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Groundwater quality analysis using multivariate statistical techniques (case study: Fars province, Iran)

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Abstract This research investigated the quality of groundwater of 298 wells during 10 years, in Fars province, southern Iran, to survey spatial variation of groundwater quality and also major sources of hydro-chemical components for drinking and agricultural uses. To classify the sampling stations in each year, hierarchical cluster analysis, using the Euclidean distances and "Ward" method, was used. According to the results of cluster analysis, there were three quality groups in groundwater of the research area: first group of 170 wells with type of Ca-HCO_3, second group of 98 wells with type of Ca-HCO_3, and third group of 30 wells with type of Na-Cl. Hydro-chemical parameters were increased from the first to the third group, and on the basis of Schoeller and USSL diagrams, the water of wells of the third group was considered unsuitable for irrigation and drinking. Principal component (PC) analysis and factor analysis reduced the complex and voluminous data matrix into three main components, accounting for more than 80 % of the total variance. The first PC contained TDS, EC, TH, Na^+, Cl^-, Mg^{2+}, SO_4^{2-}, Ca^{2+}, and SAR parameters. Therefore, the first dominant factor was salinity. In PC2, HCO_3 and pH were the dominant parameters, which may indicate weathering of silicate minerals. The PC3 contained high loadings for NO_2^{2-} and NO_3^-. This factor indicates anthropogenic contaminants that may be caused by improper disposal of domestic wastes or the use of chemical fertilizers in agriculture and leaching of them.

Keywords Factor analysis · Cluster analysis · Water quality · Irrigation water · Drinking water

Introduction

Groundwater is an important supplier of irrigation and drinking water, and it has a strong impact on rivers and aquatic ecosystems for animals and plants (Twarakavi and Kaluarachchi 2006). In the developing countries like Iran, 80 % of all diseases are directly cognate with poor drinking water and unsanitary conditions (Olajire and Imeokparia 2001). Groundwater also plays a fundamental role on people's lives and economic development in developing countries such as Iran. Water consumption in Fars is about 10.5 billion cubic meters, which 8.0 billion cubic meters is provided by the groundwater and the agriculture is the largest consumer of this water (Hojjati and Boustani 2010). Furthermore, Fars province is one of the largest producers of wheat, corn, rice, and cotton in Iran. Therefore, it is essential to monitor and assess the groundwater pollution and provide measures to prevent intensification of pollutions. This assessment is more noticeable in semi-arid regions such as Iran that experience water shortage problems (Razmkhah et al. 2010). As a result, realistic

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understanding of the status of groundwater quality and the factors influencing them is necessary.

Many researchers have used multivariate techniques on water quality conditions. Kim et al. (2005) have used cluster analysis on water quality data for the coastal area of Kimje, South Korea. Groundwater samples were divided into four groups using factor analysis. Three main factors influencing the quality of groundwater in this area were seawater intrusion, microbial activity, and leaching of chemical fertilizers from agricultural farms. McNeil et al. (2005) studied assortment of 34,000 data samples of surface water, collected during 30 years in Queensland, Australia. They analyzed water quality data by using two-stage K-means clustering method and found that the major ions are sodium, magnesium, calcium, chloride, bicarbonate, and sulfate, which affected the water quality in this study. Jalali (2007) identified the chemical properties and groundwater pollution in Chah basin, Western Iran. He found that the major water type of groundwater samples is Ca-HCO_3. The results showed that cation exchange and Cl^-salt inputs are the predominant processes controlling water chemistry of the samples. Yerel (2010) analyzed the water quality in Porsuk River, Turkey, using multivariate analysis and found that urban, agricultural, and industrial waste water strongly affected the water quality of east part in the study area. Yidana (2010a) studied the groundwater aquifers in north and south of Ghana to identify the hydro-chemical variations in the quality of this water in agricultural consumptions using multivariate and graphical techniques. By using cluster analysis, he divided the data into four groups and found that the three major factors which control hydro-chemical variations were as follows: (1) cation exchange and silicate mineral weathering, (2) carbonate mineral weathering, and (3) chemical fertilizers of farms in this area.

Multivariate statistical techniques such as principle component analysis (PCA), factor analysis (FA), and cluster analysis (CA) can reveal the relationship between a huge number of variables and explain the correlation among them (Shrestha and Kazama 2007; Chen et al. 2007; Wenning and Erickson 1994). Cluster analysis classifies any number and any type of variables (chemical, physical, biological, distributed, or non-distributed) into two or more groups based on the similarity between samples with respect to a set of special characteristics, and the results can be more readily interpreted in the geological or hydro-chemical context (Daughney et al. 2012). This method of analysis has been used in many investigations to classify and characterize surface or groundwater quality data at a range of spatial and temporal scales (Kim et al. 2005; McNeil et al. 2005; Yerel 2010; Yidana 2010a; Masoud 2013; Machiwal and Singh 2015). Factor analysis describes covariance relationships among variables and reduces the number of variables and also the structure of the relationship between variables.

Water quality degradation can make it unusable for human needs, and it has negative impact on the environment. Therefore, evaluation of water quality is necessary. In the present research, multivariate statistical techniques including cluster and factor analysis were used to identify the major factors affecting water quality of deep groundwater and provide a reliable estimation of groundwater quality in Fars province during a 10-year period. This insight hopefully would aid in ensuring better water resource management in Fars province.

Methodology

Study area and data collection

Fars province with 122,608-km^2 area (7.44 % of Iran area) and population of 4,596,658 (6.11 % of Iran population) is located in southwest of Iran. The research area lies between the 27° 02′ 00″–31° 42′ 00″ north latitude and 50° 42′ 00″–55° 36′ 00″ east longitude (Fig. 1). The average minimum and maximum temperatures in the coldest and warmest months of the year change between −2 and −7 °C and 25 and 40 °C, respectively. The research area is classified as semi-arid, with a mean annual rainfall of 306.8 mm.

