<i>Medicago rodiota</i>	Fabaceae	3	leaf	<0.05	980	60	<0.05	50500	<0.05	<0.05	<0.05	<0.05	80	1070	2
			root	<0.05	3970	60	<0.05	17700	<0.05	<0.05	<0.05	<0.05	110	970	2
<i>Onosma elwendicum</i>	Boraginaceae	1	leaf	<0.05	610	1100	<0.05	10600	<0.05	<0.05	<0.05	<0.05	<0.05	700	2
			root	<0.05	1720	940	<0.05	47200	<0.05	<0.05	<0.05	<0.05	60	2000	7
<i>Picris strigosa</i>	Asteraceae	3	leaf	<0.05	1610	70	<0.05	30700	<0.05	<0.05	<0.05	<0.05	<0.05	1970	3
			root	<0.05	700	170	<0.05	37400	<0.05	<0.05	<0.05	<0.05	110	1010	7
<i>Urospermum picroides</i>	Asteraceae	2	leaf	<0.05	80	290	<0.05	34100	<0.05	<0.05	<0.05	<0.05	50	2220	2
			root	<0.05	950	230	<0.05	25100	<0.05	<0.05	<0.05	50	80	1890	7
<i>Roemeria refracta</i>	Papaveraceae	2	leaf	<0.05	1060	280	<0.05	61200	<0.05	<0.05	<0.05	<0.05	150	1470	7
			root	<0.05	1640	50	<0.05	25100	<0.05	<0.05	<0.05	<0.05	280	2600	3
Silene Sp.	Caryophyllaceae	3	leaf	<0.05	690	230	<0.05	29300	<0.05	<0.05	<0.05	<0.05	80	1520	1
			root	<0.05	13620	220	<0.05	12000	<0.05	50	<0.05	<0.05	170	880	4
<i>Sonchus oleraceus</i> L.	Asteraceae	1	leaf	<0.05	690	50	<0.05	42400	<0.05	<0.05	<0.05	<0.05	<0.05	960	4
			root	<0.05	900	50	<0.05	13300	<0.05	<0.05	<0.05	<0.05	<0.05	1120	2
<i>Steptorrhampus persicus</i>	Asteraceae	1	leaf	<0.05	690	60	<0.05	45800	<0.05	<0.05	<0.05	<0.05	<0.05	1040	1
			root	<0.05	850	70	<0.05	12000	<0.05	<0.05	<0.05	<0.05	<0.05	810	3
<i>Ziziphora tenuior</i>	Laminaceae	2	leaf	<0.05	1230	210	<0.05	38000	<0.05	<0.05	<0.05	<0.05	80	1940	7

	root	<0.05	1290	130	<0.05	12000	<0.05	<0.05	<0.05	<0.05	<0.05	1280	1780	
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Table 3 Bioconcentration factors (BCF) of shoot for plants collected from the Dehmadan mining area in Chaharmahal and Bakhtiari, Iran.

