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Metal(loid) uptake of *Sonchus oleraceus* grown around Cheshmeh-Konan copper deposit, NW Iran

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Abstract

Heavy metal(loid) contamination in the environment of mining areas has become an important problem. Cheshemeh-Konan is one of the main copper deposits in NW Iran that is currently abandoned. In the present work, the intensity of some metal(loid) pollutions in the soil of the mining area was assessed using three reliable indices. In addition, the potential of *Sonchus oleraceus* L., as the dominant plant grown in the area, in the uptake of some metal(loid)s from the soil was evaluated. The plant and soil samples were collected from the mining area and analyzed by inductively coupled plasma-mass spectrometry (ICP-MS). The results obtained revealed that the soil of the studied mining area was considerably contaminated by As (CF = 3.1), Cr (CF = 3.8), and Ni (CF = 4.07). It was confirmed that *S. oleraceus* had a good ability to accumulate Cd (0.74 mg/kg), Mo (0.67 mg/kg), Sr (285.80 mg/kg), Sn (161.10 mg/kg), and Sc (30.35 mg/kg) when mean concentrations of these metals in the soil were 0.14, 0.12, 161.05, 1.94, and 17.9 mg/kg, respectively. The plant biological absorption coefficient for these 5 elements was more than 1. The correlations between the Mo and Sr contents in the soil and plant were significantly positive. According to the results obtained, the present work provides some geochemical findings about the substrate, and leads to the increasing information about the relationship between the element concentrations in the plants and different soils.

1. Introduction

Rapid industrialization and different anthropogenic activities have led to the enhanced concentrations of different classes of pollutants, especially heavy metals; so these pollutants have become one of the main concerns in many parts of the world [1]. Different physico-chemical remediation processes such as soil replacement, electro-kinetic remediation, soil washing, and encapsulation have been recently used for cleaning heavy metal-contaminated sites [1, 2]. Most of these techniques, however, entail large cost, and impose some other negative environmental impacts. In fact, the cost involved and the environmental acceptability are two key factors that should be considered in the selection and application of remediation technologies [1, 3]. Biological approaches such as phytoremediation present a relatively low cost, serving as an eco-friendly and sustainable strategy for the remediation of the polluted environments [4-6]. Since the persistence of heavy metals in the soil is more than any other components of biosphere, plants are the primary recipients of such environmental pollutants [7]. Phytoextraction is one of the main strategies of phytoremediation; plants take up the contaminants such as heavy metals and accumulate them at extremely elevated levels in the shoots. Identification of the tolerant plant species that can accumulate a high level of elements in their above-ground parts and their application for the remediation of heavy metal contaminated soils can be useful in the effective

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treatment of an environment. Meanwhile, shoot metal concentration and shoot biomass could be regarded as two important factors that should be noted regarding such suitable remediator plants [8-11]. The potential of some plant species for accumulating a high level of heavy metal(loid)s in their above ground parts has been confirmed in some previous studies. For instance, the high ability of *Dactylis glomerata* [12], *Polypogon fugax* [13], *Viola principis* [14], and *Salvia minima* [15] in accumulating As, Cu, Cd, and Ni has been reported. The accumulator plants can not only be used for the bio-remediation of the polluted environments but also some of them have been identified as a useful indicator of metal mineralization, thereby, contributing to the mineral exploration [6, 13, 16].

Iran is one of the most mineral-rich countries, and has much metal-contaminated soil, especially in mining areas; this country faces many difficulties in the management of mine tailing [12]. Although there are numerous natural metal-contaminated soils in Iran's different mining areas, there is little information available regarding the concentration of different elements in the native plants grown in the areas; also not much is known about the relationship between the element concentrations in the plants and different soils [13, 17].

The Cheshmeh-Konan copper deposit and two other main copper deposits are three main sediment-hosted stratiform copper (SSC) deposits that are known from the Miocene Upper Red Formation (URF) in NW Iran. Copper grades range from 2% to 4%, and silver has been recovered as a by-product, with a grade of 80–100 g/t [18]. According to the literature, there is almost no information about the assessment of bio-accumulation potential of the plants grown in the mining area. *Sonchus oleraceus* L. from the Asteraceae family is a dominant plant species in the mining area. It was selected for the determination of the relationship between the element concentrations in the soil of the mining area and in the plant. Therefore, investigation of the metal pollution intensity in the Cheshmeh-Konan copper deposit and determination of the plant potential for the absorption and remediation of some metal(loid)s were the two main objectives of the present work. Moreover, calculation of the biological absorption coefficient (BAC) as an indicator of element absorptions by the plant and determination of correlation between the metal(loid) contents in the soil and the plant were the other objectives of the present work. With such information, it is possible to suggest the plant suitability for use in the remediation of metal(loid)-contaminated lands.

2. Material and method

2.1. Studied area

The Cheshmeh-Konan copper mine is located ~15 km of NW Tasuj, East Azerbaijan Province, NW Iran (45º 24' E and 38º 34' N). This area is located near the boundary between the Alborz Block and the Tabriz-Khoy Basin, which is outlined by the regional-scale Tasuj and Tabriz Faults [18]. Numerous gray sandstone layers with the indications of Cu mineralization are exposed in the area. Figure 1 shows the location map of the studied area.

