DESERT

Desert
Online at http://desert.ut.ac.ir

Desert 25-1 (2020) 101-108

The effect of bauxite mining on soil and dominant plant pollution in arid rangelands of Taft in Yazd Province

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Received: 18 February 2019; Received in revised form: 18 May 2019; Accepted: 1 July 2019

Abstract

Environmental contaminations resulting from mining operations play an important role in the collapse of ecosystems balance. In order to measure vegetation characteristics and to study soil and plant contamination in rangelands surrounding bauxite mine, a systematic random sampling was done according to physiognomy and homogeneity of vegetation cover. Sampling was performed using a 50-meter transect in three areas including near the mine (0-200 m), medium distance from the mine (200 to 500 m) and long distance from the mine (500 to 1000 m). Soil sampling sites were systematically selected from the middle of transects. In each region, three samples of the aerial parts and leaveswere randomly taken from *Zygophyllum eurypterum* plant with three replications. Then the concentration of heavy metals in soil and plant samples was evaluated using X-ray Fluorescence Spectroscopy, S4-Explorer model. The results showed that the highest and lowest metals concentrations in all soil and plant samples were obtained at a distance of 200 and 1500 meters from the mine, respectively. The overall evaluation results based on the integrated pollution index and mean of pollution degree showed that the pollution potential of the study area is low to moderate. The findings also indicated that the soil surrounding the mine is contaminated with aluminum, titanium, antimony and iodine.

Keywords: Mining; Arid Rangelands; Heavy Elements; *Zygophyllum eurypterum*; Pollution

1. Introduction

The mineral waste and wastewater generated by mineral activities have made mining one of the most important sources of metal contamination in the environment (Chen *et al*., 2007); therefore, high concentrations of metals can often be found in soil surface and plants grown in areas affected by mining activities (Liu *et al*., 2006). Soil is the main source of plants mineral nutrition. Plants are regarded as the first organisms that respond to the changes insoil conditions, hence excellent biomarkers for determining adverse soil changes such as heavy metal accumulation (Pareja-Carrera *et al*., 2014). Some plant populations are resistant against heavy metals and can grow in contaminated soils; their dominant strategy is to prevent metal absorptionand restrict its transfer while some species may become distinct or scarce in pastures surrounding mines over time. Density and diversity of vegetation cover in soils contaminated with heavy metals are usually less than non-contaminated surrounding regions (Schultz and Hutchinson, 1991). Mining has many environmental impacts,causing a great deal ofdamage to plant canopy covers. Inappropriate exploitation or management reducesplant and animal habitats, leading toquick erosion in mining areas. Uncovered and unprotected soil may result in increased soil erosion, climate changes, and dust storms; under these conditions, the need for water purification seems necessary (Vaghar *et al.*, 2002). Aluminum is one of the most abundant and important metals. Bauxite is the only viable source for the production of aluminum oxide and Fe_2O_3 and TiO_2 being the

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most important its impurities (Madanie, 1999). Pollutants are considered as ecosystem disruptors and important metal pollutants, likeheavy metals, due to their physiological effects on living organisms at low concentrations (Zhang, 1997).The concentration of heavy metals may exceed the 106 times permissible limitin surface soils surrounding the Kushak mine of Yazd Province. The agricultural soils around the mines also have high heavy metal concentrations and are exposed to soil contamination (Chen*et al*., 2007; Eslami, 2010; Nikolaidis *et al*., 2010; Ikenaka *et al*., 2010).Mining has caused undesirable environmental impacts such as reduction in canopy cover percentage, production, density, and vegetation in soils surrounding the mine (Mir Ghaffari, 2005), resulting in soil erosion and degradation (Chen*et al*., 2007). Dayani *et al.* (2010) studied a geostatic approach to analyzing and interpreting the near surface soil Pb concentration data and other related soil chemical and physical parameters collected from around Sepahanshahr town, Isfahan.Variography indicated that the lead concentrations insoil were spatially correlated, and the spatial estimation was valid. Among other soilvariables, only clay content data exhibited lack of spatial structure.

According to the fact that metal concentrations in plants are affected by soil metal concentrations andspecificplants species are able to grow and adapt them to this condition. One of the highestheavy metal concentrations was reported to be 2.5 times higher of standard value (Akhvan Ghalibaf, 2004; Mir Ghaffari, 2005; Pari Zangeneh *et al*., 2010; Khani *et al.*, 2011).

