

Hydrochemical characteristic and evaluation of groundwater quality in Wadi As Sab'an, western Saudi Arabia

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Abstract

An attempt has been made for the first time in this area to appreciate the hydrochemical investigation of groundwater and also to determine the suitability of water for drinking and irrigation purposes. So, to achieve this objective a total of 41 water samples were collected from hand dug wells located along Wadi As Sab'an area and its tributary. Physical and chemical groundwater parameters were determined such as Electrical conductivity(EC), PH, Total Dissolved Solids (TDS), major ions (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , HCO_3^- , SO_4^{2-} and NO_3^-). The abundance of the major ions is as follows: $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{NO}_3^-$. Groundwater in the study area is generally hard, fresh to brackish and alkaline in nature.

The dominant hydrochemical facieses of groundwater are mixed Ca-Mg-Cl and mixed Ca-Cl types in addition to the alkaline earth ($\text{Ca}^{2+} + \text{Mg}^{2+}$) exceeds alkalis ($\text{Na}^+ + \text{K}^+$) and strong acid ($\text{Cl}^- + \text{SO}_4^{2-}$) exceeds weak acid ($\text{HCO}_3^- + \text{CO}_3^{2-}$). On the other hand some parameters were calculated in this study such as Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Percent of sodium % and Permeability Index (PI) which were used to determine the suitability of groundwater for drinking and irrigation uses.

Key words: Groundwater quality, Hydrochemical, Wadi As Sab'an, Saudi Arabia

1 INTRODUCTION

Groundwater is the major source for drinking water where it was estimated that approximately one third of the world's population used groundwater for drinking [1]. So, groundwater is an important water resource in urban and especially for rural areas in the Kingdom of Saudi Arabia (KSA), which is located in the arid zone belt of the world where the fresh water resources are limited. There are no perennial rivers or surface water, and hence the groundwater is considered as the main water source for drinking, domestic uses and irrigation purposes. The alluvial aquifer depends on direct recharge from rainfall. In western and south western part of the KSA shallow alluvial aquifers and fractured Precambrian basement rocks are available with the most important renewable water resource [2].

Wadi As Sab'an is one of the most important wadis in the western part of the KSA to the northeast of Jeddah city. Due to growing population and agricultural expansion has taken place with heavy demand on groundwater resource as a challenging issue in arid region where water resources are limited. Moreover, it is an important agricultural area in the coastal region, which supplies Jeddah and Makkah cities with the requirements of fruits and vegetables.

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Increasing groundwater extraction leads to some serious consequences like water-level decline, increasing salinity, change in agricultural land and increasing people migrating to major cities.

There has been a tremendous increase in demand for groundwater and hence determination of its quality becomes necessary to assess the utility of this resource. Groundwater in wadi As Sab'an area is the only resource which is used for drinking and irrigation purposes where resident mainly depends on groundwater for their daily life.

In this study the hydrochemical investigation is carried out in wadi As Sab'an area for chemical characteristics determinations for the purpose of groundwater suitability for drinking and irrigation purposes.

2 DESCRIPTION OF THE STUDY AREA

Wadi As Sab'an is located in the Rabigh region of western part of the KSA and it is bounded by latitudes $22^\circ 20'$ and $22^\circ 28'$ N and longitudes $39^\circ 50'$ and $40^\circ 05'$ E (Fig.1). It is about 80 km northeast of Jeddah City. This wadi is considered as part of the scarp-Hijaz Mountains of the Arabian Shield where it extends from north to south parallel to Read Sea.

The Wadi As Sab'an area is characterized by an average elevation of about 1200 m above mean sea level (amsl) in the mountainous part that is totally made up of Precambrian basement rocks,

