

## Factors Controlling Groundwater Chemistry in the Hail Province of Saudi Arabia

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**Abstract:** The present study focuses on evaluating the groundwater quality in parts of the Hail Province of Saudi Arabia. Hail province is the home to the Hail Agricultural Development Company (HADCO) and is dependent entirely on the groundwater resources available from the Saq aquifer for the agricultural productivity. So, twenty four groundwater samples from parts of this were analyzed for their major ions concentration. TDS values of the collected samples ranged from good to acceptable whereas the EC values were below the maximum limits prescribe by WHO for drinking water. The cation and anion concentrations were in the following order:  $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$  and  $\text{HCO}_3^{2-} > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^{2-}$ . The major groundwater facies identified included the Ca(Mg)-Na(K)-Cl-SO<sub>4</sub>-HCO<sub>3</sub> type, Ca(Mg)-Na(K)-HCO<sub>3</sub>-Cl-SO<sub>4</sub> type and the Na(K)-Ca(Mg)-Cl-SO<sub>4</sub>-HCO<sub>3</sub> type. The samples fall in the rock-water interaction zone on the Gibb's plot though evaporation does play some role in controlling the groundwater chemistry. Carbonate weathering, silicate weathering and reverse ion exchange are the major chemical processes which govern the chemistry of the groundwater in the studied area. The water is good in terms of sodium hazard for suitability for irrigation though it falls within the medium to high salinity zone in terms of EC values. Nitrate concentrations are within the acceptable limits but their occurrence in groundwater is attributed to the agricultural activities.

**Key words:** Arid Environment • Saq aquifer • Rock water interaction • Carbonate weathering • Reverse ion exchange

### INTRODUCTION

Saudi Arabia is an arid country characterized by limited rainfall and absence of surface water bodies. The groundwater stored in the deep seated Paleozoic/Mesozoic sedimentary aquifers forms the most important source of water supply in these regions especially for agricultural activities. The low rainfall and high evaporation rates result in a practically negligible recharge from precipitation in arid regions, [1] which in turn leads increase the groundwater salinity [2, 3]. This is especially true for the groundwater resources in the deep seated sedimentary aquifers of Saudi Arabia. The Cambrian-Ordovician Saq aquifer forms one of the major principal aquifers in the North Western part of the country. The recharge rate for the Saq aquifer has been estimated to be 5 cm/yr in the unconfined part whereas it is less than 2.5 mm/yr in the confined part [4]. The non-renewable groundwater reserves from this aquifer have led to the development of extensive

agricultural tracts in Tabuk, Jouf, Hayil and Qassim provinces. Extensive agricultural developments from the 1980's resulted in an increased abstraction of the nonrenewable groundwater to an extent that it was 10 times the total available renewable water resources [5]. The average decline in groundwater levels from 1980 to 2006 in the Saq, Tawil and Kahfah aquifer was 3.00, 1.77 and 1.50 m respectively [4]. At the same time the impact of anthropogenic activities, especially in the agricultural and urban areas can lead to deterioration in groundwater quality thereby restricting its usage in many regions.

Rock water interaction is the major factor which governs the groundwater chemistry in an area [6, 7]. Evaporation and crystallization and dilution due to precipitation are other factors which might affect the overall groundwater chemistry. In arid regions, limited recharge and high rate of evaporation does have an effect on the groundwater chemistry [8]. The present study focuses on evaluating the groundwater quality in parts of the Hail Province of Saudi Arabia. Hail province is the

