IJABBR- 2014- eISSN: 2322-4827

International Journal of Advanced Biological and Biomedical Research

Journal homepage: www.ijabbr.com

Original Article

Metal Pollution Assessment in Soil Samples of Mining Area, Shahr-E-Babak, Iran

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ARTICLE INFO

Article history:
Received: 03 Dec, 2014
Revised: 29 Jan, 2015
Accepted: 28 Feb, 2015
ePublished: 30 Mar, 2015

Key words:
Shahr-e-Babak
Heavy metals
Soil pollution
Index
Mining

ABSTRACT

Objective: Metal concentrations in 53 soil samples of Shahr-e-Babak were determined. **Methods:** Assessment of enrichment factor and geo-accumulation index revealed higher degree of contamination of Cd, Pb, and Cu in soil samples. Moreover, results of metal fractionation study revealed high amount of Cd and Pb are associated in weakly bounds may lead to environmental risk of these metals. **Results:** According to the results of risk assessment code and pollution index, Cd and Pb have the high risk of release and pollution degree in soil samples of Shahr-e-Babak. A new quality index named industrial pollution index was developed based on background values of metal and their toxicity in soil samples. Results exhibits higher degree of pollution based on new index (I_{ind}) in south-eastern and central part of the study area where is close to the main anthropogenic sources.

1.INTRODUCTION

Mining, processing, and smelting activities considered as one of the main anthropogenic source of metal contamination in the environment (Chopin and Alloway, 2007; Chen et al., 2007; Alloway and Ayres, 1997; Valery and Eugene, 1998). During the smelting of metalliferous ores, toxic metals such as Cu, Pb, Hg, Ni, As, Cd, Cr, Co, and Zn and metalloids could be potentially released into the soil (Selinus, 2005; Khorasanipour and Aftabi, 2011). Anthropogenic inputs especially as a result of smelting of ores may lead to exceed metals concentration from natural background in soil (Siegel 2004; Callender 2005; Khorasanipour and Aftabi, 2011). Thus, superficial soil and vegetation usually contain high metals content compared with their background value in areas affected by mining activities (Liu et al., 2006; Dudka and Adriano 1997). Soil can purify only slowly and partially that leads to toxic metal pollutants tend to be accumulated in soil (Lim et al. 2005; Luo et al. 2005; Meers et al. 2005; Khorasanipour and Aftabi, 2011). Therefore, metal pollution in soil and plants affected by mining and smelting activities and their environmental impacts have been investigated by many researchers due to importance of food safety and human health (Chen 1988; Selim and Sparks 2001; Callender 2005; Selinus 2005; Adriano 1986; Chuan et al. 1996; Cambier 1997; Dijkstra 1998; Sheppard et al. 2000; Cezary and Bal Ram 2001; Burt et al. 2003; Soylak and Turkoglu 1999; Saracoglu et al. 2009).

Heavy metals accumulated in soil could easily enter the food chain and make serious health problem when physical-chemical properties of soil change into a suitable state for metals release (Saeedi et al., 2013; Calmano et al., 1993; Jamshidi-Zanjani et al., 2014). Thus,

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investigation of potential risk of release of heavy metals considered as crucial issue. However, total metal content is not suitable indicative of risk of release. Determinations of different metals fraction in soil provide deeper insight about potential risk of release of metals (Maiz et al, 2000; Wang et al, 2003). In other words, metal partitioning using the sequential extraction method (SEM) affect their availability and uptake by organisms (Gue et al, 2006).

Different metal quality indexes are the appropriate tools to assess metals pollution state in soil samples. Some of them calculate metal pollution state based on total metal content such as enrichment factor (EF) and geo-accumulation index (I_{geo}), and some others like risk assessment code (RAC) and pollution index (I_{poll}) include metal partitioning to estimate their pollution state (Jamshidi-Zanjani and Saeedi, 2013; Karbassi, 2008).

In the present study, metal pollution state in soil samples of Shahr-e-Babak using different quality indexes was investigated. Moreover, metal fractionation study applied on selected samples according to Tessier et al. (1979) to assess potential risk of release of toxic metals. A new index based on background values of metal and their toxicity degree is introduced to assess metal pollution state in the study area.

2. MATERIALS AND METHODS

2.1. Study area

The Shahre-e-Babak covers an area of 13572 km^2 in the north-western part of Kerman Province, south part of Iran. The Shahre-e-Babak is located between approximately N54º23' to 55º48' and E29º49' to 31º10'. There are major anthropogenic sources of metals such as Maiduk Copper Complex and Khatoon-Abad Copper Smelter in the central and south-eastern part of the study area, respectively. They enter toxic metals from mining activities to their adjacent environment which has adverse effect on soil, plants, animals, and public health. It should be mentioned that, agricultural activities and animal breading are the main job of the people in the study area. These anthropogenic sources of metals not only affect public health, but also have adverse effect on economic state of the residents due to interference with their activities. Although the Shahr-e-Baback receives considerable amount of toxic metals, there are not any deep studies about metal pollution state in the study area.

