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Evaluating a Sediment Pollution using Contamination Indices and Risk Assessment in Mineralized Zones, Eastern Iran

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Abstract

In this work, the results of nearly 1400 stream sediment sample analysis are processed to better understand environmental pollution caused by mining activities in Eastern Iran. The stream sediment samples are analyzed for As, Sb, Fe, Cr, Ni, Co, Cu, Zn, Pb, Sr, and Hg. The mean concentration of these elements follows the decreasing order of Fe > Sr > Zn > Cr > Cu > Ni > Co > Pb > As > Sb > Hg. Based on the assessment of pollution, extremely severe enrichment factor Co (EF > 25), and high enrichment of Sb, Hg, Cr, and Sr (EF > 10) are detected. Specifically, Cr and Ni in southern stream sediments show significantly elevated concentrations compared to the others. The range of the contamination factor varies from CF < 1 to CF > 6 for most elements. Geo-accumulation index shows high contamination levels by Cr and Co and high to severe contamination by Sb. The risk indices are low for all elements except for As and Co in the eastern part of the studied area. Principal component analysis, Spearman correlation coefficient, and cluster analysis are used to demonstrate similarities and differences between the elements. Pollution indices show that contaminations in some samples are the consequence of gold mineralization. The high correlation of Cu, Zn, and Sb is due to the sulfide mineralization of gold. The high correlation of Cr and Ni corresponds to ultramafic rocks and ophiolitic series. This study focuses on the impact of mining activities, even at early stages on the dispersion of some heavy metals in stream sediments. Based on the results presented here, while most contamination in the target area is rooted in geochemical and mineralization processes, mining activity also contributes to soil pollution for certain elements such as Cu and Zn. The most affected stream sediments are those within the vicinity of mining areas and attention should be paid to potential risks to the environment particularly during gold mining activities.

1. Introduction

Heavy metals (HMs) move in the soil, sediment, and water through natural or anthropogenic sources (e.g. agriculture, mining, industrial plants, sewage, and vehicles). Researchers use soil and sediments to assess the heavy metal environmental pollution [1]. The accumulation of HMs in stream sediment has a major influence on the wider environment. This problem may cause various negative health implications.

Mining is one of the major contributors to the contamination of soil, sediment, and water resources around the world [2-4]. Pollution from gold mining has been recognized globally for its impact on ground and surface waters [5]. It is a source of some metals that cause serious health and environmental problems [6]. Similarly, it has caused many environmental HMs pollution in Ghana [7, 8]. Gold mining in Oman has contaminated the environment with elements such as iron, aluminum, lead, zinc, cadmium, and manganese [9]. High values of arsenic in soil samples have been reported in gold mining areas around the world. Up to 278.6 $mg.kg^{-1}$ arsenic was found in gold mining soil samples, and up to 294.38 $mg.kg^{-1}$ of arsenic was found at Afema industrial mining area [10, 11]. Small gold mines in Senegal have created high mercury contamination [12]. In addition to mineralization,

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hydrothermal alteration is also effective in heavy metal pollution. Comparison soil samples with the background value of upper crust in Demirören (Turkey) show elevated levels of metal concentrations resulted from the alteration area [13]. The alteration area of gold-silver-bearing lead, zinc, and copper in the southern part of the Black Sea (Turkey) show soil pollution is associated with alteration area [14]. Hydrothermal alteration also lead to concentrations high values of gold and silver in the plants [15].

There are many Mining activities around South Khorasan province, eastern Iran. Various types of metallic mineralization are identified, e.g. Qaleh Zari IOCG Deposit, Maherabad Cu–Au porphyry, Sheikhabad high-sulfidation, Hanich low sulfidation, and Khunik epithermal gold deposits [16]. Possibly, some areas might be impacted by trace elements from anthropogenic origins. While most of the research interests are focused on geological mapping for the mineralization area, the aim of this study is to evaluate environmental indices and assess the effects of lithology or mineralization processes in the extent of 1:100000 Scale geological maps of Sarchah Shur and Mokhtaran [39, 41]. Geochemical information of stream sediments is used to evaluate the concentration, extent, and origin of pollution and the geochemical impact of HMs on the environment. Various indices such as enrichment factor, contamination factor, and geo-accumulation are introduced to evaluate the level of stream sediment pollution [17]. Multivariate statistical methods were utilized to specify sources of potentially toxic elements.

This study provides the first detailed database on heavy metal concentration and ecological risks in stream sediments in eastern Iran. The aim of this research work is to assess the heavy metal contamination of the soil and sediment in the extent of the studied area. The origin and behavior of toxic elements and their effect on the quality of soil is crucial to future endeavors. In this study, it has been attempted to investigate the origin of pollution and its impact on the environment using geochemical data. To date, very few studies have investigated on effect of Cu-Au mining activities on soil and sediment pollution in Eastern Iran. To address this critical gap in knowledge, this study will discuss pollution associated with mining activity in eastern Iran. This study focuses on the level of influence mining activities even at early stages may have on the distribution of some heavy metals in stream sediments. Attention should be paid to potential risks to the environment particularly caused by trace elements during gold mining activities.

2. Materials and methods

2.1. Studied area

The studied area extended from 58° 30′ to 59° 30′ eastern longitude, and 32° to 32° 30′northern latitudes (4000 Km^2). Rock outcrops are divided into several categories including limestone, sandstone, shale, and marl, volcanic and intrusive rocks, ophiolite units, metamorphic rocks, and recent deposits (Figure 1). Volcanic and pyroclastic rocks comprise of andesite, dacite, trachy andesite, agglomerate, andesitic tuff, and tuff. The intrusive rocks consist mainly of diorite to monzonite and rare granite (Figure 1). The distribution of seasonal drainages is shown in Figure 1, which is important in investigating the source of pollution upstream of drainages. The location of villages is also shown to emphasize the populated area (Figure 1).

2.2. Sampling and chemical analysis

Stream sediment samples were collected and analyzed by the Geological Survey of Iran [19]. The samples were gathered from a depth range of 15-20 cm (using a hand shovel) in dry season, homogenized, air-dried, and sieved to remove unwanted materials during the same period. All samples (n = 1361) were placed in polyethylene bags and sent to the laboratory of GSI to determine the concentration of elements by ICP-MS method. 34 sample from soil and sediment of some Au mineralization areas were used to follow the effect of primary mining activities over time (part 3.4) [20-22].

