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Water Quality Assessment and Hydrochemical Characteristics of Groundwater in Abhar Plain, Zanjan, Iran

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Abstract

In this research, the groundwater quality of Abhar Plain was studied for drinking, domestic and irrigation uses. To assess the evaluation of hydrochemistry and quality, 26 groundwater samples were collected and analyzed for the physicochemical factors such as pH, electric conductivity (EC), total dissolved solids (TDS), total hardness (TH), Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-} during Oct 2009. Groundwater suitability for domestic and irrigation purposes was assessed by using WHO standard (2004). Hydrochemical groundwater evaluations revealed that most of the groundwater belongs to the $CaHCO_3$ and mixed CaMgCl type. Gibbs diagram suggests that the chemical weathering of rock-forming minerals and evaporation influence the groundwater quality. The study area was evaluated for the parameters such as Magnesium Absorption Ratio (MAR), Sodium Absorption Ratio (SAR), Sodium Solution Percent (SSP), Residual Sodium Bicarbonate (RSBC), Permeability Index (PI), Kelly Index (KI) and Sodium Percent (Na%). Interpretation of these hydrochemical parameters indicates that most of the groundwater samples were suitable for drinking, domestic and irrigation uses except in a few locations.

Keywords: Groundwater quality; Drinking and irrigation suitability; WHO standards; Iran.

1- Introduction

Water quality refers to the physical, chemical and biological characteristics of water (Santhosh and Revathi, 2014). Groundwater is the most important source of water supply for drinking, irrigation and industrial uses in arid to semi-arid countries like Iran. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and the accelerated pace of industrialization (Dohare *et al*., 2014). Hydrogeochemical processes such as dissolution, precipitation, ion exchange processes and the residence time along the flow path control the chemical composition of groundwater (Nwankwoala and Udom, 2011). The flow path and residence time also influence the contaminant fate. Increased knowledge of geochemical processes regulating the groundwater chemical constituents will help to understand the hydrochemical systems for effective management and utilization of the groundwater resource by clarifying relations among groundwater quality and quantifying any future quality changes (Srinivasamoorthy *et al*., 2014). In this study the water samples were collected and analysed to characterize the groundwater hydrochemical, and classify the water in order to evaluate its suitability for drinking, domestic and irrigation uses in Abhar Plain, Iran.

2- The study area

The Abhar Plain is located in Zanjan province (Northwest of Iran) and is bordered by the watershed basin of Ghezel Ozan River to the north and Khar Rood River to the south and is limited to the basin of river to the west. The total area of the watershed is 1960 km^2, which 45.5% of the area is located in the plain and the rest is mountainous. The basin is placed between 48º 48´ to 49 º 30´ east longitude and 35º 57´to 36º 36´north latitude (Moghimi *et al.*, 2014) (Fig. 1). On the basis of Aqanabati classification (2006), the study area is located in western Alborz structural zone. Many different methods have been used to determine the climatic type of the basin of Abhar River. De Martonne and Emberger were the two most important methods that were used and according to the calculations, the area is considered a partially dry and cold region (Moghimi, 2006). Annual precipitation of Abhar plain is 299.4 mm, which the maximum and minimum amounts were in February and August months. Annual mean of potential evapotranspiration in the studied area was 949 mm. Underground water is the most important source for providing water for irrigational, industrial, and drinking purposes of Abhar plain.

3- Materials and methods

In order to study the quality variation of groundwater in the study area, 26 groundwater samples were collected from the pumping wells during Oct, 2009 and locations were marked using Global Positioning System (GPS). Samples were collected with high density polyethylene (HDPE) bottles of one-liter capacity and samples were stored at suitable conditions till analysis in the laboratory. At the time of sampling, the chemical and physical parameters of the water samples such as pH, EC, TH and TDS were measured using a Hach SensION 156 Multi-parameter probe. The groundwater samples for cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}) analysis were acidified and collected separately. The samples were filtered using vacuum filtration unit and analyzed by using the standard methods given by the American Public Health Association (APHA, 2005) (Table 1).

Table 1) Main cations and anions amounts and hydrogeochemical parameters of study area wells.