Groundwater quality data were collected from 298 wells over 10 years (2000–2010) from different parts of Fars province including Shiraz, Marvdasht, Pasargad, Khorambid, Farashband, Fasa, Firoozabad, Kazeroun, Larestan, Ghir and Karzin, Mohr, Neyriz, Estahban, Arsanjan, Abadeh, and Eqlid (Fig. 1). Quality parameters were measured by the Fars rural water and waste water company on the basis of standard guidelines (APHA 2005).

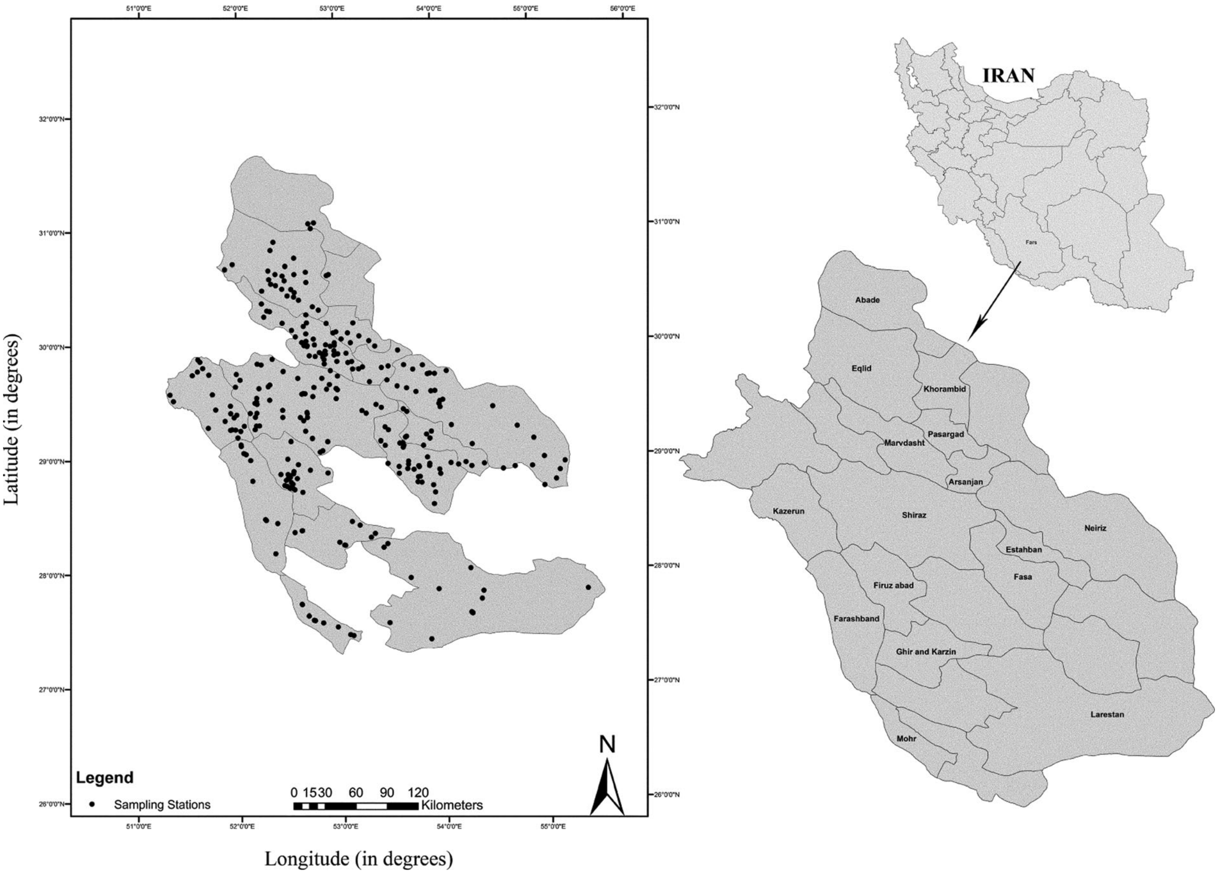


Fig. 1 Location map of the wells in study area

Data analysis

Before analyzing the data, the degree of chemical accuracy was identified as ion balance error or reaction error (RE) using the following equation:

$$RE = \frac{\sum \text{Cations-} \sum \text{Anions}}{\sum (\text{Cations} + \text{Anions})} * 100 \quad (1)$$

In Eq. (1), RE value greater than 5 % would indicate that the accuracy of data is questionable (Metcalf and Eddy 2003; Freeze and Cherry 1979). If RE is in permissive extent, Shapiro-Wilk test should be used to check the normality of data distribution (Shapiro and Wilk 1965).

Data standardization in multivariate cluster analysis is necessary because it improves homogeneity of data and this makes sure that the data are in the vicinity of the variance and ensures that all variables are weighted equally in hierarchical cluster analysis (HCA) (Daughney et al. 2012). In this research, data were normalized by the following equation:

$$Z = \frac{\left(x - \overline{x}\right)}{S} \quad (2)$$

In Eq. (2), x, $\overline{x}$, and S are unedited values, respectively, representing variable, mean and standard deviation.

The purpose of cluster analysis is classification of objects into two or more groups based on the similarity between objects with respect to a set of special characteristics. To classify the sampling stations in each year, HCA, using Euclidean distances and "Ward" method, was used. The Ward method is an alternative method for cluster analysis, which includes an agglomerative algorithm. This method is the best method for quantitative variables. The Ward method uses variance analysis to estimate the distance between clusters (Gupta et al. 2009).