Elements	Al	Ba	Ca	Cu	Fe	K	Mg	Mn	Na	Ni	P	S	Si	Sr	Ti
Plant species															
<i>Acinus graveolens</i>	0.126	0.276	0.530	0	0.030	4.935	1.693	0	0.538	0	37.931	2.194	0.158	0	0.030
<i>Anthemis odontostephana</i>	0.027	0	0.694	0.852	0.059	10.909	0.429	0	0.614	0	19.056	2.761	0.239	0.980	0.027
<i>Astragalus</i> Sp.	0.014	0	0.715	0	0.025	7.825	1.782	0	0.316	0	36.298	2.203	0.115	0.613	0
<i>Callipeltis macrostegia</i>	0.034	0.253	2.014	0	0.028	7.468	3.089	0	0.474	0	35.145	3.122	0.180	0.726	1.611
<i>Centaurea iberica</i>	0.034	0.376	0.928	0.341	0.059	18.571	3.089	0	0.398	2.890	13.975	2.110	0.139	0.980	0.019
<i>Centaureum pulchellum</i>	0.073	0	0.604	0	0.042	7.500	0.364	0	0.771	0	34.301	2.887	0.149	0.613	0
<i>Crepis pulchra</i>	0.017	0	1.932	0.064	0.031	15.673	2.156	0.172	0.394	0	34.903	3.089	0.252	0.726	0
<i>Crepis Sancata</i>	0.067	0.177	2.145	0.038	0.045	13.013	0.494	0	0.504	0	28.140	4.361	0.159	0.871	0
<i>Crupina crupinastrum</i>	0.021	0	0.860	0	0.038	6.169	0.418	0	0.316	0	47.187	2.877	0.215	0.858	0
<i>Geranium rotundifolium</i>	0.029	0.677	0.823	0	0.041	5.779	2.164	0	0.432	0	94.374	1.791	0.135	0.980	0.019
<i>Heliotropium europaeum</i>	0.012	0	1.444	0	0.052	1.818	3.407	0	0.145	0	23.049	2.090	0.173	1.103	0
<i>Medicago rigidula</i>	0.012	0	0.873	0.284	0.061	5.649	2.582	0	0.702	4.046	17.604	1.761	0.012	0.858	0
<i>Medicago rodota</i>	0.019	0.152	2.440	0.034	0.027	9.487	1.965	0	0.600	0	20.531	3.198	0.235	1.451	0
<i>Onosma elwendicum</i>	0.010	2.757	0.207	0	0.020	7.825	1.050	0	0.184	0	20.508	0.791	0.273	1.716	0
<i>Picris strigosa</i>	0.031	0.177	1.483	0	0.049	10.288	0.424	0	0.550	2.389	23.309	3.642	0.194	0.726	0
<i>Urospermum picroides</i>	0.001	1.051	0.611	0.003	0.040	9.091	2.593	0	1.494	0	53.672	2.102	0.076	0.988	0
<i>Roemeria refracta</i>	0.018	1.014	1.097	0.009	0.026	3.831	2.565	0	1.598	0	13.672	2.146	0.089	1.812	0.018
<i>Silene</i> Sp.	0.013	0.582	1.415	0.034	0.038	16.571	3.588	0	0.552	0	40.459	3.751	0.183	0.726	0
<i>Sonchus oleraceus</i> L.	0.012	0.125	0.827	0	0.027	13.961	2.704	0.222	0.364	0	46.279	2.870	0.157	0.613	0
<i>Steptorrhaphus persicus</i>	0.012	0.150	0.893	0	0.029	17.468	2.900	0.626	0.386	0	34.301	2.887	0.149	0.613	0
<i>Ziziphora tenuior</i>	0.021	0.761	0.681	0.005	0.035	6.234	0.340	0	1.445	0	21.469	2.213	0.090	0.988	0

Table 4 Bioconcentration factors (BCF) of roots for plants collected from the Dehmadan mining area in Chaharmahal and Bakhtiari, Iran.