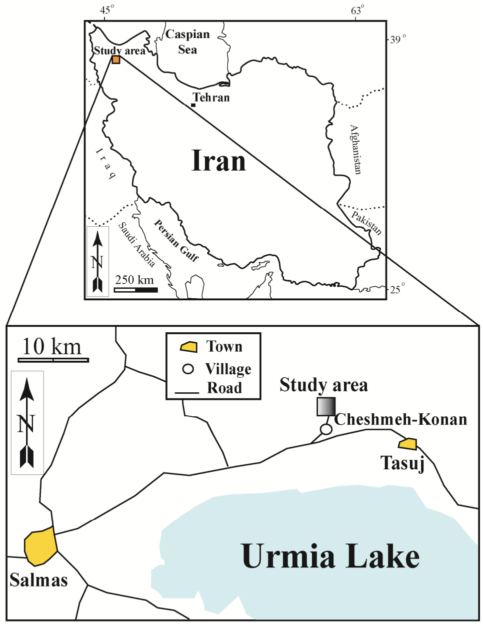

Figure 1. Location map of the studied area.

2.2. Soil and plant sampling, preparation, and characterization

During spring 2017, the soils and aerial parts (shoot) of *Sonchus oleraceus* (Figure 2) (at 10 studied sites) were collected form the Cheshmeh-Konan mining area.

The soil samples were collected randomly from the 30-40 cm depth around the rhizosphere of the sampled plants. They were kept in labeled sampling bags and transported to the laboratory. For the preparation of the samples, they were air-dried at room temperature, oven-dried at 100 ºC for 3 h. and then ground and passed through a 2-mm sieve. These prepared soil samples were used for the determination of soil physico-chemical properties such as pH, electrical conductivity (EC) (µs/ms), soil organic matter (SOM, %), and salinity (g/L).

Determination of pH, EC, and salinity was done using a pH-meter (Hanna instrument Inc., Romania), an EC-meter (Carison, Spain), and a refractometer (MT-110, Taiwan), respectively.
The soil organic matters were determined by the loss-on-ignition (LOI) procedure [19, 20]. Briefly, 5 g of the soil samples was heated at 105 ºC for 2 h, and the weight was determined. Consequently, they were kept in a furnace at 375 ºC for 17 h and then weighed again. Eq. 1 was used for the determination of SOM.

$$SOM\ (g/kg) = (W_{105\,°C} - W_{375\,°C} / W_{105\,°C}) \times 1000 \qquad (1)$$

To determine the elemental content, the soil samples were digested by a $HCl\text{-}HNO_3\text{-}H_2O$ mixture at 95 ºC for 1 h. The digests were analyzed using HP Agilent 4500 ICP/MS (USA) at Zarazma Co., Iran.
The plant shoot samples were first washed with tap water and subsequently with distilled water; then they were dried at the ambient temperature for several days. The air-dried plant samples were digested in HNO_3 for 1 h; then they were kept in the $HCl\text{-}HNO_3\text{-}H_2O$ mixture for 1 h at 95 ºC and analyzed by ICP-MS.

Figure 2. *Sonchus oleracе*us from Cheshmeh-Konan copper mining area.

2.3. Biological absorption coefficient

The biological absorption coefficient (BAC) was calculated for the determination of the absorption intensity of the plants from their substrates using Eq. (2) [21]:

$$BAC = C_p / C_s \qquad (2)$$

where C_p is the concentration of an element in the plant and C_s is the concentration of the same element in the soil samples.

2.4. Assessment of soil contamination

In the present work, three different indices were used to assess the degree of some metal(loid) contaminations in the soil of the Cheshmeh-Konan copper deposit.
The first index, enrichment factor (EF), is usually used to assess the source (anthropogenic or geogenic) of metal contaminations in the soils, and it is calculated based on the normalization of one metal content in the sample with respect to the reference element concentration [22]. A reference element is an element with a particularly stable amount in diffident soils. In the present work, Fe was used as a reference element (RE) for determination of EF, as represented in Eq. (3):

$$EF = (C_{metal} / C_{RE}) \text{ in sample} / (C_{metal} / C_{RE}) \text{ in the earth crust} \qquad (3)$$

The values reported by Taylor as the average crustal abundance of the metals were used for the determination of metal concentration and the amount of RE in the earth crust [23]. When EF < 1, there is no enrichment of the metals; there is a minor enrichment when EF is 1 to 3; EF = 3 to 5 confirms the moderate enrichments, and EF = 5 to 10 shows a moderately severe enrichment. Also EF 10 to 25 shows a severe enrichment, and EF 25-50 represents a very severe enrichment, and finally, EF > 50 confirms the extremely severe enrichment [20].
As with the previous index, the contamination factor (CF) can be used for determination of the level of metal enrichment in the soils. This factor refers to the amount of metal in the sample as compared with the background concentration levels; it can be calculated using Eq. (4) [24, 25].

$$CF = C_s / C_{background} \qquad (4)$$

The Taylor's average crustal abundance values of the metal were used as $C_{background}$ for each metal [23]. When CF was lesser than 1, there was no metal contamination in the sediments; CF < 3 confirmed a moderate contamination; in CF < 6,

there was a considerable contamination; and CF > 6 indicated a very high contamination for that metal [25].
The geo-accumulation index has been described by Muller [26] and used for the determination of metal pollution in the studied soils. The indices were calculated using the following equation:

$$I_{geo} = log_2[(Cn/(1.5 \times Bn)] \quad (5)$$

where Cn is the measured metal in the soil, Bn refers to the average crustal abundance values for that metal, and 1.5 is a coefficient for the normalization of the background metal concentration. According to the classification described by Muller [26], when $I_{geo} < 0$, the soil is uncontaminated with that metal; I_{geo} between 0-1 refers to uncontaminated to moderately contaminated. When it ranges from 1 to 2, it shows a moderately polluted state; also 3-4 = strongly polluted. Finally, I_{geo} between 4 and 5 shows strongly to extremely contaminated, and finally, $I_{geo} > 5$ = extremely contaminated.

2.5. Statistical analysis

In order to identify any relationship between each metal in the plant samples and their related soils, the Pearson correlation analysis was carried out using the IBM SPSS (version 24) statistical software.

