

Full Length Research Paper

Hydrogeochemical and isotopic evaluation of groundwater in Jabal Hafit area, Eastern Abu Dhabi Emirate, United Arab Emirates (UAE)

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This study deals with groundwater quality of the Jabal Hafit area in the southeastern part of the UAE. In order to assess groundwater in the study area, 21 samples were collected from groundwater wells. Of these, 12 samples were analyzed for stable isotopes of δD and $\delta^{18}O$. The results showed that the sequence of cations dominance in groundwater in the study area is: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, while the sequence of anions dominance is: $Cl^- > SO_4^{2-} > HCO_3^{2-} > NO_3^-$. The groundwater of the study area is mostly old marine water origin and is characterized by high TDS which is due to the evaporation process and agricultural activities. The sodium adsorption ratio (SAR) values of collected groundwater samples indicate that the groundwater of the study area is not suitable for domestic and agricultural purposes. The results of oxygen and hydrogen isotopes suggested that both the slope and intercept values of the regression equation of the groundwater scatters are significantly different from those for LMWL suggesting that groundwater has gone through evaporation process before or during its underground transit. The scattered correlation between Cl^- and δD indicated that there is more than one source of Cl^- in groundwater of the study area.

Key words: Groundwater quality, sodium adsorption ratio (SAR), isotope of oxygen and hydrogen, evaporation, agricultural activities.

INTRODUCTION

Groundwater is subjected to dynamic change with respect to lithological characteristics and geo-climatic conditions. Hydrogeochemical analysis of groundwater can provide a fingerprint about the origin and the history of the passage through materials with which water has been in contact (Prasanna et al., 2011). The exploitation of groundwater in the United Arab Emirates (UAE) has been increased significantly during the last decades. In meantime, the water availability in arid region and in particular in the UAE is extremely a significant factor for urbanization and economic development. Groundwater

resources in the UAE have been used intensively in the region for agricultural activities and domestic uses, in which agricultural activities account for more than 70% of groundwater production in the country (MEW, 2008). Al-Ain area, where the study area is located, is one of biggest oases in the Arabian Peninsula owing to its water source for groundwater recharged from Oman Mountains (Hunting, 1979). The area around Jabal Hafit is touristic area and landscaping for beautification spread around the area. The landscaping is mainly irrigated with treated wastewater. Date palm is the main practice of agriculture in the area.

The climatic conditions of the UAE were contributed negatively to the availability of water resources in the region by reducing the quantities of shallow groundwater and accumulated water after heavy period of rainfall

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through the evaporation process which accompanied with low amount of rainfall. The average annual rainfall in Al-Ain area is about 113.3 mm (National Center of Seismology and Meteorology, 2009), while the evaporation rate is high in the entire of study area. Generally, annual experienced ET ranges between 1,909 and 2,124 mm (Ministry of Agriculture and Fisheries, 1993). There are many factors affecting the sustainability of water resources in the UAE and in particular groundwater resources. Those factors include human activities, urbanization, and the climate of dry region. The location of the UAE within an arid zone could restrict the availability of water by increasing the evaporation rate which is reducing the quality and quantity of recharge water to groundwater aquifer. Salinity is the main problem of the groundwater deterioration in the country and this problem is increasing over the time (Murad et al., 2007).

At the present, the deficit in groundwater resources is covered mainly by desalinated water. More detailed knowledge about capacity of the aquifer and the quality is essential to meet the needs of drinking water for future generations. Using conventional hydrogeochemical approaches are not sufficient to determine sources affecting water quality. Since the isotopic compositions of oxygen and hydrogen do not change in groundwater due to water-rock interactions at low temperature, it could provide a comprehensive assessment to quality of groundwater (Sidle, 1998). Using isotope techniques to address water quality and environmental studies is well established (Clark and Fritz, 1999; Cook and Herczeg, 1999). Implementation of hydrogeochemical and stable isotopes have been used to characterize the hydrogeochemistry of groundwater (Long and Putnam, 2004; Barbieri et al., 2005).

This study is aimed to characterize the hydrogeochemical evolution of groundwater and identify factors affecting the quality of the aquifer in the study area. Stable isotopes of oxygen and hydrogen were used as a supplementary tool with conventional chemical approach to understand the origin of water, or processes that have affected water since it was formed (Drever, 1997).

Geology and hydrogeology

The UAE is situated at the southern tip of the Arabian Gulf (Figure 1). The study region is situated in Jabal Hafit in the south of Al Ain. Al Ain region is situated in the structural transition area among the lifted and extremely distorted rocks of Oman Mountains to the east and the hidden flat-lying to quietly creased division of western Abu Dhabi. The rocks depicted in Oman Mountains, east of Al Ain city, have gone through complex and compressive wrap for the most part, as a consequence of the Late Cretaceous abstraction of Semail ophiolites and related rocks (Glennie et al; 1974; Coleman, 1981; Lippard et al.; 1986). The stratigraphic succession in Al Ain region is made up of Upper Cretaceous, Paleocene,

Eocene, Oligocene, Miocene, and Quaternary sediments (Baghdady, 1998; Al-Saiy, 2002).

Jabal Hafit and many other southeastern hilly mountains shape noticeable geological characteristics in Al Ain area and are expanded by the side of the western foothills of the Northern Oman Mountains (El-Ghawaby and El-Sayed, 1997). Jabal Hafit is situated in the southeast of Al Ain city between Latitudes 24°00'-24°13' N and Longitudes 55°44'-55°49' and it is one of the well-known and important characteristics of Al Ain region. Its length is approximately 29 km and its width is approximately 5 km. Its elevation from sea level is around 1160 m (Hamdan and El-Deeb, 1990).

The east and west declining edges of the anticline of Jabal Hafit are cut down by extremely carved sharp drains. Marl is less resistant to erosion leading to the development of two subsequent wadis parallel to the axis of the mountain: wadi Tarabat to the east and wadi Al Nahayan to the west. North of the core of the anticline, the rocks are eroded forming a low-lying area with small hills enclosed between strike ridges more resistant limestone. These two strike ridges are called in the recent study "East cuesta" (beds dipping about 70°) which reaches in some parts an elevation of 320 m, and the "West cuesta" (bed dipping about 29°) with maximum elevation of 460 m (Figure 1) (Hunting, 1979).

The structure of Jabal Hafit, placed at the split among the Northern and Central Oman Mountains at a space of approximately 20 Km to the west of the border of the allochthon (Glennie et al.; 1974). The core of Jabal Hafit anticline consists of Lower Eocene dolomitized limestone (Rus Formation), flanked on both limbs by younger fossiliferous limestone and marls of Middle Eocene to Miocene age (Dammam, Asmari, and Fars formations) (Cherif and El-Deeb, 1984). In accordance with Noweir (2000), Hafit structure is comprised of two obviously enechelon anticlines, Hafit anticline and Al Ain anticline, which are related by the thin Rwaidhat Syncline. The major structure of Jabal Hafit is anticline. It has a NNW-SSE tendency and it is asymmetrical (the western limb declines 25-35°W, and eastern limb declines 45-85°E, with beds nearby reversed) (Figure 2) (Noweir, 2000).