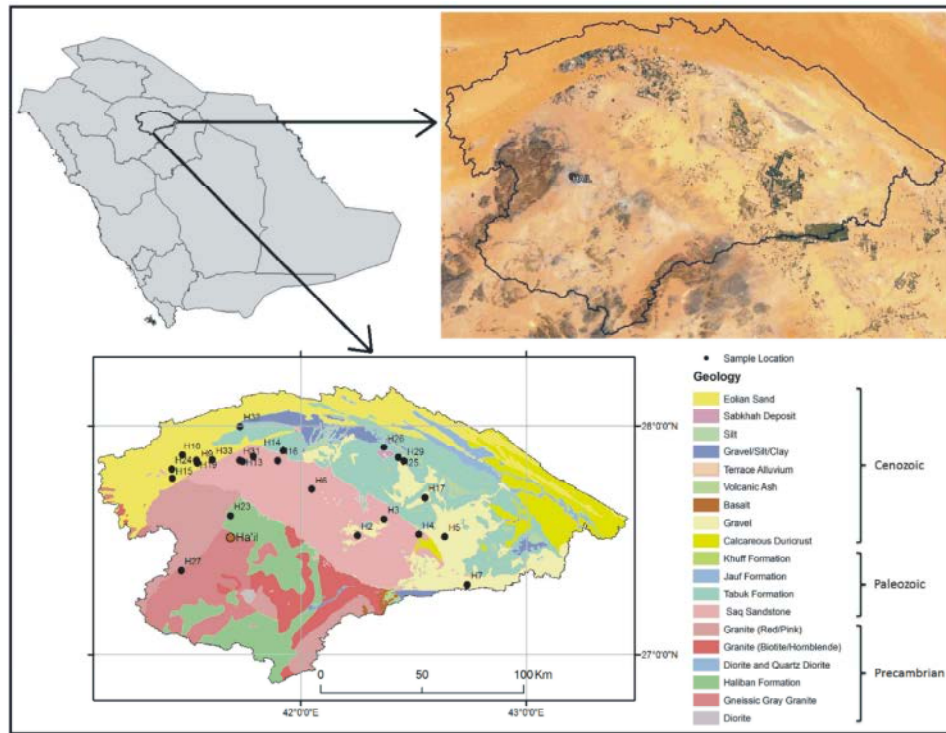


Fig 1: Location map including the geology and the groundwater sampling locations.

home to the Hail Agricultural Development Company (HADCO) and is dependent entirely on the groundwater resources available from the Saq aquifer for the agricultural productivity.

**Study area Description:** The study area forms a part of the Hail province of Saudi Arabia (Fig. 1) and is located between latitudes 26.8°N to 28.3°N and longitude 41.1°E and 43.5°E. The study area in fact is a closed watershed with the main surface water outlet at the eastern end and was demarcated using the hydrological processing tool in ARC GIS from the ASTER DEM data. Water samples were collected from 24 agricultural bore wells falling inside the watershed. The city of Hail lies in the central west part of this watershed and is the only major settlement in the area.

The region is famous for the Hail Agricultural Development Company (HADCO) which is the oldest of the six agricultural companies in Saudi Arabia and was established in 1982 [9]. The western and south western regions comprise of highlands with elevation reaching up to 1500 meters amsl. The city of Hail lies to the immediate east of these highlands. There is a general decline in elevation from the west to east. The central and eastern regions have a gently rolling type of topography with elevations going down to 660 meters.

The region experiences a continental desert type of climate with hot summers and cool winters with temperature ranging from a high of 45°C to 27°C and a low of 23°C to 3°C [10]. The average annual rainfall for the region is around 100 mm/yr with negligible or no rainfall in the month of June, July, August and September [11].

**Geology and Hydrogeology:** Geologically the study area (Fig. 1) comprises of the Precambrian basement rocks, the Paleozoic sedimentary formations and the Cenozoic unconsolidated sediments [12]. The formations become progressively younger in age in the south west-north east direction. The Precambrian basement rocks comprises of diorite, granite andesite-trachite-rhyolite of the Haliban formation. The contact between the Saq formation and the Precambrian basement is marked by the presence of red and pink granites.

The sedimentary formation of the Paleozoic era comprises of the Saq formation, Tabuk formation, Jauf formation and the Khuff formation. The Saq formation ranges in age from Cambrian to Ordovician and is the principal aquifer exposed in the study area. Geologically the formation comprises of medium to coarse grained sandstone and is generally devoid of shales. It is present in the unconfined conditions where it is exposed between

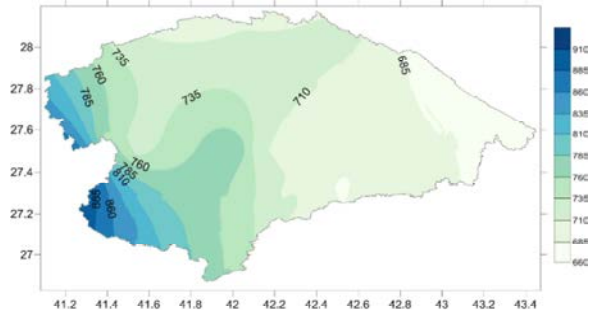


Fig 2: Piezometric map of the study area. Values are in meters above mean sea level.

the Precambrian basement and the Tabuk formation. It is present as a confined aquifer in the north and north eastern part of the study area.

