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REVIEW ARTICLE

EVALUATION OF HEAVY METALS CONCENTRATION IN JAJARM BAUXITE DEPOSIT IN NORTHEAST OF IRAN USING ENVIRONMENTAL POLLUTION INDICES

Ali Rezaei^{1*}, Hossein Hassani¹, Seyedeh Belgheys Fard Mousavi², Nima Jabbari³¹Department of Mining and Metallurgy Engineering, Amirkabir University of Technology, Tehran, Iran²Department of Agriculture and Environmental Engineering, Tehran University, Tehran, Iran³Department of Civil and Environmental Engineering, Southern California, USA*Corresponding Author E-mail: Alirezaei2013@aut.ac.ir, hhassani@aut.ac.ir

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ABSTRACT

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Heavy metals are known as an important group of pollutants in soil. Major sources of heavy metals are modern industries such as mining. In this study, spatial distribution and environmental behavior of heavy metals in the Jajarm bauxite mine have been investigated. The study area is one of the most important deposits in Iran, which includes about 22 million tons of reserve. Contamination factor (CF), the average concentration (AV), the enrichment factor (EF) and geoaccumulation index (GI) were factors used to assess the risk of pollution from heavy metals in the study area. Robust principal component analysis of compositional data (RPCA) was also applied as a multivariate method to find the relationship among metals. According to the compositional bi-plots, the RPC1 and RPC2 account for 57.55% and 33.79% of the total variation, respectively. The RPC1 showed positive loadings for Pb and Ni. Also, the RPC2 showed positive loadings for Cu and Zn. In general, the results indicated that mining activities in the bauxite mine have not created serious environmental hazards in the study area except for lead and nickel. Finding potential relations between mining work and elevated heavy metals concentrations in the Jajarm bauxite mine area necessitates developing and implementing holistic monitoring activities.

KEYWORDS

Environmental behavior, Contamination criteria, Heavy metals, Multivariate statistical analyses, Jajarm bauxite deposit.

1. INTRODUCTION

Based on a study, soil contamination has always been a matter of discussion as an important environmental issue in both developed and developing countries, mainly because of the effects of soil pollution on changes in the land use patterns and also due to the complicated cleanup processes once a soil is contaminated [1]. Among numerous soil pollutants, heavy metals are especially of high importance as they are highly carcinogenic, toxic and persistent in the environment. According to research, heavy metals are naturally occurring elements that have a high atomic weight and a density of at least five times greater than that of water [2]. In the environment, heavy metals are spatially distributed in forms of ores [3]. Based on a study, heavy metal contamination is a serious threat to aquatic systems due to their toxicity, abundance, persistence in the environment [4]. Their multiple industrial, domestic, agricultural, medical, and technological applications have resulted in widespread distribution of heavy metals in the environment which in turn has been raising concerns regarding potential effects on human health and the environment. According to a scholar, accumulation of heavy metals in soil and water resources is a function of both anthropogenic activities and lithogenic resources [5]. Two primary sources have been identified for heavy metals pollution: natural or geological inputs including rock weathering and thermal springs, and anthropogenic sources including metalliferous mining and associated industries [6]. In many countries without stringent environmental regulations, mining is a practice with potential impacts on human health. Resource extraction and mining activities may lead to release of highly mobile metals into the environment particularly in areas near mines [7,8]. Impact of the mining industry on the environment has been a public concern and has increased awareness of the possible harmful effects of the industry. As an anthropogenic activity, mining has facilitated the movement and distribution of heavy metals in natural

formations. The extractive nature of mining operations creates a variety of impacts on the environment before, during and after mining operations [9]. The extent and nature of impacts can range from minimal to significant depending on a range of factors associated with each mine. Mining activities, in particular, open-pit mining, cause environmental pollution and heavy metals contamination with accentuated effects in the surrounding areas. In previous study, environmental impact assessments for mining are, thus, imperative to identify the magnitude and spatial extension of the pollution [10]. Variability and uncertainty in the extraction of ore, operational, and health parameters are among the most important factors that significantly affect the movement of pollutants [11,12].