The purpose of factor analysis is to describe the fundamental covariance relationships among many variables, but by latent and random factors. The main application of factor analysis is to reduce the number of variables and also the structure of the relationship between variables. The two common forms of factor analysis are R-type and Q-type factor analysis.

R-type factor analysis is used to inference a relationship between the variables, whereas Q-type factor analysis is used to consider the relationship between objects or specimens. In this research, R-type factor analysis was used to determine the sources of variability in hydro-chemical variations on the standardized data. Rotation of loading factors causes the dependence of this component to be more clear with the principal components, and detection of changes in each component can be done more easily. Rotation methods include varimax, quartimax, and equimax methods. In varimax rotation, an orthogonal rotation on the factor coefficients is done. In this research, a varimax rotation was used to maximize the difference between the factors. The Kaiser criterion was used to identify the number of main factors with eigenvalues greater than 1 (Kaiser 1960). Groundwater characterization and chemical evolutionary history were determined by plotting water quality diagrams (Schoeller 1962; Stiff 1951). These diagrams support the interpretations of the results of multivariate analysis (Yidana 2010a). The quality of groundwater for irrigation activities was plotted on United State Salinity Laboratory (USSL) diagram (Hem 1985; Richards 1954).

Results

General hydro-chemistry

The values of RE during the study period (2000–2010) were less than 5 % (Table 1). Therefore, the differences between the sum of cations and anions per year were small, indicating data suitability to analyze water quality.

Each parameter was checked for normality using the Shapiro-Wilk test (Table 2). The values of this test in all cases except magnesium (Mg) were equal or higher than 0.05, which indicates that all the parameters except Mg are normally distributed. Parameters not following the normal distribution can be used in the analysis if the skewness coefficient is less than 2 (Lix et al. 1996). Skewness of magnesium was 1.34, so all data were used in the water quality analysis.

Table 1 Reaction error (RE) values in each year

Year	Sum of cations (meq/l)	Sum of anions (meq/l)	RE (%)
2001	12.34	12.32	0.08
2002	12.71	12.80	0.35
2003	10.58	10.55	0.14
2004	11.35	11.43	0.35
2005	10.96	10.97	0.05
2006	14.35	14.56	0.73
2007	12.24	12.15	0.37
2008	12.25	11.68	2.38
2009	11.49	11.28	0.92
2010	11.85	11.96	0.46

Statistical characteristics of parameters are shown in Table 2. Based on the FAO[1] (Ayers and Westcot 1985) and WHO[2] (WHO 1993) standards, the mean value of HCO_3^-, NO_3^-, total dissolved solid (TDS), and TH for drinking purpose and the mean value of NO_3^- and electrical conductivity (EC) for irrigation purpose exceed the standards.

Percentage frequency diagram is a useful tool that can determine the most influential cation and anion (Jalali 2007). In these diagrams (Fig. 2), the percentage (vertical axis) indicates the relative concentration of each cation or anion relative to total concentration of cation or anion in terms of millimole per liter and the horizontal axis indicates the frequency of each concentration. In this research, the Ca^{+2} and HCO_3^- ions were most influential cations and anions, respectively, because of high occurrence frequencies.

Spatial clustering of sampling wells

Figure 3 shows the hierarchical cluster analysis (HCA) of clusters as dendrogram. By drawing the phenon line, the studied wells can be classified into three groups. According to this line, groups 1 and 2 are connected to each other, which indicates the similarities of these two groups. However, group 3 is quite distinct from them, which represents different values than the two other groups. The mean values of water quality parameters

[1] Food and Agricultural Organization

[2] World Health Organization

Table 2 Statistical description of the major chemical parameters

Parameters	Mean	Median	Std. dev.	Maximum	Minimum	Shapiro-Wilk test	FAO standards	WHO standards (2003)
Ca (mg/l)	83.60	72.20	2.22	403.00	13.60	0.73	420	200
Cl (mg/l)	145.91	44.38	8.01	2215.91	2.49	0.18	1065	250
HCO_3 (mg/l)	239.73	227.53	0.97	477.02	86.01	0.06	518	120
Mg (mg/l)	40.50	33.92	2.99	352.21	4.64	0.03	61	150
Na (mg/l)	100.28	29.21	8.48	1961.67	2.30	0.90	920	200
NO_2 (mg/l)	0.0003	0.0002	0.0004	0.0059	0.00	0.05	–	0.2
NO_3 (mg/l)	21.70	18.60	0.27	166.78	2.48	0.05	10	10
pH	7.97	7.96	0.15	8.44	7.55	0.09	6–8.5	6.5–8.5
SO_4 (mg/l)	162.24	86.40	4.89	1836.48	1.92	0.13	960	400
TDS (mg/l)	691.33	482.30	746.20	7426.59	139.13	0.70	2000	500
TH (mg/l)	652.14	443.41	732.28	7263.63	139.60	0.70	–	500
EC (μmho/cm)	1117.84	743.05	1232.73	12,556.58	279.50	0.14	3000	–
SAR	1.87	0.73	2.69	17.20	0.07	0.12	15	–

confirm the division of wells into three groups (Table 3). The values of most parameters were increased from the first to the third group and indicate degradation of groundwater quality (Table 3).

Figure 4 illustrates the spatial classification of wells on the basis of water quality. The wells of the first group with good groundwater quality are scattered throughout the province but not in the south. As Fig. 4 shows, the wells of the second and third groups are concentrated in the central and southern parts of the province, respectively. Therefore, in an overall view, it can be concluded that the groundwater quality has been degrading from north to south.

