Hydrogeochemistry and groundwater mixing close to an oil field: an example from Asmari karstic aquifer, Khuzestan, Iran
H. Rouhi and N. Kalantari

ABSTRACT
Both carbonate (as the oil-gas reservoir) and evaporite rocks (as caprock) coexist in the Masjed Soleyman oil field. The Asmari karstic aquifer is formed within Oligo-Miocene carbonate rocks in the south of the oil reservoir. A mixing between fresh karstic groundwater and oil-field brines is to be expected because of underground migration of the brines toward the aquifer. This process can reduce the groundwater quality by both increasing the water salinity and by adding hydrocarbon and sulfur contaminants into the groundwater. Tembi river contains saline water that can affect groundwater resources. Leaking of these brines into the aquifer was distinguished using total dissolved solids, the relative concentration of major elements, bromide ion (as a trace element), total organic carbon, ion ratios, and mixing curve diagrams. The polluted zone was determined by tracking the hydrochemistry changes across the groundwater flow direction. The volume percentage of different water sources in mixed groundwater was calculated and validated using PHREEQC software. The results revealed that the contribution of the oil-field brine in the groundwater is much lower than the salty river brine, but even this low amount has a considerable impact on water quality by increasing water salinity and adding hydrocarbon and sulfur into the groundwater.

Key words | groundwater pollution, Karstic aquifer, mixing, oil-field brine, salty river water

INTRODUCTION
Karstic aquifers are one of the most important water resources and generally contain high-quality water, except for those deteriorated by sources of salinity and contamination. The recognition of different sources of salinity is the first step to preventing the degradation of groundwater quality. The knowledge of hydrochemistry is a very helpful tool in the understanding of inter-aquifer mixing and detection of polluted zones. It seems essential to determine the origin of the chemical composition of groundwater (Zaporozec 1972; Dogramaci & Herczeg 2002; Edmunds 2009; Raiber et al. 2009; Hofmann & Cartwright 2013). Major potential sources of groundwater salinization include evaporation, oil-field and gas-field brines, sea water intrusion, geothermal and deep-basin water, and dissolution of evaporite rocks (Zarei et al. 2012).

Oil-field brines are dominated by Na and Cl in halite proportions and may contain significant concentrations of other anions and cations including B, Ba, Li, Mn, Sr, Zn, Br and I (Fan et al. 2010; Peterman et al. 2012). Major elements Ca, Mg, Na, Cl, SO4, and HCO3 and also their ratios such as Na/Cl, SO4/Cl, and SO4/TDS (total dissolved solids) are suggested by investigators to distinguish halite dissolution from other potential sources, such as oil-field brines (Gogel 1979; Whittemore & Pollock 1979; Kreitler 1993; Mace et al. 2006). However, minor trace elements such as Br, B, and Li are used to avoid change in these ratios by mechanisms other than mixing or dilution (Kreitler et al. 1984; Morton 1986; Richter & Kreitler 1986a; Kreitler et al. 1990; Richter et al. 1990). Albeit the concentration of Br ranges between several tens to greater than 2,000 mg/l

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in oil-field brines, just a small amount of it incorporates into the crystal structure of halite during evaporation of seawater. Since they have different affinities, Cl is more prone than Br to form salts (Kreitler 1993). Therefore, the Br/Cl ratio is typically one or more orders of magnitude smaller in halite dissolution brines than oil-field brines.

Groundwater quality gets altered when moving along its flow path from recharge to discharge areas by mixing of waters and other processes (Appelo & Postma 1996). The mixing processes of brine and fresh water were described by Gillespie & Hargadine (1981), Whittmore & Pollock (1979), and Richter & Kreitler (1986b). Each source of brines leaves an individual fingerprint in groundwater chemistry. Chemical fingerprinting techniques have been used to determine the mixing percentage of different waters in addition to identifying the source of brines.

The salinity resources make about 12.5 million cubic meters of fresh water from Asmari karstic aquifer unusable annually. The potential sources of salinity in the region of interest are oil-field brines and Gypsum-halite formations. The study of groundwater chemistry in this area is concerned with the aim of helping to manage the aquifer in order to exploit more fresh water, beside controlling the groundwater pollution. The pollution in Asmari karstic aquifer occurs when the intrusion of oil-field brine increases the dissolved materials in groundwater, especially Na-Cl, hydrocarbon and H₂S, to the extent that hydrocarbons are visible in spring water and there is a strong smell of H₂S.