In this study, we aim to investigate the distribution and environmental behavior of heavy metals and evaluate the anthropogenic and lithogenic contribution in the Jajarm bauxite mine in Iran using environmental pollution indices. The main goals of this research are to assess the risk of pollution from heavy metals through quantitative criteria and then to evaluate spatial frequencies and distributions of heavy metals concentration by applying multivariate statistical methods (Principal Component Analysis).

2. MATERIALS AND METHODS

2.1 Study Area

The Jajarm bauxite deposit is the largest deposit in Iran and located in North Khorasan Province (northeast Iran) and 15 km North-East Jajarm town. The deposit is situated in 56° 27' 30" longitude and 37° 2' to 37° 4' latitude (Fig.1) and is more than 8 km long and 20 m thick and has over 22 million tons of storage. This region has a dry desert climate and low

rainfall, about 150 mm a year. The population of this region is close to 12 thousand people [13].

There are a number of reasons why bauxite mining in Iran can cause an environmental problem which will subsequently propagate to human health hazards if the issue is not resolved or controlled. One of the reasons is related to the location of mine which is close to a human settlement area. Another reason is associated with unsustainable mining practices that have led to very extensive and aggressive mining activities and yet environmentally unfriendly. Potential impacts on human health can be direct and indirect as shown in Figure 2.

Figure 1: Location of the Jajarm bauxite deposit on the geological map of Iran [14].

Figure 1: Linkages between bauxite mining activities and potentials impacts [15].

2.2 Geological Setting

The Jajarm bauxite deposit is situated in the eastern part of the Alborz structural zone (Fig.3). One of the most important characteristics of this deposit is its asymmetrical morphology along the tectonic structure of the area. Lower Devonian sandstone evaporates, and limestone of the Padha formation are the oldest rocks in the area [16]. The upper Devonian Khosh Yeylagh formation consists of fossiliferous limestone, dolomite, shale, and sandstone, and is overlain by Lower Carboniferous shale and carbonate of the Mobarak formation (Fig.3). There are no Middle and Upper Carboniferous sediments in the area. Brown indurated claystone and siltstones with small iron concretions overlie the Mobarak formation. In the sense of a scholar, this layer is equivalent of Sorkh Shale formation named by other scholar in eastern central Iran (Tabas area and Shotori Range) [17]. In this area, Shemshak formation is located as discontinuities over the Elika formation (approximately 215 m thick) and bauxite horizon is formed between the two formations (Fig.4). The karstified carbonate-hosted Jajarm bauxite is buried by several thousand meters of younger sediments, beginning with the Jurassic Shemshak formation and other younger units [18].

The Jajarm bauxite deposit is located in an area folded into an E-W trending anticline cut by several reverse faults that its northern extension is thrust on to the southern part. This over thrusting has hidden the bauxite deposit beneath Quaternary units. As a result, the bauxite deposit is only exposed on the northern flank of the anticline in a length of about 8 km. Exposure of the ore body is discontinuous along its length, with the

deposit occurring as isolated blocks subdivided into eight blocks in the Golbini area and four in the Zoo area for mining purposes (Fig. 3). Based on the obtained information of analysis results, the Al_2O_3 : SiO_2 ratio varies from 0.87 to 7.52 throughout the deposit so the ore grade is locally heterogeneous. Natural bauxite ore consists of aluminum hydroxide, iron oxide, titanium oxide, and reactive silica.

Figure 2: Simplified geological map of the Jajarm bauxite deposit and its surrounding units.

Figure 3: Outcrops of the Jajarm bauxite with its footwall (Elika formation) and hanging wall (Shemshak formation)

2.3 Sampling and analytical methods

Ninety-three soil samples were collected from Jajarm bauxite area in clean polythene covers avoiding the all possible contamination. Soil samples were collected from the top 5-30 cm layer of the soil using a plastic spatula. The soil samples were then transferred to the laboratory and were dried for 5 days at 60°C to avoid the moisture content. The dry soil sample was powdered to -200 mesh size (US Standard) using a swing grinding mill and homogenized. In order to determine the heavy metals concentration, soil samples were analyzed using Inductively Coupled Plasma-Mass Spectrometer (ICP- MS) method. Cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) were selected as priority control heavy metals based on the results of pollution and health risk assessments. Chemical analyses were carried out at the Lab West Laboratories, Australia. The location of sample collected points is shown in Fig. 5.