ID	**X** m	**Y** m	**Ca^{2+}** mg/l	**Na^+** mg/l	**Mg^{2+}** mg/l	**^{+}K** mg/l	**CO_3^{2-}** mg/l	**HCO_3^-** mg/l	**^{-}Cl** mg/l	**SO_4^{2-}** mg/l	**TDS** mg/l	**pH** pH	**TH** mg/l	**EC** µS/cm
W1	311961	4027000	68.73	131	44.84	1.56	0.00	234.3	52.82	368.4	858.0	7.64	356	1388
W2	314058	4024000	67.93	101.2	33.18	1.17	0.40	234.3	39	277.1	718.3	7.6	306	1135
W3	316589	4029000	29.66	69.66	21.02	0.39	1.00	187.9	17.73	134	418.9	7.92	160.5	672
W4	316624	4025000	70.34	101.2	32.2	1.17	0.00	231.9	39	280	718.3	7.62	308	1138
W5	322727	4022000	31.26	52.65	28.8	0.78	0.00	256.3	37.23	49.95	398.9	7.63	196.5	654
W6	323012	4027000	28.86	32.65	17.62	0.78	0.78	197.7	10.64	39.87	279.2	7.77	144.5	455
W7	326909	4021000	32.06	31.04	14.58	0.39	0.82	168.4	14.54	49.47	269.3	7.66	140	439
W8	327508	4018000	58.31	43.68	27.34	1.17	0.00	314.8	26.59	62.92	448.8	7.52	258	748
W9	329306	4013000	31.26	69.66	22.48	0.78	0.00	266	25.53	69.65	418.9	7.62	170.5	684
W10	329473	4008000	41.68	50.58	25.4	0.78	0.40	285.6	20.56	59.08	408.9	7.62	208.5	676
W11	330347	4011000	30.46	43.68	31.23	1.17	0.00	251.4	21.63	64.36	379	7.63	204.5	631
W12	331012	4021000	43.28	22.07	16.65	0.39	0.38	224.5	12.76	24.02	279.2	7.14	176.5	471
W13	332288	4016000	29.66	26.44	16.65	0.39	0.46	175.7	33.33	12.01	259.3	7.69	142.5	432
W14	334550	4006000	48.09	59.31	29.29	1.17	0.42	329.5	30.49	59.08	468.8	7.57	240.5	776
W15	336567	4011000	43.28	25.06	6.805	0.39	0.24	173.3	12.76	32.18	249.3	7.71	136	404
W16	337125	4015000	30.46	25.75	16.65	0.39	0.36	173.3	13.83	39.39	259.3	7.95	144.5	422
W17	337179	4007000	52.7	35.17	24.43	0.78	0.60	292.9	17.73	47.07	389	7.49	232	653
W18	338046	4003000	46.49	55.87	39.01	2.34	0.20	336.8	31.2	81.17	498.7	7.62	276.5	838
W19	341632	4009000	27.25	29.43	19.08	0.39	0.42	180.6	15.6	42.27	269.3	6.82	146.5	444
W20	341797	4012000	46.49	41.15	20.54	0.39	0.64	192.8	15.6	108.1	379	7.63	200.5	612
W21	341805	4002000	64.73	66.67	32.2	1.17	0.80	388.1	47.86	58.12	558.6	7.36	294	922
W22	344615	3993000	36.87	24.37	34.15	0.39	0.52	258.7	16.66	52.84	359	7.71	232.5	602
W23	344944	4005000	129.7	130.4	94.67	2.34	0.60	912.8	101.7	118.2	1257	6.68	713	2120
W24	349711	3991000	49.7	59.31	33.66	1.17	0.48	346.6	34.39	64.84	498.7	7.87	262.5	826
W25	351852	3995000	80.76	109.7	24.91	0.78	0.80	192.8	48.92	314.1	738.2	7.23	304	1172
W26	351968	3992000	47.29	45.52	39.5	1.17	0.20	314.8	20.56	96.06	488.7	7.74	280.5	806

Table 2) Water chemistry analysis of groundwater samples compared with WHO (2004).

P.	**TH**	**K^+**	**Na^+**	**Mg^{2+}**	**Ca^{2+}**	**SO_4^{2-}**	**Cl^-**	**HCO_3^-**	**pH**	**TDS**	**EC**
AVE	239.81	0.92	57.05	28.73	48.74	100.16	29.18	273.92	7.56	471.87	773.85
MAX	713.00	2.35	131.00	94.67	129.70	368.40	101.70	912.80	7.95	1257.00	2120.00
MIN	136.00	0.39	22.07	6.81	27.25	12.01	10.64	168.40	6.68	250.00	404.00
Median	220.25	0.78	48.05	26.37	44.88	61.00	23.58	242.85	7.62	413.90	674.00
WHO	500	200	200	150	200	250	250	240	6.5-9.2	1000	1500

Units of all parameters are in mg/l except EC (µS/cm) and pH.

Other parameters such as MAR, SAR, SSP, RSBC, PI, KR and Na% were analyzed in the laboratory. The accuracy of the chemical analysis was verified by calculating ion-balance errors where the errors are generally around 5% (Subramani *et al.*, 2005). In order to study the quality of water, the obtained chemical data was evaluated in terms of its suitability for drinking, domestic and irrigation purposes. All samples were analyzed in applied research center of Geological Survey of Iran. The results were evaluated in accordance with the drinking water quality standards (Table 2) given by the World Health Organization (WHO, 2004).