3. Results and discussion

3.1. Soil physico-chemical parameters and pollution indices

Table 1 shows the sampling locations and some physico-chemical parameters of the soil samples in the mining area. The soil parameters such as pH, EC, SOM, and also some biological factors such as plant root exudates and plant species are the main factors that can affect the bio-availability of the elements [7, 27]. According to the results obtained, the soil pH values in 10 sampling sites were in the range of 8.2-8.5 (Table 1). EC was used for determination of the soluble salt concentrations in soil, commonly serving as a measure of salinity. A soil with an EC below 400 µS/cm is considered non-saline, while soils above 800 µS/cm are taken as severely saline [28]. In the present work, EC ranged from 40.7 to 95.5 µS/cm, and therefore, soils of all the sampling sites were found to be non-saline.
In addition, the soil organic matter (SOM) content of the samples was in the range of 0.75-1.86(%). The minimum SOM content was observed in the soil of the second sampling site, and the soil of the 8th sampling site had the maximum amount of SOM (Table 1).
Figure 3 shows the three studied pollution indices EF, CF, and I_{geo} in the 10 sampling sites of the mining area. According to the Muller's classification, most metals show a minor enrichment in the soils (Sn, Sc, Pb, Co, Fe, Mn, Zn, and V). As, Cr, and Ni were moderately enriched, and there was no enrichment for Cd, Mo, Sn, and Al. An intensive usage of phosphate fertilizers containing high amounts of some metal(loid)s such as As could also be one of the main reasons of such an EF amount [29].
CF is another pollution index used to assess the contamination level directly by the individual element content in the soil of a particular site [30]. According to the results obtained, the mean CF values were in the order of Ni (4.06) > As (3.15) > Cr (3.10) > Zn (1.40) > Co (1.24) > Sn (0.97) > Mn (0.91) > Fe, Sc, Pb, V (0.80) > Al (0.77) > Cd (0.70) > Sr (0.42) > Mo (0.08) (Figure 3). Based on the Hakanson categorization [24], As, Cr, and Ni had a considerable contamination in the soil samples ($3 \le CF < 6$), Co and Zn had a moderate contamination, and the other studied metals had no contamination in the soil samples. Moreover, the geo-accumulation index indicated that the soil samples were moderately contaminated by As (I_{geo} = 1.03), Cr (I_{geo} = 0.99), and Ni (I_{geo} = 1.43) (Figure 3).

Table 1. Physico-chemical parameters of soil samples in the studied area.

Sampling site	Longitude	Latitude	pH	EC (µS/cm)	SOM (%)
1	45º13' 00"	38º20' 29"	8.5	66	1.04
2	45º 13' 00"	38º 20' 28"	8.2	95.5	0.75
3	45º 12' 57"	38º 20' 23"	8.4	50.6	1.11
4	45º 12' 58"	38º 20' 24"	8.4	40.7	1.22
5	45º 12' 54"	38º 20' 18"	8.3	80.5	0.91
6	45º 12' 52"	38º 20' 17"	8.4	46.5	0.8
7	45º 12' 52"	38º 20' 17"	8.3	65.1	1.1
8	45º 12' 44"	38º 20' 16"	8.4	46.3	1.86
9	45º 12' 40"	38º 20' 15"	8.3	69.2	0.93
10	45º 12' 38"	38º 20' 16"	8.4	48.6	1.05