Elements		Mn	Mo	Na	Ni	P	Pb	Rb	S	Sb	SC	Si	Sn	Sr	Th	Ti
Plant species																
<i>Acinus graveolens</i>	leaf	<0.05	<0.05	5270	<0.05	20900	<0.05	<0.05	66030	<0.05	<0.05	2370	<0.05	<0.05	<0.05	80
	root	<0.05	<0.05	2770	50	14200	<0.05	<0.05	47600	<0.05	<0.05	2000	<0.05	<0.05	<0.05	50
<i>Anthemis odontostephana</i>	leaf	<0.05	<0.05	6020	<0.05	10500	<0.05	<0.05	83100	<0.05	<0.05	3590	<0.05	80	<0.05	70
	root	<0.05	<0.05	5430	<0.05	7100	<0.05	<0.05	67700	<0.05	<0.05	2330	<0.05	50	<0.05	50
<i>Astragalus</i> Sp.	leaf	<0.05	<0.05	3100	<0.05	20000	<0.05	<0.05	66300	<0.05	<0.05	1730	<0.05	50	<0.05	<0.05
	root	170	<0.05	5670	<0.05	26000	<0.05	<0.05	13900	<0.05	<0.05	2670	<0.05	50	<0.05	<0.05
<i>Callipeltis macrostegia</i>	leaf	<0.05	<0.05	4790	<0.05	29100	<0.05	<0.05	65500	<0.05	<0.05	1870	<0.05	50	<0.05	50
	root	<0.05	<0.05	5230	<0.05	23400	<0.05	<0.05	76800	<0.05	<0.05	3370	<0.05	290	60	22
<i>Centaurea iberica</i>	leaf	<0.05	<0.05	3900	50	7700	<0.05	<0.05	63500	<0.05	<0.05	2080	<0.05	80	<0.05	50
	root	<0.05	<0.05	4220	50	11500	<0.05	<0.05	50700	<0.05	<0.05	2010	<0.05	80	<0.05	60
<i>Centaureum pulchellum</i>	leaf	<0.05	<0.05	7560	<0.05	18900	<0.05	<0.05	86900	<0.05	<0.05	2240	<0.05	50	<0.05	<0.05
	root	<0.05	<0.05	2010	<0.05	20500	<0.05	<0.05	41600	<0.05	<0.05	1720	<0.05	50	<0.05	<0.05
<i>Crepis pulchra</i>	leaf	120	<0.05	3980	<0.05	28900	<0.05	<0.05	64800	<0.05	<0.05	2620	<0.05	50	<0.05	<0.05
	root	<0.05	<0.05	6540	<0.05	15400	<0.05	<0.05	49100	<0.05	<0.05	2230	<0.05	50	<0.05	<0.05
<i>Crepis Sancata</i>	leaf	<0.05	<0.05	5090	<0.05	23300	<0.05	<0.05	91500	<0.05	<0.05	1650	<0.05	60	<0.05	<0.05
	root	120	<0.05	6340	<0.05	15400	<0.05	<0.05	59800	<0.05	<0.05	2020	<0.05	60	<0.05	<0.05
<i>Crupina crupinastrum</i>	leaf	<0.05	<0.05	3100	<0.05	26000	<0.05	<0.05	86600	<0.05	<0.05	3230	<0.05	70	<0.05	<0.05
	root	100	<0.05	4880	<0.05	13400	<0.05	<0.05	66900	<0.05	<0.05	2380	<0.05	50	<0.05	70
<i>Geranium rotundifolium</i> L.	leaf	<0.05	<0.05	4230	<0.05	52000	<0.05	<0.05	53900	<0.05	<0.05	2030	<0.05	80	<0.05	50
	root	100	<0.05	3890	<0.05	7500	<0.05	<0.05	69700	<0.05	<0.05	2130	<0.05	50	<0.05	<0.05
<i>Heliotropium europaeum</i>	leaf	<0.05	<0.05	1420	<0.05	12700	<0.05	<0.05	62900	<0.05	<0.05	2600	<0.05	90	<0.05	<0.05
	root	<0.05	<0.05	2280	<0.05	7500	<0.05	<0.05	69700	<0.05	<0.05	2130	<0.05	50	<0.05	<0.05
<i>Medicago rigidula</i>	leaf	<0.05	<0.05	6880	70	9700	<0.05	<0.05	53000	<0.05	<0.05	180	<0.05	70	<0.05	<0.05
	root	<0.05	<0.05	6220	50	13000	<0.05	<0.05	42900	<0.05	<0.05	2430	<0.05	70	<0.05	60
<i>Medicago rodota</i>	leaf	<0.05	<0.05	6060	<0.05	17000	<0.05	<0.05	67100	<0.05	<0.05	2440	<0.05	100	<0.05	<0.05
	root	<0.05	<0.05	3930	<0.05	13500	<0.05	<0.05	63000	<0.05	<0.05	3530	<0.05	60	<0.05	12
<i>Onosma elwendicum</i>	leaf	<0.05	<0.05	1800	<0.05	11300	<0.05	<0.05	23800	<0.05	<0.05	4100	<0.05	140	<0.05	<0.05
	root	100	<0.05	1960	<0.05	10900	<0.05	<0.05	60000	<0.05	<0.05	3320	<0.05	80	50	60
<i>Picris strigosa</i>	leaf	<0.05	<0.05	5560	70	19300	<0.05	<0.05	76400	<0.05	<0.05	2020	<0.05	50	<0.05	<0.05
	root	100	<0.05	5550	50	9300	<0.05	<0.05	48100	<0.05	<0.05	1650	<0.05	70	<0.05	<0.05
<i>Urospermum picroides</i>	leaf	<0.05	<0.05	7020	<0.05	47500	<0.05	<0.05	71900	<0.05	<0.05	1670	<0.05	60	<0.05	<0.05
	root	<0.05	<0.05	9300	<0.05	27800	<0.05	<0.05	61400	<0.05	<0.05	1890	<0.05	50	<0.05	<0.05
<i>Roemeria refracta</i>	leaf	<0.05	<0.05	7510	<0.05	12100	<0.05	<0.05	73400	<0.05	<0.05	1950	<0.05	110	<0.05	50
	root	<0.05	<0.05	3910	<0.05	16200	<0.05	<0.05	62500	<0.05	<0.05	3020	<0.05	80	<0.05	50
<i>Silene</i> Sp.	leaf	<0.05	<0.05	5580	<0.05	33500	<0.05	<0.05	78700	<0.05	<0.05	1900	<0.05	50	<0.05	<0.05
	root	<0.05	<0.05	3910	<0.05	34800	<0.05	<0.05	73400	<0.05	<0.05	3630	<0.05	50	<0.05	21
<i>Sonchus oleraceus</i> L.	leaf	110	<0.05	3570	<0.05	25500	<0.05	<0.05	86400	<0.05	<0.05	2360	<0.05	50	<0.05	<0.05
	root	100	<0.05	4670	<0.05	10900	<0.05	<0.05	60000	<0.05	<0.05	3320	<0.05	80	<0.05	60
<i>Steptorrhampus persicus</i>	leaf	310	<0.05	3780	<0.05	18900	<0.05	<0.05	86900	<0.05	<0.05	2240	<0.05	50	<0.05	<0.05
	root	100	<0.05	4800	<0.05	20500	<0.05	<0.05	41600	<0.05	<0.05	1720	<0.05	50	<0.05	<0.05
<i>Ziziphora tenuior</i>	leaf	<0.05	<0.05	6790	<0.05	19000	<0.05	<0.05	75700	<0.05	<0.05	1970	<0.05	60	<0.05	<0.05