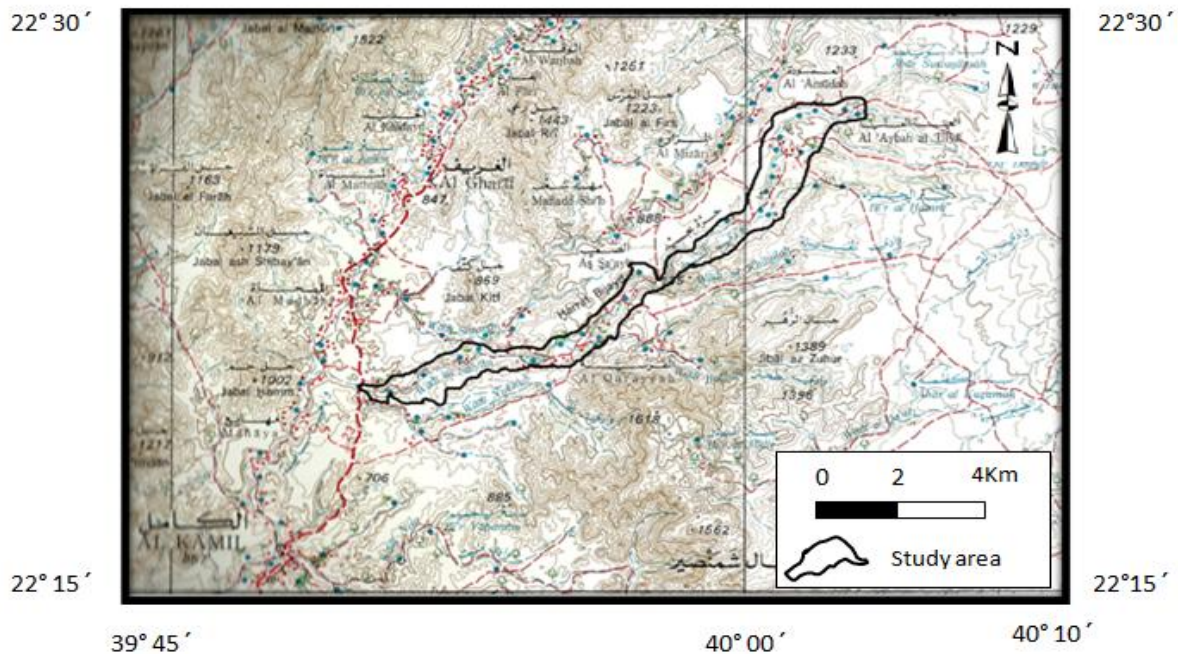


Fig. 1 Location map of study area

whereas the wadi floor is a plain with an elevation varying between 480 and 720m amsl.

The area is characterized by hot summer and mild winter with low rainfall. The air temperature ranges between 40°C (summer) and 20°C (winter). The precipitation in western part of the KSA is characterized by scare and predictable but by very extensive local storms. Runoff occurs as flash floods associated with heavy short-duration storms. Most of this runoff water is lost by infiltration through highly permeable alluvial deposits filling the wadi channels, where possible recharge of the underlying shallow aquifer can occur; sometimes the floods and flash floods may reach the Red Sea and lost forever [3]. The rainfall in the study area generally increases from the west to east where it is relatively high in the eastern boundaries of the catchment.

Geologically, the study area is a part of South Hijaz region in the Western part of the KSA. This area occupies a sector of the Arabian Shield which is composed of Precambrian igneous and metamorphic rocks [4]. The dominant rock unit in the study area is alkali olive basalts, subordinate alkali intermediate, minor pyroclastics and some feldspathoidal lava which is represented by Hammah formation as a part of Rahat group of Palaeocene to Miocene age. Quaternary sediments fill the Wadi As Sab'an area with the thickness ranging from 3 to 7m in the upstream while in lower part of the wadi it reaches to 16 m. The

alluvial deposits are products of rock weathering which is mainly composed of medium to coarse grained gravel along the wadi channels and fine sands and clay in flat area [4].

The bedrocks of the basin are highly weathered and fractured which are ideal places for groundwater storages. In addition the units are intensively faulted and folded.

In this study field measurements are carried out to investigate geology and measurements water level in 41 hand dug wells distributed along wadi As Sab'an and its tributaries. Groundwater in the study area is available under water table (unconfined aquifer) conditions in the alluvial deposits, weathered and fractured crystalline rocks. The depth of wells in this area reaches 28.5 m. Most of them are large diameter dug wells with diameters ranging between 3 and 5m. Some of the area is covered by agricultural land. Groundwater is discharge from shallow alluvial aquifer where the depth of water table ranges from 3.5m (well 12) to 26m (well 34) below the ground surface. The levels of water table in the study area are between 717 m amsl in the upstream to 470 m amsl in the downstream. The groundwater flows from northeast toward southwest along the wadi direction. The aquifer of this region is recharge by precipitation and from irrigation return waters but the precipitation recharge is predominant. Groundwater is abstracted for domestic and agricultural uses in order to meet the local requirements.

3 MATERIALS AND METHODS

Forty one groundwater samples were collected from different private dug wells, representing the shallow unconfined aquifer. The samples were taken in one liter polyethylene bottles during field study in March 2010. Prior to sampling all the sampling containers were washed and rinsed thoroughly with the groundwater. The locations of sampling sites are shown in Fig. 2. Great care was taken for the spatial distribution of the samples.

