

# Multidisciplinary approach to evaluate groundwater salinity in Saveh Plain, Iran

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**Abstract** Salinity is one of the most important groundwater quality problems in arid and semi-arid regions, such as Saveh Plain, Iran. Principal component analysis and factor analysis (PCA/FA) in collaboration with structural equation modelling (SEM) revealed that  $\text{Na}^+$ ,  $\text{Cl}^-$ , EC, TDS, and salinity significantly influenced the groundwater quality in the study area. The spatial distribution map of factor score one represents high loading of salinity on the central, eastern, and south-eastern side of the plain. Groundwater quality evaluation using TDS versus total hardness suggested that around 90 % of the total samples are hard-brackish type, representing their unsuitability for drinking purposes. Ionic abundance is in the order of  $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$  and  $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$ , indicating that the groundwater facies varied from Na–Mg–Ca–Cl, Na–Mg–Cl to Na–Cl types. Hydrogeochemical evaluation showed that the salinity in the groundwater had geogenic sources mostly from the evaporitic formation in the study area. Bivariate plots of  $\text{Ca}^{2+}/\text{Na}^+$  vs  $\text{HCO}_3^-$  and  $\text{Ca}^{2+}/\text{Na}^+$  vs  $\text{Mg}^{2+}/\text{Na}^+$  supported that evaporite dissolution and silicate weathering are the major sources of the salinity process in the Saveh Plain.

**Keywords** Factor analysis · Structural equation modeling · Spatial distribution · Hydrogeochemistry · Saveh Plain

## Introduction

Water resources have played a vital role in the growth and development of human civilization. Groundwater is the primary source of water for domestic, agriculture, and industrial usage in many countries, especially in arid and semi-arid regions, and areas with rapid industrialization and urbanization. The hydrogeochemical processes responsible for the chemistry of the groundwater are an important factor determining the quality of water for different purposes (Subramani et al. 2010). Salinization is one of the most widespread forms of groundwater contamination in the world (Wen et al. 2005; Jalali 2007a; Elgettafi et al. 2013). High quality water (low salinity) should be saved for drinking, irrigation, and some specific industrial activities. Salinity and sodicity are the main water quality concerns in irrigated areas using poor water quality for irrigation purposes. However, high salinity characterizes most of the groundwater, regardless of its origin, in arid and semi-arid areas. Understanding the sources and mechanisms of the salinization process is crucial for preventing further deterioration of the groundwater resources (Farid et al. 2013). The groundwater chemistry in the arid and semi-arid areas is mostly controlled by several factors including geology, local hydrogeology-hydrology, evaporation, rock-water interaction, dissolution, deposition, rainfall, and anthropogenic activities (Kumar 2014). The amount of dissolved salt in groundwater mainly depends on the solubility of the aquifer materials that are in hydraulic connection with the aquifer. Although an understanding of

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the geochemical evaluation of groundwater is significant for the sustainable development of water resources, very limited research has been conducted in Iran to assess the chemical composition of groundwater. Numerous studies have been carried out by researchers to evaluate the origin of saline water in the world. Several salinity sources have been identified, such as evaporite dissolution (Daniele et al. 2013), saltwater intrusion from the sea (Kura et al. 2014), fossil saline water (Akouvi et al. 2008), and anthropogenic sources (Kumar 2014).

In the current study, a combination of multivariate statistical analysis, structural equation modelling (SEM), and geochemical methods are applied as useful tools to identify the sources of contamination in the study area. Geostatistical interpolation methods were also applied to analyze the spatial variability of groundwater quality parameters in the study area.

Recently, a considerable number of researchers have shown an increased interest in the use of geochemical methods and multivariate statistical analyses to evaluate the groundwater chemistry and salinity (Reghunath 2002; Cloutier et al. 2008; Kumar 2014). Multivariate statistical analyses, such as principal component analysis/factor analysis (PCA/FA) were carried out to establish a large groundwater quality dataset without losing important information. Moreover, it can play a significant role in evaluating the hydrochemical characteristics of groundwater (Cloutier et al. 2008). Mondal et al. (2010) tested the hypothesis that groundwater major ions chemistry can be employed to determine the interaction between the groundwater and saline water along the southern coast of India. The results from hydrochemical processes and factor analysis highlighted that the intrusion of seawater was identified using ionic changes. Kumar (2014) combined geochemical methods with factor analysis to understand the natural and anthropogenic influences on groundwater quality in Vaniyambadi industrial area, in South India.

Structural equation modelling describes multiple relationships among a number of latent variables by integrating multivariate techniques such as measurement theory, regression, factor analysis, and simultaneous equation modelling (Malaeb et al. 2000). Although SEM has been widely used in social sciences and psychological studies (Ko and Stewart 2002; Cole and Maxwell 2003; McNeill et al. 2006), very limited studies have applied it in natural sciences and environmental research (Belkhiri and Narany 2015; Mustapha and Aris 2012). In SEM one latent variable can be a dependent variable in one set of relationships and at the same time can be an independent variable in another set, which is considered to be an advantage of this method (Tenenhaus 2008). Belkhiri and Narany (2015) used SEM to confirm the grouping of parameters resultant

by factor analysis and one-way analysis of variance in the Ain Azel Plain, Algeria.

This study focuses on the groundwater salinity assessment, which provides information about the current status of the groundwater quality and also identifies the possible sources of salinity for future prediction of areas affected by salinity. Therefore, the objective of this study was to investigate the groundwater quality evaluation process and identify the sources of salinity in the groundwater of Saveh Plain, Iran, using multivariate statistical analysis, SEM, geostatistical technique, and geochemical methods.