The Saq formation is overlain by the Tabuk formation which ranges in age from Ordovician to Silurian. Geologically the Tabuk formation consists of interbedded layers of sandstone, shale and siltstone. Tabuk formation forms the other principal aquifer exposed in the study area. It is conformably overlain by the rocks of the Jauf formation. Jauf formation is Devonian in age and consists mainly of quartz sandstones but the lower part comprises of shale and dolomite. The Jauf aquifer is one of the secondary aquifers of Saudi Arabia [13]. The Jauf formation is overlain by the Khuff formation which is upper Permian in age and comprises chiefly of limestone and shale. Khuff formation is also one of the secondary aquifers found in the study area.

The Cenozoic era is represented by the unconsolidated deposits which belong to the Quaternary period and ranges from calcareous duricrust to volcanic ash, sabkhah deposits and aeolian sand. The northern part of the study area is covered by the aeolian sand deposits which form a part of the Nafud desert.

Fig. 2 shows the piezometric level of the area. The piezometric levels range from 910 meters to 660 meters with a general flow direction from the west to east. The hydraulic gradient is steeper in the west and gradually flattens out towards the eastern side. The depths to water levels are also deeper in the eastern part especially around the city of Hail where it is approximately 250 meters below the ground surface and gradually becomes shallower (less than 50 meters) towards the eastern side. The depth of the wells from which the water samples were collected range from 150 meters to 800 meters and all the wells tap the Saq aquifer.

**MATERIALS AND METHODS**

A total of 24 groundwater samples were collected from the study area (Fig. 1). All the samples were collected from agricultural farms. Samples were collected in polyethylene bottles of one-liter capacity and were rinsed with sampled water prior to their filling to minimize the chance of any contamination. The sample preservation and the used analytical techniques were in accordance with the standard methods from American Public Health Association [14]. Unstable parameters such as hydrogen ion concentration (pH), total dissolved solids (TDS) and electrical conductivity (EC) were determined at the sampling sites with the help of a pH-meter, a portable EC-meter and a TDS-meter. The major element concentrations including nitrates were carried out at the analytical facility in the Chemistry department of King Saud University. The results of the analysis were then interpreted using the trilinear plots and various ionic relationships to understand the major processes governing the groundwater chemistry of the area.

Table 1: Statistics of the different parameters for the analyzed samples.

Parameter	Minimum	Maximum	Average	Std Deviation
PH	6.80	8.30	7.48	0.42
EC	330.00	1356.00	813.38	340.67
TDS	245.90	869.20	532.68	205.76
Ca	29.40	130.00	71.29	26.39
K	1.40	5.90	3.38	1.32
Mg	3.90	23.80	10.42	4.42
Na	15.60	148.90	77.11	43.04
Cl	12.90	243.00	120.25	73.77
SO <sub>4</sub>	23.90	188.50	88.64	46.85
HCO <sub>3</sub>	76.00	300.00	128.17	51.32
NO <sub>3</sub>	11.30	68.60	33.42	17.33

**RESULTS AND DISCUSSIONS**

The chemical signature of groundwater in a region is dependent on the type of recharge water, geology of the area through which the percolating water interacts, the residence time of groundwater, the prevailing climate of the region and the influence of anthropogenic activities [15].

Table 1 shows the maximum, minimum, average and standard deviation of the various measured parameters in the collected groundwater samples from the study area. The groundwater ranges from slightly acidic to slightly alkaline in nature. The pH value ranges from 6.80 to 8.30. The EC value ranges from 330  $\mu\text{S}/\text{cm}$  to 1350  $\mu\text{S}/\text{cm}$  with an average value of 813.38  $\mu\text{S}/\text{cm}$ . All the samples have EC values well within the WHO acceptable limits of 1400  $\mu\text{S}/\text{cm}$ . The TDS values of the analyzed samples ranges from 245.90 mg/l to 869.20 mg/l with an average of 532.68 mg/l. The TDS values fall within the excellent to fair range [16].

The major cations according to their decreasing concentration expressed in mg/l are as follows:  $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ . The average concentration of Na is 77.11 mg/l and is derived mainly from the dissolution of evaporates (halite) and to a lesser extent by the weathering of silicate minerals. The average Ca concentration is 71.29 mg/l and is derived mainly from the weathering of calcite and dolomite present in sedimentary formations of the study area. Mg which has an average concentration of 10.42 mg/l has been derived mainly from the weathering of dolomites and clay minerals. The mobility of K ion is low as compared to Na and hence is normally found in small quantities in groundwater. The average concentration of K in the study area is 3.38 mg/l and has probably been derived from the potassium bearing silicate rocks. In general all the major cations are well below the WHO prescribed limits [16].