This paper first describes the hydrochemistry of groundwater and surface water sources in the study area, then detects the presence of different sources of brines in the karstic aquifer. Eventually it provides the contributing percentage of each source in the salinization and pollution of fresh groundwater. These studies are necessary to prevent the degradation of groundwater resources in other regions under similar conditions.

Geology and hydrogeology

Masjed Soleyman oil field is situated in Khuzestan province, southwestern Iran. The crest of the oil reservoir is at a depth of 183 m, which makes it one of the shallowest oil reservoirs of the Middle East (Khedri & Rangzan 2014). Calcareous Oligo-Miocene sediments formed the reservoir rocks of this oil field, covered by Miocene gypsum-halite-marl deposits. These sediments are exposed as a double plunge anticline in the south part of the oil field, called the Asmari anticline. Geographically, the Asmari anticline is located between latitude 31°38 and 31°47 N and longitude 49°30 and 49°45 E and has an area of approximately 90 km². Infiltration of precipitations in fractured limestone and the dissolution process resulted in the formation of the Asmari karstic aquifer in the study area (Figure 1). An impermeable clay core limited the interaction between the two flanks of the Asmari anticline. The eastern flank contains high-quality groundwater, while some parts of the western flank contain saline and contaminated groundwater. Since no oil production activities are conducted around the aquifer boundaries, the contamination has occurred as a result of geological processes.

The main discharge point of the aquifer is Garoo spring, with about 400 l/s average annual discharge, issuing from the northwest plunge of the anticline, which has several adjacent outputs and discharges into the Tembi River. The river passes from the adjacent anticline plunge with an annual discharge of 50 l/s maximum, 670 l/s minimum and an average of 150 l/s before the spring water enters into it. The general direction of the internal karst flow in the aquifer is from the southeast plunge towards the northwest one. Surface and subsurface dissolution features have developed in the Asmari anticline. The intersection of deep longitudinal and transverse faults with bedding surfaces create the flow channels and change the matrix flow to channel flow; in addition, this provides places for the springs to issue. The flow paths of groundwater and oil-field brine in the limestone layers are shown by a conceptual model (Figure 2). This figure suggests three different sources, fresh karstic aquifer water, oil-field brine and the Tembi River, can affect on the quality and quantity of Garoo spring water.

MATERIALS AND METHODS

Fieldwork was carried out from November 2014 to January 2015 for geological investigations and hydrogeological measurements. Samples were collected in December 2014 from different water bodies for chemical analysis: three
samples from exploration well water (EXP1, EXP2, Exp3), two samples from the Tembi River (R1, R2), and 11 samples from Garoo spring water (G1–G11), (Figure 1, Table 1). The depth of exploration wells that were drilled in the karstic aquifer ranged between 150 to 490 m.

To determine the concentrations of major ions (Ca, Na, K, HCO₃, SO₄, and Cl), chemical measurements were made shortly after the field mission. The alkalinity was determined by titration with HCl. The other anions and cations and also Br were analyzed by the ion-chromatography method. Total organic carbon (TOC) was measured by a Shimadzu LCMS-2010EV laboratory instrument. Water temperature, pH, TDS, and electrical conductivity (EC) were measured by a Hach sensION 156 portable instrument in the field. TDS (mg/l) was calculated as the sum of dissolved cation and anion concentrations. Samples were collected in 0.5 L polyethylene bottles, which were thoroughly cleaned and rinsed several times with distilled water in the field. The charge balances were calculated to check the quality of the data using PHREEQC software. Any sample with charge imbalance >5% was rejected.

RESULTS AND DISCUSSION

Chemical characteristics of surface water and groundwater

Groundwater and surface water resources in the study area have different origins that are reflected in their hydrochemical characteristics. Classification and discussions around the chemical composition of these two water resources are briefly presented in the following.

There are two sources for springs in the study area: fresh karstic aquifer water and waters deteriorated by gypsum-halite formations. Some of the springs reveal
mixing of these two water sources. Generally, springs that
originate from limestone and gypsum formations show
Ca-HCO₃ and Ca-SO₄ facies, respectively. In the study
area, Exp3 and Exp2 samples show Ca-HCO₃ facies, chan-
gring to Na-Cl facies toward the discharge area (Table 1).
Therefore, in the Piper diagram (Piper 1944) Exp1 and
Garoo spring samples (G1 to G11) are plotted near the
Na-Cl side while Exp3 and Exp2 samples are located near
the center of the diagram (Figure 3). It points out that
groundwater reveals some clues about Na-Cl waters in its
hydrochemical composition near the discharge area.

