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ORIGINAL ARTICLE

Assessment of the metals contamination and their grading by SAW method: a case study in Sarcheshmeh copper complex, Kerman, Iran

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Abstract Studying the distribution of metals in the soil of mineral regions is one of the most important environmental issues. These metals are transferred to the cycle of nature by geogenic and anthropogenic resources, causing serious short- and long-term effects, and posing serious risks for the survival of living organisms. Various mining activities, smelting and beneficiation processes are important anthropogenic factors in the presence of metals in soil, which play a far more effective role in soil pollution than natural factors. Sarcheshmeh copper mine in Kerman is one of the largest copper sulfide mines in the world, for which evaluation and grading of metals contamination has paramount importance due to the high volume of mining. In this study, in order to determine the metal content in the surface soil from the Sarcheshmeh copper complex soils area, 120 surface soil samples were taken from a depth of 30 cm, and analyzed for the metals Pb, Ni, Se, Mo and Zn using the ICP-MS method. Then, the contamination coefficient, enrichment factor and geoaccumulation index of these metals were calculated. Based on expert views on the relative importance of each of the indicators and their final weight, risk assessment and grading by the simple additive weighting (SAW) method was performed. According to the results, the highest risk of pollution was obtained for nickel and the lowest was for selenium.

Keywords Metals · Contamination factors · SAW techniques · Sarcheshmeh copper complex

Introduction

This study is one of very few dealing with the distribution and the origin of metals in Sarcheshmeh copper complex soils area. In many industrialized countries, soil contamination has become a serious problem. Significant increases in soil metal content are found in areas of high industrial activity where accumulation may be several times higher than the average content in non-contaminated areas. Additionally, areas distant from industrial centers also show increased metal concentrations due to long-range atmospheric transport. The impact of metal pollution on ecosystems due to anthropogenic activities like smelting or mining activities has been frequently investigated (Adriano 1986; Cambier 1997; Dijkstra 1998; Sheppard et al. 2000). In industrial countries, atmospheric pollutants have affected forests and soils during the last century. Particularly, long-range atmospheric transport of metals can lead to pollutant deposition even in supposedly pristine areas (De Vries et al. 2002).

Thus, there is a considerable variation in how the impact of anthropogenic pollution on a given site is quantified. Such variation has subsequent implications for the overall assessment, monitoring and management of contaminant effects. Much of this impact relates to the dispersion of metal contamination into soils, sediments, ground and surface waters, and subsequent uptake by biota. Relating effects of contamination on the environment commonly

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requires separation of background population(s) and patterns related to natural or geogenic processes from populations or outlying values relating to the effects of mineralization or anthropogenic environmental contamination. This is particularly important in agricultural areas (Tlili-Zrelli et al. 2013).

Furthermore, knowledge of soil geochemistry is fundamental when we attempt to determine the effects stemming from an anthropogenic activity and its impact on the geoecosystems as a result of its toxicities (Albanese et al. 2007; Cicchella et al. 2008; Giaccio et al. 2012; Guillén et al. 2011, 2012). In this respect, it is essential to establish geochemical maps for chemical elements associated with different lithologies in order to distinguish if their source is geogenic or anthropogenic (Plant et al. 2001). In assessing the impact of metal pollution on mining environments, a number of different reference materials and enrichment calculation methods have been used by various workers (Salomons and Förstner 1984; Müller 1969; Hakanson 1980). In addition to the scientific or mining standpoint, geochemical maps constitute an effective tool for environmental planning (Ferguson and Kasamas 1999; Li et al. 2004). They reveal information about source, distribution, and dynamics of chemical elements. Geochemical maps include both the geogenic concentration or geochemical background (GB) value, and the concentration that is the result of anthropogenic activity (Guillén et al. 2011). This explains why GB defined by Hawkes and Webb (1962) as "the normal abundance of a chemical element in barren earth material" has become crucial in environmental studies. It was introduced to differentiate between normal and abnormal element concentration (Martínez et al. 2007). Exploratory Data Analysis (EDA) has been recommended as an effective tool to determine the GB (Zhou and Xia 2010). According to the literature, this method was tested and proven by numerous authors (Bounessah and Atkin 2003; Reimann et al. 2005).

A focused and strategic approach to assessing the ecological risk of contaminants can be effective in preventing or reducing contamination (Hayaty et al. 2014). In fact, knowing the quantity and concentration of contaminants in the soils, and recognizing and correctly ranking the risk factors associated with each, is essential for proper evaluation and an appropriate response to environmental risks to reduce down-gradient damage (Hwang and Yoon 1981).

The Sarcheshmeh Copper Mine in Iran is one of the world's largest copper sulfide mines (Hayaty et al. 2014). In this study, we determined evaluation criteria, including the contamination factor (CF), enrichment factor (EF), pollution load index (PLI), and geoaccumulation index (I_{geo}), to assess the risk of pollution from metals (Pb, Ni, Se, Mo, and Zn) around the mines soils. Although it is relatively easy to assess each of these criteria, considering all of them simultaneously is more challenging. The soil contaminants in the studied area were assessed using the simple additive weighting (SAW) technique. Fuzzy techniques have been used alone or in combination with other methods in previous environmental studies (Tzeng and Hwang 2011).

Materials and methodology

The study area

The Sarcheshmeh Copper Mine is located 160 km southwest of Kerman Province and 50 km from the city of Rafsanjan (Hayaty et al. 2014). The location of the Sarcheshmeh copper complex is shown in Fig. 1.

Sampling and analysis

Special consideration was given to the used criteria to select sampling point locations. After a review of topographic and geologic maps, and according to previous studies on the Sarcheshmeh Copper Mine (Shayestehfar and Rezaei 2010), soil sampling was established in different areas. The sampling design was made to compare the concentration gradient and possible chemical element mobilization. In order to estimate the metals ratio in the surface soils of the Sarcheshmeh copper mine area and to evaluate the pollution level, 120 surface soil samples were collected up to a depth of 30 cm.

Samples were taken within the first 30 cm of soil using a stainless steel shovel.