The Stiff diagram (Fig. 5) is used to illustrate the differences between the groups. According to Fig. 5a, which represents the values of the first group and encompasses more than 57 % of the research wells, calcium and bicarbonate are the dominant cation and anion, respectively. The second group (Fig. 5b) includes about 33 % of the wells. For the first and second groups, the type of water is Ca-HCO_3. This type of water can be the result of dissolution of carbonate minerals, weathering of silicate minerals, or inverse cation exchange, whereby the sodium absorbed to surfaces of clay mineral and calcium is released (Yidana 2010a). This water is suitable for all municipal consumptions, as indicated by most wells in the research area. Also, the similarity in water type confirms the results of dendrogram (Fig. 3). In the third group (Fig. 5c), Na-Cl is the type of water and it includes about 10 % of the wells under research. This type of water contains high levels of salt and is generally not suitable for drinking or irrigation. There are several types of water in the groundwater, and it is natural because the integration of the chemical composition with groundwater is due to the groundwater flow on different structures of geology (Miller and Gonthier 1984). The EC and TDS values are increased, moving from groups 1 to 3 (Table 3 and Fig. 5). According to Table 3, the pH values in all groups approached the neutralize border. The weathering of silicate mineral increased with the increase of pH values. The weathering of silicate mineral increased the accumulation of major cations (Yidana 2010b). The HCO_3^- and NO_3^- levels in all groups far exceeded the World Health Organization standards. High bicarbonate contents in water increase its unsuitability for irrigation. High and simultaneous amounts of bicarbonate and nitrate could be due to carbonate weathering and reflect the influence of acid-base equilibrium conditions on groundwater chemistry (Kraiem et al. 2014). In Fars province, 95 % of annual water consumption is used for agriculture (Hojjati and Boustani 2010). Jalali (2010) declared that when agriculture is the dominant land use of an area, application of N fertilizers increases the amount of nitrate in the groundwater. Freeze and Cherry (1979) showed that when surface water was charged by atmospheric and biogenic CO_2 and infiltrates into the soil, CO_2 attacks the aluminosilicates including micas and feldspars, causing liberation of Ca and Mg cations into the water.

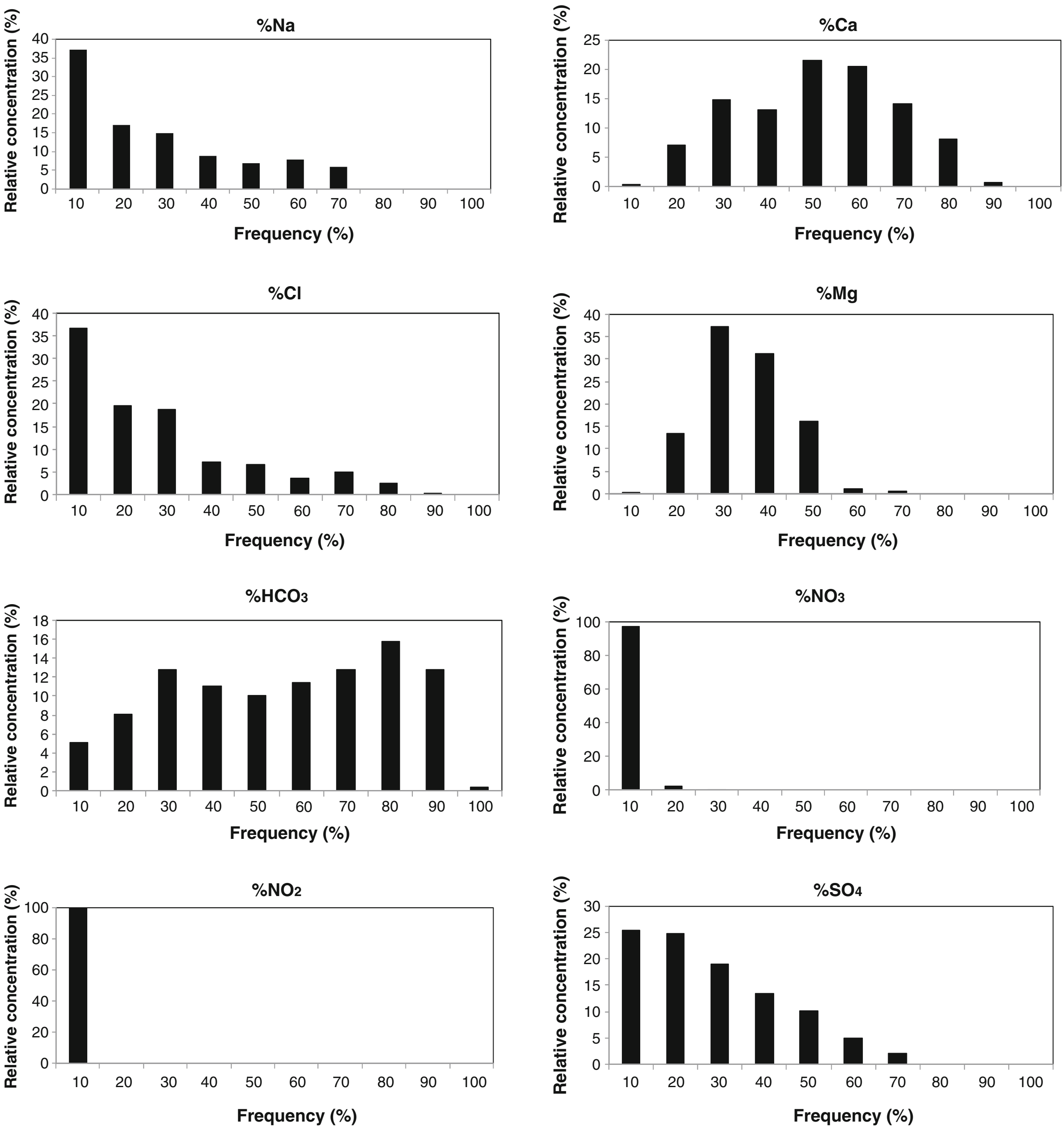


Fig. 2 Relative frequency distribution of cations and anions in groundwater samples

The mean values of chemical parameters in each group are shown in the Schoeller diagram (Fig. 6). Based on this figure, the third group has the highest levels of major elements and TDS, and also, well water of groups 1 to 3 is, respectively, suitable, acceptable, and unsuitable for drinking. According to this diagram, the differences between major ions are quite evident, causing those wells to be classified into different groups.