2.3. Quantification of pollution

An evaluation of distribution of HMs in the sediments should be done to assess environment contamination [23]. In the present study, Enrichment Factor, geo-accumulation index, and contamination factor were used to assess the presence and intensities of contaminants of HMs [17, 18 and 24]. Potential ecological risk index was used to measure the hazardous level that may have any potential threat to the biological community [25]. Geological maps, satellite images, distribution of drainages, and soil and stream sediments data were also utilized. Principal component analysis (PCA) and cluster analysis (CA) also have been used to find relationships between elements. PCA is a multivariate statistical

technique capable of discerning patterns in large environmental datasets.

2.3.1. Enrichment factor

The enrichment factor (EF) is used to determine the levels of anthropogenic trace element contamination [24]. The EF values are carried out for a reference element to reduce the alterations generated by various samples as follows (Equation 1):

$$EF = [C_n/C_{ref}(Sample)]/ B_n/B_{ref}(Background)] \quad (1)$$

where C_n and B_n are the element concentration in the sample and the background, respectively. C_{ref} and B_{ref} is the geochemical background value of a normalizing reference element in the sediment sample and background, respectively. Elements such as Si, Fe, and Al are used by many researchers [26]. Fe element has similar geochemistry compared to other traces elements with uniform natural concentration [27, 28]. Thus, Fe was used as a reference element. Background values were used from world average shale (ASV) concentration [29]. The classification of EF level is shown in Table 1.

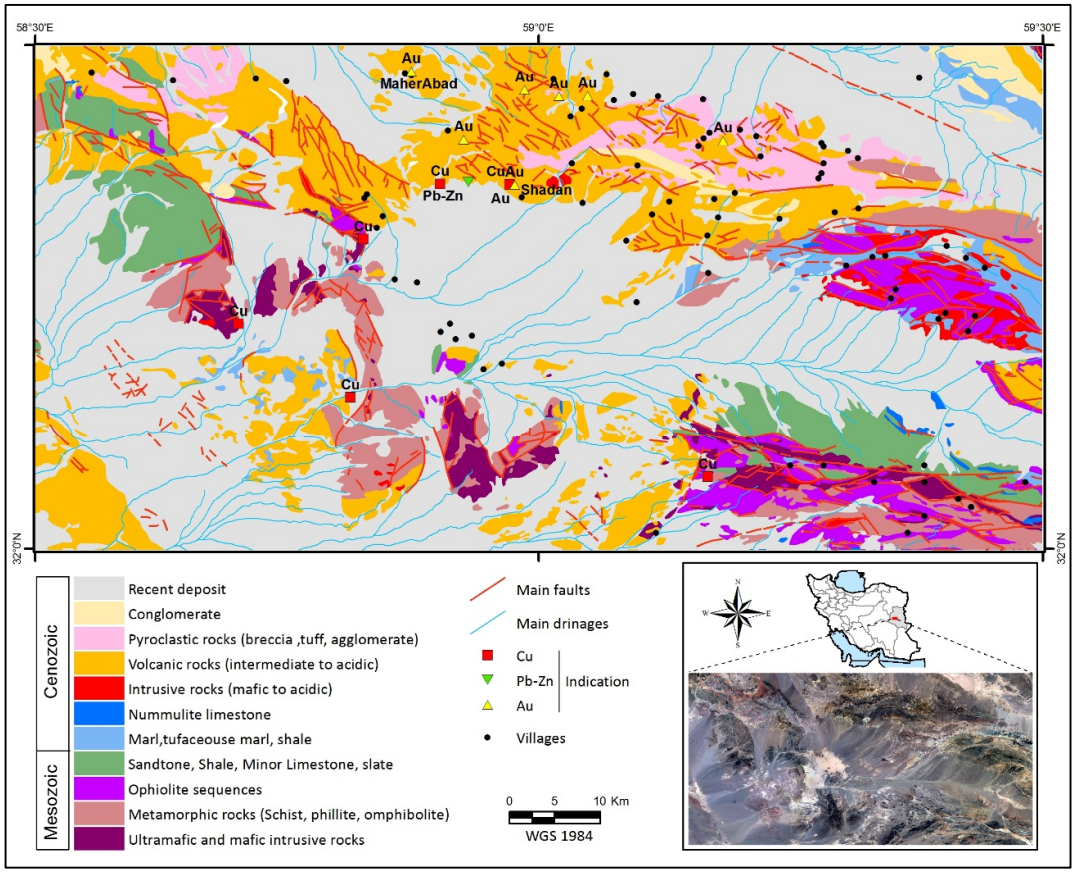

Figure 1. Geological map of studied area, scale 1:100000 (Simplified after [28, 40]).

2.3.2. Contamination factor (CF)

To measure pollution to a specific element, the contamination factor is calculated by the concentration ratio of the element in a sample to the same element in a reference environment. CF is categorized in to seven groups (Table 1), from unpolluted (CF = 0) to very strong contamination (CF = 6) [18].

2.3.3. Geoaccumulation index (Igeo)

(I_{geo}) introduced is calculated by Equation (2) [17].

$$I_{geo} = \text{Log}_2 [C_n/1.5B_n] \quad (2)$$

In the above equation, C_n is the concentration of the element in sediments, B_n is the concentration of an element in the background, and 1.5 is a constant number for correction lithospheric effects. I_{geo} has been classified into seven classes (Table 1), from extremely polluted to unpolluted [30].

Table 1. Classifications of enrichment factor, geoaccumulation index, contamination factor, and potential ecological risk.

Degree of enrichment	EF	Degree of contamination	I_{geo}
No enrichment	< 1	Non contaminated	<=0
Low enrichment	1-3	Non to medium contaminated	0-1
Medium enrichment	3-5	Medium contaminated	1-2
Medium to severe enrichment	5-10	Medium to high contaminated	2-3
Severe enrichment	10-25	High contaminated	3-4
Highly severe enrichment	25-50	High to severe contaminated	4-5
Extremely severe enrichment	> 50	Severe contaminated	> 5

Degree of contamination	CF	Risk assessment			
		E_i^r	Risk level	RI	Risk level
Non-contaminated	0	< 40	Low	< 150	Low
Non to medium contaminated contamination average	1	40-80	Moderate	150-300	Moderate
Medium contaminated	2	80-160	High	300-600	Sever
Medium to strong contaminated	3	160-320	Higher	> 600	Serious
Strong contaminated	4	> 320	Serious		
Strong to very strong contaminated	5				
Very strong contaminated	6				

2.3.4. Risk assessment

The Potential Ecological Risk Index (PERI) method is used to assess the level of pollution of the hazardous elements in the samples that may have a potential threat to the biological community [25]. PERI was applied to assess the risk index (RI) of the sampling site as follows:

$$E_i^r = T_i^r \times CF$$

$$RI = \Sigma E_i^r$$

where E_i^r show the PERI for single hazardous element pollution, CF is the element's pollution factor, T_i^r specifies the biological toxic response for a certain element. It considered different values for Zn (1), Cr (2), Co (5), Cu (5), Ni (5), Pb (6), As (10), Hg (40), and Sb (7) [25, 31]. It represents the biological community's sensitivity to the toxic substance and shows the potential ecological risk made by the total contamination. The limits used for the interpretation are listed in Table 1.