2.4 Environmental pollution indices

Various methods and factors have been proposed to assess the heavy metal contamination in a mining district [19]. For this study selected environmental pollution parameters are as follows: the enrichment factor (EF), contamination factor (CF), Geo-accumulation index (I_{geo}) and pollution load index (PLI).

2.4.1 Enrichment factor (EF)

Based on a study, the enrichment factor (EF) is broadly used to estimate the anthropogenic impacts on sediments and soils [20-22]. This factor compares the concentration of an element in samples with the concentration of the same element in non-contaminated areas [23]. In order to evaluate natural or anthropogenic sources of heavy metal content in samples, an enrichment factor is calculated as follows:

$$EF_{El} = \frac{[El]_{sample}/[X]_{sample}}{[El]_{crust}/[X]_{crust}} \quad (1)$$

where "El" refers to the element under consideration, the square brackets indicate concentrations (usually in mass/ mass units, such as mg/ kg), and "X" is the selected reference element. Crust subscription in equation 1 refers to Clarke of Earth's crust, most often Continental or Upper Continental Crust (UCC).

Figure 4: Map showing the sampling stations in the Jajarm bauxite mine

2.4.2 Contamination Factor (CF)

Contamination factor (CF) is an indicator of soil and sediment heavy metals contamination ratio and is obtained by dividing the concentration of the element in the sample taken by the concentration of the same element in the background [24].

$$CF = \frac{C_{Sample}}{C_{Background}} \quad (2)$$

where C_{sample} is the concentration of an element in the sample and $C_{background}$ is the concentration of the element in global shale. If CF is higher than 1, indicating the increased concentration of pollutant due to human factors.

2.4.3 Geoaccumulation index

According to research, geoaccumulation index was first introduced by Muller and was initially named as the Muller index [25]. The Muller index is used to measure the amount of contamination with heavy metals in the soil. This assessment index was used in soil and sediment contamination studies [26,27]. Geoaccumulation index is used for classification of soils, from non-contaminated to heavily contaminate and is calculated using the following formula [28]:

$$I_{geo} = \log_2 \left[\frac{C_n}{1.5B_n} \right] \quad (3)$$

In equation 3, C_n is the measured concentration of the element in the collected sample and B_n represents the concentration of the element in the background sample. The coefficient of 1.5 is used to eliminate possible changes in the background due to the geological effects [29,30].

2.4.4 The Modified degree of contamination (mC_d)

A scholar presented a modified and generalized form of the previous scholar equation for the calculation of the overall degree of contamination as below [31,32]:

$$mC_d = \frac{\sum_{i=1}^n C_f_i}{n} \quad (4)$$

where n is the number of analyzed elements, i refers to the i^{th} element (or pollutant) and C_f is the contamination factor. Using this generalized formula to calculate the mC_d allows the incorporation of as many metals as possible with no upper limit. The expanded range of possible pollutants can, therefore, include both heavy metals and organic pollutants should the latter be available for the studied samples. For the classification and description of the modified degree of contamination (mC_d) in sediments and soil, the following gradations were proposed by a scholar:

$mC_d < 1.5$ nil to the very low degree of contamination
 $1.5 \leq mC_d < 2$ low degree of contamination
 $2 \leq mC_d < 4$ moderate degree of contamination
 $4 \leq mC_d < 8$ high degree of contamination
 $8 \leq mC_d < 16$ very high degree of contamination
 $16 \leq mC_d < 32$ extremely high degree of contamination
 $mC_d \geq 32$ ultra-high degree of contamination

An intrinsic feature of the mC_d calculation is that it produces an overall average value for a range of pollutants. As with any averaging procedure, care must, however, be taken in evaluating the final results as the effect of significant metal enrichment spikes for individual samples may be hidden within the overall average result [33].

