

## **Hydrogeochemistry and Groundwater Quality Assessment in an Arid Region: A Case Study from Al Salameh Area, Shabwah, Yemen**

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### Abstract

Due to the highly inadequate supply of safe water for domestic and irrigation purposes, the economic development of the arid regions of Yemen has become a challenging problem to the government. In order to study the major geochemical processes that control the chemistry of the groundwater in a typical arid region, Al-Salameh Area in the lower part of Wadi Meifaah within the arid climate zone of Yemen have been selected. Hydrogeochemical investigations for the assessment of water quality have been carried out to study the sources of dissolved ions and quality of groundwater. The study area is lies between latitudes 14° 12' 00" and 14° 21' 00" N and between longitudes 47° 26' 2.4" and 47° 40' 1.2" E and covers a total geographical area of about 414 km<sup>2</sup>. Being a part of the desert, the region under study receives very low rainfall with mean annual rainfall of about 50 mm.

Based on the variations on the geomorphological, geological and hydrogeological factors, a network of 25 samples were collected in plastic containers of one-liter capacity for detailed chemical analysis, from the selected dug and bore wells. The major ion chemistry data revealed that Na and Ca are the most predominant cationic constituents followed by Mg. For the major anions (SO<sub>4</sub>, Cl, HCO<sub>3</sub>, and NO<sub>3</sub>), the sulphate and chloride are found to be the most predominant anions followed by bicarbonate and nitrate. In general, the values of cationic concentration in the groundwater increase in the downstream part, suggesting control of geology and hydrogeology on the composition of groundwater.

The major elements data were plotted on Piper's trilinear diagram which indicated that, three hydrogeochemical type facies were identified from different aquifers occurring in the study area. They are scattered in the Ca + Mg, Na + K cation subfacies, and Cl + SO<sub>4</sub> and Cl + SO<sub>4</sub>, HCO<sub>3</sub> anion subfacies.

The plotting of the chemical data for waters from the study area in Gibbs diagram suggests that evaporation is the dominant factor controlling the groundwater chemistry of the area. The aqueous geochemistry of aquifer types have been further studied by adopting equilibrium thermodynamic approach. The data were processed by using PHREEQC Interactive aqueous

model computer programme. The solubility-equilibrium hypothesis was tested by computing ion activity products (IAP) from the activities of the uncomplexed ions based on the stoichiometries of the minerals and other solids in the PHREEQC Interactive data base. The calculated saturation indices indicate that the groundwater is undersaturated with respect to anhydrite, gypsum and halite, and supersaturated with respect to calcite, dolomite and aragonite in the most of the samples. This indicates that the incongruent dissolution of carbonate minerals is among the major controlling process in the study area aquifers. It's also concluded that, the high concentrations of calcium and sulphate in the groundwater, is related to dissolution of gypsum ( $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ ) and anhydrite ( $\text{CaSO}_4$ ) while high concentrations of Na and Cl could be related to dissolution of halite ( $\text{NaCl}$ ).

The data on chemistry of the groundwater have been used for the evaluation of quality of water for drinking and irrigation purposes. Comparisons of data with the water quality standards indicate that, out of 25 groundwater samples from Al-Salameh area, 17 samples are suitable for drinking purposes.

The suitability of groundwater for irrigation use was evaluated by calculating SAR, Kelly's Ratio (KR), Residual sodium carbonate (RSC), Soluble Sodium Percentage (SSP) and Permeability Index (PI) and it has been concluded that, the water from the study area can thus, be graded as good for irrigation use.

The results of the study may provide a theoretical basis for the government to make utilization strategies for water resources and development policies in the arid regions of the country.

Keywords: Hydrogeochemistry, Arid Climate , Quality Assessment Shabwah, Yemen

## Introduction

The successful and sustainable development of the water resources in Yemen is under great threat. The most serious and obvious problem is the rapid depletion of groundwater resources. Almost all the important groundwater systems in Yemen are being over-exploited at an alarming rate. The socioeconomic consequences of groundwater resources depletion are dramatic since groundwater will become too expensive for use in agriculture and, as a result, regional agricultural economies based on groundwater irrigation are doomed to collapse if the water resources are not adequately controlled. Due to that, the arid regions of Yemen have become a challenging problem to the government (Al-Amry, 2007).

Al-Salameh area is lies between latitudes  $14^{\circ} 12' 00''$  N and  $14^{\circ} 21' 00''$  N and between longitudes  $47^{\circ} 26' 2.4''$  E and  $47^{\circ} 40' 1.2''$  E in the lower part of Wadi Meifaah Basin, Shabwah governorate within the arid zone of the Republic of Yemen, covering a total geographical area of about 414 km<sup>2</sup> (Fig.1). Arid mountains of the Himyar range bound it on the southwest and by expanse of sand dunes and desert on the northeast. The mean annual rainfall in the lower part of Wadi Meifaah basin is only 50 mm.

## Geology And Hydrogeology

The geological map of Al-Salameh area is given in Fig.2. It's observed from the geological map that, the oldest stratigraphic unit exposed in Al-Salameh area is belong to Tawilah sandstone group (cretaceous). Um Ar Radumah formation overlies Tawilah sandstone group with stratigraphic break and it is exposed in the south and southeast of the study area. The Shihr group is representative by Irqah formation, which is, consists of conglomerate and exposed in two small patches of the study area. Quaternary sediments are the major deposits cover more than half of Al-Salameh area. These sediments are composed of unconsolidated and loose such as gravel, sand and silt produced by the dumping of sediments along the Wadi banks during floods. The north-east part of Al-Salameh area covered by sand fields, detached patches of these sediments are also observed in the right bank and along the main course of Wadi Meifaah in the study area.

Quaternary sediments are the most important water bearing formations over a greater part of the study area. The rocks belong to Irqah conglomerate formation and Mayfa'ah sandstone formation are other aquifers in the study area, which are concealed below the cover of alluvium and aeolian sands, and are seen to be exposed only in the form of isolated hills. The groundwater in these rocks occurs in joints, fractures and other porosity forms. The groundwater occurs in the unconsolidated quaternary sediments dominated by gravel, sand, silt and clay. The gravely and sandy horizons in these area are form one of the best aquifers. Although, clayey and silty beds are poor aquifers, at many places, these have been tapped in open wells. The presence of clay and silt in many horizons, gives rise to semi-confining to confining aquifer conditions. The groundwater also occurs under semi-confined and confined conditions, besides being recorded under unconfined aquifer conditions in the shallow zones (Al-Amry 2005). At places, where the conglomerate and sandstone are at shallow depth, only phreratic aquifer is observed. The depth to water level ranges from 2.1 m to 38m below the ground level.

## Methodology

Water samples were collected in plastic containers of one-liter capacity for detail chemical analysis, from the selected dug and bore wells. These containers were washed thoroughly with distilled water and dried before being filled with water samples. The containers were numbered serially along with a proper record of well/sample location, date, static water level, odour, color, turbidity, operating conditions of well etc. prior to the sampling. Groundwater samples were collected after the well was subjected to pumping for at least half an hour to obtain the composite sample.

