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Geochemical and environmental assessment of heavy metals in soils and sediments of Forumad Chromite mine, NE of Iran

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Abstract

Heavy metal concentration in the soils and sediments has increased worldwide during the last century due to the mining, smelting, and industrial activities. The Forumad chromite deposit is located in the Sabzevar ophiolitic complex (SOC), with a long history of mining activities, yet very little is known about the heavy metal contamination in its surrounding environment. In this research work, the soil pollution by heavy metals was investigated with respect to the geochemical, statistical, and environmental indicators over the chromite mine in Forumad. The concentrations of heavy metals were analyzed, and the results obtained showed that the mean concentrations of Cr (5837.5 ppm) and Ni (570.7 ppm) in the nearby soils and sediments were significantly high. On the other hand, the mean concentrations of the other heavy metals present such as As, Cd, Co, Cu, Pb, and V were close to the geological background values. The multivariate statistical analyses (Pearson coefficient analysis, Cluster analysis, and principal component analysis) were used to understand the various anthropogenic and geological (lithogenic) sources. Our geochemical and environmental assessments suggested that Cr, Ni, Co, and V had similar properties, and their presence in the soils was mainly from the ultramafic rocks and chromite deposits. However, the calculated enrichment factors for Cr and Ni were more than 10, suggesting their anthropogenic sources due to the mining activities. The significant Cr and Ni contaminations in the Forumad nearby soils indicated that the status of heavy metal contaminations of the area should receive further considerations in the metal mine areas throughout SOC.

Keywords: *Geochemical, Environmental Assessment, Heavy Metal Contaminations, Enrichment Factor, Sabzevar Ophiolite Complex (SOC).*

1. Introduction

Soil contamination by heavy metals is one of the major environmental concerns, and it has been considered by many researchers in the last few decades. The sources of heavy metal contaminations are classified into the two groups, *lithogenic* (parent materials) and anthropogenic. The dominant factor determining the total concentration of heavy metals in the world soils is the lithogenic sources including geological formations, mineral springs, and salty waters [1-3]. *In contrast, the* anthropogenic sources are caused by the human activities such as mining and industrial activities, chemical fertilizers, insecticides, and pesticides [4-6]. Mining activities, in particular, open-pit mining, causes environmental pollution and heavy metal contaminations in the surrounding areas [7, 8]. Sabzevar ophiolitic complex (SOC) is one of the major ophiolitic belts in the NE of Iran that hosts a number of active chromite mines [9-11]. Mining activities in this region can release large amounts of heavy metals (e.g. Cr, Ni, and Co) in the nearby soils and water resources [12]. Ultramafic rocks of various types including peridotites, serpentinites, and pyroxenites are particularly notable because of the high concentrations of the Ni, Cr, Cu, and Co elements [13]. Although, relatively low concentrations of Ni and Cr are essential for plants and other living organisms including humans, both are toxic for all living organisms if present in excessive concentrations [14-16]. Due to the stability and bio-availability of heavy metals, they are the most dangerous pollutants in the environment [17, 18]. The chromite mine in Forumad is the largest chromite mine present in Iran. Due to the geomorphological disturbance caused by the activities taking place in the Forumad chromite mine and the geological composition of the region, the potential for production of pollution in the soils exists around the mine. In this work, new geochemical characteristics were presented in the plain soils and sediments from near the Forumad mine. We used the multivariate statistical analysis to determine their spatial distribution with regard to the lithogenic and anthropogenic sources.

2. Geology of region

The studied area is located in the NW of SOC (Figure 1). SOC is located along the northern boundary of the central Iranian microcontinent (CIM), and dates back to the Mesozoic era [19]. The rock units present in the studied area include Mesozoic ophiolitic series (including serpentinite, harzburgite, dunite, chromitite, layered gabbros, and basalts), Neogene volcanic and pyroclastic rocks (including tuff, tuffit, and agglomerate), Cretaceous pelagic limestone, sandstone and conglomerates, and quaternary deposits (Figure 1). The Forumad podiform chromite deposit is located within the ophiolitic zone of SOC [20]. The chromite ore shoots are hosted in the highly serpentinized harzburgites. The petrographic studies carried out on these rocks suggest that chromite ($FeCr_2O_4$) forms the major and bulk volume of the deposit. Other mafic minerals (olivine and pyroxene) and serpentine group minerals (chrysotile and Lizardite) are also present in the samples (Figure 2). Furthermore, sulfide minerals (pyrite and pyrrhotite) and accessory minerals (magnetite, calcite, brucite, and *clinochlore chlorite*) can be found in the rocks. Chromite is present as discontinuous layers, pencil and lens-shaped, vein, granular, and nodules in the ophiolite rocks [11, 21].