	root	<0.05	<0.05	3710	<0.05	6600	<0.05	<0.05	25600	<0.05	<0.05	1780	<0.05	50	<0.05	<C
Elements	Al	Ba	Ca	Cu	Fe	K	Mg	Mn	Na	Ni	P	S	Si	Sr	Ti	
Plant species																
<i>Acinus graveolens</i>	0.017	0.150	0.589	0.341	0.068	3.929	2.754	0	0.283	2.890	25.771	1.581	0.133	0	0.019	
<i>Anthemis odontostephana</i>	0.024	0	0.366	0.284	0.035	9.448	3.500	0	0.554	0	12.886	2.249	0.155	0.613	0.019	
<i>Astragalus</i> Sp.	0.028	0.125	1.852	2.386	0.032	2.695	2.643	0.003	0.579	0	47.187	0.462	0.178	0.613	0	
<i>Callipeltis macrostegia</i>	0.176	0.354	1.812	0.030	0.065	6.410	2.093	0	0.518	0	28.261	3.661	0.324	4.209	7.088	
<i>Centaurea iberica</i>	0.085	0.351	0.402	0	0.019	9.188	1.104	0	0.431	2.890	20.871	1.684	0.134	0.980	0.023	
<i>Centaureum pulchellum</i>	0.038	0.201	0.339	0.284	0.034	5.227	2.804	0	0.205	0	37.205	1.382	0.115	0.613	0	
<i>Crepis pulchra</i>	0.022	0.127	0.744	0.307	0.004	17.147	0.953	0	0.648	0	18.599	2.340	0.214	0.726	0	
<i>Crepis Sancata</i>	0.021	0.152	0.778	0.094	0.038	12.468	2.047	0.002	0.628	0	18.599	2.850	0.194	0.871	0	
<i>Crupina crupinastrum</i>	0.038	0	0.384	0.284	0.046	7.338	0.407	0.202	0.498	0	24.319	2.223	0.159	0.613	0.027	
<i>Geranium rotundifolium</i>	0.014	0.927	0.347	0	0.032	10.097	2.736	0.202	0.397	0	13.612	2.316	0.142	0.613	0	
<i>Heliotropium europaeum</i>	0.017	0.251	0.372	0	0.057	1.948	0.479	0	0.233	0	13.612	2.316	0.142	0.613	0	
<i>Medicago rigidula</i>	0.031	0.201	0.359	0.455	0.020	7.955	0.996	0	0.635	2.890	23.593	1.425	0.162	0.858	0.023	
<i>Medicago rodiota</i>	0.076	0.152	0.855	0.047	0.024	8.878	1.043	0	0.389	0	16.304	3.003	0.339	0.871	3.866	
<i>Onosma elwendicum</i>	0.029	2.356	0.920	0.341	0.056	6.136	0.396	0.202	0.200	0	19.782	1.993	0.221	0.980	0.023	
<i>Picris strigosa</i>	0.013	0.430	1.807	0.047	0.025	3.686	2.981	0.143	0.550	1.706	11.232	2.293	0.159	1.016	0	
<i>Urospermum picroides</i>	0.016	0.833	0.450	0.005	0.034	6.266	2.503	0	1.979	0	31.412	1.795	0.086	0.824	0	
<i>Roemeria refracta</i>	0.028	0.181	0.450	0.017	0.047	10.227	2.374	0	0.832	0	18.305	1.827	0.137	1.318	0.018	
<i>Silene</i> Sp.	0.262	0.557	0.580	0.073	0.022	13.205	2.074	0	0.387	0	42.029	3.499	0.349	0.726	6.765	
<i>Sonchus oleraceus</i> L.	0.015	0.125	0.259	0	0.031	8.149	3.336	0.202	0.477	0	19.782	1.993	0.221	0.980	0.023	
<i>Steptorrhampus persicus</i>	0.014	0.175	0.234	0	0.023	9.870	0.611	0.202	0.490	0	37.205	1.382	0.115	0.613	0	
<i>Ziziphora tenuior</i>	0.022	0.471	0.215	0.077	0.032	4.188	1.115	0	0.789	0	7.458	0.749	0.081	0.824	0	