HCO_3^- was determined by titration against standard HCl. Cl^- was estimated by titration against standard solution of AgNO_3 . Sulfate (SO_4^{2-}) was determined gravimetrically. Ca^{2+} and Mg^{2+} were analyzed by compleximetric titration against standard EDTA solution. Na^+ and K^+ were analyzed by flame photometry. NO_3^- was determined colorimetrically using spectrophotometric technique [5]. The analytical precision for the measurements of cations and

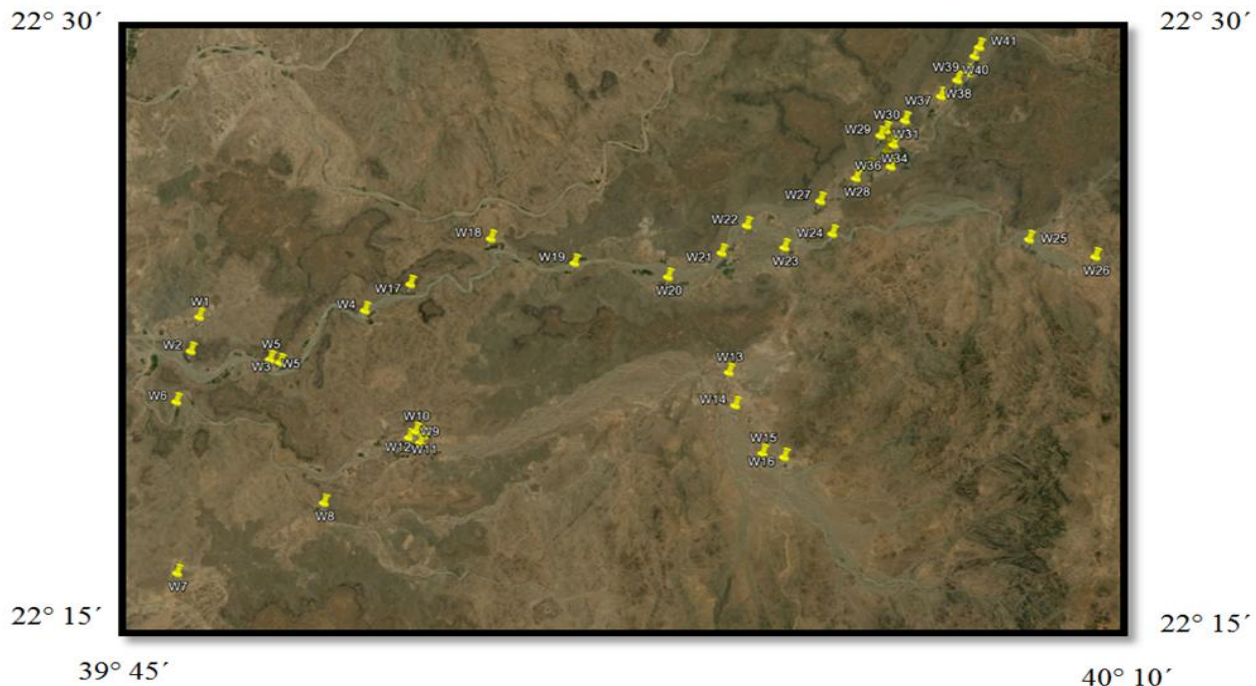


Fig. 2 Location map of groundwater samples in the study area

On the other hand, the water samples were taken after intensive pumping of the wells in order to avoid any local contamination or evaporation. The selected wells are used for domestic and agricultural purposes as the only major resource for the people in the area. All the samples were analysis for major ions (calcium Ca^{2+} , magnesium Mg^{2+} , sodium Na^+ , potassium K^+ , bicarbonate HCO_3^- , sulfate SO_4^{2-} , and chloride Cl^-) and some minor ions (nitrate NO_3^-) using the standard methods [5]. Some physical parameters like hydrogen ion concentration (pH) and electrical conductivity (EC) were measured in the situ at the time of sample collections using portable EC and pH-meter. Chemical analyses for major and some minor ions were performed at the Laboratory of Faculty of Earth Sciences, King Abdulaziz University, KSA. Total dissolved solids (TDS) were measured by sample evaporation techniques.

anions is indicated by the ionic balance error, which was computed on the basis of ions expressed in milliequivalent per liter.

The analytical precision of ions measurements was determined by calculating the absolute error in ionic balance, which was found less than 10% in all samples.

RESULTS AND DISCUSSIONS

4.1 General parameters

The results of the physical and chemical concentration for all groundwater samples are summarized in the study area (see Table 1). The pH values range between 7.12- 8.15 with an average value of 7.48, which elaborates a trend of alkaline chemical reaction within the groundwater system. The EC values in water samples range from 862 to 8820 $\mu\text{S}/\text{cm}$ with an average 2546 $\mu\text{S}/\text{cm}$ which shows that about 16 water samples

(39%) are marginal waters (500–1500 $\mu\text{S}/\text{cm}$), while the rest (61%) show brackish water type. The highest value (8820 $\mu\text{S}/\text{cm}$) was recorded in well no. 9, which is affected by water-rock interaction and soil erosion. The TDS content is usually the main factor, which limits or helps to determine the use of groundwater for any purpose [6]. These TDS values were found to range from 590 mg/l in upstream part to 5330 mg/l in the downstream with an average value of 571.17 mg/l. The wide variation in the values reflects the change in water level, differential weathering and leaching of minerals into groundwater. The increase in salinity can be explained by the chemical reaction that takes place during water-rock interaction, and led to dissolution and precipitation of minerals phases.

halite and anthropogenic source as domestic and animal wastes [7]. This point is clear as the igneous and metamorphic rocks cover the study area.

