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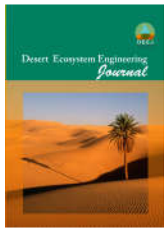

The qualitative and quantitative trend analysis of groundwater in Jiroft plain using Modified Mann-Kendall Test

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Abstract

As a dry province in the center of Iran, Kerman has faced a major groundwater depression over the past few years. Reduced groundwater levels in this region have created myriad problems in the agricultural sector, particularly in the southern and southeastern areas with relatively warmer weather. In this research, the temporal and spatial trends and change-point time of quantitative and qualitative variables of groundwater (EC, pH, Na, Ca, Mg, Cl, SO4, HCO3, TDS and groundwater) in Jiroft plain were investigated during 2002-2015. The results revealed that, on average, the water level of the studied plain was significantly reduced by approximately 8 meters during the statistical period at a significant level of 5%. The central areas of the plain were reduced. A year after the change-point of groundwater data, a significant increase was observed in the qualitative data in the region. The highest increase in groundwater salinity was also found in the main river route, indicating a reduction in surface water discharge in the aquifer. During the specified period, the amounts of Ca, EC, Cl, SO4, Mg and Na in the studied plain increased (decreased) by an average 27, 18, 40, 0.4, (-24) and (-2.3) %, respectively. In 2007, the decline trend of groundwater levels in Jiroft plain was, on average, significant and failure was observed in the data. Finally, the groundwater quality in Jiroft plain was investigated using the Wilcox diagram, which showed that agricultural water in certain areas with C2-S1 classes was acceptable.

Keywords: Mann-Kendall, Standard Normal Homogeneity Test, trend change time, water quality, Wilcox digram.

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1. Introduction

The main purpose of the time series analysis is to identify, describe and quantify the time series components for a set of consecutive data (Shahin et al., 1993). Hydrological time series analysis is carried out to pursue different goals, the most important of which is to identify the trend of hydrological variables. Temporal analyses are often performed on data collected from individual wells using methods such as the (seasonal) Mann-Kendall test for determining trends (Donohue et al. 2001) or a Student's t-test when testing the significance of the change in water quality between different periods (Harris et al. 1987). Although several researchers have proposed different methods for assessing the regional consistency between trends observed in different sampling points (Dennis et al. (2006); Van Belle and Hughes (1984)), a real integrated spatiotemporal (ST-) modeling of groundwater quality data is rarely conducted.

Various studies have been performed on the groundwater quality changes in Iran and different parts of the world. According to these studies, the most prevalent and optimal approach to analyzing the temporal datasets is the Mann–Kendall test (Mann 1945; Kendall 1975; Duhan and Pandey 2013). This method is a statistics-based distribution-free test explored by numerous researchers concerning the trend analysis of groundwater and other hydrological data (Tabari et al. 2012; Sivapragasam et al., 2015). For instance, Panda et al. (2007) studied the repeated droughts which impact the effect of anthropogenic events on the groundwater level. The results of trend analysis showed that there was a seasonal spatial difference affecting the landscape and aquifer properties. The investigation of time-based trends for annual and seasonal groundwater level has revealed a mixture between upward (positive) and downward (negative) trends (Burn and Elnur 2002; Abdullahi et al. 2015). Demir et al. (2009) examined the spatial variations of groundwater salinity in northern Turkey in 2004, observing that the eastern part of the study area ran the highest risk of salinity. Masoud et al. (2016) investigated the spatial-temporal trends and change factors of groundwater quality in Tanta District, Egypt, using P-spline modeling, Manne-Kendall and Thiele Sen methods in over the period of 2010-2012. In the 20 studied wells, they found significant upward trends (>95% level) regarding the total hardness (30%), total alkalinity (20%), TDS (15%), Fe^{2+} (15%), Mn^{2+} (15%), NO2 (10%), and 10% for the NH_4, PO_4, and SiO_2. Babakhani et al. (2016) studied the trend of groundwater quality parameters in Ravar plain over a ten-year statistical period. Their results showed an increase in TDS over the studied period. Given the amount of dissolved solids, EC amount is highly variable. Barkhori et al. (2017) investigated the temporal and spatial changes of groundwater quality for drinking purposes in Jiroft plain. According to their findings, the groundwater quality decreased overtime, a trend spread from the south to the center and the north of the region. Soleimani Sardou et al. (2017) investigated the spatial and temporal changes in the parameters of calcium, magnesium, pH, chloride, sodium sulfate and water in Jiroft plain from 2002 to 2012. Based on their results, the amount of pH, Sodium, Chlorine, and Sulfate increased, yet calcium and magnesium were reduced in amount . However, in general, in 2012 the quality of groundwater resources of Jiroft plain decreased compared to 2002, and the change trend showed water quality was further reduced towards south and west. Gejl et al., (2019) examined the impacts of groundwater abstraction through long-term trends on water quality parameters pertaining to 28 well fields around Copenhagen, Denmark. According to their findings, in the 1980s, when water consumption (abstraction) and drawdown were at their maximum, water abstraction caused a steady increase in sulfate and calcium, considered unsustainable by the authors.

Various studies have revealed the effectiveness of the Mann-Kendall test and its revised versions as regards estimating the process of changing the values of hydrogeological parameters. It is particularly important to undersrtand the quantitative and qualitative changes of groundwater in dry areas of Iran such as Kerman province, which is a relatively dry area in Iran. Due to the climate changes of the present day and the paucity of groundwater, groundwater levels have fallen in the plains of the province. Because of its geographical location and weather, Jiroft city is considered as a major pole of citrus production and tropical agricultural products in the region. The area has been affected by water scarcity over the recent years, and there have been variations in groundwater quality and aquifer level, hence the necessity to study the qualitative and quantitative changes of groundwater so as to identify the critical areas. Therefore, the objective of the present research was to analyze the qualitative and quantitative variables of groundwater in Jiroft plain during the statistical period of 2002-2015.

2. Materials and Methods

2.1. The study area

Located in Jiroft plain, the study area is a part of the western Jazmurian basin, which is located between the geographical latitudes of 57° 15′ and 58° 17E and the geographical latitudes of 28° 12′ and 29° 13′N in the southeast of Iran with an area of about 4654 km^2. The average height of the plain from mean sea level varies between 500-800 m. The average annual rainfall in Jiroft watershed is 170 mm. Due to low rainfall and high evaporation, the recharge is limited, hence the fact that groundwater has been reduced, and the average trend of water drop in Jiroft plain was 58 cm during the statistical period. In this study, use was made of groundwater quality parameters (EC, pH, Na, Ca, Mg, Cl, SO4, HCO3 and TDS) of the 56 sampled wells and 68 pizometric wells located in Jiroft plain from 2002 to 2015. The location of the study area is illustrated in Fig. 1.

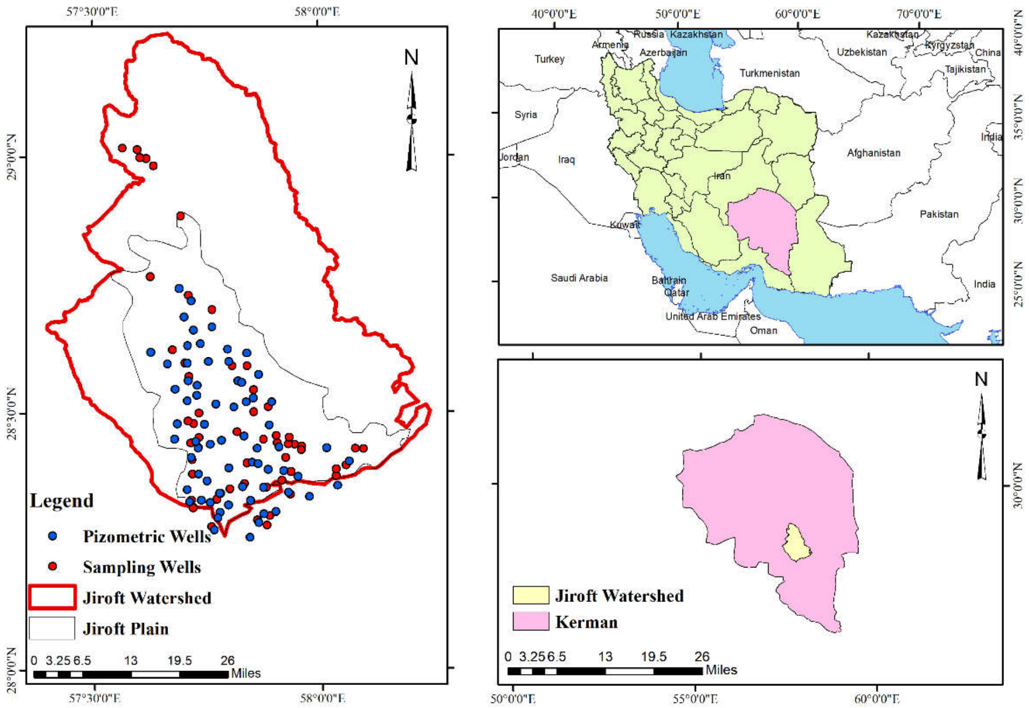


Figure (1): Location of Kerman province, Jiroft plain and Jiroft watershed

2.2. Trend analysis

2.2.1. Mann-Kendall Test (MK)

Mann–Kendall test is one of the most well-known nonparametric tests (Mann, 1945; Kendall, 1975; Kumar, 2009; Khalili et al., 2016 and Zamani et al., 2018). The aim of the trend test is to specify whether an ascending or a descending trend exists in the data series. Parametric tests include assumptions such as normality, stability, and independence of variables, most of which do not apply to hydrologic variables; therefore, nonparametric methods are more preferred in meteorological and hydrological studies. Concerning the examination of trends, nonparametric methods are less sensitive to extreme values compared to parametric tests . Nonparametric tests can also be utilized for time series data regardless of the linearity or nonlinearity of the trend.

