

Evaluating hydrogeochemistry and turbidity problem of a carbonate aquifer, Shiraz, Iran

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Abstract

Important karstic aquifers exist in west and southwest of Iran. Mansour-Abad Karstic region is located in Shiraz, southwest of Iran. It supplies the drinking water for the whole area by 4 pumping water wells, some of which have water turbidity problem. The present research aims to assess the hydrogeochemistry and turbidity problem in the karstic water production wells. The EC varies between 703 (in well No.1) and 1096 $\mu\text{mhos/cm}$ (in well No.4). All water wells have similar ion concentration trend, indicating the same origin. The dissolution of gypsum during dedolomitization process induces the transformation of dolomite to calcite in the study area, especially in well No.4. The concentrations of most trace elements in the study area are lower than the standard value. Bacteriological water parameters are outside the accepted limits recommended by WHO for drinking water. Wells No. 1, 2 and 3 have turbidity values greater than limited values for drinking water which is about 5 TU; therefore, only well No.4 is used as drinking water resource in the study area. Most probably, interference of clay mineral layers with groundwater flow is one of the main causes of turbidity in some wells.

Keywords: Drinking Water, Hydrochemistry, Karst Aquifer, Microorganism, Turbidity.

Introduction

Karstic aquifers are vulnerable to contamination. They are different from other aquifers due to their complex and unique characteristics (Dupont, 2007; Wicks, 1997; Massei, 2001). The quality of groundwater results from the interaction of water and minerals in the aquifer (Bruce Banoeng-Yakubo, 2008). The chemical composition of ground water is influenced by many factors including the composition of precipitation, mineralogy of the watershed and aquifers, climate and topography (Bagheri *et al.*, 2013). In literature, different methodologies have been applied to study, evaluate and characterize the sources of variation in groundwater chemistry (Knauth, 1988; Richter and Kreitler, 1993; Mohammadi *et al.*, 2010; Bagheri *et al.*, 2013a, 2013b; Bagheri *et al.*, 2014; Taheri-Tizro *et al.*, 2007; Mondal *et al.*, 2010). Geochemical investigation often leads to an understanding of the groundwater quality and can occasionally result in making useful predictions.

Turbidity occurs when fine suspended particles of clay, silt, organic and inorganic matter, plankton and other microorganisms are picked up by water (Gibs, 2001). Some authors suggest that turbidity indicates the presence of microbial pathogens (Nebbache, 1997; Auckenthaler and Huggenberger, 2003). In the rural karst areas, fecal bacteria often originate from agricultural activities (Drew, 1999). Sand pumping and consequent turbidity is a

problem associated with some consolidated, poorly consolidated and unconsolidated formations. Turbidity, measured in nephelometric unit (NTU), ranges from less than 1 NTU to more than 1000 NTU, so that at 5 NTU, the water color is visibly cloudy, and at 25 NTU it is murky. The water from deep wells is usually clear without significant amount of turbidity. Our knowledge of the agents and behavior of turbidity process in groundwater is still in its infancy. To this date, only a few studies have investigated the turbidity phenomena in groundwater (Gabber, 1998; Hargreaves, 1999).

Groundwater is an important source of water for industrial, agricultural, and domestic purposes in Iran. Water shortage has recently become an important issue due to climate change. Important karstic aquifers are located in west and southwest of Iran. The study area is located in Mansour-Abad Karstic region, Shiraz, southwest of Iran. It supplies the drinking water for the entire area by 4 pumping water wells, some of which have water turbidity problem. The main objectives of this study are to investigate the water quality and hydrogeochemistry evolution of the karstic water wells.

Geological and Hydrogeological settings

The study was conducted in a karstic anticline of Mansour-Abad karstic region, southwest of Iran. The study area is situated in Zagros Simple Folded

Zone (Talbot and Jarvis, 1984) which is one of the major geological units of the Iranian plateau (Stocklin, 1968; Alavi, 2004). Zagros Simple Folded Zone is characterized by a repetition of long and regular anticlinal and synclinal folds (Miliareisis, 2001). Anticlines are well exposed and separated by broad valleys. Fold axes have a northwest to southeast orientation. The High Zagros is very close to the main Zagros thrust fault where it is crushed and intensively faulted. The stratigraphic and structural setting of the Zagros sedimentary sequence has been described in detail by James and Wyned (1965), Falcon (1967), Bordenave (2008), and Alavi (2004). The elevation of study area ranges from 1540 to 2000 m.a.s.l. Many faults in the study area have been reported to be created by different formations outcrop. These faults exhibit the same trend as the main Zagros thrust fault (Fig. 1). This anticline is mainly composed of limestone and dolomite of Asmari and Jahrum karstic formations. The main outcrop formations in decreasing order of age are Gurpi marl and marly-limestone formation (Cretaceous), Jahrum dolomite-limestone, and marly-limestone (Eocene), Asmari limestone formation (Oligocene to early Miocene) and recent alluvium (Fig. 1). Tectonic activity plays a role in the development of fractures and fissures in the limestone formations and the subsequent karstification in the area. In the study area, four water wells were drilled on the north limb of the anticline in the karstic aquifer. These wells are supplies of potable water in the area, three of which have turbidity problem. The depths of wells vary between 240 m in well No.1, and 300 m in well No.4. Drilling logs of these wells are shown in

Figure 2. The Iso-potential map of Shiraz plain is depicted in Figure 3. The flow direction is from north towards the south and southeast parts; therefore, the karstic aquifer recharges the recent adjacent deposits. The study area is characterized by the average annual precipitation range between 127 and 275 mm, and the average temperature of 17.6°C.

Samplings and Methods

The water samples in the study area were collected in two different times: Dec-2014, and Apr-2015. The waters of 4 karst production wells were sampled from the well heads (Fig. 1). First, the wellhead production valve was opened for a few hours to flush the accompanying old water. Water samples were collected in polyethylene bottles, which were rinsed with the sample water several times prior to being filled below the surface. Temperature, pH and the electrical conductivity (EC) of the water samples were measured in situ. All water samples were filtered through 0.45µm filters. For cation analysis, the samples were acidified to a pH of less than 2 using 37% HCl (12 M). The major ion concentrations (Mg^{2+} , Ca^{2+} , HCO_3^- , Na^+ , Cl^- , SO_4^{2-} , K^+) were analyzed at Shiraz Sewer Services Laboratory, Iran. The accuracy of the analyses was checked by calculating the charge balance. The water samples for measuring heavy metals were also collected in separate bottles. They were acidified by 10 % nitric acid to a pH of lower than 2 in order to prevent precipitation and/or sorption reactions.