Table 5 Translocation factors (TF) for plants collected from the Dehmadan mining area in Chaharmahal and Bakhtiari, Iran.

Elements	Al	Ba	Ca	Cu	Fe	K	Mg	Mn	Na	Ni	P	S	Si	Sr	Ti	Zn
Plant species																
<i>Acinus graveolens</i>	7.6	1.8	0.9	0	0.4	1.3	0.6	0	1.9	0	1.5	1.4	1.2	0	1.6	0
<i>Anthemis odontostephana</i>	1.1	0	1.9	3.0	1.7	1.2	0.1	0	1.1	0	1.5	1.2	1.5	1.6	1.4	1.4
<i>Astragalus</i> Sp.	0.5	0	0.4	0	0.8	2.9	0.7	0	0.5	0	0.8	4.8	0.6	1.0	0	2.0
<i>Callipeltis macrostegia</i>	0.2	0.7	1.1	0	0.4	1.2	1.5	0	0.9	0	1.2	0.9	0.6	0.2	0.2	0.0
<i>Centaurea iberica</i>	0.4	1.1	2.3	0	3.1	2.0	2.8	0	0.9	1.0	0.7	1.3	1.0	1.0	0.8	0
<i>Centaurium pulchellum</i>	1.9	0	1.8	0	1.2	1.4	0.1	0	3.8	0	0.9	2.1	1.3	1.0	0	4.6
<i>Crepis pulchra</i>	0.8	0	2.6	0.2	7.2	0.9	2.3	0	0.6	0	1.9	1.3	1.2	1.0	0	0.6
<i>Crepis Saccata</i>	3.3	1.2	2.8	0.4	1.2	1.0	0.2	0	0.8	0	1.5	1.5	0.8	1.0	0	1.0
<i>Crupina crupinastrum</i>	0.6	0	2.2	0	0.8	0.8	1.0	0	0.6	0	1.9	1.3	1.4	1.4	0	2.2
<i>Geranium rotundifolium</i>	2.0	0.7	2.4	0	1.3	0.6	0.8	0	1.1	0	6.9	0.8	1.0	1.6	0	13.8
<i>Heliotropium europaeum</i>	0.7	0	3.9	0	0.9	0.9	7.1	0	0.6	0	1.7	0.9	1.2	1.8	0	1.7
<i>Medicago rigidula</i>	0.4	0	2.4	0.6	3.1	0.7	2.6	0	1.1	1.4	0.7	1.2	0.1	1.0	0	0.1
<i>Medicago rodota</i>	0.2	1.0	2.9	0.7	1.1	1.1	1.9	0	1.5	0	1.3	1.1	0.7	1.7	0	0.8
<i>Onosma elwendicum</i>	0.4	1.2	0.2	0	0.4	1.3	2.6	0	0.9	0	1.0	0.4	1.2	1.8	0	0.2
<i>Picris strigosa</i>	2.3	0.4	0.8	0	2.0	2.8	0.1	0	1.0	1.4	2.1	1.6	1.2	0.7	0	0.3
<i>Urospermum picroides</i>	0.1	1.3	1.4	0.6	1.2	1.5	1.0	0	0.8	0	1.7	1.2	0.9	1.2	0	0.7
<i>Roemeria refracta</i>	0.6	5.6	2.4	0.5	0.6	0.4	1.1	0	1.9	0	0.7	1.2	0.6	1.4	1.0	2.8
<i>Silene</i> Sp.	0.1	1.0	2.4	0.5	1.7	1.3	1.7	0	1.4	0	1.0	1.1	0.5	1.0	0	0.9
<i>Sonchus oleraceus</i> L.	0.8	1.0	3.2	0	0.9	1.7	0.8	1.1	0.8	0	2.3	1.4	0.7	0.6	0	0.8
<i>Steptorrhampus persicus</i>	0.8	0.9	3.8	0	1.3	1.8	4.7	3.1	0.8	0	0.9	2.1	1.3	1.0	0	4.6
<i>Ziziphora tenuior</i>	1.0	1.6	3.2	0.1	1.1	1.5	0.3	0	1.8	0	2.9	3.0	1.1	1.2	0	1.5

