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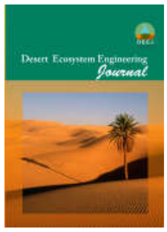

Assessment of Surface Water Quality in the Vanak-Soolegan Basin, Western Iran

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Abstract

As monitoring and assessment of water quality are assumed as important factors in the improvement of the communities' sanitary status the in 21st century, optimal management of freshwater resources should be taken as an integral part of d. evelopment programs worldwide. The main objective of the current study was, therefore, to assess the characteristics of surface water quality in the Vanak-Soolegan basin and to identify its long-term trend of variations, using graphical methods. To this end, the required data were collected from three hydrometric stations (Soolegan, Tagarg-ab, and Tange Zardaloo). Then, for a better understanding of water quality, the data were analyzed based on 11 different parameters including Electrical Conductivity (Ec), Total Dissolved Solids (TDS), Acidity (pH), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Bicarbonate (Hco3), Carbonate (Co3), Chlorine (CL) and Sulphate (So4). Assessment of water quality was also performed by drawing Schoeller, Piper and Wilcox diagrams. As revealed by the Piper diagram, the dominant water type was calcium-bicarbonate. The results of the Schoeller-diagram demonstration showed that the water samples fell in potable and acceptable class and that based on the Wilcox Diagram, the majority of samples were classified into low salinity class (c2s1) which is suitable for farming. Moreover, the trend analysis of selected parameters was performed via the Mann–Kendall test on a 18-year period (from 1995 to 2012). The results indicated a positive trend in Ec, T.D.S, Ca, K, and So4 at the Soolegan and Tagarg-ab stations. In general, it seems that several factors are involved in water quality changes including the weathering of the hard rocks, lithology, drought, and increase in water consumption.

Keywords: Mann-Kendall, Trend Analysis, Vanak-Soolegan Basin, Water Quality.

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1. Introduction

Over the past few decades, growing demands for freshwater have been made due to agricultural development activities, rapid urbanization, and population growth all over the world, particularly in developing countries such as Iran. Surface water is regarded as one of the most significant resources for drinking and irrigation purposes. The physical and chemical properties of surface water have both direct and indirect effects on human health. According to the WHO organization, about 80% of all diseases in human beings are caused by unsuitable water (Ramakrishnaiah et al., 2009). Each freshwater body has its own distinct pattern of physical and chemical characteristics which are largely determined by prevalent climatic, geomorphological, and geochemical conditions in the drainage basin and underlying aquifer (UNESCO/WHO/UNEP, 1996). The water quality index is considered by managers and policymakers in different nations as one of the most effective tools for understanding the status of water quality (Ramakrishnaiah et al., 2009). Taking water chemical properties into consideration, determination of surface water quality would be very helpful in designing and performing irrigation systems, playing a significant role in drinking water supply, fish production, and many other purposes (Prasad et al., 2013; Moshood Keke, 2008; Bouza-Deano et al., 2008; Zang et al., 2012; Gharibi et al., 2012). Miyittah et al. (2020) has assessed the surface water quality of the lagoon system in the western region of Ghana, recommending monitoring programs to be instituted and implemented together with effective management measures for the sustainability of the lagoon and the Tano River Basin.

Classification of water quality is the most remarkable step in surface water quality assessment which is accomplished for different purposes including drinking water, industrial and agricultural usages. In this regard, water quality standards such as Wilcox and Schoeller diagrams were generated and defined in this study for drinking and irrigation.

To better understand the behavior of surface water quality, a trend analysis could be useful in analyzing water quality time series which are measured in rivers. Trend analysis is commonly used for detecting changes in climatic and hydrologic time series. Two groups of mathematical tools can be distinguished in trend variations: parametric and non-parametric methods. The parametric method is mainly based on linear and residual models; however, there are also several non-parametric methods to assess the significance of trends in time series (Bouza-Deano et al., 2008), many of which are based on the Mann–Kendall's Test (Mann, 1945: Kendal, 1975).

A review of non-parametric tests indicated that the Mann-Whitney, Spearman, and Kendall are the best choices for trend detection in water quality time series (Berryman et al., 1988). One of the main advantages of Mann–Kendall's Test in hydrology sciences is that it could be used for detecting any increase or decrease in the trend of water quality data (Bouza-Deano et al., 2008). As found by recent studies, the Mann Kendall test could be used for trend analysis of both annual and seasonal hydro-meteorological data (Nyikadzino et al. 2020).