2.3.5. Statistical analysis

Multivariate statistical analysis is one of the available tools for environmental data interpretation; multivariate statistical analysis is widely utilized for HMs concentration evaluation studies. In this study, Spearman correlation (SC), cluster analysis (CA), and principal component analysis (PCA) were utilized to assess the geochemical behaviors and sources of different geochemical groups [32]. In general, element concentrations in plant and soil did not show normal distribution [33]. Therefore, instead of a Pearson correlation (PC) matrix, a Spearman correlation (SC) matrix was calculated to ascertain the correlation between elements [33]. For datasets containing a large number of m variables, PCA method is used to reduce the number of variables; the new space is referred to as Principal Components (PCs). The two PCs with the highest variance are mostly desirable. CA technique also helps with grouping similar observations in order to create meaningful clusters [34].

3. Results and Discussion

3.1. Metal concentration in stream sediments

Statistical summary of chemical analysis including Cu, Pb, Zn, Fe, As, Au, Sr, Sb, Hg, Cr, Ni, and Co is presented in Table 2. The Fe concentration is greater than other elements. The arrangement of mean frequency of other elements is Sr > Cr > Ni > Zn > Co > Cu > Pb > As > Sb > Hg. Iron concentration (25200-180000 $mg.kg^{-1}$) is higher than the ASV concentration (47200 $mg.kg^{-1}$) in most samples.

Arsenic (As) in the stream sediment samples accumulated between 0.2 and 78 $mg.kg^{-1}$ (Figure 2, Table 2), where abundance of this element in the Earth's crust varies between 0.5 and 2.5 $mg.kg^{-1}$ and exceeded the ASV (13 $mg.kg^{-1}$) [35, 36]. In Eastern part of the studied area, arsenic is accumulated ranging from 52 to 78 $mg.kg^{-1}$ in some stream sediment samples (Figure 2).

The chemical analysis indicated the occurrence of Pb varies from 2.3 to 151.4 $mg.kg^{-1}$ in stream sediment samples (Figure 2, Table 2). The concentration of Pb in more than 38% of samples are higher than ASV value (20 $mg.kg^{-1}$).

Pb accumulated 45 to 151 mg.kg^{-1} in some stream sediment samples can be found in western part of the studied area (Figure 2).

Antimony (Sb) concentrations varies from 0.2 to 18.7 mg.kg^{-1} (Figure 2, Table 2). The Antimony in most of the samples is lower than the ASV except for the sample located in the west section of the studied area. Figure 2 illustrates the samples with Sb concentration between 15 and 19 mg.kg^{-1}.

Copper (Cu) was detected from 0.1 to 376.9 mg.kg^{-1} (Table 2). High values of this element (300 to 377 mg.kg^{-1}) are presented in the west section of the studied area (Figure 2). Strontium (Sr) was detected from 110 to 1825 mg.kg^{-1} (Table 2). The central part contains the highest values of Sr. Figure 2 demonstrates samples with Sr concentration between 800 and 1825 mg.kg^{-1}.

Chrome (Cr) changes from 40.8 to 1697.6 mg.kg^{-1} (Table 2) and Nickel (Ni) varies from 10.3 to 550 mg.kg^{-1} (Table 2). Southern drainage contains more values of Cr and Ni. The samples with Cr concentration higher than 300 mg.kg^{-1} and Ni concentration higher than 250 mg.kg^{-1} are located in the southern part of the studied area (Fig 2).

Cobalt (Co) was detected from 9.4 to 631.9 mg.kg^{-1} and high values (> 300 mg.kg^{-1}) were located in the North-Eastern part (Figure 2, Table 2). Mercury (Hg) was detected from 0.003 to 0.44 mg.kg^{-1} (Table 2). Sediment in the central part contains the highest values of Hg.

Table 2. Heavy metals concentrations (mg.kg^{-1}) in stream sediment samples.

Sample	Cu	Pb	Zn	Fe	As	Sr	Sb	Hg	Cr	Ni	Co
Min	0.1	2.3	10.0	25200	0.20	109.9	0.19	0.003	40.8	10.3	9.4
Max	376. 9	151.4	498.0	180000	78.00	1824.7	18.67	0.44	1697.6	550.0	631.9
Average	102.7	24.5	169.8	53532	7.14	401.8	5.93	0.07	133.5	75.3	40. 0
Median	38.5	22.6	89.0	42580	6.20	393.6	1.20	0.03	119.0	65.6	19.4
STDEV	87.8	9.7	125.2	27435	5.75	128.4	6.01	0.06	75.9	41.7	53.3
ASV	45.0	20.0	95.0	47200	13.00	300.0	1.50	0.04	40.8	10.3	19.0

(ASV: average shale values reported by [29])