Calcium (Ca^{2+}) ion is one of the most abundant substances found in natural water in high quantities. It occurs in the rocks with minerals which contain feldspars, pyroxenes and amphiboles. In the present study, it has the second dominance. Calcium concentration in the study area varied widely from 37.80 mg/l to 797.70 mg/l with the mean value of 94.49 mg/l.

Magnesium (Mg^{2+}) is the third cation found in the study area groundwater and it ranges from 23.80 mg/l to 498.70 mg/l with the mean of 94.49 mg/l. Generally Mg^{2+} concentration in

Table 1 Summary Statistics of the hydrochemical variables for the data in the study area

Parameters	Units	Minimum	Maximum	Mean	Median	Stand. Dev.	WHO(2004)
PH	-	7.12	8.15	7.45	7.48	0.32	6.5 – 8.5
EC	$\mu\text{S}/\text{cm}$	862.00	8820.00	2546.29	1613.00	2234.56	1400
TDS	mg/l	590.00	5330.00	1639.05	1145.00	1308.13	1000
Ca	mg/l	37.80	797.70	197.27	115.90	187.98	200
Mg	mg/l	23.80	498.70	94.07	46.20	113.01	150
Na	mg/l	65.80	1030.60	238.92	134.40	237.70	200
K	mg/l	0.70	15.10	5.25	5.70	3.11	200
Cl	mg/l	109.90	2463.50	619.14	336.70	688.63	250
HCO_3	mg/l	67.30	378.50	238.31	233.60	60.23	240
SO_4	mg/l	58.30	1284.10	318.30	187.50	311.77	250
NO_3	mg/l	11.80	658.60	106.10	39.80	168.09	70
TH	mg/l	206.70	3491.20	879.73	515.30	841.18	500
SAR	-	1.44	8.23	3.25	2.67	1.62	-
RSC	meq/l	-66.02	-1.04	-13.67	6.33	16.67	-
PI	%	34.05	71.35	47.79	48.48	8.24	-
%Na	%	19.72	51.18	37.17	36.81	6.66	-
CAL	meq/l	-15.07	1.13	-5.33	5.37	4.53	-

PH : Hydrogen ion concentration
EC : Electrical conductivity
TDS : Total dissolved solids
TH : Total Hardness
CAL : Chloro alkaline index

SAR : Sodium absorption ratio
RSC : Residual sodium carbonate
PI : Permeability index
%Na : Sodium percent

4.2 Cations and Anions chemistry

The major cations and anions make the bulk of groundwater quality. The general dominance of cations was in the order of $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$. Sodium (Na^+) is one of the primary natural cation and it is found in the fresh water generally in low concentrations than the other cations (Ca^{2+} and Mg^{2+}). It is the most dominant constituent in the groundwater in the study area. It was found that the average concentration of Na^+ is higher than the concentration of Ca^{2+} and Mg^{2+} where the concentration ranges from 65.80 to 1030.60 mg/l. The high values of Na^+ is due to weathering of rock forming minerals like sodium plagioclase,

groundwater remains less than Ca^{2+} , but it was found in this study that (17 %) of the samples show high Mg^{2+} concentration over Ca^{2+} . The main source of magnesium in the groundwater is due to ions exchange of minerals in the rocks and soils by water.

Potassium (K^+) is the cation which is normally found at low concentrations in groundwater [8]. The concentration of K^+ in groundwater sample in the study area has very low values and it ranges between 0.7 mg/l to 15.10 mg/l with a mean value of 5.25 mg/l.

The general dominance of anions in the groundwater in wadi As Sab' an area appears in the order of $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$.

Chloride (Cl^-) occurs naturally in all types of water, and it is the most common anion in natural water. Its concentration is the most dominant anion in the groundwater in the study area which ranges between 109.90 mg/l and 2463.50 mg/l with an average of 619.14mg/l, and increases from the recharge to discharge area. High concentration values in the groundwater are due to weathering of minerals, fertilizer, septic tanks and cleachatee from landfill [9] Seven wells (1, 7, 9, 10, 11, 13 and 14) have high chloride contents of about 2000.20, 1013.90, 2463.50, 2443.90, 1059.80, 2253.70 and 2384.80 all in mg/l, respectively. These values seem to be related to anthropogenic local pollution because they are associated with high nitrate concentration of about 380.50, 658.40, 616.50, 644.20, 179.90, 229.80 and 256.30 all in mg/l, respectively.