2.4.5 Pollution load index (PLI)

Pollution load index (PLI) is often used to evaluate and estimate the degree of pollution in soils and sediments. This index is based on the coefficient of each element in soil and is calculated by dividing the concentration of each element in a soil sample by its concentration in the reference sample (CF) [34]. PLI can, then, be calculated for a set of contaminant metals as the geometric mean of the concentration of all metals. If the PLI concentration is close to 1, this indicates that the concentrations are close to the background concentration, while the PLI concentrations above 1 show soil contamination [35,36]. The total heavy metal contamination in the region is obtained using this indicator, and by equation 5 [37]:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n} \quad (5)$$

2.5 Statistical analyses

In this research, multivariate and basic statistical analyses were applied to determine the relationship among heavy metals. Application of multivariate statistical techniques facilitates interpretation of complex data matrices for a better understanding a variety of environmental factors [38]. Correlation analysis and principal component analysis (PCA) are performed using the commercial statistical software package SPSS version 18.0 for Windows [39]. Principal component analysis (PCA) was implemented to reduce the number of variables and to detect the relationship between variables. This method allows us to display most of the original variability in a smaller number of dimensions and has been widely used in geochemical and hydrochemical studies [40].

Multivariate statistical methods are used in analytical chemistry to quantify relationships between more than two variables under simultaneous consideration of their interactions [41]. Heavy metals usually have complex relationships among them [42]. The identification of pollutant sources is often determined with the aid of multivariate statistical analysis methods, such as correlation analysis and principal component analysis (PCA).

The correlation coefficient between each pair of variable elements in the soil samples was calculated using the Pearson's correlation matrix approach to quantitatively analyze and confirm the relationship among various metal. In general, significant correlations between pairs of heavy metals suggest a common or combined origin, whereas weak correlations indicate different origins [43].

Based on a study, principal component analysis (PCA) is the most common multivariate statistical method used in environmental studies [44]. The PCA method is widely used to reduce data and to extract a small number of latent factors for analyzing relationships among the observed variables. It has been reported that PCA methods have been widely used in

geochemical applications to identify soil pollution sources and distinguish natural versus anthropogenic contribution [45].

According to recent studies, the PCA is a versatile tool for the integration of multi-element concentration values into single principle components (PCs) and for the reduction of dimensionality of data sets into uncorrelated PCs based on the correlation matrix of variables [46,47]. Ordinary PCA decomposes the correlation matrix of variables into two matrices of scores and loadings using eigenvectors and eigenvalues. The mutually independent PCs are determined by the scores and loading matrices [48]. The information about the relationship between PCs and original variables is described by loadings which are the correlations between PCs and variables. Moreover, the information about the relationship between PCs and samples is described by the scores which are a linear combination of variables weighted by eigenvectors. The value of variance explained by each PC is expressed by eigenvalues. Significant PCs could be retained based on the eigenvalues of greater than 1 [49]. Generally, most of the total variance and information about the data set are summarized in the first PC, and thus, the first PC is the most significant component [50,51].

In this study, we applied a robust principle component analysis of compositional data (RPCA), as a multivariate method, to find a multi-element geochemical signature [52]. Initially, the raw data of five analyzed elements (Cd, Cu, Ni, Pb, and Zn) were transformed using the Isometric log ratio (ilr) transformation to address the data closure problem [53,54]. Robust principle component analysis was then applied on ilr-transformed data to integrate geochemical variables into robust PCs (RPCs) and to reduce the dimensionality of the data set. Because the ilr-transformation does not yield into a one-to-one transformation from simplex space to Euclidean space, the resulting loading matrix and scores were back-transformed to the Centered log ratio (clr) space, where interpretations are possible via compositional biplots [55-57]. The Rob Compositions software package of R free software environment was employed for ilr transformation of the data and performing the RPCA [58].

Table 2: Modified degree of contamination (mc_d) and contamination factors (CF) for heavy metals in the soil samples of the Jajarm bauxite deposit

Baseline	Contamination Factor					Sum CF	mc_d
Element	Cd	Cu	Ni	Pb	Zn		
CF (Average continental crust)	0.1	0.025	0.04	0.06	0.01	0.236	0.05
CF (Background)	0.007	0.46	1.85	2.10	0.28	4.697	0.94

The PLI average value calculated for all samples is 0.31. As presented in Figure 6, the PLI values in the samples are below the background concentration (PLI < 1) showing that the Jajarm bauxite mine is not contaminated.

Figure 5: PLI calculated values for samples in Jajarm bauxite mine

3.2 Background values from average crustal concentration

According to Figure 7, a comparison of the mean concentrations of potentially toxic metals in samples with the average crust values for non-contaminated soils and average shale shows that the higher levels of contaminated metals are Ni and Pb compared to the average crust values. Cadmium, copper, and zinc are less than the average shale. Therefore, when compared with the background values of world soils the elevated concentrations of Pb and Ni in the Jajarm bauxite mine suggest anthropogenic sources for these elements.