The data on pH, temperature and electrical conductivity were obtained in the field. The conductivity and temperature of the groundwater of the wells were measured by using EIJKELKAMP conductivity meter and thermometer, whereas the pH of the groundwater was measured by using Jenway pH-meter

model 3051. The samples were collected and stored below 4° C and analyzed in the Central Research Laboratory of the University of Aden.

For the determination of chloride, precipitation argentometric method of titration was used. The complexometric method of titration with EDTA (disodium salt) was used for the analysis of total hardness of groundwater.

The sulphates in the groundwater samples were determined by the turbidimetric method and the ultraviolet spectrophotometric method was employed for nitrate analysis. The AAS has two types of analytical modes: (1) the absorption mode: was used for determination of Ca & Mg (2) the emission mode: was used for determination of Na & K.

## Results and Discussion

The results of the chemical analysis of groundwaters are presented in Table1. The pH of groundwater varied from 6.6 to 8.24 with a mean of 7.31, indicating a weak alkaline groundwater in nature. Concentration of TDS, a measure of quality, ranged from 413 to 4264 mg/l with a mean of 1442 mg/l. according to the TDS classification, 60% of the samples of groundwater belonged to the brackish type (TDS> 1000 mg/l). Among the cations, the concentrations of Ca, Mg, Na, and K ions ranged from 38 to 509, 16 to 185, 36 to 643 and 2 to 32 mg/l with a mean of 170, 58, 182 and 11 mg/l, respectively. The major ion chemistry data revealed that Na and Ca are the most predominant cationic constituents followed by Mg. The dissolved anions of SO<sub>4</sub>, Cl, HCO<sub>3</sub> and NO<sub>3</sub> ions ranged from 58 to 1320, 64 to 1732, 85 to 325 and 8 to 83 mg/l with a mean of 379, 345, 188 and 29 mg/l respectively. For the major anions (SO<sub>4</sub>, Cl, HCO<sub>3</sub>, and NO<sub>3</sub>), the sulphate and chloride are found to be the most predominant anions followed by bicarbonate and nitrate.

The data of cations and anions were plotted by using AquaChem software version 3.6.4. The piper's Trilinear diagram showing chemical relationship of groundwater constituents from Alsalameh area is given in Fig.3 from which it can be seen that the dominant cations are calcium and magnesium, while the sulfate and chloride are the dominant anions. Three hydrogeochemical type facies were identified from different aquifers occurring in the study area. They are scattered in the Ca + Mg, Na + K cation subfacies, and Cl + SO<sub>4</sub> and Cl + SO<sub>4</sub>, HCO<sub>3</sub> anion subfacies.

Equilibrium thermodynamic modeling:

In order to study the chemical equilibrium existing in groundwater from the study area, the concept of speciation modeling have been used. The most important results of speciation calculations are saturation indices (SI) for minerals, which indicate whether a mineral should dissolve or precipitate (USGS, 2002). the major element data on groundwaters from the study area was processed by using PHREEQC Interactive, a computer programme of U.S. Geological Survey, version 2.8 (2003).

The computed chemical properties of the groundwaters, viz. saturation indices and ionic ratios values are given in Tables 2. It is observed from that table, 15 samples out of 25 show positive values of (SI) for carbonates (calcite, dolomite aragonite) minerals and only 10 samples show negative values. This suggests that the groundwaters in Al-Salameh area are super

saturated with respect to these minerals in some places and under saturated in other places. The evaporite minerals (anhydrite, gypsum, and halite) show negative values of (SI). This is indicative of the fact that, these minerals from the study area are undergoing the process of dissolution.

Sources of major ions:

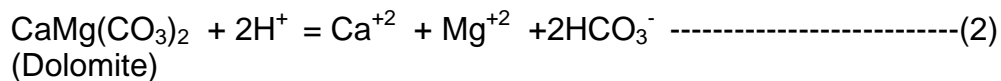
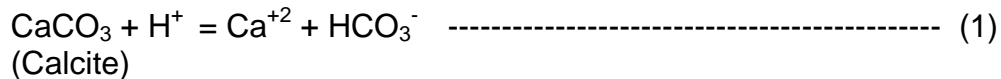
The plot of (Ca+Mg) vs.  $\text{HCO}_3$  for aquifer types in Fig.4 shows that, all the conglomerate and sandstone aquifer samples lie above the line  $(\text{Ca}+\text{Mg}) = \text{HCO}_3$  and only two samples from the alluvium aquifers fall below the equiline. The abundance of (Ca+Mg) in most of the groundwater samples probably, can be attributed to carbonate weathering. The climate also plays a vital role in the arid areas. Hence another reason for Ca+Mg may be related to evaporative concentration. On the other hand, the excess of  $\text{Cl}+\text{SO}_4$  over Ca+Mg in all the samples indicates contribution from different sources of Cl and  $\text{SO}_4$  (Fig.5). Since the aquifer lithology is characterized by presence of gypsum, anhydrite and halite in predominant proportions, logically they are the sources of Cl and  $\text{SO}_4$ . The plot of sodium against chloride concentration shows that most of the points fall close to the 1:1 line suggesting input from halite dissolution (Fig.6). In the conglomerate aquifers, chloride increases more rapidly than sodium, thus, indicating predominance of Cl over sodium in the groundwater. The relationship between sulphate and chloride concentrations is given in Fig.7. It is observed that there is an excess of Cl over  $\text{SO}_4$ . Hardie and Eugester (1970) reported that, the loss of  $\text{SO}_4$  might be related to precipitation of gypsum, but the water samples are highly under saturated with respect to gypsum. This suggests that contribution of ions is proportionally higher from halite than the anhydrite. Drever 1997, relate this anomaly due to wetting and drying mechanism in arid climate. When rain falls on an arid area it normally wets the ground to a depth of less than one meter. After the rainstorm, the water evaporates, leaving behind any dissolved salts from either the rain itself or from interaction between the rain and rock. Very occasionally, there will be a rainstorm of sufficient intensity for the water to percolate through the soil zone and recharge the groundwater system. The percolating water will dissolve completely all highly soluble salts (such as NaCl), but only partially dissolve sparingly soluble salts such as gypsum. The water reaching the groundwater system will thus appear to have lost sulphate relative to chloride, but will be under saturated with respect to gypsum, because there was not sufficient contact time between gypsum and water for equilibrium to be established.

Gibbs (1970) has pointed out that the rate of evaporation, chemical compositions of rocks and chemical composition of rainwater generally control the chemistry of water. In order to evaluate the sources of various ions in the waters from Al-Salameh area, the chemical data for waters from the study area were plotted in Gibbs diagram (Fig.8). The data points on the Gibbs diagram suggests that, groundwater chemistry is controlled by rock weathering to some extent and evaporation is the dominant factor, leading to the poor quality of groundwater (Rao, 2002). This is expected, as evaporation greatly increases the concentrations of ions formed by chemical weathering of the rock, leading to higher salinity.