The main assumption of the Mann–Kendall test is that the sample data has no significant autocorrelation while some hydrological series might have a significant autocorrelation coefficient (Khalili et al., 2016). When a series has a positive autocorrelation coefficient, there is an increased chance for the Mann–Kendall test to reveal the existence of a trend in this series.. The modified Mann–Kendall test was presented by Hamed and Rao (1998) and employed by Kumar et al. (2009) for analyzing the trend of Indian rivers. In this method, the effect of all significant autocorrelation coefficients is removed from the time series and applied to series whose autocorrelation coefficients are significant in one or more cases (Kumar et al., 2009; Sen, 1968; Thiel, 1950).

The classic form of the Mann-Kendall test (Mann, 1945; Kendal, 1975) has been employed in many studies. If the number of data time series is *n* within the study period, the statistic *S* is calculated as follows (Kumar et al. 2009):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (1)$$

where x_j indicates the value of j^{th} data, *n* indicates the number of data, and *sgn (θ)* is called the sign function which is defined as below:

$$sgn(x) = \begin{cases} +1 & if(x_j - x_k) > 0 \\ 0 & if(x_j - x_k) = 0 \\ -1 & if\ (x_j - x_k) < 0 \end{cases} \quad (2)$$

when $n \geq 8$, the statistic *S* has a normal distribution whose mean and variance is calculated as follows:

$$E(s) = 0 \quad (3)$$

$$Var(S) = \frac{n-(n-1)(2n+5)-C}{18} \quad (4)$$

where *C* is a factor related to variance correction. If the same successive data exist in the time series, *C* should be calculated by Eq. (5) and applied to Eq. (4):

$$C = \sum_{t=1}^{m} t_i(t_i - 1)(2t_i - 5) \quad (5)$$

where t_i is the number of tie data within the i^{th} group. Finally, the MK test statistic (*Z*) is calculated as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(s)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(s)}} & if\ S < 0 \end{cases} \quad (6)$$

The null hypothesis (no trends) will be accepted when $-Z_{1-\alpha/2} \leq Z \leq Z_{1-\alpha/2}$, otherwise the opposite hypothesis (H_0), meaning the existence of a significant increasing or decreasing trend, will be accepted (Gajbhiye et al., 2015).

2.2.2. The Modified Mann-Kendall Test (MMK)

Prior to applying the Mann-Kendall test, it should be ensured that the considered data series have no significant autocorrelation. However, most of the hydro-climatological time series may have a significant autocorrelation (Kumar et al., 2009). The presence of a significant autocorrelation in the time series results in the detection of a significant trend and the rejection of the null hypothesis (lack of significant trends) which should not in fact be rejected (Dinpashoh et al., 2014). The modified version of the Mann-Kendall (MMK) test was suggested by Hamed and Rao (1998) and applied by Dinpashoh et al. (2014) to the trend analysis of precipitation over Iran. In this method, before applying the Mann-Kendall test, the effect of all significant autocorrelation coefficients is eliminated from the time series. In the MMK test, the modified variance *V (S)** is calculated as follows:

$$V(S)^* = V(S)\frac{n}{n^*} \quad (7)$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \cdot \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2)r_i \quad (8)$$

where r_i indicate the *i* delayed autocorrelation coefficient and *V(S)* is calculated by Eq. (4). To calculate the *Z* statistic in the MMK test in Eq. (6), *V(S)* is substituted by *V(S)** from Eq. (7). Finally, the value of the *Z* statistic estimated by Eq (6) is compared with a normal standard *Z* value at α significance level. In this study, the last version of Mann-Kendall test (MMK) was used.

2.3. Sens's slope estimator

A highly useful indicator in the Mann-Kendall test is the slope of the trend line, also called

Sen's slope, which indicates the magnitude of the uniform trend. The trend line slope was estimated using the method presented by Thiel (1950) and Sen (1968) via the following relation:

$$\beta = Median\left(\frac{x_j - x_i}{j - i}\right) \quad \forall i < j \qquad (9)$$

where β is the trend slope estimator and x_i, x_j are the ith and jth values of the observed data, respectively. Positive values indicate an increasing trend, and the negative values show a decreasing trend. This method has been used widely in hydrological studies. It is to be noted that estimation of the Sen's slope is required for the calculation of the modified Mann-Kendall test.

2.4. Standard Normal Homogeneity Test

Standard normal homogeneity test (SNHT) was used to examine the time series homogeneity and change-point time of the existing variables. The zero assumption of this test is the homogeneity of the experimental series (Alexandersson, 1986). The statistics for this test are as follows:

$$T_k = K\bar{z}_k^2 + (n-k)\bar{z}_{n-k}^2 \qquad (10)$$

where $\bar{z}$ is the standardized series of the studied parameter, k = 1,2,. . ., n-1, $\bar{z}_k$ is the mean first K data and $\bar{z}_{n-k}^2$ is the mean of n-k data. Maximum values of T_k are known as change-point time or critical point. The standard normal homogeneity test is based on the simulation of 10,000 Monte Carlo simulations. The flowchart of the mentioned methodology is shown in Fig. 2.

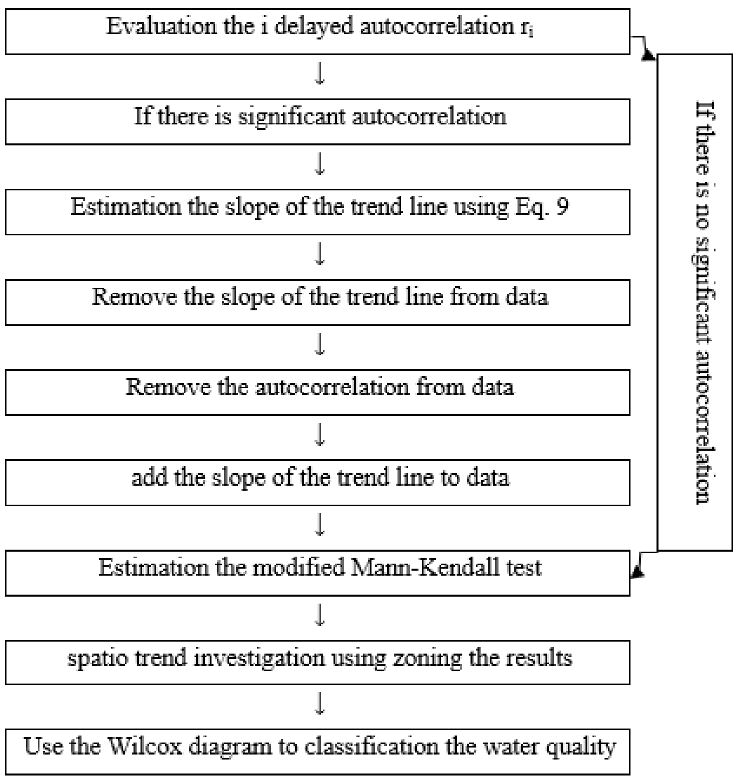
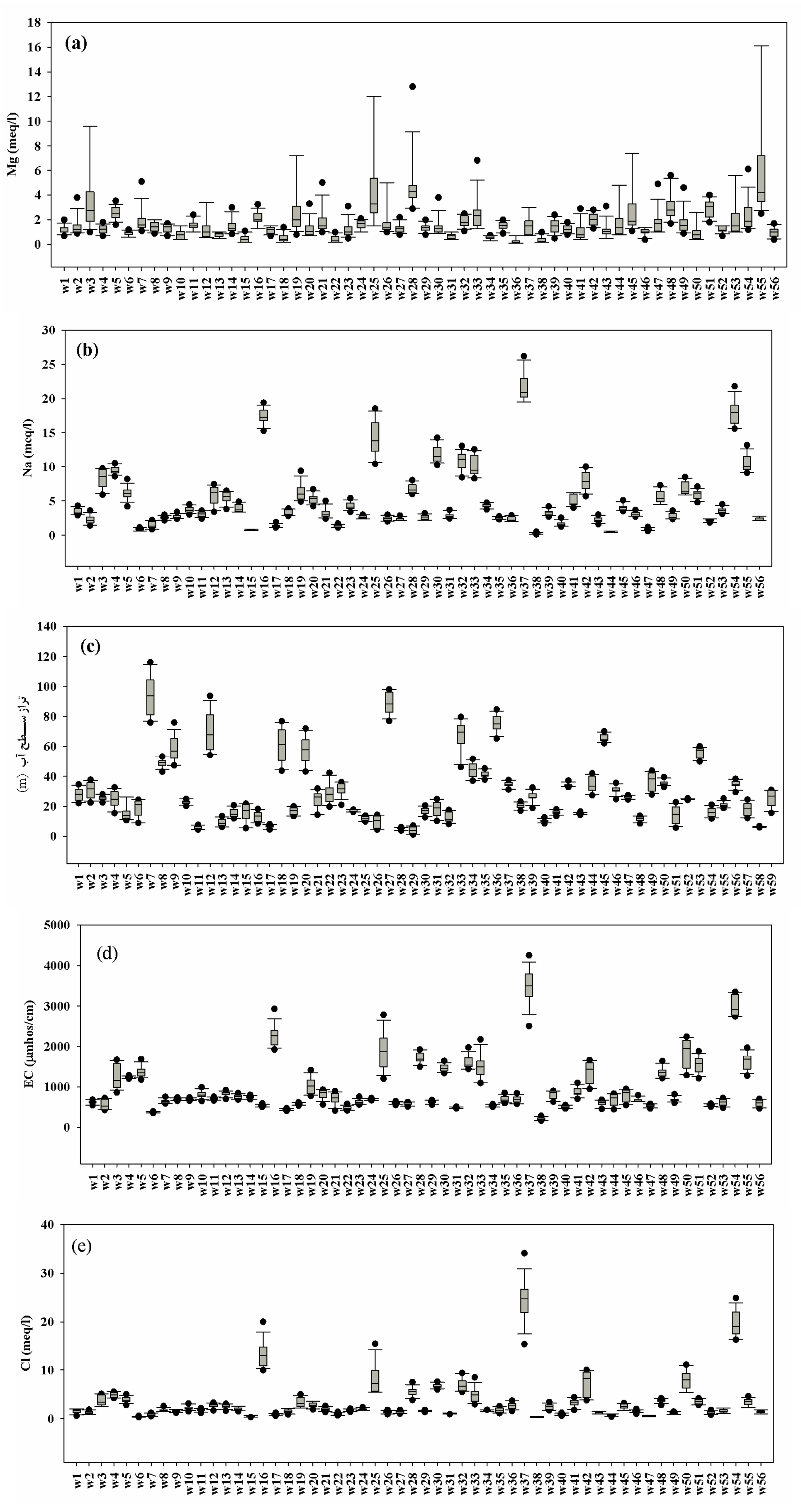


