Evaluation of effect factors on water quality of Karun River in downstream and lake of the Gotvand-e-Olya Dam (SW Iran)

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Abstract

Outcrop of Gachsaran evaporative formation in the lake of Gotvand-e-Olya Dam in SW IRAN has posed a major challenge in terms of water quality. In the present study, multivariate statistical analysis, ionic ratios, and Piper diagram were utilized to investigate the effect of formation dissolution on water quality. Sampling was performed two times with a time interval of 6 months. The result showed that the types of downstream samples are Cl–Na and Cl–Ca, which are affected by the dissolution of Gachsaran Formation and reverse ion exchange. Due to the transmission of the saline water to the depth and layering of reservoir, the water types in the upper levels of dam's lake are (SO₄–Ca and HCO₃–Ca) and (Cl–Ca and SO₄–Ca) upon the first and second sampling, respectively. In both times, the clustering of the EC, TDS, Na, and Cl parameters demonstrates the effect of halite dissolution on water quality in downstream and lake of the dam. At the first sampling, the SO₄ and HCO₃ parameters are in one cluster that shows increasing calcareous formation dissolution. At the second time, the grouping of the Ca and SO₄ parameters shows the effect of gypsum and anhydrite dissolution on water quality. In both sampling times, the stations are grouped based on distance to the dam such that upstream stations are in one cluster. Results of principal component analysis show that data of the first-time sampling are summarized into two factors that show the effect of the formation dissolution and rainfall effect on water quality, respectively. At the second-time sampling, studied parameters are summarized in one factor. Local conditions of the studied area indicate the dominant effect of formation dissolution on water quality. The results of ionic ratios confirm the effect of geological formation on water quality in the lake and downstream of the dam. Due to the water layering, in terms of salinity in the dam's lake, the rate and discharge of water outflow of the dam also affect the water quality in downstream.

Keywords Gotvand-e-Olya Dam · Gachsaran Formation · Cluster analysis · Principal component analysis

Introduction

Depending on the time and place where the river flows, various natural (such as lithology and atmospheric precipitation) and artificial (such as discharge of various wastewater and dams) factors affect the quality of its water. Dams as important hydraulic structures that are built worldwide for surface waters management have closely related to the geological conditions of the site. Changes in water quality including salinity are among the important issues related to the quality of dam's lake water and their associated rivers in the downstream and upstream.

Several factors are effective in selecting the dam site, important of which being topographic conditions, geological structures, and the status of the basin. Water quality of the dam's lake is directly related to the lithology of the basin. The Gotvand-e-Olya Dam is the lowest dam built on

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the Karun River. Passing this dam, the river enters the plain of Khuzestan. In the upstream of Gotvand-e-Olya Dam, the Gachsaran, Mishan, Aghajari, and Bakhtiari formations are exposed in the course of the Karun River. In this region, the river flows in a bed where more than 50% of its length is composed of Gachsaran Formation and river water is in direct and permanent contact with it (Mozaffarizadeh and Chitsazan 2007). This formation has thick layers of gypsum and halite that their dissolution causes salting, sulfation, and increasing the hardness of water. Therefore, rivers passing through Gachsaran Formation are not suitable for drinking and agriculture (Fakoor and Namdar 2003). In the southern hillsides of Zagros Zone, outcrop of the Gachsaran Formation and the addition of relatively high saline branches increase the salinity of the Karun River (Hossein Zare et al. 2006). The Marghab, Andika salty, and Lali salty branches are located upstream of the Gotvand-e-Olya Dam and account for approximately 32% of the total EC of dam's lake (Hasanvand et al. 2010).

The Gotvand-e-Olya Dam has been built on the Aghajari Formation and the Lahbari member of Bakhtiari Formation. In addition to the downstream of the dam, the Gachsaran Formation has outcrop at 5–9 km to the upstream of the dam and on both sides of the river with the length of 2.9, width of 1.45 km, and a total area of 4.2 km². The major part of this formation, however, is located on the left shore of the river. The main concern is the dissolution of the salt available in the second member of this formation that, after the dewatering of the dam, is in contact with the water in the lake.

Regarding the key importance of Gotvand-e-Olya Dam for scientific communities and several issues about the effect of the geological conditions of the site and lake of dam on water quality, the present study was conducted to evaluate the factors affecting water quality in the lake and upstream of the dam using multivariate statistical methods. Figure 1 shows the outcrop location of this salt dome in the Lake of Dam. It should be noted that in recent years several studies have been carried out on Gotvand-e-Olya Dam (Hossein Zare et al. 2006; Hasanvand et al. 2010, 2011; Rostamy Paydar et al. 2011; Mansournejad et al. 2015).