The  $\text{Cl}/\text{HCO}_3$  ratio ranges from 0.51 to 10.45 and the average value is 2.87. The  $\text{Cl}/\text{HCO}_3$  ratio with values  $< 1.0$  is suggestive of the occurrence of

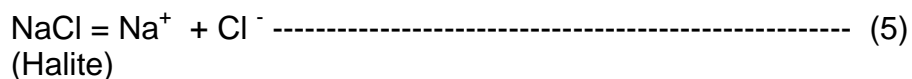
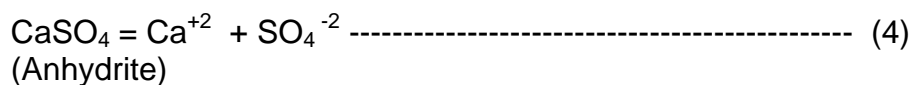
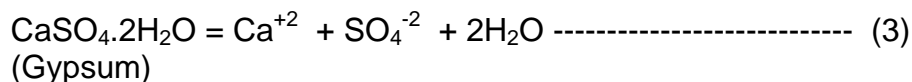
non-saline water. There are only few wells having Cl/HCO<sub>3</sub> ratio < 1.0 they are well No.BW46 and BW78. The molar ratio of Ca/Mg ranges from 0.89 to 3.55 and the average value is 1.83. In general, Ca/Mg values are more than unity in most of the samples, which indicate an excess of Ca over Mg. The Na/Cl molar ratio is in the range of 0.49 to 1.28 and the average value is 0.89 which are close to the Na/Cl molar ratio in halite (0.65) indicating that the dissolution of this mineral plays a significant role in the evolution of this water (Al-Mooji, 1995). The average value of SO<sub>4</sub>/Cl molar ratio is 0.92, which is near unity indicating a linear increase of SO<sub>4</sub> with the increasing of Cl at higher concentrations. This signifies that the dissolution of sulphate minerals is contributing to the increasing salinity in the waters. The Ca/SO<sub>4</sub> molar ratio averages to 1.14 in the study area. Significantly, the increase in Ca corresponds to a simultaneous increase in SO<sub>4</sub>, and the molar ratio near unity, probably suggesting a common source for these ions, especially anhydrite in the area.

Normally, the dissolution of the carbonate minerals of calcite and dolomite can be written as follows (Hete and Cheng, 1996):



If dolomite dissolves according to equation 2, the molar proportions of [Ca+Mg] to [HCO<sub>3</sub>] should be linear, with a slope of 1. A fair relation exists between [Ca+Mg] and [HCO<sub>3</sub>] for some alluvial aquifer type water (Fig.4) however, some of the conglomerate aquifer water types do not follow the trend predicted by the dolomite dissolution model and are highly enriched in calcium and magnesium relative to bicarbonate ([Ca+Mg]/ [HCO<sub>3</sub>] > 1). This reflects that additional sources of Ca+Mg exist within the subsurface. In general, there is an increase of Ca and Mg concentrations with the increase of HCO<sub>3</sub>, suggesting a contribution of carbonate minerals dissolution to the groundwater in the area under study.

The high concentrations of calcium and sulphate in the groundwaters, probably related to dissolution of gypsum (CaSO<sub>4</sub>.H<sub>2</sub>O) and anhydrite (CaSO<sub>4</sub>) while high concentrations of Na and Cl could be related to dissolution of halite (NaCl). The dissolution of these minerals can be represented by the following reactions:



The predominance of sulphate and chloride over bicarbonate in the groundwaters indicates that other processes are controlling water chemistry in this area. Groundwater that moves through the aquifer initially dissolves calcite, dolomite and gypsum (or anhydrite). Gypsum and anhydrite dissolve according to reactions (3) and (4) respectively. Once calcite and dolomite reach saturation, gypsum and anhydrite are still under saturated and continue to dissolve, adding calcium and sulphate to the water. Consequently, calcite becomes oversaturated and, as it precipitates, the bicarbonate concentration decreases. The scatter plot of Ca against SO<sub>4</sub> (Fig.9) indicates an increase in Ca corresponds to a simultaneous increase in SO<sub>4</sub>, suggesting a common source for these ions.

### Groundwater Quality

The quality of water is very important to the mankind, because it has a direct link with human welfare. The data on chemistry of the groundwater have been used for the evaluation of quality of water for drinking and irrigation purposes.

#### Groundwater quality for drinking purposes:

The water to be used for drinking purposes must meet very high standards of physical, chemical and biological purity. Certain minimum quality parameters for this requirement have been suggested by World Health Organization (WHO, 1971). This has been included in Table 3. The minimum and maximum values of groundwater samples from the study area have also been given. It is evident from these values that major ions are far beyond the permissible limits for some of the samples.

It is observed from this table that, out of 25 groundwater samples, 17 samples have shown TDS values below the maximum permissible limit of 1500 mg/l. Water with high TDS indicates more ionic concentration, which is of inferior palatability and can induce an unfavorable physiological reaction in the consumers (Rao et al, 2002). Also seen, out of 25 groundwater samples from Al-Salameh area, 18 samples have shown sulphate values below the maximum permissible limit of 400 mg/l.. High concentration of SO<sub>4</sub> in the drinking water could cause a cathartic action on human beings and can also cause respiratory problems (Rao, 1993). Generally, the groundwater in the study area are suitable in some places and unsuitable in other places for drinking purposes.

#### Groundwater quality for irrigation purposes:

The suitability of water for irrigation depends upon TDS (salinity) and the sodium content in relation to the amounts of calcium and magnesium or SAR. (Alagbe, 2006). The suitability of groundwater for irrigation use was evaluated by calculating SAR, Kelly's Ratio (KR), Residual sodium carbonate (RSC), Soluble Sodium Percentage (SSP) and Permeability Index (PI).

SAR for the groundwater from the study area was estimated by the formula:

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

The waters having SAR values less than 10 are considered excellent, 10 to 18 as good, 18 to 26 as fair, and above 26 are unsuitable for irrigation use (USDA, 1954). In the present study the SAR values are less than 10 can thus, be graded as excellent for irrigation use (Table 4).

Kelly's ratio was calculated by using the following expression

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

where, concentrations are expressed in meq/l.

The Kelly's ratio of unity or less than one is indicative of good quality of water for irrigation whereas above one is suggestive of unsuitability for agricultural purpose due to alkali hazards (Karanth, 1987). It is observed from Table 4 that, all the samples in the study area is below the unity. This suggests that, all the samples from study area are good for irrigation regarding alkali hazards.

The residual sodium carbonate (RCS) determined by using the following formula:

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

where, the concentrations of ions are expressed in meq/l.

If RSC exceeds 2.5 meq/l, the water is generally unsuitable for irrigation. If the value of RSC is between 1.25 and 2.5 meq/l, the water is marginally suitable, while a value less than 1.25 meq/l indicates safe water quality (USDA, 1954).

It is evident from Table 4 that, RCS values for all the samples from Al-Salameh area, are less than 1.25, suggesting that all the water samples are safe for irrigation use.

