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The role of Mineral Salts Company in pollution of Mighan playa sediments with heavy metals by contamination indices and multivariate analysis methods, Arak, Iran

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ABSTRACT

Heavy metal concentrations were investigated for 30 sediments collected from different regions of Mighan playa/lake. The means of Cr, Cu, Ni, Pb, Zn, and Cd in sediments of playa/lake were much lower than the soil guideline values of Iran and background values of the region (BVR). However, the maximum concentrations of Cr, Cu, Ni, Pb, Zn, and Cd were higher than BVR. Only 7% of Cr, Cu, Zn, 27% of Ni, 14% of Pb, and 38% of Cd concentration exceeded the BVR. The heavy metal Cr, Zn, Ni, and Cd are the most important metals in different land use. About 11% of the samples in the lake land use contain Cr, Ni, Pb, and Zn have concentrations higher than BVR. The concentration of Cu and Pb in 33% and 67% samples is exceeded the BVR in the tail of Mineral Salts Company. The spatial distribution patterns of Cr, Cu, Ni, Pb, Zn, and Cd were generally similar and increase from Mighan playa/lake to the Arak city and mainly affected by anthropogenic sources. Among the six types of land use, the concentrations of Cr, Ni, Zn, and Cd in the rangeland and wastewater sludge were significantly higher than those in the other land use ($p<0.05$). In factor analysis, Cr, Ni, Zn in factor1, Cd in factor2, Pb, Zn in factor3 were originated from the municipal sewage, industrial plants activities, and Arak urban traffic.

Keywords: *Heavy metal pollution, Soil and sediment contamination, Anthropogenic sources, Statistical methods, Mighan playa/lake*

1. Introduction

Heavy metal pollution has a potential threat to aquatic environments[1-3]. Heavy metals can be originated from different natural and anthropogenic sources [4-6]. The term *anthropogenic* designates an effect or object resulting from human activity (including fertilizer leaching, sewage discharge, industrial wastewater, and urban construction). Geological weathering, soil erosion, airborne dust, atmospheric precipitation, and anthropogenic activities are the most important pollutions[7-8]. Anthropogenic activities are the major cause of heavy metal pollution in many playas[9-11]. Sediments are the ultimate regions for heavy metals discharged into the environment [12-13]. The sediment could be a potential source of heavy metals, and an adverse effect on animal health [14-15]. Some toxic metals in the sediment can be mobilized by biochemical progress, causing water pollution and/or contamination of the metal in the food chain [16-17]. Heavy metals were easily deposited on the sediment surfaces and immobilized through adsorption. More than 90% of heavy metals were related to the suspended particles and their distributions can provide evidence of anthropogenic influences on aquatic environments[18-21].

The Mighan playa/lake is an enclosed lake in the central part of Iran in the Markazi province. The playa/lake is composed of a major island and a saline lake on the island. Four main types of deposits are found in playa[22]. The first type is very soluble evaporites, such as sodium sulfates. The second type is soluble precipitates, such as gypsum and calcite which formed during early diagenesis. The third type of sediments is clastic inorganic materials, which are transported into the playa by wind and runoff. The fourth type is organic detritus and other vegetation[22].

With the rapid development of industrialization and urbanization, anthropogenic activities have appeared around the Mighan playa in recent decades(such as the wastewater treatment plant, Mineral Salts Company, and industrial estates[23-24]. Various kinds of contaminants have entered the playa/lake and caused serious heavy metal contamination[25]. The ecosystem health of the playa/lake has attracted attention in recent years due to tourist attractions along the coastline and islands. The playa/lake suffers from rapid industrialization and urbanization of adjacent terrestrial areas[4-5]. The playa/lake was formerly a famous immigrant bird's home with different species of Dorna [6]. High industrial intensity, environmental pollution, and bird degradation have resulted in the tourist decline in recent years[6]. An urgent concern is that the Mighan playa/lake will degrade into a dead playa if no effective protection action is implemented. Thus, investigation and assessment of heavy metals of the playa/lake have been essential.

In this study, the main objectives were to (1) investigate the spatial distribution characteristics of heavy metals (Cr, Cu, Ni, Pb, Zn, and Cd) in soils and sludge from playa/lake and the differences and similarity of their concentrations in six types of land use, including the island of Mighan playa(Is); lake sludge of Mighan playa(La); rangeland in the margin of a playa(Ra); wastewater sludge(Wa); tail (Ta) and dump(Du) of Mineral Salts Company; (2) evaluate the heavy metals contamination with indices of pollution index (C_d), ecological risk factor(R_i) and Nemerow pollution index;(3) the possible sources of these heavy metals were identified through multivariate statistical analysis; (4) the effect of

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land use on heavy metal concentrations and (6) it tried to determine the role of Mineral Salts Company in the production of heavy metals compared to other sources.