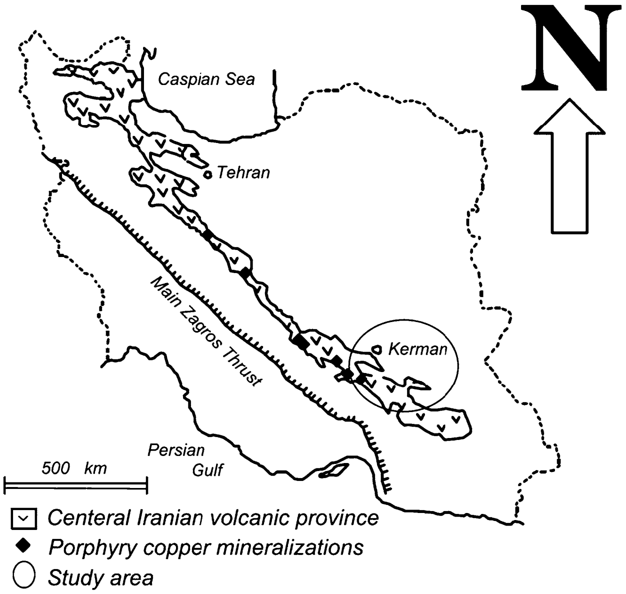


Fig. 1 Geographic location of Sarcheshmeh copper complex

To minimize sampling errors, each sample underwent a quartering operation, and then was stored in a polyethylene bag. After this step, each sample was dried in an oven at 100 °C in the laboratory and then sieved through a 2-mm mesh. The sample which was smaller than 2 mm was ground in agate mortar until it was a fraction smaller than 63 µm for subsequent chemical analysis. Chemical analyses were carried out at Acme Analytical Laboratories Ltd. (Vancouver, Canada), and were analyzed for the metals of Pb, Ni, Se, Mo and Zn with the help of inductively coupled plasma-mass spectrometer (ICP-MS). The data quality was assessed using duplicate sample analyses, blanks, and concentration measurement accuracy estimation. The accuracy and precision of the analysis was confirmed by sending duplicate samples to the Tarbiat Modares University laboratory in Iran. The analytical precision and the accuracy were better than ±5 % for the analyzed elements. Figure 2 shows the location of sampling stations.

Statistical analysis

Descriptive statistics

The following statistical parameters were determined for the five considered and analyzed elements: minimum, maximum, mean for the central tendency measurement, standard deviation for the data dispersion measurement; while the data distribution was tested for normality using the Kolmogorov–Smirnov (K–S) test, (Table 1). These parameters will be helpful for comparing datasets, and subsequently summarizing the obtained results and facilitating its consequent interpretations (Burgos et al. 2005; Cai et al. 2012; Martínez et al. 2007). Figure 3 shows the histogram of the metals Pb, Ni, Se, Mo, and Zn.

Investigating the statistical distribution of concentrations of Pb, Zn and Mo metals shows the abnormal distribution with positive skewness, indicating anthropogenic factors, in addition to geogenic factors and weathered rock units in the concentration of these elements in different parts of the soil. In other words, a sort of enriched earth was observed in some samples and their statistical distribution was also characterized. This fact can be interpreted from the histogram of metals. Maximum concentrations of metals Pb, Ni, Se, Mo and Zn samples are measured, and the result is 1124, 88.7, 4.8, 39 and 2652 mg/kg, respectively. The average concentration of metal prevalence is: Zn > Pb > Ni > Mo > Se.

The map of variations in the concentration of metals Pb, Ni, Se, Mo and Zn in the studied area is shown in Figs. 4, 5, 6, 7 and 8.

Methods for estimating background and baseline concentration

A crucial first step in evaluating the impact of soil pollution and the level of contamination affecting a given area is to establish a reference background or baseline sample of known metal composition. Two methods are considered. The first being the use of average crustal values as reference concentrations, and the second method seeks to establish a local baseline by analyzing comparable local soil unaffected by anthropogenic activity.

Background values from average crustal concentrations

In earlier environmental work (Salomons and Förstner 1984), a common method for comparing soil metal concentrations with precivilization background levels was to compare the present-day metal levels with their concentrations in standard earth materials such as average shale (Turekian and Wedepohl 1961) or average crustal values (Taylor 1964). Abundances of the studied metals in average continental shale and crust are presented in Table 2.

According to Fig. 9, a comparison of the mean concentrations of potentially toxic metals in soil samples with the average crust values for uncontaminated soils and average shale shows that the higher levels of contaminated metals are Pb, Se, Mo and Zn compared to the average crust values. The Ni metal is less than the average shale. The mean average of the Ni element is less than the average in the shale. According to Table 2, the correlation between Pb and Zn is very high. In addition, a very good correlation between Mo and Se can be clearly recognized.

Results and discussion

Determination of assessment criteria of soil risk

The quantitative results of analysis of the studied soils indicated variable concentrations of metals, and therefore the statistical parameters listed in Table 1 were used to show their range in the sampling stations.

When the geochemical distribution of elements in the environment is due to natural and human factors, to assess the trend of changing contaminant concentration in environmental studies, factors such as contamination factor, pollution load index, enrichment factor and geoaccumulation index are used (Adama et al. 2005; Vardes et al. 2005; Reddy et al. 2004; Selvaraj et al. 2004). In this