Jabal Hafit is composed of 1500 m thick limestone and marl interbeds with gypsum and dolomite and evaporite formations of Lower Eocene to Miocene age. Limestone of the Middle Eocene Dammam Formation constitutes an aquifer in Jabal Hafit. The limestone aquifer of the study area is characterized by extensive dolomitization and is affected by numerous faults and fractures (Whittle and Al sharhan, 1994). There are two drainage systems in Al-Ain region. One is in the Northern Oman Mountains and the second is in the Jabal Hafit. The drainage sinks of Jabal Hafit take place in the west of the Al Jaww Plain and south of Al Ain region. In general, drainage outline of this system is to a certain extent sub radial. The pattern ranges from dendritic to braid with some parallel or rectangular patterns especially in the structurally

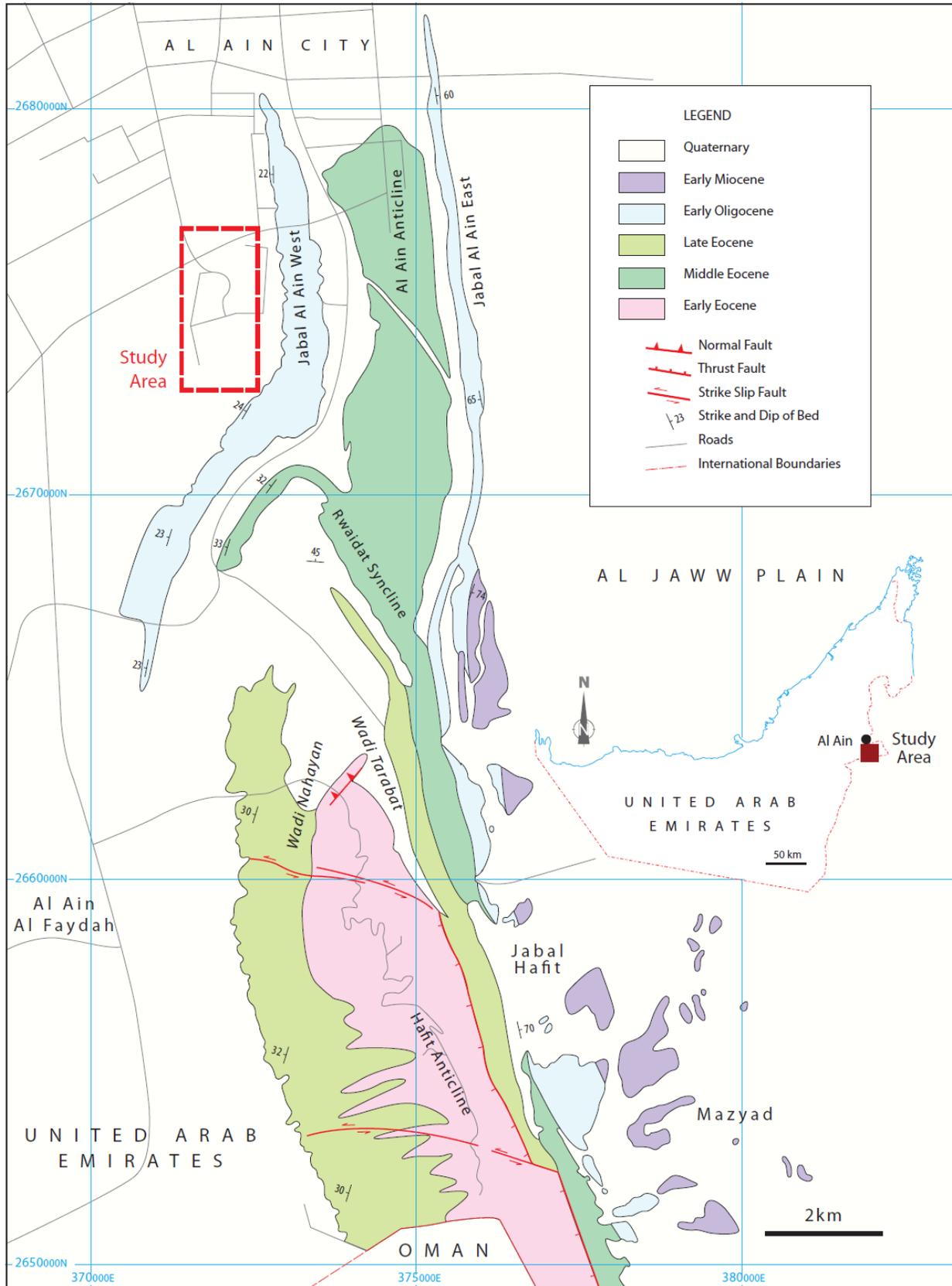


Figure 1. Geological map of Jabal Hafit showing as inset map the location of the study area (adapted from Cherif and El-Deeb, 1984).