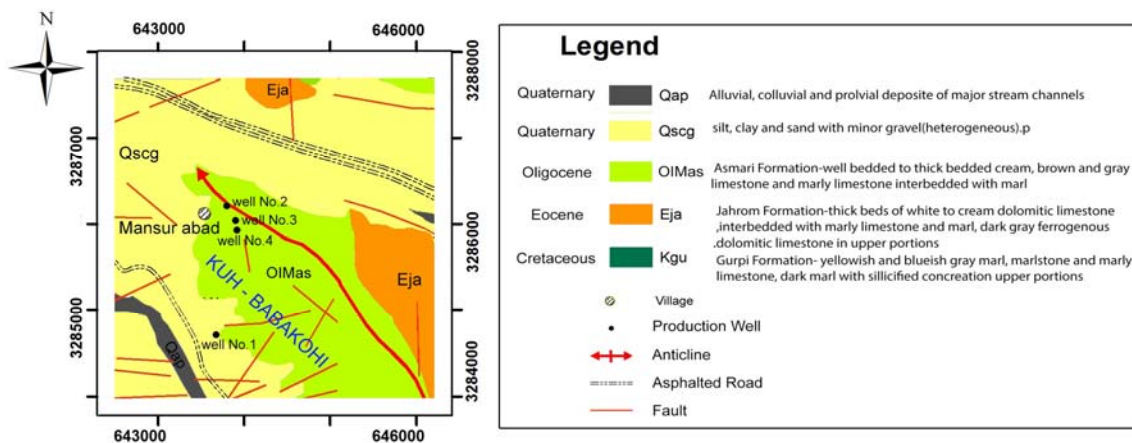


Figure 1. Geological map and sampling points of the study area

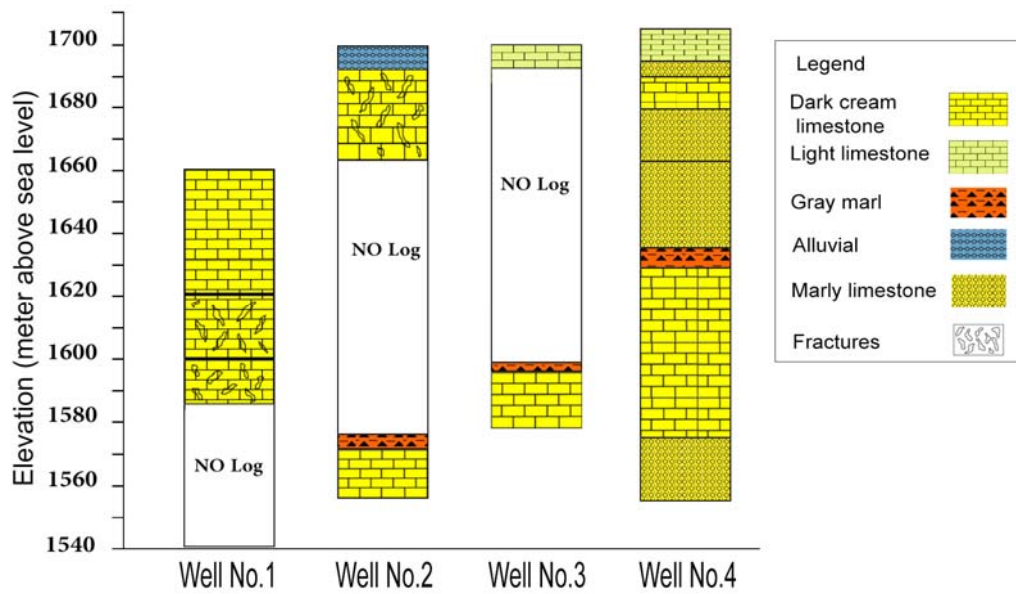


Figure 2. Geological logs of the Karstic wells

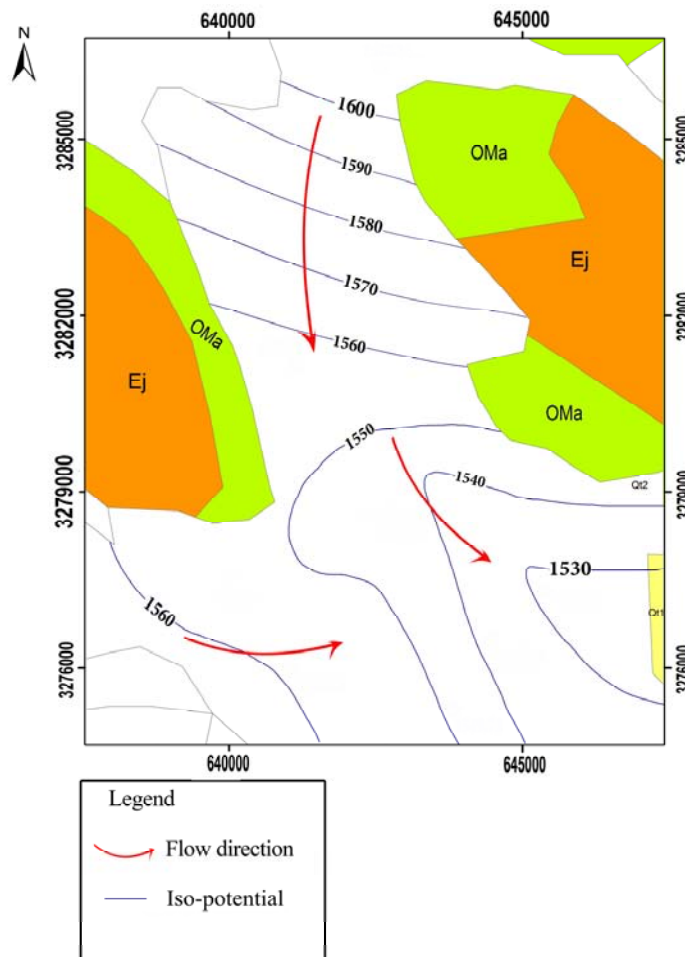


Figure 3. Iso-potential and flow line map of the study area

The concentration of heavy metal was determined by inductively coupled plasma optical emission spectrometry (ICP-OES) analytical technique in the chemistry laboratory of Zanjan University, Iran. The multiple-tube fermentation (MTF) technique was used to count the coliforms of water. The concentration of heavy metal was determined by inductively coupled plasma optical emission spectrometry (ICP-OES) analytical technique in the chemistry laboratory of Zanjan University, Iran. The multiple-tube fermentation (MTF) technique was used to count the coliforms of water.

The coliforms samples were analyzed at Shiraz Sewer Services Laboratory, Iran. The method consists of a series of tubes with appropriate decimal diluted water samples. The results of the MTF technique are expressed in terms of the most probable number (MPN) of microorganisms present. This number is a statistical estimate of the mean number of coliforms in the sample. XRD analysis was used in order to determine the mineralogical components of sediment in water samples. Large quantities of water were sampled to deposit the required sediments. The sediment samples were analyzed at the X-ray Mineralogy Laboratory at Shahrood University of Technology, Iran.

Results and Discussions

Understanding the quality of groundwater, especially turbidity is as important as its quantity, because it is the main factor determining its suitability for drinking, domestic, agricultural and industrial purposes. The hydrochemical data of four sampled wells in Mansour-Abad, north of Shiraz are presented in Table 1. The hydrogeochemistry evaluation and turbidity problem of Mansour-Abad carbonate aquifer was investigated.

General groundwater hydrochemistry

The electrical conductivity (EC) of groundwater samples ranged from 703 in well No.1 to 1096 $\mu\text{mohs/cm}$ in well No.4 with a mean value of 700 $\mu\text{mohs/cm}$. The pH values and water temperatures did not show any significant abnormalities. Groundwater temperatures varied from 18 to 30 °C. The pH value fluctuations between 7 and 7.7 showed that the groundwaters were generally neutral to slightly alkaline.

HCO_3 and SO_4 are major anions and Ca and Mg were the major cations in the studied carbonate aquifer (Fig. 4). The relative abundance of the ions

were $\text{Ca} > \text{Mg} > \text{Na} > \text{K}$ and $\text{HCO}_3 > \text{SO}_4 > \text{Cl}$ (in meq/L basis) (Table 1). Based on the Schoeller diagram (Fig. 4), all water wells had the same ion concentrations trend, indicating the same origin. The major ionic contents were compared on Durov diagram (Fig. 5). The water samples fall into three distinct groups. It is apparent that despite the contrasts in aquifer lithology, all the waters fall on relatively linear mixing lines in the diagram. The mean concentration of Mg, Ca and Na were 4.8, 3.5 and 2.7 meq/L, respectively. The value of SO_4 ion ranges between 1 and 5.1 meq/L. The presence of HCO_3 ion ranging from 4.8 to 6.3 meq/L was due to dissolution of carbonate rocks. Rocks that are most soluble include limestone, dolomite, gypsum, halite, so on. They serve as the principal sources of Ca, Mg, Na, K, CO_3 , SO_4 , and Cl in the groundwater. The prevailing common lithology in the study area is Asmari-Jahrum carbonate formation which is mainly composed of limestone and dolomite.