Table 6 Comparing the highest concentration of elements in the shoots, bioconcentration factors (BCF) of shoots and translocation factors (TF) between plants with the highest elements concentrations, BCF_{shoot} and TF. Yellow color represents the same plants species with highest shoot element concentration, highest BCF_{shoot} , highest TF for a specific element. Pink color represents the same plants species with highest shoot element concentration and highest BCF_{shoot} . Blue color represents the same plants species with highest shoot element concentration and highest TF for a specific element.

Element	Highest shoot element concentration			Highest BCFshoot			Highest TF		
	Element con.	BCF	TF	Element con.	BCF	TF	Element con.	BCF	TF
Al	<i>Acinus graveolens</i>			<i>Acinus graveolens</i>			<i>Acinus graveolens</i>		
	7400	0.126	7.6	7400	0.126	7.6	7400	0.126	7.6
Ba	<i>Onosma elwendicum</i>			<i>Onosma elwendicum</i>			<i>Roemeria refracta</i>		
	1100	2.757	1.2	1100	2.757	1.2	280	1.014	5.6
Ca	<i>Heliotropium europaeum</i>			<i>Medicago rodota</i>			<i>Heliotropium europaeum</i>		
	74100	1.444	3.9	44800	2.440	2.4	74100	1.444	3.9
Cu	<i>Anthemis odontostephana</i>			<i>Anthemis odontostephana</i>			<i>Anthemis odontostephana</i>		
	150	0.852	3.0	150	0.852	3.0	150	0.852	3.0
Fe	<i>Urospermum picroides</i>			<i>Medicago rigidula</i>			<i>Crepis pulchra</i>		
	2220	0.052	1.2	2190	0.061	3.1	1230	0.031	7.2
K	<i>Centaurea iberica</i>			<i>Centaurea iberica</i>			<i>Astragalus Sp.</i>		
	572000	18.571	2.0	572000	18.571	2.0	241000	5.649	2.9
Mg	<i>Heliotropium europaeum</i>			<i>Silene. sp</i>			<i>Heliotropium europaeum</i>		
	95400	18.57	7.1	92200	3.558	1.7	95400	18.57	7.1
Mn	<i>Steptorrhampus persicus</i>			<i>Steptorrhampus persicus</i>			<i>Steptorrhampus persicus</i>		
	310	0.626	3.1	310	0.626	3.1	310	0.626	3.1
Na	<i>Centaureum pulchellum</i>			<i>Roemeria refracta</i>			<i>Centaureum pulchellum</i>		
	7560	0.771	3.8	7510	1.598	1.9	7560	0.771	3.8
Ni	<i>Medicago rigidula</i>			<i>Medicago rigidula</i>			<i>Medicago rigidula</i>		
	70	4.046	1.4	70	4.046	1.4	70	4.046	1.4
P	<i>Geranium rotundifolium</i>			<i>Geranium rotundifolium</i>			<i>Geranium rotundifolium</i>		
	52000	94.374	6.9	52000	94.374	6.9	52000	94.374	6.9
S	<i>Crepis Sancata</i>			<i>Crepis Sancata</i>			<i>Ziziphora tenuior</i>		
	91500	4.361	1.5	91500	4.361	1.5	75700	2.213	3.0
Si	<i>Onosma elwendicum</i>			<i>Onosma elwendicum</i>			<i>Anthemis odontostephana</i>		
	4100	0.273	1.2	4100	0.273	1.2	3590	0.239	1.5
Sr	<i>Onosma elwendicum</i>			<i>Roemeria refracta</i>			<i>Onosma elwendicum</i>		
	140	1.716	1.8	110	1.812	1.4	140	1.716	1.8
Ti	<i>Acinus graveolens</i>			<i>Callipeltis macrostegia</i>			<i>Acinus graveolens</i>		
	80	0.030	1.6	50	1.611	0.2	80	0.030	1.6
Zn	<i>Geranium rotundifolium</i>			<i>Geranium rotundifolium</i>			<i>Geranium rotundifolium</i>		
	2210	33.740	13.8	2210	33.740	13.8	2210	33.740	13.8