3. RESULTS AND DISCUSSION

3.1 Environmental assessment of heavy metal contamination

To determine the extent of mining contamination with heavy metals the elements of a studied area are compared with thresholds defined by international standards (Table 1). Calculated environmental pollution indices are listed in Table 1. The mean EF of Cd, Cu, Ni, Pb, and Zn are close to or higher than 3. The EF values vary from non-enriched (Cd, Cu, and Zn) to low-enriched (Ni and Pb) for the Jajarm bauxite mine samples. This indicates that the anthropogenic origin is probable for Ni and Pb in the study area.

The lowest contamination with a CF value (i.e. less than 1) is related to Cd, Cu, and Zn. Also, the elements such as Ni and Pb, based on the average values have contamination coefficients 1.85 and 2.10, respectively which indicates the increased concentration of these pollutants due to human factors. The obtained results show the anthropogenic (mining activities) origin of Pb and Ni in the study area.

Table 1: Enrichment factor, concentration factor, and an average of elements in Earth's crust and global shale [59,60]

Element	Cd	Cu	Ni	Pb	Zn
EF	0.009	0.47	1.99	3.58	0.33
CF	0.007	0.46	1.85	2.10	0.28
Average(Crust)	12.5	41	40	14.8	50
Average(Shale)	2.6	100	68	20	95

The I_{geo} classes were calculated for each sampling station. Results of geoaccumulation index calculation show that the environment and contamination levels ranged from non-contaminated (Cd, Cu, and Zn, $I_{geo} < 0$, natural origins) to low contamination (Pb and Ni, $I_{geo} > 0$, anthropogenic sources). Further, the analysis of the modified degree of contamination (mc_d) indicates Nil to the very low degree of contamination (Table 2).

Figure 6: A comparisons of the mean concentrations of potentially toxic metals in all samples of the Jajarm bauxite mine with the average crust values for non-contaminated soils and average shale

3.3 Spatial distribution of heavy metals

The ordinary inverse distance weighting (IDW) method was used to populate spatially distributed results in the study area based on raw samples. Figures 8, 9, 10, 11 and 12 illustrate the spatial distribution from different metals as discussed in the following sections.

3.3.1 Cadmium

Based on a study, cadmium is a non-essential element that negatively affects plant growth and development [61]. Cadmium is released into the environment by natural weathering processes, atmospheric deposition, use of phosphate fertilizers and sewage treatment plants [62,63]. According to a scholar, natural Cd concentration found in the Earth's crust is in the range of 0.1-0.5 mg/kg [64,65]. Cadmium concentrations (mg/kg)

ranged between 0.01 to 0.25 in the study area which is lower than average crustal values (Fig. 8).

Figure 7: Spatial distribution map of Cd metal

3.3.2 Copper

Based on a study, copper is released into the environment from natural sources such as volcanic eruptions, decaying vegetation, forest fires, and sea spray etc. up to 50 mg/kg and anthropogenic activities, including municipal and industrial wastewater [66-69]. The results show that Cu concentrations (mg/kg) in the soils of the study area ranged from 1 to 64. The comparison between Cu concentrations in the soil of the Jajarm bauxite mine shows that Cu levels in the near mine and waste dumps had higher levels than other measured stations in the study area (Fig. 9).

3.3.3 Nickel

Nickel is a transition element that occurs in the environment only at very low levels. According to research, the major sources of nickel contamination in the soil are metal plating industries, combustion of fossil fuels, and nickel mining and electroplating [70]. The results show that Ni concentrations (mg/kg) in the soils ranged from 10 to 161. The comparison between Ni concentrations in the soils of the Jajarm bauxite mine shows that Ni levels in the near mine and waste dumps had higher levels than other measured stations in the study area (Fig. 10).