Wilcox (1955) has proposed classification scheme for rating irrigation waters on the basis of soluble sodium percentage (SSP). The SSP was calculated by using following formula:

$$SSP = \frac{Na \times 100}{Ca + Mg + Na}$$

where, the concentrations of ions are expressed in meq/l.

The values of SSP less than 50 indicate good quality of water and higher values (i.e. > 50) show that the water is unsafe for irrigation (USDA, 1954).

It is observed from Table 4 that, all the groundwater samples have SSP values less than 50, which can be graded as good quality for irrigation.

The permeability index is calculated by the following formula:

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



where, all the values are in meq/l.

The PI values > 75 indicate excellent quality of water for irrigation. If the PI values are between 25 and 75, they indicate good quality of water for irrigation. However, if the PI values are less than 25, they reflect unsuitable nature of water for irrigation. On the basis of PI, (Table 4) the groundwater from the study area can be classified as good class for agricultural use

### Conclusions

The study provides significant information on the development of groundwater quality in Al-Salameh area, Shabwah, Yemen. The groundwater is mostly brackish in nature. The major ion chemistry data revealed that Na and Ca are the most predominant cationic constituents and  $\text{SO}_4$  & Cl are the most predominant anionic constituents. Three hydrogeochemical type facies were identified from different aquifers. The abundance of (Ca+Mg) in most of the groundwater samples could be related to carbonate weathering and evaporative concentration. It's concluded that, the predominance of Cl over Na in the groundwater samples (from conglomerate aquifer), is related to wetting and drying mechanism in arid climate. It's also concluded that, the high concentrations of calcium and sulphate in the groundwater, is related to dissolution of gypsum and anhydrite while high concentrations of Na and Cl could be related to dissolution of halite. The data points on the Gibbs diagram suggests that, groundwater chemistry is controlled by rock weathering to some extent and evaporation is the dominant factor, leading to the poor quality of groundwater. The calculated saturation indices indicate that the groundwater is undersaturated with respect to anhydrite, gypsum and halite, and supersaturated with respect to calcite, dolomite and aragonite in the most of the samples.

Comparisons of data with the water quality standards indicate that, out of 25 groundwater samples from Al-Salameh area, 17 samples are suitable for drinking purposes and graded as good for irrigation use.

### Acknowledgment

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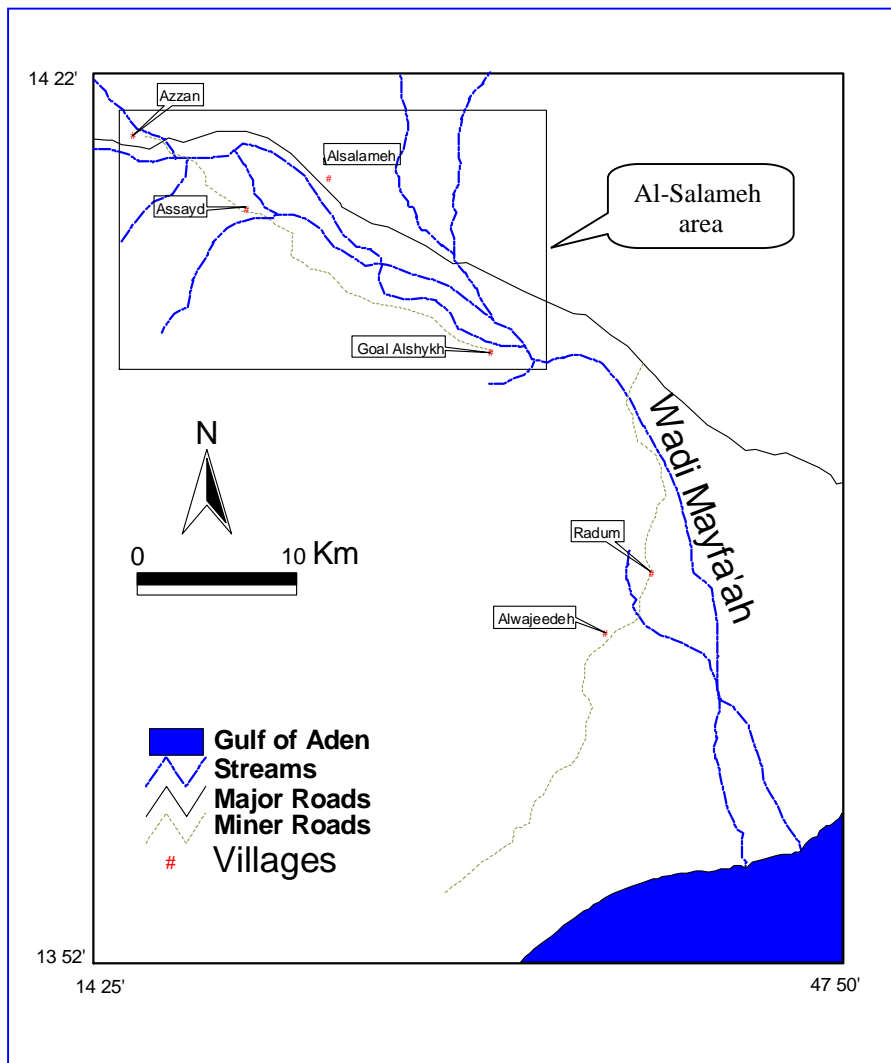
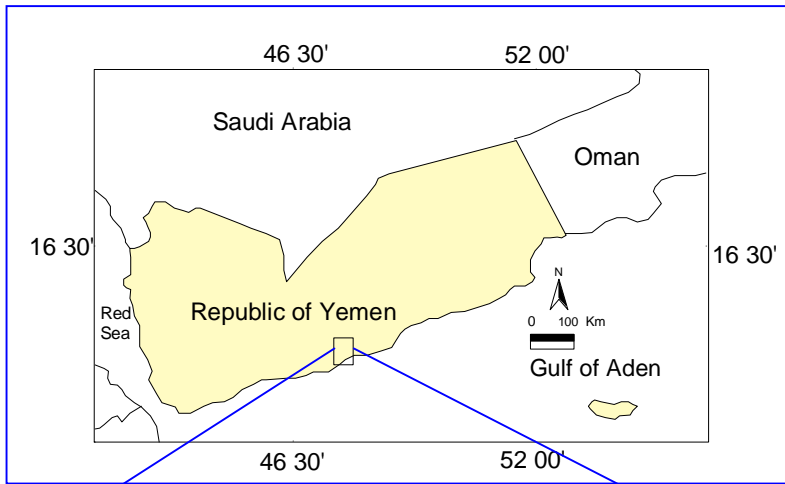