2. Materials and methods

2.1. Description of the study area

Mighan playa/lake is located in the north of Arak city and is in the center of Iran(Fig.1). Mighan playa/lake is one of the most important closed basins in Iran, because of its mineable sodium sulfate deposit. Also, the vicinity of the playa/lake to Arak has important effects on the climate, groundwater, agriculture, and ecology of this city [22]. Mighan playa/lake with an area of about 100–110 km^2 is enclosed by mountains with a height of about 2,000 – 3,000 meters above sea level. This playa/lake formed in a tectonic depression that drains an extensive catchment area. Temperature ranges from approximately -30^{oC} in winter to+40 °C in summer. The average annual precipitation and evaporation of playa are 320 and 2,070 mm respectively [22]. Water influx into the basin is mainly via groundwater discharges, ephemeral rivers (including Gharah-Kahriz river, Ashtian river, Farahan river, Aman Abad river, and Ebrahim-Abad river). During the wet months, the ephemeral rivers carry sediment-loaded rain waters from the catchment into the lake basin. Large quantities of industrial and domestic wastewater discharge into Mighan playa/lake by channels of wastewater treatment plant (200-800 L/s)[4].

Mighan playa/lake is formed by tectonic movements. Structurally, this basin is shaped as a graben in the Sanandaj–Sirjan tectonic and central Iran zones (Orumieh–Dokhtar magmatic arc) [22]. The Sanandaj–Sirjan zone is mainly dominated by Jurassic schists, sandstones, and Cretaceous limestones, dolomites. These units mainly crop out in the northwest and southeast of Mighan playa. The volcanic of Orumieh–Dokhtar magmatic arc is present in the north and east of playa (Fig.1)

Minerals of Mighan lake/playa are mainly evaporites and fine-grained clastic components. Evaporite minerals are calcite, gypsum, halite, sylvite, glauberite, thernadite, polyhalite, natronite, and bassanite [22]. Gypsum and halite abundances increase from margin to the center of the playa. Clastic components are quartz, muscovite, clay minerals(illite and chlorite), calcite, and organic matter. The Na–SO_4–Cl type brine is formed during the geochemical evolution and mineral deposition [22].

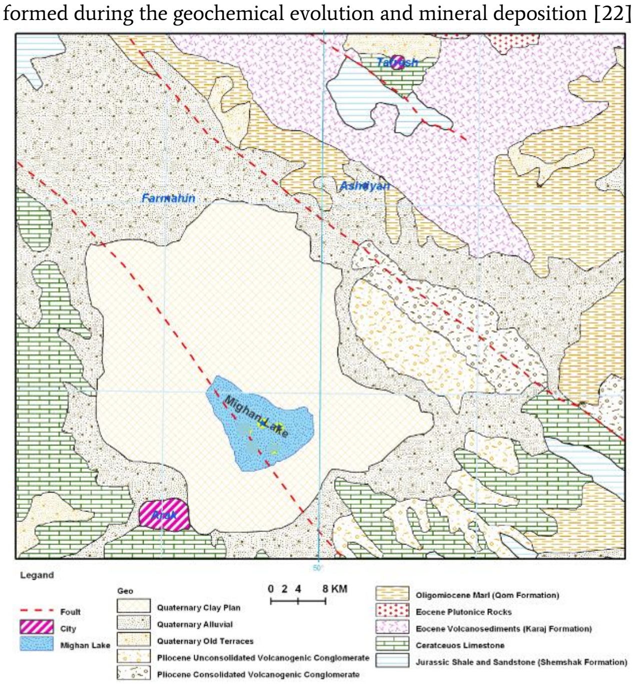

Fig.1 Geological map of the study area and Arak alluvial plain is located southwest of saline Mighan playa.

2.2. Sampling and measurement

A total of 30 sampling sites were prepared over the playa/lake. These sites were mainly from seven regions, including island of Mighan playa (4 sites;sample1,4,5,7); lake sludge of Mighan playa(9 sites; sample2,3,6,8,9,13,16,17,20); rangeland in margin of playa (8 sites; sample12,14,15,18,19,22,23,28); wastewater sludge (4 sites; sample21,24,25,27); tail of Mineral Salts Company (3 sites; sample10,26,29); dump of Mineral Salts Company (1 site; sample 11) and background of region (1 site; sample 30)(Fig.2). Sampling sites were selected to cover the important land uses and peripheral areas of the playa. Throughout the survey, a global positioning system (GPS) was used to locate all sampling sites. Surface soils and sludge samples (0–10 cm) were collected using a grab sampler in September 2018. At each site, two surface soil and sludge samples were collected and placed into dark-colored poly-ethylene bags and sealed. After sampling, the samples were transported to the laboratory of Zar - Azma in Tehran, and samples were stored at 4 °C for further analysis. Approximately 0.5 g of soil sieved through a 0.2- mm sieve used for digestion using the United States Environmental Protection Agency (USEPA) 3050B method [26]. The digested solution was filtered through a 4 - µm filter and diluted to 100 mL to measure Cr, Cu, Ni, Pb, Zn, and Cd using inductively coupled plasma- mass spectrometry (ICP- MS, 7500ce, Agilent Technologies, Inc., Santa Clara, CA, USA)[27]. Three replicates were conducted for the determination of the total content of the metals. All analyses were carried out in duplicate, and the results were expressed as the mean. The relative error(R%) was performed and checked the accuracy of the ICP analyses (Eq.1)[28].