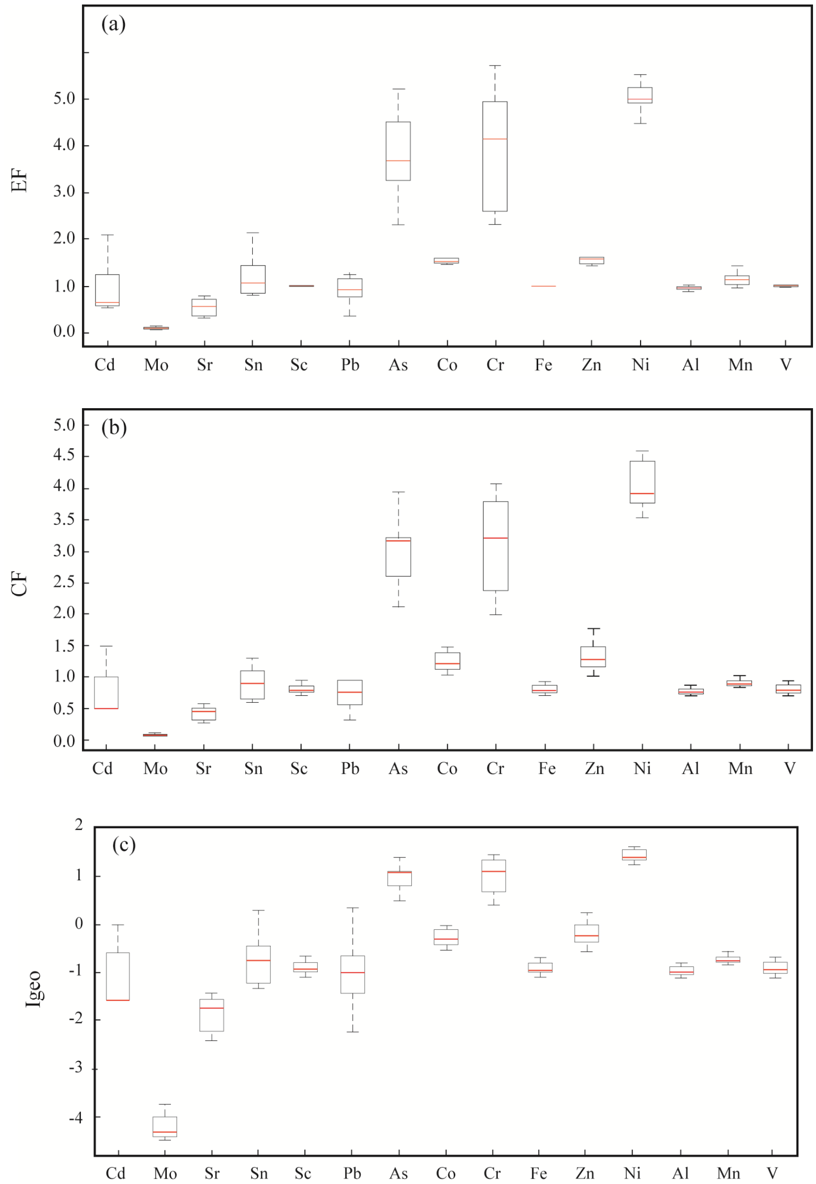

Figure 3. The studied pollution indices for metal(loid)s in soil samples: a) EF, b) CF, and c) I_{geo}.

3.2. Metal(loid) distribution in soil and their uptake by *S. oleraceus*

According to the results obtained, 5 elements (out of the 15 studied ones) were accumulated in the shoots of *S. oleraceus*. In fact, the amounts of Cd, Mo, Sr, Sn, and Sc in the plant shoots were more than their background contents (Figure 4).

Cd is considered as one of the important eco-toxic metals with negative effects on all biological processes in different organisms. Different parameters such as soil texture, pH, and SOM are important factors governing the metal content of soils. The amount of Cd in the Earth's crust is, on average, 0.1 mg/kg. Meanwhile, its overall mean value in the world soils has been estimated to be 0.41 mg/kg [31]. According to the pollution indices obtained in the Cheshmeh-Konan soils, the soil of sampling areas was uncontaminated by Cd, and its mean amount in the soil samples was 0.14 mg/kg. It has been reported that in the uncontaminated soils, the Cd contents range from 0.01 to 0.3 mg kg^{-1} [31], and therefore, the obtained content was in agreement with such a reported range. In contrast, the elemental mean content of Cd in the plant shoots was determined to be about 0.74 mg/kg. It means that the Cd contents in the plant shoots were more than their background content in all the 10 sampling sites (Figure 4a), and its mean amount in the plant shoots was 5.3-folds more than that amount for soil. The findings, therefore, showed that *S. oleraceus* had a good potential in the uptake and accumulation of Cd from soil.

The Mo average content of the Earth's crust has been reported to be 1.5 mg/kg; meanwhile, the world average amount of Mo in the soils has been established to be 1.1 mg/kg. Various factors such as drought, soil pH, and texture, and also plant species can affect the Mo phyto-availability [32]. The Mo content in the soil samples of the Cheshmeh-Konan copper mine (0.12 mg/kg) was about 10 times less than its reported mean value for the world soils. Meanwhile, its amount in all the 10 plant shoot samples (0.31-1.4 mg/kg) was more than that of the soil samples (0.10-0.17 mg/kg) (Figure 4b). The element is one of the essential micronutrients in the plants that plays an important role in the nitrogen metabolism, biosynthesis of plant hormones, metabolism of sulfur, and plant protein synthesis [33]. It seems that the plant attempted as much as possible to uptake Mo from the soil, insofar as the mean amount of Mo in the plant shoots was 5.5-folds more than that of the soil samples. Moreover, it has been reported that there is a positive correlation between the Mo concentration in the soil solution and soil pH, and thus Mo uptake by plants from alkaline soils occurred easily [34]. It was confirmed that the soil samples in the Cheshmeh-Konan copper mine had pH > 8 (Table 1); accordingly, the plant could uptake more Mo from its background.

Another element that possesses a high amount in the plant shoot, as compared to its background, was strontium. Its content in the earth crust as a relatively common element ranges from 260 to 370 mg/kg. Moreover, its average amount in worldwide soils is 130-240 mg/kg, and also the mean content of Sr in all soil samples of the Cheshmeh-Konan copper mining area was in that range (161 mg/kg). It has been reported that the Sr content in minerals is highly controlled by Ca, and the Ca to Sr ratio refers to the abundance of Sr and its bio-geochemical properties. A Ca to Sr ratio less than 8 indicates the possible toxicity of Sr [31]. The ratio for all of the sampling sites in the present work was more than 300, confirming that there was no Sr contamination in the soil samples. This finding was verified by the results of pollution indices for Sr, with its EF, CF, and I_{geo} being 0.55, 0.43, and -1.84, respectively. Except 2 plant samples, the Sr amount in all sampled plant shoots was more than their background, and the plant showed a good performance for its uptake (Figure 4c). According to the literature, in the calcareous soils and in the soils with a high pH, Sr can be concentrated in the soil upper horizons [31]. Probably, the plant acidified the rhizosphere by its exudates, and increased the Sr availability, and consequently, its uptake. The Sr content in the plants was variable, and its highest amount was reported for the vegetable leaves (45-74 mg/kg). For instance, the Sr content in lettuce leaves, as a member of the Asteraceae family, was 74 mg/kg [31]. Meanwhile, the mean amount of Sr in the shoot samples of *S. oleraceus* was about 286 mg/kg, and hence, it was 4 times more than the reported amount.