Multivariate statistical methods such as cluster analysis and principal component analysis, also known as chemometric techniques (Sojka et al. 2008), have a wide and effective application to identify and describe the quality of water resources, evaluate spatial and temporal variations of water sources under the influence of natural, and identify the underlying causes of water pollution (Shrestha and Kazama 2007; Zhou et al. 2007; Adebola et al. 2013; Wang et al. 2013; Azhar et al. 2015; Ogwueleka 2015; Muangthong and Shrestha 2015; Jung et al. 2016; Monica and Choi 2016; Chow et al. 2016; Le et al. 2017; Rehman et al. 2018; Ren et al. 2018; Kilic and Yucel 2019; Kwami et al. 2019). Using these techniques: (1) the multivariate nature of a natural system is more accurately determined, (2) a way is provided

for managing large datasets, and (3) a tool is provided to identify and quantify multivariate patterns, which is driven from the correlation structure of variable sets (McGarigal et al. 2000; Boyacioglu and Boyacioglu 2008).

In order to evaluate the quality of water, several variables must be measured at the same time in a specific period (Chapman 1992). Subsequently, it is determined whether the origin of these variables is natural or due to human activities (Pesce and Wunderlin 2000). Water samples with similar chemical and physical properties, based on the mineralogy, climate conditions, and durability period, often have a hydrological history, feeding sources, and similar flow paths. Multivariate methods and data exploration analysis are suitable solutions for simultaneously examining physical, chemical, and biological parameters and the origin of their source (Wenning and Erickson 1994). In fact, these methods, while reducing and categorizing variables in several groups, explain their correlation without losing necessary information (Nadiri et al. 2013).

In the present study, ionic ratios were used to confirm the results of multivariate statistical methods. Ionic ratios are appropriate indicators to evaluate the chemistry of water resources and their use is very effective to determine the origin of salts (Hounslow 1995). Various ionic ratios of the water chemical composition are affected by the chemical composition and value of the soluble minerals (Howard and Mullings 1996).

Materials and methods

Regarding the geographical location of Gotvand-e-Olya Dam and its lake, the studied area covers a range of 220 km. A total of 25 samples were extracted from selected stations including 20 locations in downstream and five locations in the dam's lake (Fig. 1). The sampling stations were selected on a random basis. In the lake of the dam, samples were taken only from the lake surface. Because the flow at downstream is an artificial stream affected by the outflow of the dam, it is simply not possible to determine the wet and dry seasons. Therefore, samplings were carried out at two temporal points of the water year, each with a period of 6 months; in late November 2015 and late June 2016. Precipitation in the region begins from November and continues until May.

One of the common methods for classifying water variables is cluster analysis (Belkhir et al. 2010; Mirzaei et al. 2013; Abdolabadi et al. 2014). Cluster analysis is performed in a variety of ways, including the hierarchical cluster analysis (HCA), K-means cluster analysis (K-MCA), and two-step cluster analysis (T-SCA). Because of the widespread use of HCA method in quality assessment (Ribeiro and Macedo 1995; Güler et al. 2002; Zarechahoki 2013), this method was used in this study. An important property of this method is the presentation of the Dendrogram diagram. In addition, in

Fig. 1 Location of sampling stations including five stations in the lake and 20 stations in downstream of the Gotvand-e-Olya Dam

this method, the number of clusters is determined automatically and a single sample can form a cluster.

The HCA method has several algorithms for linking clusters and calculating the distance index; however, none of these algorithms has been proved as the best method. According to the results of various methods and other

studies (Güler et al. 2002; Suvedha et al. 2009; Belkhiri et al. 2010; Mirzaei et al. 2013), in this research, the Wards method and squared Euclidean distance were used to link clusters and to calculate the distance index, respectively. Before the data analysis, the nearest neighbor method was used to determine the variables with the least dependency.

Since the studied variables have different units and dimensions, before the analysis, the values of various variables must first be standardized so that they have the same significance for the analysis of similarity (Güler et al. 2002).

Factor analysis is a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors.

This method consists of three steps: (1) the preparation of the correlation matrix of all variables, (2) the extraction of factors, and (3) the interpretation of the results. Since the factor analysis method on the correlation between the variables, the correlation matrix of the variables must first be computed. To determine the usability of data for factor analysis, it is recommended excluding variables having no significant correlation with any variables from the analysis. The Kaiser–Meyer–Olkin (KMO) coefficient and Bartlett's test of sphericity are used to determine the suitability of data for the factor analysis. The value of the KMO coefficient always varies between 0 and 1, where values less than 0.5 represent the inappropriateness of the analysis. If the value is between 0.5 and 0.69, the factor analysis must be done with caution. Finally, if it is more than 0.7, the available correlation between the data can be analyzed by factor analysis (Zarechahoki 2013).

Based on the value and type of variance explained using the variables of each factor in the model, there are several methods such as principal components analysis (PCA) for factors extraction. There are several methods for extracting the criteria of the factors such as the criterion of cumulative variance percentage, which was employed in this research because of its widespread use. In this method, those factors with a higher percentage of variance are extracted. Another method for extracting these factors is the scree plot, which is plotted in terms of special values versus components, and a curve turning point (usually a specific value of 1) is used to identify the factors. The number of effective factors is equal to the number of components before the turning point (Zarechahoki 2013). The origin of each factor is determined and interpreted based on factor loads, hydrochemical processes, and hydrological and geological conditions.