Hydrochemical water type

Piper diagram was used to evaluate the geochemical evolution of the groundwater at the study area (Fig. 6). Aqua software was used for plotting the piper diagram. The water samples dominantly have Ca–Mg– HCO_3 – SO_4 water type. The water samples are also plotted on the $(\text{CO}_3 + \text{HCO}_3)$ – $(\text{Cl} + \text{SO}_4)$ vs. $(\text{Ca} + \text{Mg})$ – $(\text{Na} + \text{K})$ graph (Chadha, 1999), which is used for geochemical classification of natural water and interpretation of chemical data. The graph is a modification of Piper diagram with respecting to extend its applicability in representing water analysis in the simplest way possible. The plot shows that a few of the groundwater samples fall under the subdivision of alkaline earths (Ca–Mg– HCO_3 water type) and the others (well No.4) reveal the Ca–Mg–Cl water type (Fig. 7). Finally, two main groups of groundwater type can be identified. Group 1, including wells No.1, 2 and 3, is made up of water, the ion compositions of which are dominated by Ca and Mg, HCO_3 and then SO_4 . Group 2, includes well No.4, with more salinity than others, and an element abundance order of $\text{Ca} > \text{Mg} > \text{Na} > \text{K}$ and $\text{SO}_4 > \text{HCO}_3 > \text{Cl}$.

Saturation Index (SI) and Chemical evolution

PhreeQC software was used to calculate mineral saturation index (SI) of water samples in the study area. Different types of information can be obtained from saturation data such as equilibrium with the host minerals and precipitation process.

Table 1. Physico-chemical characteristics of the water samples

Well No.	date	EC (µmoh s/cm)	pH	T (oC)	Concentration of ions (meq/lit)						SO ₄	HCO ₃	TH (mg/L)	TDS (mg/L)
					Ca	Mg	Na	K	Cl					
1	6/7/2010	759.4	7.43	30.2	4.1	3.1	1.76	0.03	1.2	1.385	5.6	356.2	430.44	
1	18/7/2010	752	7.43	27.3	4.1	3	1.79	0.04	1.2	1.396	5.6	356.2	434.86	
1	15/6/2011	780.9	7.64	27.4	4	3.5	1.82	0.04	1.1	1.425	5.9	376	-	
1	14/11/2011	792.7	7.3	22.2	4.5	2.8	2.16	0.04	1.2	1.537	5.9	368	-	
1	16/3/2013	824.8	7.43	21.2	5.4	2.4	1.80	0.03	1.9	1.951	5.4	392	483.21	
1	18/8/2013	747.6	7.2	21.8	4.2	3.3	1.80	0.03	1.4	1.513	5.6	372	445.72	
1	1/7/2014	761.4	7.74	26	3.8	3.5	1.93	0.04	1.5	1.361	5.8	370.2	446.48	
1	22/4/2015	746.8	7.33	25.1	4.1	2.8	2.05	0.04	1.4	1.484	5.7	399.2	479	
2	6/7/2011	886.6	7.41	26.1	4.4	3.9	2.23	0.03	1.7	2.784	5.5	417.7	-	
2	13/6/2012	877.9	7.6	26.4	4.6	4.1	2.38	0.04	1.9	2.789	4.4	438.8	527.77	
2	18/8/2013	890.7	7.63	26.7	4.5	3.9	2.12	0.03	2	2.844	5.3	417.3	522.59	
2	16/3/2013	812.5	7.45	22.1	5.2	2.5	2.10	0.03	2	2.576	4.8	384	494.8	
2	17/12/2014	895.5	7.43	18.2	6.1	3.5	2.22	0.04	2.1	3.077	5.6	483.2	580.94	
2	22/4/2015	740.7	7.45	23.9	4.2	3.5	2.17	0.04	2.1	2.53	4.1	374	459	
3	19/7/2010	854.6	7.43	26.5	4.7	3.1	2.15	0.04	1.4	1.502	6.3	392.7	483.46	
3	4/1/2011	768.2	7.3	18.2	4.3	2.8	1.95	0.03	1.2	0.995	6	355.3	430.51	
3	22/4/2015	703.2	7.3	21.8	4.5	3.1	2.24	0.05	1.4	1.275	6.2	386.7	409	
4	12/7/2011	1108	7.43	26.7	4.9	4.1	3.76	0.05	2.9	4.461	4.7	453.8	-	
4	17/12/2011	1091	7.53	19.6	4.9	4.8	3.47	0.05	2.8	4.526	4.4	488	652.69	
4	12/5/2012	1135	7.26	24.2	6.1	3.9	4.36	0.06	2.9	4.537	4.8	501.8	694.52	
4	11/2/2013	1053	7.21	20.2	5.1	4.3	4.34	0.06	3.3	5.131	4.3	472	700.96	
4	14/5/2013	1088	7.13	25.3	5.6	4.7	4.38	0.05	3.3	5.056	4.5	516	716.84	
4	11/11/2013	1068	7.16	21.9	5.5	4.3	4.08	0.05	3.3	4.655	4.4	492	686.01	
4	21/7/2014	1096	7.11	23.4	5.9	4.1	4.42	0.06	3.4	3.717	4.7	502	660.67	
4	20/12/2014	1080	7.21	18.7	6.3	4.1	3.94	0.052	3.008	4.979	4.8	521	721.18	