Monitoring the water quality data and making decisions based on that is quite challenging; however, attempts have been made to define water quality index through different parameters (Parmar and Parmar, 2010).

The Vanak-Soolegan basin is considered as the main base for agriculture and animal husbandry in Iranian provinces of Chaharmahal and Bakhtiari and Isfahan. As the water quality directly influences the human and ecosystem health, this research sought to evaluate the quality of surface water used for drinking and agriculture purposes in the Vanak-Soolegan basin. To this end, chemical components of surface water were analyzed and trend analysis was carried out, using the Mann-Kendall test to detect changes in quality characteristics.

2. Material and Methods

2.1. The Study area

Vanak_Solegan River basin is located in Isfahan and Chahar_Mahal and Bakhtiari provinces, east of Zagros Mountains, Iran, at longitude 49° 30′-53° 30′ E and latitude 31° 30′-33° N. The river starts from the northern Esfahan called Semirom and moves forward southward towards Borojen and Gandoman in Chaharmahal and Bakhtiari province, flowing into Karoon River, and is thus regarded as a Sub-basin of Karoon River. covered by semi-dense forests and limy and marly soils, the basin under study is approximately 3500 km2 and its annual discharge volume is about 36.3m3/s. The mean rainfall of the basin is about 600mm, which is a considerable amount in Iran. In this study area, a new dam is going to be constructed for industrial, drinking, and agricultural purposed. In the present study, three hydrometric stations were selected. The sampling stations included Soolegan (station 1), Tagarg-ab (station 2), and Tange Zardaloo (station 3). Figure (1) displays the spatial distribution of stations that were used for analysis.