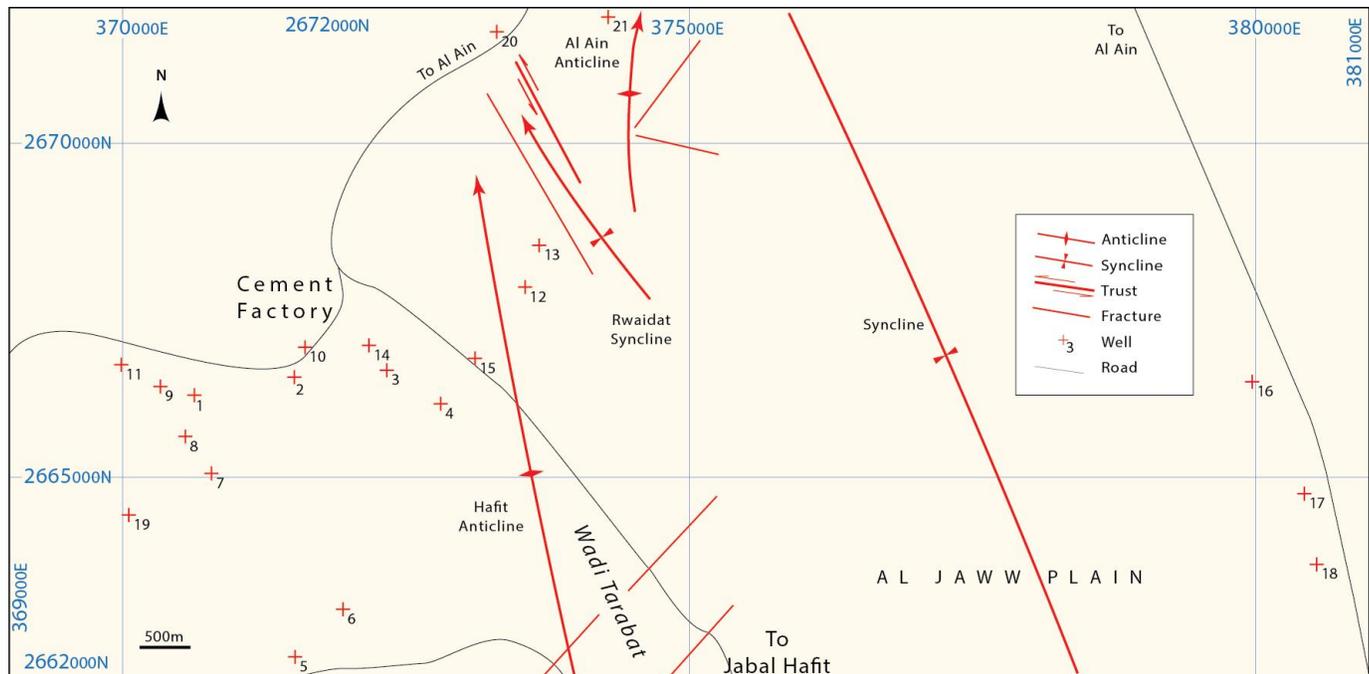


Figure 2. Structural map of the study area showing the sampling points (modified from Warrak, 1987).

controlled areas (Hunting, 1979; Abou El-Enin, 1993).

METHODOLOGY

Groundwater samples were collected from area surrounded Jabal Hafit for chemical and isotopic analyses. Twenty one samples were collected from different production wells in the study area (Figure 2). Produced groundwater from these wells mainly used for agricultural activities. Groundwater wells were emptied several times before sampling. The sampling of groundwater started in June 2009 and focused in one season as the conditions of two main seasons (summer and winter) are mostly similar. Collected samples for major cations were acidified with nitric acid (HNO_3 65%), while other bottle of sample was preserved cool at 4°C .

The samples undergo different field measurements such as pH, EC (Electrical Conductivity), temperature, salinity, and TDS (Total Dissolved Solids) by using pH meter (Hanna Instrument). The data were presented using AquaChem (version 5) and Surfer 9 at the Geology Department of UAE University.

The laboratory measurements for collected groundwater samples went through different advanced instruments for major cations, anions, and trace elements. The inductively coupled plasma mass spectrometry (ICP-MS) is used to analyze groundwater samples for major cations (K^+ , Na^+ , Ca^{++} , Mg^{++}) and trace elements such as (As, Ba, Bi, Cd, Cr, Cu, Mn, Pb, Zn, and V). This analysis was performed in Chemical Defense Laboratory in Seweihan. The ionic chromatography (IC) is used to detect major anions (Cl^- , SO_4^{--} , NO_3^-). The analysis was performed in Metrohm Middle East FZC laboratories in Sharjah. The analytical error of all samples is 0.5%, while the detection limit errors are in the range of 0.001 to 0.017.

Carbonate and bicarbonate are analyzed by using the 848 titrimo plus. The titrimo plus instrument can be put to use in a matter of minutes. Their robustness also makes them the ideal titrators for routine determinations in day-to-day laboratory work. The analysis

was performed in Metrohm Middle East FZC laboratories in Sharjah.

In addition to that, 12 groundwater samples were collected from different private and governmental wells in June 2009. Groundwater samples were placed in sealed air-tight glass bottles for isotopic analysis. Water samples for oxygen isotopic analysis were equilibrated with CO_2 gas at 25°C (Epstein and Mayeda, 1953). However, water samples for deuterium analysis were reduced to hydrogen gas using metallic zinc (Coleman et al., 1982). The isotope ratio mass spectrometer (IRMS) was used for measuring delta D and delta ^{18}O . The accuracy/precision for ^{18}O are about $+0.1\text{‰}$ and for D is about $+1\text{‰}$. The analysis was performed in Atomic Energy Authority- Environmental Department - Isotope Hydrology Lab in Egypt.

RESULTS

All the chemical results of this study are presented in Table 1. The measured TDS in the study area ranges from 3120 to 12600 mg/l (Figure 3). The order of the major cations of the limestone aquifer at the study area is $\text{Na}^+ > \text{Ca}^{+2} > \text{Mg}^{+2} > \text{K}^+$, while the major anions has the following order: $\text{Cl}^- > \text{SO}_4^{-2} > \text{HCO}_3^- > \text{NO}_3^-$. Piper and durov plots were constructed to determine the geochemical process occurring within the aquifer of the study area (Figures 4 and 5).

The sodium ion concentrations of groundwater samples ranged from 533 to 2891.4 mg/l in The Na ions concentration increased to northeast of study area. At the present study, the lowest Ca^{+2} concentration is 77.9 mg/l, while the highest concentration is 604.7 mg/l. The Ca^{+2} concentration increases to southwest of the study area.

Table 1. Isotopic and chemical results in mg/l of groundwater from the study area.

Well ID	X-E	Y-N	pH	Temp.°C	Cond. S/cm	TDS	Na	K	Ca	Mg	Mn	V	Pb	Cr
1	370661	2666326	7	33.9	17.18	10995	2146.5	63.4	461.6	204.3	0.002	0.02	0.0003	0.01
2	371507	2666510	7.3	33.7	10.45	6688	1558.2	47.4	399.2	152.7	0.0010	0.01	0.000166	0.01
3	372368	2666668	7.2	34.2	15.47	9888	808.9	24.9	249.6	88.5	0.0004	0.02	0.000963	0.004
4	372779	2666118	7.4	45	11.82	7564.8	1024.8	36	288.2	91.4	0.002	0.02	0.000566	0.003
5	371510	2662382	7.4	35	15.54	9945.6	1614.9	48.7	572.4	160.8	0.001	0.02	0.002451	0.003
6	371290	2663093	7.8	35.6	14.03	8979.2	1695.1	50.5	639	163.7	0.000402	0.02	0.000722	0.003
7	370701	2665078	7.6	35.5	14.05	8992	831.2	30.7	238	86	0.0005	0.02	0.000009	0.003
8	370534	2665633	7.4	33.7	15.9	10176	1429.9	43.4	341.4	128.8	0.0004	0.02	0.000037	0.01
9	370340	2666430	7.6	34.4	9.63	6163.2	1392.8	45	290.1	132.7	0.0005	0.01	0.000068	0.008
10	371630	2666964	7.8	33.7	6.95	3660	591.9	22.3	144.2	54.6	0.000797	0.008	0.000038	0.003
11	369970	2666673	7.5	33.45	13.12	8396.8	879.1	33.4	182	77.5	0.008	0.02	0.000013	0.01
12	373540	2667824	8	42.7	11.1	7104	804	29.4	232.6	69.7	0.0005	0.01	0.001078	0.002
13	373686	2668453	7.9	41.5	13.3	8512	1784.5	51	480.2	191.5	0.001	0.02	0.00004	0.002
14	372203	2669155	8	31.9	6.09	3120	533	15.3	139.3	55.1	0.001	0.006	0.000011	0.003
15	373151	2668077	7.8	35	20.9	12540	1226.6	39.8	248.1	93.5	0.0002	0.02	0.00103	0.01
16	379900	2666438	8.5	33.7	6.25	3180	822.7	16.1	127.3	81.5	0.0004	0.03	0.00378	0.003
17	380425	2664715	8.1	33.8	7.6	3910	793.7	14.1	131.3	100.9	0.002	0.03	0.000762	0.003
18	380640	2663705	8.1	33.6	7.7	3980	800.1	20.5	77.9	57.8	0.0001	0.03	ND	0.003
19	370019	2664792	7.6		16	9600	2024.3	52.8	604.8	165.5	0.006	0.02	0.02	0.01
20	373358	2671581	8.12		10.5	6300	2891.4	32.4	462.7	340.2	0.002	0.01	0.0005	0.04
21	374289	2671797	7.72		21	12600	1755.2	28.1	299.7	153.9	0.0002	0.02	0.0002	0.01