According to the Piper diagram, four ions have the high-
est concentration of major elements in Garoo spring water,
as Cl > Na > Ca > SO₄ (meq/l). The high concentration of
Ca and Ca/HCO₃ ratio (meq/l) can be attributed to
mixing of Ca-SO₄ facies and Ca-HCO₃ facies waters. How-
ever this additional Ca can be a consequence of mixing of
oil-field brines and fresh water, because oil-field brines
often contain a high concentration of Ca and Na in addition
to Cl in their hydrochemical composition. A high concen-
tration of Ca in brines is due to an equilibrium condition
between calcite and dolomite in oil reservoirs that caused
enrichment of Ca than Mg (Helgeson 1974; Land 1987).

Albeit HCO₃ is dominant in fresh karstic aquifer water, a
strong relationship between Cl and total dissolved ions
(TDI) in the collected samples from Garoo spring indicates
that Cl is the main controller of the salinity of the waters dis-
charged from the aquifer (Figure 4(a)). A distinguished
correlation between Cl and Na indicates the same origin
for these two ions (Figure 4(b)). A positive relationship
between Cl and Ca is based on this fact, that both oil-field
brine and the gypsum-halite formation release these ions
into the groundwater simultaneously (Figure 4(c)). In con-
trast, Mg does not show an acceptable correlation with Cl
because of its different and heterogeneous origins such as
gypsum-Marl deposits and oil brines (Figure 4(d)).

Tembi River (Figure 1) is the major surface water in the
study area. Because it crosses over the gypsum-halite for-
mation, it reveals different hydrochemical characteristics
in comparison with the karstic aquifer. The river water
embraces a very high concentration of dissolved halite and
gypsum and is placed close to Na-Cl angle on the Piper
Table 1 | The physicochemical data from groundwater (G, Exp) and river water (R) (see location map, Figure 1)

<table>
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<tr>
<th>Sample code</th>
<th>Sampling date</th>
<th>TDS (mg/l)</th>
<th>Conductivity (ms/cm)</th>
<th>pH</th>
<th>Ca (mg/l)</th>
<th>Mg (mg/l)</th>
<th>Na (mg/l)</th>
<th>K (mg/l)</th>
<th>HCO₃ (mg/l)</th>
<th>SO₄ (mg/l)</th>
<th>Cl (mg/l)</th>
<th>Br (mg/l)</th>
<th>Li (mg/l)</th>
<th>TOC (mg/l)</th>
<th>Water Type</th>
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<td>208</td>
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<td>277</td>
<td>347</td>
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</tr>
<tr>
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<td>70.5</td>
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<td>273</td>
<td>335</td>
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<td>3,690</td>
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<td>182</td>
<td>58.1</td>
<td>513</td>
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<td>269</td>
<td>42.3</td>
<td>633</td>
<td>172</td>
<td>224</td>
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<td>60.8</td>
<td>300</td>
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<td>236</td>
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<td>3,750</td>
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<td>Min.</td>
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<td>3,580</td>
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<td>299</td>
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<td>178</td>
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<td>277</td>
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<td>12.1</td>
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<td>48.1</td>
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<td>Average oil-brine</td>
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<td>–</td>
<td>8,490</td>
<td>1,710</td>
<td>63,900</td>
<td>–</td>
<td>580</td>
<td>634</td>
<td>118,000</td>
<td>–</td>
<td>–</td>
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<td>Na-Cl</td>
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</table>
diagram (Figure 3). In the northwest plunge of the Asmari anticline, the river water is mixing with Garoo spring water and its salinity (EC) diminishes due to the lower salinity of the spring water. It is believed that the Tembi River also plays a role in feeding the spring. The highest percentage of Cl and Na concentration is related to a sample...
calculated by the average of eight oil-field samples collected from oil production wells.

**Intrusion of oil-field brines and mixing**

Simultaneous release of hydrocarbons and water from the Garoo spring suggest that the excessive salinity of spring may be caused by mixing of oil-field brine and fresh karstic aquifer water. The effect of mixing can be seen on the Piper diagram, where the mixing process is marked with an arrow (Figure 5), indicating the orientation of the samples on a curve line that passes from fresh water toward the mixed water in the aquifer. In addition, the following evidences can help to characterize the intrusion and mixing of oil-field brine and the fresh karstic aquifer water.