Bicarbonate (HCO_3^-) is the second dominant anions found in the water samples in this study which the concentration is found to be ranging between 67.30 mg/l and 378.50 mg/l with a mean of 238.3 mg/l. It is known that the primary source of HCO_3^- in the groundwater is from dissolution of minerals such as calcite and dolomite.

Sulfate (SO_4^{2-}) is the third abundant anion in wadi As Sab' an area where the concentration varies between 58.30 mg/l and 1284.10 mg/l with a mean value of 318.30 mg/l. It is considered as one of the major anions which occur in natural waters from oxidation of sulphate ores, presence of shale and solution of gypsum and anhydrite [10].

Nitrate (NO_3^-) is found in natural waters because of organic sources or from agricultural and industrial chemicals [11]. It is the next cation found in the study area groundwater where the concentration is found to range between 11.80 mg/l and 658.60 mg/l with an average of 106.10mg/l. It is observed that nearly 19 % of groundwater from the study area is exceeding the permissible limit of WHO (2004) standards[12]. High nitrate concentration results due to solid waste from sewage, septic tanks and from fertilizers which are used for agricultural practice in the study area.

Figure 3 represent the median of cations and anions in the groundwater in wadi As Sab' an area which shows that Na^+ and Cl^- are the

dominant cations and anion, respectively. The Ca^{2+} , Mg^{2+} , Na^+ and K^+ concentrations are represented by medians of 37%, 24%, 38% and 1% of all total cations, respectively. The order of relative abundance of major cations in groundwater in wadi As Sab' an area appears as $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$. On the other hand, the concentrations of anions Cl^- , HCO_3^- , SO_4^{2-} and NO_3^- is represented by averages of 53% , 21% , 22% and 4%, respectively, of the total anions. The order of relative abundance of major anions in the groundwater is as $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{NO}_3^-$.

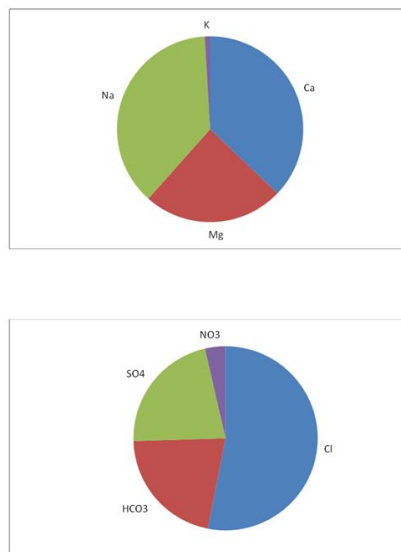


Fig. 3 Pie diagram of Median values of Major ions(epm)

4.3 Groundwater Processes

The chemical processes study in groundwater helps to understand through plotted X –Y coordinate [13] So, the results of the chemical analyses are used to identify the geological processes and mechanisms in the study area aquifer.

Figure 4A represents plot of the chemical data as $(\text{Ca}^{2+} + \text{Mg}^{2+})$ versus HCO_3^- in meq/l. This figure shows that all the data points fall above the line (1:1) which demonstrates an excess of alkalinity in the water that has been balanced by alkalis ($\text{Na}^+ + \text{K}^+$). On the other hand, the plot of $(\text{Ca}^{2+} + \text{Mg}^{2+})$ verses total cations (TC) in figure 4B shows that all points data lie far blew the

theoretical line (1:1). This gives an indication of alkalis contribution to the major cations due to silicate weathering [14]. Figure 4C shows the plot of $\text{Na}^+ + \text{K}^+$ versus TC where all the samples lie below the line 1:1 suggesting that the cations in the study area groundwater comes from silicate weathering. The plot of $(\text{SO}_4^{2-} + \text{HCO}_3^-)$ versus $(\text{Na}^+ + \text{K}^+)$ is represents in Figure 4D where it is clear that all the data points fall above the theoretical line 1:1. It shows the increase in alkalis corresponding to a simultaneous increase in $\text{Cl}^- + \text{SO}_4^{2-}$ which indicates a common source for these ions [15].

Figure 4E displays the concentration of Na^+ versus Cl^- , where it is seen that all the samples points lie below and away from the 1:1 line. This gives an indication that a reverse ion exchange could be a minor controlling factor in the chemical evolution in this area. The concentration of Na^+ versus Ca^{2+} is represents by Figure 4F, where it shows the $\text{Ca}^{2+}/\text{Na}^+$ ion exchange as increasing content of Ca in the groundwater in this area. Figure 4G shows the relationship between $\text{Na}^+ - \text{Cl}^-$ and $(\text{Ca}^{2+} + \text{Mg}^{2+}) - (\text{SO}_4^{2-} + \text{HCO}_3^-)$ with a slope of 0.8797 indicating some level of ion exchange. Graph of $(\text{Ca}^{2+} + \text{Mg}^{2+})$ versus $(\text{SO}_4^{2-} + \text{HCO}_3^-)$ in Figure 4H indicates that all the points fall below the line 1:1 and hence it shows that the deficiency of the ion exchange tendency towards $\text{SO}_4^{2-} + \text{HCO}_3^-$ relative to $\text{Ca}^{2+} + \text{Mg}^{2+}$, therefore, Cl^- should balance the excess of $\text{Ca}^{2+} + \text{Mg}^{2+}$ ions.