Fig.1: Location map of Al-Salameh area

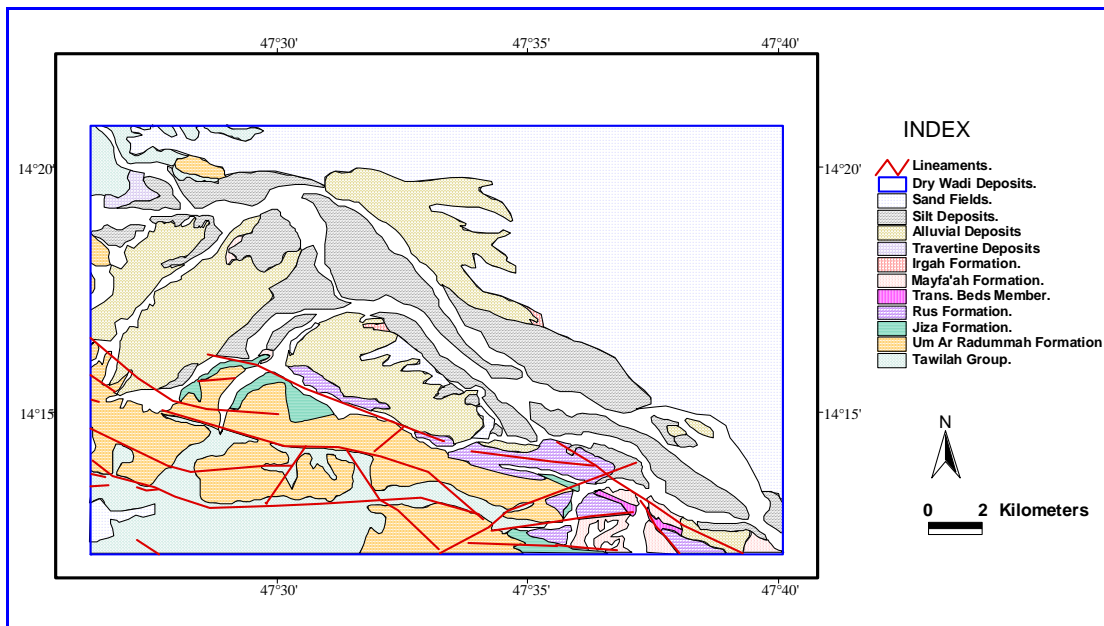


Fig.2: Geological map of Al-Salameh area (modified after Schramm et al 1986)

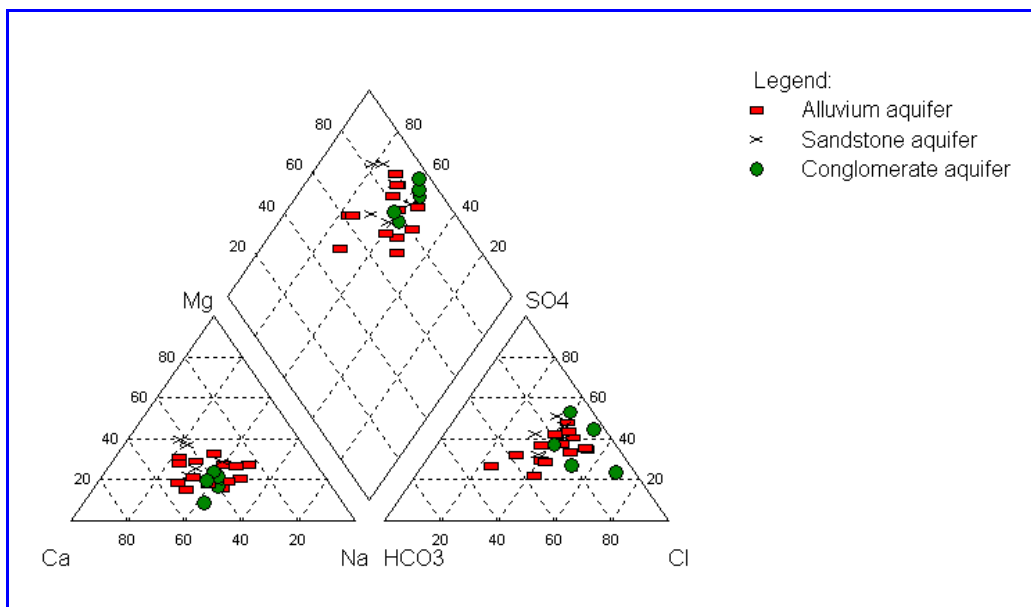


Fig.3: Piper's Trilinear diagram showing chemical relationship of groundwater from Al-Salameh area.

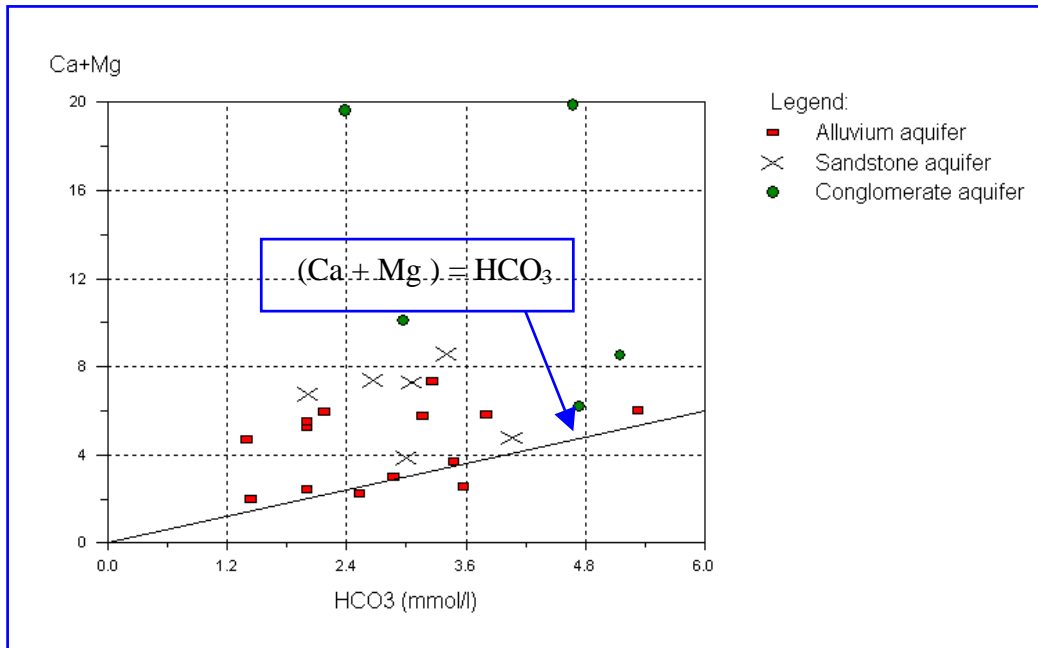


Fig.4: Scatter diagram of (Ca+Mg) vs. (HCO<sub>3</sub>) for groundwater from the study area

