Shahid Chamran University of Ahvaz

**Irrigation Sciences and Engineering (JISE)**
**Vol. 46, No. 4, Winter 2024, p. 97-116**

Journal homepage: https://jise.scu.ac.ir

**Original Paper**

# Spatiotemporal Investigation of Maroon dam effects on water quality by multivariate statistical Analysis

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ARTICLE INFO

*Artlcle history:*
Received: 30 July 2023
Revised: 04 November 2023
Accepted: 06 November 2023

*Keywords:* Modified Mann-Kendall Test, Qualitative Parameters, Significant Autocorrelation, Gachsaran Formation.

TO CITE THIS ARTICLE:

Tishehzan, P., Ebrahimi Varzaneh, S., Tafi, S., Ahmadi, F. (2024). 'Spatiotemporal Investigation of Maroon dam effects on water quality by multivariate statistical Analysis', Irrigation Sciences and Engineering, 46(4), pp. -. doi: 10.22055/jise.2023.44439.2088.

**Abstract**

Maroon River is a valuable aquatic ecosystem in Iran. The purpose of this research was to investigate the lasting impacts of the Maroon dam on river water quality (RWQ), particularly downstream, and determine those factors affecting the optimal management of the RWQ. The modified Mann-Kendall and Sen's slope estimator tests were employed to investigate the variation trend of qualitative parameters. Then, multivariate statistical analyses, including correlation assessment, cluster analysis, T-test, and factor analysis of spatiotemporal pattern, are applied to recognize factors affecting the effects of dam construction. Results showed that the total hardness and the calcium, chlorine, and sulfate concentrations significantly increased in downstream at a level of 5% confidence. The cluster analysis indicated that dam construction probably did not affect the upstream; however, the increased dissolution rates of calcium and sulfates downstream illustrated the presence of the Gachsaran formation in the river path and the dissolution of rock gypsum in the water. The factor analysis determined three and two main components before and after dam construction with 84.8% and 71.6% variances, respectively. These components and the correlation between chloride-sodium and calcium-sulfate ions could show the Sodium Chloride dissolution and the effects of the dissolution of gypsum mid-layers from the Gachsaran formation after the dam construction. The strong relationship between the magnesium and chlorine contents in the Cham Nezam station might result from the salt/detergent-contained household and urban wastes entering the river. According to the results of various tests, the dam has changed the quality of the river downstream. Still, Wilcox and Schoeller's indices demonstrated that dam construction did not significantly affect the RWQ used for drinking and agriculture.

## Introduction

The growing population and water demands, industrialization, and development of different sectors are reasons for dam construction. Constructing dams across rivers results in hydrologic changes and alteration of physical processes, such as stream and sediment transport, and consequently, water quality. On the other hand, dam construction and surface water storage may lead to increase water evaporation, water stagnation resulting in thermal stratification in the reservoir, suspended particle deposition, nutrient enrichment, and changes in the physical, chemical, and biological properties of water (Ding et al., 2018). Recognizing aquatic mediums of dams in terms of physical and chemical properties is helpful for different applications. It is often realized through evaluating the temporal and spatial variation of water quality downstream and upstream of the dam ( Amiri et al., 2021; Allia et al., 2022; Alsubih et al., 2022).

Most studies have focused on environmental investigation and finding the pollution reasons in dam basins. Achieving ecological goals requires determining applied pressure, current water quality, and trends based on records and basin characteristics. Thus, evaluating water resources conditions will be easier, developing solutions for raised issues and taking necessary actions to attain determined environmental goals (Arslan, 2013; Yenilmez, 2022). The evaluation of temporal and spatial changes of water contamination in the Akkaya Dam watershed indicated that the main reasons for water contamination are agricultural activities and household and urban wastewater imposed on the system while either not treated or treated insufficiently. Korkanç et al. (2017) claimed that the contamination problem in Akkaya can only be resolved through consistent studies and prevention at the basin scale (Korkanç et al., 2017). The water quality of the Latyan dam (2014-2017) as the drinking water resource was investigated by Mohseni-Bandpei et al. (2018) that indicating the suitability of this water. However, the authors believe that the precise and continuous evaluation of water quality is essential because of variations of the nitrate and phosphorus and the high eutrophication extension (Mohseni-Bandpei et al., 2018).

Different methods have been developed to upgrade water quality management, including mathematical models, optimization algorithms, and integrated decision support systems (Huang and Xia, 2001; Taner, Üstün, and Erdinçler, 2011). Multivariate statistical analysis is one of the methods used to study several parameters simultaneously that may have different units (Shaw, 2009). Also, investigating the correlation between parameters by principal component analysis (PCA), factor analysis (FA), and cluster analysis (CA) are other tools for this goal (Parinet et al., 2004; Yenilmez et al., 2011; Wang *et al.*, 2019). These methods find a group or a set of variables with similar features and simplify their observations by finding structures or patterns in the presence of numerous data (Ragno, et al., 2007). The investigation of water quality parameters of the Karacaören-II dam by the FA method showed that the most effective quality parameters are nitrogen, phosphorus, pH, temperature, precipitation, and evaporation. In addition, the Mann-Kendall test for examining trends of qualitative data of this dam indicated the increased values of total phosphorus (TP) and total nitrogen (TN) (Yenilmez, 2022). Using PCA, FA, and analysis of variance (ANOVA) for clustering and examining water quality data in four stations in the Coruh basin (Turkey), Bilgin (2015) found that there was a statistically significant in terms of water quality difference between the upstream of released wastewater by the Black Sea copper companies and it's downstream. The water quality comparison of the Murgul and Borcka Dams did not show a statistically significant difference. The Factor analysis determined five factors explained 81.3 % of the total variance. The results showed that domestic, industrial, and agricultural activities, in combination with physicochemical properties, were the factors affecting the water quality in the Coruh Basin (Bilgin, 2015). Studying the water quality in 2008 and 2015 (before and after the three dam construction on the Geum River) indicated increased EC, decreased TP, decreased total particulate phosphorus (TPP), and no significant difference in suspended solids (SS) (Shim et al., 2018).

In the upstream station before dam construction, the results showed parameters of $Ca^{2+}$, $Cl^{-}$, $HCO_3^{-}$, $Mg^{2+}$, and $SO_4^{2-}$ proportionate to the first principal component and $K^{+}$ with the second main component. Although, after the dam construction, only two parameters of $Ca^{2+}$ and $Cl^{-}$ commensurate to the first principal component and $SO_4^{2-}$ with the second main component. The survey of downstream data before dam construction illustrated that three parameters of $Ca^{2+}$, $Mg^{2+}$, and $SO_4^{2-}$ were proportionate to the first main component, and EC and $HCO_3^{-}$ were symmetric with the second principal component. After constructing the Jare dam, the result of water quality analysis downstream showed that the $HCO_3^{-}$ and $Na^{+}$ created the first principal component, and $Mg^{2+}$ and pH the second main component. Neissi et al. (2019) claimed the flow of the Zard River on different formations causes solute more transportation downstream of the dam. Regarding increased hardness and pollution of surface water, control of upstream agricultural activities is essential before changing the water quality needed in the long term for irrigation (Neissi et al., 2019).

Rahimi Shahid et al., (2023) showed that groundwater quality in the construction site of Shahid Dam in the south of Shahid village in Semirom County is suitable for agricultural production. Based on hierarchical clustering analysis, different types of groundwater were classified into three groups.

The study conducted on the nematode population in the Ba Lai River in Vietnam, both upstream and downstream of the dam, revealed distinct disparities in the communities. The non-uniform distribution of nematode communities indicates the influence of dam construction on the river. This could potentially lead to increased sedimentation and eutrophication, ultimately transforming the area into a methane-rich zone, as predicted based on the impact on nematodes (Quang, N. X. et al., 2022).