The abundance of tin (Sn) in the earth crust and in the soils is estimated to be 2.5 mg/kg. This is despite the fact that the occurrence of Sn in soils has not received much attention [35]. The Sn mean amount in our soil samples was 1.94 ± 0.8 mg/kg. Meanwhile, the average amount of Sn in 10 plant shoot samples was about 161 mg/kg (Figure 4d), and in some sampling sites (for example, the 2nd sampling site), the ratio of the Sn content in the plant shoot to its soil was more than 300. There is no evidence showing that Sn is essential for plants, and it is considered as toxic to the higher plants but the very high amount of Sn in the shoots of *S. oleraceus* and its high ability for the tin uptake can be important, showing the plant high potential in the Sn uptake from the soil, especially when it has been reported that the common range of Sn in the plants is just about 20-30 mg/kg [31]

The average amount of scandium in the soil samples of Cheshmeh-Konan copper mine was about 18 mg/kg. Meanwhile, the crustal and worldwide soil average content for Sc has been estimated to be 11 and 0.8-28 mg/kg, respectively. Although there is not much information about the Sc distribution in plants, the previously reported amounts of Sc in different plant species have been lower than 0.02 mg/kg [31]. On the other hand, the Sc content in our plant samples was high and its mean amount for the 10 sampling sites was 30.35 mg/kg. From 10 plant shoot samples, seven ones possessed a high amount of Sc in comparison to their background soils (Figure 4e).

The contents of the other 10 studied elements including Pb, As, Cr, Co, Ni, Fe, Zn, Mn, Al, and V in the plant shoots were less than their amount in the background soils, and the plant exhibited some degrees of avoidance and exclusion in the uptake of these elements from the soil.

Based on the results of pollution indices, the amounts of As, Cr, and Ni in the soils of the Cheshmeh-Konan mining area were high, and, for instance, their CF for these three elements was 3 < CF < 6 (considerable contamination); however, the amounts of these elements in the plant shoot samples were low (Figure 5).

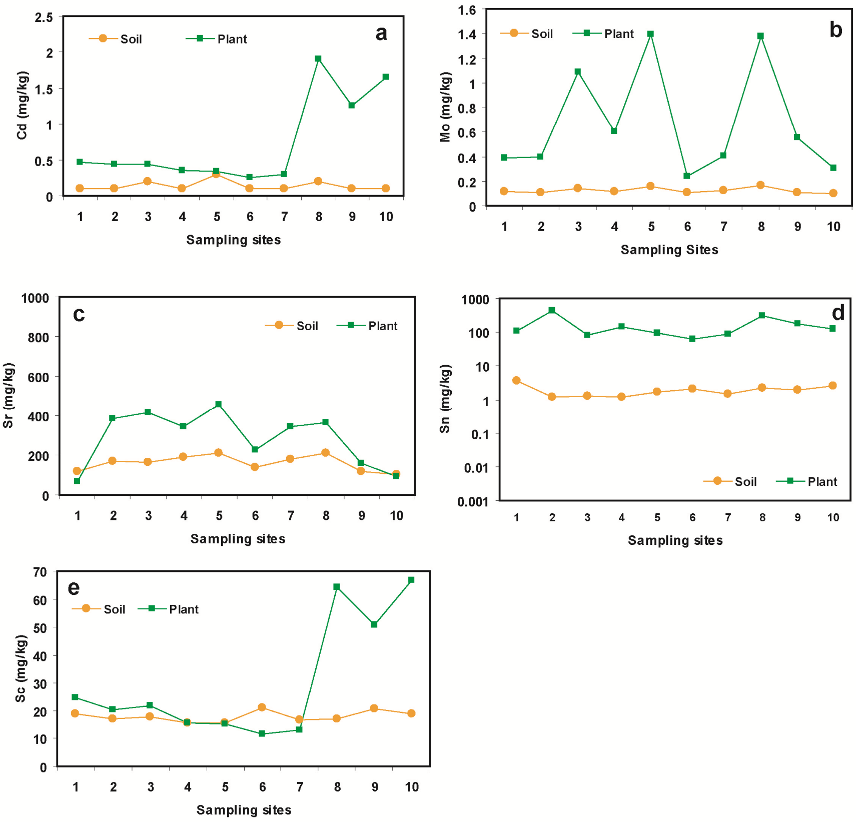

Figure 4. The a) Cd, b) Mo, c) Sr, d) Sn, and e) Sc concentrations in the plant shoot samples along the studied profile.