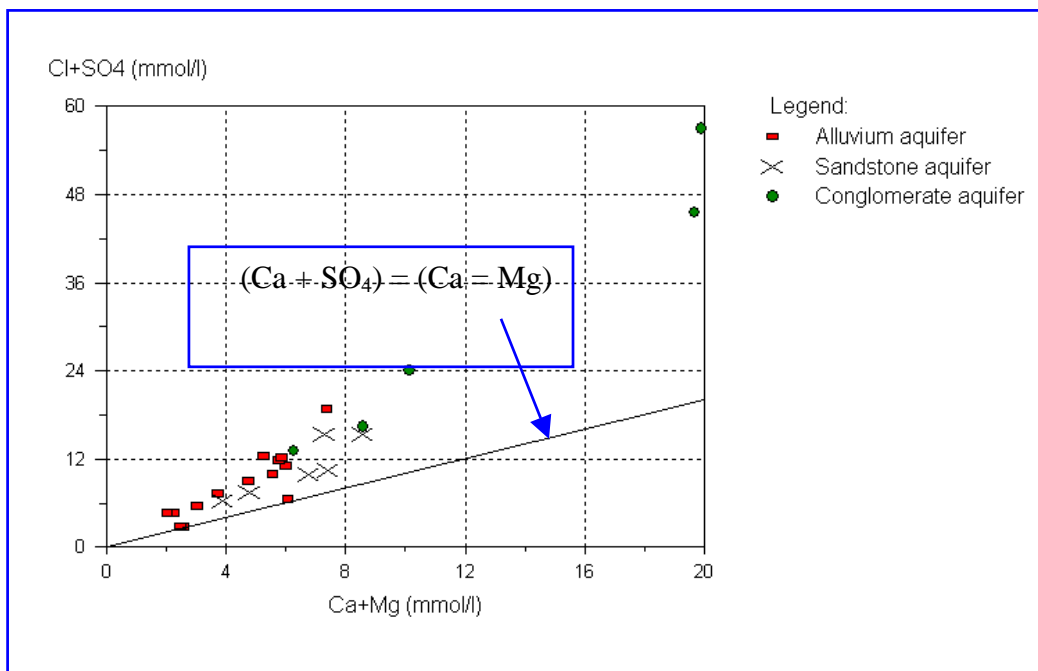


Fig.5: Scatter diagram of (Cl+SO<sub>4</sub>) vs. (Ca+Mg) for groundwater from the study area

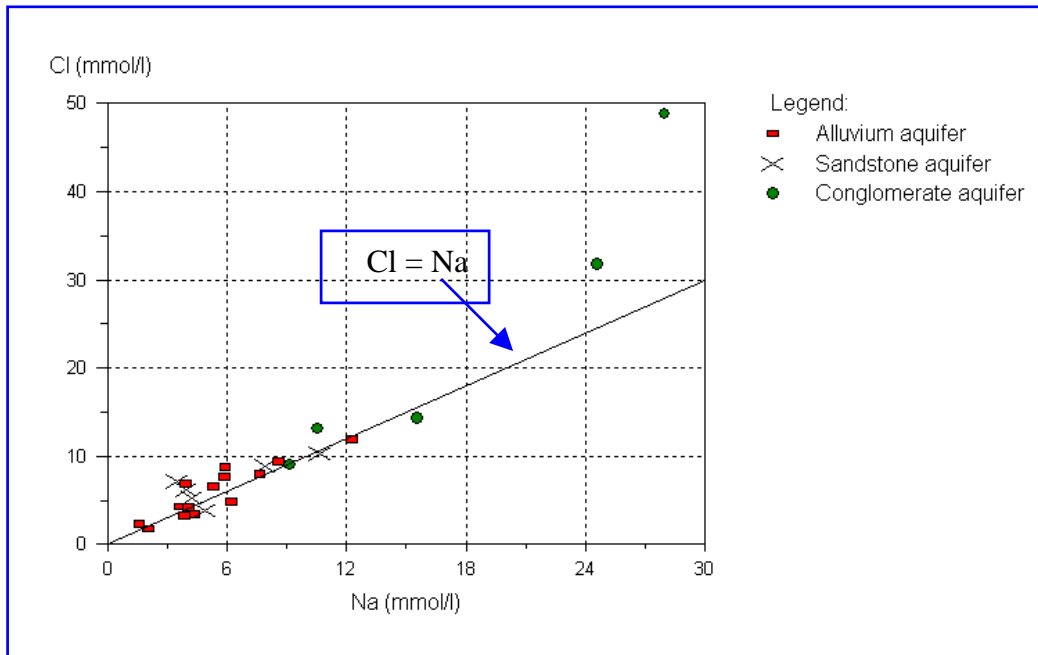


Fig.6: Scatter diagram of Cl vs. Na for groundwater from the study area

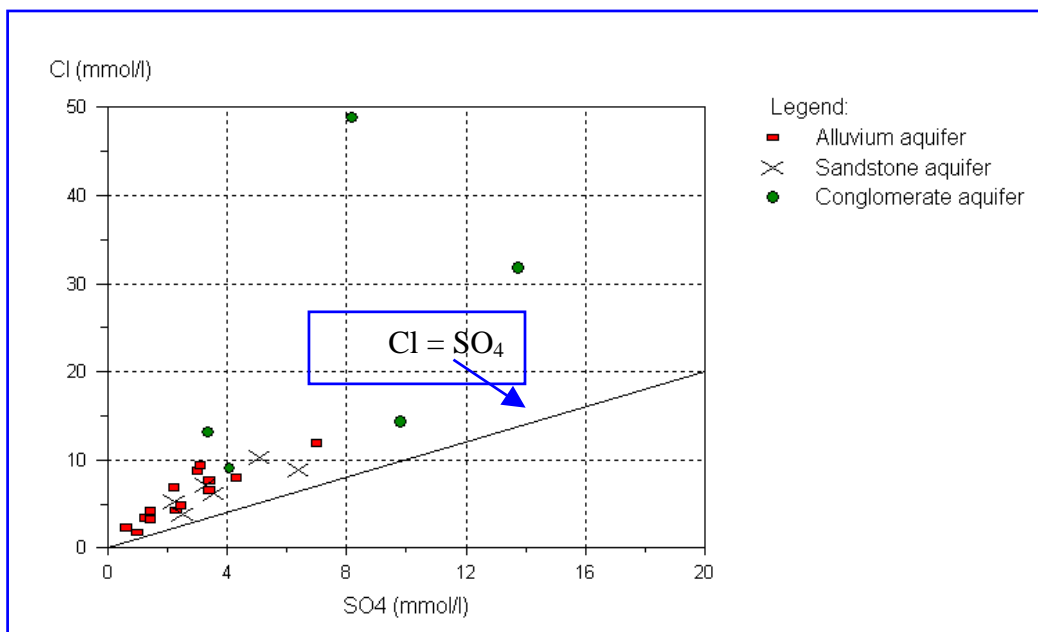


Fig.7: Scatter diagram of Cl vs. SO<sub>4</sub> for groundwater from the study area