Amongst the anions  $\text{HCO}_3^{2-}$  is the most dominant ion followed by  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{NO}_3^{2-}$ . The value of  $\text{HCO}_3$  ranges from 12.9 mg/l to 243.0 mg/l. The value of Cl ranges from 12.9 mg/l to 243.0 mg/l.  $\text{SO}_4$  values range from 23.9 mg/l to 188.5 mg/l whereas the  $\text{NO}_3$  values range from 11.30 mg/l to 68.60 mg/l.  $\text{HCO}_3$  in the groundwater of the study area has been derived from the dissolution of carbonate minerals and partly due to the weathering of silicate minerals in the presence of carbonic acid. Cl ions have been derived from the dissolution of the evaporite minerals whereas the probable source of  $\text{SO}_4$  is the weathering of shales.

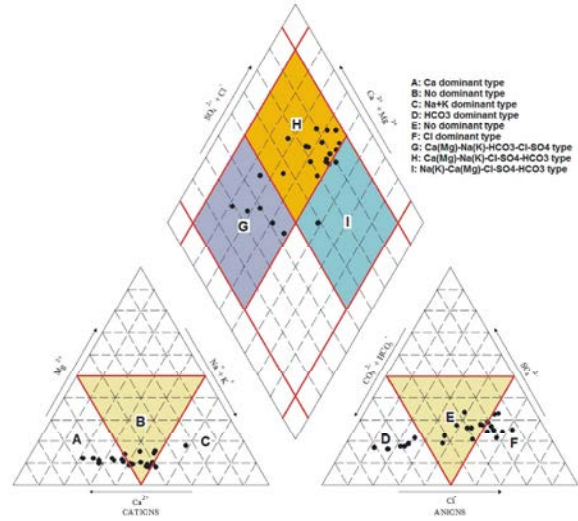


Fig 3: Piper plot showing the identified groundwater facies.

The presence of  $\text{NO}_3$  is attributed to the agricultural activities in the region. The average value of  $\text{NO}_3$  is 33.42 mg/l which is less than the WHO prescribed limit of 45 mg/l [16]. Seven groundwater samples have  $\text{NO}_3$  concentration in excess of 45 mg/l. The source of  $\text{NO}_3$  is mainly the application of the nitrate fertilizers in the agricultural farms which are abundant in the area.

**Classification of Groundwater:** The groundwater facies which reflects the chemical character of water in a hydrologic system was analyzed using the conventional Piper trilinear diagram (Fig. 3).

In terms of the cation concentration the groundwater facies was classified as Ca dominant type (A), no dominant type (B) and Na+K dominant type (C). In terms of anionic concentration the groundwater was classified as  $\text{HCO}_3$  dominant type (D), no dominant type (E) and Cl dominant type (F). The diamond of the Piper diagram reveals the actual groundwater facies. Three major groundwater facies were identified in the present case. Six of the 24 water samples fall within the Ca(Mg)-Na(K)- $\text{HCO}_3$ -Cl- $\text{SO}_4$  type (G). Five of the six groundwater samples in this category have TDS concentration of less than 300 mg/l probably indicating fresh groundwater recharge. The most abundant groundwater facies is the Ca(Mg)-Na(K)-Cl- $\text{SO}_4$ - $\text{HCO}_3$  type (H) with 16 of the 24 groundwater samples falling within this zone. However all the samples in this facies are in the mixed Ca-Mg-Cl- $\text{SO}_4$  type with no samples falling within the zone of non-carbonate hardness. Two samples fall within the Na(K)-Ca(Mg)-Cl- $\text{SO}_4$ - $\text{HCO}_3$  type (I) type of groundwater facies.