A study on water and soil contamination around old mine in Slovakia showed that there were many heavy metals in the soil due to the long-time mining extraction. According to Igeo index, copper and mercury contamination was high and dangerous and a serious threat for the environment as these elements are released into the food chain (Angelovicova and Fazekasova, 2014).Several studies have also indicated that different mines have different environmental dangers, with the highest contamination related to coal mines with high cadmium contamination (Cheng *et al.*, 2019).

Several studies have been conducted on the ability of plants to absorb and accumulate heavy metals. Franco-Hernandez *et al.* (2010) studied thepotential of several plants for re-vegetation in metal contaminated soils. They further investigated metal concentrations in plant tissues. Their results showed that metal concentrations in shoots were often more than those in roots. Panahi (2013) reported that*Heliotropiumpilifera* and *Artemisia sieberi* were the most appropriate species for contaminated soils.

Given the importance of soil and plant safety in rangelands and human health, this research was carried out in the rangelands around bauxite mine which is constantly under livestock grazing. Theeffect of bauxite mining on soil andthe dominant plant species (*Zygophyllum eurypterum*) was investigated. The results can be used to estimate the damages to rangelands and help rangeland managers find strategies for better managing these areas.

2. Materials and Methods

Steppe rangelands were chosen around Bauxite mine in Sadrabad Nodooshan of Taft County in Yazd Province. The mine is located at 31° 56'6 " northern latitude and 53° 39'11"eastern longitude (Fig. 1). The average altitude, annual precipitation, andannual temperature are 2256 m, 124 mm, and 14°C, respectively. Based on Domarton method, the region's climate is highly cold-arid. The general and main steepness of the studyarea is 2-5%. The dominant species in this region is *Zygophyllum eurypterum*, and other species include *Artemisia sieberi*, *Salsola rigida*, and *Lactuca orintalis* (Fig. 2).

The study area was determined using topographic maps and field investigation. Rangelands under livestock grazing were identified at a specified interval in the mining area. According to the physiognomic variations and vegetation cover, the sampling site was divided into three sites:site 1) near the mine (10-200 meters), site 2) average distance from the mine (200 to 500 meters), and site 3) long distance from the mine (500 to 1000 m), where pasture physiognomy did not change. Other factors, such as altitude, slope, aspect, and precipitation were the same in this region (Table1).