Figure (2): Flowchart of study methodology in this study

3. Results and Discussion

3.1. Time series evaluation

In this research, the quantitative and qualitative trends of groundwater data were analyzed in the study area during the statistical period of 2002-2015 using modified Mann-Kendall tests and standard normal homogeneity test on an annual scale. The time series of quantitative and qualitative data were evaluated in the statistical period of 2002-2015, as described in Fig 3. Box plots show the data changes during the statistical period. Moreover, boxes are the variation range of major changes to the studied parameter. The upper and lower circles further indicate the maximum and minimum data.


(a)
Mg (meq/l)
(b)
Na (meq/l)
(c)
تراز سطح آب (m)
(d)
EC (μmhos/cm)
(e)
Cl (meq/l)

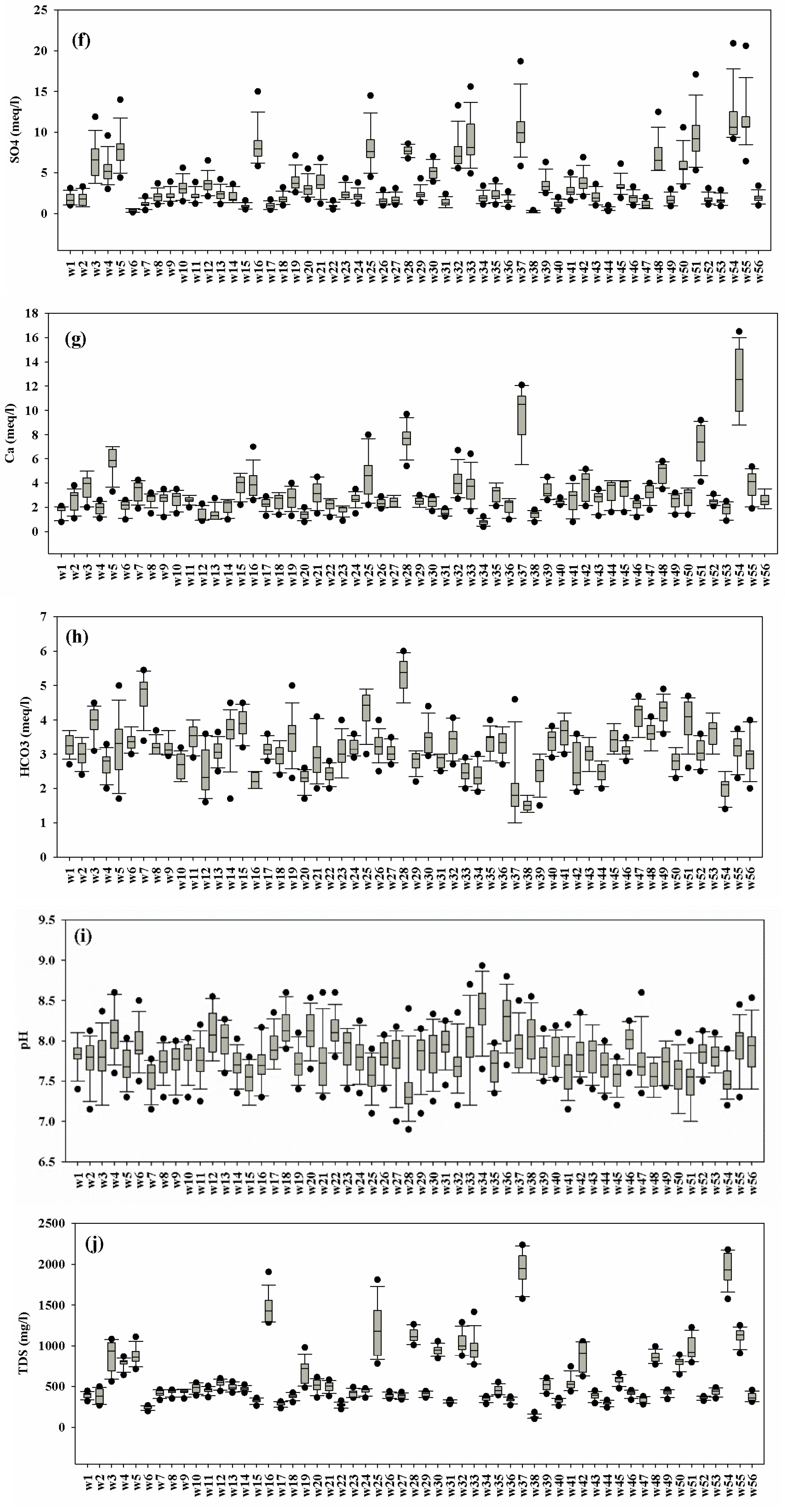


Figure (3): Changes in groundwater qulity parameters of Jiroft plain during the statistical period of 2002-2015. a:Mg; b:Na; c:Groundwater level; d:EC; e:Cl; f:SO4; g:Ca; h:HCO3; i:pH; j:TDS

3.2. Results of modified Mann-Kendall test

The 14-year time series of quantitative and qualitative data on the annual scale was evaluated using the modified Mann-Kendal test. The results of the spatial trend of quantitative and qualitative values using the modified Mann-Kendall test and the trend slope are shown in Figs 4 to 13. The Z statistics of the modified Mann-Kendall test and Sen's slope are zoning through the use of spline method in Arc GIS 10.2.

The trend of quantitative values was assessed in the study area, revealing that most of the plain areas had increased access to groundwater during the studied period. According to the results (Fig. 4), the eastern and northeastern regions and some of the central areas of the plain experienced a significant trend. In fact, by the drawdown in the groundwater level in the plain, the volume of groundwater is reduced, rendering the effect of salts on water more meaningful. The groundwater level changes were investigated in the plain by calculating the trend line slope (Sen's slope), where, on average, the groundwater level was reduced by approximately 0.55 m each year. It can be concluded that during the period of 2002-2015, the groundwater level of the plain decreased by about 8 meters. Increased access to groundwater in the plain due to the region's agriculture and changing the quality of groundwater increase the utilization and abstraction cost of the groundwater.

The investigation of the changes in the electrical conductivity and chlorine values using modified Mann-Kendall test showed that most areas of Jiroft plain were faced with an increasing trend, which was more significant in the central part of the plains (Figs 5 and 6). The northwest to the southeast route of the studied plain, located on the main river plain, had the highest concentration of EC. This shows that in recent years, the recharge of groundwater has been reduced through surface water, leading to increased electrical conductivity in these areas. Regarding the trend line slope, the changes in the electrical conductivity values in the center of the plain were observed to be higher than other points. The results of the trend line slope (Sen's slope) further showed that the average electric conductivity in Jiroft plain was increased by about 12.3 µS/cm annually; this increase was approximately172 µS/cm over the entire study period, which was higher in the plain boundaries and central region compared with other areas.

The Z statistical values of modified Mann-Kendall test further showed a significant increase in the chlorine parameter in most areas of Jiroft plain, particularly the central area and the main river route (fig 6). In areas such as Jiroft plain, which is a source of drinking water based on wells within the plain, increased chlorine in groundwater elevates the cost of water purification for drinking and sanitation. The increase in chlorine was significant in most regions of the studied area. The slope of the trend line showed that the amount of chlorine in the plain varied from 0 to 0.63 mg / L; annually, the chlorine in this area was reduced by around 0.1 mg/l, and regarding the entire statistical period, an increase of about 1.5 mg/l was observed, which was the highest in the center of the plain.