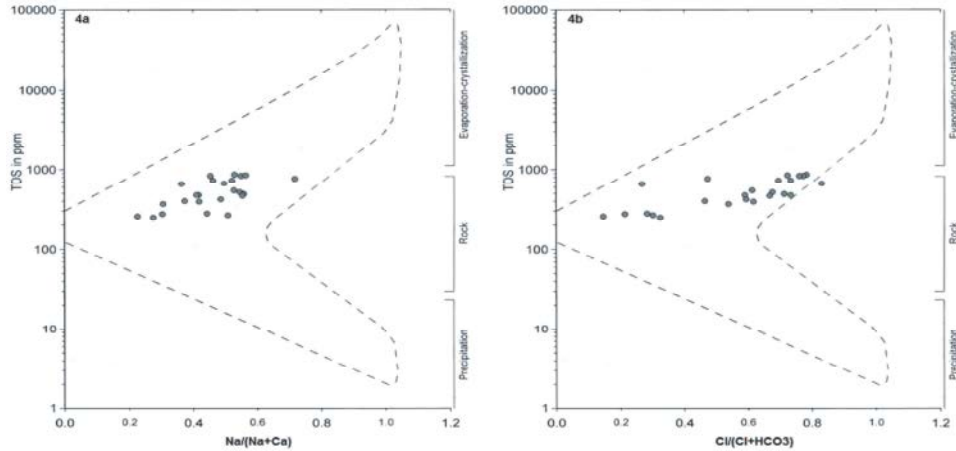


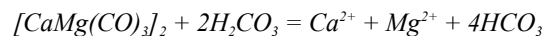
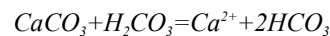
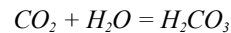
Fig 4: Gibbs Plot [4a. TDS vs Na/(Na+Ca); 4b. TDS vs Cl/(Cl+HCO<sub>3</sub>)].

**Provenance and Water-Rock Interaction:** The natural processes governing the major ion chemistry of groundwater in an area can be depicted by Gibbs plot [17]. The plot of log TDS vs Na/ (Na+Ca) and log TDS vs Cl/(Cl+HCO<sub>3</sub>) helps in assessing the source of groundwater. From the two plots (Fig. 4) it is quite evident that rock water interaction is the main process which controls the groundwater chemistry. All the samples fall within the zone dominated by rock water interaction though there is a slight shift towards evaporation dominance in figure 4b.

Since the area is dominated by an arid type of climate and a comparatively shallow groundwater table in the eastern part of the watershed, the effects of evaporation on groundwater chemistry cannot be completely ruled out. To ascertain this, the plot of Na/Cl vs EC (Fig. 5a) was assessed. In an evaporation dominant environment the ratio of Na/Cl should remain constant with the increasing EC values having a slope of 0 [18, 19]. In the present case the slope of the trend line in Fig 5a is -0.0005 showing a very slight decrease in Na/Cl ratio with increasing EC. Therefore the overall groundwater chemistry of the study area is influenced by the rock water interaction and to a small extent by the evaporation process.

**Carbonate Weathering Process:** Abundance of Calcium and Magnesium in groundwater points towards the dissolution of carbonate minerals. During the rock water interaction process, the calcite and dolomite minerals present in rocks are dissolved thereby increasing the concentration of Ca and Mg in groundwater. In a SO<sub>4</sub>+HCO<sub>3</sub> vs Ca+Mg scatter plot, the ionic concentrations falling below the 1:1 line point towards

carbonate weathering whereas those above the 1:1 line may be a combined effect of carbonate and silicate weathering [20]. The scatter plot (Fig. 5b) for the study area shows that most of the groundwater samples fall below the 1:1 line thereby pointing towards carbonate weathering as the main source of Ca in the groundwater. Carbonate weathering is usually assisted by the formation of Carbonic acid which is formed as a result of the reaction of water with CO<sub>2</sub> present in the soil. The carbonate weathering reactions can be represented as



The Na vs Ca+Mg scatter plot (Fig 5c) shows more samples below the 1:1 line. This excess of Ca over Na can also be the result of reverse ion exchange [21]. The source of Mg in the groundwater is mainly from the dissolution of dolomite present in the sedimentary formation of the study area. Carbonate and silicate weathering tend to increase the concentration of HCO<sub>3</sub> ions [22].

**Silicate Weathering Process:** As already mentioned in the previous section, the dominance of HCO<sub>3</sub>+SO<sub>4</sub> over Ca+Mg is an indicator of silicate weathering. Fig 5a reveals that though carbonate weathering is dominant in the area; some samples show evidences of silicate weathering with excess of HCO<sub>3</sub>+SO<sub>4</sub> over Ca+Mg. If silicate weathering is the dominant process the plot of HCO<sub>3</sub> vs Na should have samples falling above the 1:1 line [22]. In the present case (Fig. 5d) a few samples fall