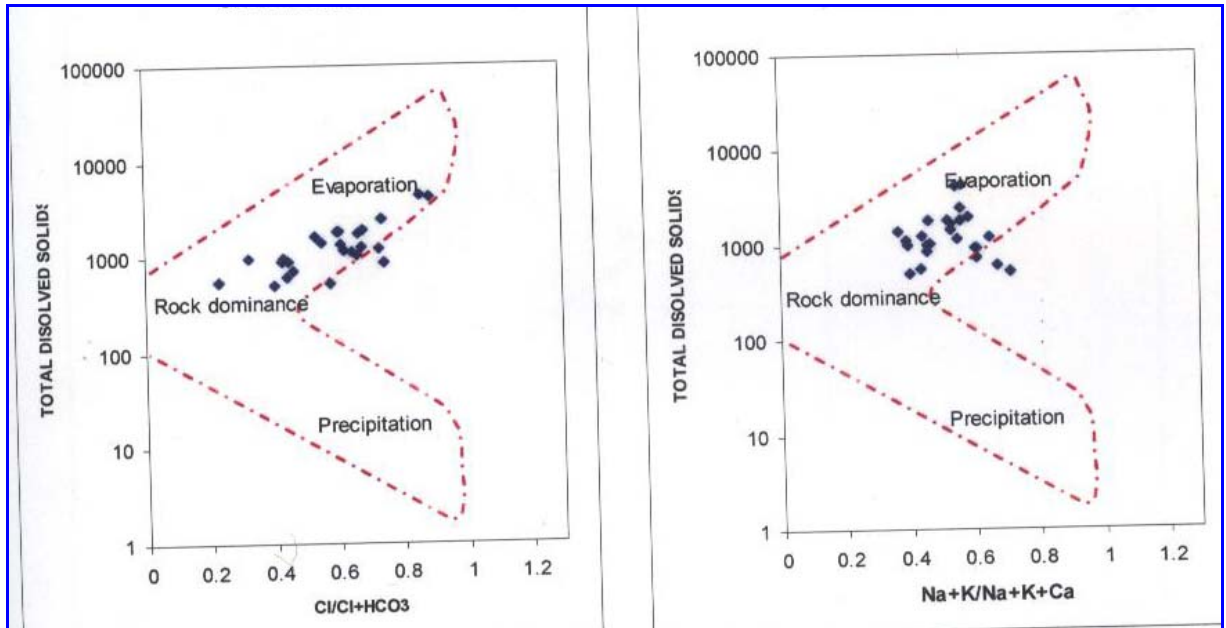


Fig. 8: Gibbs diagram for groundwater samples from Al-Salameh area

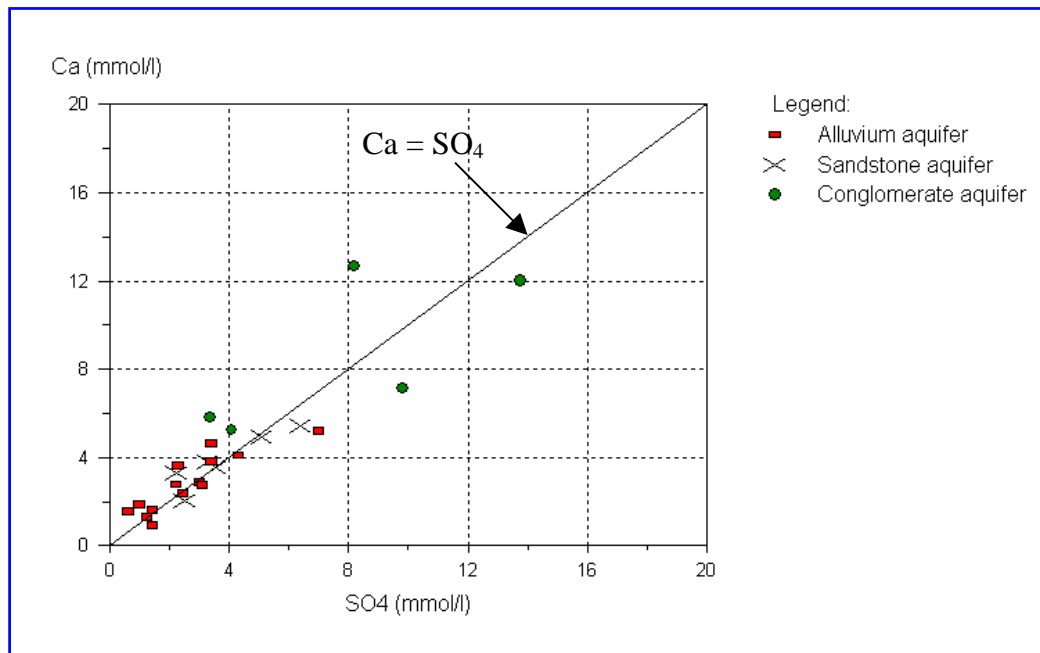


Fig.9: Scatter diagram of Ca vs. SO<sub>4</sub> for groundwater from the study area



Table1: Physico-chemical data for the groundwater from Al-Salameh area

Sr. No.	Well No.	pH	E.C.	TDS	Cations				Anions			
					Na	K	Ca	Mg	Cl	SO4	HCO3	NO3
1	BW100	6.63	2120	1378	80	8	153	87	254	313	163	34
2	BW12	6.6	948	616	100	11	54	22	123	118	154	9
3	BW14	7.57	1500	975	97	13	132	36	187	214	248	14
4	BW41	7.30	1910	1242	135	14	187	32	275	324	132	27
5	BW46	7.70	867	564	46	13	76	16	64	92	218	14
6	BW78	7.55	1500	975	83	14	147	58	153	218	325	32
7	DW37	6.95	2780	1807	182	5	218	76	316	613	208	14
8	DW02	8.13	815	530	88	6	38	26	119	136	88	24
9	DW06	7.85	1400	910	142	8	96	32	172	234	212	22
10	DW08	6.75	2970	1931	282	14	209	52	422	670	199	8
11	DW18	7.25	3820	2483	357	12	287	72	510	940	181	25
12	DW22	6.80	1740	1131	90	2	142	78	222	341	123	47
13	DW24	6.75	1770	1151	135	8	117	69	314	287	193	8
14	DW27	6.90	1120	728	93	10	66	33	149	136	175	33
15	DW31	7.12	1400	910	112	14	82	44	135	240	183	43
16	DW33	7.27	2730	1775	245	7	199	57	367	486	186	23
17	DW38	7.11	2190	1424	175	13	165	42	283	412	232	45
18	DW43	6.80	1330	865	90	5	112	47	245	212	85	33
19	DW45	7.34	6560	4264	643	22	509	175	1732	784	285	12
20	DW74	6.84	1840	1196	197	8	110	61	332	297	122	32
21	DW75	6.91	1580	1027	122	11	153	42	236	324	122	9
22	DW79	8.24	789	513	36	6	62	22	82	58	122	63
23	DW82	8.15	2560	1664	210	32	212	23	324	389	289	34
24	DW84	8.10	6400	4160	565	13	482	185	1130	1320	145	28
25	DW87	8.14	2810	1827	242	12	234	66	467	322	314	83
Avg		7.31	2217.96	1441.84	181.88	11.24	169.68	58.12	344.52	379.2	188.16	28.64
Min		6.6	789	513	36	2	38	16	64	58	85	8
Max		8.24	6560	4264	643	32	509	185	1732	1320	325	83