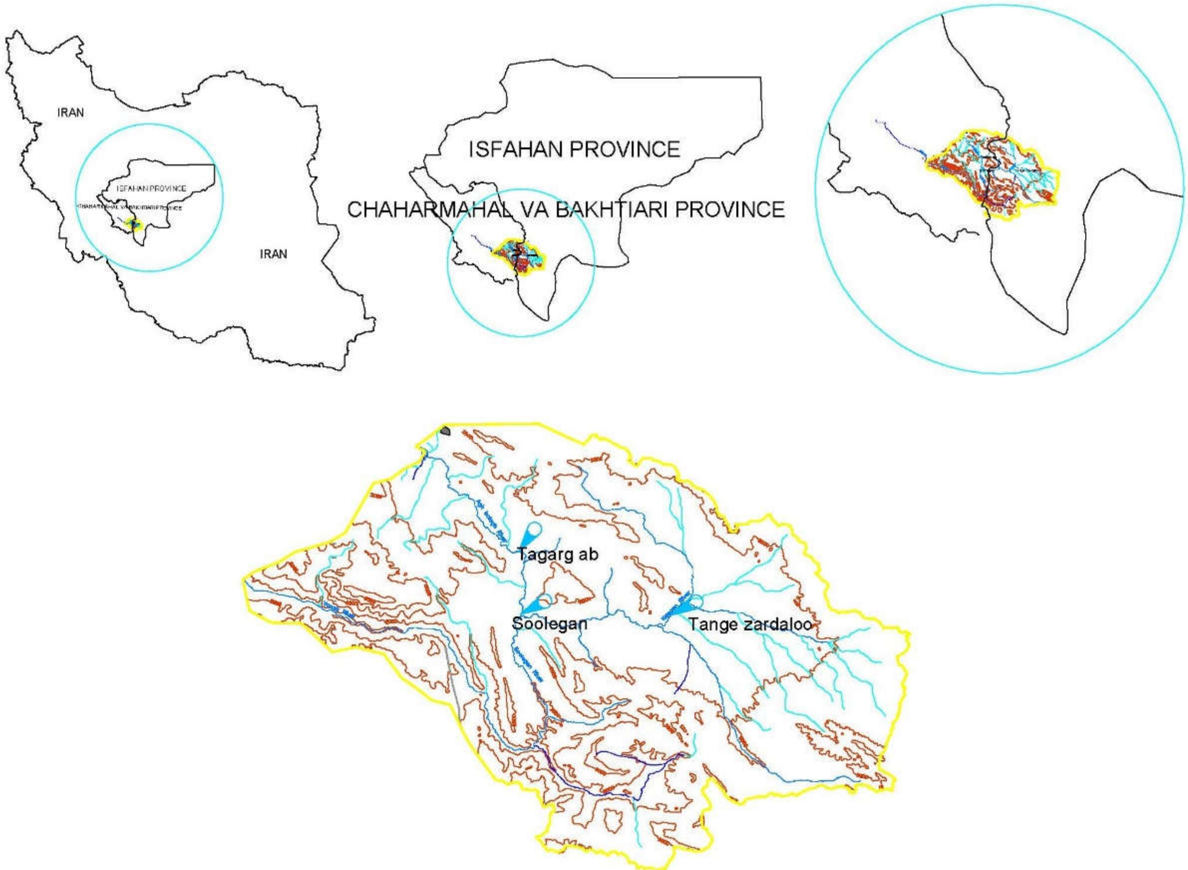

Figure (1): Location of basin and sampling stations in Iran

2.2. Methodology

The evaluation of water quality is mostly carried out based on hydrochemical analysis. In this regard, the required data were collected from the Iranian Water Resources Management Corporation database. In Iran, the classification of rivers is generally implemented based on National Sanitation

Foundation Water Quality Index (NSFWQI) by the Iranian Department of Environment (IRDOE).

To determine the water quality of the Vanak-Soolegan basin of Iran, the variations of Physico-chemical properties were investigated for a 18-year period (1995-2012). Tables (1), (2) and (3) show the chemical factors of the Vanak-Soolegan basin for Tange Zardaloo, Soolegan, and Tagarg-ab stations, respectively. The chemical parameters regarding water quality that were evaluated in this study included electrical conductivity (Ec), total dissolved solids (TDS), Acidity (pH), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Bicarbonate (Hco3), Carbonate (Co3), Chlorine (CL), and Sulphate (So4).

Table (1): The Chemical factors of Tange Zardaloo

Parameter	EC	T.D.S	pH	Ca	Mg	Na	K	HCO3	CO3	Cl	SO4
Number of samples (yearly)	18	18	18	18	18	18	18	18	18	18	18
Annual Average	459.2	276.8	7.8	2.7	1.6	0.64	0.03	3.64	0.02	0.69	0.64
Annual Maximum	522.9	298	8.27	2.94	1.85	1.03	0.14	4.49	0.14	0.93	1.08
Annual Minimum	404	262.8	7.46	2.27	0.98	0.38	0	2.73	0	0.55	0.34

*Chemical parameters described in meq/lit

Table (2): The Chemical factors of Soolegan

Parameter	EC	T.D.S	PH	Ca	Mg	Na	K	HCO3	CO3	Cl	SO4
Number of samples (yearly)	18	18	18	18	18	18	18	18	18	18	18
Annual Average	463.58	301.29	7.98	2.79	1.6	0.35	0.02	3.93	0.02	0.45	0.34
Annual Maximum	509.18	330.82	8.16	3.24	1.88	0.44	0.03	4.35	0.08	0.58	0.63
Annual Minimum	404.18	262.82	7.81	2.15	1.44	0.24	0.02	3.32	0	0.35	0.16

*Chemical parameters described in meq/lit

Table (3): The Chemical factors of Tagar-ab

Parameter	EC	T.D.S	PH	Ca	Mg	Na	K	HCO3	CO3	Cl	SO4
Number of samples (yearly)	18	18	18	18	18	18	18	18	18	18	18
Annual Average	486.76	316.33	7.97	2.99	1.69	0.3	0.02	4.1	0.01	0.41	0.44
Annual Maximum	523.58	340.33	8.14	3.54	2.2	0.4	0.03	4.57	0.07	0.55	0.88
Annual Minimum	447	290.57	7.81	2.42	1.35	0.22	0.02	3.76	0	0.33	0.19

*Chemical parameters described in meq/lit

Having processed the collected data, the "Chemistry software" which is designed based on the requirements of Water Resources (Atlas of studies and guidelines of the Iranian Ministry of Energy) was used for water classification. The results of the water quality assessment are displayed in Schoeller, Piper and Wilcox diagrams. The Schoeller diagram was also used to evaluate the potential of drinking water.

The Piper diagram is a commonly used method for determining the chemical type of water (Piper, 1944). Moreover, according to the Piper diagram, six water types are detectable:

Ca-HCo3, Na-Cl, Ca-Mg-Cl, Ca-Na-HCo3, Ca-Cl Na-HCo3 (Sajil Kumar, 2013).