Well ID	Cu	Ba	Cl	SO ₄	HCO ₃	CO ₃	NO ₃	Cd	Bi	As	Cu	Zn	δ O ⁻¹⁸ ‰ Vs SMOW	δ D ‰ Vs SMOW
1	0.01	0.03	5703.4	1780.8	180	295	29.6	0.0005	0.1226	0.028	0.0106	0.09	-0.95	-7.03
2	0.01	0.02	3144.8	1381.6	128.7	211	26.1	0.0002	0.0519	0.0142	0.0069	0.03	-1.09	-8.27
3	0.01	0.03	5125.4	1561.6	79.9	131	10.4	0.00007	0.0632	0.0293	0.01	0.03	-0.98	-8.81
4	0.01	0.1	4053.8	930.4	64.7	106	7.0	0.0004	0.2965	0.0218	0.008	0.03	-1.72	-9.55
5	0.01	0.1	5543.8	766.2	72	118	8.0	0.00002	0.0035	0.0353	0.011	0.02	-1.78	-9.26
6	0.01	0.1	4845.2	676.6	77.5	127	6.8	0.00003	0.0388	0.0305	0.01	0.03	-1.81	-9.38
7	0.01	0.05	4804.3	873.3	70.8	116	9.4	0.00004	0.0028	0.0281	0.008	0.02	-1.42	-9.15
8	0.01	0.03	5020.1	1651.9	111.6	183	15.7	0.00006	0.0183	0.0259	0.01	0.03	-1.07	-6.26
9	0.01	0.02	2598.2	1548.8	109.8	180	16.9	0.00003	0.0814	0.0114	0.006	0.03	-1.28	-7.76
10	0.004	0.02	1906.8	978.3	104.9	172	10.4	0.00006	0.0111	0.0847	0.004	0.02	-1.42	-10.44
11	0.01	0.02	4003.1	1887.5	158	259	11.5	0.00002	0.0248	0.0171	0.008	0.03	-1.39	-6.05
12	0.01	0.1	3736.3	671.7	75	123	5.5	0.0001	0.0009	0.0209	0.008	0.2	-1.86	-11.32

Table 1. Contd.

13	0.01	0.1	4506.6	952.6	87.2	143	10.6	0.0003	0.0016	0.0242	0.007	0.02
14	0.003	0.03	1434.8	1152.7	114.1	187	33.0	0.00002	0.0121	0.0059	0.003	0.1
15	0.01	0.03	7274.1	2228.5	89.7	147	71.3	0.0001	0.0765	0.0299	0.014	0.1
16	0.004	0.02	1742.5	765.8	78.1	128	6.2	0.00002	0.0045	0.0062	0.004	0.02
17	0.007	0.03	2182.4	1069.8	65.3	107	6.5	0.00002	0.0001	0.0081	0.006	0.04
18	2E-03	0.0001	1969.8	1260	84.2	138	6.6	0	0.0017	0.0067	0.00003	0.05
19	0.05	0.02	3163.2	796.5	104	163	8.3	0.0007	0.02	0.03	0.03	0.03
20	0.02	0.02	2307.79	702.12	111	202	0.12	0.0001	0.004	0.01	0.02	0.1
21	0.03	0.1	1349.10	702.12	190	318	6.02	0.0002	0.001	0.03	0.05	0.1

The concentrations of magnesium ion in this study range from 54.6 to 340 mg/l. The lowest potassium concentration in this study is 14.1 mg/l, while the highest concentration is 63.3 mg/l.

The dominant species of anion is chloride which ranged in the study area from 1349.1 to 7274.1 mg/l. The Cl⁻ concentration increased to south west of study area. The sulphate ions in ground water of the study area ranged between 671.7 and 2228.5 mg/l. The concentration of SO₄⁻² increased to northwest of study area. However, the bicarbonate concentration in this study ranged from 64.7 to 190 mg/l. In this study, the highest concentration of nitrate ions is 71.3 mg/l and the lowest concentration is 0.12 mg/l. Groundwater samples collected from the study area were analyzed for several trace metals (Mn, Cu, Pb, Bi, Ba, As, Cd, Cr, V, and Zn), but there were not significant values observed.

DISCUSSION

The field measured TDS of the groundwater showed that the groundwater salinity increases to northeast of study area in which this high salinity may be related to evaporation process and in

particular the evaporation of return flow which is mainly due to irrigation of agricultural areas. High concentration of Na⁺ in groundwater is observed and the high observed concentration of sodium may be attributed to irrigation process by utilizing brackish groundwater.

The geology of the study area is playing a role in groundwater quality. The dissolution of limestone of the Jabal Hafit leads to high Ca⁺² concentrations in the study area. The limestone exposures of the study area contain magnesium, in which the dissolution of aquifer materials could cause abundance in magnesium concentration as well as calcium (Frape et al., 1984; Hem, 1985). The presence of dolomite in the study area could elevate the magnesium concentration. However, the K⁺ concentration increases southwest of the study area, which might be attributed to the presence of clay layer in the study area.

The high concentration of chloride ions in the study area resulted from entrapped saline water within the limestone sequence of Jabal Hafit (Mirghani, 2008). While, the presence of gypsum and anhydrite (Todd, 1980) within limestone sequence of Jabal Hafit may lead to high concentration of sulphate ions in the study area. Dissolution of Jabal Hafit carbonate (Davis and

DeWeist, 1966) is considered the main source of releasing bicarbonate to the groundwater in the study area.

The presence of high concentration of nitrate ions (NO₃) in the groundwater is generally originated from several natural sources and human activities. The concentration of NO₃⁻ increased to southwest of study area as shown in Figure 6 due to the agricultural activities which are encountered in this side of the study area.

