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Assessment of Heavy Metal Contamination in Waters due to Mineral Salts Company from Mighan playa/lake, Arak, Iran

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Abstract

The Mighan playa/lake is characterized as a closed catchment. In the recent years, the rapid industrialization and urbanization has resulted in a pollution area in the city of Arak. In this work, we focus on six regions around the playa/lake to study the distribution of heavy metals in the waters and their contamination risk. A total of 32 water samples are analyzed to determine the contamination degree of heavy metals, i.e. Hg, As, Cd, Cr, Cu, Pb, and Zn. The heavy metal pollution index, heavy metal evaluation index, and degree of contamination are utilized to assess the pollution extent of these metals. The spatial distribution patterns reveal that the waters in different areas of playa/lake are in a good condition. The island, lake in playa, and the Wastewater Mineral Salts Company are most seriously polluted with Pb, being higher than the standard of drinking water quality limit. Water in the wastewater treatment plant is polluted with Hg and As. The correlation matrix, factor analysis, and cluster analysis are used to support the idea that Pb may be mainly derived from the atmospheric input, and As and Hg from the wastewater treatment plant, agricultural lands, and domestic waste. Many native and migratory birds live in the Mighan playa, which is exposed to heavy metals. Therefore, it is required to monitor heavy metals in the Arak playa and to manage the municipal, industrial, and agricultural activities around it and to reduce them.

1. Introduction

Heavy metal pollution is the most important type of pollution. With the development of industry, the rate of heavy metal pollution has increased in the ecosystems. Heavy metals can have devastating effects on the health of creatures and causes their death in lakes [1]. Playa/lakes are considered as one of the most ponds in the world and are more sensitive to the environmental pollution and anthropogenic impacts [2]. Heavy metals such as Hg, As, Cd, Cr, Cu, Pb, and Zn are commonly detected in playa [3]. Like other aquatic environments, heavy metals in playa/lakes may originate from both the natural and anthropogenic processes. The source of toxic metals can be municipal, industrial, and agricultural wastewater [4-8]. Municipal solid wastes can also contribute considerable amount of metals to playa/lake [9]. Heavy metal pollution has become a great environmental concern with their toxicity in the food chain [10, 11]. Thus heavy metals in playas might ultimately have adverse biologic effects on the consuming aquatic products [12]. Various research works have been done on heavy metals in playa. They have shown

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that different human activities along the wetland have an important role in increasing heavy metals in the Ramsar wetland of Chile [13]. The source of Cd, Cu, Mn, Pb, and Zn in wetlands in South Africa is industrial and agricultural activities are high in dry seasons [14]. It has been found that the increase in heavy metals in the Anzali wetland is not only natural and of anthropogenic origin but can also be produced by physical and chemical changes in the wetland environment [15]. It has been shown that high concentrations of elements such as Cu and Zn in the Mighan playa are due to the surrounding industrial wastewater [16]. The source of Pb, Zn, Cu, and Ni in the southern part of the Mighan playa is industrial activities in the city of Arak [17]. The spatial distribution of Fe, Mn, Pb, and Cd has revealed that Cd is higher than the standard of the World Health Organization (WHO) in the center of the Mighan playa and has been originated from the surrounding industrial effluent [18].

The Mighan playa/lake is the largest natural saline lake in the Markazi Province. It is mainly consumed for animals and birds [19]. With the rapid development of the local industrial activities, large amounts of industrial wastewater, domestic, and agricultural sources have been discharged into the lake from the city of Arak. As a result, water environment in the Mighan playa/lake has deteriorated in terms of heavy metal pollution. The aims of this work were to investigate the contamination levels and distributions of heavy metals; compare the concentrations of heavy metals with quality standard; assessment of contamination source in water in different areas of Mighan playa/lake; and role of the Mineral Salts Company in producing heavy metals.

2. Description of studied area

The Mighan playa/lake is located in the Arak region, central part of the Markazi Province (Figure 1). Mighan playa with 1700 m above the sea level has an area about 5500 km^2 and is a closed basin and playa occupying an area of about 110 Km^2 and the average depth of water is about 0.5 m and the maximum depth is about 1.5 m. The mean annual temperature and precipitation are 14 ^{o}C and 350 mm. This lake is fed by fresh water from the whole margins. The lake water chemistry is dominated by the ions Na^+, Mg^{2+}, Cl^-, and $SO4^{2-}$ and also contains smaller amounts of Ca^{2+}, K^+, and HCO_3^- [19]. Two major ephemeral streams, namely Gharakahriz and Ashtian, and many minor ephemeral streams from Farmahin, Amanabad, and Haftadgholeh area feed the playa/lake. The Gharakahriz River near the city of Arak, the largest feeder stream originates to the south of playa. The Ashtian River rises in the north near the city of Ashtian and flows south to enter the playa. In spite of a large catchment area, the Mighan playa presently receives very little run-off due to the present climatic conditions. The surface of the Mighan playa presently undergoes complete desiccation every summer, forming an efflorescent crust [20]. This crust essentially consists of gypsum, glaubrite, halite, and calcite minerals. Bedrock of playa is composed of Cretaceous limestone. The plain hosts a large number of water–wells with depths varying from 70 m to 150 m. Most of these wells supply water for drinking and agricultural needs.