$$R = \frac{2}{n}\sum\frac{[X_1-X_2]}{X_1+X_2}\times 100 \quad (1)$$

Where n is the number of duplicate samples, X_1 the value of sample analysis, X_2 the value of the repeated sample, R relative error of the analysis. The relative accuracy limit for the heavy metals was chosen to be 10%.

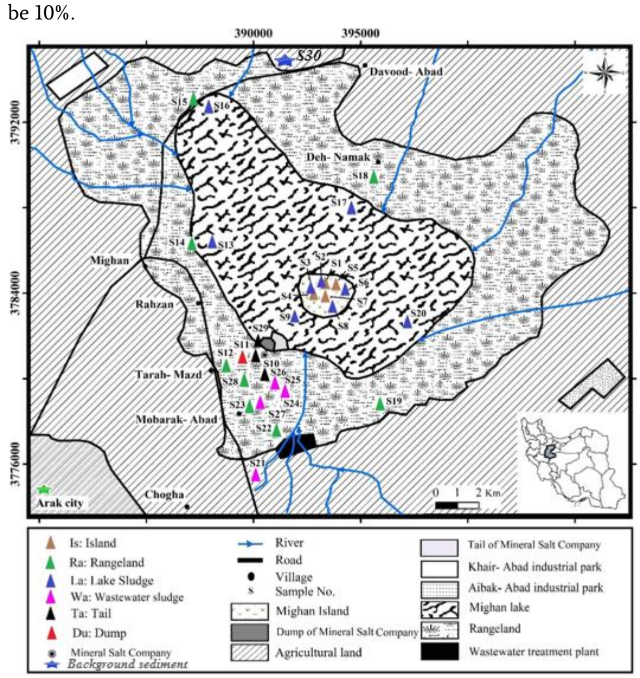

Fig.2. Sample and land use location of Mighan playa in Iran.

2.3. Assessment of metal contamination

To characterize heavy metal pollution in the soils and sludge of Mighan playa, different sediment quality guidelines were applied in this study. A sum of pollution index (PI_{sum}) can be defined as(Eq.2):

$$PI_{sum} = \sum_{i=1}^{m} P_i \quad (2)$$

where P_i is the single pollution index of heavy metal i, and m is the count of the heavy metal species. The sum of pollution index was widely used in soil and sediment quality assessment by heavy metals such as the degree of contamination and the potential ecological risk index[29-30]. The degree of contamination (C_d) was originally defined as the sum of all contamination factors (Eq.3):

$$C_d = \sum_{i=1}^{m} C_f \quad (3)$$

Where C_f is the single index of contamination factor, and m is the count of the heavy metal species. For the description of contamination degree, terminologies have been used (Table1)[31]. The potential ecological risk index (RI) was defined as the sum of the risk factors (Eq.4):

$$RI = \sum_{i=1}^{m} Er \quad (4)$$

where Er is the single index of ecological risk factor, and m is the count of the heavy metal species. Terminologies have been used for the potential ecological risk index (Table1). A Nemerow pollution index ($PI_{Nemerow}$) was applied to assess the quality of soil environment widely [32] and was defined as(Eq.5):

$$PI_{Nemerow} = \sqrt{\frac{\left(\frac{1}{m}\sum_{i=1}^{m} P_i\right)^2 + P_{imax}^2}{2}} \quad (5)$$

where P_i is the single pollution index of heavy metal i; P_{imax} is the maximum value of the single pollution indices of all heavy metals, and m is the count of the heavy metal species. The quality of the soil environment was classified into 5 grades from the Nemerow pollution index (Table1).

Table 1. Classification of pollution index (C_d), potential ecological risk index (RI), and Nemerow pollution index (PI).