According to the modified Mann-Kendall test, the major changes in magnesium parameter in the study area were significantly reduced (Fig. 7). Except for small areas in the center, southwest and southeast, other regions of the area under investigation showed reduced groundwater magnesium dispersion. Sodium in the studied area underwent both decreasing and increasing trends (Fig. 8), which is in line with the results of Soleimani Sardou et al., (2017) who studied the spatial and temporal changes regarding calcium, magnesium, pH, chloride, sodium sulfate and water in Jiroft plain from 2002 to 2012. These changes had a significantly falling trend in the northeast, northwest and parts of the southwest of the area under study . In the boundary areas of the plain, a decreasing trend was observed in sulfate (Fig. 9), meaning that the falling trend was non-significant in the eastern, western and northern boundaries, and certain other areas . In the center of the investigated area, an increasing trend was observed concerning the amount of sulfate.

The calcium parameter in the study area also had a combination of decreasing and increasing trends (Fig. 10). Over the studied period, based on modified Mann-Kendall statistics, most of the studied areas experienced an increase in calcium levels. Only parts of the western and northeastern regions of the study were reduced in calcium levels. Based on the slope of changes, the maximum variation of calcium , on average, was about 0.64 meq/l per year.

According to the results, most parts of the studied regions underwent a falling trend in terms of HCO3, with the central and western areas and parts of the northwest regions experiencing significant changes (5%). Regarding the slope of the trend line (Sen's slope), the maximum change in HCO3 parameter was about -0.32 meq/l per year.

The trend of groundwater pH values in the studied area (Fig. 12) over the 14 year period is mainly falling. Apart from the western regions of the studied plain, with significantly increasing trend, other areas had a decreasing trend regarding acidity. This decrease in most cases is 0.14 (per unit of pH) per year, which is approximately 9.1 units over the entire study period in the eastern regions of the area.

The groundwater TDS values were also significantly reduced in the northeastern and southwestern regions during the statistical period.

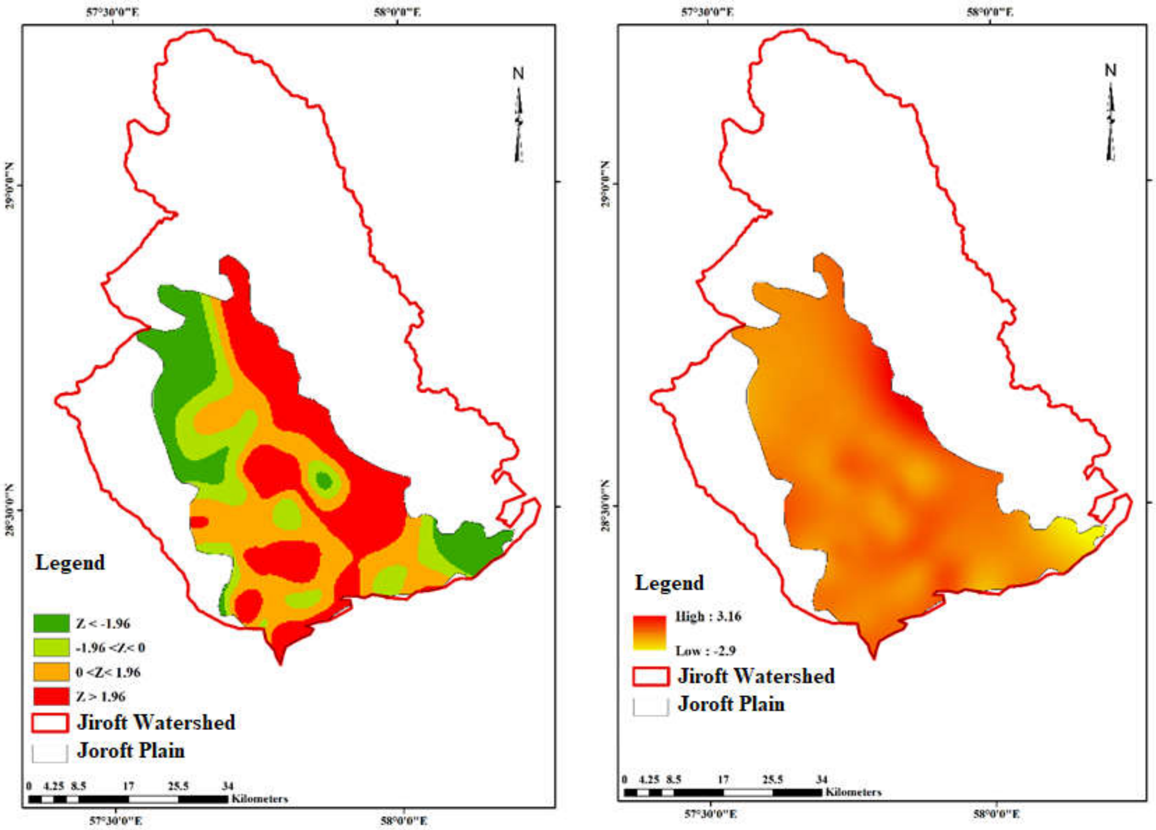


Figure (4): Results of trend analysis (left) and trend line slope (right) for groundwater level in Jiroft plain

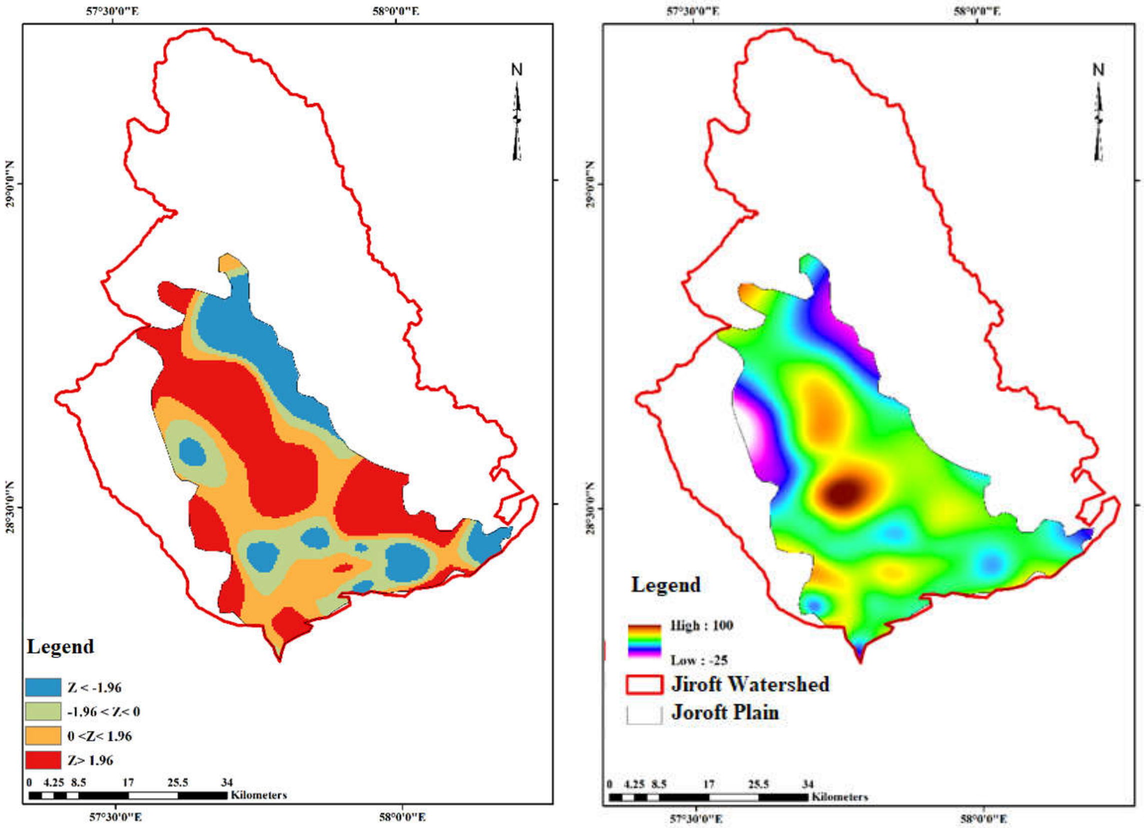


Figure (5): Results of trend analysis (left) and trend line slope (right) for electrical conductivity (EC) in Jiroft plain