2.2. Soil sampling and chemical analysis

Fifty three surfacial soil samples (0-5 cm) were collected on May 2012 from Shahr-e-Babak (Fig.1). Most of samples were collected adjacent to Khatoon-Abad Copper Smelter and Maiduk Copper Complexes. Also, some samples were collected from unpolluted sites (far from the major anthropogenic sources) to determine metals background. Collected samples were transferred to the laboratory in plastic bags then were passed through a 63µm sieve. Samples were then digested with HNO3/HCL/H2O2 according to U.S.EPA 3050B test method to determination of total metals (Cu, Pb, Ni, Cr, Cd, Zn, Mn, and Fe) concentrations (U.S.EPA, 1986).

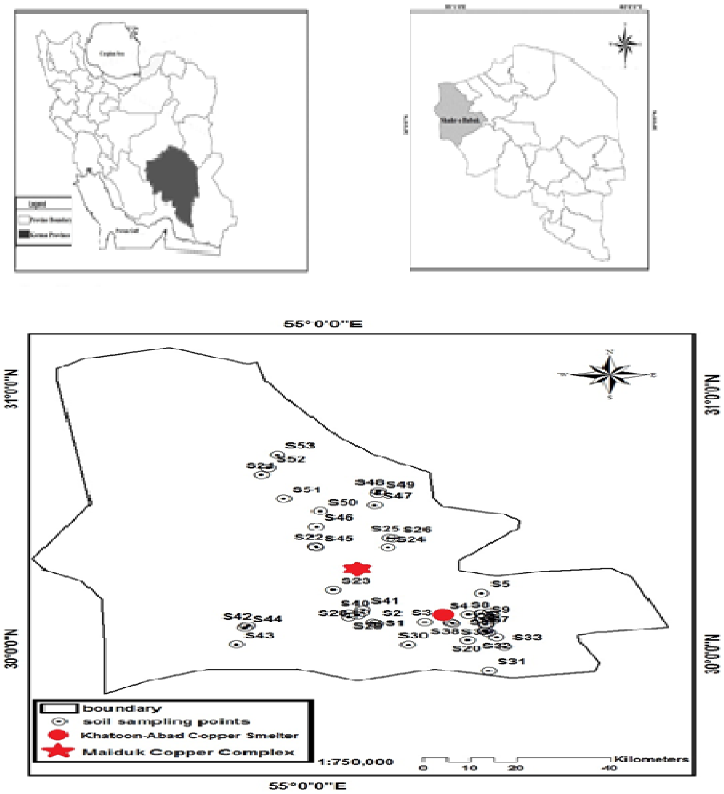


Fig. 1. Soil sampling points in Shahr-e-Babak

The five step sequential extraction methods proposed by Tessier et al. (1979) was applied on selected samples (10 of 53) to study metal partitioning.

F1. Exchangeable fraction: The weakly bound extraction procedure was conducted using 10 ml of 1M $MgCl_2$ (pH=7) for 1h at room temperature.

F2. Carbonate bound fraction: 10 ml of 1M sodium acetate added to residue obtained from the first step (F1) and adjusted with acetic acid to pH=5 then the mixture was shaken for 5h.

F3. Fe-Mn Oxide bound fraction: the residue obtained from the second step (F2) refluxed at 100ºC with 20 ml of 0.04M $NH_2OH.HCl$ in 25% (v/v) acetic acid for 6h.

F4. Organic bound fraction: 3ml of 0.02M HNO_3 and 5ml of 30% H_2O_2 were added to the residue obtained from the third step (F3) (at pH=2 with HNO_3), refluxed at 100ºC for 2h. Then 3ml of 30% H_2O_2 was added and the mixture was refluxed for 3h. To prevent adsorption of extracted metals onto oxidized soil, 5ml of 3.2M ammonium acetate in 20% (v/v) HNO_3 was added and the mixture was shaken for 2h.

F5. Residual fraction: the residue obtained from the fourth step (F4) was digested using HF-$HClO_4$.

Metals (Cd, Cu, Cr, Ni, Pb, Zn) content in digested soil samples were then determined using Atomic Absorption Spectrometry (Bulck Scientific 210VGP).

2.3. Quality control

Marine sediment reference materials (MESS-3), analysis of blanks and duplicates were run with the samples to confirm validation of provided data and quality assurance of the laboratory analyses. Analysis of MESS-3 revealed satisfactory agreement with the reported data (Table 1).