C_d	*RI*	Degree contamination	PI	Degree contamination
$C_d < m$	$RI < 150$	Low degree	P_i<0.7	Safety domain
m≤ $C_d < 2m$	150≤$RI < 300$	Moderate degree	0.7≤P_i<1	Precaution domain
$2m \le C_d < 4m$	300≤P_i<600	Considerable degree	1≤P_i<2	Slightly polluted domain
$C_d \ge 4m$	$RI > 600$	Very high degree	2≤P_i<3	Moderately polluted domain
-	-	-	p_i>3	Seriously polluted domain

2.4. Statistical Analysis

For statistical analysis, Microsoft excel and Statistica12 software were used. The data were subsequently analyzed using multivariate statistical methods such as factor analysis, cluster analysis, discriminate analysis, and correspondence analysis. The multivariate statistical methods were used to identify the possible sources of metals in the soil and sludge and group them based on their similarities. For factor analysis, variables were centered as mean[33] and varimax rotation was applied to factor loadings > 0.7[34]. Cluster analysis is used to determine the similarity of variables. The discriminate analysis is used to determines how well it is possible to separate two or more groups based on the values of several variables [35]. It uses Mahalanobis distances to assigns the case to the group with the closest mean. Correspondence analysis is used to seek relationships between samples and between variables. It performs two principal components analysis: the first one in the p-dimensional space of the variables, the other one in the n-dimensional space of the samples. This method represents graphically the row and column categories and allows for a comparison of their associations at a category level. In correspondence analysis, it can be obtained relations between cases and variables [36].

3. Results and discussion

3.1. Heavy metal concentrations in sediments

The relative error (R%) was performed to check the accuracy of the ICP analyses. The relative error (R%) for the elements As, Pb, Zn, and Cr was determined as 9.0, 7.0, 6.9, 6.5, and 9.6, respectively based on duplicate samples. The accuracy of the analysis of heavy elements was confirmed due to a relative error of less than 10%. The normality of the heavy metals was determined with respect to the skewness in the range of -2 to 2[21]. The skewness of As, Cr, Cu, Ni, Pb, Zn, and Cd with values 0.84, 0.10, 1.49, 0.02, 1.43, -0.15 and-0.98 respectively are normal.

The descriptive of heavy metal concentrations in soils and sludge of different land use in Mighan playa/lake are summarized in Table2. The ranges of the contents (mg/ kg) of Cr, Cu, Ni, Pb, Zn and Cd were 19-93, 9-93, 12-60, 2-49,13-87, and 0.07-0.30, respectively. The average Cr had the highest value(53mg/ kg) followed by Zn(50), Ni(35), Cu(23), Pb(13) and Cd(0.21). As shown in Fig.3, the spatial distribution patterns of Cr, Cu, Ni, Pb, Zn, and Cd were generally similar, with increasing concentrations from the center of Mighan playa/lake to the Arak city and wastewater treatment. Arak city is located in the south of playa and is the third polluted city in Iran due to heavy industrial activities and traffics[21]. The low concentrations of Cr, Ni, and Zn mainly existed in the island of the playa (Is) but, in other parts of the playa were relatively high. Cu and Pb concentrations were high in the soil of rangeland in the margin of the playa (Ra) and wastewater sludge(Fig.3). The distribution pattern of Cd is nearly different from Cr, Cu, Ni, Pb, and Zn, and the greatest value existed within the soil of rangeland(Ra) in the southern part of the playa/lake.

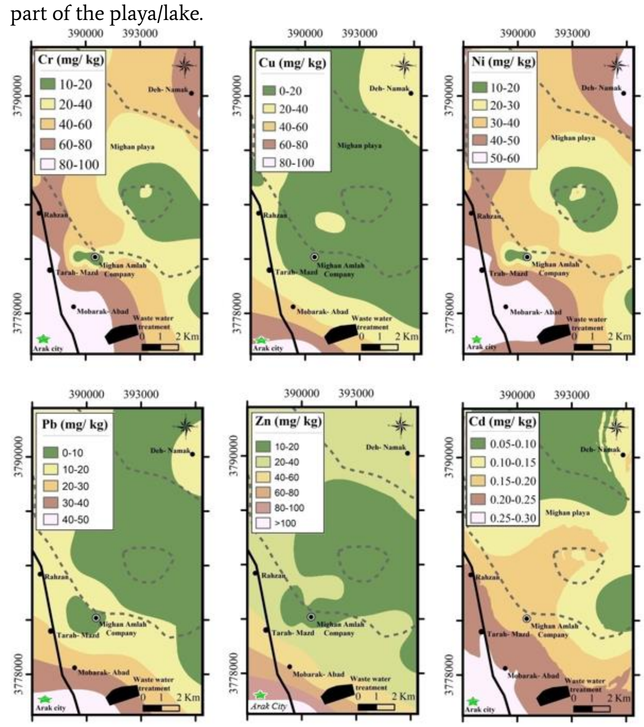

Fig.3. Maps of heavy metal distributions in soil and sludge of Mighan playa.