Figure 1) Location of study area and groundwater sampling locations.

4- Results and discussion

The classical use of water analyses in groundwater hydrology result in to produce the information concerning the water quality. The water quality may yield information about the environments through which the water has circulated (Janardhana, 2007).

4.1- Sodium and Potassium

Sodium concentration more than 50mg/l makes the water salt taste and cause health problems. Sodium concentrations were found in between 22.07 to 131.00mg/l. In general sodium salts are not actually toxic substances to humans because of the efficiency with which mature kidneys excrete sodium. Sodium concentrations were found within the desirable limit (~200mg/l) as per WHO. The main source of potassium in groundwater is weathering of potash silicate minerals, potash fertilizer and also due to surface water for irrigation. Potassium varied from 0.39 to 2.35mg/l and was found at desirable limit as per WHO.

4.2- Calcium and Magnesium

Calcium content is very common in groundwater, because they are available in most of rocks, abundantly and directly related to hardness. Calcium concentration varied between 27.25 to 129.70mg/l and was found within desirable limit (~ 75mg/l) in many locations as per WHO. Magnesium usually occurs in lesser concentration than calcium due to the fact that the dissolution of magnesium rich minerals in slow process. Magnesium concentration varied between 6.81 to 94.67mg/l and was found at desirable limit (~ 50mg/l). The order of cations abundance in the groundwater was found as Na^+ + Ca^{2+} + Mg^{2+} + K^+.

4.3- Chloride and Sulphate

The chloride concentration due to domestic sewage, fertilizers applications and/or leaching from upper soil layers in semi-arid climates. Small amounts of chlorides are required for normal cell functions in plant and animal life. Chloride concentration varied between 10.64 to 101.70mg/l and found desirable limit (~250mg/l) in all locations as per WHO. Sulphate occurs naturally in water due to leaching from gypsum, other common minerals and discharge of domestic sewage tends to increase its concentration. Sulphate concentration varied between 12.01 to 368.40 mg/l. most of the samples (about 85%) found desirable limit (~250mg/l) as per WHO. The order of anions abundance in the groundwater was found as HCO_3^- + SO_4^{2-} + Cl^- + CO_3^{2-}.

4.4- Bicarbonate and Carbonate

The primary source of CO_3^- and HCO_3^- ions in groundwater is the dissolved CO_2 in rainwater that on entering in the soil dissolves more CO_2. Bicarbonate concentration varied from 168.40 to 912.80mg/l and found exceed permissible limit (~240mg/l) in many locations as per WHO. Carbonate concentration varied from 0.00 to 1.00mg/l. Both CO_3^- and HCO_3^- contribute to the alkalinity of the water and are associated with the hardness of water which gives an unpleasant taste to water. Normally in natural water as the pH value ranges from 7.0 to 8.0 would contain much more bicarbonates than carbonates (Ramesh and Bhuvana, 2012).

4.5- pH and Electrical conductivity

The pH is a measure of the intensity of acidity or alkalinity conditions of a solution. pH has no direct adverse effects on health; however, higher values of pH hasten the scale formation in water heating apparatus and also reduce germicidal potential of chloride (Bhadja and Vaghela, 2013). Most of the water samples are slightly alkaline due to presence of carbonates and bicarbonates (Murhekar Gopalkrishna, 2011). The pH values of groundwater ranges from 6.68 to 7.95, with an average value of 7.55. This reveals that the groundwater of the study area is slightly alkaline to alkaline nature. According to the WHO (2004), the range of desirable pH values of water prescribed for drinking purposes is 6.5 – 9.2. However, in all the locations of the pH of the groundwater samples were within safe limits. EC is the most important parameter to demarcate salinity hazard and suitability of water for irrigation purposes. The EC values were lower than the maximum permissible limits of 1500μS/cm, in 96.15% (25 samples) of the total groundwater samples. The high conductivity in sample number 23 is likely due to prolonged and intensive irrigational practices and geological conditions acquiring high concentration of the dissolved minerals.

4.6- Total Hardness

Total hardness is an important parameter of water for its use in domestic purpose. According to Sawyer *et al.* (2003) classification for hardness, 23.07, 57.69 and 19.24% of total groundwater samples are moderately hard (75-150mg/l), hard (150-300mg/l) and very hard (~300mg/l) respectively (Fig. 2). Excess hardness is undesirable mostly for economic or aesthetic reasons (Ramesh and Bhuvana, 2012).