Maroon is a hydroelectric pebble dam with a clay core constructed on the Maroon River in the southeastern part of Khuzestan province. The reservoir of this dam has a capacity of 1200 million $m^3$ of water and a length of 30 kilometers. This dam is used for electricity generation and irrigation of 55000 hectares of agricultural lands in Behbahan, Jayezan, and Shadegan. This area is environmentally valuable and includes Rich biodiversity and extensive farming lands. Therefore, due to water quality's vital role in this region, it is essential to investigate the dam construction effects on the water quality in the Maroon River. However, in the review of sources, no complete study was found to investigate the significant effect of this dam on upstream and downstream water quality. This study aims to examine the variation trend of water quality downstream and upstream of the dam in two pre- and post-construction periods. Also, the principal components and factors affecting water quality were determined using PCA, FA, and CA. Finally, water suitability was evaluated for agricultural and drinking usage.

## Methods and materials

### Study area

The Maroon-Jarrahi catchment, with a surface area of 24310 $km^2$, is located in southwestern Iran. About 9802 $km^2$ of this catchment basin (40.3%) is mountainous, and about 14508 $km^2$ is composed of plains and sloped lands. Based on the stratigraphy of the study area, those sediments located in the development region of the Maroon River belong to Eocene-Oligocene, Miocene, Pliocene, and Quaternary. Formations in the Maroon basin include Sarvak-Pabdeh, Gurpi, Asmari, Mishan-Aghajari, Gachsaran, and Alluvial rocks (Gholamhaydari et al., 2021). Maroon River, with a basin area of 7385.8 $km^2$, is located between Karun and Zoherh rivers and originates from the Shuroum mountains in the southern part of Lordegan. Maroon Reservoir dam was constructed across the Maroon River at a 19 *km* distance in northeastern Behbahan with a total volume of 1274 million $m^3$ between the years 1368 and 1378. Its impoundment started in 1380 (Fig. 1).

 *DOI:* 10.22055/jise.2023.44439.2088

This pebble dam with clay core was designed and constructed for agricultural activities, flood control, drinking water supply for Behbahan, and producing hydroelectric energy.

To accurately evaluate water quality variation in the Maroon River, two stations of Idanak and Cham Nezam upstream and downstream of the Maroon dam were considered (Table 1). For this purpose, qualitative data (1981-2018) from these two stations provided by the Water and Power Organization of Khuzestan Province were employed.

After initial evaluations, eight parameters, including electrical conductivity (EC), $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $Cl^{-}$, $HCO_3^{-}$, and $SO_4^{2-}$, were selected for statistical analysis. Unfortunately, the water pollution data had not been measured in these years. The degree of accuracy and validity of data was determined by calculating the Charge Balance Error (CBE) of ions (Freeze and Cherry, 1979) using Eq. (1). In this study, all data have CBE lower than 5%.

$$RE = \frac{\sum Cation - \sum Anions}{\sum Cation + \sum Anions} \times 100 \quad (1)$$

**Investigation of variation trend**

The modified non-parametric Mann-Kendall test, eliminating the effect of all significant autocorrelation coefficients, and Sen's slope estimator test (SSET) for examining the variation trend of water quality parameters in the Maroon River were used in this study.

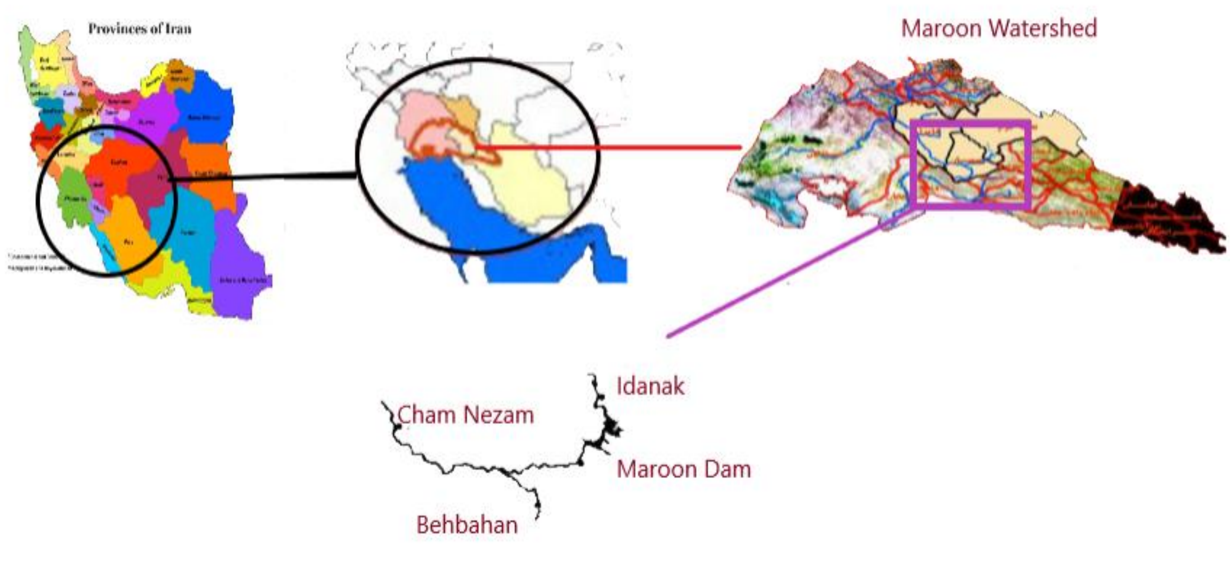


**Fig. 1- The location of the Maroon dam and the studied hydrometric stations**

**Table 1- Characteristics of Hydrometric station in the study region**

| Station | Estabilished Year | Area ($km^2$) | River | Height | Longitude | latitude |
|---|---|---|---|---|---|---|
| Idanak | 1969 | 2.2735 | Maroon | 560 | 444282 | 3424207 |
| Chamnezan | 1977 | 8.5384 | Maroon | 190 | 396307 | 3402397 |

The Mann-Kendall test is utilized for finding trends in hydrologic, climatic, and other related data. In this test, each value in the time series is compared with different values continuously and consecutively. The Statistic *S* and standardized statistic *Z* in the Mann-Kendall test are calculated using Eqs. (2) and (3), where n is the number of observations, $x_i$ is the *i*th rank of observations ($i = 1, 2, 3, \ldots, n-1$), and $x_j$ is the *j*th rank of observations ($j = i+1, 2, 3, \ldots, n$) (Mann, 1945; Kendall, 1948; Pirnia *et al.*, 2019).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right) \qquad (2)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > \circ \\ \circ & S = \circ \\ \frac{S+1}{\sqrt{Var(S)}} & S < \circ \end{cases} \qquad (3)$$

The necessary condition to use the Mann-Kendall test is the lack of autocorrelation in time series data. However, data may have significant autocorrelation. The modified Man-Kendall test (MMKT) utilizes modified variance *V(S)** instead of *V(S)* (Eq.4) to altogether deleted the effect of significant autocorrelation coefficients (Hamed and Rao, 1998). Eq. (5) calculates the modified variance.

$$V(S)^* = V(S).\frac{n}{n^*} \qquad (4)$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2).r_i \qquad (5)$$

Where $r_i$ is the autocorrelation coefficient with the delay *i* at a 10% significance level and can be calculated as follows (Kumar et al., 2009; Yue and Wang, 2004).

$$r_k = \frac{\frac{1}{n-k}\sum_{i=1}^{n-k}(x_i-\bar{x})(x_{i+k}-\bar{x})}{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2} \qquad (6)$$

**Sen’s slope estimator**

A helpful index in the Mann-Kendall test is the trend line slope or Sen’s slope, which shows the magnitude of a uniform trend. The trend line slope is estimated using Eq. (7) (Sen, 1968).

$$\beta = Median\left(\frac{x_j-x_i}{j-i}\right) \qquad \forall i < j \qquad (7)$$

Where $\beta$ is the slope estimator of a trend line, $x_i$ and $x_j$ are the *i*th and *j*th observational values, respectively. The $\beta$ positive values indicate an increasing trend while negative values show a decreasing trend.