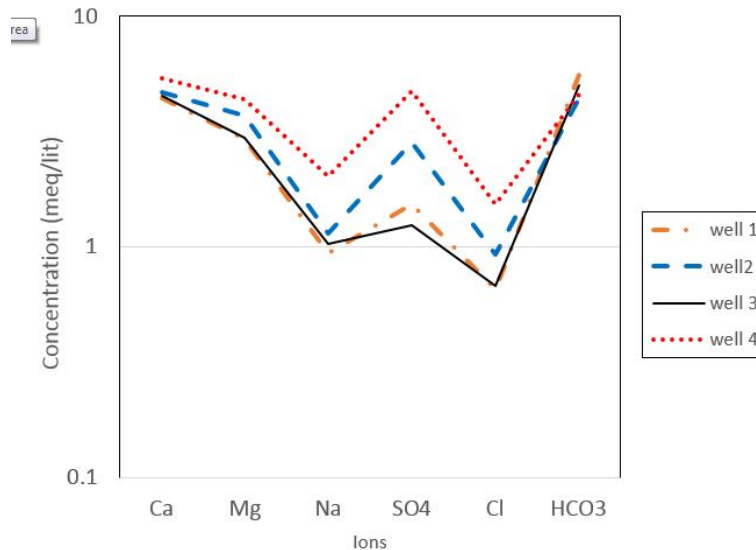


Figure 4. Schoeller diagram of the water samples

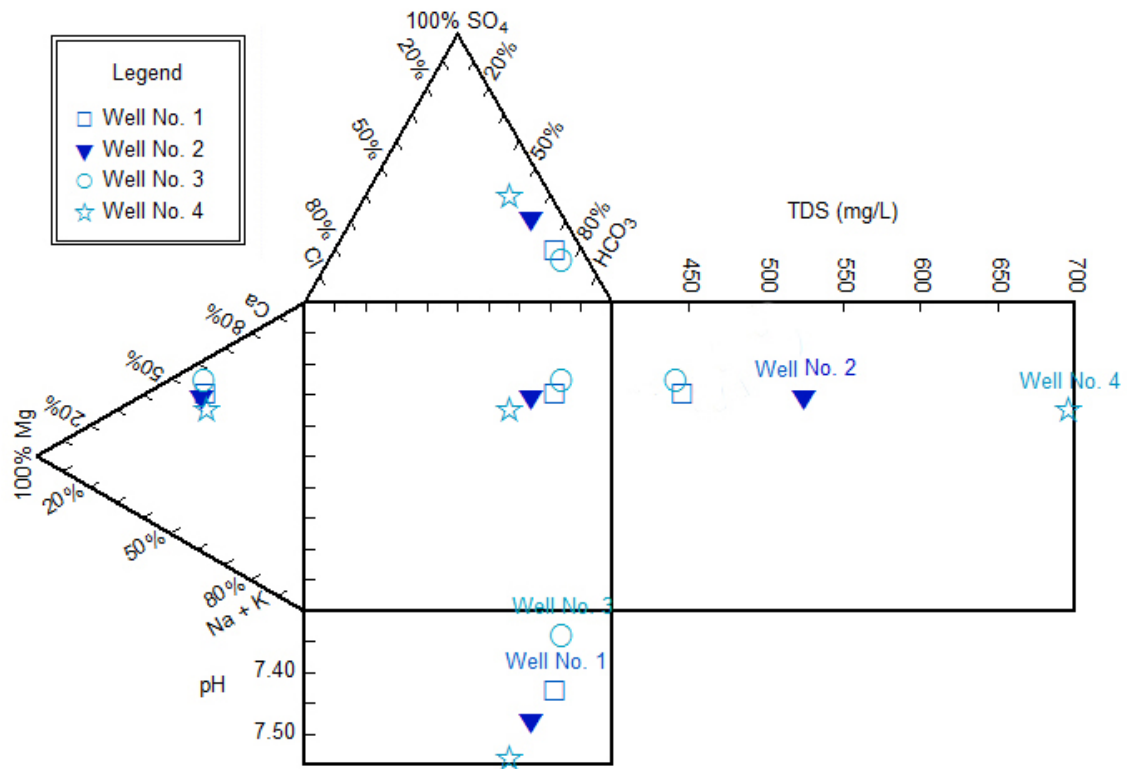


Figure 5. Durov plot of the four karst wells

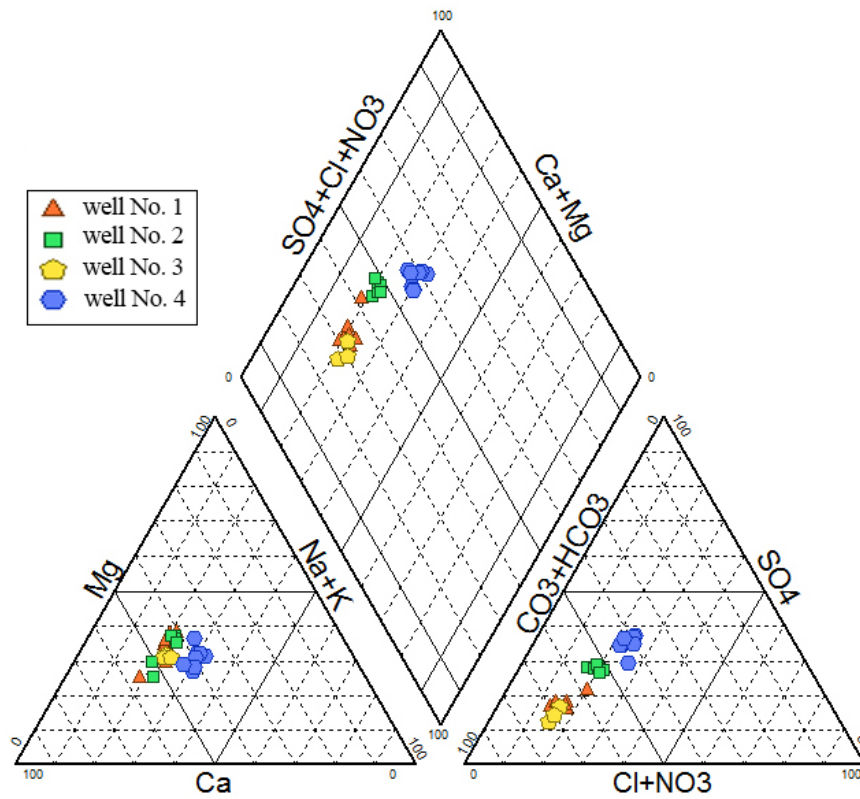


Figure 6. Piper diagram of the water samples

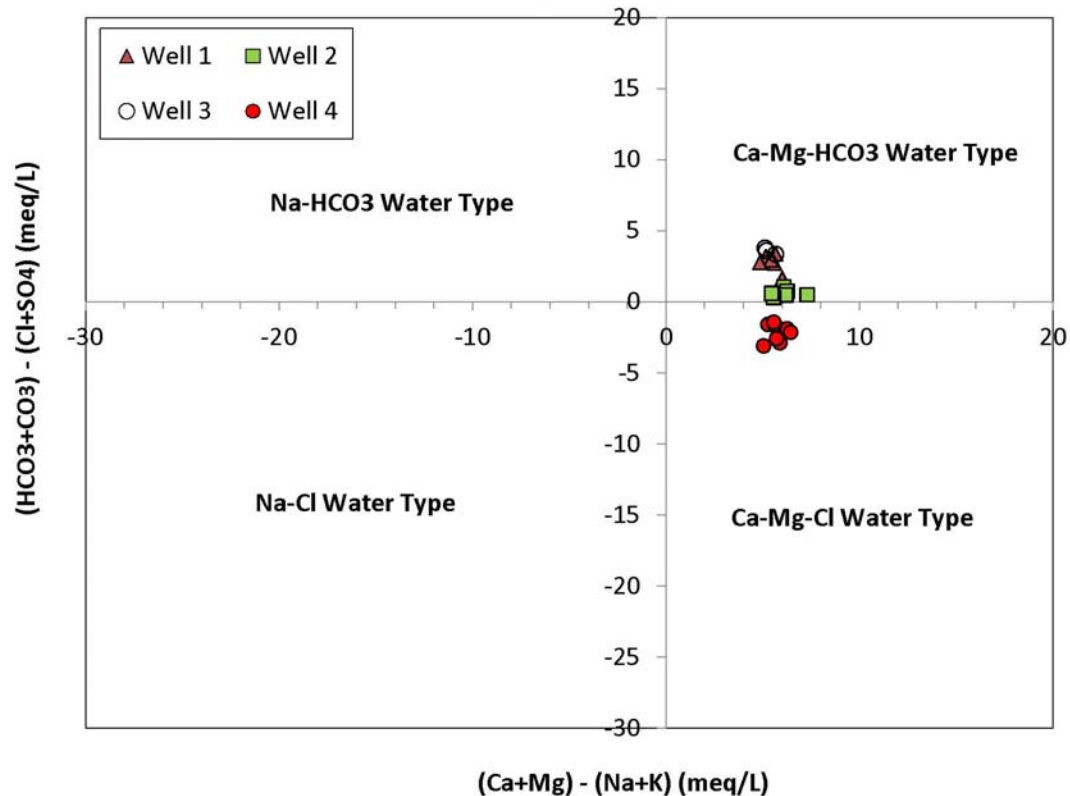


Figure 7. $(\text{CO}_3+\text{HCO}_3)-(\text{Cl}+\text{SO}_4)$ vs. $(\text{Ca}+\text{Mg})-(\text{Na}+\text{K})$ plot of the water samples (after Chadha, 1999)

Changes in saturation state are useful to distinguish different stages of hydrochemical evolution. It is also useful in detecting the effective geochemical reactions in controlling water chemistry. Saturation indices fall into three categories: under-saturated ($\text{SI}<0$), supersaturated ($\text{SI}>0$) and equilibrium ($\text{SI}=0$) regarding a particular mineral. Table 2 shows the saturation indices of the water samples. The water samples are supersaturated with calcite and dolomite and under-saturated with others such as gypsum, anhydrite, and halite. This can be explained by the greater solubility of halite and gypsum in water. Calcium and magnesium are preferentially released by atmospheric aqueous CO_2 from the dolomite and limestone formations, which are the dominant host rocks in the study area. Aquifer rocks often contain both calcite and dolomite either in separate layers or as disseminated crystals. All water samples are super-saturated with both calcite and dolomite (Fig. 8). The point at which the groundwater is in equilibrium with both calcite and dolomite has special chemical properties. The dissolution of gypsum induces the transformation of dolomite to calcite in the rock, during dedolomitization process

which produces waters with increased Mg, Ca and SO_4 concentrations (Plummer *et al.*, 1990) (Fig. 8). The increasing Ca concentration due to gypsum dissolution causes calcite to precipitate. The CO_3 concentration decreases as calcite precipitates and this provokes the dissolution of dolomite and a subsequent increase in the Mg concentration. The evaporate rock dissolution in well No.4 is greater than others, which is most probably the cause of its higher salinity compared to other wells during dedolomitization process.

Trace elements concentration

The results of heavy metal analysis are summarized in Table 3. Almost all of the trace element concentrations such as Al, Mn, Cr, Fe and Zn, in the study area were lower than the standard value. Mercury (<0.2), selenium (<0.3), cyanide (<10) values were below detection limit.