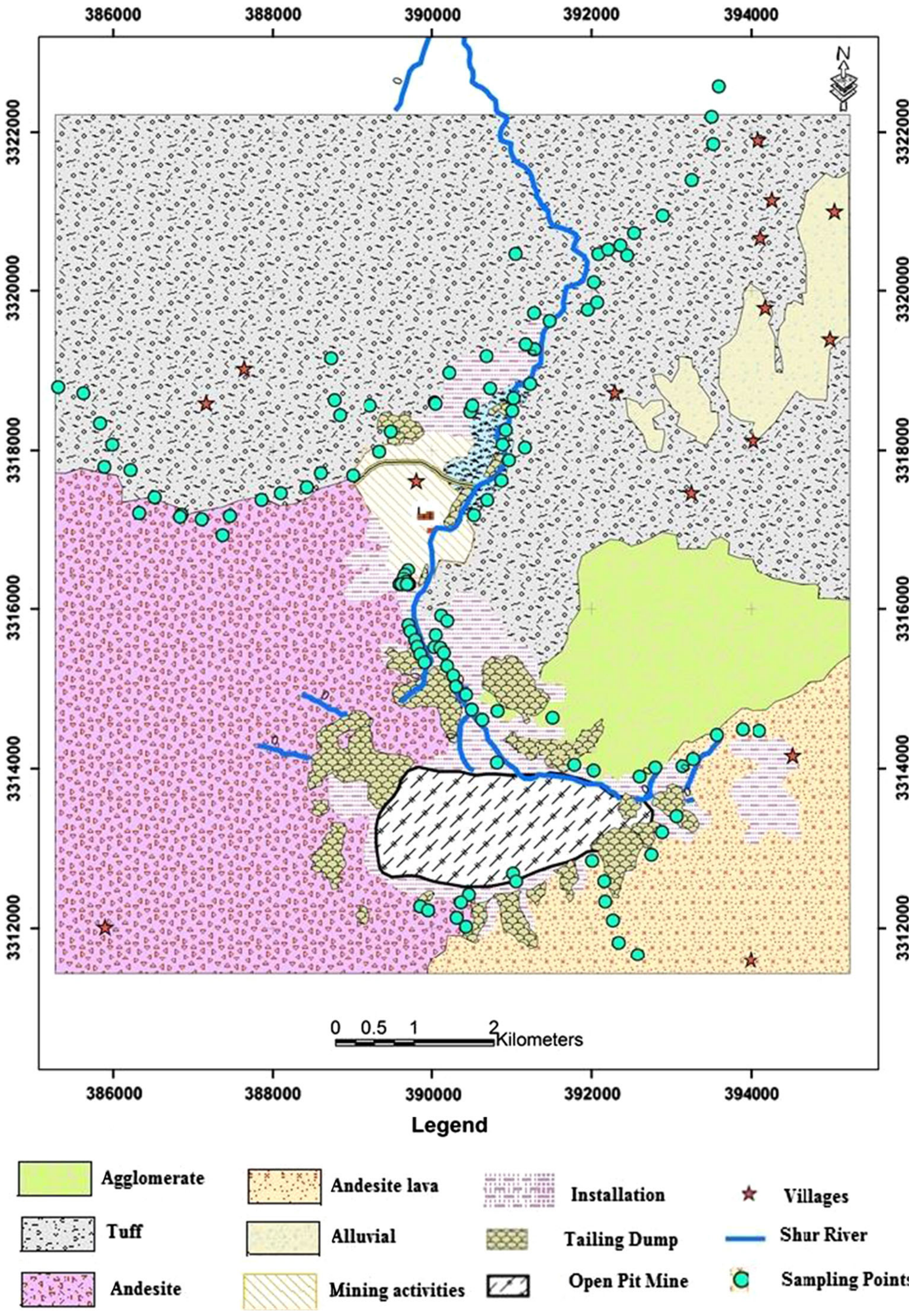


Fig. 2 Map of sampling stations of soils in the Sarcheshmeh copper complex

study, the above criteria were calculated for soils of Sarcheshmeh copper complex area, and were used as indicators of increases in the pollution risk caused by metals. Thus, the multi-criteria decision-making techniques such as simple additive weighting (SAW) were used to consider the combined and simultaneous effects of all the indicators for different elements, and the formulas were obtained as well.

Contamination factor (CF)

The CF is the ratio of the element concentration in a sample to its concentration in the background sample. CF values higher than 1 indicate contamination:

$$\mathrm{CF} = \frac{C_{\mathrm{Sample}}}{C_{\mathrm{Background}}} \tag{1}$$

Table 1 Descriptive basic statistics of the metals in the surficial soils of Sarcheshmeh copper complex (mg/kg)

Element	Valid *N*	Mean	Maximum	Minimum	Std. dev.
Pb	120	127.62	1124.40	15.04	158.02
Ni	120	27.02	88.70	6.40	12.58
Se	120	1.08	4.80	0.1	0.81
Mo	120	7.08	39.80	0.35	8.11
Zn	120	252.23	2652.50	44.30	318.90

in which C_{sample} is the concentration of an element in the sample and $C_{\text{background}}$ is the concentration of that element in the background sample. The background sample is obtained by statistical methods by comparing soil samples from the region with local soils not influenced by human factors (Abrahim and Parker 2008; Adomako et al. 2008). Table 3 shows the CF for the Sarcheshmeh complex soils area.

Pollution load index (PLI)

This index is calculated using the following equation:

$$\text{PLI} = \sqrt[n]{\text{CF}_1 \times \text{CF}_2 \times \text{CF}_3 \times \cdots \times \text{CF}_n}. \tag{2}$$

Pollution load index values higher than 1 indicate contamination and values close to one indicate similar concentrations of the contaminant in the studied sample and background sample (Adomako et al. 2008; Qishlag et al. 2007). The calculated PLI in this study was 2.49.

Enrichment factor (EF)

In order to select chemical elements that have been enriched in the Sarcheshmeh copper mine area soils, enrichment factor (EF) was calculated (Bourennane et al. 2010; Li and Feng 2012; Martínez et al. 2007). It was widely employed to identify the anthropogenic source of metallic elements (Li and Feng 2012). Based on EF, five contamination categories were recognized: (1) EF <2 states deficiency to minimal enrichment; (2) $2 \leq \text{EF} < 5$ moderate enrichment; (3) $5 \leq \text{EF} < 20$ significant enrichment; (4) $20 \leq \text{EF} \leq 40$ very high enrichment, and; (5) EF >40 extremely high enrichment (Han et al. 2006; Lu et al. 2009). The EF was calculated for the chemical elements using the following generalized equation according to Chester and Stoner (1973) and Zoller et al. (1974):

$$\text{EF}_{\text{El}} = \frac{[\text{El}]_{\text{sample}}/[X]_{\text{sample}}}{[\text{El}]_{\text{crust}}/[X]_{\text{crust}}}, \tag{3}$$

where “El” is the element under consideration, the square brackets indicate concentration (usually in mass/mass units, such as mg/kg), “*X*” is the chosen reference element (see below) and the subscripts “sample” or “crust”