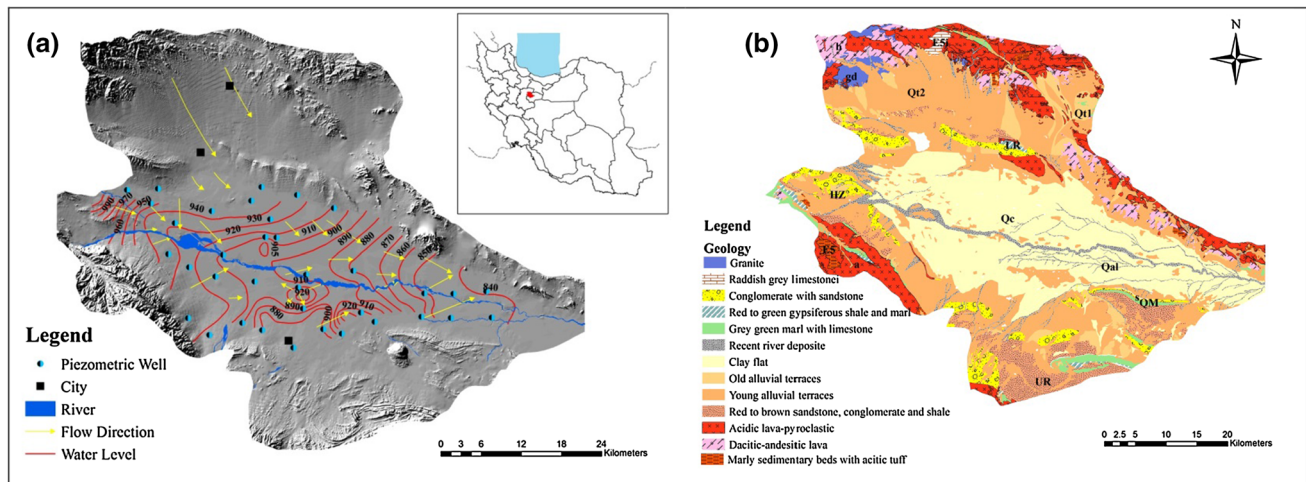
## Materials and methodology

### Study area

Saveh Plain, with an area of 1065 km<sup>2</sup>, is located in the Markazi Province, Iran, between longitude 34 45–35 06 and latitude 50 15–50 51 (Fig. 1a). Saveh is a typical arid and semi-arid area in Iran. The annual average rainfall is approximately 191 mm, which mostly occurs from October to May. October is the wettest month with a mean monthly humidity of 58 % and May and June are the driest months with a mean humidity of 26 %. The mean monthly temperature varies between 31.5° in August and 5.7 in February. The annual potential of evaporation is around 1300 mm, which far exceeds the annual rainfall in the study area (Fakharian 2010).

This region is typified by geological formations ranging from volcanic formation from Eocene to recent alluvium (Fig. 1b). Volcanic formations in the study area are comprised mainly of tuff, lava fan deposit, andesitic lava flows and their interaction with marl sediments. Overlaying this volcanic basement follows a series of red and dark grey shale, marl, with interaction of sandstone, salt and gypsum, which is called the lower red formation (LRF). The Qom formation belonging to the Oligo Miocene overlies the LRF sedimentary deposit with grey marl and sandy limestone. The formation is white-yellow in colour and generally differentiated from the LRF the upper red formation (URF) overlies the Qom formation, with red marl and grey-red sandstone and conglomerate inter lavas. This formation is covered with a thick Pliocene conglomerate. In addition, quaternary deposits are recognized by the alluvial sediment extended along the streams, alluvial fans and salt domes (Aghanabati 2004).

Groundwater is preserved and flows in the alluvial stream in the Saveh Plain. An unconfined aquifer is extended in the recharge zone on the north-western side of the plain. However, sequences of clay layer, sandy and loamy layers have changed the aquifer to a confined aquifer in the central and eastern parts of the study area. The



**Fig. 1** a Schematic map of Iran showing the study area Saveh Plain, b Geological map of Saveh Plain

groundwater level contour lines show a general trend towards the NW–SE direction, which happens to be the flow direction of the Ghare Chay River. However, local groundwater flow was observed in the southern part of the plain. The aquifer reaches maximum thickness of 360 m in the centre of the plain, along the Ghare Chay River. There are approximately 1311 wells in the aquifer. The water abstraction from the Saveh Plain during 2008–2009 was around 315 million m<sup>3</sup>, which was mostly used for irrigation purposes (Fakharian 2010).

**Groundwater sampling and analytical techniques**

A total of 58 groundwater samples were collected from the representative wells during 2009. All 58 wells were deep wells with a depth ranging from 25 to 180 m. Samples were stored in polyethylene bottles and kept at less than 4 °C in a refrigerator and were analyzed within 24 h (APHA 2005). The pH, TDS, EC, DO, salinity measurements were carried out on site using a multi-parameter WP 600 series meter. The ionic concentration of Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, CO<sub>3</sub><sup>2-</sup>, and HCO<sub>3</sub> were determined by volumetric titration. A UV visible spectrophotometer was used for analysis of sulphate. Potassium and sodium were analysed using a flame photometer. Quality assurance and quality control were enforced to obtain reliable data; for example a blank test was carried out and calibration curves were constructed for the water quality parameters. The accuracy of the results for all the samples was within ±10 %.