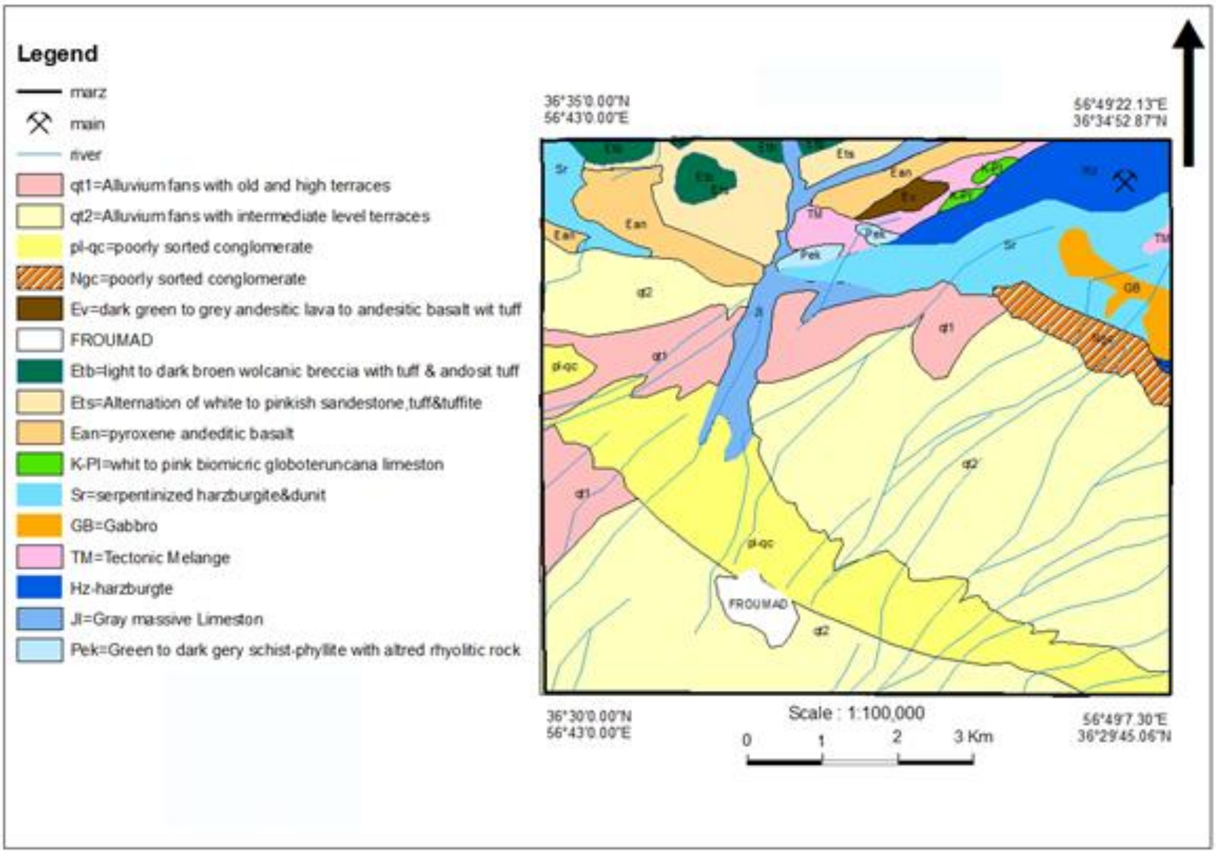

Figure 1. Simplified geological map of Forumad chromite district.

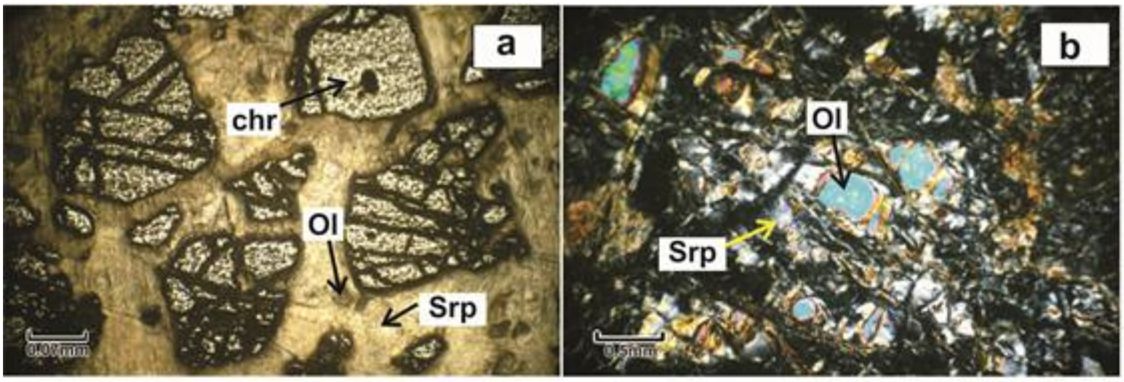

Figure 2. Microscopic image of chromite rocks (including chromite (Chr), olivine (Ol), and serpentine (Srp) minerals) in reflected light PPL (a); microscopic image of harzburgite rocks (including olivine (Ol) and serpentine (Srp) minerals) in transmitted light XPL (b).