Table 1.
Published and obtained data for MESS-3

Metals	Published metals contents*	Obtained data
Cu	33.9 (1.6)	33.6
Zn	159 (8)	162
Cr	105 (4)	103
Fe	43400 (110)	43490
Mn	324 (12)	322
Pb	21.1 (0.7)	21.6
Ni	46.9 (2.2)	47.5
Cd	0.24 (0.01)	0.25

*NRC Institute for National Measurement Standards (January 2000)
Values for trace metals are in mg/kg and standard deviations are given within parentheses.

2.4. Enrichment factor

Enrichment factor (EF) is a prevalent index to determine the degree of anthropogenic metals pollution and enrichment (Jamshidi-Zanjani and Saeedi, 2013). EF is calculated using equation 1.

$$EF = \frac{\left(\frac{C_s}{C_b}\right)\text{sample}}{\left(\frac{C_s}{C_b}\right)\text{background}} \qquad (1$$

Where, $\left(\frac{C_s}{C_b}\right)$ C_s and C_b are the concentration of a given metal and reference metal, respectively. In the present study Mn and Fe content in earth crust was selected as references metals based on the literature review (Jamshidi-Zanjani and Saeedi, 2013; Abrahim and Parker, 2008). The EF value greater than unit indicate that the sample is being enriched under the effect of either anthropogenic or natural sources (Glasby and Szefer, 1998).

2.5. Geo-accumulation index

Geo-accumulation index (I_{geo}) firstly proposed by Muller (1969) was applied on soil samples according to equation 2.

$$I_{geo} = \log_2(C_n/1.5 \times B_n) \qquad (2$$

Where, C_n and B_n are metal concentration in sample and background such as shale, respectively. There are seven categories of state of pollution based on I_{geo} calculation (Table 2).

Table 2.
Classification of pollution using Igeo (Muller, 1969)

Calculated I_{geo}	I_{geo} Index	State of Pollution
>5	6	Extremely Polluted
>4-5	5	Highly Polluted-Extremely Polluted
>3-4	4	Highly Polluted
>2-3	3	Moderately Polluted-Highly Polluted
>1-2	2	Moderately Polluted
>0-1	1	Unpolluted-Moderately Polluted
<0	0	Unpolluted

2.6. Pollution index (I_{poll})

A newly developed index called I_{poll} by Karbassi et al. (2008) used to assess metals pollution intensity according to equation 3.

$$I_{POLL} = \text{Log}_2(B_c/L_p) \qquad (3$$

Where, I_{poll}, B_c and L_p are indicative of pollution intensity, bulk concentration and lithogenous portion, respectively. According to Karbassi et al. (2008) L_p is the summation of metal content in the 4th and 5th steps of the chemical partitioning analysis. The pollution state in a given sample based on I_{poll} is categorized as same as I_{geo} classification.

2.7. Risk assessment code (RAC)

Risk assessment code (RAC) firstly proposed by Perin et al. (1985) to assess potential risk of release of metals. The risk is evaluated based on the metal fractionation study and the presence of metal in weakly bound. In other words, the percentage of metal partitioning in exchangeable and carbonate fraction makes the RAC criteria. The higher metal partitioning in weakly bounds (summation of exchangeable and carbonate fractions), reveals higher risk of release (Jain, 2004; Rath et al., 2009). The criteria and classification of RAC are presented in Table 3.

Table 3.
Criteria for risk assessment code (RAC) (Perin et al., 1985)

Risk assessment code (RAC)	Percentage of metal partitioning in exchangeable and carbonate fraction (%)
No risk	<1
Low risk	1-10
Medium risk	11-30
High risk	31-50
Very high risk	>50

2.8. Background level

There are different approaches to calculate background values of elements. The 4σ-outlier test, iterative 2σ-outlier test are prevalent approaches to determine background level based on remove outlier data among collected data. In 4σ-outlier method, mean and standard deviation (σ) are determined for the original data set then outlier data are removed according to mean ± 4σ. The mean+2σ is upper limit of background value in new data set. In iterative 2σ-outlier method, the calculated outlier data for the original data set are eliminated according to mean ± 2σ. This approach will be continued till no outliers are found in any generated data set. The mean+2σ is upper limit of background level (Matschullat et al., 2000).