**Hierarchical cluster analysis**

Hierarchical CA is the most conventional approach for CA. This analysis starts by placing each case in an individual cluster, and then groups join each other until only one collection remains, which is usually shown by a dendrogram (McKenna Jr, 2003). In this study, hierarchical CA is executed on a normalized dataset using Ward's method with squared Euclidean distance as the similarity measure. Ward's method evaluates the distance between clusters by ANOVA to minimize the sum of squared distances between each pair of groups in every step (Murtagh & Legendre, 2014). According to Eq. (8), the Ward function minimizes the sum of members' squared distances from the cluster's center of gravity.

$$W = \sum_{k-1}^{K} \sum_{j-1}^{m} \sum_{j-1}^{N_K} (Y_{iy}^{k} - Y_{wj}^{k}) \qquad (8)$$

Where *K* is the number of available clusters, m is the number of variables, $N_k$ is the number of members belonging to each cluster $Y_{wj}^{k}$ is the dimensionless mean value of the jth variable in set *k*, $Y_{iy}^{k}$ is the dimensionless value of the jth variable related to the ith member in cluster *k*. Eq. (9) is used to make variables dimensionless.

$$Y_{ij} = \frac{W_j}{\sigma_j}\left[f(x_{ij})\right] \qquad (9)$$

Where $x_{ij}$ is the value of the jth variable related to the ith member, $f(x_{ij})$ is the transformation function, *Wj* is the weight considered for the jth variable, $\sigma_j$ is the standard deviation, and $Y_{ij}$ is the nondimensionalized value of the ith variable.

**Factor analysis and principal component analysis**

The FA is a statistical method to describe the integrity between observed and correlated variables in terms of a few potential unobserved variables named factors. FA is performed in R-mode or Q-mode. In the first case, the relationships between variables, and in the second, the relationships between samples are examined (Reghunath et al., 2002). In this study, R-mode FA is used. Deriving the principal components in FA is conducted in six steps: 1) preparing the information matrix, 2) deriving the correlation coefficient matrix between variables, 3) deriving eigenvalues and eigenvectors of variables and observations from the correlation matrix, 4) determining the number of factors using fundamental metrics, 5) rotating the factor axes to simplify the structure of factor loadings, and 6) determining the factor ranking matrix (Mondal et al., 2010). By using the FA method, the affected factors on water quality could be estimated.

PCA is also a robust statistical method where some correlated variables are converted to a smaller set of uncorrelated variables or factors describing the main variations in a dataset. Reduction is achieved by altering the dataset to a new set of variables (principal components) that are orthogonal or uncorrelated relative to each other (Arslan, 2013; Jeong et al., 2014). For PCA, eigenvector calculations can be performed using a covariance matrix (Petersen et al., 2001). Factor analysis is carried out using R languages in this study.

**Average comparison using paired T-test**

The paired T-test was applied to compare the average of different parameters before and after the dam construction. This method determines the difference between every pair of observations and infers the differences in average values in the population. When the difference between pre-and post-construction values is calculated, a single value is obtained for every two values existing for every observation. So, the problem becomes similar to a one-sample T-test. If the goal is to examine the equality of average values pre and post-construction, the zero assumption of the test is that the difference between observations is zero.

**Examining the water quality in stations in terms of agricultural and drinking indices**

The water quality in the intended stations was examined through the Wilcox index during the years before the dam construction (1981-1999) and years after the dam construction (2000-2018) to supply agricultural water. In addition, the suitability of this water for drinking was examined using the Schoeller index pre and post-construction.

## Results and discussion

Idanak and Cham Nezam stations are located respectively upstream and downstream of the Maroon dam. Table (2) presents some brief statistics of these two stations. Based on statistics between 1981 and 2018, the river flow rate variation in Idanak (upstream) and Cham Nezam (downstream) stations indicate that the maximum flow rate relates to 1986 and 1987 before the dam construction (215.44 $m^3/s$ and 140.74 $m^3/s$ is Idanak and Cham Nezam, respectively). The flow rate has experienced a descending trend in both stations. However, this trend is more extreme in Cham Nezam (Fig. 2). Land use is an essential factor affecting runoff, evapotranspiration, surface erosion of the basin, and, consequently, the flow rate. Motlagh et al. (2018) indicated that changing the land use in Idanak during the past four decades caused the reduction of permeability and hydraulic conductivity of the surface and deep aquifers and subsurface flow.

For examining the trend of qualitative data and the significance of their variations during the evaluated years, MMKT and SSET were used. Table (3) shows that the results obtained from these two tests. The mean EC is 0.941 *dS/m* for Idanak and 2.28 dS/m for Cham Nezam. Based on the system of water quality classification, total dissolved solids (TDS) lower than 1000 *mg/l* denotes fresh water, and TDS between 1000 and 10000 *mg/l* marks

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brackish water (Carroll, 1962). Therefore, the upstream station has fresh water, and the downstream has brackish water.

Water quality variation in the Maroon River upstream and downstream of the dam indicates that EC and TDS have been increased in both stations. However, the intensity of this increase is more significant in the downstream stations. Increased EC may be because of the river feed reduction after the dam construction (Shim et al., 2018). Based on the MMKT, the significance level is 5% for EC and TDS in Idanak, and in Cham Nezam, it is 5% for TDS and 10% for EC (Table 3). The probable reasons for this increase are human factors, like agricultural and industrial drainages, and geological salinization agents. Other studies have also indicated this increase (Zalaki Badili et al., 2013; HaRa et al., 2020).

**Table 2- Summary of statistics in Idanak and Cham Nezam stations (1981-2018)**

| No. | Station | Parameter | Unit | Min | Max | Ave. | S.E | Skweness |
|---|---|---|---|---|---|---|---|---|
| 1 | Idanak | Flow discharche | *$m^3/s$* | 10.90 | 215.44 | 56.55 | 43.61 | 1.83 |
| | | EC | *µS/cm* | 692.67 | 1802.14 | 941.44 | 208.06 | 2.52 |
| | | pH | - | 7.33 | 8.35 | 7.87 | 0.27 | -0.73 |
| | | $SO_4^{2-}$ | *meq/l* | 1.44 | 5.95 | 2.95 | 0.76 | 1.31 |
| | | $HCO_3^-$ | *meq/l* | 2.05 | 3.68 | 2.79 | 0.42 | 0.28 |
| | | $Cl^-$ | *meq/l* | 1.99 | 4.99 | 3.37 | 0.75 | -0.13 |
| | | $Ca^{2+}$ | *meq/l* | 2.66 | 6.13 | 4.31 | 0.69 | -0.01 |
| | | $Mg^{2+}$ | *meq/l* | 0.98 | 2.23 | 1.61 | 0.28 | -0.11 |
| | | $Na^+$ | *meq/l* | 1.09 | 4.93 | 3.17 | 0.75 | -0.25 |
| 2 | Cham Nezam | Flow discharche | *$m^3/s$* | 0.00 | 140.74 | 56.91 | 32.39 | 0.53 |
| | | EC | *µS/cm* | 1783.00 | 2757.25 | 2282.93 | 246.72 | -0.02 |
| | | pH | - | 7.53 | 8.27 | 7.90 | 0.17 | -0.02 |
| | | $SO_4^{2-}$ | *meq/l* | 5.97 | 21.57 | 10.39 | 2.51 | 2.18 |
| | | $HCO_3^-$ | *meq/l* | 1.80 | 3.12 | 2.42 | 0.31 | 0.26 |
| | | $Cl^-$ | *meq/l* | 8.14 | 14.08 | 11.02 | 1.76 | 0.13 |
| | | $Ca^{2+}$ | *meq/l* | 6.68 | 12.25 | 9.31 | 1.40 | 0.04 |
| | | $Mg^{2+}$ | *meq/l* | 2.13 | 4.82 | 3.23 | 0.70 | 0.65 |
| | | $Na^+$ | *meq/l* | 8.36 | 14.04 | 11.01 | 1.66 | 0.21 |