3. Materials and Method

In order to determine the metal concentrations and geochemical measurements, a total of 9 soil samples and one sample from the tailing materials were collected during May, 2014. The soil samples were taken from a depth of 0-10 cm. The samples were transferred to a laboratory, and after drying, they were sieved through mesh (200), and then homogenized. The hydrogen ion concentration (pH) and EC values were measured at the soil contamination laboratory located in the Islamic Azad University of Mashhad, (Table 1). 10 g of each soil sample (the material passed through the sieve of mesh 200) was analyzed to determine the heavy metal concentrations in it using inductively coupled plasma-mass spectrometry (ICP-MS) (Table 1). The geochemical data obtained was then normalized, and after ensuring the normality of the data distribution and values outside of class, the SPSS 22 software was used to calculate the Pearson correlation coefficients (r) [22]. Finally, in order to process the data and environmental assessment, the other statistical parameters such as the enrichment factor (Ef), contamination factor (Cf), geo-accumulation *index* (Igeo), and pollution load index (PLI) were determined using the SPSS 22 software.

Table 1. Values for geochemical parameters, and results of ICP-MS in soil and rock samples from studied area (element values in ppm, and EC values based on µs/cm).

Sample	As	Cd	Co	Cr	Cu	Fe	Mo	Ni	Pb	V	K	Na	pH	EC
F007	9.3	0.33	61.3	2140	41	40042	0.35	956	10	61	5226	5493	7.86	2700
F010	3.6	0.78	39.7	488	27	32553	0.79	414	13	81	12385	10134	8.2	287
F018	2.2	0.78	38.5	773	25	36247	0.6	496	13	97	12017	9366	8.53	301
F039	2.4	0.8	32.4	1325	26	32006	0.75	335	15	103	12866	13436	8.41	271
F044	4.3	0.77	39.5	691	22	36251	0.66	480	13	95	10284	11929	8.06	200
F045	5.4	0.56	49.9	1007	21	36372	0.42	677	13	74	8223	9150	8.36	280
F049	3.3	0.97	33.7	380	38	35847	0.45	313	11	113	10335	16547	8.46	205
F050	5.3	0.86	49.6	1277	27	43548	0.66	594	13	117	8766	8962	8.25	196
F053	7	0.73	19	294	35	28004	0.84	164	10	115	9407	10950	8.77	226
F100	0.1	0.1	90.1	50000	6	40719	0.15	1278	14	255	80	100	8.0	1200

4. Results and Discussion

4.1. Chemical characteristics of soil samples

The hydrogen ion concentration (pH) and electrical conductivity (EC) are very important factors in controlling and mobility of heavy metals in soil. In other words, these parameters are mainly considered to control the balance between the absorption and desorption of heavy and rare elements in the soil profile along with other parameters like Eh, soil colloidal particles, organic materials, and iron and aluminum oxides and hydrides [23]. For example, a reduced pH value in the soil leads to a raise in the mobility of the elements in it [24]. Based on Soil Science Society of America, the soil samples in the studied area are in the range of 7.86-8.77 (slightly alkaline to moderately alkaline). The study of EC values has shown that EC in the region has changed from 196 to 2700 μs/cm. The data obtained suggests that the soil samples with high levels of nickel have the highest EC levels.