**Principal component analysis and factor analysis**

PCA/FA of the hydro-chemical data is performed using SPSS to analyze interrelationships among a large number of variables to explain these variables in terms of their

common underlying dimension by providing empirical estimates of the structure of the variables (Singh et al. 2004). The method provides information on the most meaningful parameters, which describe a whole dataset by data reduction with minimum loss of original information (Varol and Sen 2009). As the first step, the R-mode is applied to create a correlation matrix. Then the principal components are extracted based on the Eigen values. Kaiser (1958) suggested choosing Eigen values greater than 1. The extracted components could be rotated to obtain better results. The first factor is specified by the highest Eigen value, which explains the largest variation in the data set. Kaiser–Meyer–Olkin (Kaiser 1974) is applied for the applicability of factor analysis on a particular data set.

**Structural equation modeling**

Structural equation modeling (SEM) is a multivariate statistical methodology that encompasses factor and path analysis (Arhonditsis et al. 2006). The concept of SEM was first introduced nearly 80 years ago by the population biologist Wright (1934), and later developed by Joreskog in 1973. SEM is used as a confirmatory technique rather than exploratory, which is used to confirm a model rather than to discover a new model and modeled processes pictorially to enable a clearer conceptualization of a theory under study (Mustapha and Aris 2012). Although, PCA has also the ability to reduce a set of correlated variables to higher order components, it has a limited flexibility to specify the model structure prior to the analysis and does not account for measurement error (Arhonditsis et al. 2006). SEM is a priori statistical technique, where the modeler proposes and tests a hypothesized structure that reflects existing knowledge. The model assumes that there is an underlying

mechanism, which leads to a theoretical covariance structure between a vector of random variables (Malaeb et al. 2000). However, the model structure itself can be rejected as inappropriate if the structure of the data does not conform to the proposed model structure.

In general, this analytical approach involves a two-step process: (a) hypothesized the observed variables to measure the underlying constructs and tested using confirmatory factor analysis and (b) tested hypotheses about relationships among the variables in the structure model.

SEM provides overall tests of the model fit, while the individual parameters estimate simultaneously tests the regression coefficient, mean, and variance (Mustapha and Aris 2012). The Chi square test is one of the statistical models that is used to test if the data support the proposed model. Moreover, SEM specifies different indices, including comparative fit index (CFI), Tucker Lewis index (TLI), and root mean square error of approximation (RMSEA) to assess the model fit.

The SEM in this research was conducted using the software package AMOS to test a confirmatory model theory on how salinity contributes significantly to the overall water quality in the Saveh Plain.

### Geostatistical interpolation methods

Geostatistics is a class of statistics applied to analyze and predict the values associated with spatial or spatiotemporal phenomena. Interpolation techniques are a powerful approach with the ability to reliably estimate and present the spatial distribution from a sampling point (Assaf and Saadeh 2008). Kriging is a linear appropriate interpolation method with a minimum square error, which measures the average degree of dissimilarity between the unsampled value and a nearby data value by experimental variogram. Therefore kriging can depict the autocorrelation at various distances. The general equation for the kriging method is as follows:

$$Z^*(xp) = \sum_{i=1}^n \lambda_i Z(x_i)$$

where  $Z^*(xp)$  is the kriged value at location  $x_p$ ,  $Z(x_i)$  is the known value at location  $x_i$ ,  $\lambda_1 \dots \lambda_m$  are a set of weights obtained by solving the ordinary kriging system.

## Results

### Factor analysis of the hydrogeochemical data

Factor analysis (FA) was actually performed for differentiating the various processes acting on the

hydrogeochemistry, which reduced the multidirectional dataset to three possible factors (Table 1). Eigenvalues greater than one were taken as the criterion for extraction of the factor loading required to explain the sources of variance in the data-set (Iscen et al. 2008). Preliminary analysis prior to factor analysis was conducted to ensure that no violation of the assumption of Kaiser–Meyer–Olkin (KMO) is imposed on the sampling adequacy as well as Barlett’s test of sphericity. The KMO result was 0.730, and Bartlett sphericity test was significant (0.000,  $p < 0.05$ ), showing that factor analysis could be considered appropriate and useful to provide significant reduction in data dimensionality (Liu et al. 2003; Mustapha and Aris 2012).

A total of 20 parameters were included in the factor analysis and were classified as three major factors explaining around 70 % of the total variance (Table 1). The first varimax factor loading (VF1) explained around 45 % of the variance in the total hydrogeochemical dataset, by high factor loading for EC, Salinity, TDS,  $Mg^{2+}$ ,  $Ca^{2+}$ ,  $CaCO_3^-$ ,  $MgCO_3^-$ ,  $Na^+$ , and  $Cl^-$ . This factor indicates that the groundwater quality was strongly influenced by saline water in the study area. Salinity, EC, and TDS have a