Table 7 Comparing the highest concentration of elements in the roots, bioconcentration factors (BCF) of shoots and translocation factors (TF) between plants with the highest elements concentrations and BCF_{root}. Yellow color represents the same plants species with highest roots element concentration and highest BCF_{root} for a specific element.

Elements	Highest roots element concentration			Highest BCFroot		
	Element con.	BCF	TF	Element con.	BCF	TF
Al	<i>Silene</i> Sp.			<i>Silene</i> Sp.		
	13620	0.262	0.1	13620	0.262	0.1
Ba	<i>Onosma elwendicum</i>			<i>Onosma elwendicum</i>		
	940	2.356	1.2	1100	2.356	1.2
Ca	<i>Astragalus</i> Sp.			<i>Astragalus</i> Sp.		
	95000	1.852	0.4	95000	1.852	0.4
Cu	<i>Ziziphora tenuior</i>			<i>Astragalus</i> Sp.		
	1280	0.215	0.1	420	2.386	0
Fe	<i>Callipeltis macrostegia</i>			<i>Acinus graveolens</i>		
	2610	0.065	0.4	2420	0.068	0.4
K	<i>Crepis pulchra</i>			<i>Crepis pulchra</i>		
	535000	17.174	0.9	535000	17.174	0.9
Mg	<i>Anthemis odontostephana</i>			<i>Anthemis odontostephana</i>		
	98000	3.50	0.1	98000	3.50	0.1
Mn	<i>Astragalus</i> Sp.			<i>Steptorrhampus persicus</i>		
	170	0.003	0	100	0.202	3.1
Na	<i>Urospermum picroides</i>			<i>Urospermum picroides</i>		
	9300	1.979	0.8	7510	1.979	1.9
Ni	<i>Medicago rigidula</i>			<i>Medicago rigidula</i>		
	50	2.890	1.40	50	2.890	1.40
P	<i>Silene</i> Sp.			<i>Astragalus</i> Sp.		
	34800	42.029	1.0	26000	47.187	0.8
S	<i>Callipeltis macrostegia</i>			<i>Callipeltis macrostegia</i>		
	76800	3.661	0.9	76800	3.661	0.6
Si	<i>Silene</i> Sp.			<i>Silene</i> Sp.		
	3630	0.349	0.5	3630	0.349	0.5
Sr	<i>Callipeltis macrostegia</i>			<i>Callipeltis macrostegia</i>		
	290	4.209	0.2	290	4.209	0.2
Ti	<i>Crupina crupinastrum</i>			<i>Callipeltis macrostegia</i>		
	70	0.027	0	220	7.088	0.2
Zn	<i>Callipeltis macrostegia</i>			<i>Centaurea iberica</i>		
	19130	37.290	0	2210	197.099	13.8

Figures

Figure 1

Location of the Dehmadan mining area in Chaharmahal and Bakhtiari, Iran.

Figure 2

The frequency of families of wild plants collected from the Dehmadan mining area in Chaharmahal and Bakhtiari, Iran.