3. Materials and methods

3.1. Sample collection and analysis

In September 2018, 32 samples were collected from different waters such as island of Mighan (Is = 6), lake of Mighan (La =6), agricultural groundwater (Ag = 10), wastewater treatment plant (Wt = 4), wastewater industrial park (Wi = 2), wastewater of mineral salt company (Wa = 1), and replicate water (Rw = 3) in and around the Mighan playa/lake (Figure 1). All of these water samples were obtained using cleaned polyethylene bottles, which were washed with hydrochloric acid and then rinsed with distilled water. Subsequently, the water samples were filtered through 0.45 μm millipore filters, acidified to pH < 2 with 2 mL 6 N HCl, and transported to the laboratory for analysis. During the sample collection, a global positioning system (GPS) was used to locate the sites. Concentrations of Hg, As, Cd, Cr, Cu, Pb, and Zn in all samples were determined using an inductively coupled plasma-mass spectrometry (ICP-MS). For quality control, procedural blanks and duplicates were run for 3 samples. The standard deviations were below 10% for all elements. The detection limit for the individual metals was 0.5 to 5 ng/L for a water sample.

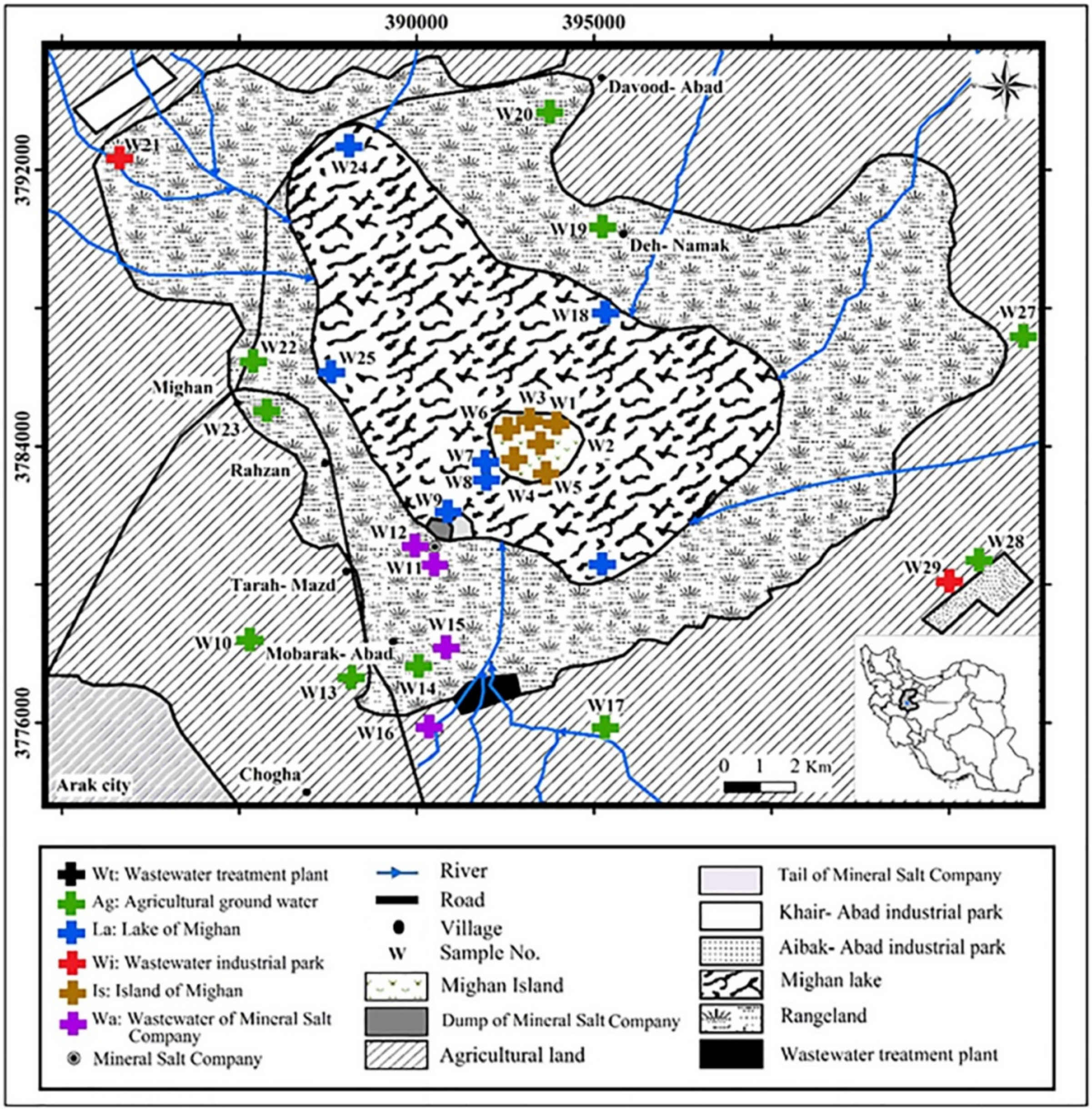

Figure 1. Location map of Mighan playa/lake and sampling sites of different waters.