**Table 1** Factor loading results

Parameter	Factor		
	1	2	3
pH	-.176	-.156	.399
EC	<b>.929</b>	.214	-.083
DO	-.161	-.200	<b>.675</b>
TDS	<b>.820</b>	.175	.046
Salinity	<b>.926</b>	.237	-.078
$K^+$	.230	-.115	-.211
$Mg^{2+}$	<b>.665</b>	.466	-.094
$MgCO_3^-$	<b>.684</b>	.490	-.166
$Ca^{2+}$	<b>.652</b>	.268	.211
$CaCO_3^-$	<b>.679</b>	.254	.170
$CO_3^{2-}$	-.058	.033	<b>.834</b>
$HCO_3^-$	.079	.016	<b>-.816</b>
$SO_4^{2-}$	.166	-.279	-.065
$NO_3^-$	.374	-.161	<b>.543</b>
$PO_4^{3-}$	.162	-.250	-.065
$Cl^-$	<b>.852</b>	-.205	-.136
$Na^+$	<b>.927</b>	.093	-.055
COD	.262	<b>.870</b>	-.007
BOD	.234	<b>.891</b>	-.125
Eigen values	6.525	2.640	1.247
% Variance	44.86	13.45	11.86
Cumulative %	44.86	58.31	70.17

Bold values indicate strong and moderate loading

very high correlation of ( $r \cong 0.900$ ,  $p < 0.05$ ) with one another and very high and moderate correlation with  $\text{Na}^+$ ,  $\text{Cl}^-$ ,  $\text{Mg}^{2+}$ , and  $\text{Ca}^{2+}$  ( $r = 0.899$ ,  $r = 0.735$ ,  $r = 0.702$ , and  $r = 0.692$ ,  $p < 0.05$ ), respectively, suggesting that salinity, EC, and TDS are conducted by these ions. The Na–Cl relationship has often been used to identify the mechanisms for acquiring salinity and saline intrusions in arid and semi-arid regions (Jalali 2007a). The second VF1 is characterized by the strong loading of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), which accounts for 13.5 % of the total variance. The BOD is used as an experimental measure of the amount of the biochemically degradable organic matter present in a water sample (Hanipha and Hussain 2013). The BOD values changed from 1 to 28.15 mg/L in the groundwater of the study area. The natural BOD value is around 1 mg/L, which occurs by organic decaying leaves and animal wastes. BOD values in excess of 10 mg/L indicate the presence of sewage pollution (EPA 2001).

The oxygen required for the chemical oxidation of organic matter is measured by COD, which varied from 1 to 64 mg/L in the study area. A high COD may cause oxygen depletion on account of the decomposition of microbes to a level detrimental to aquatic life. The inverse relationship existing between BOD and DO ( $r = -0.230$ ,  $p < 0.05$ ) is due to an increase in the bacterial population, which results in a heavy BOD and decreasing DO concentration. The runoff of untreated domestic and agricultural waste into the groundwater could be responsible for high organic pollution, and lead to high BOD and COD values.

The third VF1 is characterized by the strong loading of DO,  $\text{CO}_3^{2-}$ , and  $\text{HCO}_3^-$ , which account for 12 % of the total variance. Alkalinity in most natural groundwater is mainly derived from the dissolution of carbonate or silicate minerals.  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  have a negative correlation ( $r = -0.611$ ,  $p < 0.05$ ), indicating that the increased concentration of  $\text{HCO}_3^-$  will decrease the concentration of  $\text{CO}_3^{2-}$ . The relations between  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ , and  $\text{H}_2\text{CO}_3$  are controlled by pH and temperature. In the Saveh Plain, where the pH varied in the natural values range (6.6–8.0), bicarbonate is the dominant ion. Although the existence of bicarbonate and carbonate ions in water can remove toxic metals by precipitation, a high amount of alkalinity in water is harmful for irrigation by soil damage and reduces crop yields (Hanipha and Hussain 2013).

For further clarification, the factor score of each sample was interpolated using ordinary kriging (Fig. 2). The spatial distribution map of factor score one shows that the groundwater salinity increases from the west, north-west, and south-west to the centre and eastern part of the study area; this may be attributed to the salt-gypsum geological formations of upper and lower red in Fig. 2a. Although the

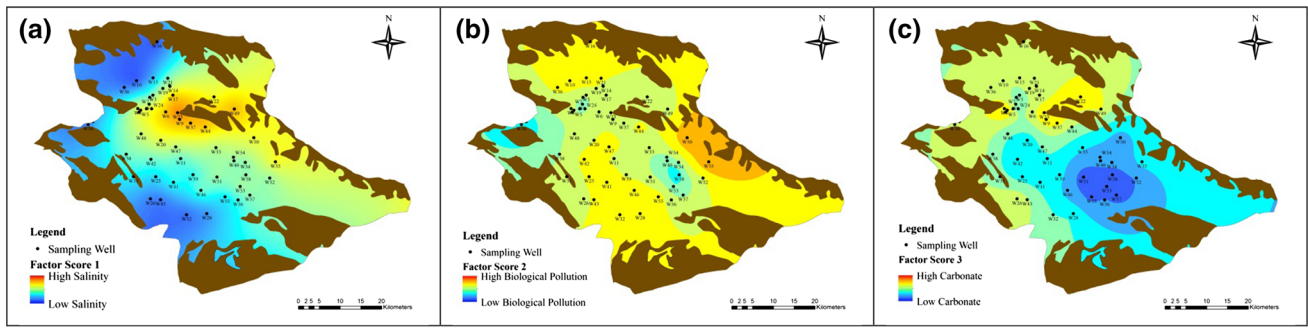
BOD and COD concentrations of around 61 % of sampling wells exceeded the permissible limits, the second factor score shows a higher loading from the northern and southern side towards the eastern side of the plain (Fig. 2b). Factor score 3 has a higher loading mainly in the elevated and recharge areas in the north, south, and west side of the plain.