3. RESULTS

3.1. Total metals content

Minimum, maximum, mean and standard deviation of metals concentration (Cu, Zn, Cr, Fe, Mn, Pb, Ni, Cd) of Shahr-e-Babak soil in totally 53 samples are presented in Table 4. Mean concentrations of Cu, Zn, Pb, and Cd are much higher than those of earth's crust. In case of Pb, and Cd the minimum contents are also higher than earth's crust content. In general, the minimum contents of metals were detected in samples from the north and north-eastern part of the study area where there is no main anthropogenic sources of pollution. The maximum metal content were detected in soil samples from south-eastern parts of the Shahr-e-Babak where is close to Khatoon-Abad Copper Smelter. Also, samples where is collected beside Maiduk Copper Complex reveal high amount of metal concentration. For example, results of chemical analysis of sample 4 reveals Cu (1707.7 mg/Kg), Zn (513.3 mg/Kg), Pb (33.4 mg/Kg), and Cd (11.2 mg/Kg) which are much higher than earth's crust contents. It seems that these parts of the study area (south-eastern and near central) are heavily affected by Khatoon-Abad Copper Smelter and Maiduk Copper Complex.

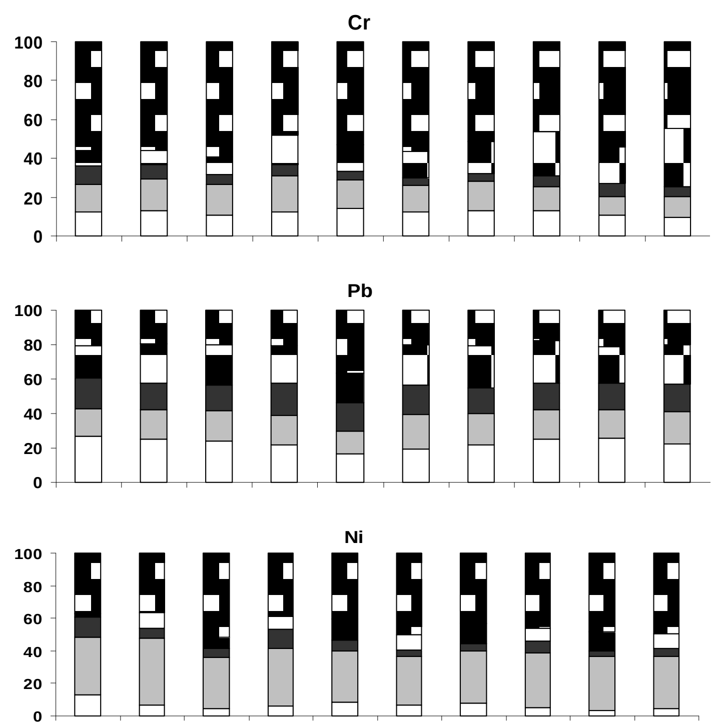
The arithmetic means of all analyzed metals are higher than their geometric means. The high standard deviations were detected for all metal content implied considerable variation of concentration in soil samples. Skewness values of all studied metals except for Cr are positive that indicates mentioned metals positively skew toward their lower values. This fact also can be confirmed by higher mean values of all metals except for Cr than their median values. Thus, it could be concluded that the geometric means for analyzed metals provide more reasonable data than the arithmetic means (Lu et al. 2010; Jamshidi-Zanjani and Saeedi, 2013). However, as same as the mean values, the geometric mean values of Cu, Zn, Pb, and Cd in the soil samples are much higher than those of earth crust.

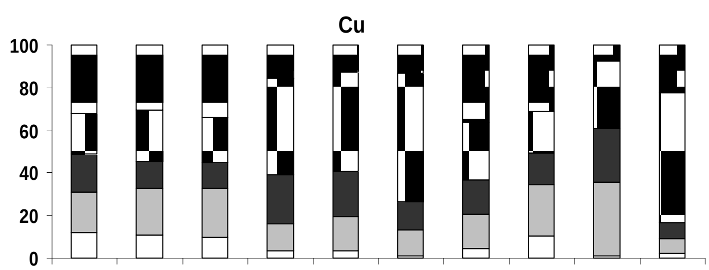
Table 4.
Metals content (mg/Kg) in soil samples of Shahr-e-Babak, Iran (n=53).

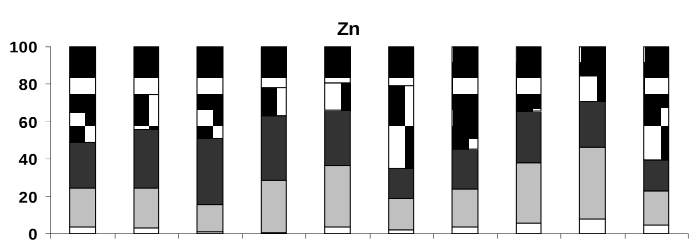
arameter	Cu	Zn	Cr	Fe	Mn	Pb	Ni	Cd
Mean	205.00	98.71	82.09	6237.31	377.57	45.96	28.04	3.60
Minimum	12.18	20.70	6.20	5809.70	190.00	20.10	2.40	0.34
Maximum	1707.70	513.30	162.20	6876.13	873.00	152.80	60.86	11.20
Std. Deviation	304.68	70.20	47.36	263.92	112.51	17.22	12.72	1.94
Median	85.66	82.10	99.83	6176.20	365.30	43.97	24.27	3.59
Geometric Mean	80.37	86.74	62.24	6231.87	363.01	44.07	24.78	3.06
Kurtosis	10.66	23.83	-1.40	-0.74	6.01	29.24	0.51	3.20
Skewness	2.84	4.36	-0.18	0.26	1.61	4.73	0.72	1.18
Earth crust content	50	75	100	41000	950	14	80	0.2