Water turbidity assessment

The summarized result of mean turbidity value in the study area is presented in Figure 9. The range of turbidity values in the wells was recorded approximately at 0.2-21 NTU in well No.1, 0.7-14

NTU in well No.2, 2.7-45 NTU in well No.3 and 0.2-5 NTU in well No.4. The turbidity limit for drinking water is proposed at about 5 TU (Hargreaves, 1999). As the results show, the turbidity value of the well No.3 is greater than the others, and well No.4 has the lowest value (turbidity problem) among the wells. As mentioned before, these wells were drilled to supply the potable water of the area, but due to the turbidity problem of wells No. 1, 2 and 3, only the well No.4 is used as drinking water resource in the study area. The first issue to solve this problem is determining the origin and cause of turbidity in the ground water supplies of the study area. Turbidity occurs when fine suspended particles of clay, silt, organic and inorganic matter, plankton and other microorganisms are picked up by water. Most probably, turbidity is a problem associated with some consolidated, poorly consolidated and unconsolidated formation. The wells are mostly drilled in Asmari limestone Formation. Silt and marl exist as interfingering layers in the fractured limestone in the area. Due to highly fractured and

loose rock units, no lithology logs were obtained during drilling (Fig. 2). The geological log of well No.4 is fractured lower than the others. Thus, considering these facts, the interfingering layers of clay minerals are most probably the main causes of turbidity in the study area.

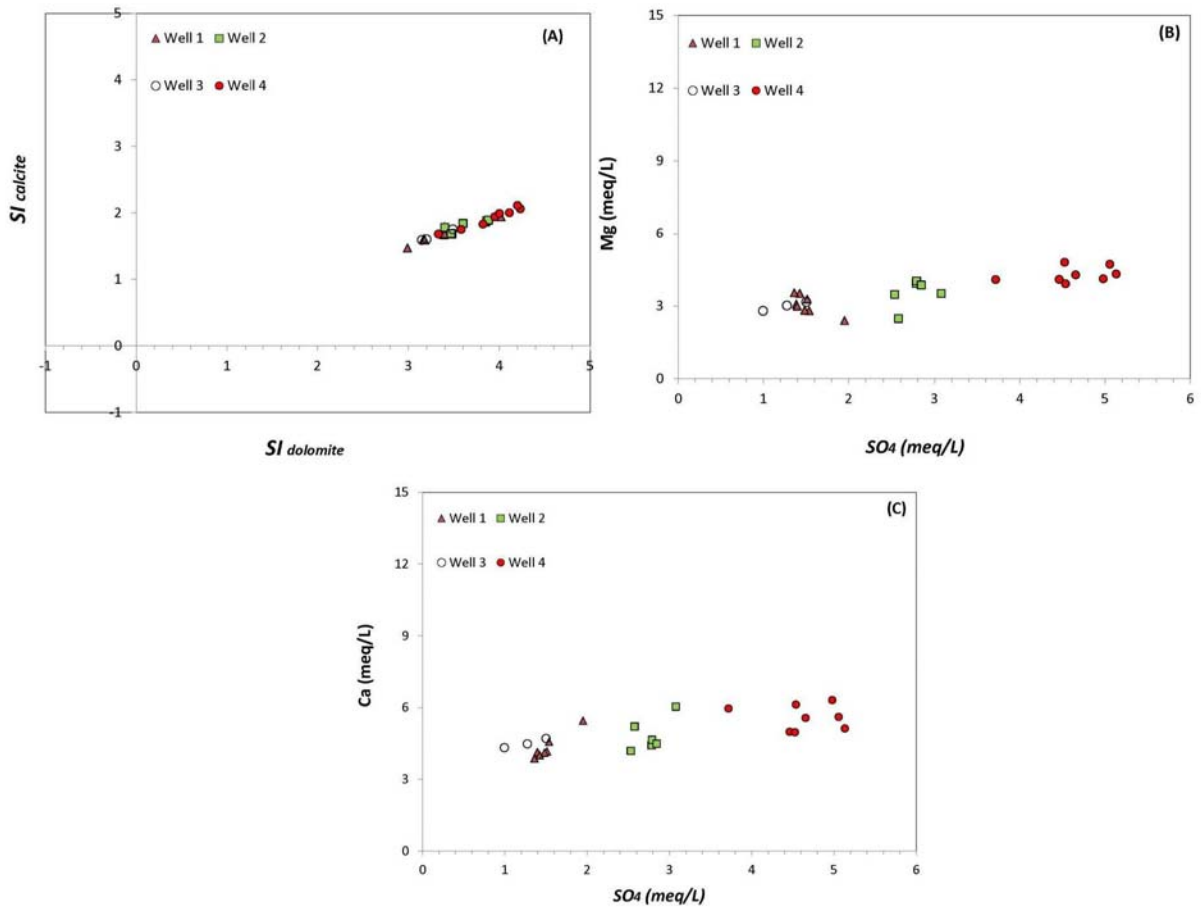
Figure 10 shows the total solid solution (TSS) in the study area, as a main factor in water turbidity. The lowest and highest TSS were measured approximately at 4 mg/lit in well No.4 and 45 mg/lit mg/lit in well No.1, respectively. XRD analysis was performed in order to determine the grain characterization of sediments in the waters, using X'pert high score software. The curves in Figure 11 represent the contribution of mineralogical phase and data points of experimental X-ray diffraction patterns and full lines after Rietved refinement of the sediments sample. The quantitative analysis according to the Rietved method showed that the sediments in this study mainly consisted of calcium carbonate (Manganese), clay (Hydro aluminum silicate with potassium and calcium) and small amounts of Hydro aluminum sulfate.

Table 2. Saturation indexes of the water samples

Well No.	date	Saturation index				
		Calcite	dolomite	Gypsum	Halite	Anhydrite
1	6/7/2010	1.67	3.39	-2.03	-5.97	-2.25
1	18/7/2010	1.68	3.4	-2.03	-5.99	-2.25
1	15/6/2011	1.86	3.85	-2.06	-5.98	-2.28
1	14/11/2011	1.61	3.17	-1.95	-5.88	-2.17
1	16/3/2013	1.79	3.4	-1.75	-5.76	-1.97
1	18/8/2013	1.47	2.99	-1.98	-5.88	-2.19
1	1/7/2014	1.94	4.02	-2.1	-5.83	-2.32
1	22/4/2015	1.59	3.18	-2	-5.82	-2.21
2	6/7/2011	1.68	3.48	-1.91	-5.72	-1.70
2	13/6/2012	1.88	3.86	-1.90	-5.64	-1.68
2	18/8/2013	1.89	3.88	-1.90	-5.67	-1.68
2	16/3/2013	1.78	3.4	-1.82	-5.66	-1.61
2	17/12/2014	1.84	3.6	-1.75	-5.64	-1.53
2	22/4/2015	1.69	3.47	-1.96	-5.65	-1.75
3	19/7/2010	1.75	3.49	-2.2	-5.81	-1.98
3	4/1/2011	1.59	3.15	-2.38	-5.92	-2.17
3	22/4/2015	1.6	3.2	-2.27	-5.81	-2.06
4	12/7/2011	1.75	3.58	-1.69	-5.26	-1.47
4	17/12/2011	1.83	3.82	-1.67	-5.3	-1.46
4	12/5/2012	1.68	3.33	-1.59	-5.2	-1.38
4	11/2/2013	2	4.11	-1.61	-5.14	-1.4
4	14/5/2013	2.06	4.23	-1.6	-5.14	-1.38
4	11/11/2013	1.94	3.95	-1.61	-5.17	-1.4
4	21/7/2014	1.99	4	-1.7	-5.12	-1.48
4	20/12/2014	2.11	4.2	-1.57	-5.23	-1.36

Table 3. Mean concentration of heavy metal in the water wells (in ppb)