3.2. Pollution indices

Generally, pollution indices are estimated for a specific use of water. The indices used in this work, namely heavy metal pollution index (HPI), heavy metal evaluation index (HEI), and degree of contamination (C_d), are determined for the purpose of evaluating playa/lake water quality. The HPI and HEI methods provide an overall quality of water with regard to heavy metals. These methods are evaluated using the ratios of monitored values of the desired number of parameters and the maximum admissible concentrations of the respective parameters. In the C_d method, the quality of water is evaluated by computation of the extent of contamination. C_d is calculated independently for every sample of water, and is computed as the sum of heavy metals.

3.2.1. Heavy metal pollution index (HPI)

HPI represents the total quality of water with respect to the heavy metals. HPI is based on the weighted arithmetic quality mean method, and is developed in two steps. First, by establishing a

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scale for each selected parameter giving the weight, and secondly, by selecting the pollution parameter on which the index is to be based [21]. HPI is a model that provides the composite influence of the individual heavy metals on the overall water quality [22]. The HPI model is given by Equation (1):

$$HPI = \frac{\sum_{i=1}^{n}(Q_i W_i)}{\sum_{i=1}^{n} W_i} \tag{1}$$

where Q_i is the sub-index of the i_{th} heavy metal parameter, W_i is the unit weight of the i_{th} parameter reflecting its relative importance, and n is the number of parameters considered. The sub-index (Q_i) is calculated by Equation (2):

$$Q_i = \frac{C_i}{S_i} * 100 \tag{2}$$

where C_i is the concentration value of the i_{th} heavy metal parameter (mg/ L) and S_i is the highest standard permissible value of the i_{th} parameter. We selected the World Health Organization (WHO) guidelines for the drinkingwater quality [23] as the source of the highest standard permissible level. The unit weight (W_i) of the parameter is calculated by Equation (3):

$$W_i = \frac{k}{S_i} \tag{3}$$

where k is a proportionality constant. In order to facilitate the calculation, we set k to 1, as Wanda *et al.* [24]. Generally, the critical HPI value for drinking water is 100 [21]. If the HPI values for the water samples are greater than 100, water is not potable. However, a modified scale using three classes is often used to better characterize moderate levels of heavy metal pollution [25]: low (HPI values < 15), medium (HPI values within 15-30), and high (HPI values > 30).

3.2.2. Heavy metal evaluation index (HEI)

HEI is a way of estimating the water quality with focus on heavy metals in water samples [26]. The water quality index is classified into three categories including low heavy metals (HEI < 400), moderate to heavy metals (400 < HEI < 800), and high heavy metals (HEI > 800). HEI gives an overall quality of water with respect to heavy metals [25], and is expressed as Equation (4):

$$HEI = \sum_{i=1}^{n} \frac{H_c}{H_{Mac}} \tag{4}$$

where H_c and H_{mac} are the monitored value and maximum admissible concentration (MAC) of the i_{th} parameter, respectively.

3.2.3. Contamination degree (C_d)

C_d summarizes the combined effects of several quality parameters considered harmful to domestic water [27], and is calculated as Equations 5 and 6:

$$c_d = \sum_{i=1}^{n} C_{f_i} \tag{5}$$

$$A_{f_i} = \frac{C_{A_i}}{C_{N_i}} \tag{6}$$

where C_{f_i}, C_{A_i}, and C_{N_i} represent the contamination factor, analytical value, and upper permissible concentration of the i_{th} component, respectively. N denotes the ‘normative value’ and C_{N_i} is taken as MAC. The resulting C_d values are grouped into three categories, as follows: $C_d < 1$ (low), $C_d = 1\text{-}3$ (medium), and $C_d > 3$ (high) [28].

3.3. Statistical analysis

Statistica for windows (version 12) was employed for the statistical analysis. Analysis of variance (ANOVA) was used to analyze the difference of heavy metal values between different waters. These differences were tested as significant with the 95% confidence interval. The discriminate analysis is used to separate two or more groups of waters based on the values of several variables for those groups [29]. In order to determine the source of heavy metals, the correlation analysis, factor analysis, and cluster analysis were employed. The factor analysis is carried out with the principal component method, which is rather the original data based on the examination of dependency among the artificial variables that are computed from the covariance and correlation coefficient matrices [30]. In other words, the eigenvalues and eigenvectors of covariance and correlation coefficient matrices are interpreted. In the meantime, to strengthen the factor loads, the varimax rotation is performed. The Ward's method and Pearson's correlation coefficient cluster analysis (hierarchical cluster analysis) was carried out, and the results obtained were given in a dendogram.