3.2. Metal fractionation

Ten soil samples were selected to study metal partitioning. The bar graph of metal partitioning in five factions is presented in Fig. 2. Based on Fig.2, geochemical fractions for Cu rank in order F4>F5>F2>F3>F1. On one hand, the higher partitioning of Cu in strong fractions (residual and organic fraction) in soil samples of Shahr-e-Babak was detected. On the other hand, partitioning of Cu in carbonate fraction is considerable. Generally, it could be concluded although residual and organic fractions are considered as the main sink of Cu, contribution of Cu in carbonate fraction may lead to considerable risk of release of Cu.







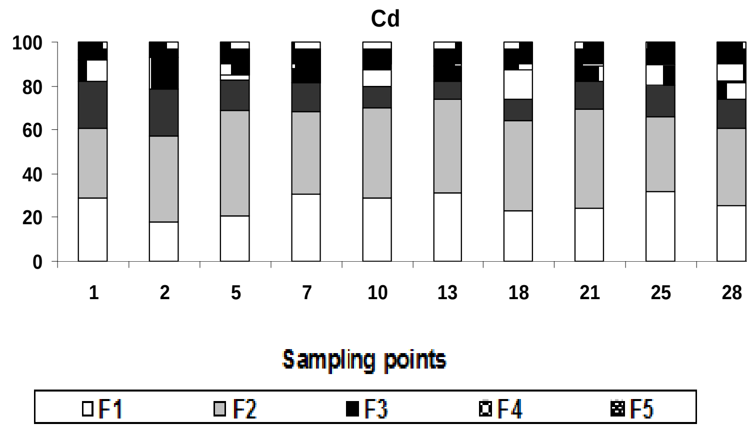


Fig. 2. Bargraph of metal partitioning in soil samples of Shahr-e-Babak

Contribution of Zn in different geochemical phase rank in order F5>F3>F2>F4>F1 indicates that residual phase and Fe-Mn oxides are the main sink of Zn in soil samples of the study area. However, portioning of Zn in carbonate fraction with the mean percent of 24.3% reveals considerable risk of release of Zn in surfacial soil samples of Shahr-e-Babak. According to Fig. 2, residual fraction is considered as the main sink of Cr in soil samples. Partitioning of Cr with the different geochemical fractions rank in order F5>F4>F2>F1>F3. It should be mentioned that, considerable amount of Cr was associated in loosely bounds (exchangeable and carbonate fractions) may indicates considerable potential risk of release of Cr in soil samples.

Contribution of Pb in different geochemical phase is in the rank of F1>F4>F5>F2>F3. Exchangeable fraction is considered as the main sick of Pb in soil samples. Besides, contribution of Pb in carbonate fraction with the mean percent of 17.3% revealed significant potential risk of release of Pb in the study area.

Results revealed that geochemical fractions for Ni rank in order F5>F2>F4>F3>F1. Although residual fraction is the main sink of Ni in soil samples, considerable partitioning of Ni in carbonate fraction with the mean percent of 33.5% indicates significant potential risk of release of Ni in the study area. According to Fig. 2, contribution of Cd in weakly bounds was quite considerable. The association of Cd with the different geochemical fractions rank in order F2>F1>F3>F5>F4. The high association of Cd with exchangeable and carbonate fractions revealed high potential risk of release of Cd in soil samples by change in physical-chemical properties (pH, redox potential) of the study area.

Generally, results of metal partitioning in soil samples of Shahr-e-Babak revealed significant contribution of analyzed metals specially Cd and Pb in loosely bounds. Thus, investigation of potential risk of release of analyzed metals could be necessary.

3.3. Clustering analysis

The cluster analysis (CA) was conducted to all analyzed metals content in soil samples of Shahr-e-Babak. The dendrogram of CA of variables based on Pearson Coefficient is presented in Fig. 3. According to Fig. 3 three main clusters are identified: A) Cr-Fe-Ni; B) Cu-Zn-Cd; C) Pb-Mn based on their similarities. The main cluster A contains heavy metals (Cr, Fe, and Ni) may indicates common natural sources of these elements. On the other hand, cluster B including toxic metals (Cu, Zn, and Cd) may reveals their common anthropogenic sources. Cluster C contains Pb and Mn may indicative of natural sources of Pb in the soil samples of the Shahr-e-Babak. Overall, according to CA it may be concluded that metals such as Cu, Zn, and Cd may be derived from anthropogenic sources in the study area. However, natural sources may be more effective to enrichment of metals including Cr, Ni, and Pb compared with anthropogenic sources.