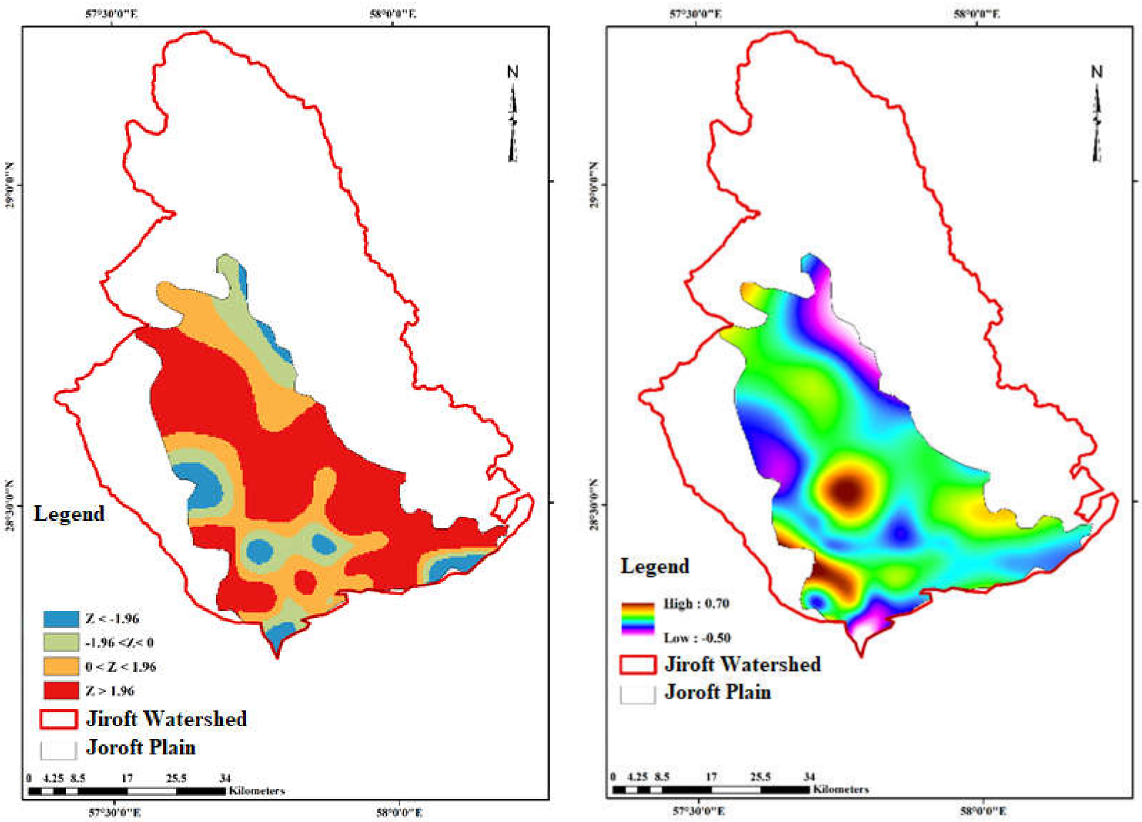


Figure (6): Results of trend analysis (left) and trend line slope (right) for chlorine (Cl) in Jiroft plain

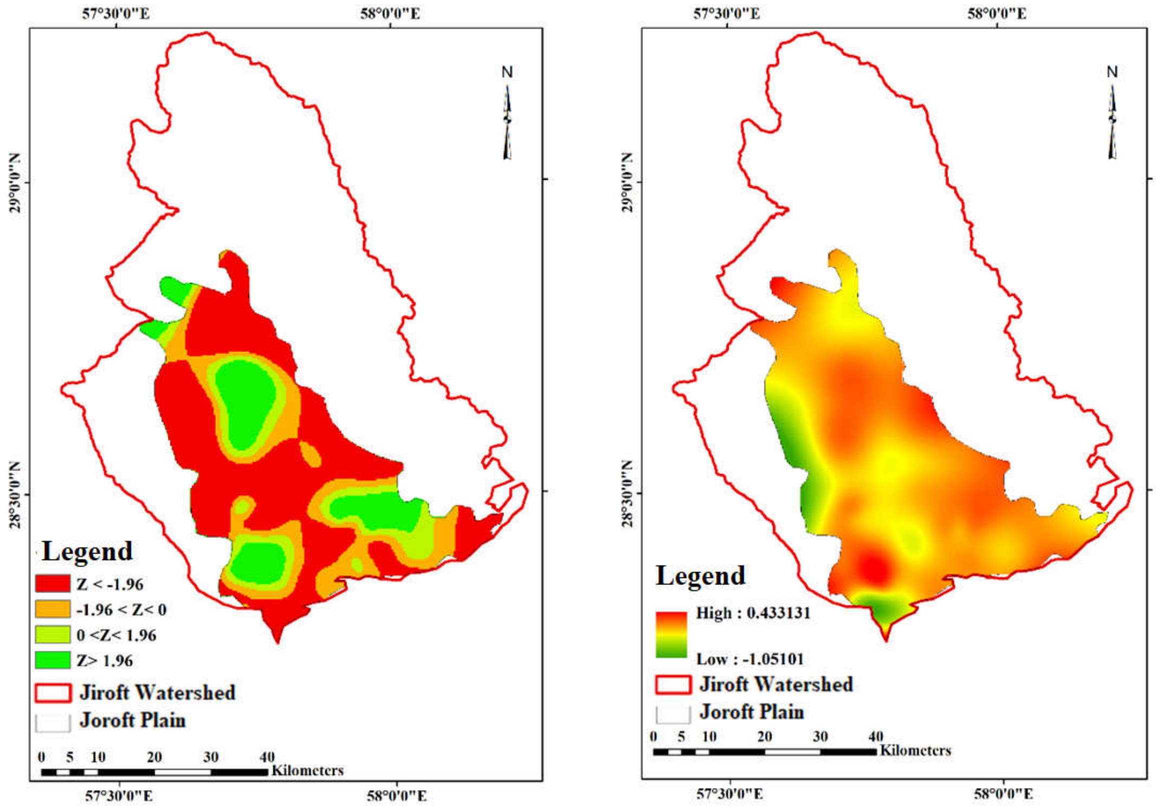


Figure (7): Results of trend analysis (left) and trend line slope (right) for magnesium (Mg) in Jiroft plain

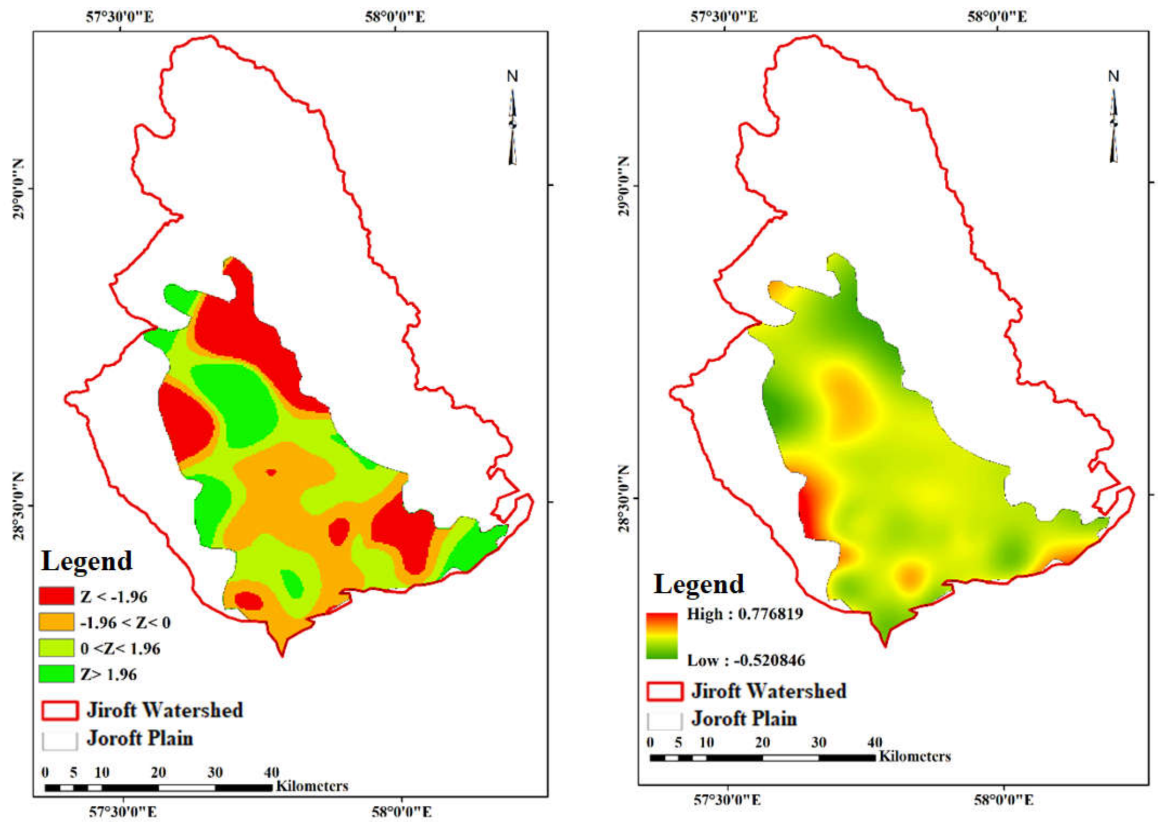


Figure (8): Results of trend analysis (left) and trend line slope (right) for Sodium (Na) in Jiroft plain