4.7- Total Dissolved Solids

To ascertain the suitability of groundwater for any purposes, it is essential to classify the groundwater depending upon its hydrochemical properties based on TDS values (Davis and Dewiest, 1966; Freeze and Cherry, 1979). Total dissolved solids of groundwater samples have ranges from 249.3 to 1257mg/l with the average values of 471.78mg/l. The study reveals that 76.92, 19.23 and 3.85% of the samples come under the categories desirable for drinking; permissible for drinking and unfit for drinking and irrigation, respectively. 80.76 and 19.23% of the groundwater samples in the study area is belong to fresh and brackish water, respectively (Davis and Dewiest, 1966; Freeze and Cherry, 1979) (Table 3).

Table 3) Groundwater classification based on total dissolved solids.

Groundwater classification (after Freeze and Cherry, 1979)			**Groundwater classification (after Davis and DeWiest, 1966)**		
TDS (mg/l)	Classification	% of samples	TDS (mg/l)	Classification	% of samples
>1000	Fresh water type	80.76	>500	Desirable for drinking	76.92
1000-10000	Brackish water type	19.23	500-1000	Permissible for drinking	19.23
<10000	Saline water type	-	<1000	Unfit for drinking	3.85

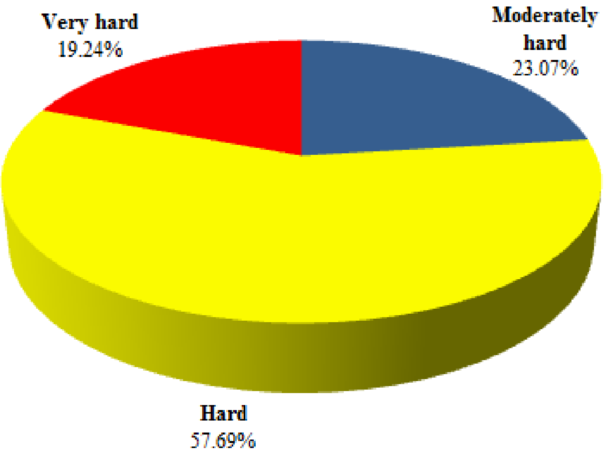

Figure 2) Groundwater classification based on total hardness.

4.8- Hydrochemical Facies

Hydrochemical facies of groundwater depends on lithology, resident time and regional flow pattern of water (Jamshidzadeh and Mirbagheri, 2011). Major cations and anions such as Na^+, K^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, HCO_3^- and CO_3^{2-} in mg/l were plotted in Piper diagram (1944) to evaluate the hydrogeochemistry of groundwater of Abhar Plain with the help of AqQA version 1.1.5.1 software (Fig. 3). The plot shows that most of groundwater samples fall in the field of bicarbonate ($CaHCO_3$) facies type of water in the study area. Some samples are also represented as mixed CaMgCl type. Because of low solubility arising from the presence of igneous and volcanic rocks around the aquifer, there have been few changes in the chemical composition of the waters in the study area.

4.9- Mechanisms of controlling groundwater chemistry (Gibbs ratio)

One of the most interesting aspects of hydrochemistry is the occurrence of water bodies within different water chemistry in very close proximity to each other. Gibbs diagram represents the ratio of $Na^+ + K^+ / Na^+ + K^+ + Ca^{2+}$ and $Cl^- / (Cl^- + HCO_3^-)$ as a function of TDS which is widely used to assess the functional sources of dissolved chemical constituents such as precipitation dominance, rock dominance and evaporation dominance (Gibbs, 1970). The chemical data of the groundwater samples from Abhar Plain are plotted in Gibbs diagram (Fig. 4) which shows that most of the samples of the study area fall in the category of rock dominance and one sample fall in the evaporation dominance, indicating that this process is also responsible for the groundwater chemistry. So, the chemical weathering of the rock minerals could be the main processes which also contribute ions to the groundwater of the study area.