Table 2: Saturation indices and ionic ratios for the groundwaters from the study area

Well No.	S.I Ar	S.I Cal	S.I Do	S.I An	S.I Gy	Ca/Mg Meq/l	Na/Ca Meq/l	Na/Cl Meq/l	Ca/So4 Meq/l	SO4/Cl Meq/l	Cl/HCO3 Meq/l
BW100	-0.54	-0.41	-0.63	-1.25	-1.07	1.07	0.46	0.49	1.17	0.91	2.69
BW12	-0.97	-0.83	-1.64	-1.90	-1.71	1.49	1.61	1.25	1.10	0.71	1.38
BW14	0.50	0.64	1.12	-1.40	-1.21	2.22	0.64	0.80	1.48	0.84	1.30
BW41	0.08	0.22	0.07	-1.13	-0.93	3.55	0.63	0.76	1.38	0.87	3.59
BW46	0.45	0.58	0.92	-1.85	-1.66	2.88	0.53	1.10	1.98	1.06	0.51
BW78	1.41	1.55	2.84	-1.37	-1.17	1.54	0.49	0.84	1.62	1.05	0.81
CW37	-0.04	0.10	0.15	-0.89	-0.71	1.74	0.73	0.89	0.85	1.43	2.61
DW02	0.14	0.28	0.81	-1.98	-1.79	0.89	2.02	1.14	0.67	0.84	2.33
DW06	0.57	0.71	1.35	-1.48	-1.28	1.82	1.29	1.27	0.98	1.00	1.39
DW08	-0.33	-0.19	-0.59	-0.88	-0.69	2.44	1.18	1.03	0.75	1.17	3.65
DW18	0.24	0.38	0.57	-0.68	-0.50	2.42	1.08	1.08	0.73	1.36	4.85
DW22	-0.55	-0.41	-0.67	-1.24	-1.05	1.10	0.55	0.63	1.00	1.13	3.10
DW24	-0.49	-0.35	-0.53	-1.38	-1.19	1.03	1.01	0.66	0.98	0.67	2.80
DW27	-0.53	-0.39	-0.65	-1.79	-1.61	1.21	1.23	0.96	1.16	0.67	1.46
DW31	-0.27	-0.13	-0.14	-1.53	-1.34	1.13	1.19	1.28	0.82	1.31	1.27
DW33	0.20	0.34	0.55	-1.00	-0.82	2.12	1.07	1.03	0.98	0.98	3.39
DW38	0.07	0.21	0.24	-1.10	-0.92	2.38	0.92	0.95	0.96	1.07	2.10
DW43	-0.78	-0.64	-1.24	-1.48	-1.27	1.45	0.70	0.57	1.27	0.64	4.97
DW45	0.89	1.03	1.85	-0.66	-0.47	1.76	1.10	0.57	1.56	0.33	10.46
DW74	-0.62	-0.48	-0.80	-1.38	-1.20	1.09	1.56	0.91	0.89	0.66	4.69
DW75	-0.42	-0.28	-0.72	-1.19	-1.00	2.21	0.70	0.80	1.13	1.01	3.33
DW79	0.63	0.77	1.52	-2.13	-1.94	1.07	0.46	0.49	1.17	0.91	2.69
DW82	1.24	1.38	2.21	-1.05	-0.86	1.49	1.61	1.25	1.10	0.71	1.38
DW84	1.06	1.20	2.37	-0.49	-0.30	2.22	0.64	0.80	1.48	0.84	1.30
DW87	1.18	1.32	2.26	-1.11	-0.92	3.55	0.63	0.76	1.38	0.87	3.59
Avg.	0.12	0.26	0.45	-1.29	-1.1	1.83	0.96	0.89	1.14	0.92	2.87
Min.	-0.97	-0.83	-1.64	-2.13	-1.94	0.89	0.46	0.49	0.67	0.33	0.51
Max.	1.41	1.55	2.84	-0.49	-0.3	3.55	2.02	1.28	1.98	1.43	10.46

Note: S.I= Saturation Indices Ar=Aragonite, Cal=Calcite, Do=Dolomite, An=Anhydrite, Gy=Gypsum.

Table 3: The standards for chemical quality of drinking water along with ranges of data obtained for Al-Salameh area

World Health Organisation			Data	
Quality	Highest desirable	Maximum permissible	Al-Salameh area (25 Samples)	Number of samples with content less than the maximum permissible limit (WHO, 1971)
TDS (mg/l)	500	1500	513 - 4264	17
Na (mg/l)	-	200	36 - 643	18
Ca (mg/l)	75	200	38 - 509	18
Mg (mg/l)	<30 if SO <sub>4</sub> >250(mg/l), Up to 150 if SO <sub>4</sub> is <250 (mg/l)	150	16 - 185	23
SO <sub>4</sub> (mg/l)	200	400	58 - 1320	18
Cl (mg/l)	200	600	64 - 1732	23
NO <sub>3</sub> (mg/l)	-	45	8 - 83	21

Table 4: Groundwater quality characteristic parameters for irrigation from Al-Salameh area

WELL No.	SAR	KS	SSP	RCS	PI
BW100	1.28	0.24	19.05	-12.12	27.99
BW12	2.90	0.97	49.15	-1.98	67.09
BW14	1.93	0.44	30.65	-5.48	45.30
BW41	2.40	0.49	32.92	-9.8	41.16
BW46	1.25	0.39	28.13	-1.54	54.70
BW78	1.47	0.30	22.96	-6.78	37.65
DW37	2.71	0.46	31.62	-13.72	38.99
DW02	2.69	0.95	48.67	-2.6	63.91
DW06	3.21	0.83	45.44	-3.94	59.16
DW08	4.52	0.83	45.48	-11.45	52.17
DW18	4.88	0.77	43.42	-17.27	48.23
DW22	1.51	0.29	22.49	-11.49	30.64
DW24	2.45	0.51	33.76	-8.36	43.98
DW27	2.34	0.68	40.30	-3.13	57.16
DW31	2.48	0.63	38.71	-4.71	52.48
DW33	3.94	0.73	42.17	-11.57	49.08
DW38	3.15	0.65	39.45	-7.88	49.56
DW43	1.80	0.41	29.30	-8.07	38.11
DW45	6.27	0.70	41.27	-35.13	44.46
DW74	3.74	0.82	44.92	-8.51	52.33
DW75	2.26	0.48	32.40	-9.08	41.03
DW79	1.00	0.32	24.27	-2.9	46.12
DW82	3.66	0.73	42.30	-7.73	52.37
DW84	5.55	0.63	38.49	-36.9	40.91
DW87	3.60	0.62	38.10	-11.96	46.31

Note: SAR = Sodium absorption ratio, KR= Kelly's ratio, SSP = Soluble Sodium Percentage, RSC = Residual sodium carbonate, PI = Permeability Index.