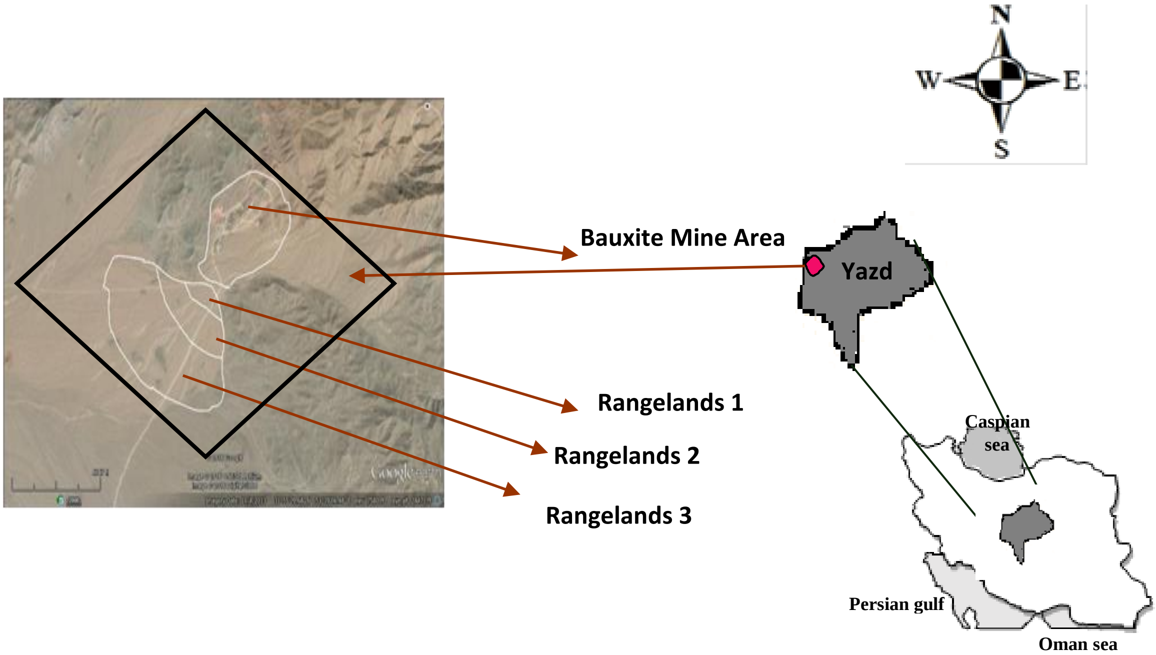

Fig.1. Study area in Iran and Yazd Province

Fig.2. View of the bauxite mine area and surrounding ranglands

Table1.Certain general characteristics of the study areas

Area	Soil texture	Height (m)	Aspect	Percent of slope
(Region1) near the mine	sandy and loamy	2298	Southwest	2
(Region2) at the middle of the mine	sandy and loamy	2294	Southwest	2
(Region3) away from the mine	sandy and loamy	2286	Southwest	2

Region 1 (rangeland up to 250 meters to mine), region 2 (rangeland up to 500 meters from the mine), region 3 (rangeland up to 1000 meters from the mine

In order to study the soil and plant, sampling sites were systematically selected in the middle of transects. Soil samples from each region were collected from the depths of 5 to 25 cm with three replications. In each region, aerial parts of *Zygophyllum eurypterum*and leaveswere randomly sampled with three replications. 50 gr of plant samples was dried in open air and shade for a week and then powdered. Soil and powdered plant samples (1 gr) were pressed with boric acid adhesive glue, and the analysis was performed using X-ray Fluorescence Spectroscopy and S4-Explorer model, at an atmospheric pressure of 30 p.

2.1. Pollution Indicators

2.1.1. Geo-accumulation Index (Igeo)

The geo-accumulation index is one of the most important geochemical factors for describing metal concentration in each region (Muller, 1969); it is calculated via Equation 1:

$$I_{geo} = \log_2\left(\frac{Cn}{1.5Bn}\right), \quad (1)$$

where Cn is the element concentration in soil sample, Bn is the concentration of pollutant indigenous rock, and 1.5 coefficient is for theremoval of lithological impact (Muller, 1969). According to Table 2, the geo-accumulation index can be divided into seven categories.

Table 2.Geo-accumulation index (Muller, 1969)

Geo-accumulation index (Igeo)	Quality contamination category
Igeo <0	Uncontaminated
0 <Igeo <1	Uncontaminated to moderately contaminated
1 <Igeo <2	Moderately contaminated
2 <Igeo <3	Moderately to strongly contaminated
3 <Igeo <4	Strongly contaminated
4 <Igeo <5	Strongly to extremely strongly contaminated
Igeo >5	Extremely contaminated

2.1.2. Integrated Pollution Index (IPI)

To achieve the value of heavy metal contamination, integrated pollution index was used. The Integrated Pollution Index is expressed as the mean value of elemental contamination (PI),

Equation 2: $PI_i = \frac{Ci}{Bi}$ (2)

The value of each element relative to background value is expressed as (PI), where Ci is the value of themeasured element, and Bi is the standard element concentration based on the soil pollution standard (Hakanson, 1980). Integrated Pollution Index was calculated based on Equation (3): $IPI = (\prod_{i=1}^{n} PIi)^{1/n}$ (3)
The amount of contamination was then determined (Table 3).

Table 3. Standardized classes of integrated pollution index (Hakanson, 1980)

Integrated Pollution Index (IPI)	Pollution level
IPI < 1	Low
1≥IPI> 2	Moderate
IPI > 2	High

2.1.3. Mean of contamination degree (mCd)

The pollution index was first introduced by Hakanson (1980), and then Abrahim (2005) presented a modified and generalized index as mCd.

Equation 4: $mC_d = \sum_{i=1}^{n} \frac{PIi}{n}$). (4)

Where PIi is the average of element contamination, n refers to the number of elements, and the contamination degree index is defined as the calculated contamination average.Next, the amount of contamination was determined (Table 4).

Table 4. Standardized classes of contamination degree (Abrahim, 2005)

Integrated Pollution Index (IPI)	Pollution level
mCd < 1.5	Uncontaminated to low contaminated
1.5 mCd <2	Low contaminated
2 mCd <4	Moderately contaminated
4 mCd <8	Strongly contaminated
8 mCd <16	Extremely contaminated

2.1.4. Statistical analysis

In order to analyze the data, SPSS software was used. Afterwards, one-way analysis of variance was used to determine the differences between elements and contamination site; the differences between mean values were compared using the Duncan test.