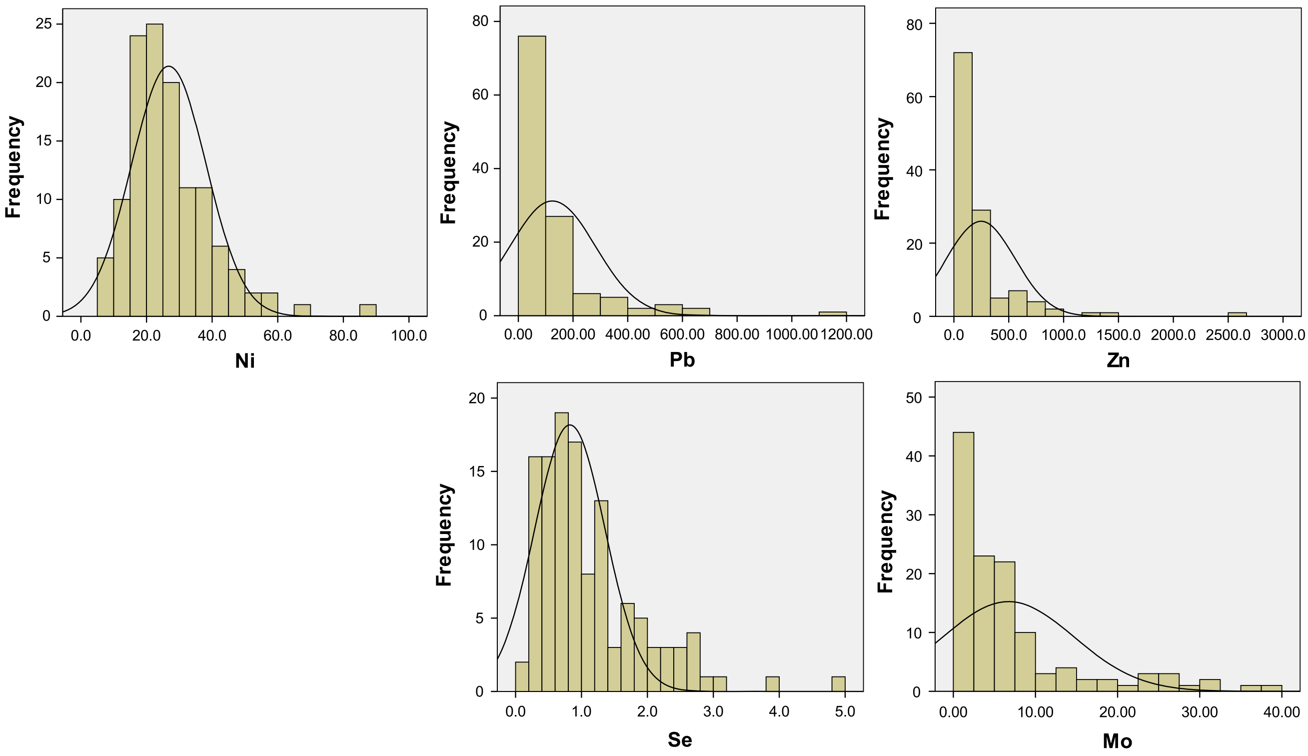


Fig. 3 Histogram of metals Pb, Ni, Se, Mo and Zn

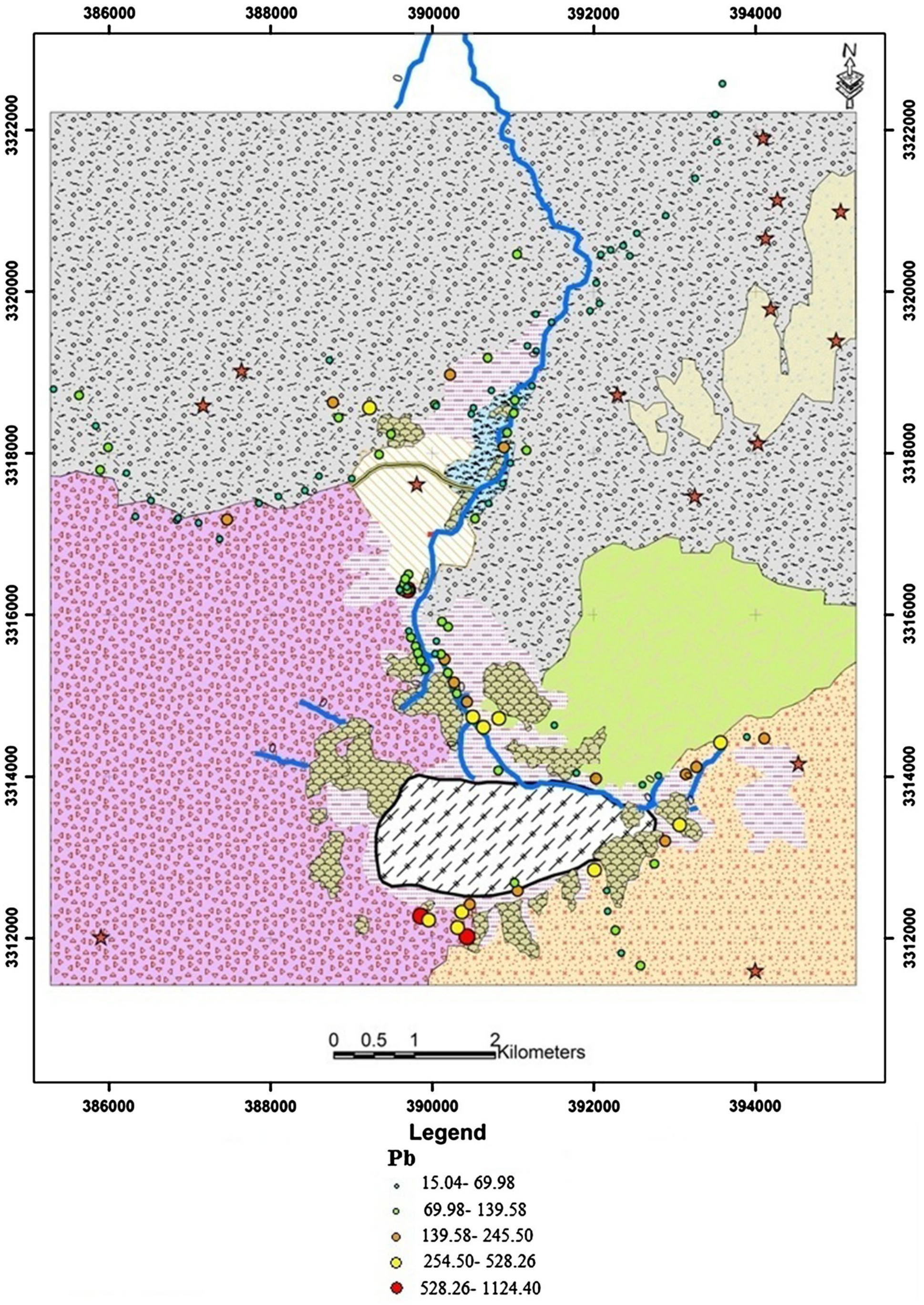


Fig. 4 Map of variation in Pb concentrations at Sarcheshmeh copper complex

indicate which medium concentration refers to. In this study, scandinum was selected to be the reference value. Indeed, Sc is the most common reference value used to calculate the EF (Bourennane et al. 2010; Buat-Menard and Chesselet 1978; Lu et al. 2009).

Table 4 summarizes EF values which indicate how many times the measured concentrations exceed the Clarke values.

Geoaccumulation index (I_{geo})

Another index used for risk assessment of metals in soils is I_{geo} (also known as the Muller index), which can be expressed as (Audry et al. 2004; Bermejo Santos et al. 2003; Munendra et al. 2002; Muller 1979):