Well No.	1	2	3	4
Mn	1.26	2.65	1.33	1.33
Fe	4.91	7.03	7.35	9.68
AL	7.92	5.16	6.1	4.59
As	1.89	1.94	1.82	1.31
Cu	2.85	2.40	<2.27	5.87
Cr	<2.63	2.74	<2.63	1.91
Cd	0.56	0.59	0.52	0.1
Pb	0.86	1.23	<0.93	1.05
Ni	0.23	2.66	2.16	0.85
Co	0.73	0.77	0.64	<0.1
Ag	<0.32	<0.32	<0.66	<0.32
Cn	<10	<10	<10	<10
V	3.67	2.47	2.76	2.37
Zn	1.35	1.76	1.06	2.05
Hg	<0.2	<0.2	<0.2	<0.2
Se	<0.3	<0.3	<0.3	<0.3
Sb	<0.5	<0.5	<0.5	1.82
Ba	-	-	-	6.36
Mo	-	-	-	1.62

Figure 8. (A) Saturation index of calcite vs. dolomite and (B) Mg and (C) Ca ions concentration vs. SO_4

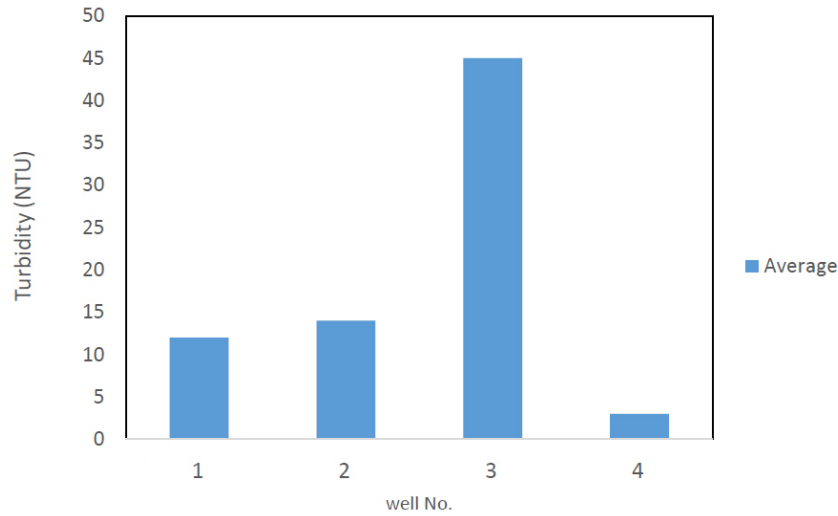


Figure 9. The mean turbidity value in water wells of the study area

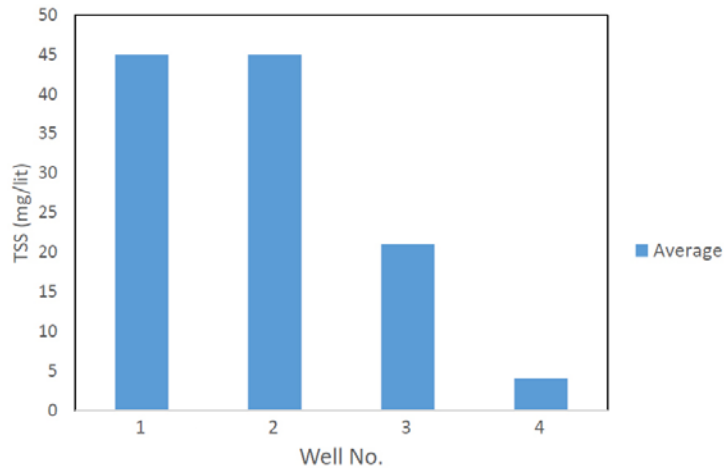


Figure 10. Total solid solution (TSS) in the study area

Drinking and irrigation water quality

The analytical results have been evaluated to ascertain the suitability of groundwater of the study area for drinking and agricultural uses. The physical, chemical and microbiological characteristics of the groundwater samples were compared with the standard guideline values recommended by world health organization (WHO) for drinking and public health purposes (Table 1). The water samples were classified based on total hardness (Todd, 2005). Total hardness (TH) values of the samples range from 373 to 535 mg/lit that fall in the “very hard” water category (Fig. 12). Most desirable limit of TH for drinking water is 100 mg/l and maximum allowable limit is 500 mg/l as per the WHO international standard (WHO, 1983). TH concentration of the water samples indicate that all groundwater samples exceed the most describe limit

but do not exceed maximum allowable limit. The highest desirable TDS is up to 500 mg/l and maximum permissible value is up to 1500 mg/l based on the WHO specification (Table 4).

Based on the TDS values, none of the groundwater samples exceed the maximum allowable limit. TDS concentration of well No.2 and 4 exceed the most desirable limits in WHO standard. Salinity and indices such as sodium percentage (%Na) are important parameters for determining the suitability of groundwater for agricultural uses. The analytical data plotted on the US salinity diagram, illustrates that about 80% of the groundwater samples, especially from well No.4, fall in the field of C3S1, indicating high salinity and low sodium water, which can be used for irrigation on all types of soil without danger of exchangeable sodium (Fig. 13). The sodium

percentage (%Na) is obtained by the following Equation:

$$\%Na = [Na] \times 100 / [Ca+Mg+Na+K]$$

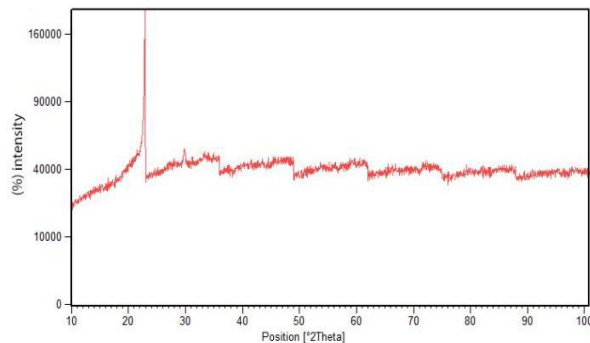
where all ionic concentrations are expressed in meq/l. The Wilcox diagram relating sodium percentage and total concentration shows that 85% of the groundwater samples fall in the field of good to permissible, and 15% of the groundwater samples fall in the field of excellent for irrigation (Fig. 14).

Microbiological analysis

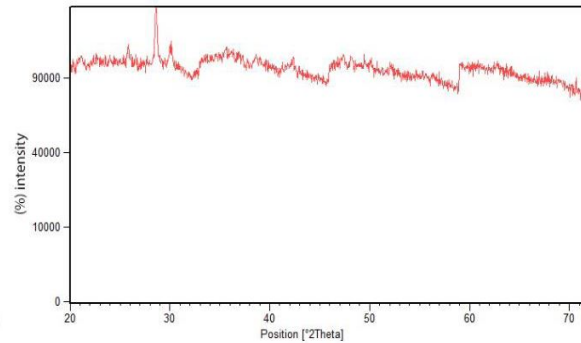
Bacteriological water analysis is a method of analyzing water to estimate the presence/absence and enumeration of various microorganisms. It represents one aspect of water quality. It is a microbiological analytical procedure which uses samples of water and determines the concentration of bacteria. It is then possible to draw inferences about the suitability of the water for use.

Table 4. Groundwater samples of the study area exceeding the permissible limits prescribed by WHO for drinking purposes

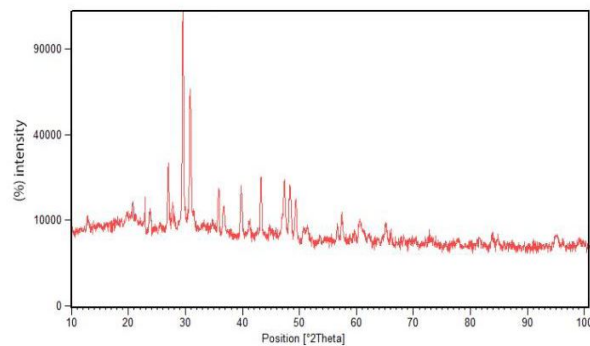
Parameters	WHO international standard (2012)		Wells exceeding permissible limits			
	Most desirable limits	Maximum allowable limit	well no. 1	well no. 2	well no. 3	well no. 4
pH	7-8.5	9.2	7.43	7.48	7.34	7.54
TDS	500	1500	453.28	525.39	440.99	696.73
TH	100	500	373.73	420.54	378.20	497.99
Na	-	200	21.73	26.27	24.30	47.09
Ca	100	200	85.89	95.78	89.95	111.63
Mg	70	150	37.11	44.37	36.32	52.15
Cl	300	600	24.30	33.76	24.02	55.46
SO ₄	300	400	72.31	135.72	60.35	222.37
F	-	1.5	0.51	0.54	0.43	0.78