4.4 Chloro Alkaline index

It is important to understand identification of the chemical reactions between the groundwater and aquifer materials during its movement and time of residence. The chloro-alkaline index (CAI) is suggested by Schoeller [16] and it describes the ion exchange between the groundwater and the water-bearing bed. The index can be expressed as:

$$CAI = [Cl - (Na + K)] / Cl$$

where all ionic concentrations are expressed in terms of meq/l.

The values of CAI can be either positive or negative. If the exchange of Na^+ and K^+ from water with Mg^{2+} and Ca^{2+} in the aquifer material the index is positive then it indicates an ion exchange. On the other hand, if the exchange of Ca^{2+} and Mg^{2+} of the water is with Na^+ and K^+ of the aquifer material, then the index is negative which confirms reverse ion exchange.

The values of CAI were calculated for the groundwater samples in the study using the previous formula as shown in Table 1. The values of CAI shows that 36 samples(88%) of the groundwater samples in the study area has

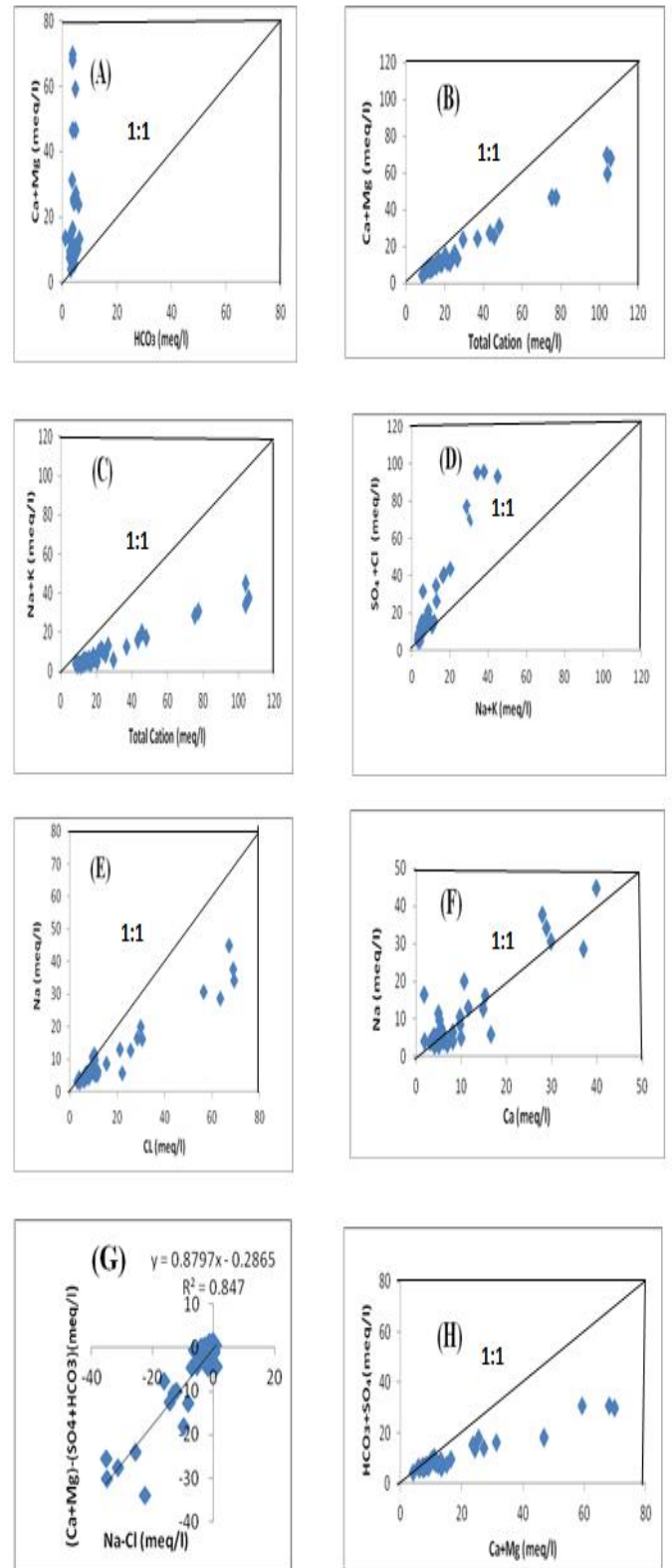


Fig. 4 Graphs of different parameters

Positive values which indicate base-exchange reaction while 5 samples (12 %) have negative value proving the Cation-anion exchange reaction.