Several researchers have used ionic ratios as a suitable tool to investigate the chemistry of water resources and determine the source of their salts (Wood and Jones 1990; Adhikary et al. 2010). In this study, the TDS and $\text{Cl}/(\text{HCO}_3 + \text{CO}_3)$ ratio were used to confirm the effect of dissolution of the outcrop of evaporative formations in the dam's lake area on water quality.

Results and discussion

As given in Table 1, sodium cation has the highest mean in both times of sampling. Chloride anion has the highest average for both times of sampling. In addition, concentration

Table 1 Descriptive indexes of the studied parameters of the Karun River in the lake and downstream of the Gotvand-e-Olya Dam

Parameters (unit)		EC ($\mu\text{S}/\text{cm}$)	TDS (mg/l)	pH (–)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)
First-time sampling	Mean	1589.26	1062.08	8.25	133.05	14.98	188.76	1.35	153.85	3.90	340.39	184.55
	Standard deviation	465.59	319.81	0.09	31.97	3.62	79.74	0.64	24.59	2.22	135.36	78.13
	Min	695.00	467.00	8.00	79.40	9.80	32.43	0.39	87.84	2.40	78.46	46.06
	Max	1938.0	1428.0	8.40	175.6	23.9	252.31	2.5	179.34	12.0	546.7	301.92
Second-time sampling	Mean	1299.05	869.41	8.14	119.45	26.73	126.97	1.15	161.68	0.00	208.27	224.9
	Standard deviation	505.21	307.99	0.15	33.68	9.47	71.48	0.39	30.53	0.00	110.56	113.5
	Min	650.0	465.00	7.80	80.00	13.80	42.55	0.39	85.4	0.00	78.10	105.12
	Max	3210.0	2054.0	8.36	251.8	50.16	388.7	1.95	204.96	0.00	605.99	642.24

of sulfate anion is high both times. These conditions demonstrate the effect of geological formation and especially dissolution of Gachsaran evaporative formation on water quality. The Piper diagram (Fig. 2) also confirms this result. Sodium and chlorine ions have the highest concentration for the first time of sampling compared to the second one, and all the downstream stations have Cl–Na type. At the second time, the downstream stations mostly have the Cl–Na or Cl–Ca types. The reverse ion exchange process is one of the factors that interfere with Na–Cl balance and cause Cl–Ca types. Because of its durability, chlorine ion preserves its high concentration. In comparison, sodium is replaced with calcium or magnesium using reverse ion exchange process, leading to a decrease in its concentration.

Compound diagrams can be used to characterize the reverse ion exchange process (Fisher and Mullican 1997; Jankowski et al. 1998; McLean and Jankowski 2000; Kortsatsi 2007; Zaidi et al. 2015). As shown in Fig. 3, this process has a very significant effect on the water quality of the Karun River in the lake and downstream of the Gotvand-e-Olya Dam. The sulfate types are observed in a few stations, which are affected by the dissolution of Gachsaran

Formation in the region. In the lake of the studied dam, the water shows the SO_4 –Ca and HCO_3 –Ca types for the first time of sampling and the Cl–Ca and SO_4 –Ca types for the second time. The dissolution of formations in the dam's lake and basin and transfer of sodium ions of Halite dissolution to the depth due to the more density are the major causes of this condition.

The Dendrogram for the first time of sampling, based on the nearest neighbor method, is presented in Fig. 4a. Because the pH, Mg, and CO_3 parameters do not show similarity to other parameters, they were removed from the analysis. In this time of sampling, the SO_4 and HCO_3 parameters are put in one cluster at the fourth level, suggesting that the dissolution rate of carbonate rocks is higher and its value is closer to the dissolution of the Gypsum. The discrepancy of these two parameters at lower levels is affected by the difference in the solubility of these minerals and the effect climate processes on the HCO_3 parameter. The Na, EC, and TDS parameters are put in the same cluster (Fig. 4b) and chlorine is added to this cluster at two levels, indicating the effect of the dissolution of evaporative rocks on water quality.

Fig. 2 Type of the water sample of the Karun River in the lake and downstream of the Gotvand-e-Olya Dam

At the second time of sampling, the pH and K parameters show the least similarity to other parameters and thus were eliminated from the cluster analysis (Fig. 5a). As shown in Fig. 5b, in the first level, the EC, TDS, and Na parameters are grouped together, while in the third level, the Cl parameter is added to this cluster. This clustering, like the first time of sampling, shows the effect of the dissolution of evaporative rocks on water quality. The dissimilarity of Na and Cl parameters at the first time is affected by the durability of chlorine ion and its non-participation in the ion exchange process (normal or inverse); meanwhile, sodium ion can play a role in this process. The Ca and SO_4 parameters are grouped together at level 10 and form another cluster. This condition shows that the dissolution of gypsum and anhydrite is not the only source of calcium ion in the water such that the dissolution of calcareous formation and the reverse ion exchange process are the other sources. The Mg and HCO_3 parameters are each in a separate cluster and grouped together at the other high levels with other parameters that have an unimportant similarity. Climate processes affect the dissimilarity of HCO_3 parameter with other parameters, especially Ca and Mg parameters.