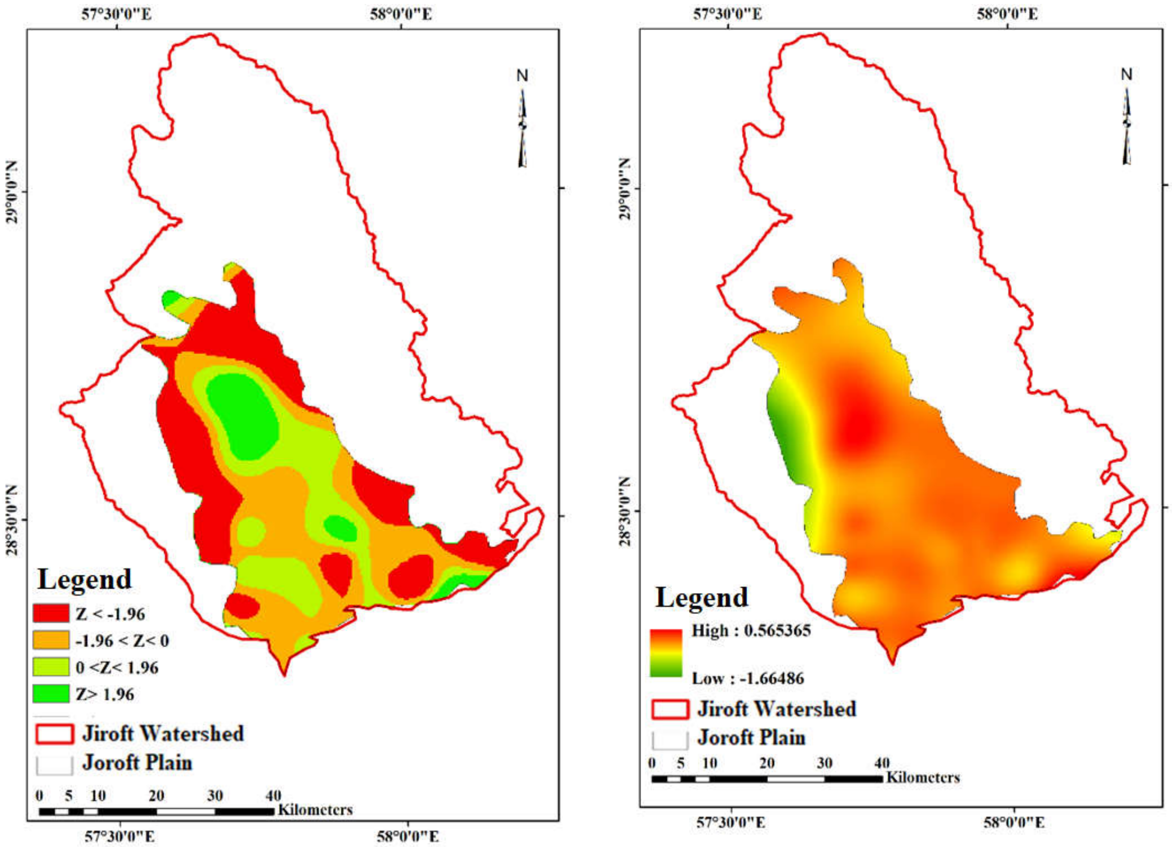


Figure (9): Results of trend analysis (left) and trend line slope (right) for Sulfate (SO4) in Jiroft plain

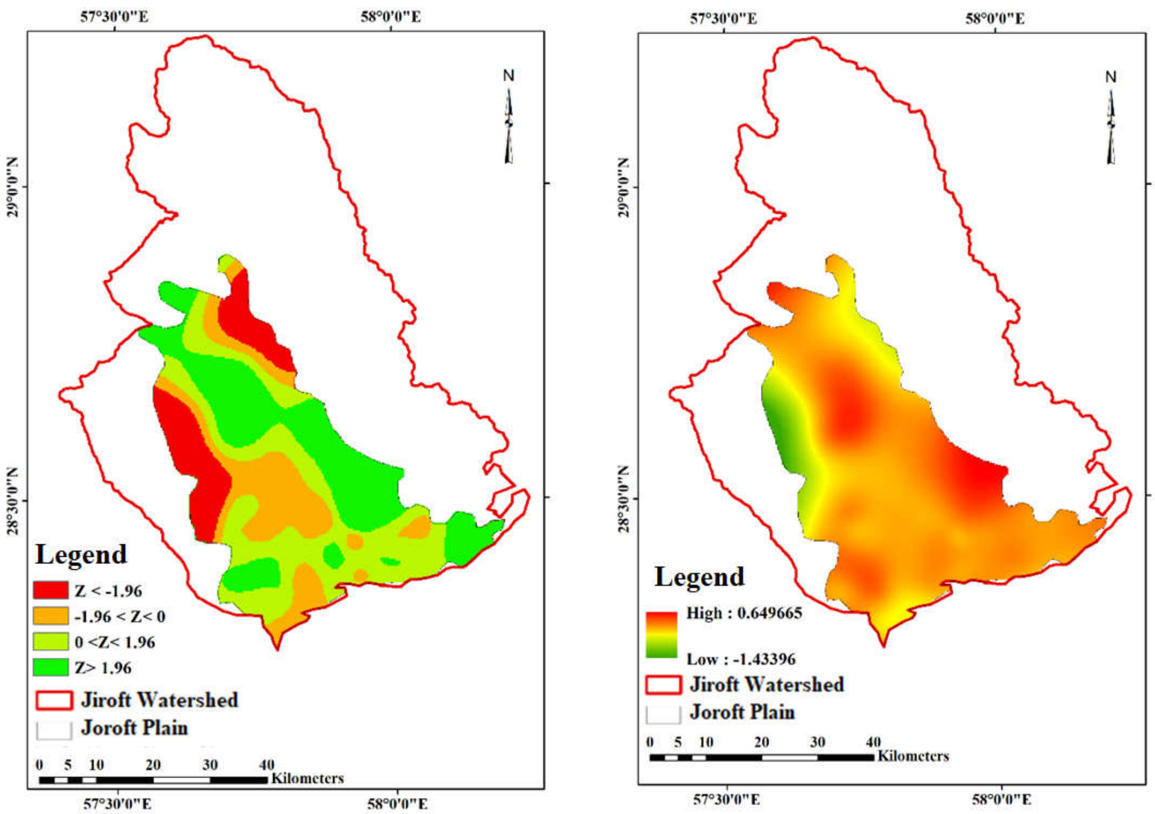


Figure (10): Results of trend analysis (left) and trend line slope (right) for Calcium (Ca) in Jiroft plain

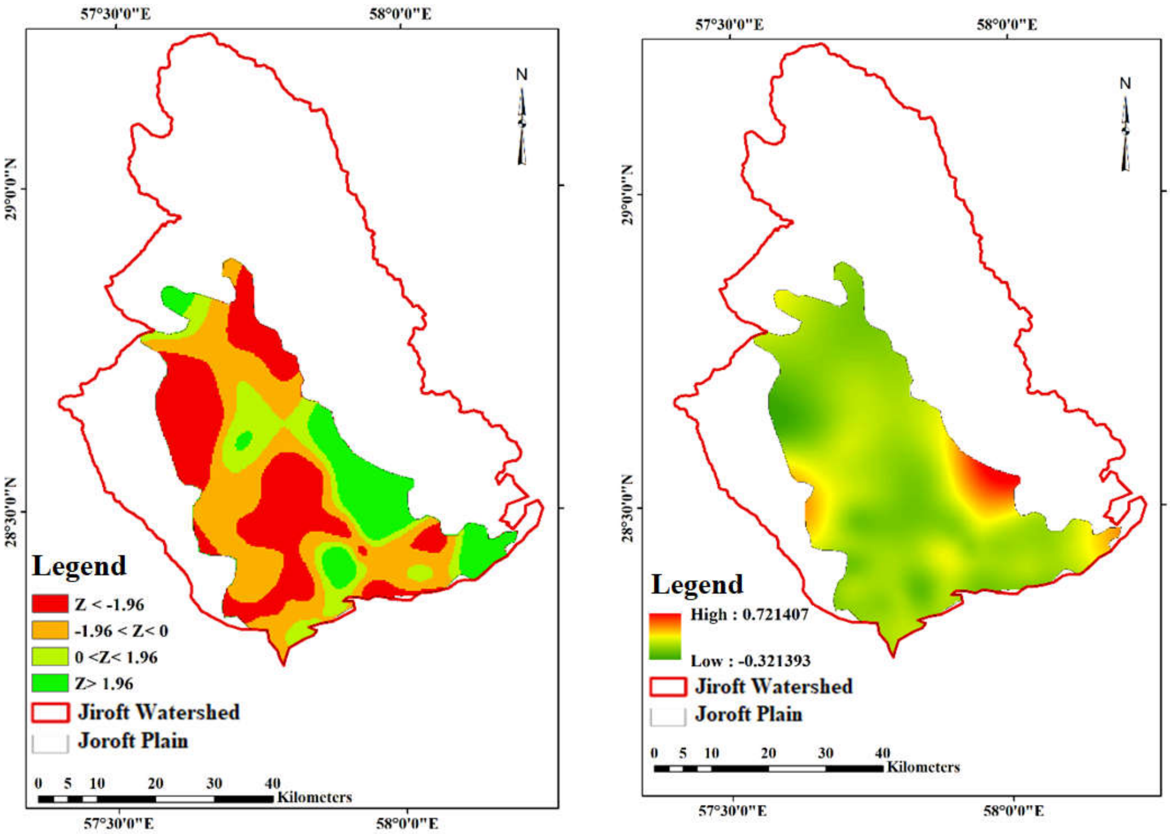


Figure (11): Results of trend analysis (left) and trend line slope (right) for HCO3 in Jiroft plain