$$I_{\mathrm{geo}} = \log_2^{[C_n/1.5B_n]}, \tag{4}$$

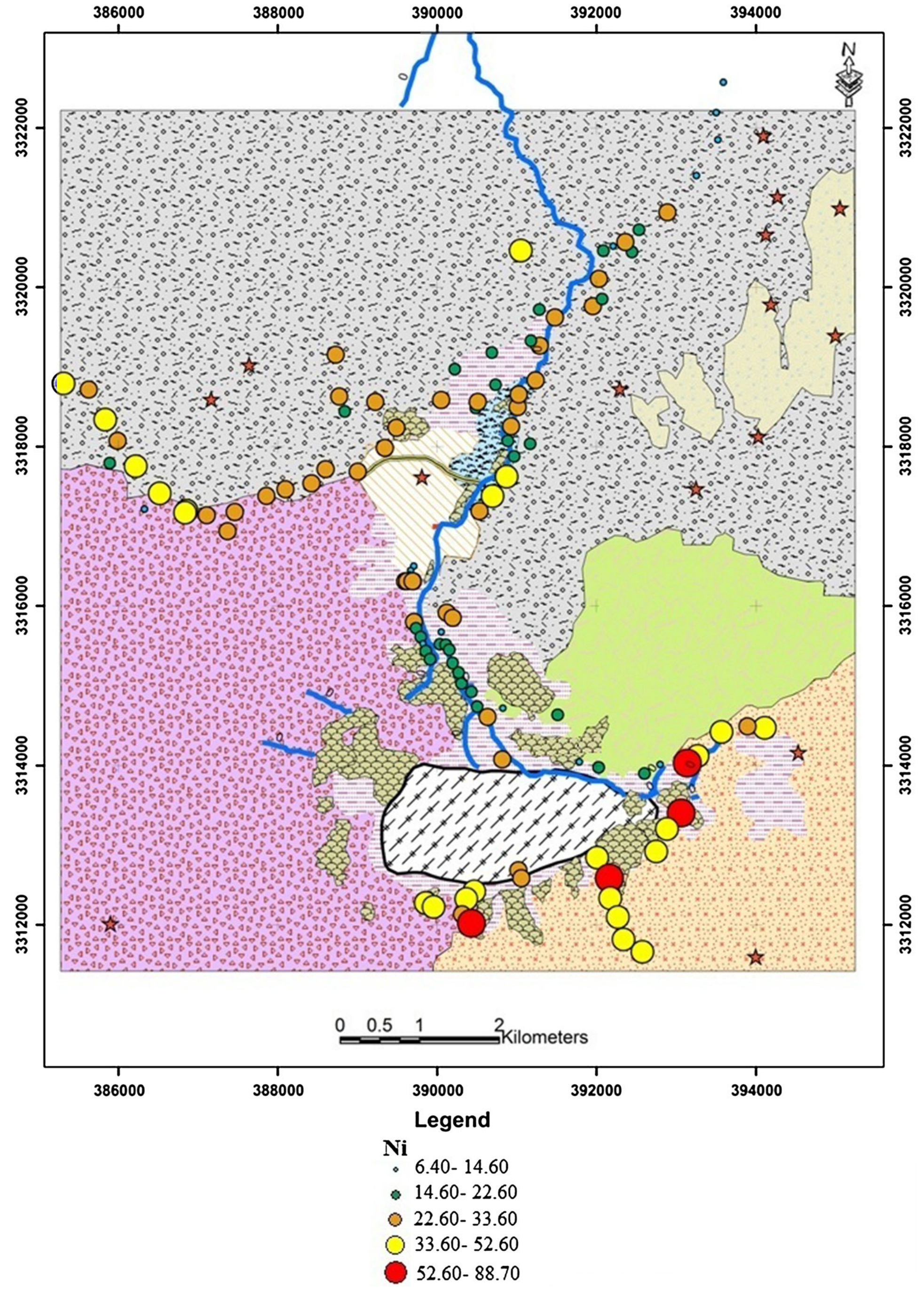


Fig. 5 Map of variation in Ni concentrations at Sarcheshmeh copper complex

where *Cn* is the measured concentration of the element in the sample and *Bn* represents the concentration of the element in the background sample. 1.5 coefficient is used to eliminate possible changes in the background due to geological effects (Chen et al. 2007; Ghrefat and Yusuf 2006). Table 4 lists the calculated values of this index for metals in the soils and the associated pollution load to the region.

FDAHP methodology

Establishment of comparison matrixes

To evaluate the risk of metal contamination and ranking them using quantitative techniques MADM, coefficient of relative importance index was calculated using experts. In order to establish the main comparison matrix using the

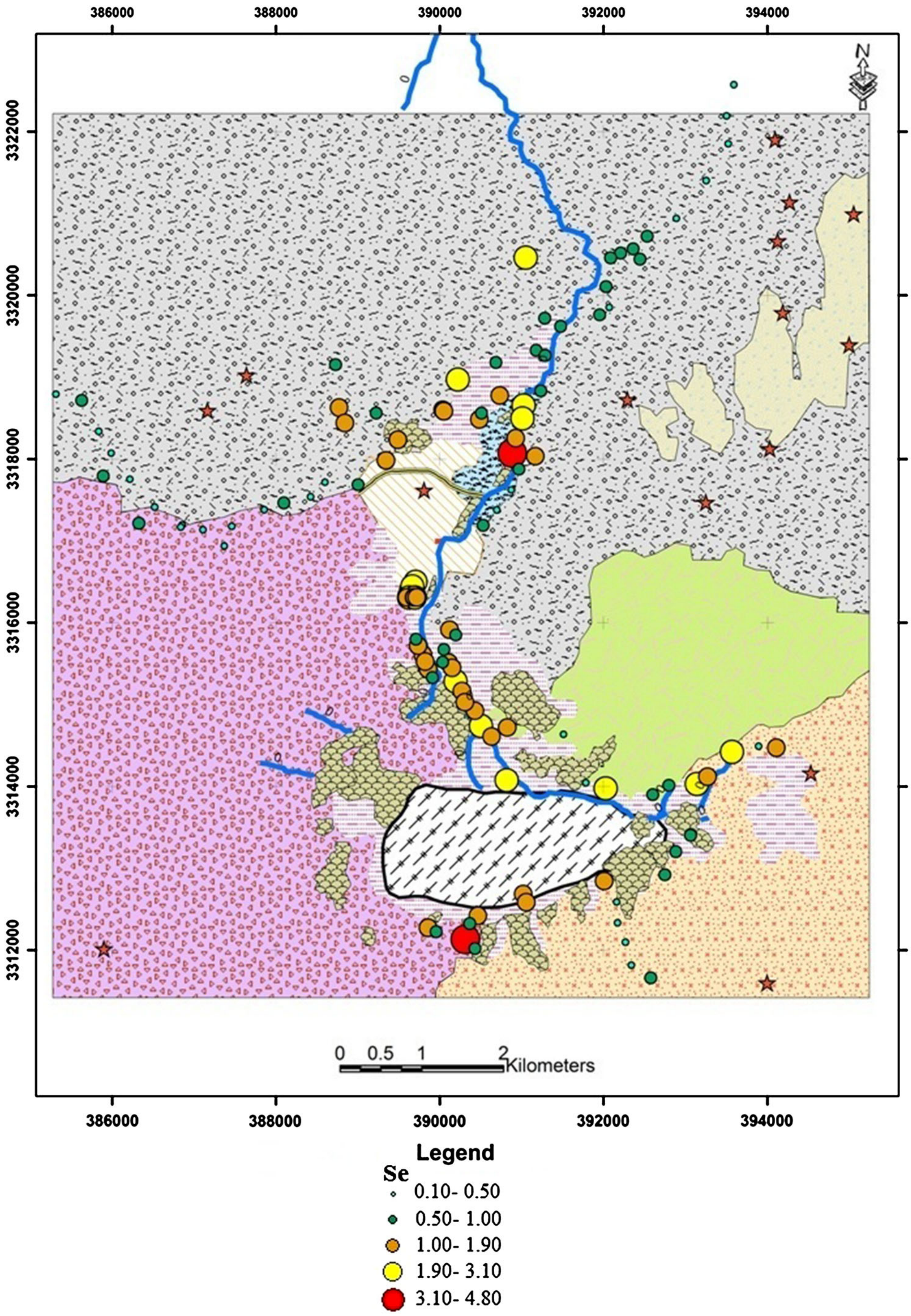


Fig. 6 Map of variation in Se concentrations at Sarcheshmeh copper complex

FDAHP method, it is essential to have comparison matrix of parameters based on each expert's opinion. For this purpose, technical questionnaires were prepared, based on the Saaty (1980) rating scale (Table 5).