3. Results

Determinedthe amount of soil pollution to heavy elements, than there was compared to the standard amounts of pollution (mg/kg) in Iran. One sample T-test showed that the highest metal concentration belonged to aluminum and iron (region 1) with values of 40560 and 1031.57 mg/kg, respectively; the lowest concentration was detected in rubidium and copper (region 3), 13.5 and 18/20 mg/kg, respectively (Table 5). The average concentrations of aluminum, antimony, titanium, and iodine were found to be higher than the standardlevelsin alkaline soils of Iran rangelands (Vaghar*et al.*, 2002). However, the average concentrations of chromium, manganese, rubidium, copper, and zinc elements were less than Iran standard levels in three regions (Vaghar*et al.*, 2002).

Table 5. Heavy metal concentrations in thesoil around bauxite mine (mg/kg)

Elements	Region1	Region2	Region3	Iran Standards for Rangeland Use(Vaghar *et al*, 2002)
I (iodine)	205.0**	178.0**	167.0**	40.0
Sb (antimony)	52.6*	41.5*	24.4**	100.0
Cr (Chromium)	33.0**	35.0**	40.0**	535.0
Mn (Manganese)	458.0ns	394.0*	377.0*	545.0
Ti (Titanium)	4949.0**	4545.0**	3995.0**	2400.0
Rb (Rubidium)	19.8**	16.4**	13.5**	120.0
Cu (Copper)	58.0**	24.1**	13.13**	500.0
Zn (Zinc)	17.4**	9.8**	6.5**	500.0
Al (Aluminum)	39131.0**	36140.0**	29966.6**	10000.0

(ns: No significant(**: P<0.01), (*: P<0.05))

Comparison of the three regions surrounding the mine using analysis of variance indicateda significant difference among Al, Fe, Mn amounts (p<u><</u>0.05) and Zn, Ti, Zr, Sb, Cu, Rb (p<u><</u>0.01); however, no significant difference was observed in Cr concentration in the regions (Table 6).

Table 6. Analysis of metalconcentration in the soil around bauxite mine

Elements	Mean of Square	df	F
I (iodine)	261.11	8	4.67 *
Sb (antimony)	18.17	8	127.02 **
Cr (Chromium)	77.29	8	0.44 ns
Mn (Manganese)	901.64	8	6.13 *
Ti (Titanium)	9494.44	8	72.64 **
Rb (Rubidium)	30.34	8	65.97 **
Cu (Copper)	46.34	8	37.02 **
Zn (Zinc)	301.37	8	362.16 **
Al (Aluminum)	100038611.10	8	7.71 *
Fe (Iron)	157509.00	8	12.76 *

(ns: No significant(**: P<0.01), (*: P<0.05))

One-way ANOVA test showed high concentrations of Ti, Al, Fe, Mn, Zr, Sb, Cu, Rn, Zr, Zn elements in the soil near the mine (Table 7); this amount was reduced moving away fromthe mine at a distance of 500 meters (region 2).

Table 7. Comparison of metal concentrations in the soil around bauxite mine

Elements	Region1	Region2	Region3
I (iodine)	205.00 $^{a}\underline{+}$ 2.88	175.00 $^{ab}\underline{+}$ 13.22	166.66 $^{b}\underline{+}$ 8.81
Sb (antimony)	52.60 $^{a}\underline{+}$ 2.32	41.57 $^{b}\underline{+}$ 3.57	24.36 $^{c}\underline{+}$ 2.32
Cr (Chromium)	33.30$^{a}\underline{+}$ 5.77	35.74$^{a}\underline{+}$ 4.24	40.00$^{a}\underline{+}$ 5.09
Mn (Manganese)	458.24 $^{a}\underline{+}$ 19.62	393.93 $^{b}\underline{+}$ 21.86	376.76 $^{b}\underline{+}$ 6.17
Ti (Titanium)	4949.99 $^{a}\underline{+}$ 83.56	4544.69 $^{b}\underline{+}$ 50.11	3994.70 $^{c}\underline{+}$ 48.56
Rb (Rubidium)	19.85 $^{a}\underline{+}$ 0.25	16.36 $^{b}\underline{+}$ 0.62	13.50 $^{c}\underline{+}$ 0.34
Cu (Copper)	47.83 $^{a}\underline{+}$ 5.48	24.12 $^{b}\underline{+}$ 4.03	13.13 $^{c}\underline{+}$ 3.94
Zn (Zinc)	17.36 $^{a}\underline{+}$ 1.58	9.84 $^{b}\underline{+}$ 0.54	6.52 $^{b}\underline{+}$ 0.92
Al (Aluminum)	39130.00 $^{a}\underline{+}$ 82.56	36140.00 $^{a}\underline{+}$ 150.11	9966.66 $^{b}\underline{+}$ 994.56
Fe (Iron)	9903.94 $^{a}\underline{+}$ 246.89	8997.36 $^{b}\underline{+}$ 296.27	8270.16 $^{b}\underline{+}$ 93.68