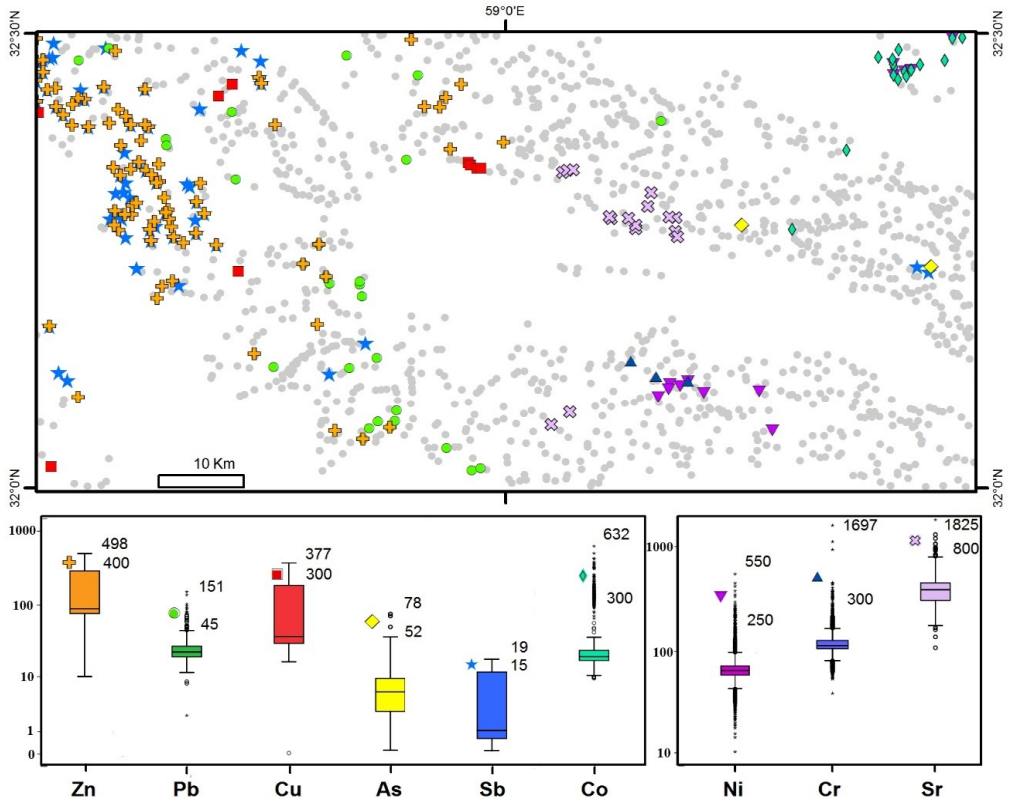

Figure 2. Variation of some elements in the stream sediments. Points show sample location. The numbers on the graph indicate the value ranges of displayed points on the map.

3.2. Assessment of metal pollution indices

Maximum EF values of Co, Sb, Cr, Sr, Hg, Ni, As, Cu, Zn, and Pb were recorded as 40.77, 15.82, 11.71, 11.39, 13.05, 8.25, 7.13, 6.19, 5.52, and 3.8, respectively, while the minimum values were 0.16 and 0.01 found in Cu and As, respectively (Figure 3, Table 3). Classification distribution based on EF values is presented in Figure 4.

Table 3. Enrichment factor (EF), geoaccumulation index (Igeo), contamination factor (CF), and E_r^i of surface sediment (minimum, maximum, and mean values).

Sample	EF			CF			Igeo			E_r^i		
	min	max	mean	min	max	mean	min	max	mean	min	max	mean
Cu	0.16	6.19	1.82	0.38	8.38	2.28	-9.40	2.48	0.02	0.01	41.88	11.41
Pb	0.09	3.80	1.18	0.12	7.57	1.22	-3.71	2.34	-0.37	0.58	37.86	6.12
Zn	0.04	5.52	1.62	0.11	5.24	1.79	-3.83	1.81	-0.11	0.11	5.24	1.79
As	0.01	7.13	0.65	0.02	6.00	0.55	-6.61	2.00	-1.81	0.15	60	5.49
Sr	0.10	11.39	1.38	0.37	6.08	1.34	-2.03	2.02	-0.22	-	-	-
Sb	0.16	15.82	3.09	0.13	12.45	3.96	-3.57	3.05	0.18	0.89	87.13	27.68
Hg	0.03	13.05	1.51	0.08	11.00	1.80	-4.32	2.87	-0.32	3.0	233.0	71.69
Cr	0.31	11.71	1.39	0.41	16.98	1.33	-1.88	3.50	-0.27	0.82	33.95	40.44
Ni	0.15	8.25	1.20	0.15	8.09	1.11	-3.31	2.43	-0.58	0.76	40.44	4.54
Co	0.34	40.77	2.51	0.49	33.26	2.11	-1.60	4.47	-0.17	2.47	166.29	10.53

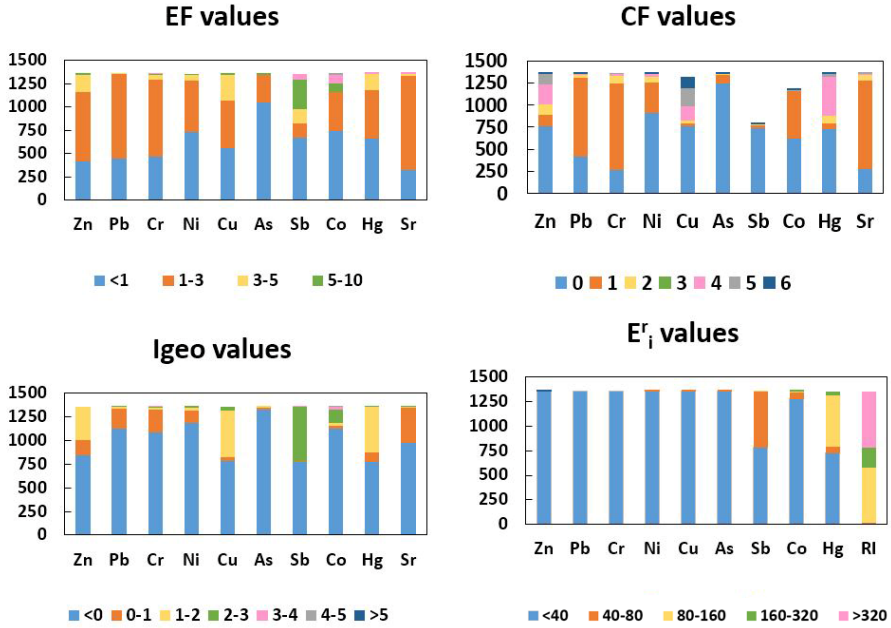

Figure 3. Frequency variation of Enrichment factor (EF), geoaccumulation index (I_{geo}), contamination factor (CF), and E_r^i in the stream sediment samples. RI (risk index values) is shown with E_r^i values. Vertical axes show the number of samples.

It can be concluded that the source of elements is mainly from natural resources when the EF values of the elements are < 1.5; otherwise, the degree of enrichment suggests other various sources of pollution. In the case of Zn, 13.5% of the samples were considered into class 3 (medium enrichment) and < 1% in class 4 (medium to severe enrichment). About 21% of the EF values for Cu samples were categorized into class 3 with medium enrichment and < 1% in class 4 with medium to severe enrichment. In the case of Ni, 4.3% of the samples were regarded as class 3 and 1% in class 4. More than 23% of Sb values were categorized into class 4 with medium to severe enrichment, and the 4% samples belonged to class 5 with severe enrichment. For Co, 6.7% of the stations were categorized into class 4 and 7.4 % in class 5 and 6. Less than 1% of the EF values for the Cr, Sr, and Hg elements are categorized into class 5.

The results show samples from northern parts

have EF values of more than 5 for Cu, Pb, As, Sr elements (Figure 4). The samples located closer to the gold mining area show Cu and Pb pollution can relate to the gold mineralization. A highly severe enrichment for Co (EF > 25) and severe enrichment of Sb, Hg, Cr, and Sr (EF > 10) were detected. The Sb enrichment in the stream sediments at the western part was found in the range of severe enrichment (EF > 10). Enrichment of Cr and Ni was found to be medium to severe in the southern part (EF > 5).