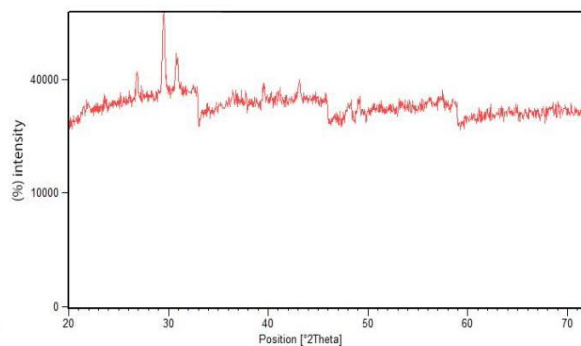
well No. 1



well No. 2



well No. 3



well No. 4

Figure 11. Data points of experimental X-ray diffraction patterns and full lines after Rietveld refinement for the sediments sample

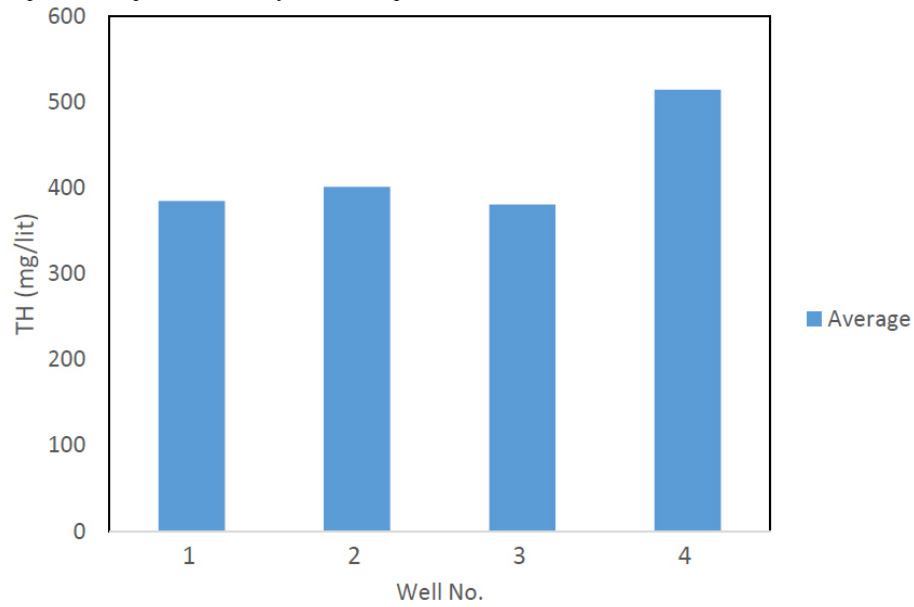


Figure 12. Total hardness (TH) values of the water samples

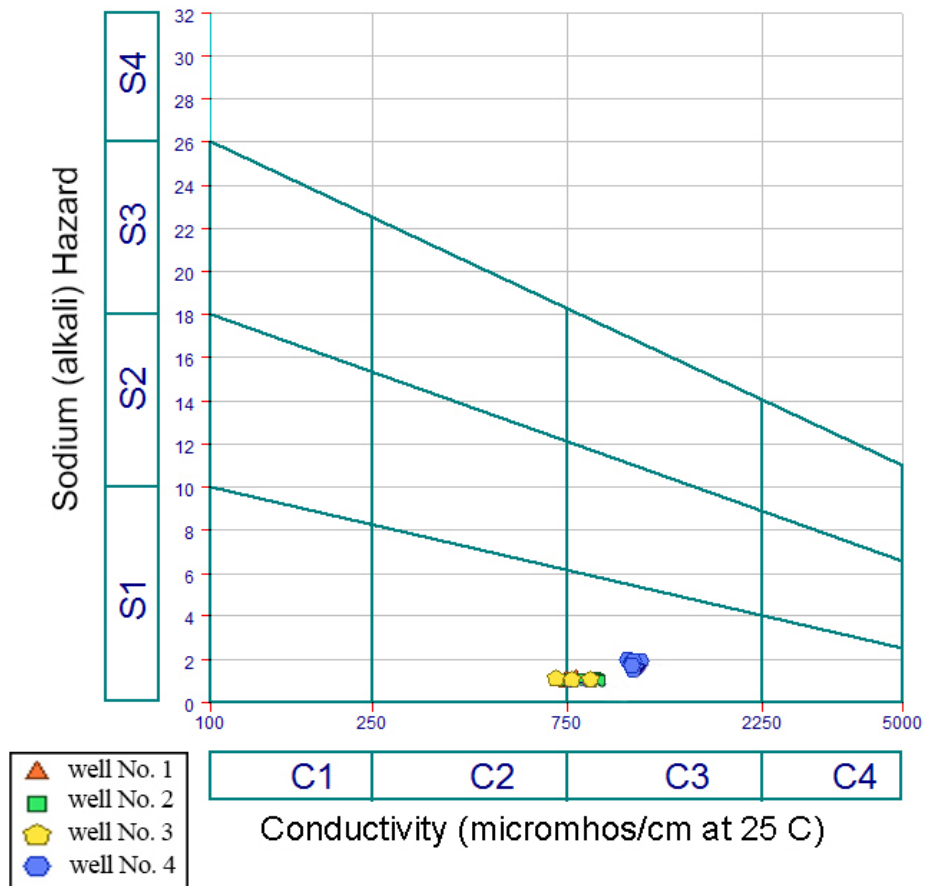


Figure 13. Rating of water samples based on the salinity and sodium hazard

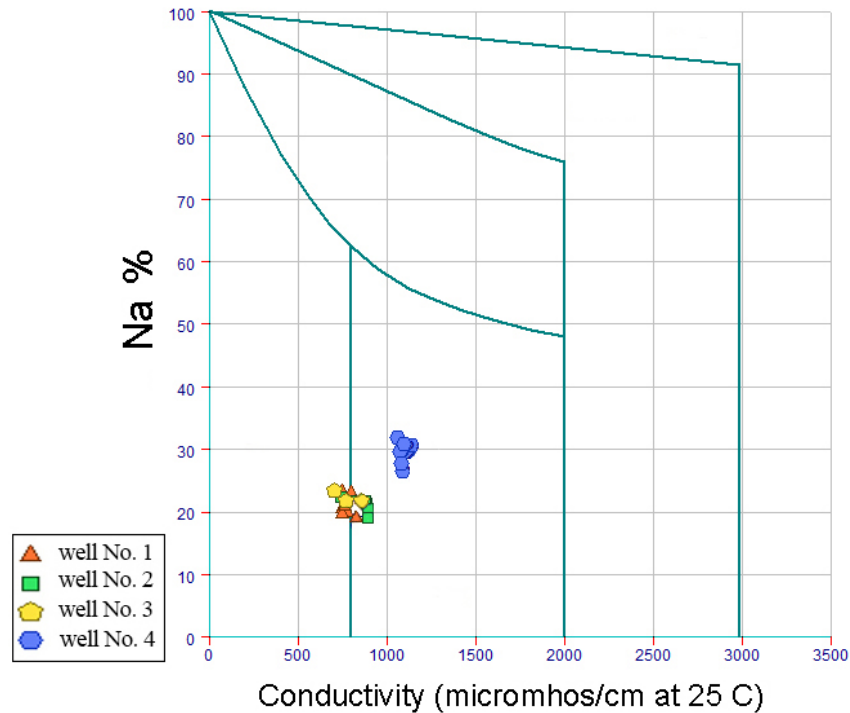


Figure 14. Groundwater samples classification based on the EC and %Na (after Wilcox, 1955)

This process is used, for example, to routinely confirm that water is safe for human consumption or that bathing and recreational waters are safe to use. Microbiological parameters of 3 wells (No.1, 2 and 3) in the study area were measured (Table 5). The results showed that bacteriological water parameters were outside the accepted limits recommended by the WHO for drinking water. All water samples contained various microorganisms including zooplankton and fecal coliform. Therefore, the ground waters should be treated if used as drinking water. The most probable number (MPN) of coliform in the water samples (Table 5) ranges from 16 to 23 MPN/100 ml, so that well No.3 has the highest coliform counts of 23 MPN/100 ml, which exceeds the standard limit for drinking water.