Igeo index showed that I, Sb, and Al elements were in moderate contamination category. Furthermore, Cr, Mn, Zr, and Rb elements were in uncontaminated category, and Ti and Fe elements were in non-contaminated to moderately contaminated categories (Table 8).

Table 8. Geo-accumulation indices of metals in the soil around bauxite mine

Elements	Region1	Region2	Region3	Contamination Degree
I (iodine)	1.80	1.73	1.51	Moderate contamination
Sb (antimony)	1.80	1.69	-	Moderate contamination
Cr (Chromium)	- 4.05	- 4.32	- 4.45	Uncontaminated
Mn (Manganese)	- 0.73	- 0.94	- 1.12	Uncontaminated
Ti (Titanium)	0.49	0.35	0.13	Uncontaminated to moderate contamination
Rb (Rubidium)	- 3.18	- 2.25	- 3.83	Uncontaminated
Cu (Copper)	- 3.83	- 4.64	-	Uncontaminated
Zn (Zinc)	- 5.64	-	-	Uncontaminated
Al (Aluminum)	1.43	1.27	1.17	Moderate contamination
Fe (Iron)	0.85	0.33	0.16	Uncontaminated to moderate contamination

3.2. Heavy metal concentrations in *Zygophyllum eurypterumaroundbauxite mine*

The amount of elements in the plant fresh leaves and stems was compared with the standard amount using one sample T-test. The results showed that the average concentration of aluminum, titanium, copper, and iron elements in aerial parts of theplants exceeded the permissible limit (Stefan & Benton Jonz, 2008); the amount of these elements was higher than the permissible limit in the plants surrounding the mine. Therefore, it can be concluded that the plants in the region are partially contaminated with aluminum, titanium, copper, and iron elements (Table 9).

Table 9. Heavy metal concentrations in Zygophyllum plant around bauxite mine (mg/kg)

Elements	Region1	Region2	Region3	Iran Standards for Rangeland Use (Vaghar*et al*, 2002)
Cu (Copper)	25.33**	18.66*	10.45ns	10.00
Ti (Titanium)	72.91**	67.00**	49.00 **	4.60
Fe (Iron)	160.51**	137.45**	133.42**	50.00
Al (Aluminum)	820.00**	754.00**	717.33**	500.00
Sr (Strontium)	313.90**	243.69 **	123.90**	15000.00
Si (Silicon)	3943.33*	3919.99*	3709.99*	5000.00

(ns: No significant(**: P<0.01), (*: P<0.05))

The results indicateda significant difference among all elements except aluminum and silicon (Al and Si) in three regions, which can be attributed to the large amount of clay in thesoils of arid regions (Table 10).

Table 10. Analysis of metal concentrations in Zygophyllum plant around bauxite mine

Elements	Mean of Square	df	F
Cu (Copper)	15.55	8	33.25 **
Ti (Titanium)	19.03	8	24.49 **
Fe (Iron)	66.89	8	9.87 **
Al (Aluminum)	5740.88	8	1.43 ns
Sr (Strontium)	2962.95	8	9.34 **
Si (Silicon)	281295.18	8	0.17 ns

(ns: No significant(**: P<0.01))

According to One-way ANOVA test, the concentrations of elements, such as Ti, Fe, Sr, and Cu in the plant near bauxite mine were high (Table 11), decreasingwith distancing from the mine to 500 meters (region 2).

Table 11. Comparing themetal concentrations of Zygophyllum plant around bauxite mine

Elements	Region1	Region2	Region3
Ti (Titanium)	72.91 a± 1.96	67.00 a± 3.61	49.00 b± 1.46
Al (Aluminum)	820.66 a± 10.14	754.00 a± 8.19	717.33 a± 6.35
Fe (Iron)	160.51 a± 6.00	137.45 b± 5.05	133.42 b± 4.68
Si (Silicon)	3943.33 a± 74.21	3919.99 a± 70.18	3709.99 a± 91.24
Cu (Copper)	25.33 a± 5.50	18.66 a± 4.50	10.45 b± 1.35
Sr (Strontium)	313.90 a± 33.38	243.69 a± 35.77	123.90 b± 23.14

3.3. IPI and MCd indices

IPI and mCd indices were calculated as geometric and arithmetic means, respectively,and PI index was calculated as an environmental index. According toTable 13ANOVA results, there was a significant difference among the study regions in terms of contamination amount.