**Significant changes in type and quality of groundwater**

**TDS and major elements**

In regions where the oil-field brines are present, mixing of groundwater with brines imposes additional changes in the type and chemistry of water. If these changes occur suddenly and locally, an unusual mechanism should be considered (Richter & Kreitler 1987). Most of the oil-field brines contain a considerable amount of NaCl and CaCl2, therefore they have high TDS (Collins 1973). As a result of mixing, the amount of Cl, Na and Ca increase in the groundwater. Such increases in the aforementioned ions occur in the Asmari karstic aquifer from upstream to downstream, which leads to sharp changes in both EC and groundwater type. According to Figure 5, these events are taking place in the aquifer at a point between the Exp2 and Exp1 wells. In fact, groundwater type changes from Ca-HCO3 to Na-Cl are consistent with the flow direction between these two wells, which represents the migration of brine from the adjacent oil reservoir to the karstic aquifer. This type of brine is leaking into the aquifer continuously and increasingly from the entry point to the discharge point (Garoo spring).

**TOC**

Detection of zones contaminated by hydrocarbons and determination of the amount of dissolved hydrocarbons can be investigated using the TOC content of groundwater. The oil-field source of organic contamination in groundwater has been proved in previous studies by GC analysis (Mirzaee et al. 2016). Exp3 and Exp2 samples located in the uncontaminated zone show low TOC (3–7 mg/l). On the other hand, the amount of TOC shows a considerable increase along the flow direction and reveals its maximum (40 mg/l) in the discharge point. Figure 5 shows the amount of leaked hydrocarbons corresponding to its location, which is in accordance with the increase in ion

![Figure 5](https://iwaponline.com/ws/article-pdf/18/2/357/206519/ws018020357.pdf)
concentration. It suggests that both hydrocarbons and oil-field brine penetrate into the aquifer simultaneously.

**Relative concentration of major ions**

Water salinity affected by dissolution of evaporites and oil-field brines increases the relative concentration of some ions such as Cl, Na and SO₄. In the study area, both evaporite formation and oil-field brines do exist. Since aquifer fresh water contains a low concentration of dissolved ions, a slight mixing with each of the brines forces the chemical composition of the mixture towards the composition of that brine. Therefore to understand the effects of these two salinity sources on the karst groundwater, both of the groundwater and river water samples (as representative of the evaporites) were plotted on the stiff diagram (Figure 6). The similarity of the relative concentration of the major elements in the water samples with oil-field or river water samples reveals the mixing effect of the two salinity sources on the groundwater. The figure shows that Exp3 and Exp2, the agents of fresh karstic aquifer water, did not comply with any of the brines. On the contrary, Exp1 illustrates a very close similarity in relative ion concentration with oil-field brine. With a remarkable difference in the amount of SO₄, samples collected from Garoo spring also reveal a similarity. Since the mixing of fresh water and oil-field brine is characterized by a low percentage of SO₄ and Mg (Dresel & Rose 2010), the high concentration percentage of SO₄ in the spring water suggests that the waters originating from evaporite formation (Tembi river water) play a role in recharging the spring. Accordingly, Garoo spring water is a mixture of three sources: fresh karstic aquifer water, oil-field brine, and evaporite dissolution brine.

**Figure 6** | The relative concentrations of major elements for water samples.
Although the amount of Mg in the river water is less than in the spring water, the relative concentration of major elements in the river water is similar to Garoo spring. This fact can be related to the absence of dolomite in the evaporite deposits.

**Ion ratios**

**Na/Cl**

*Leonard & Ward* (1962) used the Na/Cl ratio to differentiate halite solution brines. This ratio works well to distinguish halite solution brine from oil-field brine at high chloride concentrations. In most oil-field brines, the molar ratio of Na/Cl is much less than one. If the weight ratio of Na/Cl for water samples is smaller than 0.648, it may indicate intrusion of oil-field brines into the aquifer (*Kreitler* 1993). This ratio is implied for all of the groundwater and river water samples in the study area (Figure 7).

**Br/Cl**

Groundwater mixing process can be investigated by dissolved trace elements such as chloride and bromide. These elements can be used to identify the source of groundwater salinity and also to estimate the fraction of water sources in the mixture (*Dutton et al.* 1989; *Alcalá & Custodio* 2008; *Tweed et al.* 2011; *Han et al.* 2014; *Kumar et al.* 2015).