4.2. Correlations of heavy metals in soil samples

4.2.1. Pearson coefficient

The correlation coefficients between each pair of variable elements in the soil samples were calculated using the Pearson correlation matrix approach. The correlation coefficients between the elements are shown in Table 2. The results obtained show that there are both positive and negative correlations between the elements with regard to their sources. The multivariate analysis carried out shows a strong positive correlation between chromium and vanadium ($r = 0.932$, $P < 0.01$), cobalt ($r = 0.824$, $P < 0.01$), and nickel ($r = 0.770$, $P < 0.01$). On the other hand, there is a significant negative correlation between chromium and cadmium ($r = -0.768$, $P < 0.01$), molybdenum ($r = -0.0681$, $P < 0.05$), potassium ($r = -0.821$, $P<0.01$), and sodium ($r = -0.765$, $P < 0.01$). The positive correlation between the elements Cr, V, Co, and Ni reflect their same origin. Also the negative correlation between chromium, molybdenum, cadmium, sodium, and potassium shows their different origins. The same origin for the elements molybdenum, cadmium, sodium, and potassium was confirmed, with a highly positive correlation they have with each other (e.g. the correlation between sodium and cadmium ($r = 0.910$, $P < 0.01$), and potassium and molybdenum ($r = 0.825$, $P < 0.01$)). Since the soil samples in this region were relatively alkaline (pH = 7.8-8.7), the positive correlation between cobalt, iron, and nickel, and their negative correlations with pH was not unexpected. Also the positive correlation between arsenic and copper ($r = 0.719$, $P < 0.05$) indicateed their common sources. Pearson coefficients suggest that lead does not show a significant correlation with any of the elements. Iron is very active, chemically, and its chemical behavior is similar to those for cobalt and nickel [25].

Table 2. Matrix of correlation values (r) for chemical parameters and heavy metals in Forumad plain soils.

	As	Cd	Co	Cr	Cu	Fe	Mo	Ni	Pb	V	pH	EC	K	Na
As	1													
Cd	.011	1												
Co	-0.252	**-0.847****	1											
Cr	-0.548	**-0.768****	**0.824****	1										
Cu	**0.719***	0.455	-0.590	**-0.731***	1									
Fe	-0.033	-0.371	**0.738***	0.371	-0.264	1								
Mo	0.170	**0.741***	**-0.850****	**-0.681***	0.346	**-0.648***	1							
Ni	-0.132	**-0.896****	**0.985****	**0.770****	-0.519	**0.724***	**-0.860****	1						
Pb	**-0.750***	-0.020	0.254	0.320	**-0.759***	0.143	0.005	0.166	1					
V	**-0.643***	-0.518	0.619	**0.932****	**-0.693***	0.273	-0.494	0.535	0.328	1				
pH	-0.068	0.592	**-0.748***	-0.395	0.243	**-0.663***	0.558	**-0.757***	-0.134	-0.142	1			
EC	0.428	**-0.726***	0.584	0.295	0.199	0.408	-0.588	**0.682***	-0.379	0.029	**-0.672***	1		
K	0.013	**0.888****	**-0.871****	**-0.821****	0.409	-0.562	**0.825****	**-0.884****	0.106	**-0.675***	0.548	-0.625	1	
Na	0.074	**0.910****	**-0.868****	**-0.765****	0.545	-0.519	0.620	**-0.896****	-0.112	-0.562	0.565	-0.606	**0.839****	1

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

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

4.2.2. Cluster analysis (CA)

Cluster analysis (CA) classifies the studied heavy metals in terms of their similarity or difference. According to the dendrogram (Figure 3), two main clusters can be observed. The first cluster consists of cobalt, nickel, iron, chromium, vanadium, lead, and the second cluster consists of cadmium, sodium, potassium, molybdenum, arsenic, and copper. The first cluster, based on the degree of dependence on metals, can be divided into three sub-clusters: 1) cobalt, nickel, chromium, and vanadium 2) iron 3) lead. It seems that the correlation and dependence of these three sub-clusters show their similar geochemical behavior in the soils and sediments in this region.

However, the correlation and dependence of cobalt and nickel in the sub-cluster 1, and chromium and vanadium in the sub-cluster 2 are very high. In the second cluster, the two clusters can be defined as: 1) cadmium, sodium, potassium, and molybdenum 2) arsenic and copper. In general, cadmium, sodium, and potassium are highly dependent variables, while molybdenum has a lower dependence to this cluster. Based on the cluster analysis, at least two different sources can be proposed for these elements in the soil. These two sources include rocks with the ophiolitic nature (peridotite, dunite, serpentinite, gabbro, and basalt) that can be considered as the source for the Cr, V, Ni, Fe, and Co elements, and acidic rocks (conglomerate and acidic tuff) are the geochemical sources of sodium, potassium, cadmium, molybdenum, copper, and arsenic.