Table 12. Analysis of IPI and mCd indices in soil elements around bauxite mine

Contamination indices	Mean of Square	df	F
IPI	0.007	2	25.95 **
mCd	0.168	2	135.12 **

(**: P<0.01),

These indices were in low contamination category in all three regions, but the highest amounts were detected near the mine (Table 13).

Table 13. IPI and mCd indicesin soil elements around bauxite mine

Contamination indices	Region1	Region2	Region3
IPI	0.49a	0.45b	0.41c
mCd	1.33a	1.37a	0.94b

4. Discussion and Conclusion

The results showed that there was a significant difference among the areas around the mine in terms of Mn, Zn Ti, Zr, Sb, Cu, and Rb concentrations;the metal concentrations in the soil were declined by moving away from the mine to a distance1000 meters in region 3. In general, the results revealed that mining increased the metal concentrations in soil. Rashed (2010) found the highest concentrations of Cr, Cu, Zn, Ni, Ag, Au, Mn, Hg, As, Ag, Au, and Pb in the proximity of the mine.

The results of this study also showed that bauxite mining exploitation degraded and contaminated the soil, especially up to 500 meters from the mine. In addition, miningincreases dust anddestroyslarge areas,leading tomany problems for plant growth. The results of Mirghaffari (2006) study inSepahanshahr,Isfahan,indicated the significant impact of pollution on human health; this is consistent with the results of research on plants and soils around the rangelands of Pb and Zn mine that had contaminated the plants and soil pastures up to 2 km (Akhavan Ghalibaf, 2004). The geo-accumulation index is a criterionfor separating target element pollutants in soilsaround mines and has acceptable identification ability. The results of measuring soil pollution indices indicated that the soils in all three areas around bauxite mine had a low pollution index (IPI) and contamination degree (mCd). The results of Firuzabadi *et al.* (2015) study are consistent with this studyregarding IPI and mCd indices. Moreover, the results of PI and Igeo indices in all three regions showed that Igeo index for Cr, Mn, Zr, and Rb elements wasin the medium category; Igea and Sb elements were inuncontaminated category, and Tiand Feelements were in uncontaminated to moderate category. According to the PI index, I and Sb elements were highly contaminated, Ti element had moderate contamination, and other elements had a low contamination in the three regions. Comparison of soil elements indicated a significant difference among areas around the mine in terms of Mn and Zn Ti, Zr, Sb, Cu, Rb concentrations.The elements concentration in the soil was declined by moving away from the mine to a distance of 1000 meters in region 3.

Furthermore, Tongway and Hindley (2004) reported that mining is one of the most deleterious activities in an ecosystem which can cause vegetation decrease. Dalvand *et al.* (2014) studiedthe amount of heavy metals in *Artemisia aucheri* and *Astragalus gummifer*around Darreh Zereshk minie in Yazd province. They found that *Artemisia aucheri*had a higher capability for theabsorption of heavy metals from contaminated soils.

The results of this study revealed that miningactivities increasedheavy metal concentrationsin the soil. Assessment of agricultural soil contamination and waste resulting from heavy metals in an abandoned lead and zinc mine in Greece showed that thesoil samples near mining areashada high concentration of heavy metals (Nikolaidis *et al.*, 2010). Mining in Kabwe region of Zambia has contaminated soil by heavy metals, such as As, Pb, Zn, and Cd (Ikenaka *et al.*, 2010). The results of this study demonstrated that bauxite mining increased Mn, Zn, Ti, Zr, Sb, and Cu concentrations in dominant plants (*Zygophyllum eurypterum*) and soils, which can lead to health problems for the indigenous people.

According to the indices and standard amounts in the present study, there was no contamination; however, statistical analysis of theaverage of indices had an increase near the mine, which is similar to the results of Ahmadian *et al.* (2015). They found that the amount of heavy metals was not high in soil and plants around Langeroud coal mine in Mazandaran. The amount of contamination indices was also low in their study.

The results of this study can be used by natural resources experts to identify the amount of damage and devise appropriate programs for the future.Given the constant mining activity, contamination will increase and has to be investigated for the next years.

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