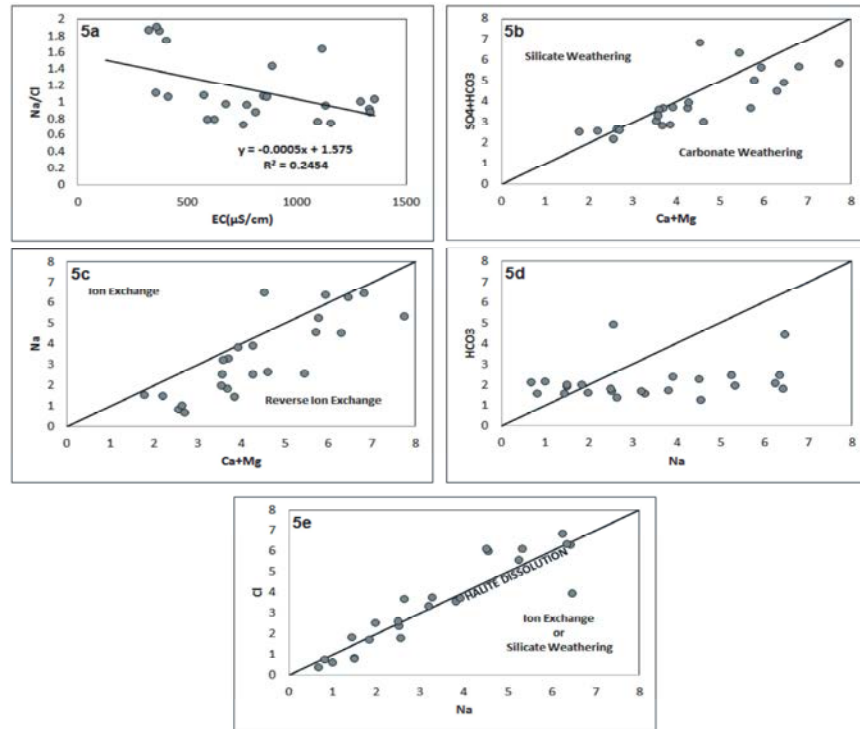
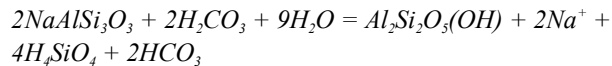


Fig 5: Ionic relationships (5a.NaCl vs Ec plot; 5b.SO<sub>4</sub>+HCO<sub>3</sub> vs Ca+Mg plot; 5c.Na vs Ca+Mg plot; 5d.HCO<sub>3</sub> vs Na plot; Cl vs Na plot). All values are in meq/l unless otherwise stated.

above the 1:1 line showing the dominance of bicarbonate ion thereby pointing towards minor amount of silicate weathering. The silicate weathering reactions can be represented as

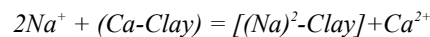


A 1:1 relationship between Na and Cl is an indicator of halite dissolution whereas an increase in Na concentration over Cl signifies silicate weathering [23]. The Cl vs Na plot (Fig. 5e) shows that most of the samples plot along the 1:1 line thereby pointing towards halite dissolution. Given the arid climatic conditions of the study area halite dissolution is possible in the soil zone.

Carbonate weathering as well as silicate weathering result in the increasing concentration of bicarbonate ion in the groundwater.

**Ion Exchange Process:** Ion exchange normally takes place in the presence of clay minerals as the cations in the clays are more easily replaceable as compared to the anions. However an increasing concentration of Ca+Mg over Na in a Ca+Mg vs Na plot may be a result of carbonate dissolution as well as reverse ion exchange [24].Fig. 5c

shows the most of the samples fall towards the Ca+Mg concentration indicating that reverse ion exchange is taking place in the area. In case of reverse ion exchange sodium in the water is replaced by calcium and magnesium in clay material. The reaction can be represented as



This excess of Ca and Mg combines with the excess of Cl to form the Ca-Mg-Cl-SO<sub>4</sub> mixed type of groundwater species as seen in the piper plot (Fig. 3).

**Suitability of Groundwater for Irrigation:** The suitability of the groundwater in the study area for irrigation purpose was assessed using different parameters such as Salinity hazard, Sodium adsorption Ratio, Sodium percentage, Residual Sodium Carbonate and Kelly's Ratio. The classifications of irrigation water into different categories for these parameters the number of samples from the study area falling in each class is given in Table 2. Table 3 shows the classification of the individual samples for irrigation purpose and the maximum, minimum and average values for the calculated parameters.

Table 2: Classification of groundwater based on Na%, SAR, EC, RSC and Kelly's Ratio

Parameters	Range	Water class	No of Samples
Na% after Wilcox (1995)	< 20	Excellent	-
	20-40	Good	9
	40-60	Permissible	15
	60-80	Doubtful	-
	>80	Unsuitable	-
Sodium Adsorption Ratio (SAR)	< 10	Excellent	24
	10-18	Good	-
	18-26	Doubtful	-
	> 26	Unsuitable	-
EC(μS/cm)	< 250	Excellent	-
	250-750	Good	10
	750-2000	Permissible	14
	2000-3000	Doubtful	-
	> 3000	Unsuitable	-
RSC	< 1.25	Good	24
	1.25-2.50	Doubtful	-
	> 2.50	Unsuitable	-
Kelly's Ratio	< 1	Suitable	22
	> 1	Unsuitable	2

Table 3: Classification of water for irrigation purpose.