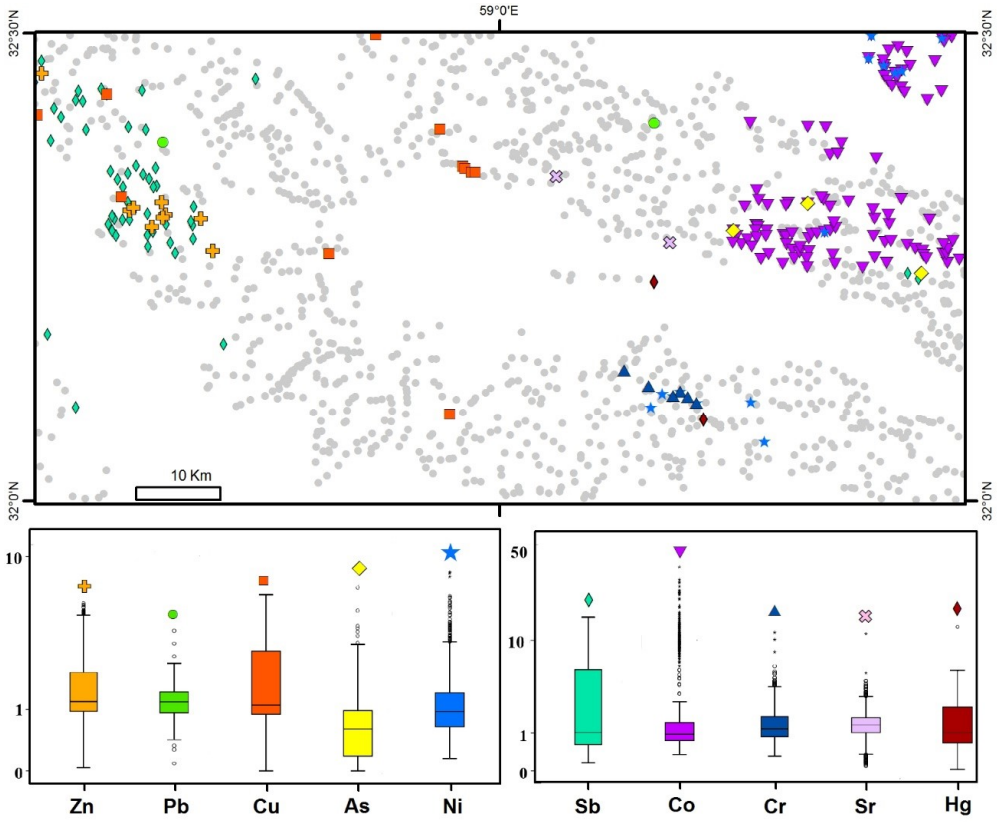

Figure 4. EF Pollution indices show medium to severe enrichment in the studied samples. Symbols for Cu, Pb, Zn, As, Ni, Cr, Sr, and Hg (EF > 5) and for Sb, and Co (EF > 10)

Assessment of CF (0.1-33) displays the stream sediment samples change from non-contaminated to very strong contamination. The average CF values reveal low to moderately contaminated (< 2) except for Co. High CF values for Cr and Ni located in southern parts highly indicate contamination (Figure 5 and Table 3). Strong to very strong contamination of Pb and As is highlighted in western and eastern parts, respectively.

The calculated I_{geo}, varies from -9.4 to 4.47 (Table 3). All I_{geo} values of Zn were less than 2, suggesting that the studied area is uncontaminated by Zn. The highest I_{geo} for Co is located in the northeastern parts indicating high to the severely contaminated area. The values of Cr in the southern part are at an alarming level (high contaminated) (Figure 6 and Table 3).

The results of the potential ecological risk index for a single element (E^i_r) are summarized in Table 3. The values of (E^i_r) suggested that the severity of pollution of the most investigated samples are low (Figure 3). Just a small subset of samples shows high-risk level for Sb, Co, and Hg. The risk index (RI) provides an essential reference for potential hazard analysis of sediments' environmental management. The majority of risk indexes are low (57.2%) to moderate (42.6%) (Figure 3). A few stations in the western part of the target area showed very high values categorizing them in the high ecological risk index (RI > 6300).

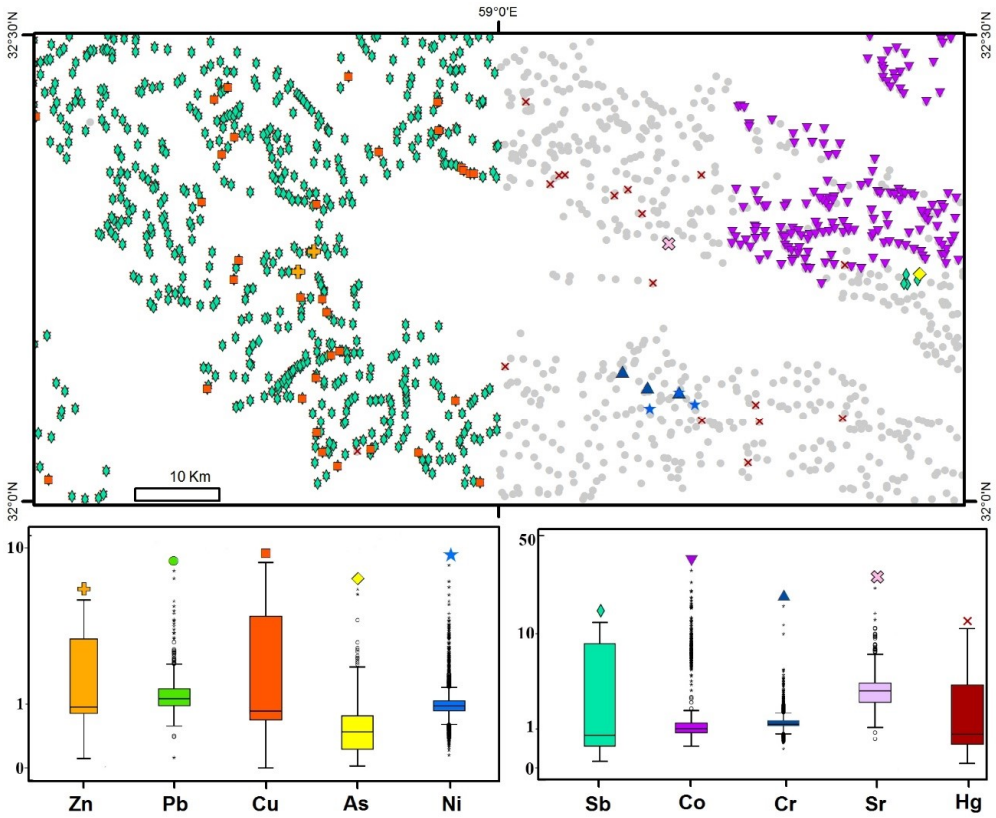

Figure 5. CF Pollution indices; box plots show the distribution of CF and symbols ponit strong to very strong contaminated (CF > 6) for all elements execept for Zn (CF > 5)