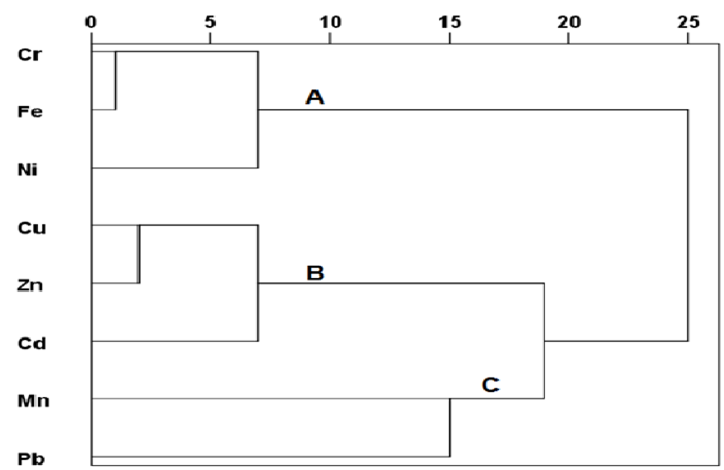


Fig. 3. Dendogram of variables in soil samples of Shahr-e-Babak

3.4. Enrichment factor (EF)

The EF's value could be calculated using concentration of Fe, Al, Mn, or Li in earth's crust as background value (Jamshidi-Zanjani and Saeedi, 2013; Windom et al. 1989; Stewart 1989; Loring 1991; Din 1992; Ravichandran et al. 1995; Niencheski et al. 2002). In this study, Mn and Fe content in earth crust were used as reference metals to calculate EF. Result of calculation of EF in soil samples of the study area is presented in Fig. 4.

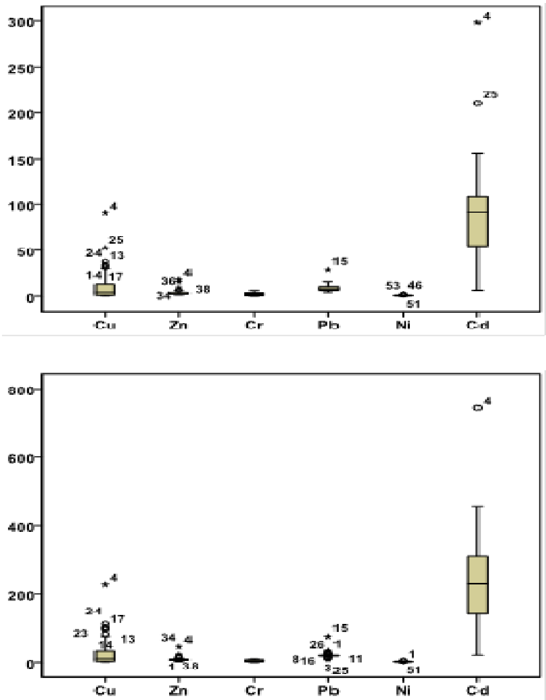


Fig. 4. Boxplot of EFs in soil samples of Shahr-e-Babak

When Mn is used as reference metal the range of EF values of toxic metals in soil samples of Shahr-e-Babak are: Cu (0.64-90.86), Zn (1.38-18.21), Cr (0.12-6.06), Pb (4.43-28.38), Ni (0.07-1.97), and Cd (6.37-297.96). On the other hand, when Fe is applied as reference metal reveals EF values in the fallowing ranges: Cu (1.56-226.87), Zn (1.85-45.46), Cr (0.41-10.2), Pb (10.08-73.56), Ni (0.2-4.73), and Cd (21.12-743.98).

Regardless of difference between EF values based on selection of Mn and Fe as reference metal, higher enrichment of Cd, Pb, and Cu in Shahr-e-Babak soil samples is detected. Results revealed that soil samples in south-eastern and central part of the study area where is close to Khatoon-abad Copper Smelter and Maiduk Copper Complex, respectively have higher enrichment degree than the other soil samples. Soil samples are located in north-eastern part of the study area where there is no significant anthropogenic sources, have the minimum EF values for all analyzed metals. This fact reveals the adverse effect of anthropogenic sources (Khatoon-abad Copper Smelter and Maiduk Copper Complex) in the study area in aspect of metal pollution state.

3.5. Geo-accumulation index (I_{geo})

The boxplot of calculated I_{geo} in soil samples of the study area is depicted in Fig. 5.