As shown in Figs. 6a and 7a, station 25 and station 1 are different from the other stations for the first-time sampling and the second-time sampling, respectively, and thus were excluded from the analysis. The clustering of stations in both times is mainly influenced by their distance from the dam so that upstream stations are in a cluster, although there are also some exceptions (Figs. 6b, 7b).

Based on the results of the correlation matrix (Table 2), at the first-time sampling the pH, Mg, and CO_3 parameters and at the second time the pH and K parameters were not significantly correlated ($\text{Sig.} > 0.5$) with other parameters and thus were eliminated from factor analysis. The values of the KMO and Bartlett statistics after the removal of non-dependent parameters confirm the suitability of the data for factor analysis (Table 3).

Based on the analysis of total variance (Table 4) for the data of the first time, two factors were extracted. These factors account 69 and 23% of the variance, respectively. In the first factor, the Na, Cl, Ca, TDS, and EC parameters have the highest load of factor influenced by the weathering of regional formation (Table 5). The second factor is related to the K, SO_4 , and HCO_3 parameters. The increase

Fig. 3 Result of the reverse ion exchange diagrams for the Karun River in the lake and downstream of the Gotvand-e-Olya Dam

Fig. 4 Dendrogram of the studied parameters of the Karun River in the lake and downstream of the Gotvand-e-Olya Dam; **a** nearest neighbor method and **b** wards method (the first-time sampling)

Fig. 5 Dendrogram of the studied parameters of the Karun River in the lake and downstream of the Gotvand-e-Olya Dam; **a** nearest neighbor method and **b** wards method (the second-time sampling)

in load factor of the HCO₃ parameter and the presence of SO₄ parameter in the second factor show the effect of atmospheric precipitations on water quality. The explanation for this result is that the increase in the dissolution of carbonate rocks, gypsum, and anhydrite is more intense for first-time sampling compared to the second time.

Results of the analysis of variance (Table 4) show that the studied parameters at the second-time sampling are summarized in only one factor, which accounts for about

82% of the total variance. This condition confirms that just one process controls almost all of the parameter changes and other processes are affected by it. Due to the conditions of the region, the weathering of rock units (carbonate and evaporative) is the major process in controlling water quality. The Cl, Na, Ca, and SO₄ parameters have the highest load of factor, which shows the effect of dissolution of Gachsaran Formation on the water quality of the river. The factor load of the Mg and HCO₃ parameters is in the second

Fig. 6 Dendrogram of sampling stations in the lake and downstream of the Gotvand-e-Olya Dam; **a** nearest neighbor method and **b** wards method (the first-time sampling)

Fig. 7 Dendrogram of sampling stations in the lake and downstream of the Gotvand-e-Olya Dam; **a** nearest neighbor method and **b** wards method (the second-time sampling)

level of importance, which shows the effect of the dissolution of carbonate rocks. The TDS and EC parameters are also affected by the concentration of ions in the water. In the second factor, with about 9% of the total variance, the bicarbonate parameter is the only parameter that has high load of factor and can partly reflect the effect of the evaporation process on the water quality. Nevertheless, due to the specific value less than 1, this factor is not important as an effective factor (Table 5 and Figs. 8, 9).

The geological formations, which outcrop at the Karun basin, are sedimentary rocks, especially carbonate and evaporative formations. This formation has a great potential for erosion and dissolution by surface water and groundwater flows. These processes increase significantly the concentration of salts in the river. However, the outcrop of the problematic formations in the dam's lake and the constant contact with water has a more pronounced effect than the salts in the input water of the upstream to the dam's lake.

Table 2 Correlation coefficient results for factor analysis for studied parameters in the lake and downstream of the Gotvand-e-Olya Dam