To investigate the possibility of using well water for irrigation purposes, the USSL diagram was used (Fig. 7). According to this diagram, group 1 showed low sodium content and medium salinity (C2-S1). This is the best water type in the research area for irrigation and can be used if moderate leaching is practiced. Group 2 lies in C3-S1 category, which means that no alkali hazard is expected to have negative effects on the crops,

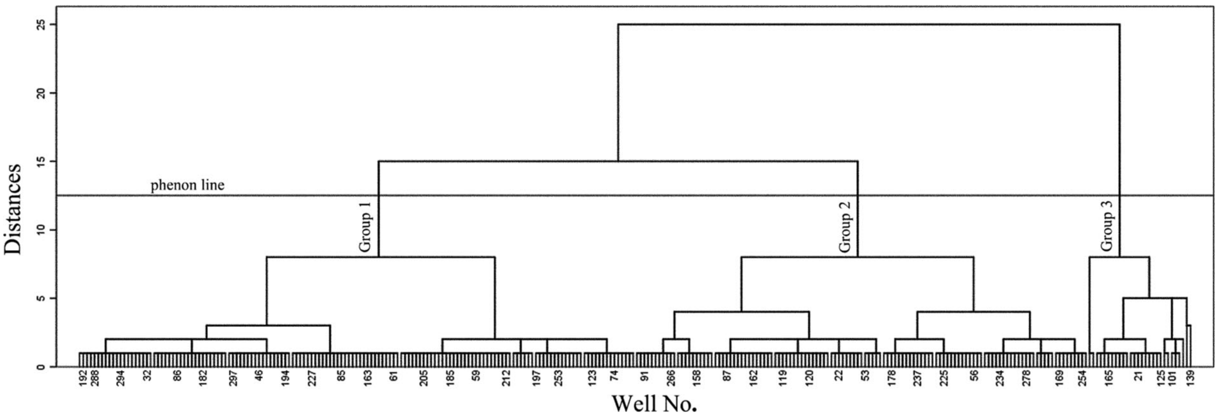


Fig. 3 Dendrogram resulting from the Q-mode HCA

but it cannot be used on soils with restricted drainage. Ostovari et al. (2015) reached close results in Marvdasht aquifer by using USSL diagram and Mamdani fuzzy inference system (MFIS). They declared that the groundwater of the aquifer has acceptable limits of salinity and sodium, and it can be used for irrigation in almost all types of soils. The group 3 lies in C4-S3 category, which implies that the well water of this group can be used only for highly permeable soils with good drainage and excessive irrigation for adequate leaching or resistant plants to salinity. Lambrakis et al. (1997) assessed the impact of drought and successive pumping on groundwater regime for Glafkos basin, western Greece. They concluded that overpumping and reduction in supply aquifer in recent decades have caused depletion of aquifers and reduction of groundwater quality. In Fars province, degradation of groundwater quality and increased salinity are due to simultaneous occurrence of droughts and excessive pumping of groundwater resources. Hojjati and Boustani (2010) showed that 37 of 57 plains in Fars province have salinity problems and 6 of them have critical salinity problems.

Multivariate analysis

In order to verify the results of the multivariate analysis, RE and the Shapiro-Wilk tests were used after computing mean values based on the entire period of each well. Based on the Kaiser criterion, three main factors were extracted for varimax rotation. Table 4 shows the percentage of total variance explained with the main components. By this table, the first, second, and third components accounted 60.72, 11.9, and 10.5 % of the total variance, respectively, but the important point is to find out which variables have high loadings in each component.

In Table 5, variables with loadings greater than 0.6 are marked in italics. In the first principal component (PC), TDS, EC, TH, Na^+, Cl^-, Mg^{2+}, SO_4^{2-}, Ca^{2+}, and SAR parameters have high positive loadings. According to high loadings for EC, TDS, Na^+, and Cl^- in PC1, the first factor would be salinity. Bencer et al. (2016) proposed that when these parameters are gathered in one factor, it reflects the effect of natural factors like dissolution of some carbonate, dolomitic, and evaporate

Table 3 Spatial clustering of sampling wells

Groups	Ca (mg/l)	Cl (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	Na (mg/l)	Mg (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	EC (μS/cm)	pH	SAR	TH (mg/l)	TDS (mg/l)	No. of stations
1	65.26	42.67	15.35	0.01	25.14	25.32	223.36	66.86	608.74	8.02	0.64	358.08	378.66	170
2	91.80	121.03	31.03	0.02	93.65	47.22	277.74	194.97	1158.83	7.91	2.02	667.16	725.74	98
3	161.03	813.35	28.88	0.02	548.35	104.09	209.88	595.25	3868.89	7.88	8.32	2269.40	2350.72	30