In Mighan playa soils, Cr, Cu, Ni, Pb, Zn, and Cd were much lower than the soil guideline values of Iran [37]and background values of the region(BVR). However, the maximum concentrations of Cr, Cu, Ni, Pb, Zn, and Cd in playa soils were much lower than the guideline values of Iran but higher than BVR. Mean concentrations of Cu and Pb were comparable to the BVR. Only 7% of Cr, Cu, Zn, 27% of Ni,14% of Pb, and 38% of Cd concentration exceeded the BVR. As shown in Table2, the mean of each heavy metal was lower than the guideline values of Canada and upper continental crust(except Cd)[38-39]. Compared with heavy metal concentrations in other cities around the world (China and Thailand), the concentrations of Cr, Cu, Ni, Pb, Zn, and Cd in the playa soils were relatively low[40-41]. The mean concentration of Cu and Cd in playa soils was comparable to Turku[42].

Table 2. Heavy metal concentrations in the Mighan playa soils (mg/kg)and compared with other countries.

	Cr	Cu	Ni	Pb	Zn	Cd	Ref.
-Mean	53	23	35	13	50	0.21	This study
-Minimum	19	9	12	2	13	0.07	-
-Maximum	93	93	60	49	87	0.30	-
-Background values of region(BVR)	73	23	45	13	66	0.25	This study (Depth of 1.5m)
-Guideline values of Iran(mean)	110	100	50	50	200	1	[37]
-Guideline values of Canada(mean)	64	63	50	140	200	10	[38]
-Upper continental crust	85	25	44	17	71	0.01	[39]
-Guideline values of China(mean)	200	100	50	300	250	0.07	[40]
-Bangkok -Thailand (mean)	26	42	25	48	118	0.29	[41]
-Turku, Finland (median)	37	19	12	20	72	0.20	[42]

3.2. Heavy metal concentrations in different land use

As shown in Table3, the p-value for several independent samples was conducted to determine whether the heavy metal concentrations differed in Is, La, Ra, Wa, Ta, and Du land use. Two independent samples test (p-value) showed that the concentrations of Cr, Ni, Pb, and Zn in Ra and Wa were significantly higher than Is, La, and Ta land use ($p<0.05$). The p-value was less than 0.05 for Cr, Ni, Pb, Zn, and Cd in Du relative to other land use. Therefore, there were no significant differences in Is, La, and Ta ($p>0.05$), which inferred that these three types of land uses were similar effects on the distributions of Cr, Ni, Pb, and Zn in the playa soils. The difference in Du land use suggested significant effects on the distribution of all metals in playa soils. Therefore, the mean concentrations of heavy metals show three different groups in the six types of land use (Is, La, Ta; Ra, Wa; Du). Only 25 percent of the samples in Is land use showed Cd higher than BVR, and Cr, Cu, Ni, Pb, and Zn are less than BVR (Table3). Meanwhile, heavy metals were lower than BVR in all samples of Du. About 11% of the samples in La land use contain Cr, Ni, Pb, and Zn higher than BVR and these values are 33% and 67% in Ta land use for Cu and Pb, respectively. The number of samples over BVR was exceeded in Ra and Wa land use.

Table 3. Mean concentrations, p-value, and higher percent of BVR of heavy metals in six types of land use in Mighan playa (mg/kg).

Landuse	Cr			Cu			Ni			Pb			Zn			Cd		
	Mean	p	BR	Mean	p	BR	Mean	p	BR	Mean	p	BR	Mean	p	BR	Mean	p	BR
Is*	35.75	0.58	0	14.75	0.12	0	25.00	0.68	0.	7.00	0.26	0	34.25	0.17	0	0.21	0.06	25
La	41.66	0.59	11	20.44	0.12	33	25.00	0.67	11	9.66	0.26	11	41.22	0.25	11	0.17	0.06	33
Ra	72.87	0.01	62	26.25	0.16	62	45.75	0.02	62	16.00	0.01	63	67.62	0.01	63	0.27	0.06	87
Wa	74.50	0.01	25	38.25	0.01	25	43.50	0.01	50	22.50	0.01	50	68.50	0.01	25	0.25	0.34	25
Ta	39.66	0.58	0	16.00	0.79	33	56.67	0.86	0	12.00	0.22	67	33.00	0.92	0	0.19	0.69	0
Du	19.00	0.03	0	11.00	0.53	0	12.00	0.03	0	2.00	0.04	0	13.00	0.04	0	0.10	0.04	0

*Is: Island of Mighan playa; La: Lake sludge of Mighan playa; Ra: Rangeland in the margin of Mighan playa; Wa: Wastewater sludge; Ta: Tail and De: Dump of Mineral Salts Company.