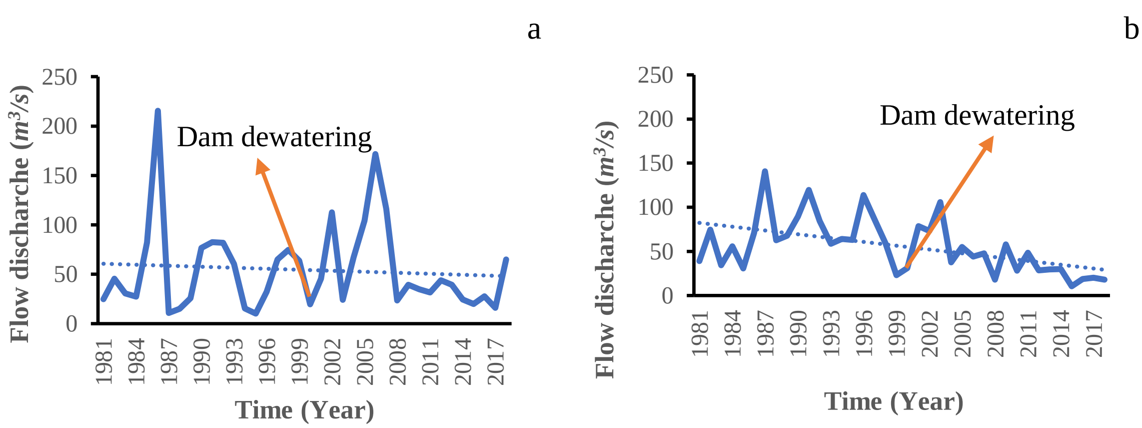


**Fig. 2- Flow rate variations: a) Idanak, b) Cham Nezam station**

Sodium is one of the effective cations in water quality evaluation. Upstream the river, $Na^+$ has insignificantly increased to a small extent; however, in Cham Nezam, it has shown a statistically insignificant decreasing trend. These observations are in contrast to the EC trend. Of course, all dissolved salts influence EC. In both stations, $Ca^{2+}$ has increased, and its increasing trend in Idanak has a lower slope than in Cham Nezam. The variation of $Ca^{2+}$ is at a significance level of 5% in both stations. $Mg^{2+}$ has increased during the evaluation years, especially downstream; however, these changes have been insignificant in both stations. The dominance of $Ca^{2+}$, $Na^+$, and $K^+$ in Idanak demonstrates that the river has probably passed through layers of dolomitic limestone and salt (Zalaki Badili et al., 2013). Gachsaran formation in the study area is dominant and affects the water quality in the Maroon Dam (Rezaei et al., 2016).

The water's temporary and total hardness has been increased in both stations. The temporary hardness variation has no significant difference between upstream and downstream. However, the water's total hardness in Cham Nezam station is lower than upstream. The total hardness variation has a significance level of 5% in both stations.

The reason for increased temporary hardness in these stations is probably the increase in the $HCO_3^-$ content. $HCO_3^-$ shows an increasing but statistically insignificant trend in both stations. Indeed, the maximum $HCO_3^-$ observed at downstream stations is lower than in the Idanak station. As presented in Table (3), the trend of $SO_4^{2-}$ in Idanak is relatively constant, but it has an increasing trend in downstream stations during the study years. The maximum amount of $SO_4^{2-}$ had occurred in Cham Nezam in 2015 (after the dam construction), which can be one of the reasons for the escalation of total hardness in this station. The increasing trend of $SO_4^{2-}$ in Cham Nezam has a significance level of 5% (Table 3). It can be said that the dissolution of rock gypsum from the Gachsaran formation caused TDS and $SO_4^{2-}$ to increase in surface and groundwater, decreasing water quality. The exceeding withdrawal of groundwater and decreasing water table level could be led to an increased dissolution rate of gypsum rocks (Mohammadian et al., 2015). Gholamhaydari et al. (2021) illustrated that the Gachsaran formation and gypsum karstification in the plain have destructive effects on the roads, utilities, agricultural lands, residential buildings, and Maroon Dam's reservoir (Gholamhaydari et al., 2021).

The variation of $Cl^-$ indicates little growth in Idanak and negative growth in Cham Nezam, which are insignificant. Based on the Piper diagram, Zalaki Badili et al. (2013) showed that the water has a hydro-chemical face of Ca-$HCO_3$-Cl.

The content of $K^+$ increases from upstream to downstream (10% significance level in both stations), and the maximum amount of $K^+$ is observed in Cham Nezam. In addition, pH has a descending trend in all stations, and the water is alkaline. However, the alkalinity level has been increased after the dam construction. Concerning the increasing trend of $HCO_3^-$ during post-construction years, the rising trend of alkalinity is natural.

**T-test**

The test of compare means was conducted in Idanak and Cham Nezam on critical parameters in two periods before and after the Maroon dam construction to evaluate and validate the variation of these variables statistically. The results shows that the variation in Idanak was not significant. Table (4) shows the results of this test for $Cl^-$, $SO_4^{2-}$ and EC for example. As can be seen, the p-value is higher than 5% in Idanak, and there is no statistically significant change in these parameters mean before and after the dam construction. Since Idanak is located upstream of the dam, this result is not far-fetched.

In Cham Nezam, all parameters experience considerable and significant changes pre-construction and post-construction (at a significance level of 1% for $Cl^-$ and $SO_4^{2-}$ and a significance level of 5% for EC). Therefore, it can be illustrated that $SO_4^{2-}$, $Cl^-$, and EC have significant variation trends. After the dam construction, they escalate due to the geology formation dissolution and contaminant discharge into the Maroon River. Examining the Third Gorges Dam's environmental impact on the chemistry of the water in the Yangtze River indicated that the concentration of all ions, except $HCO_3^-$, was increased after TGD construction (at a significance level of 1%). Researchers of this study considered the increased load of dissolved silicate due to the water-induced erosion and the role of the dam lake as the main reasons for these variations (X. Wang et al., 2018).

**Box plot comparison before and after the dam construction**

For more investigation, the Idanak and Cham Nezam stations were considered as representative of river conditions before and after the dam construction, and the box plot was drawn. Fig. (3) shows the box plot for variations of two parameters in Cham Nezam stations before and after the dam. The midline of each box represents the median value; the lower part shows the third quartile (75th percentile), and the upper part shows the first quartile (25th percentile). The maximum and minimum values are connected to the box using vertical lines. As can be seen, the parameters exhibit an increasing trend after the dam, and average concentrations have considerably increased before and after the dam. Investigation of the hydrology and biochemistry variation of nitrogen before and after dam construction was done in southern Ontario. Using box plots, researchers showed that the amount of dissolved oxygen in coastal groundwater reduced after the dam construction. In spring and autumn, nitrate nitrogen concentration decreased relative to pre-construction. However, ammonium nitrogen concentration increased (Hill & Duval, 2009).

**Table 3- Results of MMKT and SSET**

| Station | MMKT | TDS *(mg/l)* | EC *µS/cm* | pH | $HCO_3^-$ *meq/l* | $Cl^-$ *meq/l* | $SO_4^{2-}$ *meq/l* | $Ca^{2+}$ *meq/l* | $Mg^{2+}$ *meq/l* | $Na^+$ *meq/l* | $K^+$ *meq/l* | Temporary Hardness | Total Hardness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Idanak | Z | 2.03 | 2.15 | -1.46 | 1.25 | 1.60 | -0.39 | 2.76 | 0.61 | 1.52 | 1.88 | 1.31 | 2.09 |
| | Sen | 2.761 | 4.753 | -0.015 | 0.019 | 0.025 | -0.002 | 0.037 | 0.001 | 0.021 | 0.000 | 0.963 | 1.870 |
| Cham Nezam | Z | 2.260 | 1.812 | -1.498 | 1.372 | -0.190 | 2.320 | 2.296 | 1.247 | 0.009 | 1.969 | 1.273 | 2.316 |
| | Sen | 9.506 | 10.847 | -0.010 | 0.018 | -0.006 | 0.106 | 0.111 | 0.014 | 0.002 | 0.001 | 0.832 | 6.326 |

The z value at significance levels of 10%, 5%, and 1% is 1.64, 1.96, and 2.33, respectively.