4. Results and discussion

4.1. Metal pollution in different waters of playa/lake

Table 1 summarizes the heavy metal concentrations (Hg, As, Cr, Cu, Pb, and Zn) in the water collected from the different regions of playa/lake. The guidelines for comparing are drinking water quality (WHO) and standards for drinking water quality of Iran and China. In this work, Cd was zero in the water samples. The differences in metal concentrations were evident in the water of island in playa (Is); lake in playa (La); agricultural well (Ag); wastewater treatment plant (Wt); wastewater of industrial park (Wi), and wastewater of the Mineral Salts Company (Wa) (Figure 2). The highest concentrations of Hg, As, Cr, Cu, Pb, and Zn were distributed in island in playa (Is); lake in playa (La), and wastewater of the Mineral Salts Company (Wa) in this work. The mean concentrations of all metals were generally below the guideline (standards for drinking water quality of Iran, WHO, and China) in different waters. The Pb mean concentration is higher than the standards of WHO in the island in playa (Is); lake in playa (La), and wastewater of the Mineral Salts Company (Wa), and all of them were most seriously polluted. The maximum values of Hg and As were higher than WHO in the wastewater treatment plant (Wt).

Table 1. Concentrations of heavy metals (μg/L) in the waters of six areas in the Mighan playa (Is: island in playa; La: lake in playa; Ag: agricultural well; Wt: wastewater treatment plant; Wi: wastewater of industrial park; Wa: wastewater of Mineral Salts Company).

Regions	Hg	As	Cr	Cu	Pb	Zn
Is	0.00-0.92	0.00-0.00	1.50-2.40	13.45-15.50	60.36-66.50	18.40-25.60
	0.15	0.00	1.97	14.61	64.00	21.64
La	0.00-0.84	0.00-5.21	1.85-2.90	7.50-21.14	42.50-83.42	8.75-35.02
	0.14	1.06	2.34	15.06	65.17	24.20
Ag	0.00-0.00	0.00-9.07	0.00-13.59	0.00-25.26	0.00-0.00	0.00-39.84
	0.00	1.59	5.72	9.41	0.00	6.65
Wt	0.00-1.66	0.00-10.16	0.00-6.30	0.00-25.08	0.00-0.00	0.00-0.00
	0.58	2.54	1.57	6.27	0.00	0.00
Wi	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00
	0.00	0.00	0.00	0.00	0.00	0.00
Wa	0.84	0.00	2.15	13.20	59.30	24.60
Iran[a]	3	10	50	3000	10	3000
WHO[b]	1	10	50	3000	10	1000
China[c]	1	10	50	1000	10	1000
Anzali[d]wetland	1	4.15	1	0.1	0.11	-
Maharlu[e]wetland	-	-	-	0.28	5.17	0.37

[a] Iran: standards for drinking water quality [32].

[b] WHO: guidelines for drinking-water quality [17].

[c] China: standards for drinking water quality [8].

[d] Anzali: mean value in lake [15].

[e] Maharlu: mean value in lake [31].

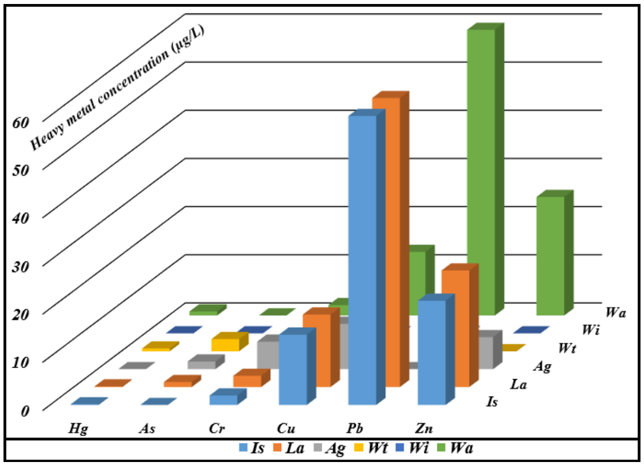

Figure 2. Comparison of the mean values of heavy metals between different waters of Mighan playa/lake.

The P-values and student's t-test were used to determine the significance of difference between the waters (Table 2). The mean values of the groups with p-values less than 0.05 determined by the analysis of variance were compared using the student's t-test for independent samples. There are a great difference in heavy metals according to the different water regions and type of heavy metal. For example, all waters are similar in Hg and As (except for the Wa water) ($p > 0.05$ and $T_{critical} > 1.80$). The Is, La, Ag, Wt, and Wa waters are also similar based on Cr and Cu (except for Wi water). The Is, La, and Wa waters are similar based on Pb and Zn. Therefore, waters of various areas in playa/lake are classified into two different groups in terms of heavy metals (except for As). In other words, Hg in the Wa water, Cr and Cu in the Wi water, and Pb and Zn in the Ag, Wt, and Wi waters are different from other waters (Table 2). According to Table 1, the Hg average concentration in the Wa water is higher than the other waters (0.84 µg/L). The Wi water is free from Cr and Cu. The Pb average in the Is, La, and Wa waters were 64.00, 65.17, and 59.30 µg/L, and for Zn, theywere 21.64, 24.20, and 24.60 µg/L, respectively.

Table 2. T and p values calculated for each heavy metal using analysis of variance in different waters of playa/lake.