3.3. Potential contamination indices of heavy metal

The Sum of pollution index (C_d) for different land use is shown in Fig.4. The concentration of reference metals such, Cu, Ni, Pb, Zn, and Cd according to Table 2 in the calculation of contamination factor (C_d) are:73, 23,45,13,66, and 0.25, respectively. The calculated C_d values of the study areas indicated that different land use is low degree polluted (C_d>6 (Fig.4). The potential risk of the combination of multiple metals was determined using the ecological risk factor (R_i). The calculated R_i values can be categorized into four classes of potential ecological risks(Table1). The calculated R_i values of the current study show that different land use is at low ecological risk (as $R_i<150$). Therefore, they are under the potential ecological risk areas (Fig.4). The Nemerow pollution index(P_i) shows that the soils of different land use are safety domain ($P_i<0.7$), while rangeland in margin of playa(Ra) soils is precaution domain with no metal(Fig.4). The study results demonstrate that in all three methods, different land uses are low degrees of heavy metal pollution. Maximum values of the sum of pollution index (C_d) and ecological risk factor (R_i) are the same and explain the low degrees of heavy metal pollution. Maximum values are precaution domain based on Nemerow pollution index (P_i) in the lake sludge of Mighan playa (La), rangeland (Ra), and wastewater sludge(Wa). Therefore, there are some samples are heavy metal pollution above in three land use due to anthropogenic activities.

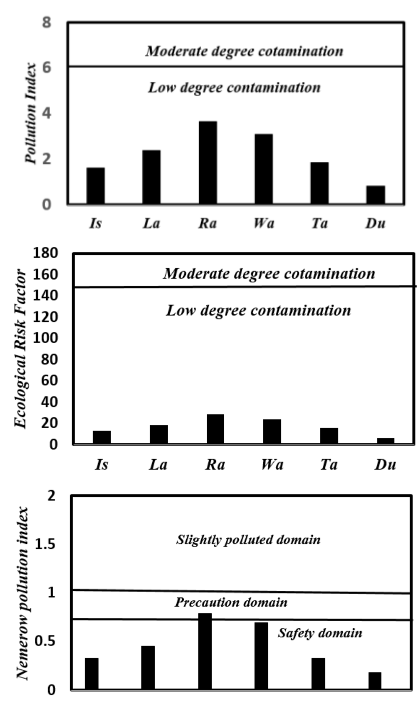

Fig.4. Potential contamination indices of heavy metals in different land uses.

3.4. Multivariat statistical analysis of heavy metals

Factor analysis is a statistical procedure often used to identify heavy metals [41-43]. In this study, factor analysis was used on the six heavy metals from 29 sampling sites. The Kaiser-Meyer-Olkin (KMO) index indicated that factor analysis is suitable for the reduction of data[33]. The results of the factor analysis showed three factors and all factors include 97.75% of the total variance (Fig.5). Analysis of cluster analysis also showed three clusters that confirm the factor analysis (Fig.6). The first cluster with Cr, Ni, and Zn, the second cluster with Cd, and the third cluster with Cu and Pb correspond to factors 1, 2, and 3 in factor analysis, respectively. Factor 1 explains 71.03% of total variance and Cr, Ni, and Zn had higher positive loads. The spatial distribution of factor 1 is much high in rangeland, wastewater sludge, and lake sludge (Fig.7). This concentration is more in rural areas, which can be due to airborne dust, atmospheric precipitation, and municipal sewage [4,20-21,23]. Factor2 was dominated by Cd and includes 15.51% of the variance. The distribution of factor2 is mainly on the southern and central margins of the Mighan playa/lake and is in rural areas (Fig.7). This metal signifies chemical and petrochemical discharge. Cd is well known to be used in material plastic stabilizers (cadmium oxide). Industrial estates are likely the source of Cd in this study[21,23].Factor3 was formed 11.21% of the variance and, composed of Pb and Cu. Factor3 has different dispersion and its focus is towards Arak city and municipal sewage (Fig.7). These metals are found in traditional electroplating and metal-surface-processing industries. Industrial plants and urban traffic are the sources of Pb and Cu in the southern of Mighan playa/lake [5,24-25]. Therefore, factor3 should be targeted in future environmental monitoring plans.

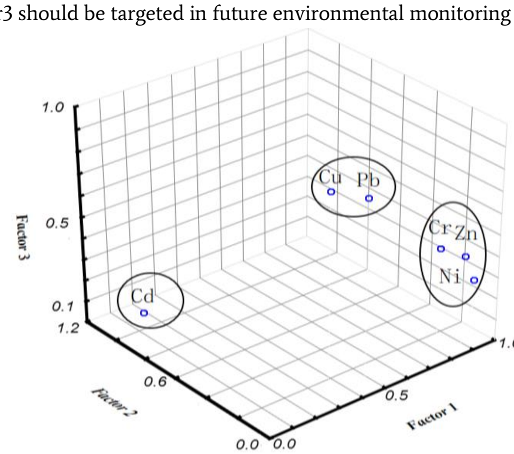

Fig.5. Factor analysis loading of the heavy metal variable.