3.3. Pollution source identification

CA, PCA, and associated correlations can be utilized to identify metal pollution sources [37]. Based on the Spearman correlation coefficient (r) analysis (Table 4), there is a positive correlation between the Cu-Pb-Zn and Sb-Hg elements, which could be related to their origins. Sulphide minerals especially pyrite and Chalcopyrite can be responsible for the releasing elements such as Cd, Cu, Pb, and Zn. The environmental risk of each toxic element directly depended on the stability of corresponding mineral [38]. Sulphide minerals especially pyrite were responsible for releasing Cd, Cu, Mo, Pb, Zn, and Cr in Sarcheshmeh copper mine [38]. In samples by low paste pH values, hydroxysulphate minerals can be responsible for releasing cobalt and nickel into environment [39].

There is also a significant correlation between the Fe-Sb and Cr-Ni pairs (Table 4). High correlations indicate similar geochemical behavior and similar source for elements and low correlation indicates a lack of correlation between the distribution of geochemical elements and mineralization (Table 4). In the Northern part, the positively correlated ($p < 0.01$) Hg-Sb elements are typically found in areas polluted by the gold mining area. The Cu, Pb, and Zn elements in the sediments can be attributed to both their lithological origin and mining activities, where the third group (Cr, Ni) relates to the lithological origin. From a geological perspective, high values of Ni and Cr correspond to ophiolitic rocks.

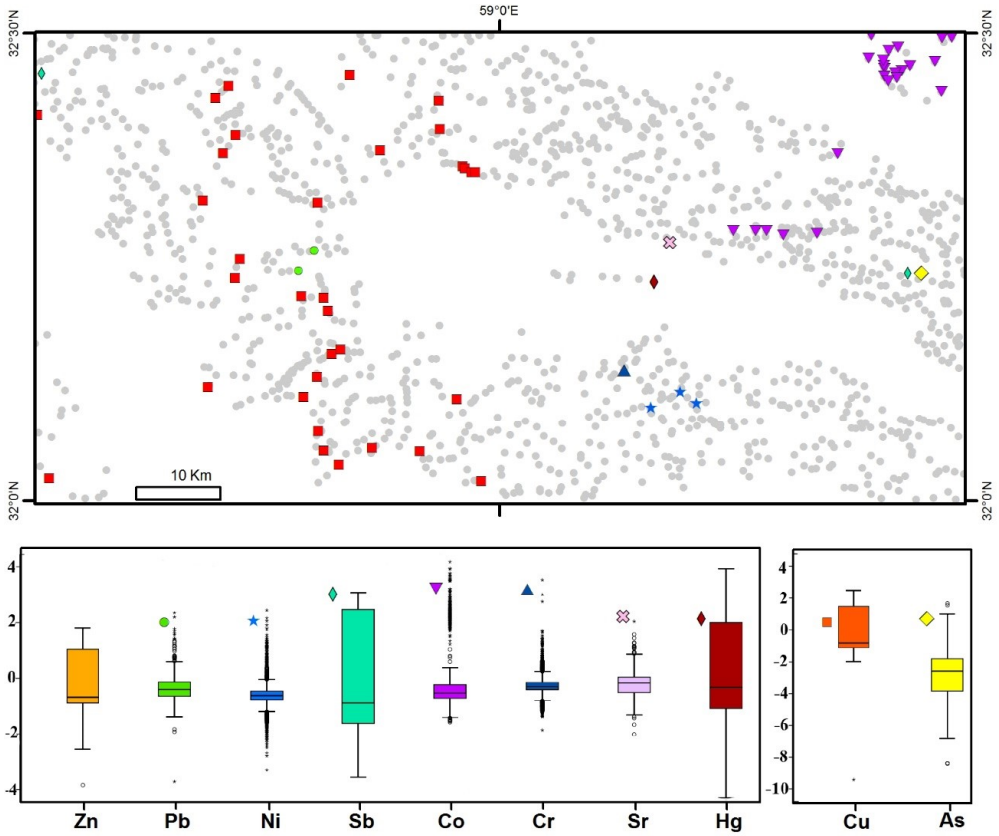

Figure 6. Igeo pollution indices; box plots show the distribution of Igeo and symbols show high contaminated, I_{geo} > 3 for Sb, Cr, and Co and medium to high contaminated I_{geo} > 2 for other elemnets.

Table 4. Correlation matrix of heavy metals in stream sediment samples.

	Zn	Pb	Cr	Ni	Cu	As	Sb	Co	Hg	Sr	Fe
Zn	1										
Pb	0.625**	1									
Cr	-.104**	-0.233**	1								
Ni	0.063*	-0.135**	0.320**	1							
Cu	0.720**	0.617**	-0.072**	-0.152**	1						
As	-.643**	-0.665**	0.205**	0.148**	-0.748**	1					
Sb	0.743**	0.519**	0.118**	-0.004	0.713**	-0.581**	1				
Co	0.043	0.176**	-0.159**	0.354**	0.098**	-0.237**	-0.146**	1			
Hg	0.796**	0.540**	-0.075**	-0.040	0.732**	-0.686**	0.770**	0.029	1		
Sr	0.007	-0.024	-0.230**	-0.386**	0.052	-0.070**	0.086**	-0.451**	0.039	1	
Fe	0.528**	0.512**	0.037	-0.333**	0.744**	-0.737**	0.647**	0.024	0.614**	0.186**	1

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

* Correlation is significant at the 0.05 level (2-tailed)

For better understanding, the cluster analysis (CA) was also executed. CA retains three main clusters. The cluster graph shows high correlation between Sb-Hg-Cu-Zn, indicating the same origin. In addition, Pb-Fe and Co-Cr-Ni indicate they have a similar origin (Figure 7).