	EC	TDS	pH	Ca	Mg	Na	K	HCO ₃	CO ₃	Cl	SO ₄
First-time sampling											
Correlation coefficient											
EC	1.00	0.98	− 0.16	0.89	0.08	0.98	0.38	0.49	0	0.93	0.68
TDS		1.00	− 0.14	0.91	0.07	0.97	0.31	0.50	0.01	0.89	0.74
pH			1.00	− 0.05	− 0.01	− 0.13	− 0.27	0.07	0.09	− 0.24	0.16
Ca				1.00	− 0.06	0.84	0.20	0.49	0.11	0.78	0.74
Mg					1.00	0.02	− 0.01	− 0.02	− 0.23	0.13	− 0.01
Na						1.00	0.41	0.43	0.04	0.93	0.68
K							1.00	− 0.40	0.17	0.57	− 0.14
HCO ₃								1.00	− 0.01	0.14	0.80
CO ₃									1.00	0.00	0.13
Cl										1.00	0.41
Sig. level											
EC		0.00	0.23	0.00	0.35	0.00	0.04	0.01	0.50	0.00	0.00
TDS			0.25	0.00	0.37	0.00	0.07	0.01	0.49	0.00	0.00
pH				0.41	0.49	0.28	0.10	0.37	0.33	0.13	0.22
Ca					0.39	0.00	0.18	0.01	0.30	0.00	0.00
Mg						0.46	0.48	0.46	0.14	0.27	0.48
Na							0.02	0.02	0.42	0.00	0.00
K								0.03	0.22	0.00	0.25
HCO ₃									0.48	0.25	0.00
CO ₃										0.50	0.28
Cl											0.02
	EC	TDS	pH	Ca	Mg	Na	K	HCO ₃	CO ₃	Cl	SO ₄
Second-time sampling											
Correlation coefficient											
EC	1.00	0.99	− 0.36	0.92	0.73	0.99	− 0.04	0.60	−	0.95	0.88
TDS		1.00	− 0.36	0.93	0.76	0.99	− 0.03	0.56	−	0.94	0.90
pH			1.00	− 0.36	− 0.04	− 0.37	0.22	− 0.03	−	− 0.32	− 0.27
Ca				1.00	0.62	0.90	0.15	0.53	−	0.84	0.91
Mg					1.00	0.71	− 0.04	0.48	−	0.67	0.72
Na						1.00	− 0.06	0.60	−	0.96	0.87
K							1.00	0.17	−	− 0.07	0.03
HCO ₃								1.00	−	0.65	0.39
CO ₃									−	−	−
Cl										1.00	0.78
Sig. level											
EC		0.00	0.05	0.00	0.00	0.00	0.42	0.00	−	0.00	0.00
TDS			0.06	0.00	0.00	0.00	0.45	0.00	−	0.00	0.00
pH				0.05	0.45	0.05	0.16	0.45	−	0.07	0.11
Ca					0.00	0.00	0.26	0.01	−	0.00	0.00
Mg						0.00	0.43	0.01	−	0.00	0.00
Na							0.39	0.00	−	0.00	0.00
K								0.23	−	0.37	0.45
HCO ₃									−	0.00	0.04
CO ₃										−	−
Cl											0.00

The results of different ionic ratios at both times of sampling clearly show the effect of dissolution of different

Table 3 Results of KMO and Bartlett test for studied parameters in the lake and downstream of the Gotvand-e-Olya Dam

Statistics	First-time sampling	Second-time sampling
KMO	0.725	0.776
Bartlett's of sphericity		
χ^2	340.517	313.74
Sig.	0.00	0.00

Table 4 Results of factor analysis for studied parameters in the lake and downstream of the Gotvand-e-Olya Dam

Component	First-time sampling			Second-time sampling		
	Initial eigenvalues			Initial eigenvalues		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	5.533	69.158	69.158	6.537	81.708	81.708
2	1.821	22.776	91.924	0.697	8.71	90.417
3	0.298	3.73	95.654	0.453	5.67	96.086
4	0.200	2.501	98.155	0.212	2.645	98.731
5	0.119	1.49	99.645	0.056	0.699	99.43
6	0.018	0.219	99.864	0.036	0.451	99.881
7	0.008	0.106	99.97	0.007	0.085	99.996
8	0.002	0.031	1	0.003	0.034	100

Table 5 Rotated component matrix for studied parameters in the lake and downstream of the Gotvand-e-Olya Dam

	First-time sampling			Second-time sampling	
	1	2		1	2
EC	0.973	0.189	EC	0.905	0.397
TDS	0.957	0.255	TDS	0.931	0.344
Ca	0.868	0.323	Ca	0.901	0.276
Na	0.972	0.149	Na	0.897	0.405
K	0.546	-0.737	Mg	0.718	0.315
HCO ₃	0.307	0.888	HCO ₃	0.260	0.953
Cl	0.966	-0.154	Cl	0.811	0.496
SO ₄	0.591	0.730	SO ₄	0.953	0.108

formations, especially Gachsaran evaporative formation, on water quality (Fig. 10). Due to the layering of the dam's lake caused by the difference of salinity from the surface to the depth, the quality of samples taken from the lake surface is not significantly affected by the dissolution of evaporative formations. The water outflow of the dam is not just from

the surface of the lake and includes lower levels. Therefore, the salt concentration in the downstream samples is higher than in the lake-surface samples. Another important point is the difference in salt concentration at both sampling times. At the second-time sampling, which coincides with the peak of hot season in the region, water quality in the dam's lake is reduced by the increase in evaporation. On the other hand, because of an increase in rainfall and a decrease in evaporation in the wet season, water quality is expected to improve. However, in downstream, the first-time samples have higher solute concentrations and therefore lower quality than the second-time sampling. These conditions are affected by the increase in dam output that occurs during the wet season, leading to water drainage from a lower depth of lake. The first time of sampling coincides with the wet season in the region. It is of note that due to an increase in solubility of different formations, an increase in precipitation level may also increase the salt concentration and decrease water quality.