Heavy metals	T-test p value	La	Ag	Wt	Wi	Wa
Is_{Hg}	T	0.06	1.32	1.20	0.54	**-2.45**
	p	0.95	0.20	0.26	0.60	**0.04**
Is_{As}	T	-1.29	-1.32	-1.26	-1.29	-1.42
	p	0.22	0.21	0.24	0.21	0.23
Is_{Cr}	T	-1.65	-1.6٠	0.31	**4.10**	0.62
	p	0.13	0.12	0.76	**0.00**	0.55
Is_{Cu}	T	0.21	1.06	1.67	**21.22**	1.70
	p	0.83	0.30	0.13	**0.00**	2.19
Is_{Pb}	T	-0.21	**56**	**50**	**21.22**	0.07
	p	-0.63	**0.00**	**0.00**	**0.02**	0.35
Is_{Zn}	T	-0.67	**2.82**	**17.27**	**0.98**	-1.61
	p	0.54	**0.01**	**0.00**	**0.01**	0.15

The discriminate analysis showed that separations of the Is, Wa, Wt, and Wi waters were about 66%, 50%, 25%, and 50%, respectively (Table 3), while this separation was 100% in both the Wa and Ag waters (Table 3). In addition, it shows that the Is, La, and Wa waters can be classified into one group ($p > 0.05$), and the Ag, Wt, and Wi waters in other groups. It is evident that the similarity of Wt with Ag water is weak (p-value is 0.04), and between the Wt and Wi waters is high (p-value is 0.16). Figure 3 shows that the Is, La, and Wa waters are overlapped in many samples, and they have the same heavy metal source. This overlap and similarity can also be seen in the Wt, Wi, and Ag waters. The Wilks´ Lambda, Partial Lambda, F-Remove, and P-value tests were performed to determine which elements were important in the separation of the regions (Table 4). Pb in the Wilks'Lambda test, Pb, Hg, and Zn in the Partial Lambda, F-remove, and p-value tests are the most important heavy metals in separation of all waters.

Table 3. Matrix of p-value in different waters of playa/lake.

	Percent correct	Is	La	Wa	Ag	Wt	Wi
Is	33						
La	50	0.82					
Wa	100	0.08	0.01				
Ag	100	0.00	0.00	0.00			
Wt	75	0.00	0.00	0.00	0.04		
Wi	50	0.00	0.00	0.00	0.10	0.16	

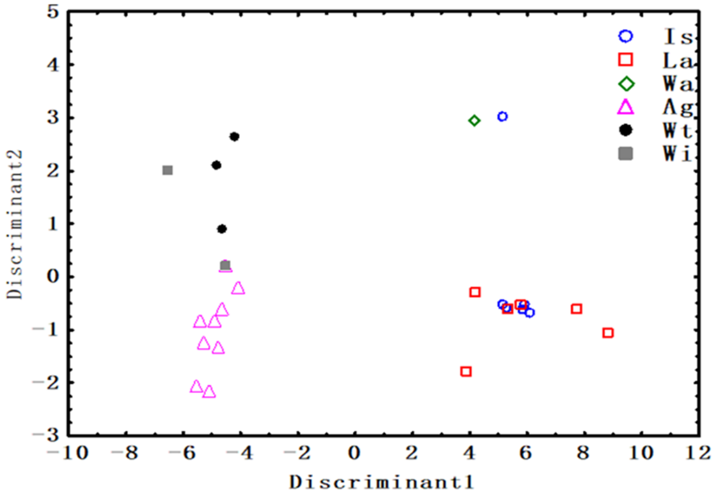

Figure 3. The discriminate plot in different waters of playa/lake.

Table 4. Discriminant function analysis summary in different waters of playa/lake.

	Wilks' Lambda	Partial Lambda	F-remove	p-value
Hg	0.01	**0.40**	**5/65**	**0.00**
As	0.01	0.62.	2/29	0.09
Cr	0.01	0.79	0/95	0.47
Cu	0.01	0.88	0/51	0.76
Pb	**0.09**	**0.06**	**59/39**	**0/01**
Zn	0.01	**0.57**	**2/81**	**0/05**