Designed based on the values of electrical conductivity (EC) and sodium absorption ratio (SAR), the Willcox diagram is typically used for representing the classification of water consumed for agricultural purposes. From among 16 classes identified in this regard, C1S1 (the lowest SAR and EC) which shows the minimum salinity and alkalinity is considered as the best class, and C4S4 (salinity and alkalinity levels were too high) is regarded as the worst one. On the other hand, sodium adsorption ratio represents the losses caused by sodium. Accordingly, high production of alkaline in the soil and eventually reduction of soil permeability could be obtained based on the following formula:

$$SAR = \frac{Na}{\sqrt{Ca+Mg}} \qquad (1)$$

Where SAR stands for sodium adsorption ratio, Na represents sodium ions, Mg shows magnesium ions, and Ca stands for calcium ions. As for the trend analysis, the Mann_Kendall test was used to identify water quality changes from 1995 to 2012.

3. Results

In this study, Wilcox test was administered for the classification of water which used for agricultural and irrigation purposes. Wilcox diagram classifies the samples in 16 different classes based on two factors (SAR, EC). Among these 16 classes, the best class is known as C1S1 (the lowest SAR, EC) which shows the minimum salinity and alkalinity, and the worst class is C4S4 (salinity and alkalinity levels were too high). Sodium adsorption ratio Wilcox diagram also represents the losses caused by sodium. Accordingly, High production of alkaline in the soil and eventually reduction of soil permeability could be obtained from the following formula:

$$SAR = \frac{Na}{\sqrt{Ca+Mg}} \qquad (2)$$

Where SAR stands for sodium adsorption ratio, Na stands for sodium ions, Mg represents magnesium ions, and Ca shows the calcium ions. Figure 2 displays the Wilcox diagram for Tange Zardaloo, Soolegan, and Tagar_ab stations. As found by the results, the quality of the water used for agricultural purposes was classified within the C2-S1 class.

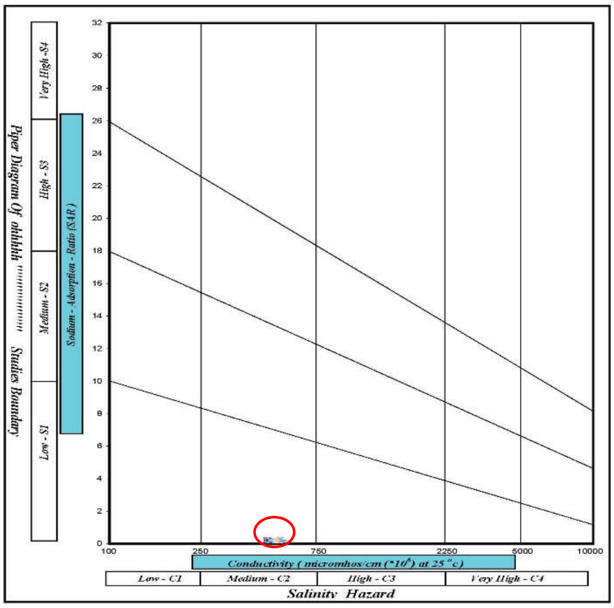

Figure (2): Wilcox diagram for Tange zardaloo, Soolegan and Tagarg-ab stations

This classification proved that the water was appropriate for agriculture. Table (4) shows the average values for SAR and EC in all 18 samples collected.

Table (4): Average value of SAR and EC and the class of water quality by Wilcox

Station	EC*	SAR	Class of water quality
Tange zardaloo	459.2	0.44	A little salty, appropriate for agriculture.
Soolegan	463.6	0.24	A little salty, appropriate for agriculture.
Tagarg-ab	486.8	0.20	A little salty, appropriate for agriculture.

*Unit of EC is µmhos/cm

The concentration of calcium carbonate as the remaining of carbonate and bicarbonate ions was calculated and the RSC was obtained through the following equation:

$$RSC= (HCO3\times CO3)-(Ca\times Mg) \quad (3)$$

Parameters in the above equation were described in meq/lit. Table (5) shows the extent of sodium carbonate remaining and the sodium percentage in irrigation water. As could be seen in the table, the class of water quality according to Na% is excellent in all stations and is appropriate based on RSC.