Conclusion

The order of the main parameters in the studied samples is $\text{Cl} > \text{SO}_4 > \text{HCO}_3$ and $\text{Na} > \text{Ca} > \text{Mg}$. Hence, the water in the downstream stations at the first-time sampling its shows Cl-Na while for the second-time sampling shows Cl-Na or Cl-Ca type. The reverse ion exchange process is one of the factors that interfere with Na-Cl balance and cause the type of water of Cl-Ca . The ion exchange diagrams confirm this process. At the lake of the dam, the water types of the first-time sampling are the $\text{SO}_4\text{-Ca}$ and $\text{HCO}_3\text{-Ca}$ and at the second-time sampling they are $\text{SO}_4\text{-Ca}$ and $\text{HCO}_3\text{-Ca}$ types. These conditions are affected by the dissolution of the formations at the basin and dam. Another important factor in these conditions is the transmission of sodium ions resulting from the dissolution of halite to the depth because of the higher density.

The results of the cluster analysis show that the EC, TDS, and Na parameters and with a slight difference the Cl parameter are grouped in one cluster, suggesting the effect of the dissolution of evaporative formations on water quality. The dissimilarity of Na and Cl parameters in the first level is due to the durability of ion chloride and its non-participation in the ion exchange process. At level 10, the Ca and SO_4 parameters are grouped together. This clustering shows that the dissolution of gypsum and anhydrite is not the only source of calcium in the river and the dissolution of calcareous formation and the reverse ion exchange are the other sources of calcium ions. At the first-time sampling, SO_4 and HCO_3 parameters are grouped at level 4, indicating an

Fig. 8 Scree plot for studied parameters in the lake and downstream of the Gotvand-e-Olya Dam

Fig. 9 Plot of initial eigenvalues for studied parameters in the lake and downstream of the Gotvand-e-Olya Dam

increase in the dissolution rate of carbonate and approaching its value to the dissolution of gypsum and anhydrite. The clustering of the stations in both times is affected by their distance from the dam, so that upstream stations are located in only one cluster.

Based on the results of the factor analysis for the first-time sampling, two factors were extracted. The first factor, which includes being Na, Cl, Ca, TDS, and EC parameters, is affected by the weathering of the regional formations. The second factor, which includes SO_4 and HCO_3 , shows the effect of atmospheric precipitations on water quality because of the increased dissolution of carbonate formations, gypsum, and anhydrite. At the second-time sampling, the weathering process controls almost all the changes in

the parameters studied and other processes are affected by it. The Cl, Na, Ca, and SO_4 parameters have the highest factor load and confirm the effect of dissolution of Gachsaran Formation on river water quality. The factor load of Mg and HCO_3 is in the second rank of importance, indicating the effect of the dissolution of carbonate formations.

As for the geological location of Gotvand-e-Olya Dam and its lake, the weathering process in the form of dissolution of rocks is the most important factor in controlling water quality and other natural factors are important at the next degree. The results of ionic ratios also confirm the effect of the dissolution of geological formations on water quality. However, the volume of water outflow from the dam has a significant impact on the water quality downstream.

Fig. 10 Results of TDS and $Cl/(HCO_3 + CO_3)$ ratio to evaluate the chemistry of the Karun River in the lake and downstream of the Gotvand-e-Olya Dam