HPI is an effective method used to characterize water pollution. It represents the composite influence of metals on the overall water quality [33, 34]. The evaluation of HPI in different waters of playa/lake shows that HPI is mainly higher in the Is (49-129), La (39-117), Wa (117), and Wt (0-144) waters to the other Ag and Wi waters (Table 5). The results of indices showed that HPI for all waters were below the critical limit. Prasad and Bose [21] have proposed the 100 value for drinking water. About 17% of the samples in the Is and La waters, 25% in the Wt water, and 100% in the Wa water are above the critical limit. The average HPI is almost the same in the two Is and La waters but HPI in the Wa water (117) is much higher than the other waters. It is evident that the Is and La waters have the same source due to the interconnection within the Playa. The source of the Wa water is the La water but this water returns to playa after treatment by the Mineral Salts Company. The Is, La, and Wa waters are saline. The Wt water is due to the treatment of the municipal sewage that enters the lake (La) in the playa/lake. The contamination of Wt is due to the lack of absorption of heavy elements in the wastewater treatment plant [16]. Since groundwater in the Ag and Wi waters has a low HPI index, it can be noted that the origin of heavy metals in the Is and La waters is caused by wastewater treatment plant (Wt) and atmospheric deposition or dust [35-37]. The HEI index average in the La and Wa waters is more than the other waters. The value of HEI is 6.10 to 7.43, 4.82 to 8.61, and 6.84 in the Is, La and Wa waters, respectively (Table 5). It is evident that the HEI values are approximately the same in the above waters and are of the same origin. The low HEI index in the Ag, Wt, and Wi waters is 0.28, 0.86, and 0.02, respectively, indicating that there is no pollution in these waters. The HPI values for all samples were below the water quality index (HEI < 400), proposed by Edet and Offiong [25]. Also the average of C_d index is 0.62, 0.85, and 0.84 in the Is, La, and Wa waters, and is higher than the other waters. The C_d value shows that all waters are in the class of low contamination ($C_d < 1$). The HPI and HEI indices show the same origin of these waters. According to HEI and C_d, it is clear that water in Ag, Wa, and Wi is predominantly in the class of very low contamination.

Table 5. HPI, HEI, and C_d indices in waters of the different waters of Mighan playa/lake.

Area	HPI	HEI	Cd
Is	49-128	6.10-7.43	0.10-1.47
	65	6.62	0.62
La	39-117	4.82-8.61	-1.18-2.61
	66	6.85	0.85
Ag	0.00-7.73	0.00-1.14	-6.00-(-4.85)
	1.49	0.28	-5.71
Wt	0-144	0-2.82	-3.19-(-5.13)
	49	0.86	-6
Wi	0.00-0.01	0.00-0.04	-6.00-(-5.95)
	0.01	0.02	-5.97
Wa	117	6.84	0.84

4.2. Sources of heavy metals

Inner heavy metal relationships can suggest the sources of elements in waters and their pathways in the environment. Table 6 shows the correlation matrix of the six heavy metals in the different waters of playa/lake. Based on the Pearson correlation coefficients, Hg showed a significant moderate positive correlation with As (r = 0.44) and weak correlations with Cr, Cu, Pb, and Zn. Pb, and Zn had a significant high positive correlation as well (r = 0.64). There was a weak correlation of Pb and Zn with Cr, Cu, Hg, and As. Cr had a weak positive correlation with Cu (r = 0.23).

Table 6. Correlation matrix of heavy metals in waters of Mighan playa/lake (p > 0.05).

	Hg	As	Cr	Cu	Pb	Zn
Hg	1.00					
As	**0.44**	1.00				
Cr	0.03	0.30	1.00			
Cu	0.23	0.31	0.23	1.00		
Pb	-0.02	-0.23	-0.23	0.34	1.00	
Zn	-0.11	0.06	-0.06	0.36	**0.64**	1.00

We used the principal component analysis for extraction of factors. Furthermore, we applied the varimax rotation of factors [38]. Then we used a three-step factor analysis to extract the components representing contamination of the multi-element signatures [39]. In the first step, factor analysis yielded two rotated components, each with eigenvalues greater than 1 (step 1 in Table 7). Six elements were combined to produce two significant factors, explaining 62.59% of the variance of the original dataset. The variance is 32.72% in factor 1, which is associated with the component Pb, Zn, and Cu (Table 7). Factor 2 explains 29.86% of the variance, and is mainly related to As and Hg. We can reduce the number of factors and increase the contamination intensity using the stepwise factor analysis. In order to achieve this, the data for Cr that had weak correlations was omitted in two factors. The rotated factor matrix in rotated space for the second stepwise factor analysis is shown in step 2 in Table 7. Factor 1 represents the Pb and Zn association, and factor 2 is related to As and Hg. According to Table 7, the total variance relevant to the Pb and Zn association increased from 32.72% in the first factor analysis to 39.26% in the second factor analysis. Likewise, the total variances relevant to As and Ag increased from 29.86% to 32.31% in the second factor and the total variance increased from 62.59% in step 1 to 71.58% in step 2. In step 3, Cu was deleted and the total variance changed to 77.10%. Factor 1 explains 42.98% of the variance, and is mainly related to Pb and Zn (Figure 4). Factor 2 represents the As and Hg association, and the variance of this factor is 34.10%. Therefore, the total variance changed from 71.58% in step 2 to 77.10% in step 3. Consequently, through the stepwise factor analysis, the poor indicator elements were removed from the data and the total variance related to each factor was increased. In order to reveal the relationship between the elements and element groups in the third factor analysis, the other multivariate analysis techniques such as cluster were performed. Using the Ward's method, the Pearson's correlation coefficient cluster analysis (hierarchical cluster analysis) was carried out, and the results obtained were given in a dendogram (Figure 5). The results of cluster analysis indicate that the elements comprise two main groups. The first group is composed of Pb and Zn. The second group is composed of As and Hg. Both groups coincide with the results of the factor analysis and correlation coefficients in the correlation analysis (Tables 6 and 7).