**Table 4- Independent T-Test results in two station**

| Station | Parameter | t | df | Sig | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Upper | Lower |
| Idanak | $CL^-$ | -1.797 | 51 | 0.083 | -0.399 | 0.222 | -0.846 | 0.046 |
| Cham Nezam | | -4.466 | 41 | 0.000 | -2.02 | 0.45 | -2.94 | -1.11 |
| Idanak | $SO_4^{2-}$ | -0.433 | 51 | 0.667 | -0.085 | 0.196 | -0.479 | 0.309 |
| Cham Nezam | | 3.079 | 41 | 0.004 | 1.50 | 0.49 | 0.52 | 2.49 |
| Idanak | EC | -2.005 | 51 | 0.053 | -67.845 | 33.835 | -135.772 | 0.082 |
| Cham Nezam | | -2.476 | 41 | 0.037 | -38.77 | 81.51 | -203.38 | 125.84 |

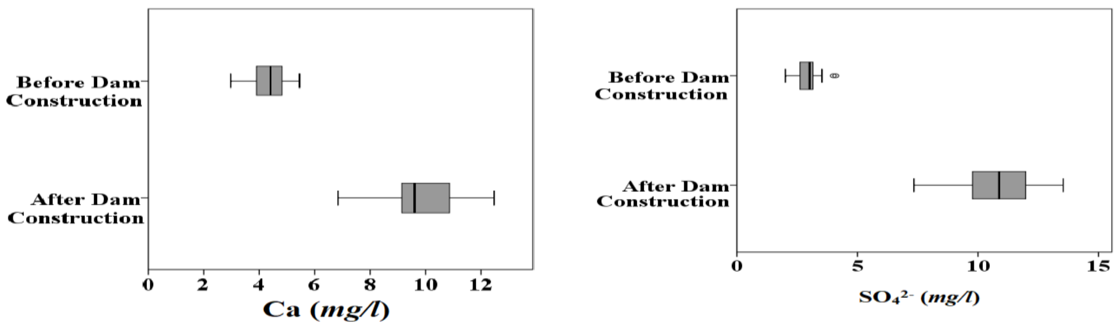


**Fig. 3- Box plot of qualitative parameters in Cham Nezam after and before the dam construction**

**Cluster analysis of qualitative parameters in Idanak and Cham Nezam stations**

The tree diagram shows the clustering process, cluster images, and their proximity with a considerable reduction of initial data dimensions. This diagram was drawn for the water quality parameters of the Idanak and Cham Nezam stations before and after the dam construction (Figs. 4 and 5). Based on Fig. (4), EC, TDS, Cl, and Na are placed in the same cluster before and after the dam construction, and their variations correspond. It is observed that the distance between $Ca^{2+}$ and $SO_4^{2-}$ is similar in both diagrams, and the ascending trend due to the $CaSO_4$ dissolution cannot be seen. $HCO_3^-$ has the farthest distance from other parameters. However, in the second diagram, after the dam construction, the increased spread of $HCO_3^-$ from 25 to 17 indicates the rising of this parameter. Generally, how the qualitative parameters are classified in this station upstream of the dam is the same as pre-and post-construction. It seems that the dam did not affect the parameters in this station.

As can be observed in Fig. (5), there is no significant difference between the two diagrams. However, the similarity of $Ca^{2+}$ and $SO_4^{2-}$ parameters is significantly increased after the dam construction (Table 5), which can be seen in the shortening of Euclidean distance along the horizontal axis of the diagram. The distance index of these parameters decreases from 5 to 2.5, indicating the increasing dissolution rate for these parameters along the river path after the dam. Results illustrate that the presence of Gachsaran formation on the way to the river and dam probably causes the dissolution of gypsum rock and increment of $Ca^{2+}$ and $SO_4^{2}$. Red circles in Fig. (6) related to post-construction have moved upward, which confirms the increased dissolution rate and concentration. Indeed, the strong correlation between these parameters (Fig. 6) authorizes the effect of gypsum dissolution from the Gachsaran formation (Mohammadian et al., 2015; Gholamhaydari et al., 2021). Parameters of $Na^+$, $Cl^-$, and EC have no significant variation.

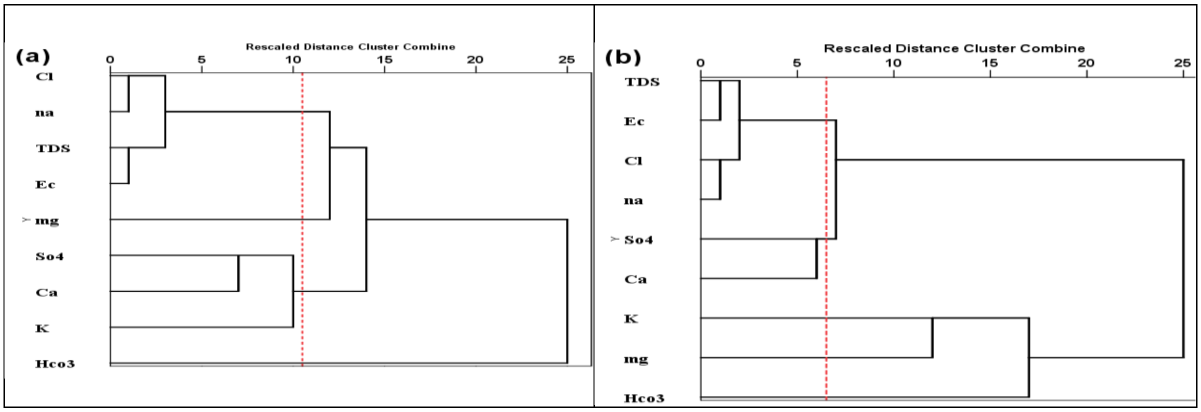


**Fig. 4- Dendrogram of Idanak station: a) pre-construction, and b) post-construction**

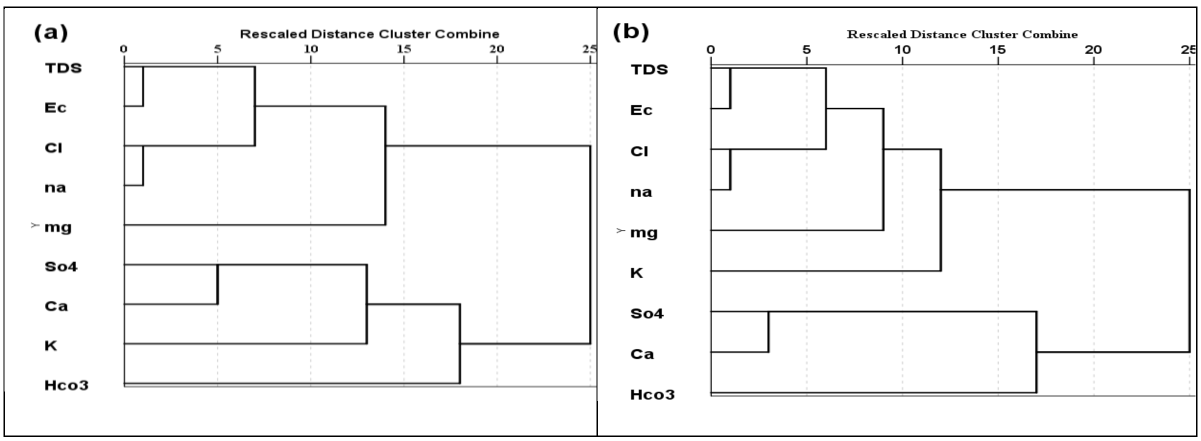


**Fig. 5- Dendrogram of Cham Nezam station: a) pre-construction, and b) post-construction**

**Table 5-levation of Ca and $SO_4$ parameters in Cham Nezam before and after the dam construction**

| Parameter | $SO_4^{2+}$ | | $Ca^{2+}$ | |
|---|---|---|---|---|
| | Before Dam | After Dam | Before Dam | After Dam |
| Mean | 9.74 | 11.61 | 8.70 | 10.89 |
| Min | 1.19 | 4.79 | 2.50 | 3.70 |
| Max | 23.28 | 21.17 | 23.65 | 17.63 |
| Variation | 22.09 | 16.38 | 21.15 | 13.93 |