The water type is represented by each anion and cation that exceeds 15 equivalent percentages, and then arranged from the lowest to the highest cationic and anionic concentrations in the hydrochemical formula (Altoviski, 1962). Accordingly, among twenty one analyzed water samples, one anionic group with their two equivalent cationic combinations, are distinguished which could give rise to the following different water types: SO₄, Chloride, Ca, Mg, Sodium (samples 16, 17, 18 and 20) Mg, Ca, Sodium (samples 1-15, 19 and 21). The anionic and cationic compositions of water indicate that the chloride and sodium ions often acquire the highest concentrations, while the sulphate with magnesium and calcium ions compositions reveal the second order in their concentrations after sodium

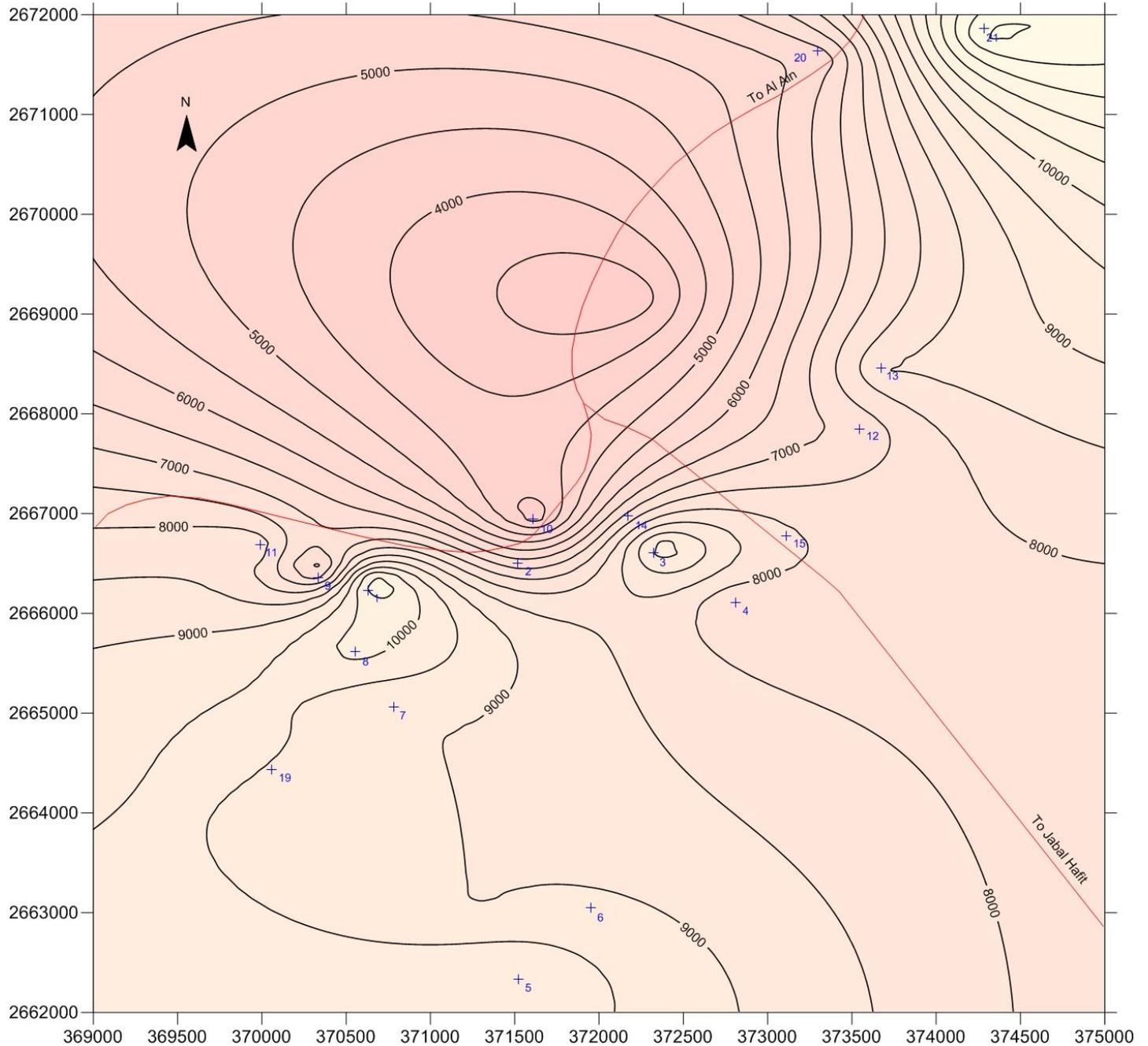


Figure 3. Contour map of TDS distribution of groundwater samples in the study area.

and chloride ones. The existence of sulphate anion concentration reflects the depth and distance from the catchment area as well as the leaching processes of the evaporite rock constituents such as gypsum and anhydrite, rich with calcium, magnesium and sulphate ions. This may be the same reason for calcium and magnesium ion concentrations that lie next to the sodium ion concentration among the cationic composition. On the other hand, the dissolution of carbonate and dolomitic

rocks may lead to increase the concentration of calcium and magnesium in the groundwater.

The interpretation of hydrochemical compositions of the collected water samples from the study area was done according to the Sulin (1948) for the genetic classification of water. It shows the occurrence of two water types; one reflects old marine origin (basinal) and the other indicates meteoric origin. Two water samples only among the twenty one samples reflect the meteoric

origin (samples 20 and 21). The first type of meteoric origin is NaHCO_3 of the surface and shallow meteoric water conditions, whereas $r \text{ (K+Na)-r (Cl/rSO}_4) > 1$ (r indicates milliequivalent per liter). This reveals the KCl , NaCl , MgSO_4 , MgCl_2 , CaSO_4 and $\text{Ca (HCO}_3)_2$ for well# 20 and KCl , NaCl , Na_2SO_4 , MgSO_4 , CaSO_4 and $\text{Ca (HCO}_3)_2$ for well # 21 as hypothetical salt combinations. Despite the meteoric origin of the water samples, the salts of temporary hardness in the solution is only represented by $\text{Ca (HCO}_3)_2$. On the other hand, salts of permanent hardness are of obvious existence within two samples and are represented by MgSO_4 and CaSO_4 . The appearance of such salts may be affected by the leaching processes of lithological constituents rich in calcium, magnesium and sulphate ions under heavy groundwater pumping as well as lacking of recharge sources.

The second type is CaCl_2 which reveals the marine origin whereas, $r\text{Cl-r (K+Na) /rMg} > 1$ (samples no.1-19) and can be represented by the following assemblages of hypothetical salts:

KCl , NaCl , MgCl_2 , MgSO_4 , CaSO_4 and $\text{Ca (HCO}_3)_2$ (samples 1, 8, 11, 20, 2, 15 and 17).

KCl , NaCl , MgCl_2 , CaCl_2 and CaSO_4 (samples 3, 4, 6, 7 and 19). KCl , NaCl , MgCl_2 , CaCl_2 , CaSO_4 and $\text{Ca (HCO}_3)_2$ (samples 5, 12, 13).