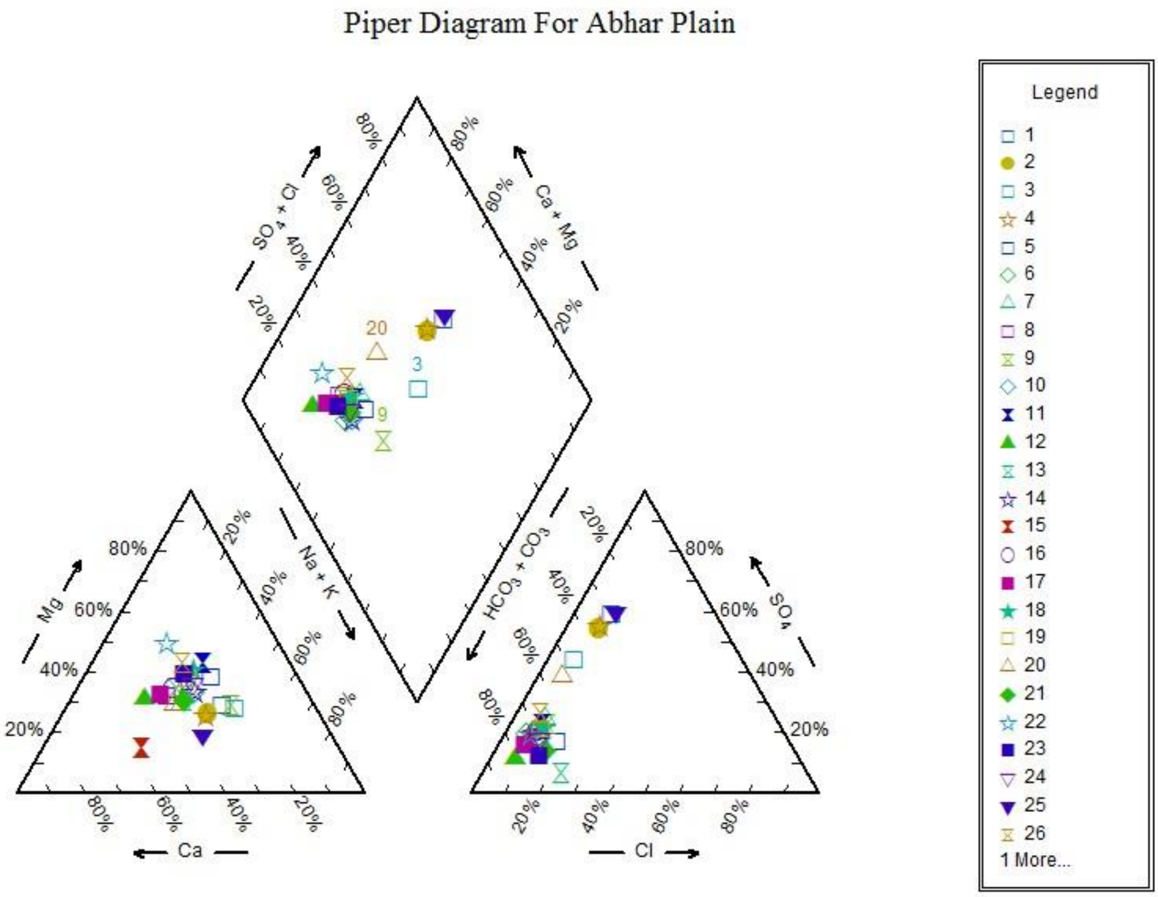

Figure 3) Piper diagram for groundwater samples.

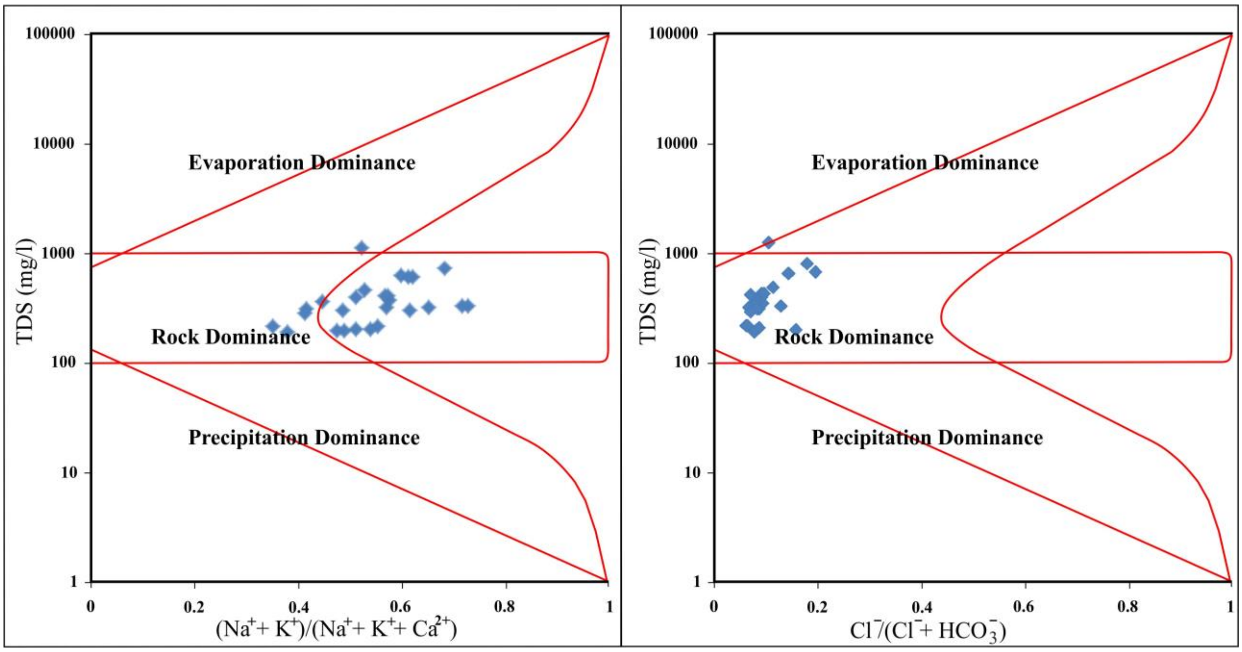

Figure 4) Gibbs diagram for groundwater samples.