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References

- Abdolabadi H, Ardestani M, Hasanlou H (2014) Evaluation of water quality parameters using multivariate statistical analysis (case study: Atrak River). *J Water Wastewater* 25(3):110–117 (in Persian)
- Adebola AO, Seun MA, Oladele O (2013) Water quality assessment of river Ogun using multivariate statistical techniques. *J Environ Prot* 4:466–479. <https://doi.org/10.4236/jep.2013.45055>
- Adhikary PP, Chandrasekharan H, Chakraborty D, Kamble K (2010) Assessment of groundwater pollution in West Delhi, India using geostatistical approach. *Environ Monit Assess* 167:599–615. <https://doi.org/10.1007/s10661-009-1076-5>
- Azhar SC, Aris AZ, Yusoff MK, Ramli MF, Juahir H (2015) Classification of river water quality using multivariate analysis. *Procedia Environ Sci* 30:79–84. <https://doi.org/10.1016/j.proenv.2015.10.014>
- Belkhir L, Boudoukha A, Mouni L, Baoza T (2010) Application of multivariate statistical methods and inverse geochemical modeling for characterization of groundwater—a case study: Ain Azel Plain (Algeria). *Geoderma* 159:390–398. <https://doi.org/10.1016/j.geoderma.2010.08.016>
- Boyacioglu H, Boyacioglu H (2008) Water pollution sources assessment by multivariate statistical methods in the Tahtali Basin, Turkey. *Environ Geol* 54(2):275–282. <https://doi.org/10.1007/s00254-007-0815-6>
- Chapman D (1992) Water quality assessment. In: Chapman D (ed) On behalf of UNESCO, WHO and UNEP. Chapman & Hall, London
- Chow MF, Shiah FK, Lai CC, Kuo HY, Wang KW, Lin CH, Chen TY, Kobayashi Y, Ko CY (2016) Evaluation of surface water quality using multivariate statistical techniques: a case study of Fei-Tsui Reservoir basin, Taiwan. *Environ Earth Sci* 75(1):1–15. <https://doi.org/10.1007/s12665-015-4922-5>
- Fakoor H, Namdar H (2003) Determine the salinity factors of Batvand River and possible exploitation of it. In: 7th International river engineering conference, Ahvaz. (in Persian)
- Fisher RS, Mullican WF (1997) Hydrochemical evolution of sodium-sulphate and sodium-chloride groundwater beneath the Northern Chihuahuan desert, Trans-Pecos, Texas, USA. *Hydrogeol J* 5:4–16. <https://doi.org/10.1007/s100400050102>
- Güler C, Thyne GD, McCray JE, Turner AK (2002) Evaluation of graphical and multivariate statistical methods for classification of water chemistry data. *Hydrogeol J* 10:455–474. <https://doi.org/10.1007/s10040-002-0196-6>
- Hasanvand M, Dhrazma B, Hafezi Moghaddas N (2010) Investigate the effect of Indica, Lali and Murghab Saline Branches on water quality of upstream cofferdam Gotvand-Olia Dam. In: 14th Symposium of geological society of Iran, Urmia. (in Persian)
- Hasanvand M, Dhrazma B, Hafezi Moghaddas N (2011) The estimation of formations area in Gotvand Dam Reservoir and changes in water quality in different levels after impounding Dam. In: The 7th Iranian conference of engineering geology and the Environment, Shahrood. (in Persian)
- Hossein Zare N, Saadati N, Mooied P (2006) Water quality of Karun Branches and its role and importance in offsetting the salinity of natural saline rivers and watercourses in the middle basin. In: The first regional optimal utilization of water resources of Karun and Zayandehrood basins conference, Shahr e Kord. (in Persian)
- Hounsflow AW (1995) Water quality data—analysis and interpretation. CRC Press LLC, Boca Raton. <https://doi.org/10.1201/9780203734117>
- Howard FW, Mullings E (1996) Hydrochemical analysis of groundwater flow and saline intrusion in the Clarendon Basin, Jamaica. *Groundwater* 34(6):801–810. <https://doi.org/10.1111/j.1745-6584.1996.tb02074.x>
- Jankowski J, Acworth RL, Shekarforoush S (1998) Reverse ion-exchange in deeply weathered porphyritic dacite fractured aquifer system, Yass, New South Wales, Australia. In: Arehart GB, Hulston JR (eds) Proceedings of 9th International symposium on water-rock interaction. Taupo, New Zealand, March–April, Balkema, Rotterdam
- Jung KY, Lee KL, Im TH, Lee JJ, Kim S, Cheon SU, Ahn JM (2016) Evaluation of water quality for the Nakdong River watershed using multivariate analysis. *Environ Technol Innov* 5:67–82. <https://doi.org/10.1016/j.eti.2015.12.001>
- Kilic E, Yucel N (2019) Determination of spatial and temporal changes in water quality at Asi River using multivariate statistical techniques. *Turk J Fisher Aquat Sci* 19(9):727–737. https://doi.org/10.4194/1303-2712-v19_9_02
- Kortatsi BK (2007) Hydrochemical framework of groundwater in the Ankobra Basin, Ghana. *Aquat Geochem* 13:41. <https://doi.org/10.1007/s10498-006-9006-4>
- Kwami IA, Ishaku JM, Hamza YS, Bello AM, Mukkafa S (2019) Application of multivariate statistical techniques for the interpretation of groundwater quality in Gombe and Environs, North-East Nigeria. *J Geosci Geomat* 7(1):9–14. <https://doi.org/10.12691/jgg-7-1-2>
- Le TTH, Zeunert S, Lorenz M, Meon G (2017) Multivariate statistical assessment of a polluted river under nitrification inhibition in the tropics. *Environ Sci Pollut Res* 24(15):13845–13862. <https://doi.org/10.1007/s11356-017-8989-2>
- Mansournejad M, Kalantari B, Mahdavi Adeli M (2015) The investigation of negative effects of salt dome on the quality of water in Gotvand Olya dam and the use of cut-off wall as treatment. *Am J Civ Eng* 3(2–2):53–56. <https://doi.org/10.11648/j.ajce.s.2015030202.20>
- McGarigal K, Cushman SA, Stafford S (2000) Multivariate statistics for wildlife and ecology research. Springer, New York
- McLean W, Jankowski J (2000) Groundwater quality and sustainability in an alluvial aquifer, Australia. In: Sililo et al (eds) Proceedings of XXX IAH congress on groundwater: past achievements and future challenges. Cape Town South Africa, November–December. AA Balkema, Rotterdam
- Mirzaei M, Riahi-Bakhtiar A, Salman-Mahini A, Gholamalifard M (2013) Analysis of the physical and chemical quality of Mazandaran Province (Iran) rivers using multivariate statistical methods. *J Mazandaran Univ Med Sci* 23(108):41–52 (in Persian)
- Monica N, Choi K (2016) Temporal and spatial analysis of water quality in Saemangeum watershed using multivariate statistical techniques. *Paddy Water Environ* 14(1):3–17. <https://doi.org/10.1007/s10333-014-0475-6>
- Mozaffarizadeh J, Chitsazan M (2007) The impact of geological formations on the water quality of Karun River in the range of Gotvand–Shushtar. In: 14th Symposium of crystallography and mineralogy of Iran, Birjand. (in Persian)
- Muangthong S, Shrestha S (2015) Assessment of surface water quality using multivariate statistical techniques: case study of the Nampong River and Songkhram River, Thailand. *Environ Monit Assess* 187(9):1–12. <https://doi.org/10.1007/s10661-015-4774-1>
- Nadiri AT, Moghaddam AA, Tsai FT, Fijani E (2013) Hydrogeochemical analysis for Tasuj plain aquifer, Iran. *J Earth Syst Sci* 122(4):1091–1105. <https://doi.org/10.1007/s12040-013-0329-4>
- Ogwueleka TC (2015) Use of multivariate statistical techniques for the evaluation of temporal and spatial variations in water quality of the Kaduna River, Nigeria. *Environ Monit Assess* 187(3):1–17. <https://doi.org/10.1007/s10661-015-4354-4>
- Pesce SF, Wunderlin DA (2000) Use of water quality indices to verify the impact of Cordoba City (Argentina) on Sucuia River. *Water Res* 34:15–29. [https://doi.org/10.1016/S0043-1354\(00\)00036-1](https://doi.org/10.1016/S0043-1354(00)00036-1)