 *DOI:* 10.22055/jise.2023.44439.2088

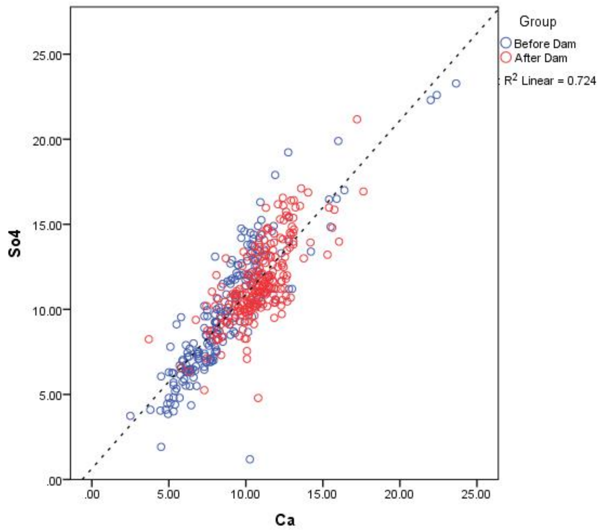


**Fig. 6- Correlation diagram between $SO_4^{2-}$ and $Ca^{2+}$ in Cham Nezam station before and after the dam construction**

**Correlation between parameters in Idanak and Cham Nezam stations**

The Pearson correlation coefficient can measure the strength of the linear relationship between parameters and determine the relationships between different elements to recognize origination and how it transfers in the medium under similar conditions. The correlation values vary between -1 and +1. Zero value shows that variables are independent (Hauke & Kossowski, 2011). According to Fig. (7a), the correlation between $Ca^{2+}$ and $SO_4^{2-}$ (at the Idanak station with r=0.64, P<0.01) is lower than at the Cham Nezam station downstream of the dam (Fig. 7b). In addition, $HCO_3^{-1}$ and K parameters have the lowest influence. Fig. (8) (for Idanak statoin) shows the linear chart between $Ca^{2+}$ and $SO_4^{2+}$ with a higher dispersion and lower r with blue color. These parameters increased in the Cham Nezam station, where their linear relationship is shown in purple (Fig. 9). Also, in the Cham Nezam station, the strong correlation between EC and primary ions, including $Na^+$ (r=0.87, p>0.01), Cl (r=0.87, p<0.01), and $SO_4^{2-}$ (r=0.71, p<0.01), indicate the outstanding contribution of each ion in the water salinity in Cham Nezam downstream of the dam. The correlation between $Cl^-$ and $Na^+$ ions (r=0.95, p<0.01) may reveal the dissolution of NaCl. Indeed the dissolution of salt formations in the water releases $Na^+$ and $Cl^-$ ions. Regarding the formations in the study area, the correlation between $Ca^{2+}$ and $SO_4^{2-}$ (r=0.85, p<0.01) may represent the dissolution of gypsum mid-layers from the Gachsaran formation. In Fig. (9), the purple line nicely shows the strong correlation and mutual effects of parameters Ca-Na and $SO_4$-Mg. $HCO_3^-$ and $K^+$ exhibit a weaker correlation than other parameters. The strong correlation between $Mg^{2+}$ and $Cl^-$ may be due to the discharge of household garbage and urban waste containing salts and detergents that they have $MgCl_2$. In addition, the moderate correlation between $Mg^{2+}$ and $SO_4^{2-}$ may be attributed to using organic and chemical fertilizers.

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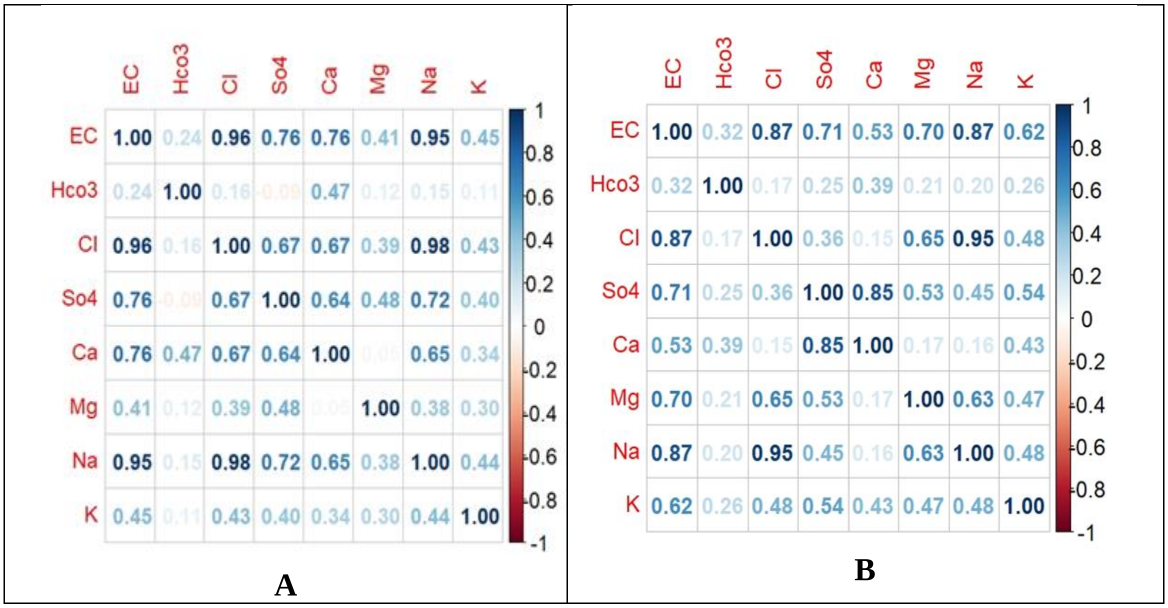



**Fig. 7- Correlation between water quality parameters: a)Idanak station, and b)Cham Nezam station**

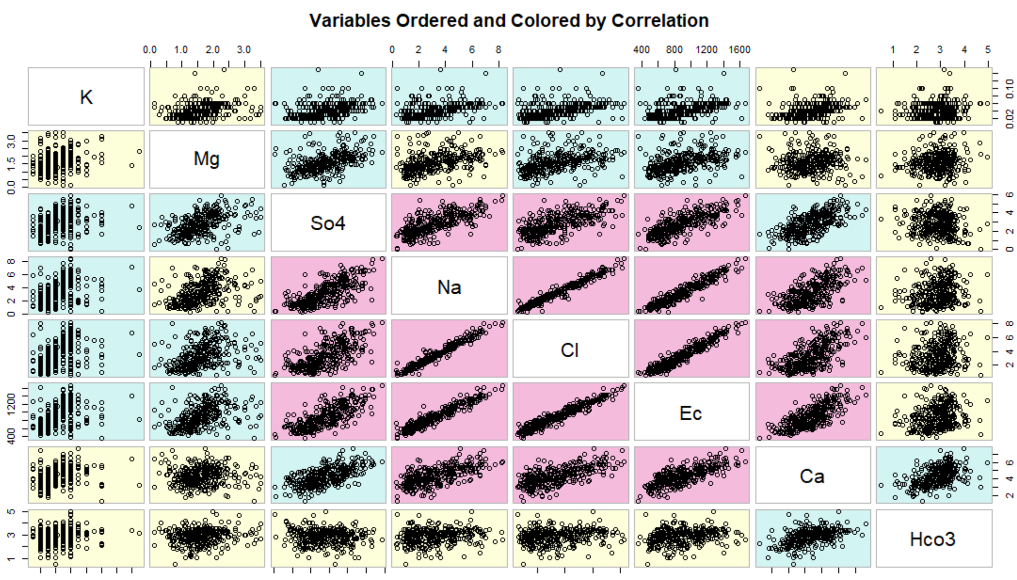



**Fig. 8- Linear relationship between qualitative parameters in Idanak station based on the correlation between parameters**