4.10- Suitability for Irrigation Use

Excessive sodium and salinity concentrations in irrigation water result in sodium hazard, as well as salinity hazard. Sodium ion in water replacing calcium and magnesium ions in soil causes reduced permeability and soil hardness (Shaki and Adeloye, 2006). To assess irrigation water quality, the parameters such as MAR, SAR, SSP, RSBC, PI, KI, Na%, EC and TDS were calculated based on the chemical variables of water samples (Singh *et al.*, 2005) (see table 4).

Table 4) Calculated statistical parameters for different groundwater samples index in studied area.

ID	PI	KI	SSP	MAR	SAR	RSC	Na%	Class
W1	59.75	0.8	44.63	51.83	3.02	-3.33	44.43	C3-S1
W2	60.45	0.72	41.99	44.61	2.52	-2.31	41.83	C3-S1
W3	76.68	0.94	48.64	53.89	2.39	-0.12	48.44	C2-S1
W4	60.13	0.71	41.83	43.02	2.51	-2.40	41.67	C3-S1
W5	69.77	0.58	37.02	60.31	1.63	0.24	36.82	C2-S1
W6	74.71	0.49	33.26	50.17	1.18	0.36	33.09	C2-S1
W7	72.56	0.48	32.69	42.86	1.14	-0.03	32.54	C2-S1
W8	59.09	0.37	27.22	43.6	1.18	-0.03	27.08	C2-S1
W9	79.47	0.89	47.21	54.25	2.32	0.92	47.01	C2-S1
W10	68.5	0.53	34.74	50.12	1.52	0.49	34.57	C2-S1
W11	65.61	0.46	32.06	62.84	1.33	0.00	31.86	C2-S1
W12	64.11	0.27	21.56	38.81	0.72	0.14	21.45	C2-S1
W13	71.18	0.4	28.93	48.07	0.96	0.03	28.77	C2-S1
W14	66.36	0.54	35.18	50.1	1.66	0.57	35.00	C3-S1
W15	72.84	0.4	28.8	20.59	0.93	0.12	28.70	C2-S1
W16	69.96	0.39	28.11	47.4	0.93	-0.06	27.96	C2-S1
W17	60.31	0.33	25.04	43.32	1.00	0.15	24.91	C2-S1
W18	60.04	0.44	31.05	58.05	1.46	-0.05	30.87	C3-S1
W19	71.27	0.44	30.57	53.58	1.06	0.02	30.40	C2-S1
W20	61.51	0.45	30.98	42.14	1.26	-0.85	30.83	C2-S1
W21	61.75	0.49	33.26	45.07	1.69	0.47	33.10	C3-S1
W22	54.63	0.23	18.71	60.43	0.70	-0.43	18.57	C2-S1
W23	47.86	0.4	28.66	54.63	2.12	0.61	28.50	C3-S1
W24	63.39	0.49	33.21	52.76	1.59	0.41	33.03	C3-S1
W25	60.35	0.78	44.07	33.72	2.74	-2.93	43.93	C3-S1
W26	56.02	0.35	26.38	57.93	1.18	-0.49	26.21	C3-S1

4.10.1- Salinity Hazard

Water with high salinity is toxic to plants and poses a salinity hazard. Soils with high levels of total salinity are called saline soils. High concentration of salt in the soil can result in a physiological drought condition. That is, even though the field appears to have plenty of moisture, the plants wilt because the roots are unable to absorb the water (Nishanthiny *et al.*, 2010). Water salinity is usually measured by the TDS or the EC. The large variation in EC is mainly attributed to lithologic composition and anthropogenic activities prevailing in this region (Khodapanah *et al.*, 2009). Classification of groundwater based on salinity hazard was done according to the recommendation of Wilcox (1955). It was grouped as Excellent (100-250μS/cm), Good (250-750μS/cm), Doubtful (750-2,250μS/cm) and Unsuitable (>2,250μS/cm). Based on EC, 61.53% of the wells have good quality (medium salinity water) and 38.46% have doubtful quality (High salinity water).

4.10.2- Alkali Hazard

The Na^+ alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed as the SAR. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soils. Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil caused by excessive amounts of colloidally absorbed sodium. This breakdown results in the dispersion of clay soil that causes the soil to become hard and compact when dry which increases impervious to water penetration due to dispersion and swelling when wet. Fine-textured soils, those high in clay, are especially subject to this action (Khodapanah *et al.*, 2009). SAR is calculated using the following equation:

$$SAR = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+} / 2)} \qquad (1)$$

Where the ionic concentrations are expressed in meq/l.