### Confirmation of impact of salinity on water quality

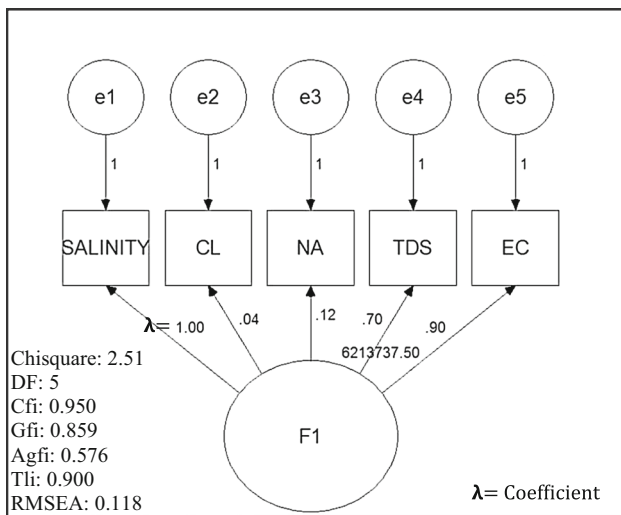
Structural equation modeling using analysis of moment structure (AMOS) is employed to confirm the grouping of salinity factors including  $\text{Na}^+$ ,  $\text{Cl}^-$ , EC, TDS, and salinity revealed by PCA/FA as the most statistically important variables. The model is tested using goodness-of-fit, to determine if the pattern of variance and covariance in the data is consistent with the structural pass.

In this study, the null hypothesis is stated: salinity has no effect on water quality variation while the alternative hypothesis is stated as: salinity has a positive effect on water quality variation. The graphical relationship between exogenous and endogenous is presented in Fig. 3. Several conventions are used in developing SEM model. Measured variables (exogenous) and factors (endogenous) are represented by squares and circles, respectively). Moreover, lines indicate relations between variables and a line with one arrow represents a hypothesized direct relationship between two variables. Regression weight of exogenous variables shows that all salinity parameters are significant at  $p < 0.001$  (Table 2). The result shows that RMSEA is 0.118 (Table 3), and based on these results the fit is acceptable. Hu and Bentler (1999) suggested RMSEA  $< 0.2$  as a cut-off for a good fit. However, the exact values for the cut-offs can be considered arbitrary (Fan et al. 1999).

The goodness of model fit indicators used to analyze the results included, Chi square divided by the freedom ( $C_{\text{MIN}}/df$ ) as a measure of minimum sample discrepancy. The result of the Chi square ( $C_{\text{MIN}}$ ) is  $12.591/5 = 2.51$ , which shows that the model fits (Table 3). Arbuckle (1999) suggested that any value less than 5 is an indicator of an adequate fitting model. The Bentler CFI vary from 0 to 1; a CFI close to 1 indicates a very good fit (Fan et al. 1999). The result shows that the value of CFI is 0.95 (Table 3), indicating that 95 % of the covariation in the data can be reproduced by the given model. The TLI are relatively independent of sample size and range from 0 to 1. The TLI indicates that  $\chi^2/df$  ratio for the null hypothesis is less than the ratio for a given model. The result of the TLI of this model is 0.90 (Table 3). Hu and Bentler (1999) suggested TLI  $> 0.80$  as a cut-off for good model fit.



**Fig. 2** Spatial distribution of factor scores in the study area; **a** Factor 1, **b** Factor 2, **c** Factor3



**Fig. 3** Structural model of the study

**Table 2** Regression weights of salinity parameters

		Estimate	SE	CR	p
Salinity	F1	1			
Cl	F1	0.045	0.005	8.464	***
Na	F1	0.123	0.008	15.272	***
TDS	F1	0.696	0.065	10.727	***
EC	F1	0.899	0.006	148.08	***

SE standard error

\*\*\*  $p < 0.0001$

### Hydrogeochemistry and water type

#### Classification of water type

Electrical conductivity (EC) can be an indicator of water type based on Wilcox and Durum (1967). Electrical conductivity in the Saveh groundwater varied from 647 to 9439  $\mu\text{S}/\text{cm}$ , with an average of 4142  $\mu\text{S}/\text{cm}$ . Based on Table 4, about 39.7 % of groundwater samples were

within doubtful limit, 34.5 % were unsuitable, 24.1 % were permissible, and 1.7 % were good. Based on the Na %, the majority of samples (around 65.5 %) were classified in doubtful classification, 25.9 % were permissible, 6.9 % were unsuitable and only 1 sampling well was shown to be good according to the classification (Table 4). According to Richards (1954), water samples can be classified on the basis of sodium adsorption ratio (SAR) into four classes, which shows that around 70.7 % of groundwater samples have excellent SAR concentration. Moreover, Richards (1954) classified water samples based on the residual sodium carbonate (RSC), showing carbonate and bicarbonate problems for water. According to the RSC classification, 96.6 of sampling wells showed good condition, and only two sampling wells were classified as being in bad condition. In general, it seems that salinity is the major problem in most sampling wells in the Saveh Plain.