4.5 Gibb's Plots

Gibb's diagram is widely used to study the relationship of water composition and aquifer lithological characteristics [17] indicating three distinct fields as precipitation dominance, evaporation dominance and rock-water interaction dominance.

Figure 5 shows plot of Gibb's diagram where it is clear that the water samples of the study area fall in the rock-water interaction and evaporation dominance suggests chemical weathering of rock-forming minerals and evaporation is the main process that contributes to the ions concentrations in the water.

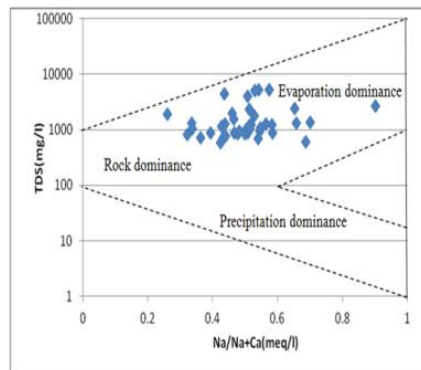


Fig. 5 Gibbs Diagram of water samples

4.6 Hydrochemical Facies

Hydrochemical facies are generally distinct zones that cation and anion concentrations are described within defined composition categories [18]. The facies appears as a function of the lithologic, solution kinetic and flow patterns of the aquifer [19].

Piper diagram [20] is a useful graph, which is used to explain these facies where the upper part of this diagram (diamond-shaped) is divided into six classes as follows: (1) CaHCO_3 Type, (2) NaCl Type, (3) Mixed CaNaHCO_3 , (4) Mixed CaMgCl , (5) CaCl Type and (6) NaHCO_3 types. The hydrochemical data of groundwater from study area was plotted on the Piper diagram as in Figure 6 where most of the groundwater samples fall in the field as a mixture of Ca-Mg-Cl and CaCl types. From this figure, it is observed that the alkaline earth (Ca^{2+} and Mg^{2+}) signification exceeds the alkalis (Na^+ and K^+) and the strong acids (Cl^- and SO_4^{2-}) exceed the weak acid (HCO_3^- and CO_3^{2-}). Aquachem software was used for plotting the Piper diagram.

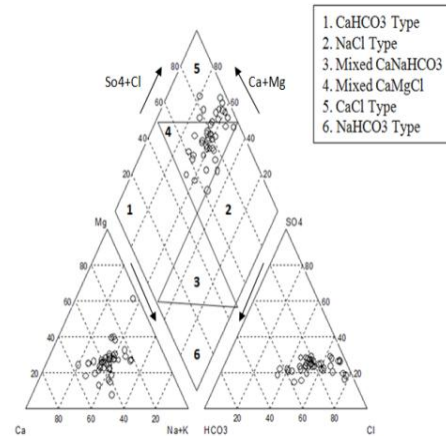


Fig. 6 Hydrochemical classification of groundwater in the study area base on Piper Trilinear diagram

4.7 Drinking and irrigation water quality

The analytical results of water samples have been assessed for drinking suitability and agricultural uses. It is essential to classify the groundwater depending on their hydrochemical properties based on their TDS values [21]; [22]. This is presented in Table 2. It clears from this table and according to WHO (2004) that 39% of the samples is within the permissible limits and the remaining (61%) are exceeding the limits. On the other hand, the classification of groundwater in study area (Table 2) based on the total Hardness [23] shows that all the samples fall in very hard water category. WHO maximum allowable limit of TH for using as drinking water is 500 mg/l. The most desirable limits is 100mg/l. Comparison of the TH results from this area with the maximum limit of WHO shows that 54% of the samples have concentration greater than the maximum allowable limits, and hence, samples cannot be used for domestic purposes.

The assessment of the groundwater suitability for irrigation purposes needs some considerations of certain indices which are EC, Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC) and Permeability Index (PI).

Electric conductivity

EC is a very important parameter in classifying water for irrigation purposes. Wilcox [24] classified irrigation waters on the basis of EC into five groups (Table 2). The EC in the groundwater samples in the study area was found to vary from 862 to 8820 $\mu\text{S}/\text{cm}$ with an average of 2546.29 $\mu\text{S}/\text{cm}$ (Table 1). The variations of EC in this study shows that 71% of the samples fall on permissible categories whereas 17% is located on doubtful categories while the rest (12%) belong to

unsuitable categories. On the other hand, water samples falling in doubtful categories can be used if a moderate amount of leaching occurs while the samples which are (12%) cannot be used on soil with restricted drainage (Table 2).

Sodium adsorption ration (SAR)

It is an important factor for determining the suitability of groundwater for irrigation. This is due to the fact that it measures the effects of alkali/sodium hazard to crops. It can be calculated for the groundwater samples according to the following formula:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

Where all concentrate are in meq/l.