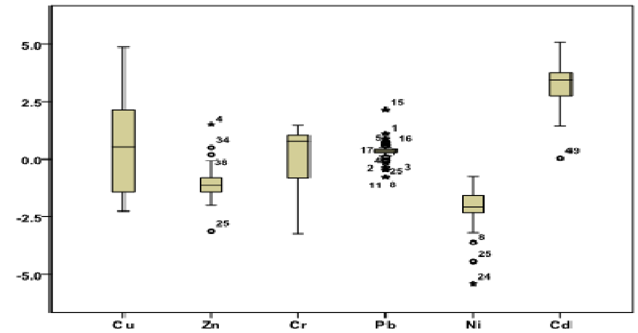
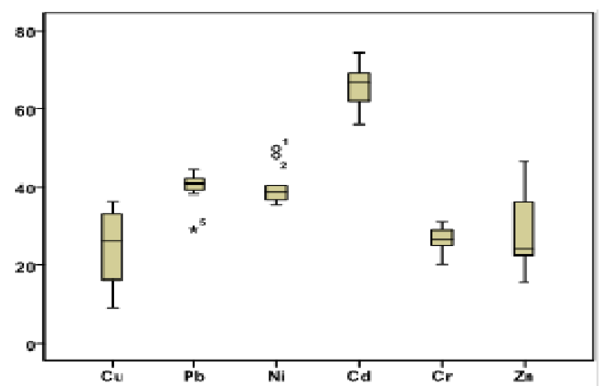


Fig. 5. Boxplot of I_{geo} in soil samples of Shahr-e-Babak

The I_{geo} values vary in the following rang: Cu (-2.26_4.87), Zn (-3.12_1.51), Cr (-3.24_1.47), Pb (-0.78_2.15), Ni (-5.41_-0.74), and Cd (0.04_5.08). Results revealed that Cd, Pb, and Cu have higher degree of pollution according to I_{geo} values. This fact is in accordance with EF values for analyzed metals in soil samples of Shahr-e-Babak. Also, soil samples beside the mentioned anthropogenic sources have the higher degree of pollution compared with other samples.

3.6. Risk assessment code (RAC) and pollution index (I_{poll})

Fig 5. depicts RAC and I_{poll} values for analyzed metals in selected soil samples of Shahr-e-Babak. Results revealed that RAC values vary in the range of Cu (9.09-36.28), Pb (29.19-44.36), Ni (35.36-49.79), Cd (56.03-74.29), Cr (20.12-31.23), and Zn (15.78-46.68). The I_{poll} values, also vary in the following range: Cu (0.29-1.32), Pb (0.92-1.31), Ni (0.73-1.32), Cd (1.94-2.53), Cr (0.41-0.67), and Zn (0.59-1.76).



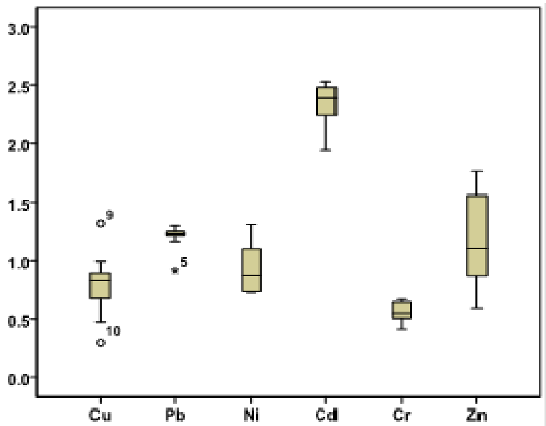


Fig. 6. Boxplot of RAC and I_{poll} in soil samples of Shahr-e-Babak

Overall, despite of difference between RAC and I_{poll} values metals such as Cd, Pb, and Ni have the highest degree of pollution risk. According to RAC values, Cd in all soil samples categorized as very high risk which is indicated very high potential risk of release of Cd in the study area. Also, Pb and Ni have high potential risk of release. It could be concluded that Cd, Pb, and Ni may be easily released from soil in Shahr-e-Babak and be available for plant uptake. Moreover, soil samples where are closed to anthropogenic sources show higher risk of release for all analyzed metals compared with other samples. Generally, order of the potential risk of release for analyzed metals in soil samples of the study area according to mean RAC values are as: Cd>Ni>Pb>Zn>Cr>Cu. According to I_{poll} values, Cd is categorized in moderately-high pollution degree in most soil samples of the study area. Moreover, Pb, Ni, and Zn are categorized as moderately pollution degree in most of the soil samples in Shahr-e-Babak.

3.7. Background

Results of determination of metal background level based on 4σ-technique and iterative-2σ method in soil samples of Shahr-e-Babak are presented in Table 5. The heavily polluted samples (very close to Khatoon-Abad Copper Smelter area) were removed to calculate metal background values in a acceptably manner.