In Figure 8, the Br/Cl ratio is used to detect mixing of fresh karstic aquifer water with oil-field brine or halite brine based on geochemical methods. These methods primarily involve plots of the constituent mass ratios of Br/Cl and SO₄/Cl versus Cl concentration. Each mixing curve is generated using an algebraic equation for conservative mixing of two end-member waters, one with a low Cl and one with a high Cl concentration (*Whittemore* 1995). The high Cl end members for the curves are from the brines of the Masjed Soleyman oil-field (the solid curves) and also saltwaters formed from evaporites around the study area (the dashed curves). The freshwater end members for the curves are based on fresh groundwaters from the wells to the west of the study area. As seen in Figure 8, Exp1 and Garoo spring samples were plotted in the zone of mixing of freshwater and oil-field brine. Because of the low concentration of Br, Exp3, and Exp2 samples are not plotted in the diagram. This diagram confirms previous findings of the mixing of oil-field brines with fresh karstic aquifer water in the study area.

**SO₄/Cl**

The SO₄/Cl ratio is an indicator used to recognize the mixing of fresh water and oil-field brines (*Whittemore*...
Groundwater and surface water samples in the study area were plotted in the SO4/Cl versus Cl diagram (Figure 9). All of the Garoo spring samples and the Exp1 sample reveal the mixing of fresh water and brine. It is worth mentioning that the river water sample collected before joining the spring water (R1) were plotted outside the mixing zone. As expected, fresh karstic aquifer water samples were located outside the diagram.

Groundwater mixing

A method using sulfate ion concentration was presented to determine the mixing of brines and fresh water by Mast (1985). Factor pairs of calcium–sulfate, magnesium–sulfate, chloride–sulfate and TDS–sulfate were used in this method. The TDS factor includes the combined effect of all the ions existing in the water sources. The chloride factor is the best factor, because there exist wide differences in the concentrations of chloride and sulfate ions relative to each other in oil-field brine and salty river water, with high chlorides in the former and high sulfates in the latter (Mast 1985). Accordingly, in this study the diagram of sulfate versus chloride was used to determine the fraction of fresh water, salty river water and oil-field brine in the karst groundwater (Figure 10). These three water sources were considered as end members and were chosen as Exp2, a river water sample before mixing, and the average composition of the waters from eight oil wells, respectively. Furthermore, the TDS factor was used to provide an overall view of the pollutants in the brines.

Figure 10 shows that Exp1 is plotted very close to the mixing line of fresh water and oil-field brine. It is located on the upstream of Garoo spring and has no interaction with the river. This fact emphasizes that just two water sources are contributing to the Exp1 composition. According to the location of the spring samples on the diagram, it can be found that the salty river water has a more prominent contribution than oil-field brine to feeding the spring. In other words, the volume percentage of river water is several times greater than the oil reservoir brine in the spring.

Determine the percentage of different sources in mixture

Mast (1985) devised a method based on three simultaneous linear equations to determine the percent volume of three sources of water in a mixed water as shown below:

\[ C_{if}.P_i + C_{iw}.P_w + C_{io}.P_o = C_{ia} \quad (1 - a) \]
\[ C_{2f}P_f + C_{2o}P_o + C_{2w}P_w = C_{2a} \]  

(1 - b)

\[ P_f + P_o + P_w = 1 \]  

(1 - c)

where:

- \( C_{1f} \) = chemical concentration of Factor 1 in the fresh water
- \( C_{2f} \) = chemical concentration of Factor 2 in the fresh water
- \( P_f \) = volumetric percentage of fresh water
- \( C_{1o} \) = chemical concentration of Factor 1 in the oil-field brine
- \( C_{2o} \) = chemical concentration of Factor 2 in the oil-field brine
- \( P_o \) = volumetric percentage of oil-field brine
- \( C_{1w} \) = chemical concentration of Factor 1 in salty river water
- \( C_{2w} \) = chemical concentration of Factor 2 in salty river water
- \( P_w \) = volumetric percentage of salty river water
- \( C_{1a} \) = chemical concentration of Factor 1 in mixture
- \( C_{2a} \) = chemical concentration of Factor 2 in mixture

Then, by solving the simultaneous equations, the results are:

\[
P_f = \frac{\begin{bmatrix} C_{1a} & C_{1o} & C_{1w} \\ C_{2a} & C_{2o} & C_{2w} \end{bmatrix}}{\text{DELT}}
\]

\[
P_o = \frac{\begin{bmatrix} C_{1f} & C_{1a} & C_{1w} \\ C_{2f} & C_{2a} & C_{2w} \end{bmatrix}}{\text{DELT}}
\]

\[
P_w = \frac{\begin{bmatrix} C_{1a} & C_{1o} & C_{1a} \\ C_{2a} & C_{2o} & C_{2a} \end{bmatrix}}{\text{DELT}}
\]

Where:

\[
\text{DELT} = \begin{bmatrix} C_{1f} & C_{1o} & C_{1w} \\ C_{2f} & C_{2o} & C_{2w} \end{bmatrix}
\]

This method takes into account that Cl is a conservative tracer (Tellam 1993). In fact, Cl is not usually removed from the system due to its high solubility (Appelo & Postma 1996). In this study, Cls is the chloride content of the oil-field brine and Clf is the chloride content of karst freshwater.