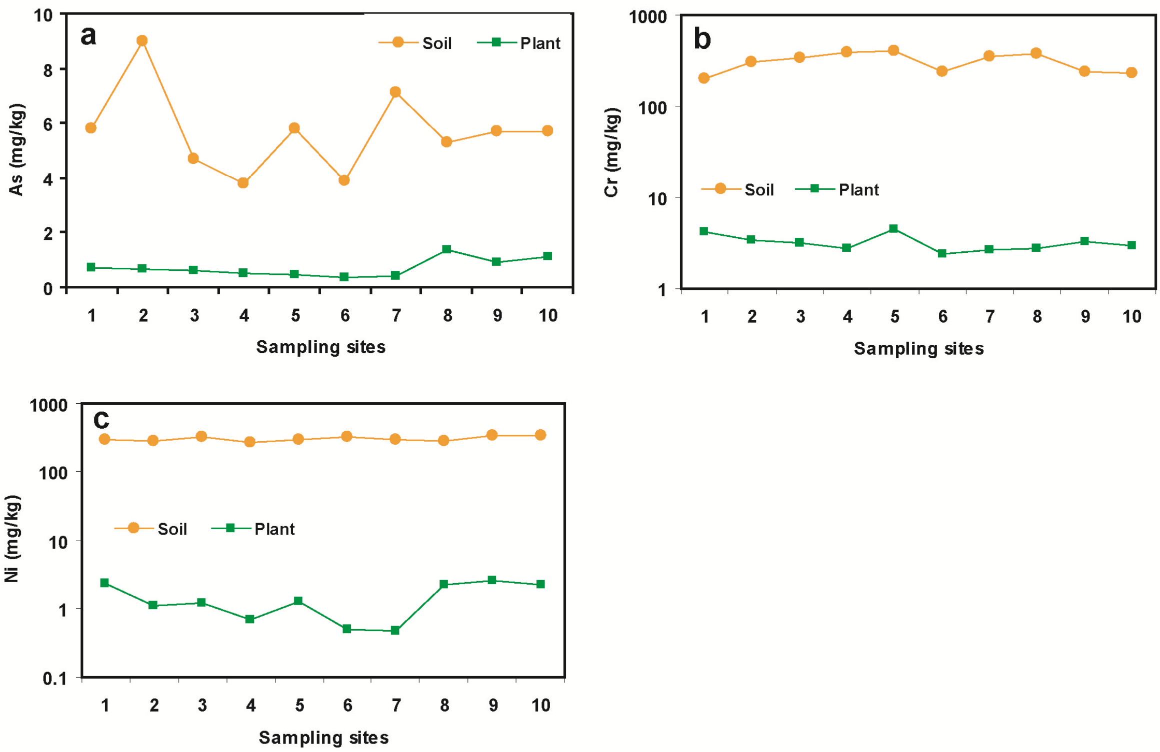

Figure 5. The a) As, b) Cr, and c) Ni concentrations in the plant shoot samples along the studied profile.

Arsenic is a highly toxic metalloid that is the 20th most abundant element in the Earth's crust, with an average concentration of approximately 3 mg/kg [36]. The As existence in food chain and in drinking water is one of the main environmental problems, and identification of the plant species with a high capability in the uptake and accumulation of As can be useful in the reduction of its concentration in the environment [37]. *Pteris vitatta* was the first discovered As hyper-accumulator plant, and after that, around 12 other plant species, all belonging to the Pteridaceae family of ferns, were identified as As hyper-accumulators. As concentrations in the above ground part of the plants growing in the uncontaminated soils are typically in the range of 0.5-80 µg/kg [36]. Although its mean content in our plant samples was slightly high (700 µg/kg), considering the mentioned range and the amount of As in our soil samples (mean, 5.68 mg/kg) as compared to the worldwide soils (3 mg/kg), nevertheless *S. oleraceus* was determined as an excluder plant for As (Figure 5a).

Due to the chromium significance as an essential micronutrient for the humans and its carcinogenic effects in high concentrations, the Cr content in the plants and their ability in Cr, the uptake from the soils has recently received much attention [31]. Cr is the seventh most abundant element in the earth's crust (100 mg/kg), and its average content in the world soils has been established to be 60 mg/kg; however, it is slightly available to plants and not easily translocated within them. The Cr mean content in the soil of the Cheshmeh-Konan copper mining area was about 308 mg/kg, and despite its considerable contamination in the soil, the Cr mean amount in the plant shoot was 3.2 mg/kg (Figure 5b). It has been reported that the Cr concentration in the shoots of the Indian mustard and the fodder radish growing in Cr-polluted soils (247 mg/kg) does not exceed 10 mg/kg [38]. Moreover, the amount of Cr in *Lectuca sativa* (another plant species from Asteraceae) has been reported to be near 0.05 mg/kg. It has been confirmed that the capability of the plant to convert Cr^{3+} to easily available Cr^{6+} is the key process in the Cr phyto-availability and absorption. The conversion is a very slow process at a pH level above 5 [39]. Since the pH of the Cheshmeh-Konan copper mine was about 8.3, the Cr^{6+} abundance was low, and less amounts of Cr could be uptaken by the plant root. Following the Cr entry through the roots and transport by translocation to the shoots occurs very slowly. These could be the main reasons of the less amount of Cr in that plant shoot [40].

Naturally occurring concentrations of Ni in the soils are lower than 100 mg/kg and its mean concentrations, as reported for various countries, are within the range of 13-37 mg/kg [41]. Moreover, Ni crustal abundance has been estimated to be around 20 mg/kg. The Ni mean content of the Cheshmeh-Konan soil was obtained to be about 305 mg/kg but its mean amount in the plant shoot samples was determined to be around 1.4 mg/kg (Figure 5c). Different environmental and biological factors can affect the Ni content in the plants. The overall uptake of Ni by the plants depends on different environmental and biological factors such as the concentration of Ni^{2+}, plant metabolism, pH, and the presence of other metals and organic matter composition. According to the literature, the Ni uptake is usually declined at high pH values; in such pH values, most Ni exists as insoluble hydroxides [41]. Therefore, a high pH of the soil could be one of the important factors in the reduction of Ni uptake by the plants.

The crustal average contents of Co and Zn have been estimated to be about 25 and 70 mg/kg, respectively. The mean amounts obtained for these two elements in the Cheshmeh-Konan copper deposit were 31 and 98 mg/kg, respectively. Moreover, the CF amount for Co and Zn was 1.2 and 1.4, respectively, and the soil of the studied area was moderately contaminated for Co and Zn according to the CF index. However, *S. oleraceus* showed a weak performance in the uptake and translocation of these two metals from the soil. The mean amounts of Co and Zn in the plant shoot samples were 0.7 and 26.2 mg/kg, respectively (Figures 6a and 6b). According to the previous reports, the Co mean content in the food plants such as legumes from various countries ranges from 0.1 to 0.6 mg/kg [31]. Moreover, although Zn plays essential metabolic roles in the plants, its concentration does not differ widely; in most cases, it is under 50 mg/kg [31], which is in agreement with the mean amount for the Zn content obtained in the *S. oleraceus* shoot (26.2 mg/kg).

Figures 7(a-e) illustrate other examined trace element contents in the soil samples and the plant shoots at 10 different sampling sites. As shown in Figure 6, the amount of other studied 5 elements (Pb, Fe, Al, Mn, and V) in the plant shoot samples was less than their backgrounds. On the other hand, according to the pollution indices obtained for these 5 metals, the soil of the Cheshmeh-Konan copper mine was unpolluted.