Well Name	Na%	Water Class	SAR	Water Class	EC	Water Class	RSC	Water Class	Kelly's Ratio	Water Class
H2	49.02	Permissible	3.49	Excellent	1356	Permissible	-5.05	Good	0.94	Suitable
H3	37.92	Good	1.73	Excellent	417	Good	-2.61	Good	0.59	Suitable
H4	58.97	Permissible	4.30	Excellent	1120	Permissible	-0.12	Good	1.42	Unsuitable
H7	49.59	Permissible	3.48	Excellent	1333	Permissible	-4.43	Good	0.97	Suitable
H5	49.79	Permissible	2.72	Excellent	850	Permissible	-2.22	Good	0.97	Suitable
H6	25.51	Good	0.72	Excellent	362	Good	-1.04	Good	0.32	Suitable
H9	48.14	Permissible	1.60	Excellent	377	Good	0.10	Good	0.85	Suitable
H10	34.06	Good	1.35	Excellent	581	Good	-1.72	Good	0.50	Suitable
H11	51.83	Permissible	3.69	Excellent	1292	Permissible	-3.49	Good	1.07	Unsuitable
H13	47.81	Permissible	3.09	Excellent	1135	Permissible	-3.33	Good	0.91	Suitable
H14	44.92	Permissible	2.70	Excellent	1097	Permissible	-4.48	Good	0.80	Suitable
H15	28.61	Good	0.87	Excellent	406	Good	-0.53	Good	0.38	Suitable
H16	42.27	Permissible	2.55	Excellent	1157	Permissible	-4.07	Good	0.72	Suitable
H17	36.78	Good	1.49	Excellent	628	Good	-1.96	Good	0.56	Suitable
H19	41.01	Permissible	1.42	Excellent	364	Good	-0.24	Good	0.67	Suitable
H23	27.87	Good	1.04	Excellent	596	Good	-2.29	Good	0.37	Suitable
H24	33.04	Good	1.55	Excellent	892	Permissible	-0.54	Good	0.47	Suitable
H25	48.03	Permissible	2.41	Excellent	814	Permissible	-2.18	Good	0.88	Suitable
H26	48.08	Permissible	2.39	Excellent	775	Permissible	-1.93	Good	0.89	Suitable
H27	21.50	Good	0.58	Excellent	330	Good	-0.60	Good	0.25	Suitable
H29	42.27	Permissible	1.87	Excellent	678	Good	-1.80	Good	0.70	Suitable
H31	47.97	Permissible	2.67	Excellent	866	Permissible	-1.91	Good	0.91	Suitable
H32	37.21	Good	1.74	Excellent	758	Permissible	-3.28	Good	0.57	Suitable
H33	41.22	Permissible	2.72	Excellent	1337	Permissible	-5.80	Good	0.69	Suitable
Minimum		21.50		0.58		330.00		-5.80		0.25
Maximum		58.97		4.30		1356.00		0.10		1.42
Average		41.39		2.17		813.38		-2.31		0.73

**Sodium Percentage (Na %):** The high concentration of Na in irrigation water may result in a decrease in the soil permeability [25]. It is normally expressed as percentage and is calculated as:

$$Na^+ = \left( \frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{+2} + Mg^{+2}} \right) \times 100$$

where all the ionic concentrations are expressed in meq/l. The values fall within the good to permissible range in terms of Na%. 9 samples fall within the good range whereas 15 samples fall within the permissible range (Table 2). The values of Na% varies between 21.49% and 58.96%. The average Na% value is 41.39% (Table 3).

**Sodium Adsorption Ratio (SAR):** The SAR is also an indicator of the alkalinity hazard and refers to the proportion of Na to Ca and Mg in groundwater. The SAR values which indicates the Sodium hazard for groundwater is calculated as

$$\frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

where all the ionic concentrations are expressed in meq/l. The SAR for the groundwater samples are below 10 indicating low sodium hazard. The USSL plot (Fig. 6) classifies the irrigation water in two classes; C2S1 and

C3S1. The C2S1 class is very good for irrigation as it is characterized by medium salinity and low alkalinity. The C3S1 class is characterized by high salinity and low alkalinity and is suitable for salinity tolerant crops.

**Salinity Hazard:** Electrical Conductivity (EC) concentration in groundwater is an indicator of the salinity hazard to the crops as it is directly related to the TDS of groundwater. In terms of salinity hazard 11 samples fall within the medium salinity hazard whereas 14 samples fall within the high salinity hazard (Table 2). Proper care should be taken while using the high salinity hazard water for irrigation purpose.