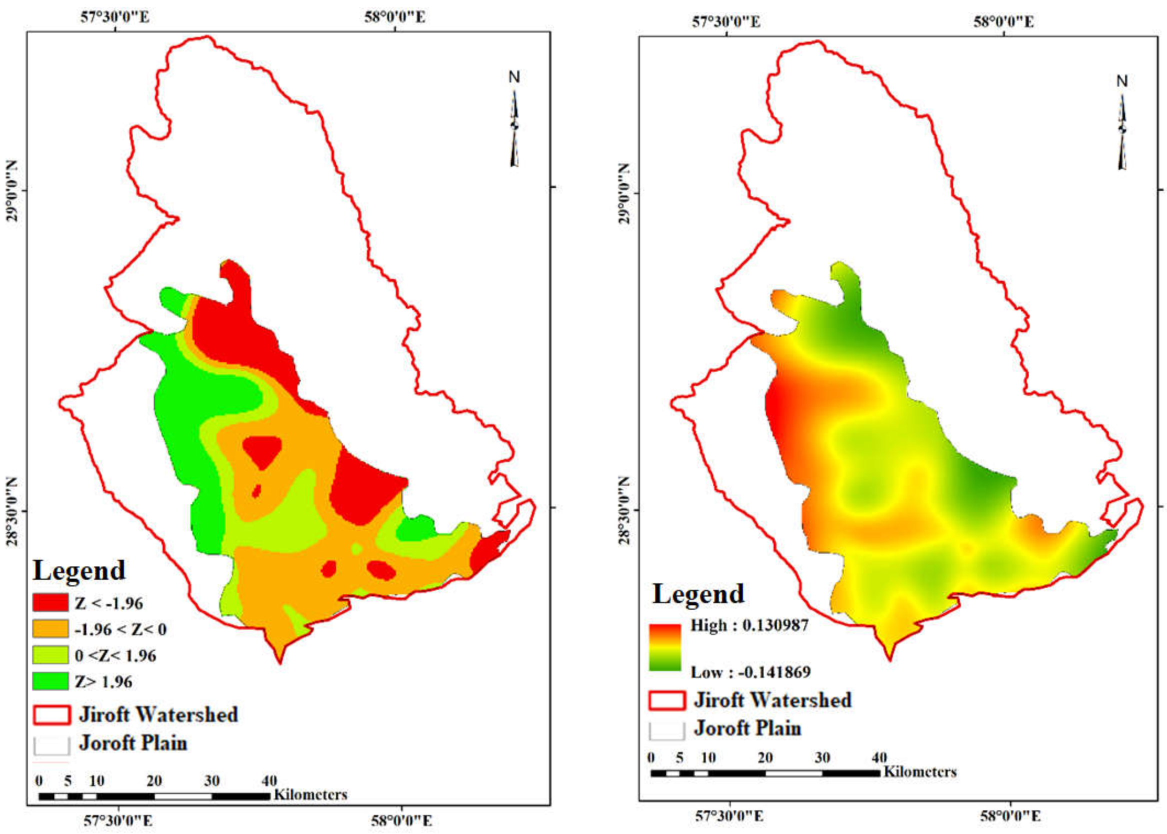


Figure (12): Results of trend analysis (left) and trend line slope (right) for pH in Jiroft plain

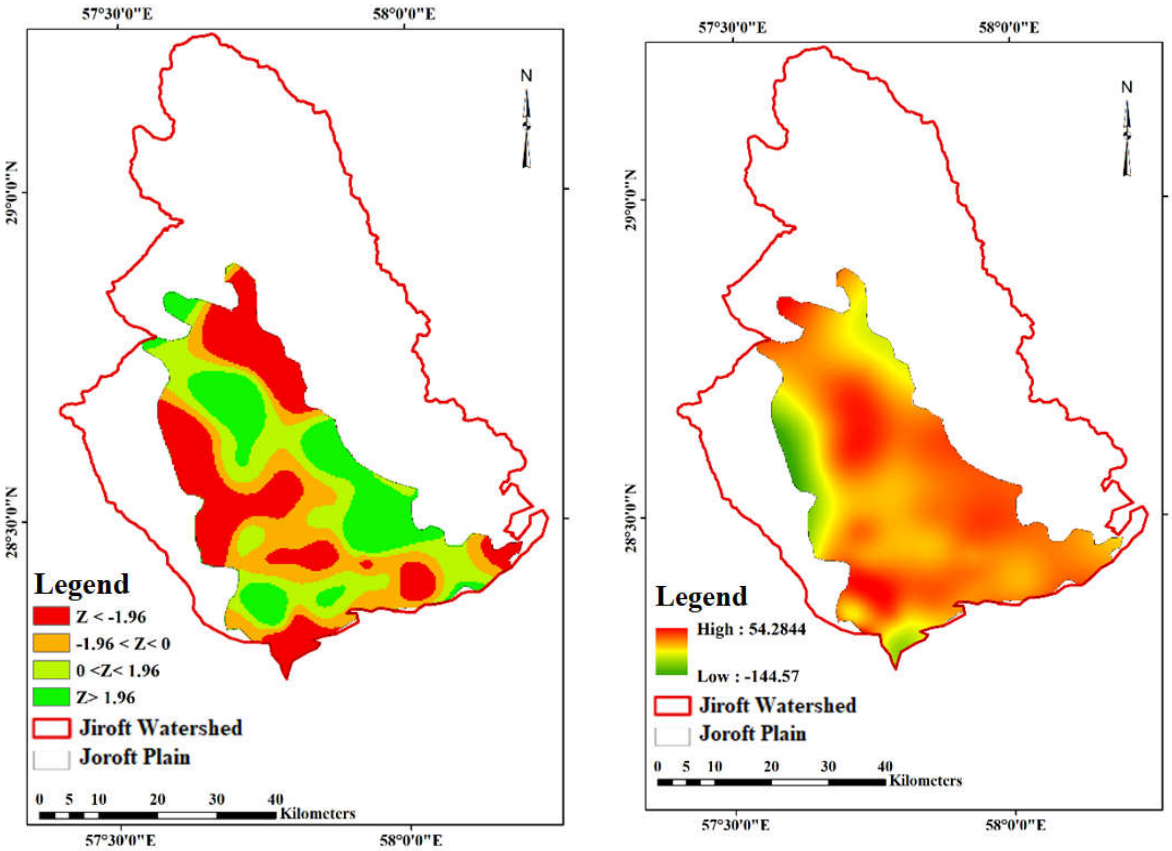


Figure (13): Results of trend analysis (left) and trend line slope (right) for TDS in Jiroft plain

The amount and percentage of changes in the studied parameters determined by use of Sen's Slope statistics presented in Table 1.

Table (1): Calculation of changes in the studied parameters in the statistical period of 2002-2015

Parameter	Water Level (m)	Mg (meq/l)	Na (meq/l)	EC (µS.cm⁻¹)	Cl (mg/l)	SO4 (meq/l)	TDS (mg/l)	HCO3 (meq/l)	Ca (meq/l)	pH
Rise or Decline (%)	26.45	-24.00	-2.31	19.23	45.45	0.33	44.96	-0.39	27.2	-0.15
Rise or Decline (amount)	7.78	-0.70	-0.13	172.35	1.28	0.011	7.05	-11.82	0.85	-1.89

As observed in Table 1, the highest percentage of increase belonged to chlorine and the highest reduction percentage was related to the magnesium parameter in this area.

3.3. Results of change-point time After assessing the trend of quantitative and qualitative changes in Jiroft plain, the homogeneity of the data was further analyzed using standard normal homogeneity test (SNHT). The results of this test are shown in Fig. 14.

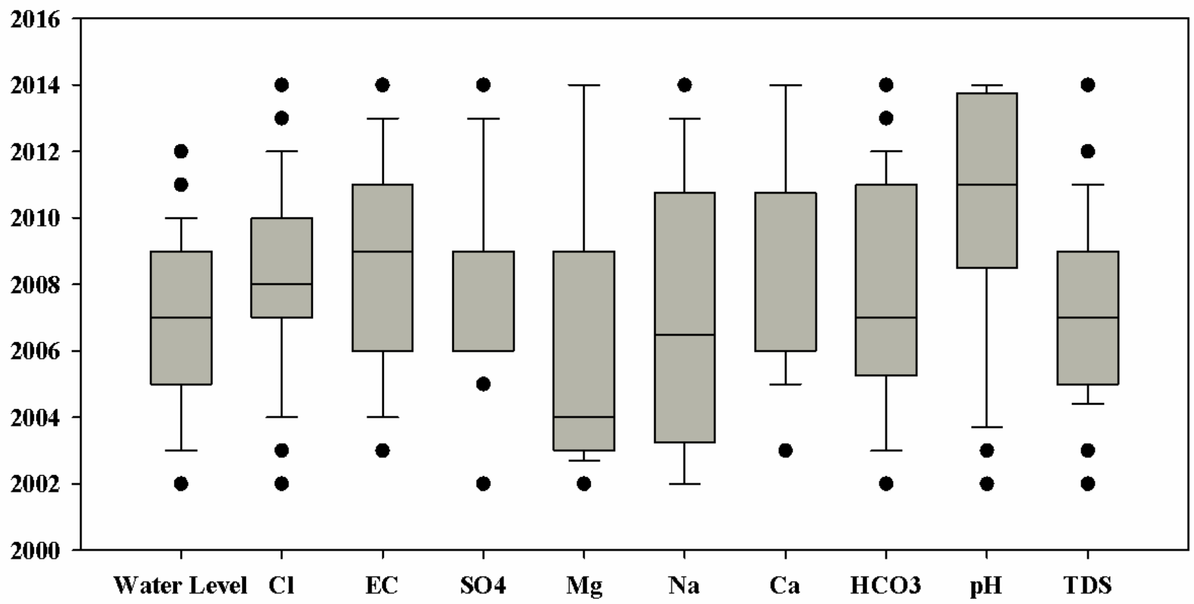


Figure (14): Results of the time of change point analysis in the studied time series using the SNHT test

The results of the change-point time and homogeneity of the studied time series using the SNHT test and middle line of box plot showed that the most changes in groundwater level occurred in all existing pizometric wells (68 piezometers) of Jiroft plain between 2005 and 2009. The change trendof Cl, EC, SO4, Mg, Na, Ca, HCO3, pH and TDS variables occurred in 2008, 2009, 2007, 2007, 2007, 2008, 2007, 2010 and 2007, respectively. Based on the results, the change in the quantity of groundwater was the beginning of the change in groundwater quality. As shown in Fig. 14, the year 2007 can be described as the year of change in quantitative and qualitative variables in Jiroft plain. Increased area under cultivation of crops, inter-basin water transfers and most importantly, reduction in precipitation and climate change lowered the groundwater levels in the studied area. The existence of a decreasing precipitation trend further confirms other studies (Kousari et al., 2011; Some'e et al., 2012; Khalili et al, 2016). It is of note that the construction of an earth dam with a capacity of 40 million cubic meters in the upstream of the studied plain in the city of Baft during 2003-2008 also had a great impact on groundwater reduction. Due to the reduction in groundwater level and water volume, the concentration of the existing quality parameters has increased. The increase in the extreme values of precipitation over the recent decades is another reason for the reduction in water penetration to the groundwater level, decreasing groundwater levels. The reduced quality of groundwater in Jiroft plain over the recent years is line with Barkhori et al., (2017) who investigated the trend of groundwater quality parameters such as EC, Cl, Ca, Mg, Na and SO4 based on drinking purposes in Jiroft plain.