KCl , NaCl , Na_2SO_4 , MgSO_4 , CaSO_4 and $\text{Ca (HCO}_3)_2$ (samples 9, 10, 14, 18 and 21).

KCl , NaCl , MgSO_4 , CaSO_4 and $\text{Ca (HCO}_3)_2$ (sample 16).

The above assemblages of hypothetical salts reveal that temporary hardness salts are of limited occurrence and represented by $\text{Ca (HCO}_3)_2$. However, the water marine origin is dominant mainly of CaCl_2 water type.

A complete disappearance of $\text{Mg (HCO}_3)_2$ as a temporary hardness salt could be attributed to the small equivalent percentage of CaSO_4 that exists which might affect the appearance of $\text{Mg (HCO}_3)_2$ (Kamaneski, et al., 1953). The CaCl_2 water origin shows that the dominant salts of permanent hardness are MgSO_4 and CaSO_4 . This may reflect the influence of leaching processes on the evaporite deposits which are rich in calcium, magnesium and sulfates within the lithological constituents of the water bearing formations. In addition to the above mentioned reasons; the structural control elements especially the faults may play a pivotal role in the occurrence of these different water types and origin within the study area as shown on the structural map of the study area (Figure 2).

The hydrochemical compositions of the collected water samples from the studied aquifer are plotted on Piper and Durov's graph to reveal the water-rock interaction under different water depths (Ovitchinikov, 1955) as well as to understand the processes affecting the groundwater.

Accordingly, the collected groundwater samples were

plotted on a Piper diagram and positioned towards the sea water portion of Ca+Mg percentage ranging between 20-40 (Figure 4). This means that most of the studied wells show the similarity in their compositions which consist with mixed cations (Ca , Mg , Sodium) with dominance of the chloride ion among the anions and hence lie close near each other.

The interpretation of the hydrochemical compositions on Durov's graph (Figure 5) indicates the most investigated samples within relatively one portion of the upper triangle to assure the marine water origin with the dominance of sodium and chloride ions as 1st order among the cationic and anionic compositions while that Ca , Mg and SO_4 ions represent the second order. The effect of water-rock interaction and the cationic exchange process is highly obvious and confirmed by the existence of Ca and Mg ions concentrations that come in the second order after sodium ion composition. The leaching processes of the water bearing formations of evaporitic origin (Gypsum and Anhydrite) as well as the upward leakage of the deep marine water play a noticeable role in the appearance of such ions in the groundwater compositions.

The groundwater in this study area is not suitable for domestic use because of high TDS concentration. The suitability of groundwater for agricultural irrigation depends on the sodium adsorption ratio (SAR). In this study area, the SAR ranged from 10 in well no.14 to 21 in well no.1. From the result, the study area is characterized by groundwater with medium to very high damaging risk if it is used for irrigation (Figure 7).

The stable isotopic composition of the different water samples are presented in Table 1. The $\delta\text{D}-\delta^{18}\text{O}$ plot was constructed (Figure 8), together with the local meteoric water line (LMWL) ($\delta\text{D} = 8\delta^{18}\text{O}+15$). The isotopic signature of groundwater samples of the study area is described by: $\delta\text{D} = 3.1 \delta^{18}\text{O}-4.3$. The $\delta^{18}\text{O}$ and δD contents for groundwater ranged from -1.86 to -0.98‰ for $\delta^{18}\text{O}$ and from -11.32 to -6.05‰ for δD . The linear correlation shows that at equilibrium, the concentration between water and its vapor is about 3 times bigger for δD than for $\delta^{18}\text{O}$. This lower slope value (< 8) is associated in general with the evaporation process, which in nature, normally occurs under non-equilibrium conditions. The slope and the intercept values for groundwater line are significantly different from those for LMWL. This clearly suggests that groundwater has gone through extensive evaporation process before or during its underground transit. Scatter correlation between Cl^- and δD indicates that there is more than one source of Cl^- in groundwater of the study area (Figure 9).

Conclusion

The UAE suffers from deficiency in fresh water resources and the water demands tend to increase over time. Most

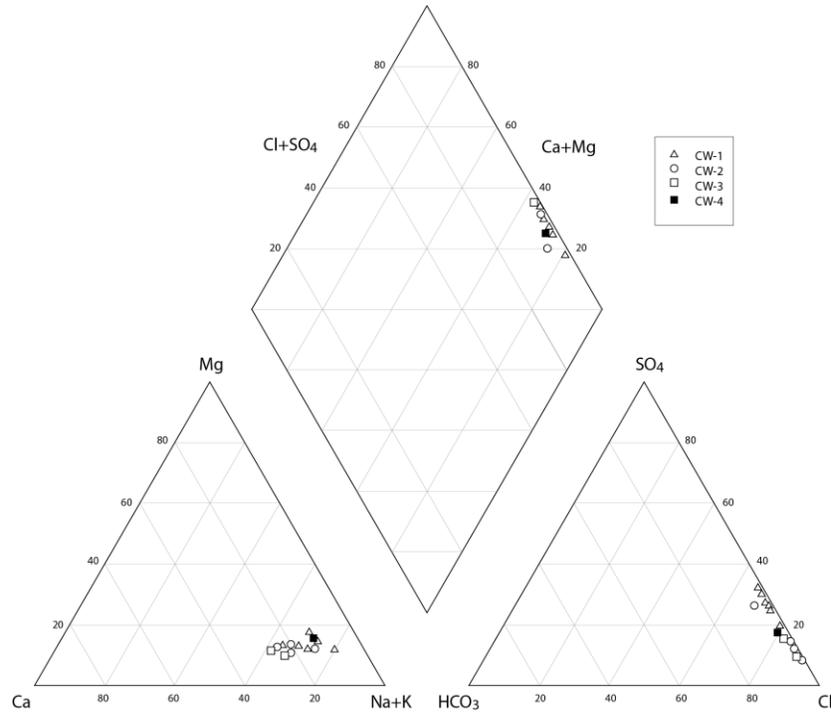


Figure 4. Piper plot for groundwater of the study area.