Table 5. Result of microbiological analysis of the water samples

Samples water	Fecal coliform (MPN/100 ml)	Total coliform (MPN/100 ml)
Well NO.1	1.1	16
Well NO.2	1.1	23
Well NO.3	23	23

Conclusions

Despite extensive research on the hydrogeology of karst systems in Iran, only few studies are available about karst pollution, especially water turbidity. Four drinking water wells were drilled on north limb of anticline in Mansour Abad karstic aquifer, southwest of Iran; three of them are out of usage due to the water turbidity problem. As a vital step to manage water turbidity issues, the geology, and hydrogeochemistry as well as microbiological characteristics of the sampling waters were evaluated. Well No.4 with greater depth has more EC, but no turbidity problem compared to the other wells. Therefore only well No.4 is used as drinking water resource in the study area. The relative abundance of the ions in well No.4 is $Ca > Mg > Na > K$ and $SO_4 > HCO_3 > Cl$. The water samples are supersaturated with calcite and dolomite and undersaturated with gypsum, anhydrite, and halite. The dissolution of evaporate rocks especially gypsum inter layers is the main reason of elevated EC in well No.4. Dedolomitization process produces waters with increased Mg, Ca and SO_4 and decreased CO_3 and HCO_3 concentrations, especially in well No.4. Geological factors and human activities are the two main factors that affect the turbidity in wells of study area. The results showed

that the moving interfingering layers of clay minerals along the fractures with groundwater flow is one of the main causes of turbidity in wells No. 1, 2 and 3. Turbidity can also be due to the residual bentonite which is used as drilling fluid during well construction. Bacteriological water parameters were outside the accepted limits recommended by the WHO for drinking water. Several methods are proposed below to reduce the turbidity value of the water resources in study area. Chlorination and ozonation and/or using membrane filtration are useful methods to remove biological turbidity of drinking water. Installing well screens with smaller slot size and resetting the screen at the formations with lower interlayer sand and marl may help to improve the water quality for drinking. Also, installing suitable gravel-packed and water pumping

pumping during well completion may effectively reduce turbidity of water resources in the study area. It is recommended that a combination of the above-mentioned methods, and extra tools such as hydrogeological approaches, be applied for determining turbidity source in such complex systems, thus reducing the level of uncertainty.

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References

- Alavi, M., 2004. Regional stratigraphy of the Zagros fold-thrust belt of Iran and its pro-foreland evolution. *Am. J. Sci.* 304: 1–20.
- Auckenthaler, A., Huggenberger, P., 2003. Pathogene Mikroorganismen im Grund- und Trinkwasser. *Transport Nachweismethoden Wassermanagement (Pathogenic microorganisms in groundwater and drinking water. Transport, analytical methods and water management)*, 196.
- Bagheri, R., Nadri, A., Raeisi, E., Eggenkamp, H.G.M., Kazemi, G.A., Montaseri, A., 2014. Hydrochemical and isotopic ($\delta^{18}\text{O}$, $\delta^2\text{H}$, $87\text{Sr}/86\text{Sr}$, $\delta^{37}\text{Cl}$ and $\delta^{81}\text{Br}$) evidence for the origin of saline formation water in a gas reservoir, *Chemical Geology*. 384: 62–75.
- Bagheri, R., Nadri, A., Raeisi, E., Kazemi, G.A., Eggenkamp, H.G.M., Montaseri, A., 2013. Origin of brine in the Kangan gasfield: isotopic and hydrogeochemical approaches. *Environ Earth Sci.* DOI 10.1007/s12665-013-3022-7.
- Bagheri, R., Nadri, A., Raeisi, E., Shariati, A., Mirbagheri, M., Bahadori, F., 2013. Chemical evolution of a gas-capped deep aquifer, southwest of Iran. *Environ Earth Sci.* doi:10.1007/s12665-013-2705-4.
- Bordenave, M.L., 2008. The origin of Permo-Triassic gas accumulations in the Iranian Zagros fold belt and contiguous offshore areas: a review of the Paleozoic petroleum system. *J Petrol Geol.* 31: 3–42.
- Bruce, Banoeng-Yakubo, S.M., 2008. Hydrochemical characterization of groundwater in the Akyem area, Ghana. *The Electronic Journal of the International Association for Environmental Hydrology On the World Wide Web*, 16.
- Chadha, D.K., 1999. A proposed new diagram for geochemical classification of natural water and interpretation of chemical data, *Hydrogeology Journal*. 7: 431–439.
- Drew, D.H.H., 1999. Karst Hydrogeology and Human Activities impact. *Consequences and Implications International Contributions to hydrogeology*, 20.
- Dupont, M.F.B., 2007. Using turbidity dynamics and geochemical variability as a tool for understanding the behavior and vulnerability of a karst aquifer. *Hydrogeology Journal*. 689–704.
- Falcon, N.L., 1967. Southern Iran, Zagros Mountains. In: Spencer AM (ed) *Mesozoic-Cenozoic orogenic belts*. Geological Society London. 4: 199- 211 (Spec Publ)
- Gabber, M., 1998. Water Wells Producing Sand or Turbidity. *Drinking Water and Radiological Protection Division*.
- Gibs, F.W., 2001. U.S. Geological Survey TWRI Book 9. U.S.
- Hargreaves, J.A., 1999. control of clay turbidity in ponds. SRAC publication.
- James, G.A., Wyned, J.G., 1965. Stratigraphic nomenclature of Iranian oil consortium agreement area. *Am Assoc Petrol Geol Bull* . 49: 2188–2245
- Knauth, L.P., 1988. Origin and mixing history of brines, of Palo Duro Basin, Texas, USA. *Appl Geochem*. 3: 455–474
- Massei, N., 2001. Transport de particules en suspension dans l'aquifère crayeux karstique et à l'interface craie/alluvions. PhD Thesis, Rouen
- Miliaresis, G.C., 2001. Geomorphometric mapping of Zagros ranges at regional scale. *Comput Geosci* 27:775–786
- Mohammadi, Z., Bagheri, R., Jahanshahi R., 2010. "Hydrogeochemistry and geothermometry of Chagal thermal springs, Zagros region, Iran". *Geothermics*. 39: 242–249.
- Mondal, N.C., Singh, V.P., Singh, V.S., Saxena, V.K., 2010. Determining the interaction between groundwater and saline

- saline water through groundwater major ions chemistry. *Journal of Hydrology*. 388: 100–111.
- Nebbache, S.L.M.A., 1997. Turbidity and microorganisms in a karst spring. *Europ J Soil Biol*, 89–103.
- Plummer, L.N., Busby, J.F., Lee, R.W. and Hanshaw, B.B., 1990. Geochemical modeling in the Madison aquifer in parts of Montana, Wyoming and South Dakota. *Water Resour. Res.* 26: 1981–2014.
- Richter, B.C., Kreitler, C.W., 1993. *Geochemical Techniques for Identifying Sources of Ground-Water Salinization*. CRC Press, Boca Raton
- Stocklin, J., Setudehnia, A., 1977. *Stratigraphic Lexicon of Iran*. Geological Survey of Iran, Tehran, Iran, 376 pp.
- Taheri-Tizro, A., Voudouris, K.S., 2008. Groundwater quality in the semi-arid region of the Chahardouly basin, West Iran. *Hydrol. Process.* 22: 3066- 3078
- Talbot, C.J., Jarvis, R.J., 1984. Age, budget and dynamics of an active salt extrusion in Iran. *J Struct Geol* 6:521–533
- Todd, D.K., Mays, L.W., 2005. *Groundwater hydrology*. John Wiley & Sons Inc.
- Wicks, C.E., 1997. Geochemical evolution of a karst stream in Devils Icebox Cave, Missouri, USA. *J.Hydrol*, 30–41.
- WHO. 1983. *guidlines to drinking water quality world helth organisation*. geneva.