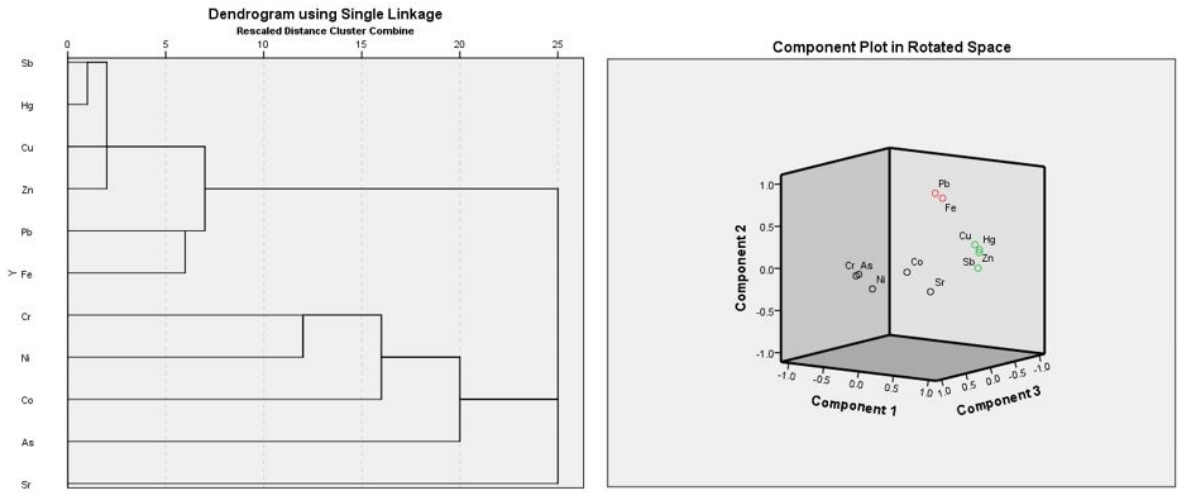

Figure 7. Dendrogram obtained for hierarchical cluster analysis and component plot for the studied samples.

The PCA analysis displays different sets of studied metals in all sampling locations (Figure 7). PC1 created 45% of the total variance with positive factor loadings for Cu, Zn, Sb, and Hg. It was specific for the sediments at the west part of the studied area. The points highlighted in the PCA graphs that tend to be within the vicinity of each other, yield similarity in patterns. Using PCA analysis to identify the source of HMs, most of Cu, Zn, Sb, and Hg (variables with an eigenvalue greater than 0.85) are thought to have come from both geogenic and anthropogenic sources. The second principal component (PC2) generated 14.7% of the total variance and indicates positive coefficient factor loadings for Pb and Fe variables with an eigenvalue greater than 0.8. The second group comprised of elements come from both the geogenic and anthropogenic sources. The higher concentration of Fe in the studied area can relate to the Fe-oxides or sulfide minerals in the Cu-Au mineralization. The third group (PC3) accounts for 11.5% of the total variance, and comprised of Cr and Ni (with an eigenvalue greater than 0.74) showing a concentration higher than the average shale value would be considered to the geogenic source. One group containing As and Sr with a concentration greater than the average shale value would be of the anthropogenic cause.

Based on the statistical analysis, there are three major element classes: (1) Sb-Hg association mostly related to mining activities, (2) mixed origin (Cu-Pb-Zn), mainly related to mine and partly to lithology (3) natural origin (Cr, Ni, Co).

The chemical composition of stream sediments samples can change depending on the involvement of different rocks resources. Geomorphology and Physiographic studies of the southern part of Mokhtaran Basin (928 Km^2) show poorly to moderately sorted sediment in the area. The observed facies include mud supported gravel, grain supported gravel, massive sand, planar laminated sand, slightly cross-laminated sand, trough laminated sand, laminated mud), and massive mud [40]. Modified Pacific Southwest Inter-Agency Committee (MPSIAC) model suggests class II (weak) and III (moderate) ranges for sediment and erosion with 1.51 and 40.55 ton in year per hectare for sediment production and erosion respectively [40].

Heavy metals originate naturally in soil and sediments and the rock type, environmental conditions, and weathering processes determine their concentration. The high correlation of Cr and Ni in the studied area corresponds to ultramafic rocks and ophiolitic series. Comparing the mean concentrations of heavy metals with other stream sediments from different parts of Iran, which present some type of anthropogenic mining contamination that is shown in Table 5. The maximum Cu (102.7 $mg.kg^{-1}$) and Co (40 $mg.kg^{-1}$) values found in this study, while Cr and As concentration were lower than the other stream sediments (Table 5).

Table 5. HM concentrations (mg.kg^{-1}) in stream sediment samples from different parts of Iran.

Sample	Location	Cu	Pb	Zn	As	Sr	Sb	Cr	Ni	Co	reference
Mokhtaran	East	102.7	24.50	169.8	7.14	401.80	5.93	133.50	75.30	40.00	This study
Zarshuran	North west	30.31	70.19	170.39	139	-	22.05	-	50.17	15.73	[42]
Sheshtamad	North east	34.49	9.04	59.50	7.70	423.95	0.27	519.38	79.70	16.59	[45]
Kerman	Center	57.33	45.49	112.47	19.36	-	-	330.62	83.58	-	[44]
Zanjan	North	35.57	37.61	82.71	21.83	-	1.96	-	68.96	20.30	[46]

The results of this study suggest that beyond natural geochemical processes as the main driver of soil contamination, mining activities as well contribute particularly for certain elements such as Cu and Zn. The results of contamination indices and risk assessment and weak to moderate erosion condition indicate some higher heavy metal concentration than other published studies (Table 5).

3.4. Tracking pollution overtime

The diversity of rock units and mineral potentials plays an important role in the interpretation of geochemical information and the source of pollution in sediments. There are several Au-Cu mineralization's in the upper part of the studied area. These mineralization areas are not active yet and exploration operations are in progress. The study evaluated two exploration areas to show the effect during the early stages of mining activities [20-22]. The outcome of the study shows higher pollution of As, Pb, and Sb in the studied elements, wherein earlier studies were significantly lower than these studied samples (Figure 8). The higher As concentration was located in the sediment near the prospecting area. The differences in the concentration of HMs in the upstream sites appear to be related to the early stages of mining activities. Also the rate of erosion and sediment supply is weak and moderate.

Evolution of different data series is correlated with the amount of potential risk for HM pollution. The rise in HMs triggered by these early stages of mining activities may result in more contaminated environments. The pollution assessment has created an alarming situation for future mining activities in the studied area that requires immediate attention.

The main limitation of investigating the effects of mining on the environment was to acquire permit from the private sector miners to take samples in order to assess the environmental impact of their mining operations.