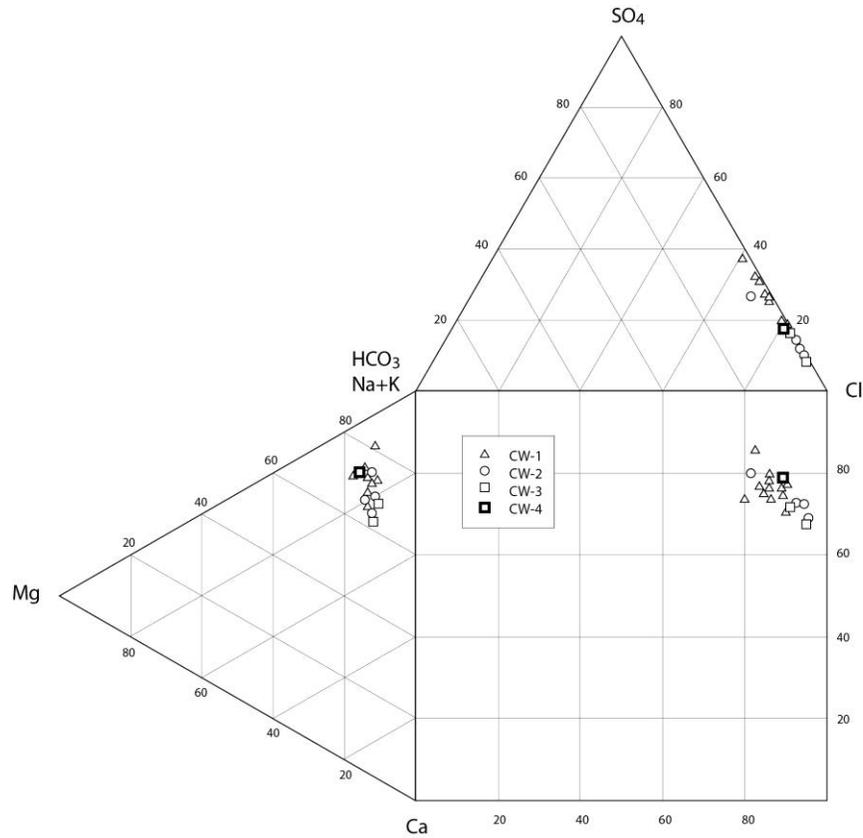


Figure 5. Durov plot for the groundwater samples of the study area.

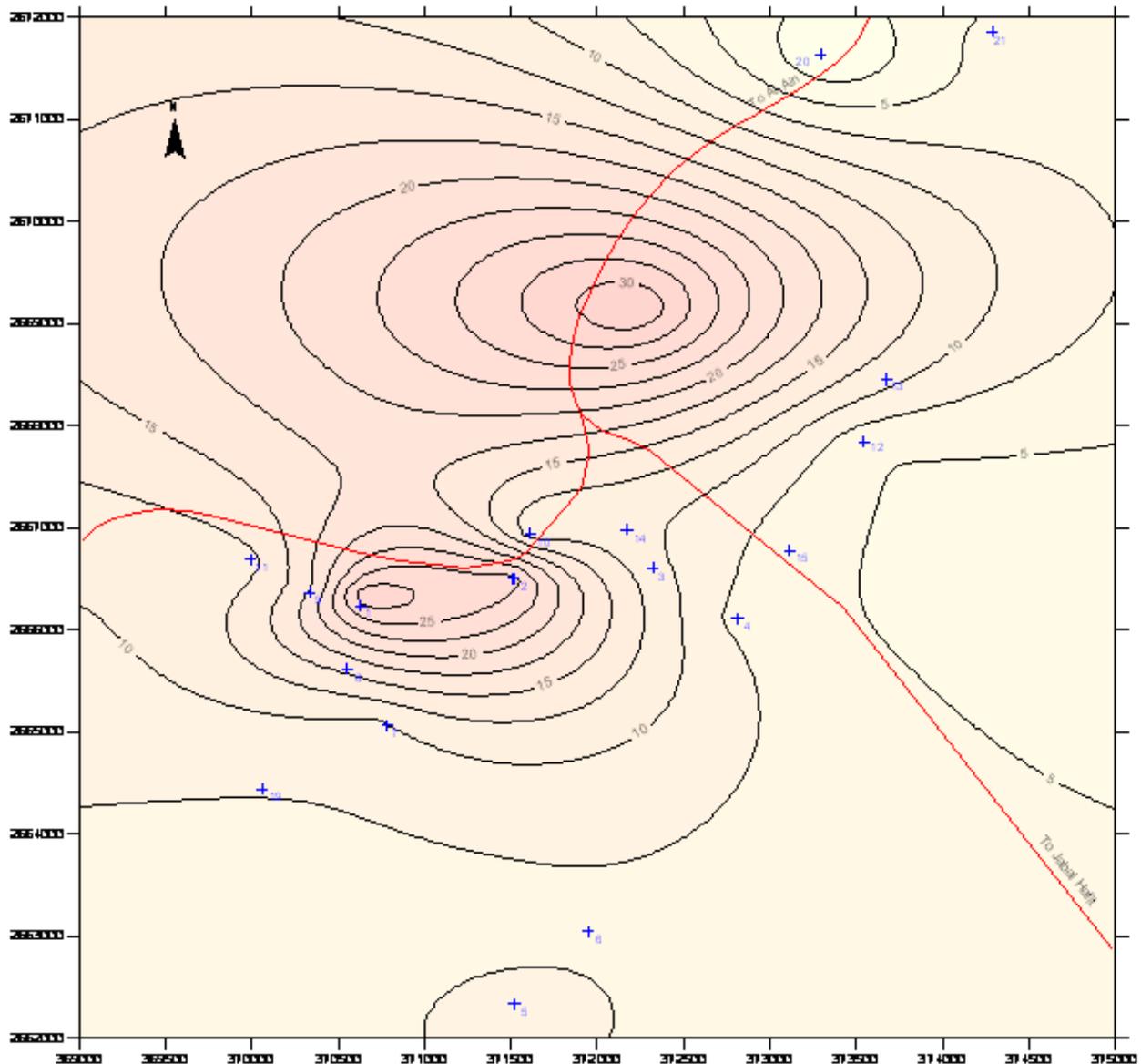


Figure 6. Contour map of nitrate concentration (mg/l) distribution in groundwater of the study area.

of the people in UAE depend on groundwater for their domestic, agricultural and industrial purposes. Salinity is the major problem that faces the future of groundwater. The present study investigated 21 samples that were collected from different wells and gone through various chemical analyses in order to characterize groundwater and identify factors affecting the groundwater quality.

The TDS in the study area ranged from 3120 -12600 mg/l and the highest concentration was observed in the northeast region of the study area. The agricultural activities, evaporation process and over exploitation of groundwater are the main reasons for that high TDS. The sequence of cations dominance in groundwater in the study area is: $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{+2} > \text{K}^+$, while the sequence

of anions dominance is: $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^{2-} > \text{NO}_3^-$. The water type of the study area is mainly old marine water (basinal water) genesis except for two wells which are meteoric water genesis as shown from Piper plot and Durov graph which confirmed that the water is old marine origin with the dominance of sodium and chloride ions as 1st order among the cationic and anionic compositions. The groundwater quality of the study area according to the (EC) and (SAR) value is characterized by strong to very strong damaging effects if it is used for irrigation.

The groundwater is not suitable for domestic use and irrigation based on the high TDS and SAR values of collected groundwater samples.