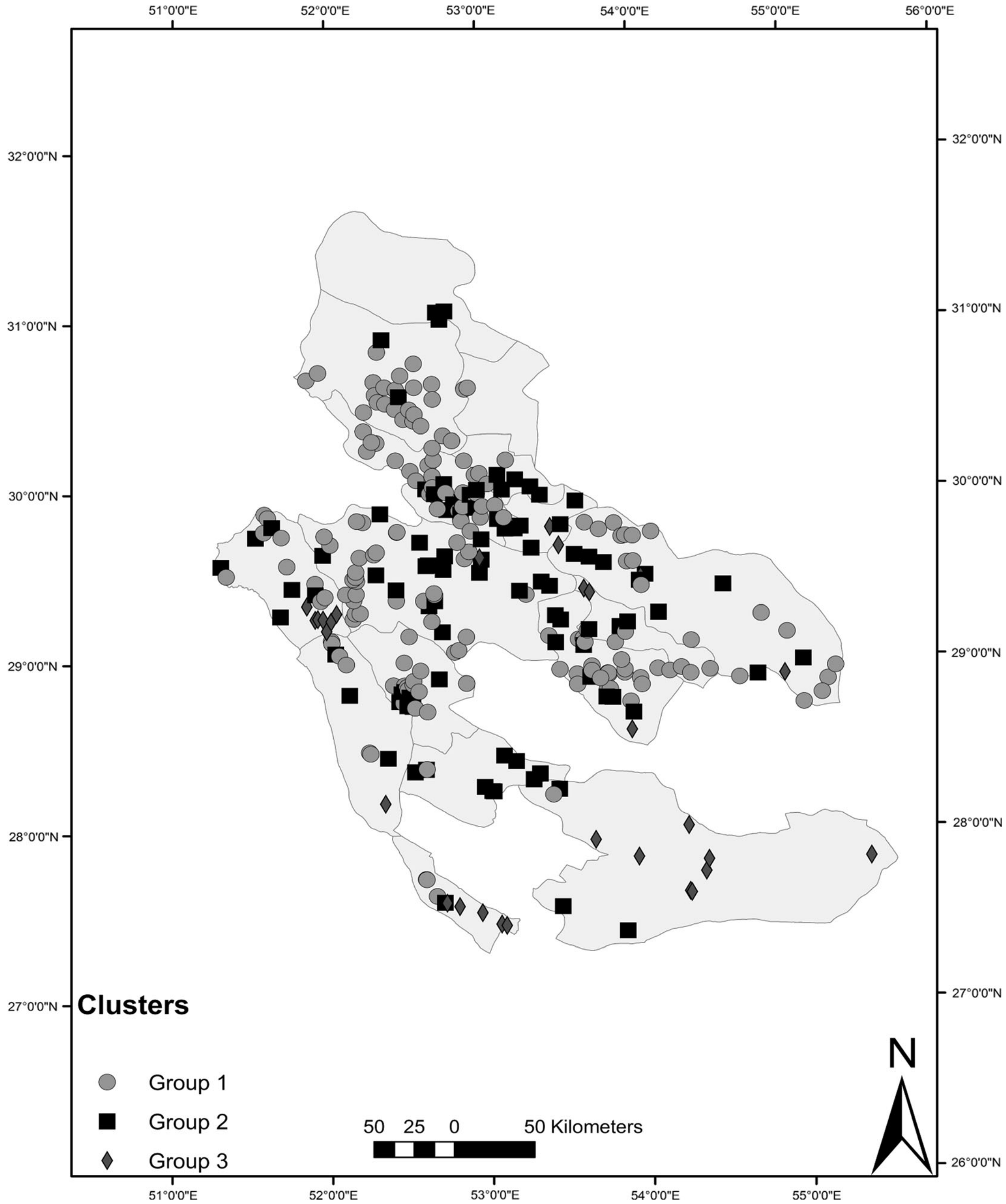


Fig. 4 Spatial clustering of sampling wells

minerals in the groundwater. In PC2, pH and HCO_3^- are the dominant parameters. More bicarbonate means more pH, so these parameters are closely related. Groundwater pH is susceptible to dissolution of carbonate minerals because of the anionic hydrolysis of the HCO_3^- ion in water (Yidana 2010a). PC3 contains high loadings for NO_2^{2-} and NO_3^{-}. This factor indicates anthropogenic contaminants that may be caused by improper disposal of domestic wastes or the use of chemical fertilizers in agriculture and leaching of nitrate from them (Jalali 2007). Mohebbi et al. (2013) applied the modified drinking water quality index (DWQI) for assessing the water quality in all of the groundwater resources that are used as the source of drinking water in urban areas of