Let C$_1$, C$_2$, …, C$_n$ denote the set of elements, while a_{ij} represents a quantified judgment on a pair of elements C_i and C_j. The relative importance of two elements is obtained from division rate of C_i on rate of C_j based on the questionnaire. This yields an $n \times n$ matrix A as follows (Hoseinie et al. 2009):

$$A = \left[a_{ij}\right] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \ldots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}. \tag{5}$$

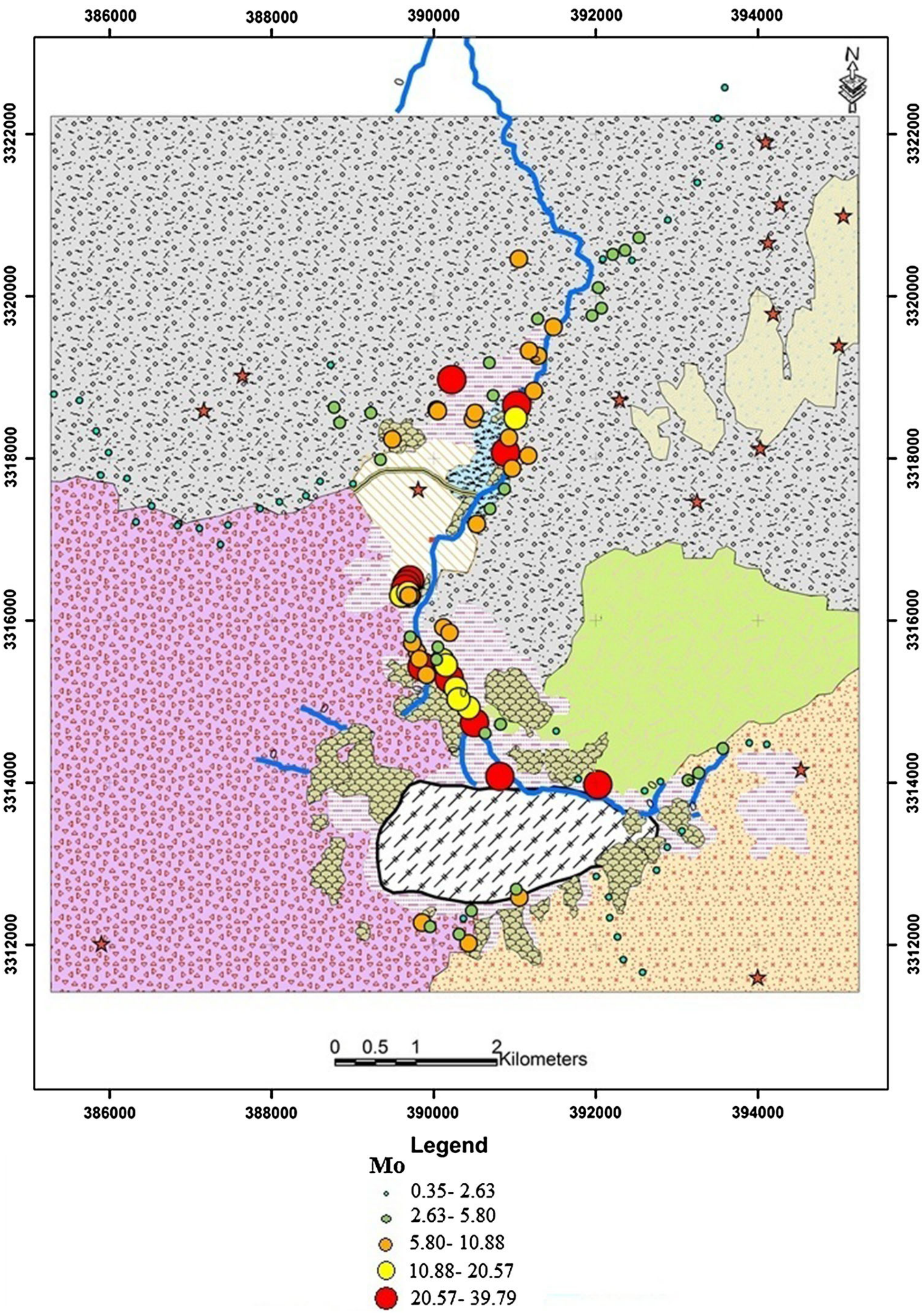


Fig. 7 Map of variation in Mo concentrations at Sarcheshmeh copper complex

Establishing the major comparison matrix

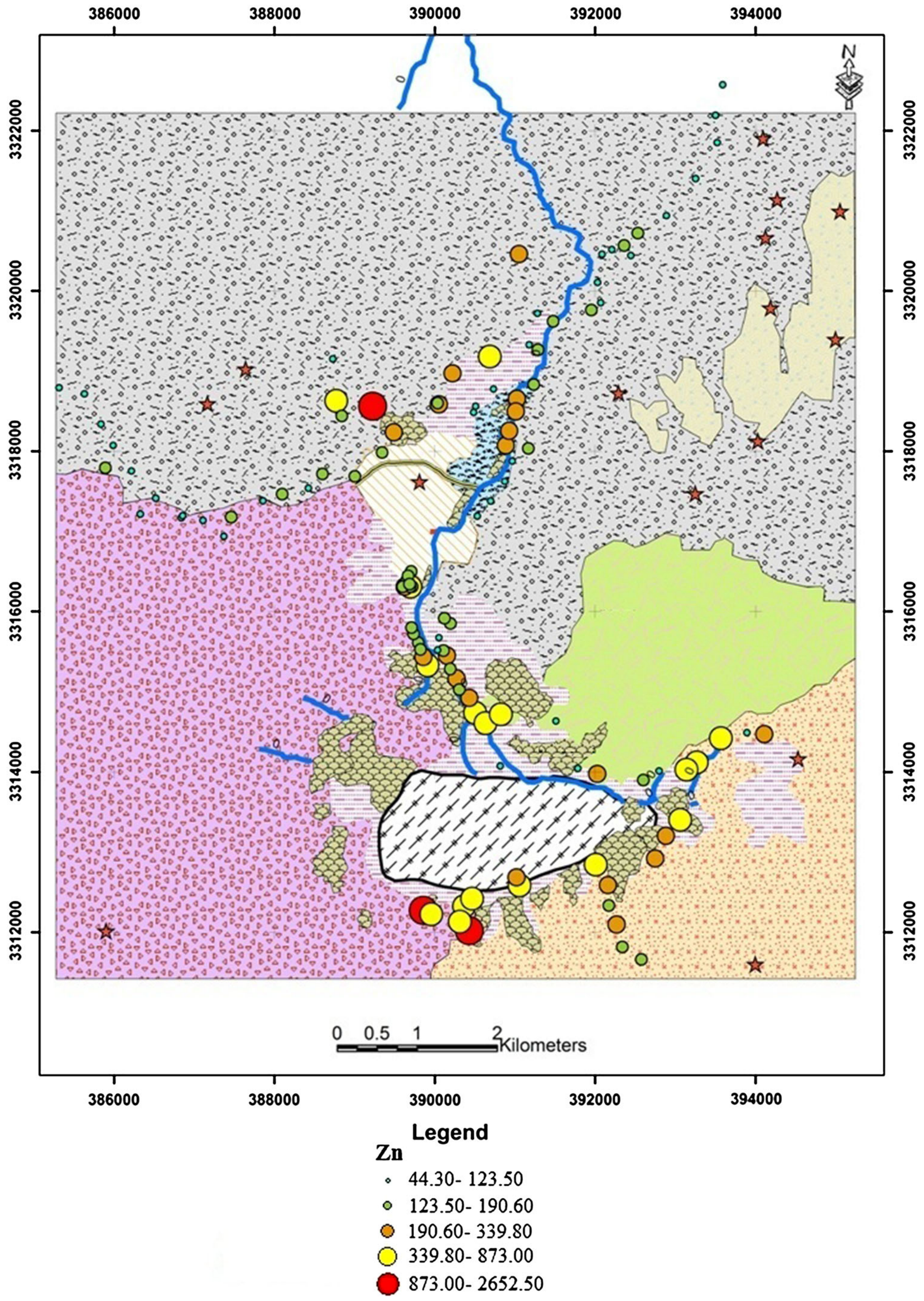
These steps should be followed to establish a major pairwise comparison matrix using the fuzzy Delphi method (Liu and Chen 2007):