Figure 8: Spatial distribution map of Cu metal

Figure 9: Spatial distribution map of Ni metal

3.3.4 Lead

Lead, a non-essential and toxic element, is released from natural and anthropogenic activities. Major sources include vehicular emissions, volcanoes, airborne soil particles, forest fires, waste incineration, effluents from leather industry, lead-containing paints and pesticides. Study showed natural concentration of Pb in the earth's crust varied from 15 to 20 mg/kg [71]. The results show that Pb concentrations (mg/kg) in the soils ranged from 10 to 128. The comparison between Pb concentrations in the soils of the Jajarm bauxite mine shows that Pb levels in the near mine and waste dumps had higher levels than other measured stations in the study area (Fig. 11) and suggest anthropogenic sources for this element (mining activities).

Figure 10: Spatial distribution map of Pb metal

3.3.5 Zinc

Based on a research, natural background levels of zinc are usually found up to 100 mg/kg in soils [72]. Sources of Zn are natural processes and human activities. The concentrations (mg/kg) of Zn in the study area ranged from 3.0 to 85.0, which are lower than average crustal values (Fig. 12).

Figure 11: Spatial distribution map of Zn metal

Spatial distribution of the metals in the soils is not uniform over the entire section of the study area. Changes in concentration are pertinent to the magnitude and temporal and spatial extension of the release of heavy metals from different natural and anthropogenic sources. Heavy metals concentration levels and distribution were found higher at the sites located in the vicinity of mine pits and waste dumps that are probable sources of metal pollution. As shown in Figures 8, 9, 10, 11 and 12, the spatial distribution patterns of all of the heavy metals tested are quite similar and relatively enriched in the near waste dumps and mines regard to Fig.5.

3.4 Statistical Analysis Methods

3.4.1 Descriptive basic statistics

The descriptive statistics for soil samples of the study area are given in Table 3. The lowest mean concentration belongs to Cd and the highest of Pb. The average abundance order of heavy metal contents in the soil samples is Pb > Ni > Zn > Cu > Cd.

Table 3: Descriptive basic statistics of the Raw data of Cd, Cu, Ni, Pb, and Zn in the study area (mg/kg)

Element	Valid N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
Cd	93	0.001	0.25	0.09	0.057	0.003	0.75	0.446
Cu	93	1.6	63.7	18.7	10.98	120.49	1.16	2.3
Ni	93	10.0	161.0	48.86	30.50	931.40	1.1	1.5
Pb	93	10.8	128.0	58.60	31.1	967.6	0.285	-0.98
Zn	93	3.7	85.0	25.7	14.8	220.08	1.1	1.8

The statistical characteristics of the heavy metals, such as the Skewness and kurtosis, suggest that the raw data (i.e. data from analysis of samples, without any transformations) do not follow normal distributions (Table 3). Histograms of the raw data (Fig. 14), obviously demonstrate that the elements follow positively skewed distributions.

To explore whether the data are log-normally distributed, the individual raw data were logarithmically transformed. The Q-Q plots of the ln-transformed data (Fig. 15) show that there are some outliers in the log-transformed data set. Based on a study, it could be inferred that there are multiple populations, which may be related to the influence of a variety of geological processes and anthropogenic factors. Box and whisker plot the data are presented in Fig. 13 [73,74].

Figure 12: Box-whisker plots showing heavy metal concentration ranges in the soil of the study area (outliers are indicated by rhomboid-shaped points)

Figure 13: Histogram of the heavy metals for Cd, Cu, Ni, Pb and Zn

Figure 14: Q-Q plots of the ln-transformed data of Cd, Cu, Ni, Pb and Zn

3.4.2 Correlation analysis

The correlation coefficients among the heavy metals are shown in Table 4. Nickel with Pb and Cu with Zn are significantly correlated according to Pearson's coefficient since data normality has been checked. The strong correlation is an indication of a similar behavior and common origin. Pearson's coefficients suggest that Cd does not show a significant correlation with any of the metals. Cadmium has a high transfer rate and high mobility in the environment so it can accumulate in relatively large amounts in plants without any apparent effects on the plants.

Table 4: Pearson's correlation coefficients among selected metals of the study area

Element	Cd	Cu	Ni	Pb	Zn
Cd	1	.008	- 0.48	0.09	0.06
Cu			0.14	0.16	0.86
Ni			1	0.88	0.14
Pb				1	0.18
Zn					1

3.4.3 Principal component analysis (PCA)

In the study area, ordinary PCA was used based on the correlation matrix of variables [74]. Also, robust principal component analysis of compositional data (RPCA) was applied as a multivariate method to derive a multi-element geochemical signature of relationships among the observed variables [52, 55]. As expected, two factors were acquired. Among these components, PC1 was of the eigenvalue of greater than 1 (Fig.