It was found that the SAR ranges between 1.44 and 8.23 with an average 3.25 (see Table 1). According to the classification by Richards [25] the water is excellent for irrigation in this area since none of the samples exceeded the SAR value of 10 (Table 2).

Sodium percent (%Na)

Sodium concentration is also important in classifying irrigation water because it reacts with soil, and hence, reduces its permeability. If there is an excess in concentration of sodium in water, it may produce undesirable effects of Channing soil properties and reducing soil permeability [26]. The sodium percent (%Na) is obtained by using the following equation:

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

Where all the concentrations are expressed in meq/l. The values of sodium percent in the water samples in this area was calculated and found to vary from 19.72% and 51.18% with the average is 37.17 According to Wilcox classification based on %Na (Table 2) it shows that 3% of samples belong to excellent category, 68% of them belong to good category while the remaining sample (29%) belong to permissible category.

Residual Sodium Carbonate (RSC)

The RSC has been calculated for groundwater samples in this study in order to determine the hazardous effects of carbonate and bicarbonate on the quality of water, which will be used for irrigation purposes:

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

Where all ionic concentration is expressed in meq/l.

The calculated RSC values of groundwater samples of the study area range from -66.02 to -1.04 with an average of -13.67 (Table 2).

According to the classification of water for irrigation by Richards (1954), it is indicated that 100% of the samples have < 1.25 and belong to good category and it is suitable for irrigation (Table 2).

Permeability Index (PI)

It is another parameters which is used for determining the water for irrigation, and it defined as follows [27]:

$$PI = \frac{(Na + \sqrt{HCO_3})}{(Ca + Mg + Na)} \times 100$$

Where all the ions concentration is expressed in epm.

The PIs of the groundwater is divided into Class I, Class II and Class III types where classes I and II waters are suitable for irrigation with 75% or more of maximum permeability; class III type of waters with 25% maximum permeability [19]. The permeability index has been computed and the values of groundwater samples range from 34% to 71% with an average of 48 % (Table 2), which indicate that the groundwater in the study area can be designated as class II (25-75%) where the groundwater is suitable for irrigation purposes.

Table 2 Classification of groundwater for drinking and irrigation purposes based on TDS, TH, SAR, RSC, %Na and EC.

Classification Scheme	Range	Categories	Number of samples	Percent of samples
TDS	< 1000	Fresh water	16	39
	1000– 10000	Brackish water	25	61
	10000 – 100000	Saline water	-	-
	>100000	Brine water	-	-
TH (Sawyer and McCarthy 1967)	< 75	Soft	-	-
	75– 150	Moderately hard	-	-
	150 – 300	Hard	-	-
	>300	Very hard	41	100
SAR (Richards 1954)	< 10	Excellent	41	100
	10– 18	Good	-	-
	18 – 26	Doubtful	-	-
	>26	Unsuitable	-	-
RSC (Richards 1954)	< 1.25	Good	41	100
	1.25 – 2.5	Medium	-	-
	> 2.5	Bad	-	-
%Na (Wilcox 1955)	<20	Excellent	1	3
	20 – 40	Good	28	68
	40 – 60	Permissible	12	29
	60 – 80	doubtful	-	-
	>80	Unsuitable	-	-
EC (Wilcox 1955)	<250	Excellent	-	-
	250 -750	Good	-	-
	750 – 2250	Permissible	29	71
	2250- 3000	Doubtful	7	17
	>5000	Unsuitable	5	12

5 CONCLUSION

Interpretation of hydrochemical analysis reveals that the groundwater in the study area is fresh to brackish, very hard and alkaline in nature. The sequence of the abundance of major ions is in the following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- >$

$\text{SO}_4^{2-} > \text{HCO}_3^- > \text{NO}_3^-$. In this area, the dominant hydrochemical facies of groundwater is mixed Ca-Mg-Cl and mixed Ca-Cl types. It was also noticed that alkaline earths ($\text{Ca}^{2+} + \text{Mg}^{2+}$) exceeded alkalis ($\text{Na}^+ + \text{K}^+$) and strong acids ($\text{Cl}^- + \text{SO}_4^{2-}$) exceeded the weak acid ($\text{HCO}_3^- + \text{CO}_3^{2-}$). The main processes governing groundwater chemistry in this area are attributed to minerals weathering and dissolution/precipitation processes taking place along weak zone.

Assessment of water samples was done according to TDS and WHO standards show that most of the water samples are suitable for drinking. The suitability of groundwater for irrigation was evaluated based on quality parameters like: SAR, RSC, EC, %Na and PI classification. The groundwater in the area is found to be good and suitable for irrigation on the basis of SAR, RSC, PI and %Na in all samples, while the EC classification shows that 88% of the water samples are suitable for irrigation but the rest (12%) of samples are not suitable for irrigation however it may be suitable in well-drained soils.

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