(a) Computation of triangular fuzzy numbers (TFNs); $\tilde{a}_{ij}$. In this work, the TFNs (as shown in Fig. 10 and Eq. 9) that represent the pessimistic, moderate and optimistic estimates are used to represent the opinions of experts about each parameter.

$$a_{ij} = \left(\alpha_{ij}, \delta_{ij}, \gamma_{ij}\right) \tag{6}$$

$$\alpha_{ij} = \mathrm{Min}\left(\beta_{ijk}\right), \quad k = 1, \ldots, n \tag{7}$$

Fig. 8 Map of variation in Zn concentrations at Sarcheshmeh copper complex



$$\delta_{ij} = \left(\prod_{k=1}^{n} \beta_{ijk} \right)^{1/n}, \quad k = 1, \ldots, n \tag{8}$$

$$\gamma_{ij} = \mathrm{Max}\left(\beta_{ijk}\right), \quad k = 1, \ldots, n \tag{9}$$

where $\alpha_{ij} \leq \delta_{ij} \leq \gamma_{ij}$ are obtained from Eqs. 10–12; α_{ij} indicates the lower bound and g_{ij} indicates the upper bound, β_{ijk} indicates the relative intensity of importance of expert k between parameters i and j, and; λ is the number of experts. (b) Following the above outlines, a fuzzy positive reciprocal matrix $\tilde{A}$ can be calculated:

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (\alpha_{12}, \delta_{12}.\gamma_{12}) & (\alpha_{13}, \delta_{13}, \gamma_{13}) \\ (1/\gamma_{12}, 1/\delta_{12}, 1/\alpha_{12}) & (1,1,1) & (\alpha_{23}, \delta_{23}, \gamma_{23}) \\ (1/\gamma_{13}, 1/\delta_{13}, 1/\alpha_{13}) & (1/\gamma_{23}, 1/\delta_{23}, 1/\alpha_{23}) & (1,1,1) \end{bmatrix} \tag{10}$$

Table 2 Selected metal concentrations in average continental shale and average continental crust

Element	Average continental crust[b]	Average continental shale[a]	Average soil samples
Se	0.4	0.5	1.08
Pb	14.8	20	127
Ni	40	68	27
Mo	2	3	7.1
Zn	65	95	252

[a] Turekian and Wedepohl (1961)

[b] Wedepohl (1995)

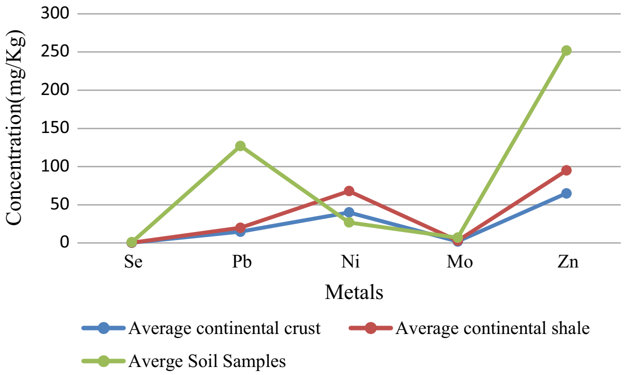


Fig. 9 A comparison of the mean concentrations of potentially toxic metals in soil samples at Sarcheshmeh copper complex with the average crust values for uncontaminated soils and average shale

Table 3 Contamination factors (CF) for metals in soils at Sarcheshmeh copper complex

Baseline	Contamination Factor				
	Se	Zn	Ni	Mo	Pb
CF (average continental crust)	2.70	4.06	1.48	3.93	4.01
CF (background)	0.98	3.82	1.80	4.53	3.85
Concentration (mg/kg)					
Average continental crust	0.4	65	40	2	14.8
Background	1.1	66	15	1.03	31

(c) The relative fuzzy weights of the evaluation factors are calculated

$$\tilde{Z}i = \left[\tilde{a}_{ij} \ldots \tilde{a}_{in}\right]^{1/n}, \quad \tilde{W}i = \tilde{Z}i\,(\tilde{Z}i \oplus \cdots \oplus \tilde{Z}n), \tag{11}$$

where $\tilde{a}_1 \otimes \tilde{a}_2 = (\alpha_1 \times \alpha_2,\ \delta_1 \times \delta_2,\ \gamma_1 \times \gamma_2)$. The symbol $\otimes$ denotes the multiplication of fuzzy numbers and the symbol $\oplus$ denotes the addition of fuzzy numbers. $\tilde{W}_i$ is arrow vector in consist of a fuzzy weight of the *i*th factor $\tilde{W}_i = (\omega_1, \omega_2,\ \omega_3, \ldots \omega_n)$. Defuzzification (changing the fuzzy number to a usual number) is based on the geometric average method (Kaufman and Gupta 1988):

$$\tilde{W}i = (\Pi_{i=1}^{3}\ \omega_j)^{1/3}. \tag{12}$$

Risk assessment using FDAHP and SAW methodology

At this stage, FDAHP method is used to obtain final weighting of the criteria and then the simple additive weighting (SAW) method is applied to determine the highest pollution and critical risk among the metals in the soils under study. A comparison matrix of parameters based on each expert's opinion is required to establish the main pair-wise comparison matrix using the FDAHP method. Since there were 4 criteria and 6 experts, six 4 × 4 pair-wise comparison matrixes (Supplementary Tables 4–6) were established for the following calculations. The total weights of criteria are listed in Table 6.