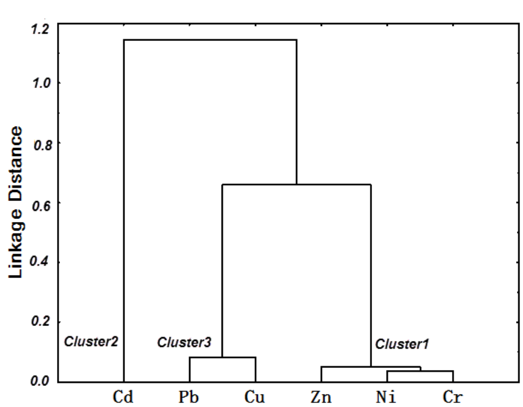

Fig.6. Cluster analysis of the heavy metal variable.

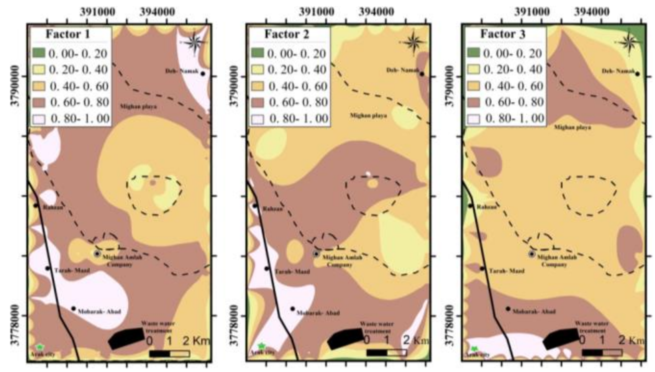

Fig.7. Maps of factor distributions in soil and sludge of Mighan playa.

Since the maximum values of heavy metals are due to anthropogenic sources in different land uses, therefore, we were considered the maximum factor scores in each factor. There is no specific order in the minimum and mean score of the factors due to background values. The maximum values of the factor scores show the importance of factor 1 in Is and La, Ra, and Wa land use. Factor 2 is important in the Ta land use. In addition, factor 3 is the most important in the Du land use. Cr, Ni, and Zn (factor 1) are the most important pollutants of soil and sludge in the Mighan playa/lake. The dust collected around the playa/lake indicates that Cr, Ni, and Zn, (factor1), and Cu and Pb (factor3), as well as Cd values (factor2), are significantly higher than the background[4,6,21,25]. For example, the value of Cr, Ni, Zn, Cu, Pb, and Cd in the dust is 136, 78, 259, 79, 86, and 0.36 mg/kg, and the value of Cr, Ni, Zn, Cu, Pb, and Cd is 73, 45, 66, 23, 13 and 0.25 mg/kg respectively in the BVR. Therefore, atmospheric precipitation plays an important role in the distribution of heavy metals in the soil and sludge of playa[4,21]. Atmospheric precipitation is mainly due to traffic and industrial activities in urban and rural areas in the margin of Mighan playa/lake. On the other hand, the source of heavy metals can be due to municipal sewage (Wa Land use) into Mighan playa/lake[20]. For example, the maximum concentrations of Cr, Ni, Zn, Cu, Pb, and Cd are 91, 46, 87, 87, 49, and 0.27 mg/kg, respectively in the sewage sludge. Ansarian (2015) considered the origin of Pb and Zn in the sediments of Mighan to be due to the treated wastewater of Arak city[46]. Mortazavi and Saberi-Nasab (2016) also believe that the source of Cu and Ni deposits in Mighan playa is due to the entry of urban, rural, industrial sewage, and agricultural water[45]. The increase in Zn, Pb, and Cu in the sediments of Gomishan playa in Golestan has been emphasized by Fazali and Malaki-Alagh (2000) due to chemical pollutants, especially industrial and agricultural effluents[47]. Babaee et al. (2013) concluded industrial, agricultural and urban sewages are the source of Cu, Zn, Pb, Cd, Cr, and Hg in the sediments of Anzali wetland[48]. Pyri (2010) concluded the high concentration of Pb, Cd, Cu, Ni, and Hg in the sediments of Hamoon playa in Sistan- Baluchestan is due to the upstream industrial activities[49]. The role of industrial and agricultural activities in the increasing Cd, Pb, and Zn has been investigated by Aghasi et al. (2015) in the Gavkhoni playa of Isfahan[50].

The corresponding analysis showed that heavy metals and samples do not have the same distribution in the study area(Fig.8). Heavy metals are divided into three groups: Zn-Ni-Cr, Cd, and Pb, Zn, and the soil samples distribution indicate the difference in their heavy metals around these variables. This study showed that Cd, Zn, Ni, and Cr (45.36, 16.46, 15.26, and 12.56% respectively) were the highest contribution to the island of Mighan playa/lake (Is). These heavy metals also showed a similar trend in other land uses. The contribution of Cu and Pb in different land uses is less and Cu is the highest (100%) in the dump of Mineral Salts Company(Du). Therefore, Cd and then Zn, Ni, and Cr are the most important heavy metals in different land uses in the region. Therefore, corresponding analysis confirms factor analysis.