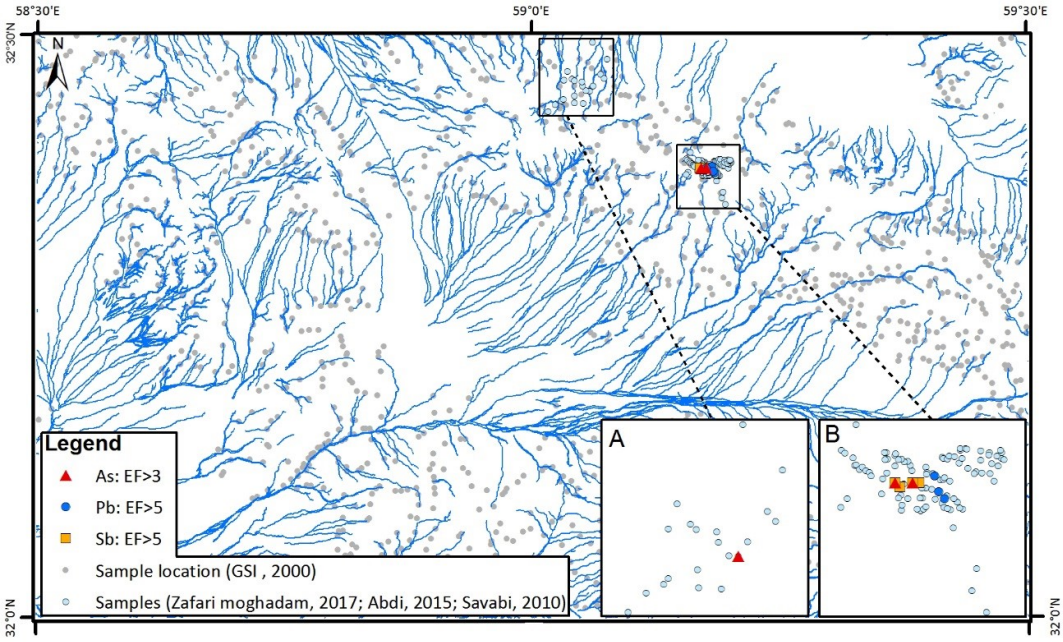

Figure 8. Comparing overtime effect of mining preliminary activities in some Au-exploration area.

4. Conclusions

Based on the metallogeny and mineralization potential of the Eastern Iran, especially for gold, copper, and associated elements, the environments are expected to have a high concentration of HMs. This study used multiple methods to investigate the contamination in stream sediments in a mineralized area in eastern Iran. The data presented here indicate that concentration of some elements are higher than that of average shale values. (i.e. As in the east, Cu, Sb, and Pb in the west, Sr an Hg in the central, and Cr and Ni in the southern part of the studiedy area.)

The heavy metal contamination of the soil and sediment in the extent of the studied area is evident in various localities. The most affected stream sediment is located close to the mining area, indicating As, Cu, and Sb pollution are related to Cu-Au mineralization.

Based on the risk index, the quality of stream sediments was relatively good in the whole studied area except for a few stations. The investigation on mining activities even at early stages of operation confirm the spreading of some heavy metals in stream sediments.

Statistical analysis and contamination indices indicate the distribution of the Cu, Pb, and Zn elements are controlled by the anthropogenic sources, mostly from the mineralization area. In contrast, the distribution of Cr, Co, and Ni has lithological sources.

The origin and behavior of toxic elements and their effect on the quality of soil is crucial to future endeavors. Attention should be paid to potential risks to the environment throughout all stages of gold mining, particularly risks associated with trace elements dispersion in the surrounding environment.

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ارزیابی آلودگی رسوبات رودخانه‌ای با استفاده از شاخص‌های آلودگی و ارزیابی ریسک در مناطق معدنی، شرق ایران

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چکیده:

در این تحقیق، نتایج تجزیه شیمیایی حدود ۱۴۰۰ نمونه از رسوبات رودخانه‌ای برای درک بهتر آلودگی‌های زیست‌محیطی ناشی از فعالیت‌های معدنی در شرق ایران مورد پردازش قرار گرفت. نمونه‌های رسوب رودخانه‌ای برای As Sb, Fe, Cr, Ni, Cu, Zn, Pb, Sr، و Hg مورد تجزیه و تحلیل قرار گرفتند. میانگین غلظت این عناصر از ترتیب کاهشی Fe > Sr > Zn > Cr > Cu > Ni > Co > Pb > As > Sb > Hg پیروی می‌کند. بر اساس ارزیابی آلودگی، فاکتور غنی‌سازی بسیار شدید برای Co (EF > 25) و غنی سازی بالا برای عناصر Sb, Cr Hg و Sr (EF > 10) مشخص گردید. به طور خاص Cr و Ni در رسوبات رودخانه‌ای بخش جنوبی غلظت قابل توجهی در مقایسه با سایر عناصر نشان می‌دهد. محدوده فاکتور آلودگی از CF < 1 تا CF > 6 برای اکثر عناصر متغیر است. شاخص زمین انباشت سطوح آلودگی بسیار بالا برای Cr و Co و آلودگی بالا تا شدید برای Sb را نشان می‌دهد. شاخص‌های ریسک برای همه عناصر، به جز As و Co در قسمت شرقی منطقه مورد مطالعه، پایین است. تجزیه و تحلیل مؤلفه‌های اصلی، ضریب همبستگی اسپیرمن و تحلیل خوشه‌ای برای نشان دادن شباهت‌ها و تفاوت‌های بین عناصر مورد استفاده قرار گرفت. شاخص‌های آلودگی نشان می‌دهد که آلودگی در برخی از نمونه‌ها ناشی از کانی‌سازی طلا در منطقه است. همبستگی بالای Cu Zn، و Sb نیز به دلیل کانی‌سازی سولفیدی طلا است. همبستگی بالای Cr و Ni در ارتباط با سنگ‌های الترامافیک و سری‌های افیولیتی است. این مطالعه بر تأثیر فعالیت‌های معدنی، حتی در مراحل اولیه فعالیت، در پراکندگی برخی فلزات سنگین در رسوبات رودخانه‌ای متمرکز است. بر اساس نتایج ارائه شده در این تحقیق، هرچند بیشتر آلودگی‌ها در مناطق مورد نظر ریشه در فرآیندهای ژئوشیمیایی و کانی‌سازی دارد، فعالیت معدنی نیز به آلودگی خاک برای عناصر خاصی مانند Cu و Zn کمک کرده است. بیشترین تاثیر آلودگی در رسوبات رودخانه‌ای مجاور مناطق معدنی وجود دارد و باید به خطرات بالقوه برای محیط زیست به ویژه در طول فعالیت‌های معدن‌کاری طلا توجه شود.

کلمات کلیدی: فلزات سنگین، کانی‌سازی، رسوبات رودخانه، شاخص‌های آلودگی، ایران.