Groundwater could be also classified based on SAR as excellent (10), good (10-18), Doubtful (18-26) and unsuitable (>26) (Richards, 1954). Out of the selected wells, based on SAR, all samples can be considered suitable for irrigation uses.

4.10.3- Bicarbonate Hazard

Bicarbonate hazard is usually expressed in terms of Residual Sodium Carbonate (RSC). RSC is calculated using the following equation:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \qquad (2)$$

Where the ionic concentrations are expressed in meq/l.

In waters having high concentration of bicarbonates, there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate (Sadashivaiah *et al.*, 2008). The classification of water quality for irrigation on the basis of RSC was proposed by Eaton (1950). Residual carbonate levels less than 1.25meq/l are considered safe. Waters with RSC of 1.25 – 2.50meq/l are within the marginal range. It was grouped as good (<1.25), doubtful (1.25-2.5) and unsuitable (>2.5). Based on RSC, all the samples have good irrigation water quality.

4.10.4- Sodium Content

High percentage of Na^+ with respect to (Ca^{2+}, Mg^{2+}, Na^+) in irrigation water causes deflocculating and impairing of soil permeability (Singh *et al.*, 2008; Arshid *et al.*, 2011). The sodium in irrigation waters is also expressed as Na% or SSP and the sodium percentage was calculated using the following equation proposed by Wilcox (1955):

$$Na\% = (Na^+ + K^+) \times 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+) \qquad (3)$$

Where the quantities of all cations are expressed in meq/l.

It was grouped as excellent (~ 20), good (20-40), permissible (40-60), suspicious (60-80) and inappropriate (~ 80). The values of Na% in the study area range from 18.06 to 48.4%. Out of selected wells, based on sodium percent, 3.84% of the wells have excellent irrigation water quality, 73.08% of the wells have good irrigation water quality and 23.8% of the wells have permissible irrigation water quality (Fig. 5).

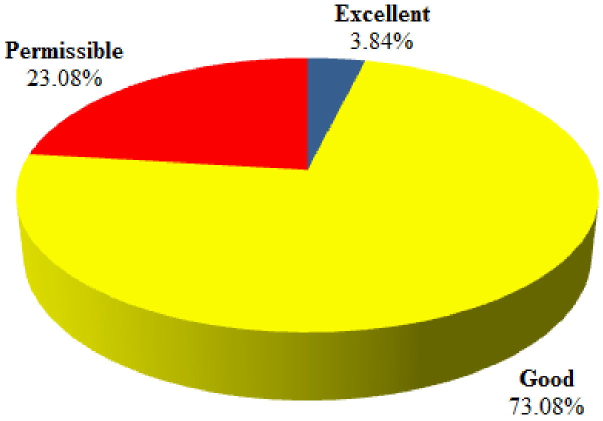

Figure 5) Irrigation water quality based on sodium content.

4.10.5- Magnesium Adsorption Ratio

Likewise, SAR, MAR is also considered as one of the significant parameters to evaluate irrigation water quality. The magnesium hazard of irrigation water is calculated using the following equation proposed by Szabolcs and Darab (1964):

$$MAR = [Mg^{2+} / (Mg^{2+} + Ca^{2+})] \times 100 \qquad (4)$$

Where, all ions are expressed in meq/l.

The computed MAR values in the study area range from 20.59 to 62.84% with mean value of 48.61%. Less than 50% of MAR is suitable for irrigation while more than 50% MAR is unsuitable for irrigation practice. Based on this classification, 54% of the samples are unsuitable for irrigational practice. Continuous use of water with high magnesium content will adversely affect crop yield and therefor suggest quick intervention.

4.10.6- Permeability Index

Continuous use of high salt bearing irrigation water may be reducing soil permeability (Singh *et al.*, 2008). Such problems can be assessed by computing PI of the irrigation water from the expression suggested by Doneen (1962).

$$PI = [(Na^{+} + HCO_3^{-}) / (Ca^{2+} + Mg^{2+} + Na^{+})] \times 100 \quad (5)$$

Where, all ions are expressed in meq/l.

According to this classification, irrigation water with high permeability (~ 75%) is classified as Class I and excellent for irrigation; Class II has permeability between 25-75% and good for irrigation; while Class III has permeability < 25% and unsuitable for irrigation purposes. In the present study, nearly 7.30% samples are class I and 92.30% samples belongs to class II. So, the groundwater in the study area is suitable for irrigation purposes (Fig. 6).

Figure 6) Irrigation water quality based on permeability index.