Table (5): The class of water quality according to RSC and Na% of water

Station	Na%	RSC	Class of water quality according to Na%	Class of water quality according to RSC
Tange Zardaloo	13.4	-0.61	Excellent	Appropriate
Soolegan	6.6	-0.45	Excellent	Appropriate
Tagarg-ab	7.8	-0.56	Excellent	Appropriate

Moreover, the classification of water quality was carried out based on the total hardness stone flooring, using the Chemistry software. Table (6) shows the softness or hardness of various classes of water (Agresti, 2002). According to the findings of the study, water quality status is very hard in all three stations. The results are presented in Table 7.

Table (6): Levels of water hardness

Station	Total hardness (mg/lit)	Temporary Hardness (mg/lit)	quality status
Tange Zardaloo	212.2	212.24	Very Hard
Soolegan	218.6	218.6	Very Hard
Tagarg-ab	232.5	232.51	Very Hard

Table (7): Water quality status according to its hardness

Hardness(mg/lit)	Quality status
0-50	Soft
51-120	Average
121-180	Hard
More than 180	Very Hard

Based on the ratio of CA/Mg reagent, reservoir rock seems to be dolomitic limestone, and concerning the ratio of Na/Ca, igneous rock is predicted to be alkaline basaltic - feldspar.

As previously mentioned, the Piper diagram was used in the current study to identify the water type and its facies, the results of which revealed that the surface water quality of the Kaskan River in Tange zardaloo station was bicarbonate type, and that its facies was made of calcic. Moreover, the water type and facies in Soolegan and Tagarg ab stations were the same as the previous one. Figure 3 shows the Piper diagram.