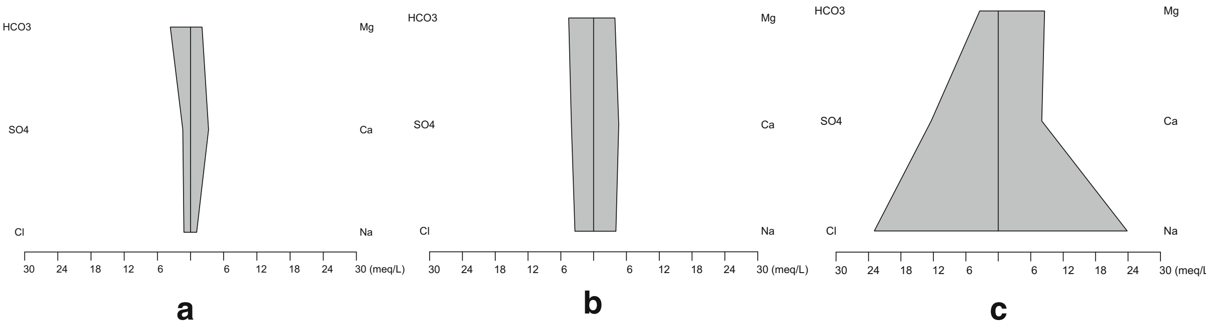
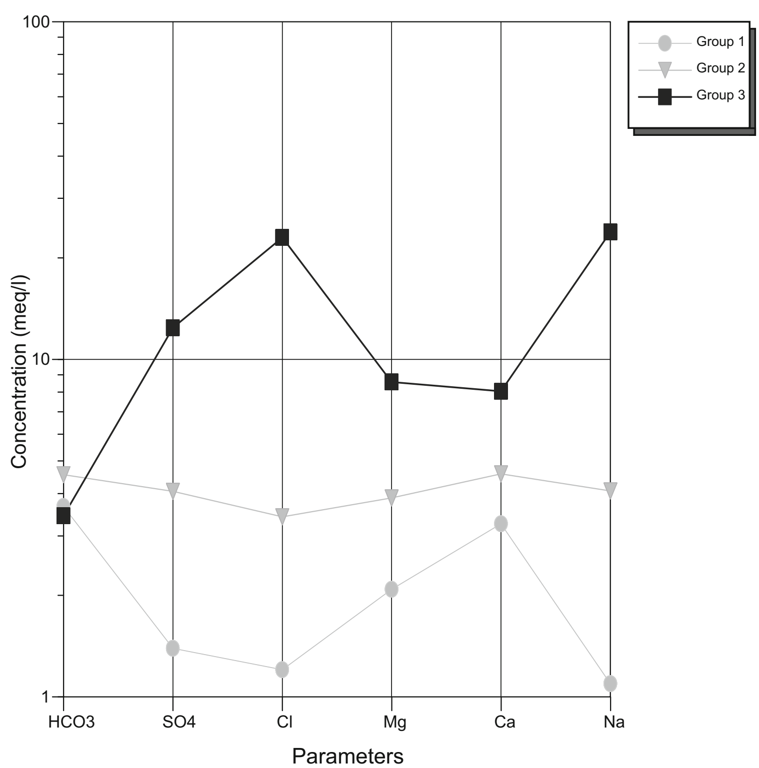


Fig. 5 Stiff diagram for cluster groups: **a** group 1, **b** group 2, and **c** group 3

Iran in 2011. They pronounced that the groundwater quality of Fars province was good and the most concerned water quality problem was high amounts of nitrate in groundwater.

To assess the better relationship between the parameters, the correlation matrix between the parameters was formed (Table 6). Strong correlation among Ca^{2+} and Mg^{2+} with TH shows that these two parameters are water hardness factors. Positive correlation of Cl^- with Na^+ and Ca^{2+} shows that in these samples, these soluble salts are dominant. Strong and positive correlation between Cl^- and Na^+($r = 0.93$) ions revealed that the existence of Na^+ ions in water is due to dissolution of halite by water (Yidana 2010a). However, Na^+ and Cl^- ions in the groundwater can come from several sources. Numerous methods have been used to identify possible sources of Na^+ and Cl^- in contaminated water. One of the most appropriate approaches is plotting ratio of halides (I^-, Cl^-, Br^-) against their own concentrations, for example, plotting the ratio of I^-/Na^+ vs. Br^- (Panno et al. 2006). In this research, the relationship between Na^+ and Cl^- was examined by drawing the scatter plot

Fig. 6 Schoeller diagram for the three clusters



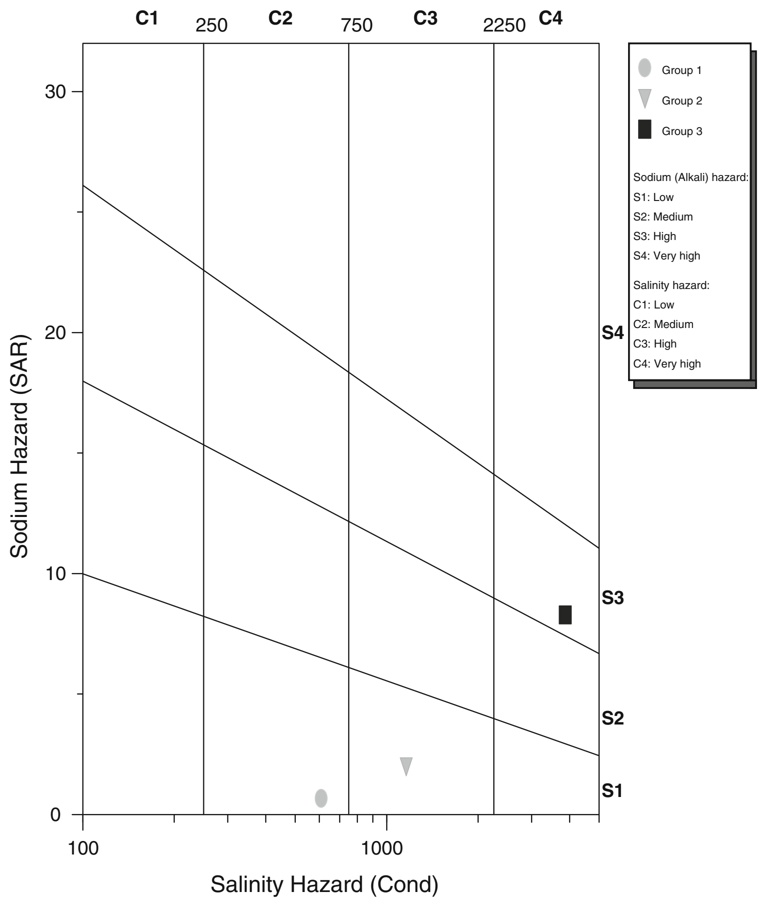


Fig. 7 USSL diagram for the three clusters

of Na^+ against Cl^- (Fig. 8). As shown in Fig. (8), most of the samples located below the 1:1 line, indicating a decreased amount of Cl^-, which may indicate silicate mineral dissolution and cation exchange. Points above the 1:1 line represent increasing chlorine concentration, which could be due to reverse ion exchange (Yidana 2010b). High positive correlation of EC with ions of Na^+, Cl^-, and SO_4^{2-} indicates the high mobility of ions. Moreover, the strong correlation between EC and TDS ($r = 0.99$) can be due to ions in TDS that conduct electricity. Strong correlation between Mg^{2+} and Cl^- ($r = 0.8$) can be as a result of domestic waste water