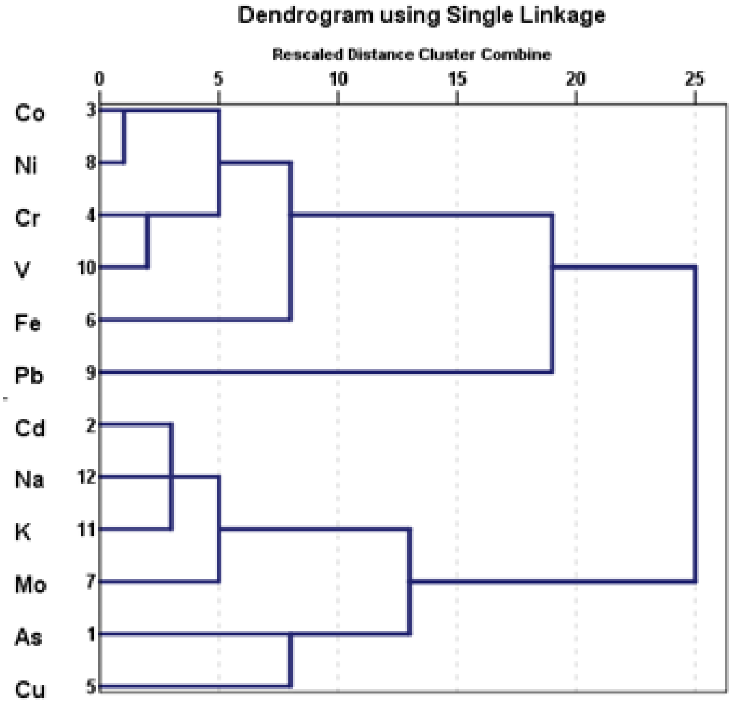

Figure 3. Hierarchical clustering results (dendrogram) for heavy metal concentrations in soil samples.

4.2.3. Principal component analysis (PCA)

Principal component analysis (PCA) is often used to perform a better determination and interpretation of the relationship between the soil variables for the soil samples. In fact, PCA is based upon the correlation matrix between the variables [26]. This method can express a lot of information about the basic structure of the data and their possible relationships [27]. In other words, the major objective of this statistical method is to determine the main controlling variables in a data series [28]. The geochemical characteristics such as the ionic radius and charge, mobility, chemical exchanges with organic materials, and clay minerals control the heavy metal distributions in the soils and sediments. PCA proposes a four-component model for the data obtained in the studied area (Figure 4 and Table 3). In the first component, chromium, nickel, vanadium, cobalt, and iron, and in the second component, molybdenum, cadmium, sodium, and potassium, and in the third component, copper and arsenic are the correlated variables. (Figure 4). Although Pb is a relatively independent variable, it shows a slight dependence on the first component (chromium, nickel, vanadium, cobalt, and iron). PCA well-matches with the cluster analysis results (Figure 3). Our statistical analysis results suggest that the origins for chromium, nickel, vanadium, cobalt, and iron are the ophiolitic rocks in this region, and molybdenum, cadmium, sodium, potassium, copper, and arsenic are sourced from the conglomeratic rocks and acidic tuffs.

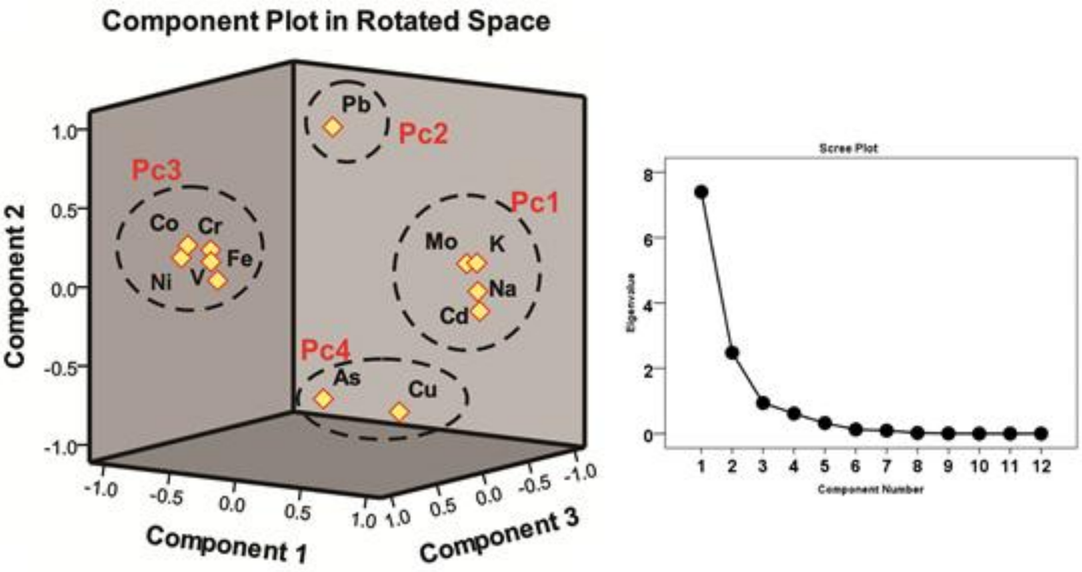

Figure 4. 3D graph of PCA for studied elements in soils of studied area.

Table 3. PCA results of the principal component analysis.