16). Figure 16 further depicts the relative importance of the two components. In the first component, strong and positive loadings related to Pb and Ni can be observed. The high correlations between heavy metals may reveal that the two metals had a similar origin in the second group of

elements consists of Zn and Cu (Fig. 16). Correlation coefficient and PCA analyses results indicated a strong correlation between Zn and Cu.

Figure 15: Graph of PCA (left) and Scree plot (right) in the soil samples of the study area

According to the compositional biplots (Fig. 17), the RPC1 and RPC2 account for 57.55% and 33.79% of the total variation (Table 5), respectively. Besides, the RPC1 shows positive loadings for Pb and Ni (Fig. 17). Also, the RPC2 shows positive loadings for Cu and Zn.

These results indicate that principal component 1 is originating from common anthropogenic sources, whereas, principal component 2 might be from natural origins. The main anthropogenic sources in the region include mining activities.

Figure 16: Bi-plots of robust PC1 versus robust PC2 of the ilr transformed raw data

Table 5: Rotated component matrix of robust factor analysis. Significant loadings (bolded values) are selected based on the absolute threshold values of 0.5

Element	Component 1	Component 2
Cd	-0.498	-0.866
Cu	-0.481	0.804
Ni	0.942	-0.127
Pb	0.938	-0.153
Zn	-0.427	0.834
% of Variance	57.55	33.79
Cumulative %	57.55	91.34

4. CONCLUSIONS

In this research, we analyzed the heavy metals concentration and their source in soil samples of the Jajarm bauxite mine, using multivariate statistical techniques combined with metal concentrations analysis and correlation analysis that has been proven to be an effective tool for source identification of heavy metals. In soil samples of the study area, the average of the recorded concentration of elements for cadmium, copper, nickel, lead, and zinc are 0.09, 18.70, 48.80, 58.60 and 25.70 (mg/kg), respectively. The comparison of the mean concentrations of potentially toxic metals in samples with the average crust values for non-contaminated soil and average shale showed that the higher levels of contaminated metals are Ni and Pb compared to the average crust values

. The Cd, Cu and Zn metals are less than the average shale. To ensure a more comprehensive and accurate assessment of heavy metals contamination results, three evaluation methods of enrichment factor, geoaccumulation index, and the contamination factor was applied. Based on the classification, the lowest contamination with a CF value of less than 1 was related to the elements such as Cd, Cu, and Zn. Also, the other elements such as Ni and Pb, based on the average values have contamination coefficients 1.85 and 2.10, respectively. The PLI average value for all samples was equal to 0.31. According to the calculation and classification of geoaccumulation index, the Jajarm bauxite mine contamination levels were from non-contaminated (Cd, Cu, and Zn, $I_{geo} < 0$, natural origins) to low contamination (Pb and Ni, $I_{geo} > 0$, anthropogenic sources). The distribution of heavy metals in the soil was not uniform over the whole section of the study area and the change in concentration was due to the release of these metals from different natural and anthropogenic sources. Heavy metals levels and distribution was found higher at that sites which were in the vicinity of mine pits and waste dumps and were probable sources of metal pollution. In this research, we applied the robust principal component analysis of compositional data (RPCA). According to the compositional biplots, the RPC1 and RPC2 account for 57.55% and 33.79% of the total variation, respectively. The RPC1 showed positive loadings for Pb and Ni while the RPC2 showed positive loadings for Cu and Zn. The results indicated that extract the mineral from the bauxite mine except for Pb and Ni, have not created more environmental hazards in the study area. Therefore, heavy metals contaminant, in the Jajarm bauxite mine should be carefully monitored and controlled in the future. In order to conduct successful plans and methods of control and prevention and for better management of wastewater and sewage contaminated in the Jajarm bauxite mine with heavy metals, it is important to observe the following points: Public education for disposal of waste containing heavy metals and compounds; Institutionalize strategies, including environmental monitoring, implementation of environmental regulations and tracking heavy metals from generation time to becoming waste

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