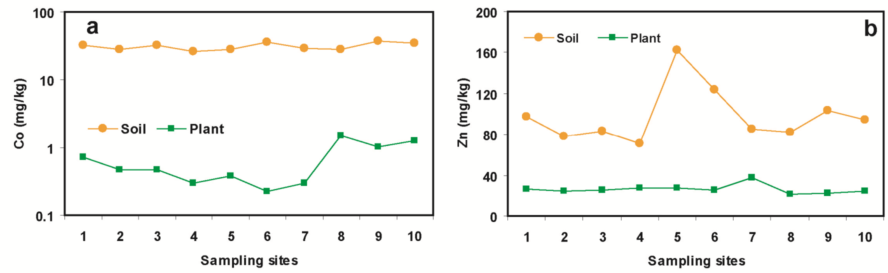

Figure 6. a) Co and b) Zn concentrations in the plant shoot samples along the studied profile.

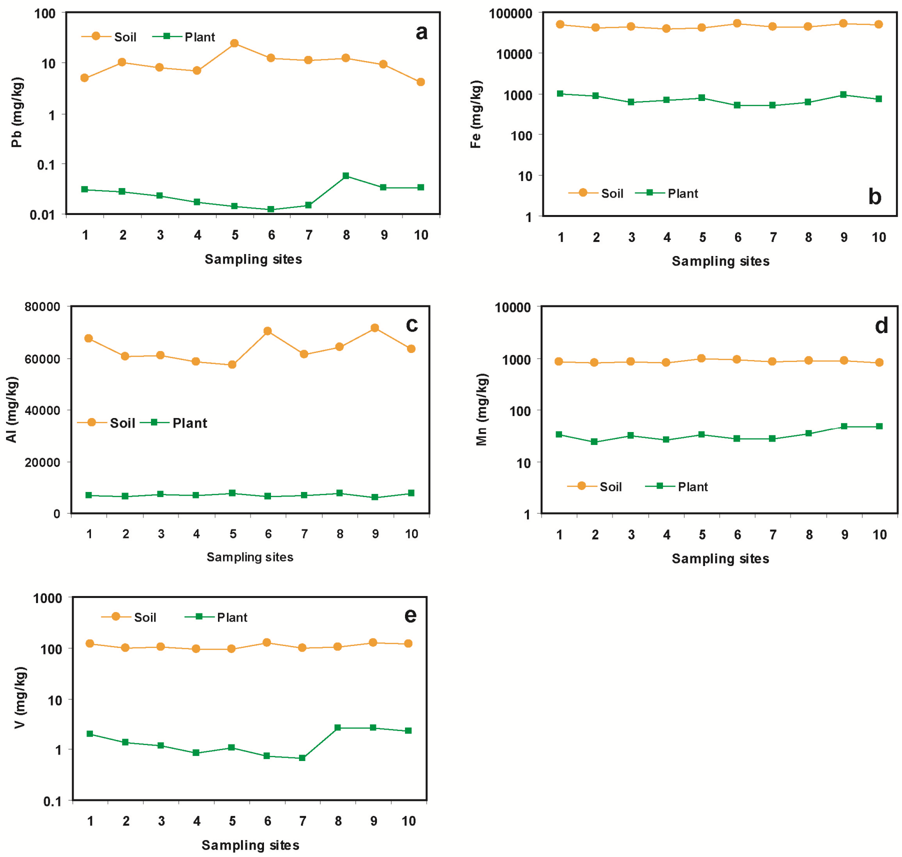

Figure 7. The a) Pb, b) Fe, c) Al, d) Mn, and e) V concentrations in the plant shoot samples along the studied profile.

3.3. Biological absorption potential

The biological absorption coefficient (BAC) could be used to compare different plant potentials in the absorption of the elements; it also reflects the relationship between the concentration of the chemical elements in the soil and in the plant [42]. According to the quantity of BAC, the bio-accumulation amount of each element by the plants was classified into five groups: BAC > 10, very strong accumulation; from 1 to 10: strong accumulation; from 0.1 to 1.0: moderate absorption; from 0.01 to 0.1: weak absorption; and from 0.001 to 0.01: very weak absorption [43].

As it can be seen in Figure 8, the average amount of BAC for Cd, Mo, Sr, Sn, and Sc was more than 1. In fact, these elements could be strongly accumulated in the studied plant. The potential of *S. oleraceus* in the biological absorption of the mentioned elements was 5.99, 5.1, 1.7, 99.2, and 1.7, respectively. In contrast, BACs of other 10 elements were in the range of 0.003-0.28 (Figure 8). Meanwhile, the soil of the Cheshmeh-Konan copper mining area was considerably to moderately contaminated by As, Cr, Ni, Co, and Zn; however, the plants avoided their uptake. Different potentials of the plants in the absorbance of the elements could be due to different reasons such as the abundance of the elements in the soil, pH and soil organic matter, bio-availability of the elements, plant age, and depth of the root system [8, 44].

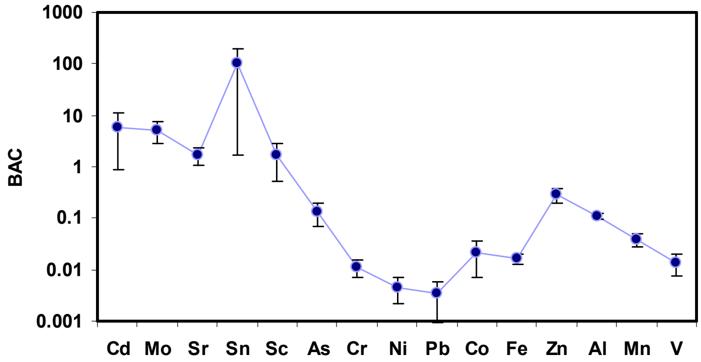

Figure 8. Comparing BAC mean values of the studied metal(loid)s for *S. oleraceus* in the studied area.