Rotated Component Matrix[a]

	Component			
	1	**2**	**3**	**4**
As	-0.127	-0.774	-0.032	**0.577**
Cd	**0.952**	-0.005	-0.174	0.179
Co	-0.733	0.227	**0.580**	-0.244
Cr	-0.651	0.321	**0.684**	-0.357
Cu	0.425	-0.806	-0.070	**0.599**
Fe	-0.264	0.101	**0.926**	0.019
Mo	**0.530**	0.060	-0.656	0.388
Ni	-0.794	0.138	**0.562**	-0.157
V	-0.604	0.337	**0.740**	-0.210
K	**0.797**	0.130	-0.384	0.415
Na	**0.921**	-0.142	-0.240	0.109
Pb	0.016	**0.979**	0.070	0.002

Extraction Method: PCA.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 7 iterations.

4.3. Geochemical and environmental assessment of heavy metal contaminations

To determine the extent of soil contamination with heavy metals, usually the elements of a studied area are compared with those of the international standards. Various methods and factors have been proposed to assess the heavy metal contaminations in soils [29]. The enrichment factor (EF), contamination factor (CF), contamination degree, pollution load index (PLI), and geo-accumulation index are usually calculated for a studied area. The international standard values for different elements used to calculate the coefficients and parameters are given in Table 4. The following is a review and evaluation of the geochemical and environmental heavy metal contaminations in the regions based on the coefficients.

Table 4. Enriched Factor, contamination factor, and average of elements in earth's crust and global shale (from US Environmental Protection Agency [30, 31]).

Element	As	Cd	Co	Cr	Cu	Fe	Mo	Ni	Pb	V	Al
Ef	5.77	7.09	4.87	220.01	1.11	2.16	0.82	32.03	2.39	2.38	1
Cf	0.33	2.22	2.38	58.37	0.59	0.76	0.2	8.39	0.62	0.85	0.46
Average elements in earth's crust	120	12.5	50	1.5	41000	55	102	25	0.2	1.8	82300
World shale	68	2.6	47200	45	100	19	0.3	13	130	20	80000

4.3.1. Enrichment factor (EF)

The present day enrichment factor (EF) is a common approach to estimate the anthropogenic impact on the sediments [32-34]. This factor compares the concentration of an element in samples with the concentration of the same element in the uncontaminated area (i.e. geological background). EF is calculated as follows:

$$EF = \frac{\frac{C_{x1}}{C_{ref\,1}} sample}{\frac{C_{x2}}{C_{ref\,2}} background} \tag{1}$$

where EF is enrichment factor, C_{x1} is the concentration of an element in the sample, C_{ref1} is the concentration of the normalizing metal (Al) in the sample, C_{x2} is the background concentration of the element in the earth's crust, and C_{ref2} is the background concentration of the normalizing element (Al) in the earth's crust. The EF values calculated for the soil samples and the average measured EF values are shown in Table 5. According to the classification made by Chen C-W, Kao C-M, Chen C-F, and Dong C-D [35] (Table 5), The EF values vary from non-enriched Mo to low-enriched Al, V, Pb, Fe, and Cu, to medium-enriched Co, to relatively severely-enriched As and Cd, to very severely-enriched Ni, and finally, to extremely enriched Cr for the Forumad soils. The EF values for Cr and Ni are more than 10, indicating the anthropogenic origin of these elements in the soils and sediments in the studied area.

Table 5. Classification of EF valuesd by Chen C-W, Kao C-M, Chen C-F, and Dong C-D [35].

Highly enriched	Non-enriched	low	Medium	Relatively severe	Severe	Very severe	Extremely
EF	<1	1-3	5-3	5-10	10-25	25-50	>50

4.3.2. Contamination factor (CF)

Contamination factor (CF) indicates the contamination of the soils and sediments with heavy metals, and is obtained by dividing the concentration of the element in the sample taken by the concentration of the same element in the background [36, 37].

$$CF = \frac{C_{sample}}{C_{background}} \tag{2}$$

where CF is the contamination factor, C_{sample} is the concentration of the studied element, and $C_{background}$ is the concentration of the element in global shale.

The CF values calculated for the soil samples are shown in Table 6. Based on the classification made by Hakanson L [38] (Table 6), the lowest contamination with a CF value less than 1 is related to the elements such as arsenic, copper, iron, molybdenum, lead, vanadium, and aluminum. Also the elements such as cadmium and cobalt, based on the average values for the contamination coefficients 2.22 and 2.38, respectively, have moderate contaminations in the area, which is expected according to the productive nature of the rocks and their geochemical correlations. However, chromium and nickel, with the average values of 58.37 and 8.39, respectively, have the highest contamination CF values among the elements. Soil contamination with chromium and nickel was also confirmed by the calculated EF values. The results obtained show that the soils and sediments are significantly contaminated by chromium and nickel, with anthropogenic origin from mining activities.