Table7. Factor analysis (FA) of heavy metals in waters of Mighan playa/lake.

	Step 1		Step 2		Step 3	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Hg	-0.03	**0.65**	-0.04	**0.79**	0.03	**0.83**
As	-0.07	**0.84**	-0.04	**0.85**	0.05	**0.86**
Cr	-0.17	0.56	Deleted	Deleted	Deleted	Deleted
Cu	**0.62**	0.57	0.52	0.49	Deleted	Deleted
Pb	**0.91**	-0.15	**0.89**	-0.16	**-0.90**	-0.13
Zn	**0.84**	0.01	**0.84**	-0.04	**-0.91**	0.04
Eigenvalue	1.96	1.79	1.96	1.61	1.71	1.36
% Total - variance	32.72	29.86	39.26	32.31	42.98	34.10
Cumulative - %	32.72	62.59	39.26	71.58	42.98	77.10

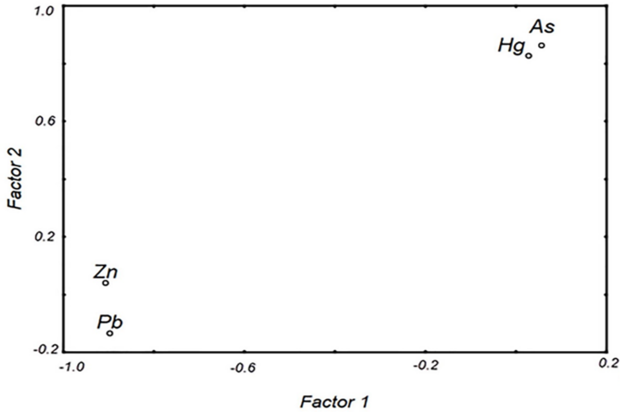

Figure 4. Factor plot in rotated space in the third step of factor analysis for heavy metals in the Mighan playa/lake.

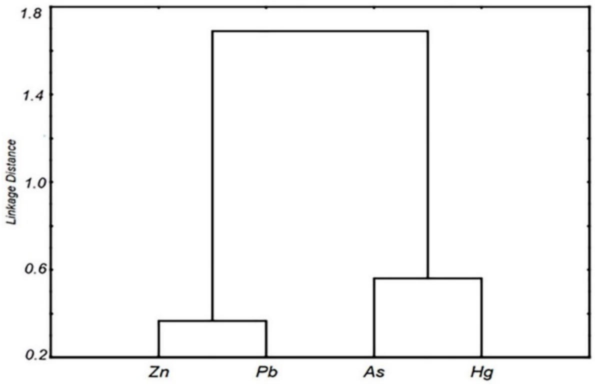

Figure 5. Dendogram depicting the hierarchical clustering of the heavy metals.

The factor analysis allows us to calculate a single value for each factor [40]. For example, instead of analyzing the separate element maps, we can establish a linear relationship among the variables and plot a single map called the factor score (FS) map showing the distribution of such a relationship [39, 41]. After FSs of each sample, the weights should be assigned to each sample to represent the probability of the presence of the contamination of the sample. The weights are here called the fuzzy factor score (FFS) map [39, 42]. In general, the factor analysis and the response variable are continuous and the values outside the range [0, 1] are inappropriate if the response variable relates to the probability. In order to constrain the values of the predicted response variable within the unit interval [0, 1], Cox and Snell [43] have recommended to use a logistic model in order to represent the probability (Equation 7).

$$FFS = e^{FS}/1 + e^{FS} \qquad (7)$$

where FS is the factor score of each sample in the factor analysis. FFS is, therefore, a fuzzy weight of each sample for each factor. In this way, the weights of different classes of maps are calculated based on FSs of the samples in the stepwise factor analysis. In this paper, the distributions of FFS for factors are represented as the interpolated values (Figure 6). The map of the first fuzzy factor score (F_1) shows high values toward the city of Arak due to the atmospheric activities. The second fuzzy factor score (F_2) represents the high-frequency contamination, which is generally related to agricultural wastewater treatment plant and wastewater of the Mineral Salts Company activities and shows high values in agricultural lands (Figure 6). Factor 1 is mostly contributed by Pb and Zn, representing the atmospheric input in the waters originating from the industrialized regions and are significantly distributed in the Is, La, and Wa waters [16, 44]. However, most of the Pb concentrations are also found as a result of anthropogenic activities such as automobile exhaust [35.]. High concentrations of As and Hg in factor 2 are possibly caused by anthropogenic inputs from wastewater treatment plant (Wi), agricultural lands, and domestic waste, and are widespread throughout the human activities and agricultural areas of the playa [16, 45].