#### Groundwater facies

The dominance of major ion chemical parameters were in the order of  $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$  and  $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$  for cations and anions, respectively. Therefore, the chemical composition of the groundwater was characterized by the Na–Cl water type (Fig. 4a), which could be supported by the mean TDS value being greater than 3200 mg/L and an average EC of around 4100  $\mu\text{S}/\text{cm}$ , which represent the brackish to saline water type. Moreover, a detailed classification of groundwater quality based on the TDS and total hardness TH, confirmed that almost 84.4 % of the samples were classified as hard-brackish water type (Fig. 4b). Two sampling points (No: W10 and W36) located on the north-western side of the plain showed soft-fresh water; this is mainly because they are near to the recharge zone covered with tuff and tuffaceous limestone. Five more sampling wells (No: W16, W14, W30, W32 and W12) near the recharge zones on the north, south and western sides of the study area show hard-fresh water type. Groundwater quality in the remaining sampling wells

**Table 3** Model fit summary

Statistical test	Goodness of fit standard or threshold value of AMOS program
Absolute goodness of fit index	
$C_{MIN}$	2.51
GFI	0.859
AGFI	0.576
RMSEA	0.118
Incremental goodness of fit index	
NFI	0.942
RFI	0.885
IFI	0.951
TLI	0.900
CFI	0.950
Parsimony goodness of fit index	
PCFI	0.475
PNFI	0.471

change to brackish water type towards the discharge zone on the eastern side.

Dominant ions were considered to evaluate the groundwater facies using a piper plot. Based on the piper diagram, groundwater facies range from  $Na^+Mg^{2+}Ca^{2+}Cl^-$  to  $Na^+Mg^{2+}Cl^-$  and  $Na^+Ca^{2+}Cl^-$  to  $Na^+Cl^-$  type. The majority of the plain (35.3 %) is covered with the Na–Mg–Cl and Na–Mg–Cl–SO<sub>4</sub> types, due to the existence of limestone and sedimentary evaporate rocks in the recharge zones. However, in the lower topographic region water is dominated by the  $Na^+Cl^-$  type, representing the discharge zone. Evaluation of the water type suggests that there is a clear indication of the contribution from the weathering and dissolution of evaporate rocks, such as the gypsy and salty rocks of upper and LRFs and limestone belonging to the Qom formation in the study area (Fig. 4c).

The application of a Durov diagram as an alternative to a piper diagram indicates the dominance of major ions  $Na^+$ ,  $Cl^-$ ,  $Mg^{2+}$ , and  $Ca^{2+}$ . In the Durov diagram, the water plots are close to the line of dissolution of rock-matrix minerals or mixing with other types of water (Fig. 4d). The wide diversity of salinities ranging from about 596 to 10370 mg/L, and increasing in the concentration of  $Na^+$ ,  $Cl^-$ ,  $Mg^{2+}$ , and  $Ca^{2+}$ , indicate the dissolution of evaporites, carbonates, or silicate weathering rather than mixing with other groundwater.

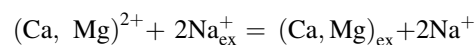
*Source of salinity*

The lithology, velocity, quantity of groundwater flow, natural geochemical process, and human activity influence the