According to Table 5, there is not any significant difference between mean and median values of calculated metal background in soil samples of the study area except for Cu and Zn. According to Roca et al. (2012) the mean background value calculated based on iterative-2σ method is considered as the metal background value in Shahr-e-Babak soil samples.

Table 5.

Determination of background level soil samples of Shahr-e-Babak

Techniques	Statistical parameters	Cu	Zn	Cr	Fe	Mn	Pb	Ni	Cd
4σ-technique	Mean	76.3	84.9	96.4	6305.5	409.7	44.6	32.8	3.7
	Median	22.2	79.8	112.5	6403.5	358.9	44	29.1	3.5
	σ (%)	160.4	28.6	48.7	276.1	124.2	7.8	12.7	2.3
	Upper limit	397.2	142	194.3	6857.7	658.1	60.2	58.2	8.3
	Loss (%)	3.4	3.4	0	0	0	0	0	0
iterative-2σ test	Mean	20.1	77.2	96.9	6305.5	393.2	43.9	24.4	3.5
	Median	20.1	72	112.5	6403.5	358	43.8	23.9	3.4
	σ (%)	4.1	18.1	48.7	276.1	88.1	0.4	3.9	1.8
	Upper limit	28.4	113.4	194.3	6857.7	569.4	44.7	32.2	7.1
	Loss (%)	27.6	13.8	0	4.2	3.4	51.7	37.9	3.4

3.8. New index

In the present study a new aggregative index to calculate metal pollution state called index of industrial pollution (I_{ind}) is introduced. Where, W_i, C_i, and B_i are toxicity factor, metal concentration, and background value of a given metal in study area, respectively. The toxicity factor for a given metal is presented by Hakanson (1980). The values of W_i for Cd, Cu, Pb, Zn, and Cr are 30, 5, 5, 1 and 2, respectively (Hakanson, 1980). The proposed pollution category is as same as I_{poll} and I_{geo} ones which is presented in Table 2.

$$I_{ind} = Log_2\left(\frac{\sum_{i=1}^{n} W_i \times \left(\frac{C_i}{B_i}\right)}{\sum_{i=1}^{n} W_i}\right) \qquad (4$$

The distribution pattern of calculated I_{ind} in soil samples of Shahr-e-Babak is depicted in Fig. 6.

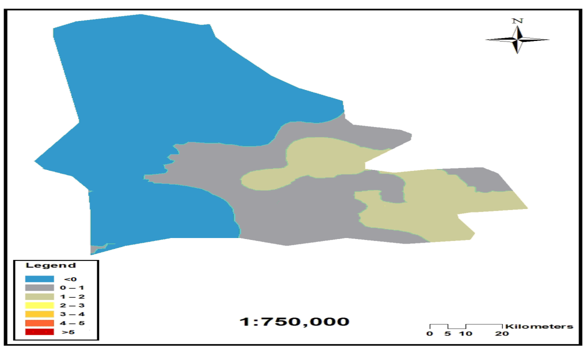


Fig. 6. Distribution of calculated I_{ind} in soil samples of Shahr-e-Babak

As depicted in Fig. 6 south-eastern and central part of the Sahr-e-Babak exhibited higher degree of metal pollution than the other part. As mentioned before, these parts are close to main anthropogenic sources of toxic metal (Khatoon-Abad Copper Smelter and Maiduk Copper Complex) and revealed higher amount of metal concentration in soil samples. Thus, higher degree of metal pollution based on calculated I_{ind} is in accordance with the results of metal content in the study area. However, west and north part of the study area which has no main anthropogenic sources revealed unpolluted degree of metal pollution.

CONCLUSION

In the present study, the metal content in soil samples of Shahr-e-Babak has been studied. Sequential extraction method was conducted on selected soil samples to study metal fractionation and their risk of release. Enrichment factor, Geo-accumulation index, Pollution index, and risk assessment code were applied to assess soil pollution. A new index (I_{ind}) was proposed to assess metal pollution state in industrial area based on metal background values and their toxicity degree.

- Results of EFs revealed high degree of enrichment of Cd, Pb, and Cu in soil samples of Shahr-e-Babak. Results of I_{geo} and EF were in agreement indicating higher degree of metal pollution in south-eastern part of the study area.
- Results of metal fractionation revealed that contribution of Cd, Pb and Ni in weakly bounds is high that may lead to high risk of release of these metals in soil samples. This fact is totally in agreement with the results of risk assessment code and pollution index in the study area.
- Results of new index (I_{ind}) revealed more metal pollution in south-eastern and central part of the Shahr-e-Babak compared with other part of the study area.
- Based on application of different indexes, it could be concluded that the main anthropogenic sources of metals including Khatoon-Abad Copper smelter and Maiduk Copper Complex had adverse effect on metal pollution in soil samples of the study area.

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