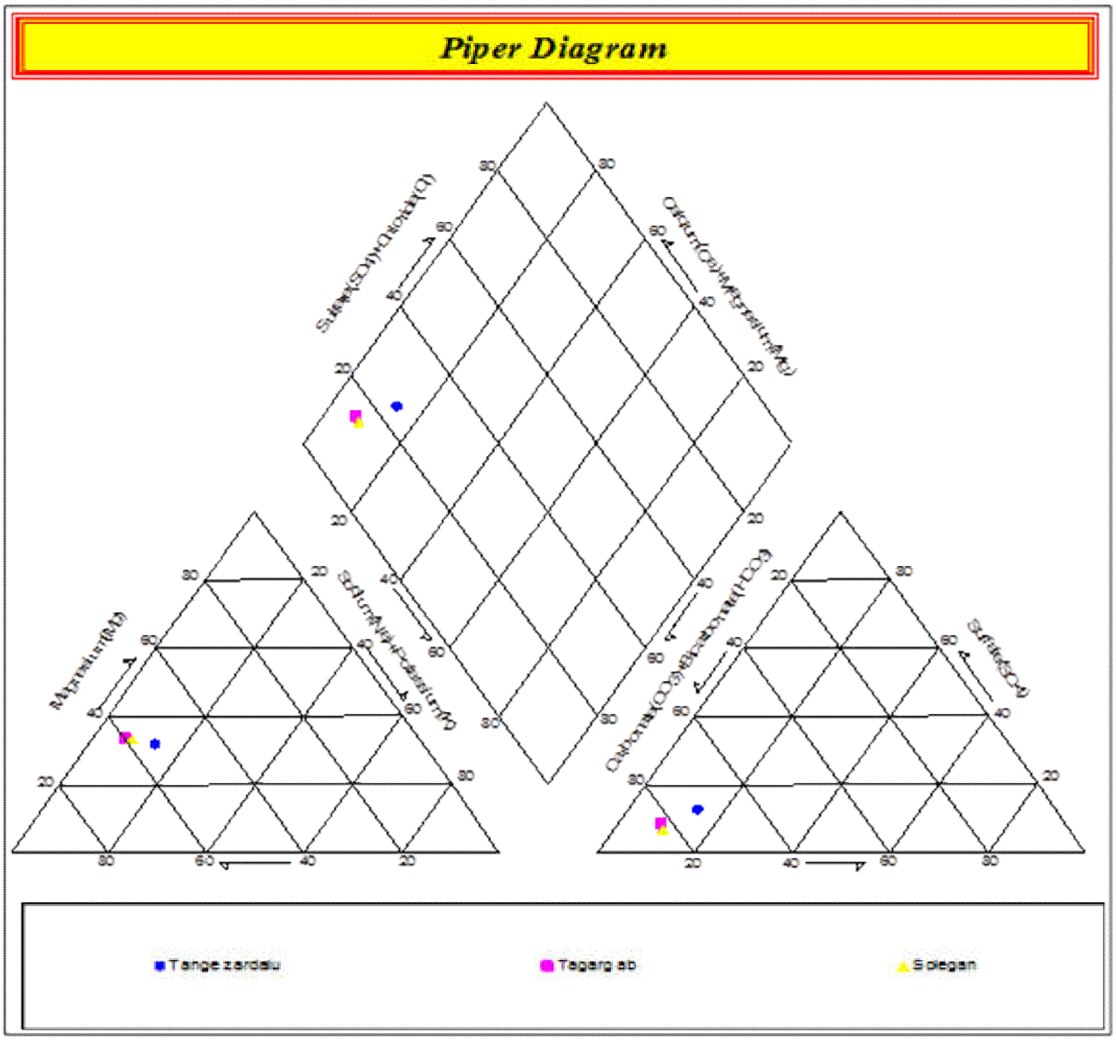

Figure (3): Average analyses by Piper diagram

Drinking water is expected to have the appropriate quality in different aspects that could be examined in terms of all physical, chemical, toxic, bacteriological, and radiological features. One of the ways of classifying water for human drinking is the application of the Schoeller Diagram. Figure 4 displays the Schoeller diagram based on chemical constituents' statistics of water for the three stations mentioned according to which, the drinking water quality was found to be good in all stations of the basin.