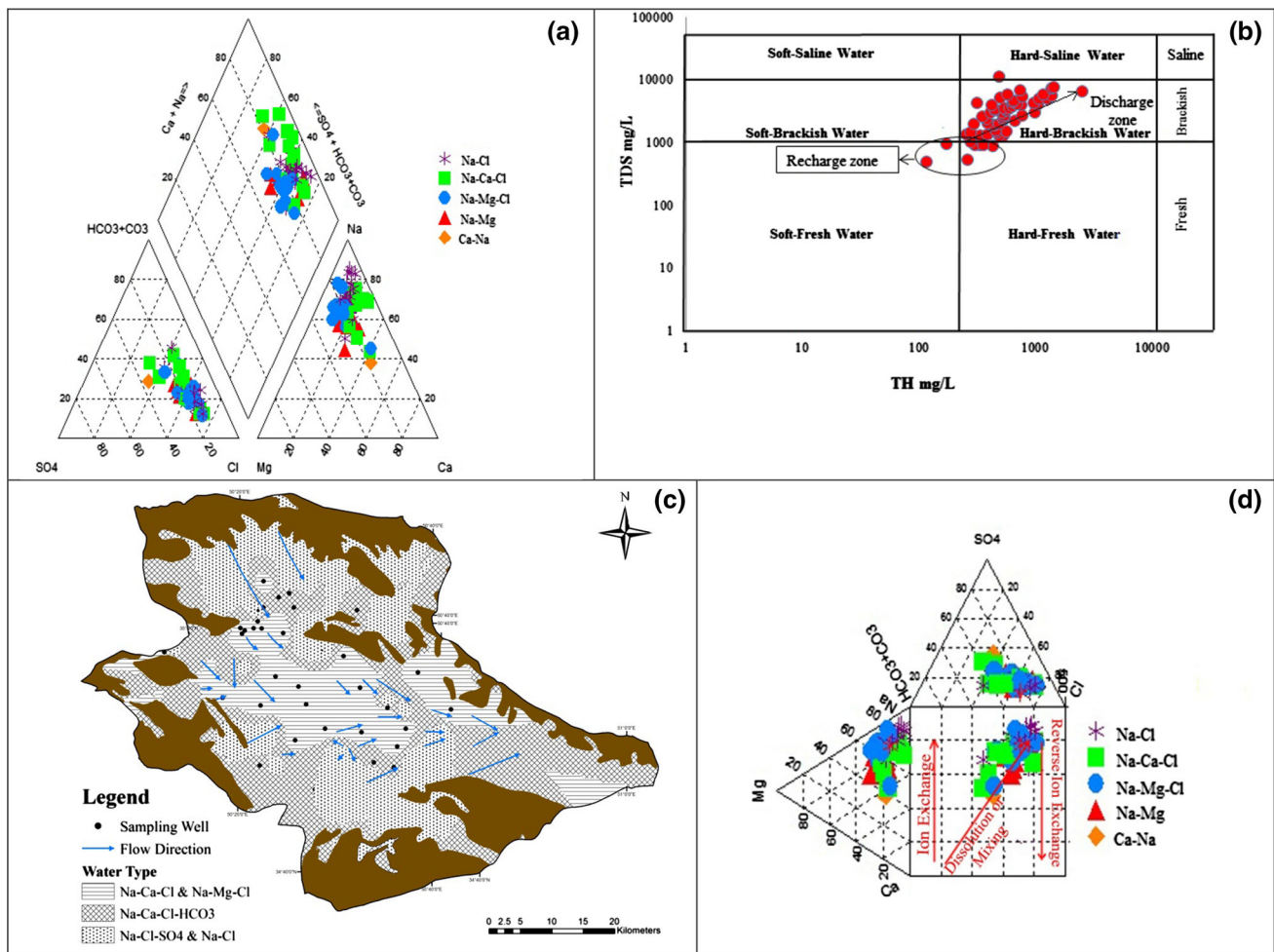
**Table 4** Water type classification

Parameter	Category	Range	Percent of samples
EC (Wilcox and Durum 1967)	Excellent	<250	–
	Good	250–750	1.72
	Permissible	750–2250	24.1
	Doubtful	2250–5000	39.7
Na % (Wilcox and Durum 1967)	Unsuitable	>5000	34.5
	Excellent	0–20	–
	Good	20–40	1.72
	Permissible	40–60	25.9
RSC (Richards 1954)	Doubtful	60–80	65.5
	Unsuitable	>80	6.9
	Good	<1.25	96.6
	Medium	1.25–2.5	1.7
SAR (Richards 1954)	Bad	>2.5	1.7
	Excellent	0–10	70.7
	Good	10–18	27.6
	Fair	18–26	1.7
	Poor	>26	–

concentration of dissolved ions in the groundwater. Sodification and salinization are often associated with irrigated regions, where high evapotranspiration rates, low precipitation, or soil textural characteristics prevent the washing of salts out of the soil, subsequently building up in the surface. Sodium is the dominant ion which can result from silicate weathering and/or dissolution of evaporite (Sheikhy Narany et al. 2014). The relation between sodium and chloride could be used to identify the source of salinity. The high concentration of  $Na^+$  and  $Cl^-$  detected in the groundwater samples may be attributed to the dissolution of chloride salts (Jalali 2007b), which can be released by an equal concentration of  $Na^+$  and  $Cl^-$  in the solution. The  $Na^+Cl^-$  diagram shows that  $Na^{2+}$  increases linearly with  $Cl^-$  along the  $Na^+Cl^-$  1:1 line in more than 20 % of the samples. The results may be indicative of the weathering of rock rich in NaCl (halite), which is highly soluble and easily dissolved. Although there is a correlation between  $Na^+$  and  $Cl^-$  ( $r = 0.83$ ) in groundwater samples, the average molar ratio of  $Na^+/Cl^- = 1.81$  indicates an excess of Na over Cl. Around 80 % of samples show  $Na^+/Cl^-$  ratio greater than one, which could be explained by different reasons: (a) dissolution of evaporate mineral, (b) the importance of water–rock interaction, and (a) Ca–Na exchange:



The average of the  $Na^+/Ca^{2+}$  molar ratio is 0.24, showing that  $Na^+$  was dominant over  $Ca^{2+}$ . The result indicates that a  $Ca^{2+}/Na^+$  ion exchange process or



**Fig. 4** Groundwater facies based on the; **a** Piper diagram, **b** TDS vs TH diagram, **c** spatial distribution map, **d** Durov diagram