Table 6. Classification of CF values by Hakanson L [38].

Amount of pollution	Low	Medium	High proportion	High
CF	<1	1-3	3-6	>6

4.3.3. Geo-accumulation index

This index was first described by Muller, and was identified as the Muller index [39]. The Muller index is used to measure the amount of contamination with heavy metals in the sediments [40]. This index is calculated using the following formula:

$$I_{geo} = \log_2^{[C_n/1.5B_n]} \tag{3}$$

where C_n is the concentration of the element in the sample and B_n is the concentration of the same element in the background sample.

In this index, a constant coefficient of 1.5 is applied for the eventual elimination of the background caused by the geologic processes [41, 42]. This index is used for the classification of soils, from non-contaminated to heavily-contaminated [43] (Table 7). According to Table 8, chromium has the highest rate of geo-accumulation in the sample F100 (from tailing materials), and thus shows an extreme contamination, whereas the rest of the samples show moderate to severe contamination. Nickel and aluminum show moderate to severe contamination. Cadmium and cobalt show non-contaminated to moderate contamination.

Table 7. Classification of geo-accumulation by [43].

Amount of pollution	Non-pollution	Non-pollution-Medium	Medium	Medium-Severe	Severe	Severe-Extremely	Extremely
Igeo	<0	0-1	1-2	2-3	3-4	4-5	>5

Table 8. Geo-accumulation index for whole studied area.

Igeo	As	Cd	Co	Cr	Cu	Fe	Mo	Ni	Pb	V	Al
F007	-1.06	-0.44	1.10	3.83	-0.71	-0.82	-3.47	3.22	-1.58	-1.67	0.92
F010	-2.43	0.79	0.47	1.70	-1.32	-1.12	-2.30	2.02	-1.20	-1.26	1.79
F018	-3.14	0.79	0.43	2.36	-1.43	-0.96	-2.70	2.28	-1.20	-1.007	1.75
F039	-3.02	0.83	0.18	3.14	-1.37	-1.14	-2.37	1.71	-1	-0.92	1.96
F044	-2.18	0.77	0.47	2.20	-1.61	-0.96	-2.56	2.23	-1.20	-1.03	1.72
F045	-1.85	0.31	0.80	2.74	-1.68	-0.96	-3.21	2.73	-1.20	-1.39	1.43
F049	-2.56	1.10	0.24	1.34	-0.82	-0.98	-3.11	1.61	-1.44	-0.78	2.10
F050	-1.87	0.93	0.79	3.08	-1.32	-0.70	-2.56	2.54	-1.20	-0.73	1.53
F053	-1.47	0.69	-0.58	0.97	-0.94	-1.33	-2.21	0.68	-1.58	-0.76	1.79
F100	-7.60	-2.16	1.66	8.38	-3.49	-0.79	-4.70	3.64	-1.09	0.38	0.75

4.3.4. Pollution load index (PLI)

Pollution load index (PLI) is often used to evaluate and estimate the degree of pollution in the soils and sediments. This index is calculated based on the coefficient of each element in the soil by dividing the concentration of each element in a soil sample by its concentration in the reference sample (CF) [44]. PLI can be calculated for a set of contaminant metals in the geometric mean of concentrations of all metals. If the PLI concentration is close to 1, this indicates that the concentrations are close to the background concentration, while the PLI concentrations above 1 show soil contamination [37, 45]. The total heavy metal contamination in the region is obtained using this indicator, and by the following equation [46]:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times ... \times CF_n} \tag{4}$$

According to the PLI equation, as in Figure 5, the PLI values in the soil samples F007, F018, F039, F044, F045, and F050 are above the background concentration (PLI > 1). This shows that the sediments are contaminated in the studied area. It seems that the soil samples are mostly contaminated by mine dumps, and possibly, drainage system and rivers made the contamination to spread further to the low land plain soils.