Table 4 Total variance explained with three principal components

Components	Total	Variance (%)	Cumulative (%)
1	7.89	60.72	60.72
2	1.55	11.89	72.61
3	1.37	10.50	83.12

Table 5 Loading factors from R-mode factor analysis with varimax rotation

Parameters	Component		
	1	2	3
Ca	*0.84*	0.34	−0.04
Cl	*0.94*	−0.02	−0.05
EC	*0.99*	0.04	0.06
HCO_3	−0.19	*0.79*	0.23
Mg	*0.90*	0.14	0.12
Na	*0.97*	−0.06	0.06
NO_2	0.02	0.02	*0.81*
NO_3	0.16	0.10	*0.75*
pH	−0.25	*0.87*	0.06
SAR	*0.87*	−0.10	0.10
SO_4	*0.87*	0.03	0.19
TDS	*0.99*	0.04	0.07
TH	*0.98*	0.01	0.10

Variables with loadings greater than 0.6 are marked in italics

Table 6 Correlation coefficient matrix of physico-chemical parameters

	Ca	Cl	EC	HCO_3	Mg	Na	NO_2	NO_3	pH	SAR	SO_4	TDS
Ca	1.00											
Cl	0.77	1.00										
EC	0.83	0.94	1.00									
HCO_3	−0.02	−0.18	−0.12	1.00								
Mg	0.83	0.80	0.91	−0.01	1.00							
Na	0.71	0.93	0.97	−0.15	0.83	1.00						
NO_2	0.03	0.03	0.08	0.16	0.10	0.08	1.00					
NO_3	0.16	0.09	0.19	0.14	0.25	0.17	0.28	1.00				
pH	−0.52	−0.22	−0.27	0.44	−0.27	−0.18	−0.03	−0.11	1.00			
SAR	0.56	0.85	0.86	−0.13	0.66	0.92	0.09	0.20	−0.15	1.00		
SO_4	0.77	0.68	0.85	−0.13	0.87	0.80	0.14	0.29	−0.22	0.69	1.00	
TDS	0.83	0.93	0.99	−0.12	0.91	0.97	0.09	0.20	−0.27	0.86	0.88	1.00

entering groundwater in this area, since municipal wastes contain salts and soaps that contain $MgCl_2$. Also, strong and positive correlation between ions of Mg^{2+} and SO_4^{2-} ($r = 0.87$) can be emanated by the use of organic and chemical fertilizers in agricultural activities in the research area. Raju et al. (2015) declared that the strong correlation between these ions might be derived from Mg sulfate mineral weathering.

Conclusions

This research represented the analysis of groundwater quality parameters of 298 wells in different parts of Fars province, whereby 14 parameters of water quality were measured during 2000–2010. According to the results of the cluster analysis, the wells can be classified into three groups. The groups 1, 2, and 3 consisted of 170, 98, and 30 wells, respectively. The type of water in groups 1 and 2 was Ca-HCO_3 and in group 3 was Na-Cl. Hydro-chemical parameters of groups 1 to 3 increased so that the third group indicated the highest values of the parameters. The quality of groundwater has been degraded from north to south.

This research illustrated that the hydro-chemical data analysis using multivariate statistical techniques such as principal component analysis, factor analysis, and cluster analysis can reveal information that, at first glance, could not be possible. Principal component analysis and factor analysis resulted in the reduction of complex and voluminous data matrix into three main components that accounted for more than 80 % of total variance. Dominant components in the first PC were TDS, EC, TH, Na^+, Cl-, Mg^{2+}, SO_4^{2-}, Ca^{2+}, and SAR parameters, which would indicate salinity as the main factor. In PC2, HCO_3^-, and pH were the dominant parameters, which may indicate weathering of silicate minerals and thereby increasing of salt. PC3 contained high loadings

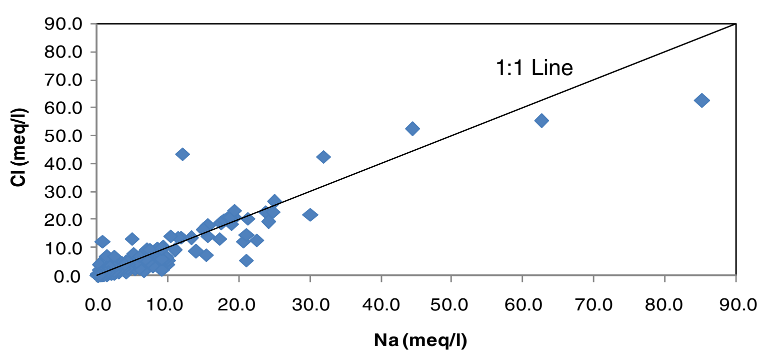


Fig. 8 Scatter plot of Na^+ (meq/l) against Cl^- (meq/l) in groundwater samples

for NO_2^{2-} and NO_3^{-}. This factor indicates anthropogenic contaminants that may be caused by improper disposal of domestic wastes or the use of chemical fertilizers in agriculture and leaching of nitrate.

The analysis of parameters using water quality diagrams showed that the predominant type of water was Ca-HCO_3 in the province that is suitable for drinking. Also, analysis obtained from irrigation plot on USSL diagram showed that the wells of the group 3, which lie in C4-S3 category, have very high salinity problems and high sodium hazard. By examining the Schoeller diagram and the effected parameters, it can be concluded that in the research area, the water of groups 1, 2, and 3 is, respectively, suitable, acceptable, and unsuitable for drinking purposes.

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