Most of data in a multi-attribute decision-making (MADM) problem are unstable and changeable, then sensitivity analysis after problem solving can effectively contribute to making accurate decisions. This study provides a new method for sensitivity analysis of MADM problems so that by using it and changing the weights of attributes, one can determine changes in the final results of a decision-making problem. This analysis applied to simple

Table 4 Calculation results of risk indicators for metals in soils at Sarcheshmeh copper complex

Element	CF	EF	Classification of concentration factor	i_{geo}	Intense pollution of the area on the basis of I_{geo}
Se	0.98	1.51	No concentration	<0	No contamination
Zn	3.82	2.88	Medium (avg.) concentration	0.32	Uncontaminated–low contamination
Ni	1.80	0.58	Low concentration	<0	No contamination
Mo	4.53	2.02	High concentration	0.14	Uncontaminated–low contamination
Pb	3.85	6.98	Medium (avg.) concentration	1.47	Low contamination

Table 5 The Saaty rating scale (1980)

Importance	Definition	Explantation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favor one over the other
5	Much more important	Experience and judgement strongly favor one over the other
7	Very much more important	Experience and judgement very strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed

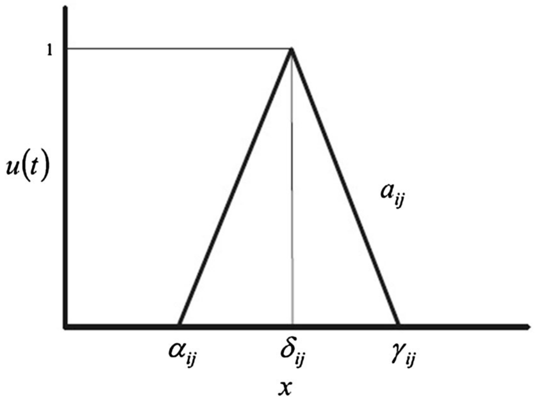


Fig. 10 The membership function of the fuzzy Delphi method

additive weighting (SAW) technique, one of the widely used multi-attribute decision-making techniques, and the formulas are obtained.

SAW technique

The SAW technique is one of the most used MADM techniques. It is simple and is the basis of most MADM techniques such as AHP and PROMETHEE that benefits from an additive property for calculating the final score of alternatives. This type of sensitivity analysis can be applied in MADM-related software for solving decision-making problems so by adding it to this software and by utilizing graphical capability of a computer, one can change the weight of one attribute arbitrarily and observe its effect on the final score and rank of alternatives, immediately. The following suggestions are proposed for future researches:

Table 6 Total weights of criteria resulted from FDAHP method

Risk assessment criteria	Total weight
Contamination factor	0.191
Average concentration	0.257
Enrichment factor	0.236
Geoaccumulation index	0.316

- Evaluating the effect of changes in one element of the decision-making matrix on the final score of alternatives in the SAW technique.
- Studying the effect of simultaneously changes in the weight of one attribute and one element of decision-making matrix on the final score of alternatives in the SAW technique.
- Applying this type of sensitivity analysis for other techniques of MADM such as PROMETHEE and AHP.

In the SAW technique, the final score of each alternative for ranking is calculated as follows:

$$A = \left\{ \frac{\Sigma_j w_j \cdot r_{ij}}{\Sigma_j w_j} \right\}, \tag{13}$$

where r_{ij} are normalized values of decision matrix elements.

The vector for weights of attributes is obtained from following relation:

$$A = \left\{ \Sigma_j w_j \cdot r_{ij} \right\}, \tag{14}$$

wherein $W_j = (W_1, W_2, \ldots, W_k)$ weights are normalized and sum of them is 1.

The SAW algorithm is summarized in two main steps (Tzeng and Huang 2011):

Step 1: Using a linear scaling of parameters by the relations 15 and 16 for indicators with positive and negative effects, respectively:

$$n_{ij} = \frac{r_{ij}}{\max_i(r_{ij})};\quad X_j^+ \tag{15}$$

$$n_{ij} = \frac{\min_i(r_{ij})}{r_{ij}};\quad X_j^-;\quad j \in j^{/}. \tag{16}$$

Note that the effect is positive for all indices. This means that with increasing the amounts of these parameters for each element, the environmental risk increases. Therefore, Eq. 15 is used for data normalization.

$$n_{ij} = \begin{bmatrix} 0.000007 & 0.338 & 0.057 & 0.107 \\ 0.000007 & 0.511 & 1.000 & 0.028 \\ 0.095 & 0.143 & 0.231 & 0.004 \\ 1.000 & 0.368 & 0.117 & 1.000 \\ 0.218 & 1.000 & 0.052 & 0.504 \end{bmatrix}$$

Table 7 The final score and risk ranking of contaminations

Risk	Score	Rank
Pb	0.47	2
Ni	0.63	1
Se	0.11	5
Mo	0.38	3
Zn	0.14	4

If there is any qualitative attribute, we can use some methods for transforming qualitative variables to quantitative ones.

Step 2: Determining the final weight (score) of each option from Eq. 14 (Table 7)

In this step, the higher final score indicates the more critical conditions of the sampled element from the point of environmental contaminant risk. In other words, the ranking occurs on the basis of descending order of index A. According to Table 7, the risk ranking of metals is as Ni > Pb > Mo > Zn > Se.

Conclusions

In this study, first, by determining risk evaluation indices such as contamination index, pollution load index, enrichment factor and geoaccumulation index, we set out to assess metals contamination (Mo, Zn, Se, Ni and Pb) in Sarcheshmeh copper complex soils area. Then, by collecting expert opinions on the relative importance of each of the indicators mentioned in the environmental contamination risk of metals, through final weighting of the indices using Fuzzy Delphi Analytic Hierarchy Process (FDAHP), ranking and clustering of metals in the soils of the studied area was performed using the simple additive weighting (SAW) method. The diversity of pollutants in the soil, along with the need to apply appropriate environmental measures to reduce the risk and irreversible negative consequences on the environment, led to this contaminant evaluation for a successful risk management process. The comparison of the metals concentration average and the toxic potential in the soil samples has shown an average with respect to the world average for the uncontaminated soil amounts and shale. The conclusion from the calculation of the concentrated factor, for some of the samples shows that the average of the lead, zinc and Mo elements stations are more than the background values and the unnatural metal concentration is covered under the studied area. In this paper, the SAW method has been investigated as a multi-attribute decision-making (MADM) method in contamination risk ranking due to metals in the soil of the Sarcheshmeh copper mine areas. With respect to the kind, quality criteria, selected slightly principle and understanding of risk assessment, data acquired for weighting indices or final score which can be considered for the contaminant risk indices of metals. The more the index for a particular place is bigger the more a sampling area has been done, and the more the criticism of the metals of this particular area is exposed at open risk. Therefore, the obtained index can be used as a criterion for risk assessment and ranking of their criticality. With this technique, one fact which can easily be observed is that the scientific and accurate possibility of ranking has been obtained. Based on the results, Ni, Pb, Mo, Zn and Se showed the greatest level of contamination and criticality. Project management will be capable of programming a timely and suitable response to these risks by identifying risk factors and their contamination level, and better reducing the risk of down-gradient contamination.

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