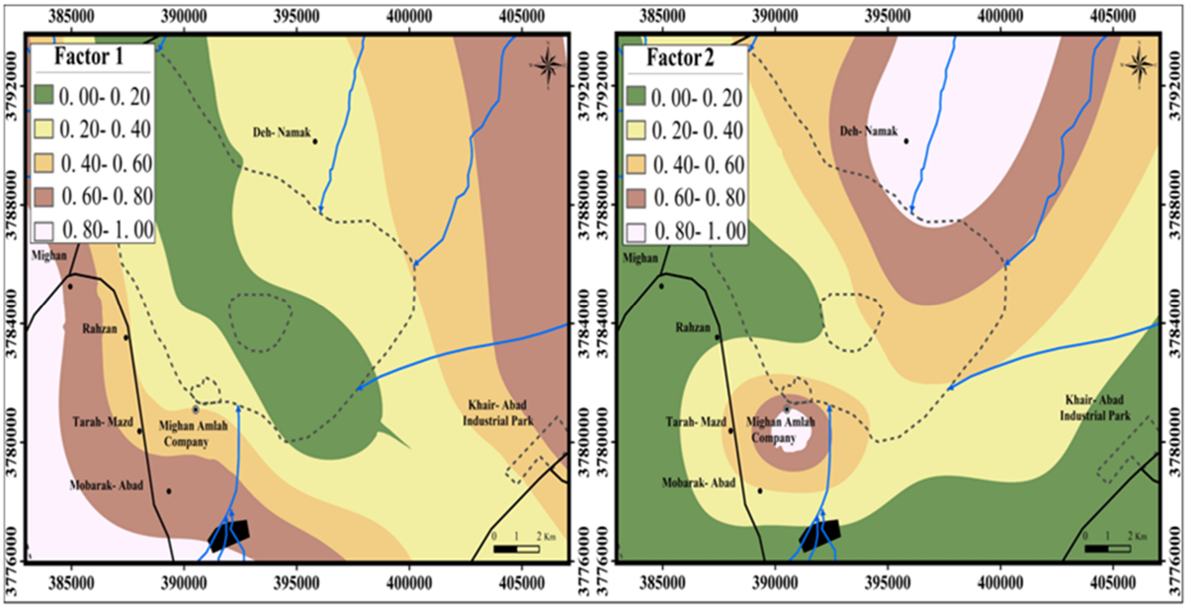

Figure 6. FFS distribution map for (A) Pb-Ag (factor 1) and (B) As-Hg (factor 2).

5. Conclusions

The Mighan playa is an eco-geotourism area, where many local and migratory animals live. All of these organisms are exposed to heavy metals in the playa. Heavy metal contamination is an important problem for the Mighan playa/lake. This work showed that the mean concentrations of Pb in the Mighan playa (island and lake) and wastewater of Mineral Salts Company and As and Hg in wastewater treatment plant were generally higher than the standard of drinking water quality limit (WHO). The sources of heavy metals were also discussed based on two clusters in the cluster analysis method. Pb and Zn were in the cluster 1, indicating human activity due to the surrounding industrialized activities, and may be mainly derived from the atmospheric input. As and Hg are the results of wastewater treatment plant, agricultural lands, and domestic waste in cluster 2. To decrease these contaminants, it is essential to decrease the industrial effluent and agricultural and municipal sewage discharge. Hence, it is necessary to monitor heavy metals in the Mighan playa and manage contamination and optimization of industrial activities in the city of Arak.

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تعیین آلودگی به فلزات سنگین دریاچه میقان اراک ناشی از شرکت املاح معدنی

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چکیده:

پلایای میقان اراک حوضهٔ داخلی و بسته‌ای بوده که در سال‌های اخیر به دلیل صنعتی شدن شهر اراک و توسعهٔ فعالیت‌های شهری در معرض آلودگی قرار گرفته است. در این تحقیق شش منطقه در اطراف پلایا که به نظر می‌رسد در آلودگی فلزات سنگین پلایا موثر باشند مورد بررسی قرار گرفت. بنابراین، 32 نمونه آب از مناطق شش گانه جهت تعیین عناصر، جیوه، آرسنیک، کادمیوم، کروم، مس، سرب و روی انتخاب شد. شاخص آلودگی فلزات سنگین، شاخص ارزیابی فلزات سنگین و درجهٔ آلودگی جهت ارزیابی شدت آلودگی انتخاب شدند. توزیع مکانی فلزات سنگین نشان داد آلودگی در آب پلایا عمدتاً در شرایط استاندارد است. اما آب دریاچه پلایا و پساب کارخانه املاح معدنی نسبت به استاندارد بین المللی شرب از سرب غنی هستند. به علاوه، پساب تصفیه شده ورودی به دریاچهٔ پلایای میقان آلوده به جیوه و آرسنیک است. تحلیل‌های ماتریکس همبستگی و عاملی نشان دادند که سرب و روی منشاء اتمسفری و جیوه، آرسنیک ناشی از پساب تصفیه شده فاضلاب شهری اراک، زمین‌های کشاورزی اطراف و پسماندهای دامی است. پرندگان محلی و مهاجر زیادی در پلایای میقان زندگی می‌کنند که در معرض فلزات سنگین هستند. بنابراین پایش فلزات سنگین در تالاب و مدیریت در کاهش آنها در فعالیت‌های شهری، صنعتی و کشاورزی ضروری است.

کلمات کلیدی: شرکت معدنی املاح، فلزات سنگین، شاخص‌های آلودگی، پساب، پلایا، میقان.