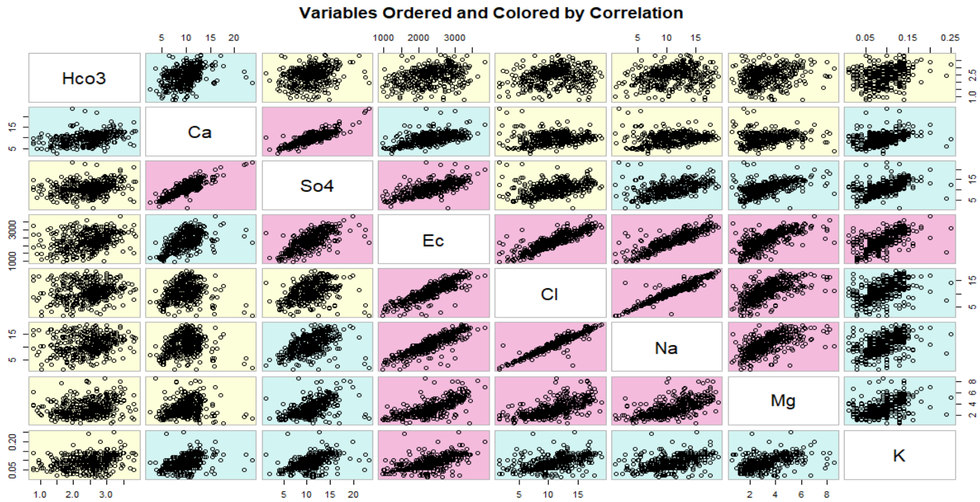



**Fig. 9- Linear relationship between qualitative parameters in Cham Nezam station based on the correlation between parameters**

**Determining the main parameters affecting water quality in two stations**

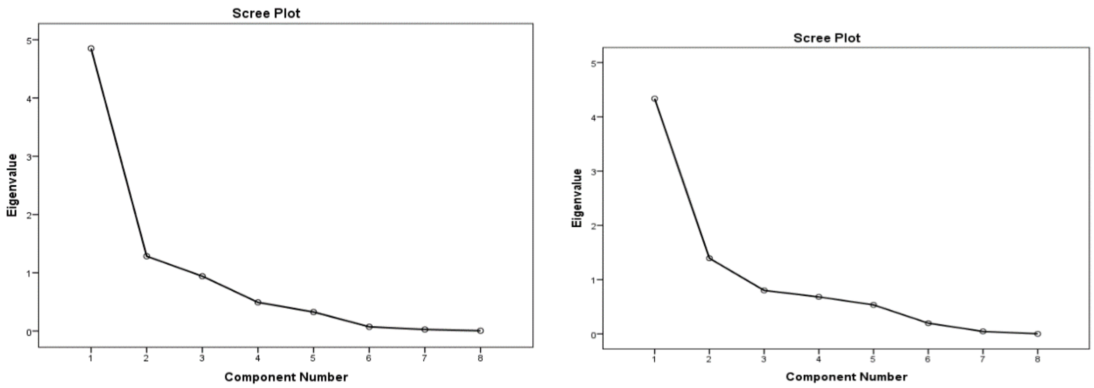
In the next stage, the FA and PCA were performed in both stations for all study years. Results showed two principal factors with total variances of 72.68% (Idanak) and 68.01 (Cham Nezam) (Table 6). The results indicate that the dam construction had affected the water quality in Cham Nezam. For determining the most influential parameters, optimal components, and the number of factors affecting the Cham Nezam water quality evaluation (before and after the dam construction), the Scree plot was produced. The Scree plot is a two-dimensional graph that can determine the contribution of each variable in total variance estimation and the optimal number of components (Fig. 10).

According to Fig. (10a), it is observed that from the third factor onward, the variation of eigenvalues becomes lower than one. Therefore, the first two factors can be derived as the principal factors with the highest contribution to the data variance estimation and can be introduced as the most influential factors in the period before the dam construction. Principal component analysis results in three components with a total variance of 84% (Table 7). Values higher than 0.75% are assumed as strong factor loading, between 0.5 and 0.75 as moderate factor loading, and between 0.3 and 0.5 as weak factor loading (Liu et al., 2003). The first factor contributing 45% of the variance and high factor loading of parameters TDS, EC, $Cl^-$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, and $Na^+$ introduces the natural flows and wastewater from the agriculture sector. This factor is attributed to different geochemical processes (dissolution, sedimentation, and ion exchange) because most anions and cations have high factor loading. Naturally, these elements in surface waters originate from geologic and sedimentation effects in groundwater and surface water flows and local geographical conditions (Menció and Mas-Pla, 2008; Hamil et al., 2018). The third factor has a factor loading of 0.5 exclusively for $Ca^{2+}$ and $SO_4^{2-}$ parameters, which is a moderate factor loading and should be compared with the value after the dam construction (Table 7). After the dam construction, two principal components are selected according to the Scree plot (Fig. 10b). The first component contributes 60% of the total variance and the high factor loading in most primary anions and cations. It also mentions the effects of natural flows (Table 7). The second component contributing to 24% of the total variance demonstrates the effects of $Ca^{2+}$ and $SO_4^{2-}$ with high factor loading. The factor loading of Ca and $SO_4$ in the first component is lower than before the dam construction (Table 7).

Spatial analysis of Idanak and Cham Nezam upstream and downstream of the dam was performed using biplots, which are two-dimensional graphs of the set of components of the first factor (F1) on the second factor (F2). The position of each ion point indicates the ion-increasing direction in samples, and the closeness of each engagement to the factor axis shows the level of correlation between the ion and that factor. In the Idanak station, EC, TDS, $Na^+$, and $Cl^-$ parameters are positioned near the horizontal axis (first factor), indicating the significant influence of these parameters on the first factor (Fig. 11a). In addition, compared to Cham Nezam, the distance between $Ca^{2+}$ and $SO_4^{2-}$ in Idanak shows the close correlation of these parameters and an increase in their concentrations downstream of the dam. As shown in Fig. 11b, $K^+$ and $HCO_3^-$ parameters are placed close in Cham Nezam. This situation, which is not seen in Idanak (upstream of the dam), implies the effects of agricultural drainages and associated pollution in the Maroon river and represents the effects of expanding agricultural lands downstream of the dam. With regard to the dissolution of bedrock and formations in the area affected by the dam, it is observed that EC and TDS are not merely susceptible to $Na^+$ and $Cl^-$. In Cham Nezam, increasing the distance between the points associated with these two parameters and the horizontal axis (first factor) reveals the contribution of other ions, such as $SO_4^{2-}$, $Ca^{2+}$, and $K^-$, to the TDS value. When points are placed in opposite directions against each other denotes the inverse correlation. As shown in Fig. (11a), the ends of pH and $HCO_3^-$ are positioned against each other, meaning that $HCO_3^-$ with positive factor loading in the proximity of the vertical axis (Second component) has placed against pH with negative factor loading (the lower part of diagram denote negative values). This situation shows that $HCO_3^-$ does not affect pH, which is justifiable concerning the type of water upstream of the Maroon River (i.e., $CaCL_2$ type). However, after the dam construction, the increasing value of $HCO_3^-$ and pH variation toward being alkaline in the Cham Nezam diagram, as well as going far away from the vertical axis (second factor) and decreasing distance with water-soluble elements indicate the susceptibility of this parameter than the pre-construction conditions.