3.4. Correlation between metals in soil and plant samples

Table 2 shows the correlation between the metal contents in the soils and plant samples. Accordingly, the correlation between the soil and plant for some studied metal(loid)s such as Mo, Sr, Sc, Co, Fe, Ni, and V was positive, and these relations were significantly positive for Mo and Sr. The correlation pattern also indicated that the concentrations of Mo and Sr in the plant were associated with their concentrations in the soil. Plants can use two different strategies in response to the elevated concentrations of elements: exclusion and accumulation. In fact, the plants can restrict the transportation of the elements to their shoots (excluder plants) or accumulate a high level of elements in their above-ground parts (accumulator plants). If the element concentration in the plant reflects its concentration in the soil, the plant is an "indicator" [10, 45], and there was a linear relationship (positive correlation) between concentration of the elements in the indicator plants and soil. According to the results obtained, *S. oleraceus* can be used as a useful indicator of Mo and Sr mineralization. It was in accordance with the results of some other previous studies confirming the existence of a positive correlation between the metals in the soils and plants [46, 47]. There were negative correlations between Sn, Pb, Zn, Al, and Mn in soils and the plant (Table 2).

Table 2. Pearson correlation coefficient between metal contents in soils and plant samples.

Metal(loid)s in soil and plant samples	Correlation coefficient value (r)
Cd	0.014
Mo	0.967 (**)
Sr	0.894(**)
Sn	-0.228
Sc	0.260
As	0.056
Cr	0.023
Ni	0.304
Pb	-0.269
Co	0.282
Fe	0.167
Zn	-0.031
Al	-0.471
Mn	-0.105
V	0.428

(**) **Correlation is significant at the 0.01 level (2-tailed).**

4. Conclusions

In the present work, the three pollution indices EF, CF, and I_{geo} were evaluated for the assessment of the metal(loid) pollution in the Cheshmeh-Konan copper mining area. The studied metal(loid)s were Cd, Mo, Sr, Sn, Sb, Pb, As, Co, Cr, Fe, Zn, Ni, Al, Mn, and V. The results obtained revealed that the concentrations of As, Co, Cr, Zn, and Ni in the 10 soil sampling sites were higher than their mean crust concentrations. According to the pollution indices, the soil of the studied mining area was considerably to moderately contaminated by those 5 mentioned metal(loides). Moreover, the bio-accumulation potentials of *S. oleraceus* for the uptake of the studied elements from the soil of mining area were probed. According to the results obtained, regarding the accumulation of the elements in the soil samples and the shoot samples of the plant, among the 15 studied elements *S. oleraceus* possessed a high ability in the uptake of Cd, Mo, Sr, Sn, and Sc. BAC of the plant for these 5 elements was more than 1, and these elements could be accumulated in the studied plant. Correlations between the metals in soil and plant samples were determined, and it was confirmed that there was a linear relationship (significant positive correlation) between the Mo and Sr concentrations in the soil and the plant. Therefore, *S. oleraceus* can be used as useful indicator of Mo and Sr mineralization and have good potential in uptake and accumulation of some elements such as Cd and Sn.

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جذب فلزات توسط شیر تیغک (Sonchus oleraceus) رشد یافته در کانسار مس چشمه کنان، شمال غرب ایران

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چکیده:

آلودگی فلزات سنگین در محیط مناطق معدنی به یک مشکل مهم بدل شده است. چشمه کنان یکی از مهم‌ترین کانسارهای مس شمال غرب ایران است که در حال حاضر متروکه است. در پژوهش حاضر، شدت آلودگی برخی فلزات در خاک منطقه معدنی با کاربرد سه شاخص آلودگی معتبر تعیین شد. همچنین توانایی گیاه شیرتیغک (Sonchus oleraceus) به عنوان گیاه غالب رشد یافته در منطقه مورد مطالعه در جذب برخی فلزات از خاک ارزیابی شد. نمونه‌های گیاهی و خاک از منطقه معدنی جمع‌آوری و توسط طیف‌سنجی جرمی پلاسمای جفت شده القائی (ICP-MS) مورد آنالیز واقع شدند. نتایج به دست آمده نشان داد که خاک منطقه مورد مطالعه به طور قابل‌توجهی به As (CF=3.1)، Cr (CF=3.8) و Ni (CF=4.07) آلوده است. معلوم شد که گیاه شیر تیغک توانایی خوبی در انباشت Cd (۰/۷۴)، Mo (۰/۶۷)، Sr (۲۸۵/۸۰)، Sn (۱۶۱/۱۰) و Sc (۳۵/۳۰) (میلی‌گرم بر کیلوگرم گیاه) دارد، در حالی که غلظت متوسط این عناصر در نمونه‌های خاک به ترتیب به میزان ۰/۱۴، ۰/۱۲، ۱۶۱/۰۵، ۱/۹۴ و ۱۷/۹ میلی‌گرم بر کیلوگرم خاک بوده است. ضریب جذب زیست‌شناختی گیاه برای این پنج عنصر مذکور بیشتر از یک به دست آمد. همبستگی بین مقدار Mo و Sr در گیاه و خاک به طور معنی‌داری مثبت تعیین شد. مطابق با نتایج به دست آمده پژوهش حاضر، برخی یافته‌های بیوژئوشیمیایی را در مورد بستر به دست می‌دهد و به افزایش اطلاعات در مورد ارتباط بین غلظت عناصر در گیاهان و خاک‌های مختلف منجر می‌شود.

کلمات کلیدی: کانسار مس چشمه کنان، زیست انباشت فلز، شاخص‌های آلودگی، شیر تیغک (Sonchus oleraceus).