- Rehman S, Hussain Z, Zafar S, Ullah H, Badshah S, Ahmad SS, Saleem J (2018) Assessment of ground water quality of Dera Ismail Khan, Pakistan, using multivariate statistical approach. *Sci Technol Dev* 37(4):173–183. <https://doi.org/10.3923/std.2018.173.183>. ISSN 0254-6418
- Ren J, Liang J, Ren B, Zheng X, Guo C (2018) New patterns of temporal and spatial variation in water quality of a highly artificialized urban river-course—a case study in the Tongzhou Section of the Beiyun River. *Water* 10:1446. <https://doi.org/10.3390/w10101446>
- Ribeiro L, Macedo ME (1995) Application of multivariate statistics, trend and cluster analysis to groundwater quality in the Tejo and Sado aquifer. In: *Groundwater quality: remediation and protection. Proceedings of the Prague conference*, May
- Rostamy Paydar GH, Shahrokhi S, Hoseinian SA (2011) The effects of environmental geology of Lali salt dome in the reservoir of Gotvand-Olia dam on agriculture and aquaculture Gotvand, Aghili plain and Shushtar. In: *First national conference on geography, environmental hazards sustainable development, Ahwaz. (in Persian)*
- Shrestha S, Kazama F (2007) Assessment of surface water quality using multivariate statistical techniques: a case study of the Fuji river basin, Japan. *Environ Model Softw* 22(4):464–475. <https://doi.org/10.1016/j.envsoft.2006.02.001>
- Sojka M, Siepak M, Ziola A, Frankowski M, Murat-Błażejewska S, Siepak J (2008) Application of multivariate statistical techniques to evaluation of water quality in the Mała Węlna River (Western Poland). *Environ Monit Assess* 147(1):159–170. <https://doi.org/10.1007/s10661-007-0107-3>
- Suvedha M, Gurugnanam B, Suganya M, Vasudevan S (2009) Multivariate statistical analysis of geochemical data of groundwater in Veeranam catchment area. *J Geol Soc India* 74(5):573–578. <https://doi.org/10.1007/s12594-009-0170-1>
- Wang Y, Wang P, Bai Y, Tian Z, Li J, Shao X, Li BL (2013) Assessment of surface water quality via multivariate statistical techniques: a case study of the Songhua River Harbin region, China. *J Hydro-Environ Res* 7(1):30–40. <https://doi.org/10.1016/j.jher.2012.10.003>
- Wenning RJ, Erickson GA (1994) Interpretation and analysis of complex environmental data using chemometric methods. *Trends Anal Chem* 13:446–457. [https://doi.org/10.1016/0165-9936\(94\)85026-7](https://doi.org/10.1016/0165-9936(94)85026-7)
- Wood WW, Jones BF (1990) Origin of solutes in saline lakes and springs on the southern High Plains of Texas and New Mexico. Bureau of Economic Geology, Austin
- Zaidi FK, Nazzal Y, Jafri MK, Naem M, Ahmed I (2015) Reverse ion exchange as a major process controlling the groundwater chemistry in an arid environment: a case study from northwestern Saudi Arabia. *Environ Monit Assess* 187(10):607. <https://doi.org/10.1007/s10661-015-4828-4>
- Zarechahoki MA (2013) Data analysis in natural resources research using SPSS software. SID Publications, Tehran University, Tehran (in Persian)
- Zhou F, Liu Y, Guo H (2007) Application of multivariate statistical methods to water quality assessment of the watercourses in Northwestern New Territories, Hong Kong. *Environ Monit Assess* 132(1–3):1–13. <https://doi.org/10.1007/s10661-006-9497-x>

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