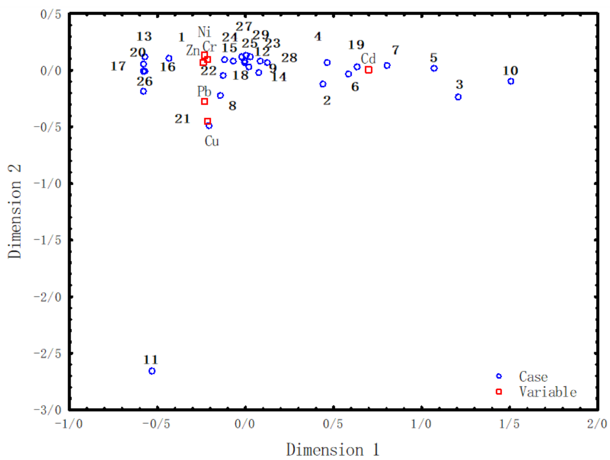

Fig.8. Projection of heavy metals in multiple correspondence analyses.

The soil samples were classified into six land use based on sampling. These samples were labeled as a combination of different sources. Overall, the discriminate function had a 70% success rate in classifying the samples according to the potential source of metal contamination. The dump of Mineral Salts Company (Du) samples was predicted the best (100%), while the island of Mighan playa/lake (Is) and wastewater sludge (Wa) samples were predicted the worst (25%). The three other land use (Ra, La, and Ta) were predicted with the same success frequency. Fig.9 shows some interesting relationships between potential pollution sources based on the Mahalanobis distances between land use means. Those land use with means close together are assumed to be similar in metal content. Similarities are represented in Fig.9 by polygons, with the overlapping of polygons indicating which land use has similar characteristics to another land use. Fig.9 represents pollution sources for the whole playa and shows six land use(Is, Ra, La, Wa, Ta, and Du) samples. Island (Is) and lake sludge (La) of Mighan playa/lake sources may be similar (75%) because they are both from similar genetic properties. Rangeland (Ra) and wastewater sludge(Wa) may also just have similar metal constituents(75%). There is no similarity between Ta and Du with other land uses. Therefore, there are four groups (Is, La; Ra, Wa; Ta, and Du groups) that effects by different heavy metals in Mighan playa/lake.

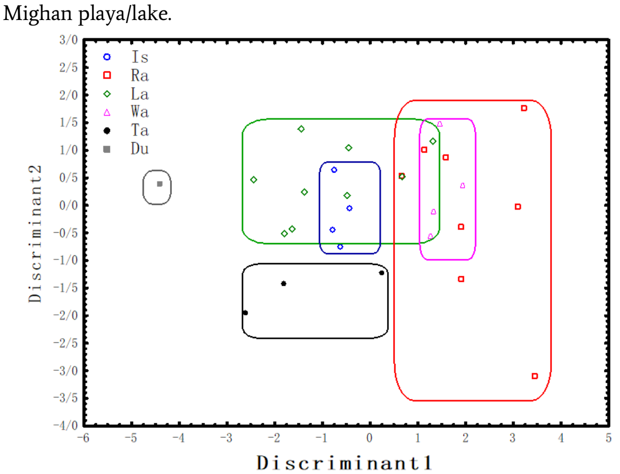

Fig.9. The relationships between six land use in the discriminated analysis.

4. Conclusion

Concentrations and spatial distributions of heavy metals (Cr, Cu, Ni, Pb, Zn, and Cd) were analyzed for the soil and sludge of six important land use of Mighan playa/lake. The study results demonstrate that the soil and sludge of playa contain significant concentrations of metals followed by rangeland, wastewater sludge, tail and dump of Mineral Salts Company, lake and island sludge of playa. The maximum concentrations of Cr, Cu, Ni, Pb, Zn, and Cd in the soil and sludge of different land use were much higher than the background values (BVR) of the study area. The different sediment quality indices as the sum of pollution index (PI_{sum}), potential ecological risk index (RI), and Nemerow pollution index ($PI_{Nemerow}$) reveal that all of the study land use are lowly polluted by heavy metals. The factor analysis stated that the three major factors comprise about 97.75% of the total variance with the dominance of the first components group (71.03%). Finally, all land use, clearly displays that among three factors, the first factor which comprises rangeland soil and wastewater sludge are highly enriched with metals (Cr, Ni, and Zn) compared with the other factors. Based on correspondence analysis, Cr, Zn and Ni, and then Cd are the most important heavy metals in different land uses in the region. Source identification inferred that the distribution of Cr, Cu, Ni, Pb, Zn, and Cd in the soils and sludge of Mighan playa/lake was mainly affected by anthropogenic sources. The source of heavy metals can be due to traffic and industrial estates in form of airborne dust, atmospheric precipitation, and municipal sewage.

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