**Residual Sodium Carbonate (RSC):** Residual Sodium Carbonate (RSC) of groundwater samples are determined to assess the hazardous impact of carbonate and bicarbonate on the quality of irrigation water and are expressed as

$$RSC = (CO_3 + HCO_3) - (Ca + Mg)$$

where all the values are in meq/l. Positive values of RSC results in the loss of Calcium from the soil resulting in the formation of lime deposits which in turn reduces the infiltration capacity of soils. At the same time an increase in bicarbonate concentration increase the pH of the soil thereby resulting in the dissolution of organic matter

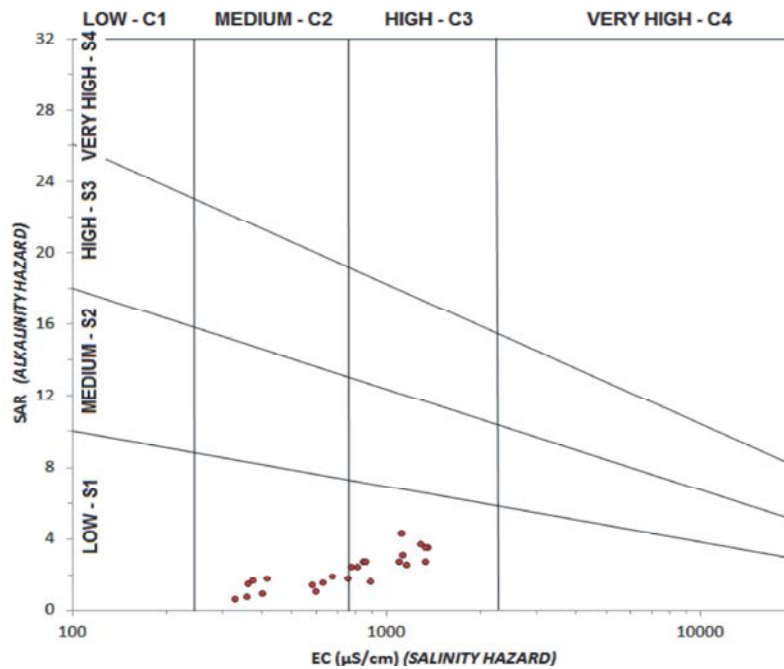


Fig 6: USSL diagram showing alkalinity vs salinity hazard for irrigation water.



which is essential for plant growth [26]. Values of RSC are less than 1.25 and are considered good. Due to the excess of Ca and Mg in the groundwater of the study area due to carbonate weathering the samples fall within the safe zone in terms of RSC (Table 2). The RSC values range from -5.80 to -2.31 for the analyzed samples (Table 3).

**Kelly's Ratio:** Kelly's Ratio is another parameter used for classification of water for irrigation purposes and is expressed as

$$\frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

where all the values are in meq/l. A Kelly's ratio of greater than 1 indicates excess of Na in water and is therefore considered unsuitable for irrigation [27]. Kelly's Ratio of less than 1 indicates water suitable for irrigation. Only 2 samples out of 24 (Table 2) has a Kelly's ratio of greater than 1 and is considered unsuitable for irrigation. The value of the Kelly's ratio for the analyzed samples ranges from 0.250 to 1.424 (Table 3).

## CONCLUSIONS

Three major groundwater facies were identified in the study area which includes the Ca(Mg)-Na(K)-Cl-SO<sub>4</sub>-HCO<sub>3</sub> type, Ca(Mg)-Na(K)-HCO<sub>3</sub>-Cl-SO<sub>4</sub> type and Na(K)-Ca(Mg)-Cl-SO<sub>4</sub>-HCO<sub>3</sub> type. The overall groundwater chemistry of the region is controlled by the rock water interaction though evaporation also plays some role. Excess of Ca and Mg are attributed to the carbonate weathering processes, though some Ca is also attributed to reverse ion exchange. Halite dissolution and silicate weathering also affects the groundwater quality. Carbonate and silicate weathering have collectively resulted in the increase in HCO<sub>3</sub> concentration. The groundwater was assessed for irrigation suitability using various parameters such as Na%, SAR, EC, RSC and Kelly's Ratio was found to be good to suitable for agriculture. Periodic groundwater monitoring is recommended to assess the changes in the water quality in the region. Efforts should be made to optimize the groundwater abstraction to prevent the deterioration in groundwater quality associated with the declining groundwater levels.

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