4.10.7- Kelly Index

Based on Kelly Index (Kelly, 1963) groundwater was classified for irrigation. Kelly Index was more than 1, indicating an excess level of sodium in water; therefore the water Kelly Index of less than 1 was suitable for irrigation. The KI values computed for the study area ranged from 0.23 to 0.94 meq/l with an average value of 0.51 meq/l. All the values are ~1, hence the groundwater quality is suitable for irrigation (Table 5).

Table 5) Classification of irrigation quality based on Kelly Index.

KR (meq/l)	Class	Samples No.
< 1	Safe	All samples
> 1	Unsuitable	Nil

4.10.8- Irrigation Water Classification

The combination of EC and SAR had also been used to determine the suitability of water for irrigation. The US salinity diagram (US Salinity Laboratory, 1954) was used to classify the groundwater samples for irrigation. In US salinity diagram, EC is taken as salinity hazard and SAR as alkalinity hazard (Fig. 7).

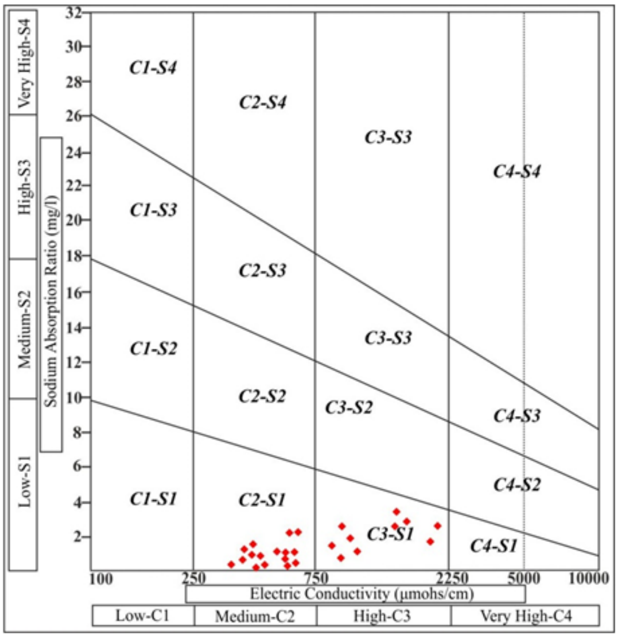

Figure 7) Salinity diagrams for classification of irrigation waters (USSL).

Out of 26 groundwater samples tested, 61.54% fall under C2-S1, indicating well to permissible quality of water for irrigation uses. These groundwater sources can be used to irrigate all types of soils with little danger of exchangeable sodium. 38.46% of samples fall under C3-S1 quality with high salinity hazard and low sodium hazard. High salinity water could not be used on soils with restricted and requires special management of salinity control. Such water can be used to irrigate salt-tolerant and semi-tolerant crop under favorable drainage conditions.

5- Conclusions

Groundwater quality of an area must be studied to understand its suitability for drinking, domestic and irrigation purposes. The major ions in most of the locations were found to be within in WHO permissible limit for drinking water. The sequence of the abundance of the major ions is in the following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $HCO_3^- > SO_4^{2-} > Cl^- > CO_3^{2-}$. The pH average value of 7.55 indicates that the groundwater of the study area is slightly alkaline to alkaline nature. The EC varies from 404 to 2120μS/cm indicating that there is fresh and brackish water types in the area. The groundwater is moderately hard, hard to very hard on the basis of TH. Based on TDS values, most of the samples are desirable for drinking.

Piper diagram revealed that most of the groundwater belongs to the $CaHCO_3$ and mixed CaMgCl type. Falling of water samples in the rock dominance area in Gibbs plot indicates the interaction between rock chemistry and the chemistry of the percolating precipitation waters in the sub-surface.

SAR values and Na % in locations indicate that majority of the groundwater samples are suitable for irrigation. Based on salinity hazard amounts, 61.53% of the wells have good quality (medium salinity water) and 38.46% have doubtful quality (High salinity water). Residual sodium carbonate amounts reveal that all the samples have good irrigation water quality. On the basis of MAR values, almost half of the samples are suitable while the other half unsuitable for irrigational uses. Based on permeability index amounts, 92.30% samples belong to class II, that is, the groundwater is suitable for irrigation. KI values with an average value of 0.51meq/l reveals that the groundwater quality in the study area is suitable for irrigation.

Based on the US Salinity Laboratory classification (1954), the salinity hazard for water samples in Abhar Plain is classified as medium (EC: 250-750μmhos/cm) to high (EC: 750-2250 μmhos/cm). Most of the groundwater samples belong to medium and high salinity hazard (C2, C3) as per the salinity hazard classification in the basin. Assessment of water samples from various methods indicated that groundwater in study area is chemically suitable for drinking, domestic and irrigational uses.

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