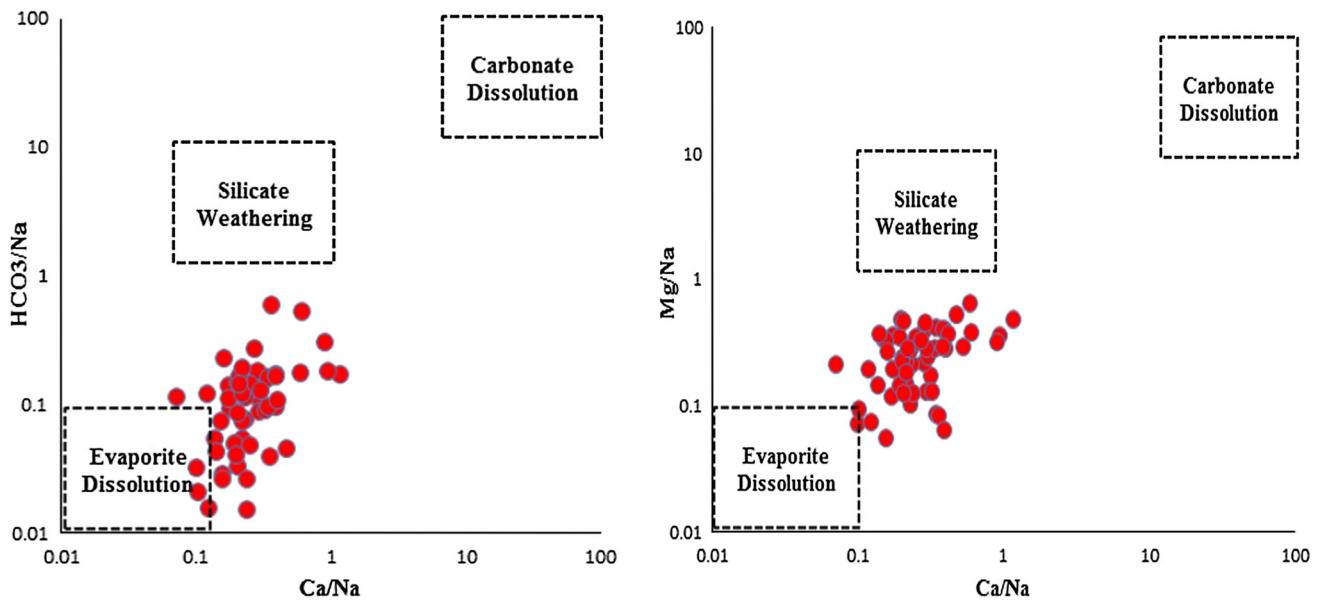
possibly due to evaporation leading to an increase in the Na content in the groundwater (Reddy and Kumar 2010). The weathering of clay and feldspar in the volcanic formations is one of the sources of sodium and potassium in groundwater in the study area. The most important cation exchange processes are those involving sodium–calcium and sodium–magnesium, mostly occurring in clay rich semi-confining layers that can cause magnesium and calcium reduction. Moreover, there are many salt sequences composed of oligo-miocene salt located in central of Iran, including Saveh and Qom Plain, which dissolves to leave behind layers of salt dissolutions residues in contact with under saturated waters. There are numbers of gypsum layers, which are typically remnants of a salt layers, at the stage where all the halite has dissolved to leave behind a carapace of gypsum and clay residues. The plots of  $Ca^{2+}/Na^{2+}$  vs  $HCO_3^-/Na^+$  and  $Ca^{2+}/Na^+$  vs  $Mg^{2+}/Na^+$  also support the groundwater argument of silicate weathering and dissolution of evaporite. According to Fig. 5,

evaporation dissolution and silicate weathering are found to be the major processes controlling the groundwater solute content.

The average ratio of  $Na^+ + K^+ / Cl^-$  is 1.88. The excess of  $Na^+ + K^+$  over  $Cl^-$  is because of the greater resistance of  $K^+$  to weathering and its fixation in clay minerals. The dominance of  $Na^+$  suggests that the ions result from the weathering of silicate and/or dissolution of soil salts, and also reflect the higher concentration of alkalis from sources other than precipitation (Wen et al. 2005). The  $Ca + Mg / Na + K$  molar ratio in the silicate of the upper crust is generally 1.0 (Taylor and McLennan 1985). The ratio which is  $>1$  in about 8.9 % of the samples and the average being 0.58, reflects that the contribution of cations via alumino-silicate weathering is high in comparison to carbonate weathering.

Based on the ionic ratio results, it could be concluded that the existence of evaporate-sedimentary formations, salt sequences, silicate and feldspar rocks in the south, west and northern side of the study area (recharge zones) play a





**Fig. 5** Bivariate plot  $Ca^{2+}/Na^+$  vs  $HCO_3^-/Na^+$  and  $Ca^{2+}/Na^+$  vs  $Mg^{2+}/Na^+$  to identify the minerals weathering in groundwater of study area

significant role in reducing the groundwater quality by increasing the salinity.

**Conclusions**

Groundwater salinity is a widespread problem in arid and semi-arid areas, such as the Saveh Plain, which causes health problems, decreases agricultural yield and increases the cost of water purification. In this study, the integration of multivariate statistical analysis, SEM, geostatistical techniques, and geochemical methods was applied to assess the groundwater quality and identify the possible sources of salinity in Saveh Plain. Based on the results, it could be concluded that:

- The application of PCA/FA revealed that  $Na^+$ ,  $Cl^-$ , EC, TDS, salinity,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $CaCO_3^-$ , and  $MgCO_3^-$  play a significant role as a first loading factor in the groundwater quality in the Saveh Plain.
- The geostatistical interpolation technique indicated that the central, eastern, north-eastern, and south-eastern sides of the plain are mostly influenced by salinity as the first factor loading.
- The SEM was applied to confirm the grouping of parameters revealed by the factor analysis. SEM revealed good fit indices between EC, TDS,  $Na^+$ ,  $Cl^-$ , and salinity, confirming the variation in water quality in the Saveh Plain by salinity parameters.
- The hydrogeochemical characteristics of groundwater revealed that Na–Mg–Cl and Na–Cl dominate the

largest part of study area, confirming the results of PCA/FA and SEM.

- The TDS versus TH diagram showed that the groundwater type varied from soft-fresh water (limited samples in recharge zones) to hard-brackish water (major samples in discharge zones).
- The geochemical evaluation showed that the salinity in the Saveh groundwater has geogenic sources rather than anthropogenic sources. After several steps of interpretation, the dissolution of evaporite minerals such as gypsum in LRF and URF and silicate weathering were identified as being the major sources of the salinity processes in the plain.
- The bivariate plots of  $Ca^{2+}/Na^+$  vs  $HCO_3^-$  and  $Ca^{2+}/Na^+$  vs  $Mg^{2+}/Na^+$  were useful to support the argument of evaporite dissolution and silicate weathering in the groundwater of the study area.
- This study showed that multiple evaluation methods could be useful in revealing sources of water quality contamination in the study area.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare that there is no conflict of interests regarding the publication of this paper.

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