The regression equation of δD and $\delta^{18}\text{O}$ for ground

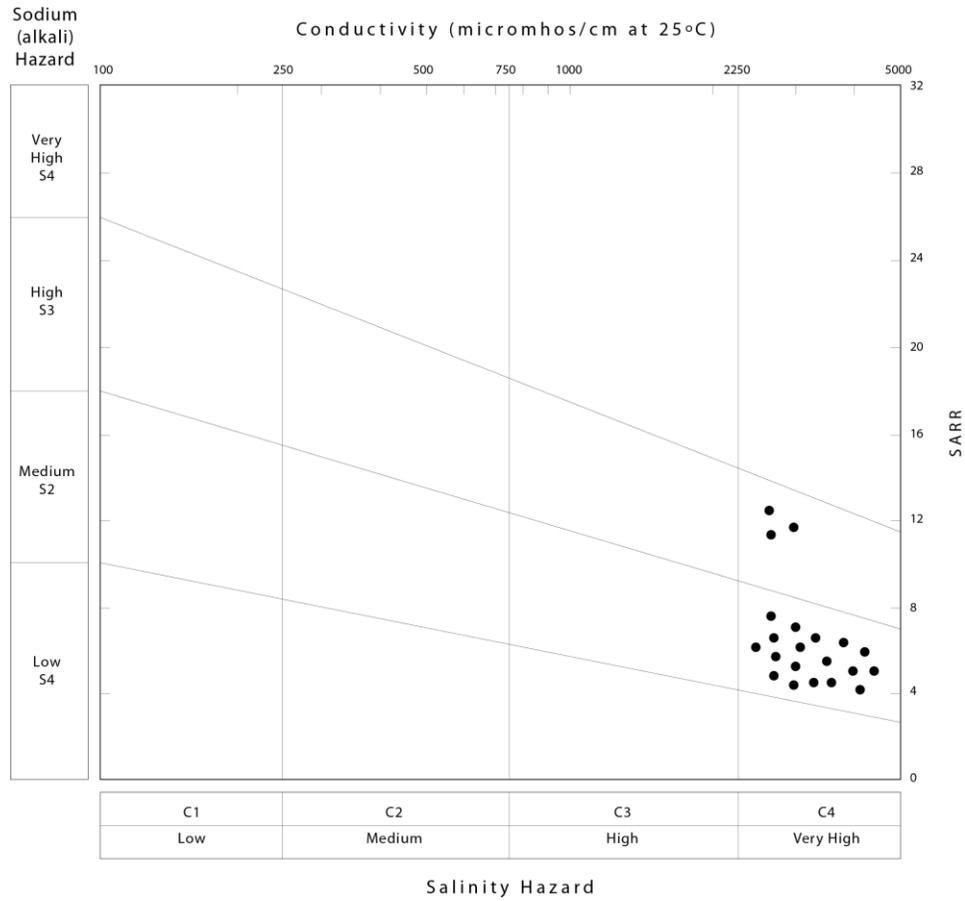


Figure 7. Wilcox diagram of collected groundwater samples for the study area.

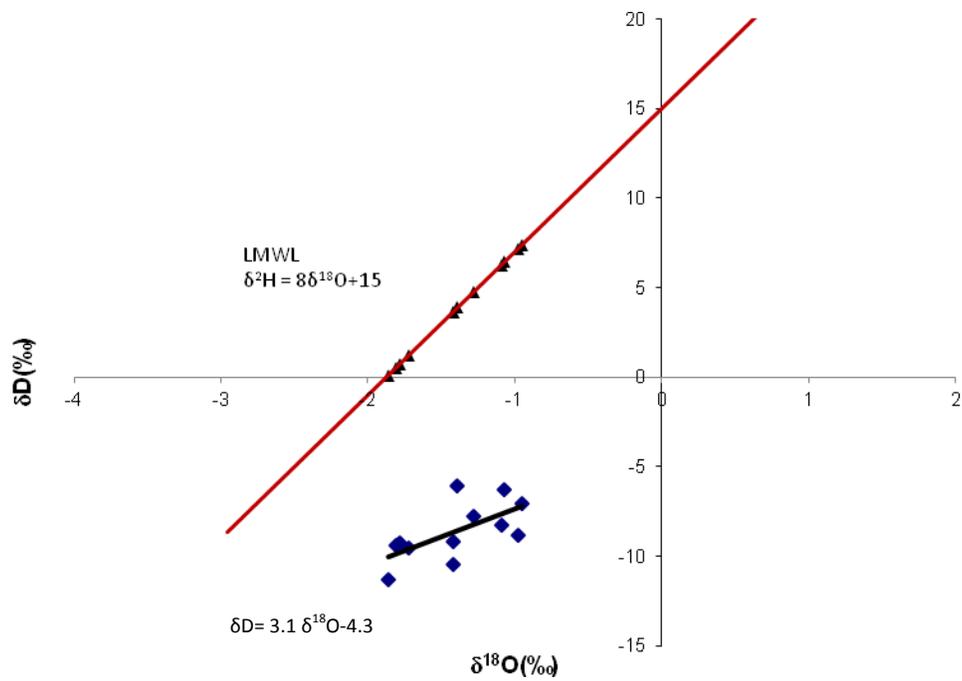


Figure 8. Regression line of δD - $\delta^{18}O$ for water samples from the study area.

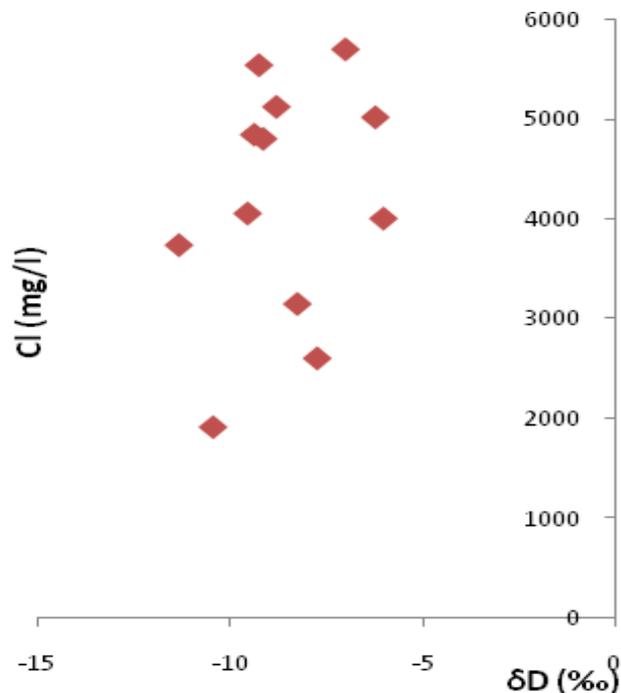


Figure 9. Regression line of $\delta\text{D}-\text{Cl}^-$ for groundwater samples from the study area.

water samples suggested that groundwater has gone through evaporation process before or during recharge. The absence of correlation between Cl^- and δD indicates that there is more than one source of Cl^- in groundwater of the study area.

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