**Table 6- Main factors in Idanak and Cham Nezam stations**

| Idanak | | | Cham Nezam | | |
|---|---|---|---|---|---|
| Parameter | PC1 | PC2 | Parameter | PC | PC2 |
| TDS | 0.949 | 0.221 | TDS | 0.794 | 0.499 |
| EC | 0.948 | 0.247 | EC | 0.888 | 0.388 |
| pH | -0.029 | -0.831 | pH | 0.259 | -0.600 |
| $HCO_3^-$ | 0.035 | 0.865 | $HCO_3^-$ | 0.379 | 0.435 |
| $Cl^-$ | 0.924 | 0.197 | $Cl^-$ | 0.925 | -0.011 |
| $SO_4^{2-}$ | 0.872 | -0.095 | $SO_4^{2-}$ | 0.491 | 0.702 |
| $Ca^{2+}$ | 0.662 | 0.568 | $Ca^{2+}$ | 0.149 | 0.899 |
| $Mg^{2+}$ | 0.527 | -0.127 | $Mg^{2+}$ | 0.704 | 0.024 |
| $Na^+$ | 0.932 | 0.170 | $Na^+$ | 0.915 | 0.061 |
| $K^+$ | 0.547 | 0.047 | $K^+$ | 0.508 | 0.457 |
| Eigenvalues | 5.301 | 1.967 | Eigenvalues | 4.339 | 2.462 |
| Variance % | 53.009 | 19.673 | Variance % | 43.388 | 24.627 |
| Cumulative % | 53.009 | 72.681 | Cumulative % | 43.338 | 68.009 |




a b

**Fig. 10- Scree plot for determining the number of principal factors in Cham Nezam: a) pre-construction, and b) post-construction**

**Table 7- Main factors in Cham Nezam before and after the dam construction**

| Before Dam | | | | After Dam | | |
|---|---|---|---|---|---|---|
| Parameter | PC1 | PC2 | PC3 | Parameter | PC1 | PC2 |
| TDS | 0.98 | 0.011 | 0.051 | EC | 0.803 | 0.529 |
| EC | 0.979 | 0.079 | -0.038 | $HCO_3^-$ | 0.372 | 0.428 |
| $HCO_3^-$ | 0.267 | -0.632 | -0.53 | $Cl^-$ | 0.935 | 0.123 |
| $Cl^-$ | 0.875 | 0.303 | -0.305 | $SO_4^{2-}$ | 0.307 | 0.839 |
| $SO_4^{2-}$ | 0.808 | -0.273 | 0.463 | $Ca^{2+}$ | -0.057 | 0.949 |
| pH | 0.015 | 0.774 | 0.355 | $Mg^{2+}$ | 0.709 | 0.144 |
| $Ca^{2+}$ | 0.634 | -0.513 | 0.54 | $Na^+$ | 0.900 | 0.212 |
| $Mg^{2+}$ | 0.831 | 0.191 | -0.133 | $K^+$ | 0.385 | 0.607 |
| $Na^+$ | 0.877 | 0.276 | -0.297 | $Ca^{2+}$ | 0.803 | 0.529 |
| $K^+$ | 0.735 | -0.07 | 0.062 | HCO3 | 0.372 | 0.428 |
| Eigenvalues | 4.557 | 2.487 | 1.436 | Eigenvalues | 3.216 | 2.515 |
| Variance % | 45.568 | 24.875 | 14.361 | Variance % | 60.197 | 11.436 |
| Cumulative % | 45.568 | 70.443 | 84.804 | Cumulative % | 60.197 | 71.633 |

a b

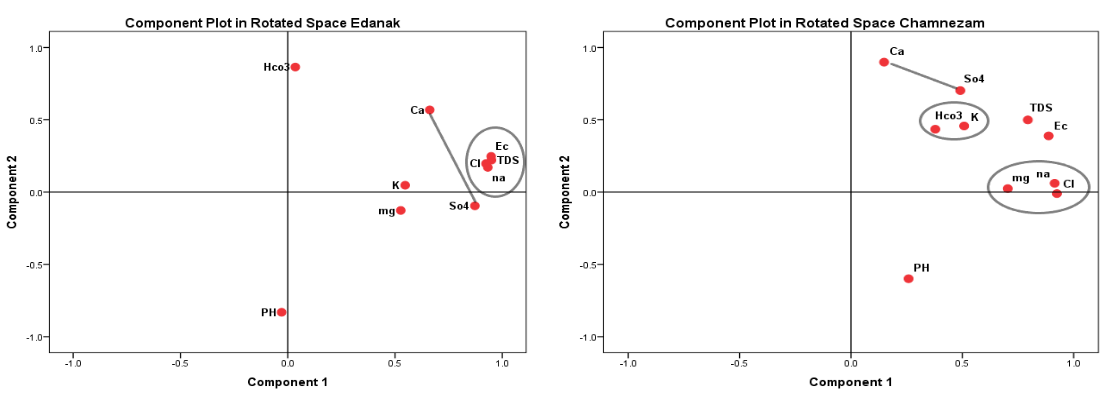



**Fig. 11- Biplot obtained from factor analysis: a) Idanak, and b) Cham Nezam station**

**Evaluating the suitability of water quality for agricultural and drinking use in both stations**

Finally, the water quality was examined in both stations before and after the dam construction for agricultural and drinking use. Wilcox classification shows that the water quality has no change after the dam construction for agricultural purposes and is still classified as C3S1. However, the EC has increased. Based on the Wilcox index, the agricultural water quality in Cham Nezam is often classified as C3S1 and C3S2 before and after the dam construction.

Schoeller index, as an index for potable water quality, was examined. After the dam construction, the water quality in terms of drinking use is suitable to acceptable in Idanak. However, water TDS increases to the medium range after the dam construction. In Cham Nezam, the water is in the acceptable range for drinking.

## Conclusion

Water quality data (1981-2018) was studied to investigate the effect of the Maroon Dam construction on river water quality upstream (Idanak station) and downstream (Cham Nezam station) of the dam. Over these years, the river's flow rate has reduced in two stations, and the EC has increased. Downstream of the dam, $Ca^{2+}$, total hardness, and CaSO4 significantly have increased at a 5% significance level. The cluster analysis reveals the increased dissolution rate of $Ca^{2+}$ and $SO_4^{2-}$ along the river after the dam construction. The authors believe that the gypsum rock is dissolved from the Gachsaran formation along the river and dam, so this causes increases in the $Ca^{2+}$ and $SO_4^{2-}$ concentrations downstream. The CA shows EC, TDS, $Cl^-$, and $Na^+$ are placed in the same group in the Idanak station before and after the dam construction. Cluster analysis reveals that upstream regions may not be affected by the dam construction.

Downstream of the dam, there is a strong correlation between EC and some ions ($Na^+$, $Cl^-$, and $SO_4^{2-}$), indicating each ion's high contribution to Cham Nezam water salinity. In the Cham Nezam station (downstream), the correlation between $Cl^-$ and Na ions can signify NaCl dissolution. The correlation between $Ca^{2+}$ and $SO_4^{2-}$ can demonstrate the effect of the dissolution of gypsum mid-layers from the Gachsaran formation after the dam construction. The discharge of household garbage and urban wastes containing salts and detergents (including $MgCl_2$) is the main reason for the highly-correlated $Mg^{2+}$ and $Cl^-$ in Cham Nezam. In addition, the moderate correlation between $Mg^{2+}$ and $SO_4^{2-}$ can be related to using organic and chemical fertilizers. The dam construction has no statistically significant effect on Schoeller and Wilcox indices.

## Acknowledgments

We thank the Research Council of Shahid Chamran University of Ahvaz for financial support (GN.SCU.WE99/3/02/87709).

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