Based on the findings of the contribution of three water sources in Garoo spring, the volumetric percentages from those three sources were calculated for each sample of...
water taken from the spring, using SO₄-Cl and SO₄-TDS factor pairs. For Exp1, which contains only two sources, oil-field brine and fresh water, the percentage of each source in the mixture was calculated using TDS and Cl concentration (Table 2). Therefore, the volumetric percentage contribution of oil-field brine in the aquifer ranges from 0.3 to 0.9 percent and 0.3 to 1.0 percent, calculated by the SO₄-Cl factor pair and SO₄-TDS pair, respectively. Moreover, salty river water seeping from the river to the spring includes almost 23.4 percent of the spring water calculated by both of the two-factor pairs. It should be noted that this calculation has been performed for the middle depth of the karstic aquifer (Exp1 = 150 m), but most probably, at the bottom of the aquifer, the oil-field brine percentages are much higher than in the middle of the aquifer. Since the mass density of the pollutant ions makes them heavier, the pollution is expected to accumulate at the bottom of the system (Mast 1985).

To ensure the accuracy of calculated percentages for mixing, a simulation was performed by PHREEQC based on the data in Table 2. In this way, the percentage of the different water sources that contributes in the spring discharge was introduced to PHREEQC and then the hydrochemistry composition of the mixture was calculated as output. The significant correlation between the simulated and analyzed concentrations of major aquatic species that control the spring water hydrochemistry can confirm the results (Figure 11).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Volumetric contribution percentages of water sources for aquifer using SO₄-Cl and SO₄-TDS pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair</td>
<td>Sample</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>SO₄-Cl</td>
<td>Oil-field brine%</td>
</tr>
<tr>
<td></td>
<td>Salty river water%</td>
</tr>
<tr>
<td></td>
<td>Fresh water%</td>
</tr>
<tr>
<td>SO₄-TDS</td>
<td>Oil-field brine%</td>
</tr>
<tr>
<td></td>
<td>Salty river water%</td>
</tr>
<tr>
<td></td>
<td>Fresh water%</td>
</tr>
</tbody>
</table>

**Figure 11** | Correlation between the concentration of major aquatic species, analyzed in the laboratory and simulated by using PHREEQC.
CONCLUSIONS

In this paper, the presence of oil-field brine in the Asmari karstic aquifer has been detected based on the best methods for geochemical differentiation of oil-field brines from other salinity sources, such as Cl/Na ratio and mixing curve relationships on plots of Br/Cl and SO$_4$/Cl ratios versus Cl concentration. The background Cl concentration of fresh groundwater in the aquifer ranges from about 15–20 mg/L. Migrating of brine from the adjacent oil-field has added over 1,000 mg/L to the chloride content of the groundwater.

A sharp increase in some parameters of water chemistry such as EC, Cl, Ca and TOC in addition to variation in groundwater type implies that leakage of the oil-field brine and hydrocarbons into the fresh karstic aquifer water occurs near the north-western plunge of the Asmari anticline, between the Exp2 and Exp1 wells. This is likely due to the operation of deep faults that transmit salt water from the Masjed Soleiman oil reservoir to the aquifer.

Albeit the salty river water, which originated from evaporite formation in the study area, was not found in the aquifer body, it is recognized in the discharge point of the aquifer (Garoo spring). The salty river water may be infiltrated into the spring by the action of a fault that imposes the river path in this part of the study area. The fraction of salty river water in the spring water was calculated at about 23.4%, but the fraction of oil-field brine does not exceed more than 1%. It should not be ignored that even this small amount of oil-field brine has a significant impact on reducing the karstic groundwater quality.

Determination of both the amount of and sites where salt waters enter into the groundwater body can be useful for management and operation of aquifers, especially when it is necessary to save the water before contamination. Although pumping of groundwater before mixing with waste water can be considered as a wise strategy, it should be noted that at high rates of pumping more brine can move upwards from the bottom of the aquifer.

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