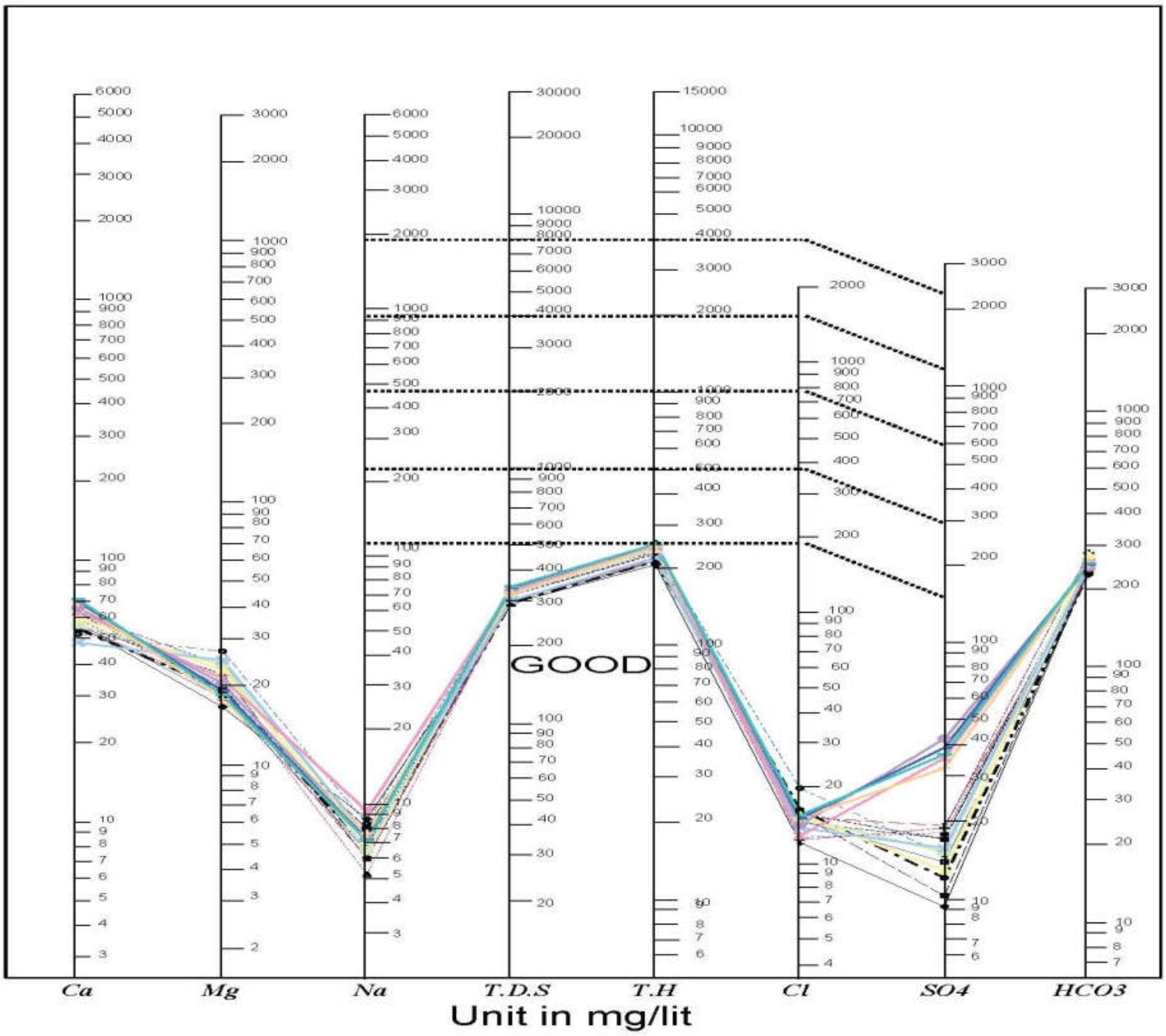

Figure (4): Schoeller diagram regarding the drinking water quality

3.1. Trend analysis

The Mann-Kendall analysis is a non-parametric statistical procedure that is used for analyzing trends of data over time (Gilbert, 1987). The results of the trend analysis in three stations of the Vanak-Soolegan basin are presented in table 8. The trend analysis of the parameters indicated that Ec, T.D.S, Ca2+, K+, HCo3- and So42- value had increased at Soolegan station while its pH and Co32 values had decreased over time. The results of the trend analysis in Tagarg-ab station showed a significant increase in Ec, T.D.S, Ca, K, and So4 parameters, and a negative trend was detected in pH and Co3 parameters. Furthermore, it appears that the acidity of water in this station had been raised. In Tange Zardaloo station, the results of trend analysis indicated a significant increase in Ec and Cl while no change was detected in other parameters.

Table (8): Trend analysis of water quality parameters

Parameter	Soolegan Station		Tagarg ab Station		Tange Zardaloo Station	
	Trend	Z	Trend	Z	Trend	Z
Ec	Increasing	3.94	Increasing	3.33	Increasing	2.12
T.D.S	Increasing	4.02	Increasing	3.33	No Trend	0.23
pH	Decreasing	-3.64	Decreasing	-3.98	No Trend	0.15
Ca	Increasing	3.48	Increasing	2.8	No Trend	1.67
Mg	No Trend	0.45	No Trend	0.83	No Trend	0.87
Na	No Trend	-0.38	No Trend	0.68	No Trend	0.15
K	Increasing	2.92	Increasing	2.27	No Trend	-0.8
Hco3	Increasing	3.18	No Trend	1.52	No Trend	1.67
Co3	Decreasing	-3.71	Decreasing	-4.43	No Trend	1.02
Cl	No Trend	-0.27	No trend	00	Increasing	2.08
So4	Increasing	2.73	Increasing	3.26	No Trend	-1.74

The direction of Z indicates the direction of the trend. A positive (negative) value of Z indicates an upward (downward) trend.

4. Conclusions

Monitoring water-quality at Vanak-Soolegan was conducted during a 18-year period (1995-2012). As a dam is to be constructed in the study area, the analysis of the area's water quality is highly important. In this study, the data which had been collected from hydrometric stations were controlled, and the missing data were predicted by the regression method. The Water quality was then analyzed for drinking and agricultural purposes. Based on the Wilcox diagram the water quality was categorized as a C2-S1 class for agriculture and irrigation. This class describes the status of a little salty, but appropriate for agricultural use. According to the Schoeller diagram, water quality is also good for drinking purposes. However, having used the Chemistry software, the quality status of the water was identified as being very hard.

To conduct the trend analysis of water quality for a 18-year period (1995–2012), the Mann–Kendall Test was administered. The results of the test revealed similar changes for The Soolegan and Tagarg-ab stations in that period, and a positive trend in Ec, T.D.S, Ca, K, and So4. As surface water plays a very significant role in supplying water resources, these results could be beneficial to water resources management in the Vanak-Soolegan basin. It seems that the lithology of the formations of the river basin is an important factor in water quality changes. On one hand, the major origins of K, Ca, and Mg ions are carbonate minerals and silicate derived from the weathering of the hard rocks in the basin. On the other hand, it may be assumed that the recent drought has affected the water consumption and subsequently the water quality in the study area. For a better understanding of this procedure, further investigation is needed. Moreover, it is highly recommended that future studies dedicate specific efforts to explore the role of pollution and its effects in that regard.

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