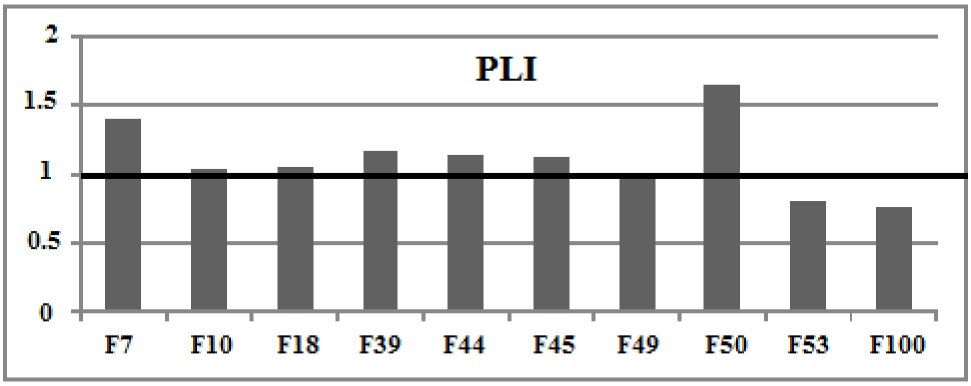

Figure 5. PLI values calculated for soils in Forumad district.

5. Conclusions

Using the results obtained for the Pearson correlation coefficient, principal component analysis, and cluster analysis in the studied area, two different sources can be proposed for heavy metal contaminations in the soils and sediments. These two sources include the ophiolite rocks (including peridotite, dunite, serpentinite, gabbro, and basalt) as the origin of Cr, V, Ni, Fe, and Co acidic rocks (including conglomerate and tuff acid) as the origin of sodium, potassium, cadmium, molybdenum, copper, and arsenic. The geochemical studies carried out on the Forumad soil samples show that the soils and sediments are extremely contaminated by chromium and nickel, compared to the global shale and its average in the earth's crust. This is also confirmed by the values for enrichment factor, contamination factor, and geo-accumulation index. Based on the above parameters, nickel is highly-contaminated; cadmium, arsenic, and cobalt are moderately-contaminated, and the other elements (copper, iron, molybdenum, lead, vanadium, and aluminum) have concentrations close to the background. The PLI calculations show that the majority of the soils in the studied area are contaminated with heavy elements. Large-scale mining activities in the region has led to the release of large amounts of heavy metals to contaminate the soils and sediments in the nearby Forumad mine. The significant contamination of Cr and Ni in the Forumad nearby soils indicate that the status of heavy metal contaminations of the area should receive further considerations in the metal mine areas throughout SOC.

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ارزیابی ژئوشیمیایی و زیست‌محیطی فلزات سنگین در خاک و رسوبات معدن کرومیت فرومد، شمال شرق ایران

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چکیده:

در قرن اخیر میزان فلزات سنگین به دلیل فعالیت‌های معدنی، ذوب و صنعتی در خاک‌ها و رسوبات سراسر جهان افزایش یافته است. کانسار کرومیت فرومد در مجموعه افیولیتی سبزوار، با قدمت طولانی در فعالیت‌های معدنکاری، واقع شده است. آلودگی فلزات سنگین در محیط اطراف آن تا به امروز ناشناخته مانده است. در این پژوهش آلودگی خاک به‌وسیله فلزات سنگین توسط شاخص‌های ژئوشیمیایی، آماری و زیست‌محیطی در اطراف معدن کرومیت فرومد بررسی شده است. میزان فلزات سنگین اندازه‌گیری شده نشان می‌دهد که میانگین غلظت کروم (۵۸۳۷/۵ پی‌پی‌ام) و نیکل (۵۷۰/۷ پی‌پی‌ام) در خاک و رسوبات به‌طور قابل‌توجهی بالا است. از سوی دیگر میانگین میزان غلظت سایر فلزات سنگین موجود مانند (آرسنیک، کادمیوم، کبالت، مس، سرب و وانادیوم) نزدیک به زمینه پوسته زمین (کلارک) است. آنالیزهای آماری چند متغیره (مانند آنالیز ضریب پیرسون، آنالیز خوشه‌ای و تحلیل مؤلفه اصلی) برای بررسی منابع انسان‌زاد و زمین‌زاد استفاده شده است. ارزیابی ژئوشیمیایی و زیست‌محیطی نشان می‌دهد که کروم، نیکل، کبالت و وانادیوم دارای ویژگی‌های مشابه بوده و در خاک‌های منطقه از سنگ‌های الترامافیک و کانسار کرومیت سرچشمه گرفته‌اند. همچنین میزان شاخص غنی‌شدگی بیش از ۱۰ در کروم و نیکل نشان از منشأ انسان‌زاد و فعالیت‌های معدنکاری دارد. میزان بالای غلظت کروم و نیکل در خاک‌های اطراف فرومد نشان می‌دهد که آلودگی فلزات سنگین در سراسر محدوده‌های معادن فلزی مجموعه افیولیتی سبزوار بایستی مورد توجه قرار گیرد.

کلمات کلیدی: ژئوشیمیایی، ارزیابی زیست‌محیطی، آلودگی‌های فلزات سنگین، شاخص غنی‌شدگی، مجموعه افیولیتی سبزوار.