3.4. Water quality classification

Finally, the Wilcox diagram was used to assess the current quality of groundwater in the study area for agricultural use (Fig. 15 and Table 2). The results showed that groundwater quality was acceptable in most areas based on the agriculture water classification, also confirmed by the results of the Wilcox diagram.

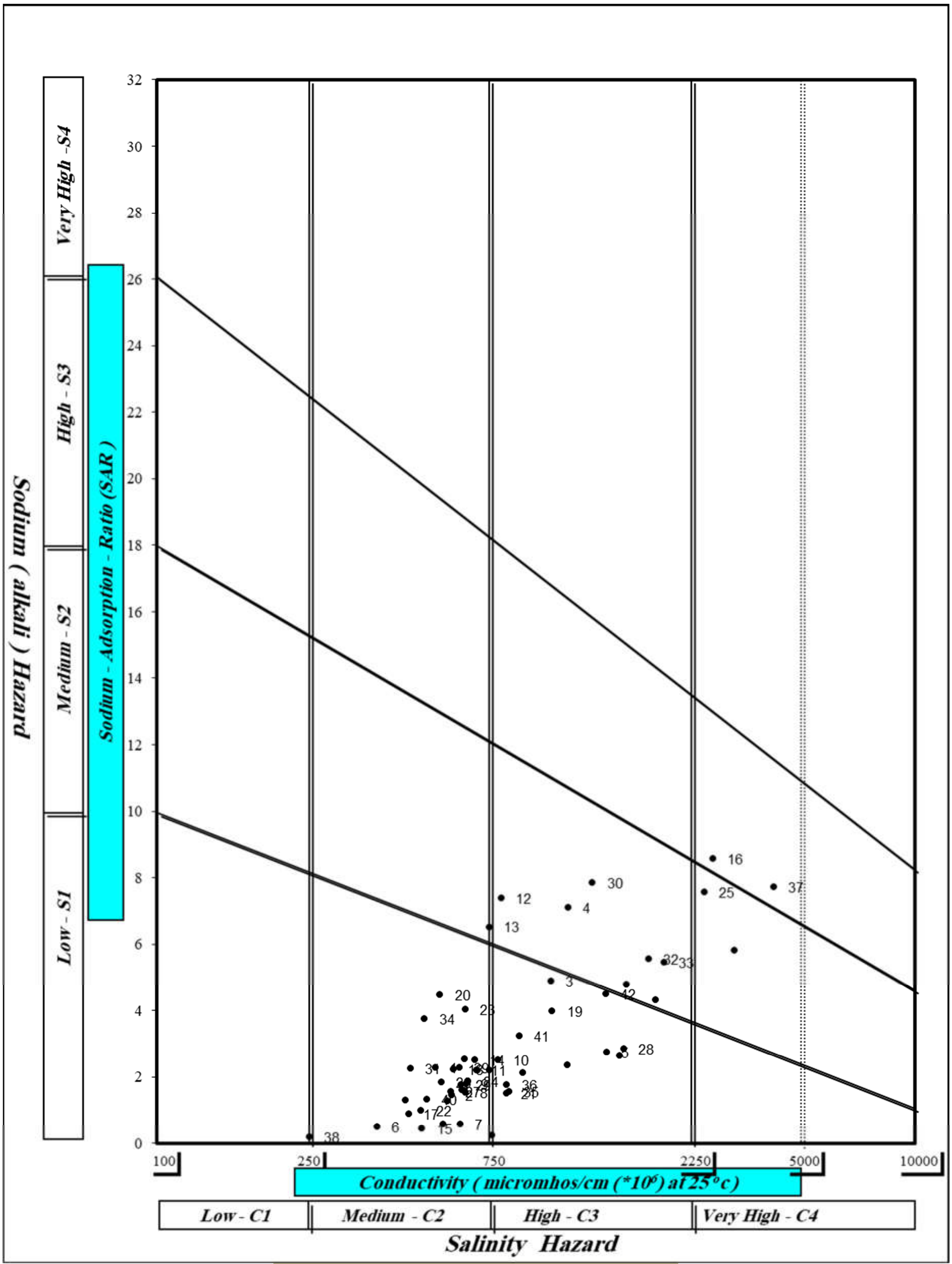


Figure (15): Wilcox diagram of studied plain

Table (2): Water quality classification based on agricultural use

Well	EC	Class	Quality	Well	EC	Class	Quality
W1	545	C2-S1	Slightly salty	W29	637	C2-S1	Slightly salty
W2	600	C2-S1	Slightly salty	W30	1414	C3-S2	Salty
W3	1098	C3-S1	Salty	W31	468	C2-S1	Slightly salty
W4	1221	C3-S2	Salty	W32	1983	C3-S2	Salty
W5	1543	C3-S1	Salty	W33	2180	C3-S2	Salty
W6	383	C2-S1	Slightly salty	W34	510	C2-S1	Slightly salty
W7	634	C2-S1	Slightly salty	W35	850	C3-S1	Salty
W8	653	C2-S1	Slightly salty	W36	840	C3-S1	Salty
W9	657	C2-S1	Slightly salty	W37	4252	C4-S3	Very salty
W10	797	C3-S1	Salty	W38	254	C2-S1	Slightly salty
W11	699	C2-S1	Slightly salty	W39	630	C2-S1	Slightly salty
W12	813	C3-S2	Salty	W40	515	C2-S1	Slightly salty
W13	755	C3-S2	Salty	W41	907	C3-S1	Salty
W14	690	C2-S1	Slightly salty	W42	1530	C3-S1	Salty
W15	502	C2-S1	Slightly salty	W43	454	C2-S1	Slightly salty
W16	2930	C4-S3	Very salty	W44	767	C3-S1	Salty
W17	463	C2-S1	Slightly salty	W45	925	C3-S1	Salty
W18	606	C2-S1	Slightly salty	W46	755	C3-S1	Salty
W19	1108	C3-S1	Salty	W47	570	C2-S1	Slightly salty
W20	560	C2-S1	Slightly salty	W48	1215	C3-S1	Salty
W21	838	C3-S1	Salty	W49	640	C2-S1	Slightly salty
W22	500	C2-S1	Slightly salty	W50	2072	C3-S2	Salty
W23	653	C2-S1	Slightly salty	W51	1667	C3-S1	Salty
W24	665	C2-S1	Slightly salty	W52	585	C2-S1	Slightly salty
W25	2785	C4-S2	Very salty	W53	650	C2-S1	Slightly salty
W26	565	C2-S1	Slightly salty	W54	3350	C4-S2	Very salty
W27	598	C2-S1	Slightly salty	W55	1734	C3-S2	Salty
W28	1710	C3-S1	Salty	W56	650	C2-S1	Slightly salty

*Slightly salty: Suitable for farming, Salty: Applicable for farming, Very salty: Inappropriate farming

Among the studied wells, wells No. 38 and 37 had the best and worst water quality in Jiroft plain, respectively. The results of classifying the quality parameters of the area under study indicated that 51.8%, 26.7%, 14.3%, 3.6% and 3.6% of the studied wells are in C2-S1, C3-S1, C3-S2, C4-S3 and C4-S2 classes, respectivily.

4. Conclusion

Using the modified Mann-Kendall test and standard normal homogeneity test, the quantitative and qualitative trend of groundwater were evaluated in Jiroft plain in the southeast of Kerman province during the statistical period of 2002-2015 . The qualitive values were electrical conductivity, chlorine, sulfate, magnesium, and sodium, annually, and the quantities were the amounts of groundwater level. A falling trend was observed in most areas of Jiroft plain, where a reduction of about 8 meters was observed in groundwater level over the 14-year period.

Groundwater losses in Jiroft plain, considered as the center of citrus and agricultural products in southern Kerman, have been damaging the agricultural and economic sectors of the city. On the other hand, reduction in aquifer level, caused by the decrease in the distribution of rainfall in recent decades, has also increased the cost of groundwater extraction. Groundwater reduction is also the cause of the increase in the concentration of pollutants in the aquifer, which results in elevated concentrations of parameters such as salinity and chlorine. As a result of groundwater decline, 18 %increase was seen in groundwater salinity over the entire study period . The sulfate, magnesium, and sodium parameters also changed by about 0.014, -0.7 and -0.126 meq/l, respectively, in the research period. HCO3 and pH were reduced by approximately 0.39 and 0.15%, and TDS and Ca increased by 7 and 27 %, respectively. According to the standard normal homogeneity test, the change-point time in groundwater quality data occurred one year after the significant change in groundwater level data. Major changes in quality parameters were further observed in 2007 and 2008. Since all water consumption in the studied area is based on groundwater and agricultural water consumption is high, reduction in groundwater level can quickly impact the quality of water for agriculture.

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