*DOI: 10.24996/ijs.2019.60.6.17*

**ISSN: 0067-2904**

# Hydrochemical of Groundwater for Al Dammam unconfined Aquifer within Al-Salman Basin, Al-Muthana Governorate, South West Iraq

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## Abstract

The quality of groundwater is just as important as its quantity. The kinds and concentration of salts in groundwater depend on the environment, movement, and the source of the groundwater. During the field work, 20 samples have been collected from water wells from Al-Salman basin for two seasons represent wet and dry seasons in November 2017 and April 2018. After water well samples have been analyzed the Electrical conductivity values range from (2260 to 5500) µS/cm for dry season and range from (2540 to 5630) µS/cm for wet season, the Total dissolved solids values range from (1289 to 3582) ppm for dry season and range from (1710 to 3960) ppm for wet season, and pH values range from (7.11 to 7.3) for dry and wet seasons. The Hydrochemical classification which applied using Piper's Diagram revealed there are three type of water (sulphate type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^-$ – $SO_4$, sulphate type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^-$ - $SO_4$, NaCl), and two water type by applying Chadha's diagram (sulphate type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^-$ - $SO_4$, $Na^+$- $Cl^-$), the variation of water type in the study area due to influence of Rus Formation which consists of anhydrite, and structure roles where made precipitation concentrate in Al-Salman depressions and streams flow faults that ended with playa.

**Keywords:** Groundwater, Hydrochemical classification, Dammam, Al-Salman.

# هيدروكيميائية المياه الجوفية لخزان الدمام غير المحصور ضمن حوض السلمان في محافظة المثنى جنوب غرب العراق

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## الخلاصة

نوعية المياه الجوفية مهمة بقدر اهمية كميتها. نوعية وتركيز الاملاح في المياه الجوفية تعتمد على البيئة وحركة ومصدر المياه الجوفية. خلال العمل الحقلي تم جمع 20 نموذج من المياه الجوفية من الابار في منطقة الدراسة لموسمين الرطب والجاف في تشرين الثاني 2017 ونيسان 2018. بينت نتائج التحليل الكيميائي للنماذج المائية ان قيم التوصيلية الكهربائية تتراوح بين (2260 الى 5500) مايكروسمنز/سنتمتر للموسم الجاف وتتراوح بين (2540 الى 5630) مايكروسمنز/سنتمتر للموسم الرطب، وقيم الاملاح الذائبة الكلية تتراوح بين ( 1289 الى 3582) ملغم/لتر للموسم الجاف وتتراوح بين (1710 الى 3960) ملغم/لتر للموسم الرطب، بينما قيم الحامضية تراوح بين (7.11 الى 7.3) للموسمين الجاف والرطب. تطبيق التصنيف

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الهيدروكيميائـــي باستخدام مخطط بايبر وجد ثلاث انواع من المياه (sulphate type $Ca^{+2} – Mg^{+2} – Cl^{-}$ 
$– SO_4$, sulphate type $Ca^{+2} – Mg^{+2} – Cl^{-} – SO_4$ NaCl, ) وباستخدام مخطط جادا وجد نوعين 
من المياه ضمن منطقة الدراسة ( sulphate type $Ca^{+2} – Mg^{+2} – Cl^{-} – SO_4$, $Na^{+}– Cl^{-}$) ، ان 
تغير نوعية المياه الجوفية في منطقة الدراسة يعود لتأثير تكوين الرص الانهيدرتي وتأثير تركيبي من خلال 
تركيز مياه الامطار في منخفض السلمان وشبكة تصريف مياه الامطار والتي تجري بموازاة الفوالق والتي تنتهي 
بفيضات.

## 1- Introduction

Groundwater quality is a consequence of the natural physical and chemical state of the water as well as any alterations that may have occurred as a consequence of human activity. One basic measure of water quality is the total dissolved solids (TDS) in mg/L. The main cations and anions are ($Na^{+1}$, $Mg^{+2}$, $Ca^{+2}$ and $K^{+1}$) and ($Cl^{-1}$, $SO_4^{-2}$, $HCO_3^{-1}$ and $NO_3^{-1}$ ) respectively [1]. The map of the regional distribution of the water composition serves as water analyses in hydrology. Such maps help environmental authorities, water resource managers, drilling operators, and other practitioners to identify the suitability of groundwater for different purposes [2]. During the fieldwork 20 samples have been collected from water wells in the study area for two season represent wet and dry seasons in November 2017 and April 2018 (Table-1) (Figure-1), all samples were gathered from wells not more than 100m in depth due to the thickness of Dammam aquifer. The General Commission of Groundwater Laboratory was handled the hydrochemical analyses of the samples.

**Table 1-**Information of the water wells in the study area for Al-Dammam aquifer collected during field work in April 2018.

| S. No | Longitude | Latitude | Well depth (m) | Depth to water (m) | Elevation (m.a.s.l.) |
|---|---|---|---|---|---|
| 1 | E44$^{o}$ 26' 22.40'' | N30$^{o}$ 20' 20.50'' | 95 | 39 | 259 |
| 2 | E44$^{o}$ 28' 31.19'' | N30$^{o}$ 25' 29.9'' | 90 | 36 | 238 |
| 3 | E44$^{o}$ 31' 56.8'' | N30$^{o}$ 27' 17.23'' | 80 | 11 | 204 |
| 4 | E44$^{o}$ 45' 9.9'' | N30$^{o}$ 24' 33.9'' | 85 | 51.4 | 247 |
| 5 | E44$^{o}$ 40' 3.15'' | N30$^{o}$ 28' 4.36'' | 45 | 19.6 | 200 |
| 6 | E44$^{o}$ 34' 33.34'' | N30$^{o}$ 34' 22.6'' | 80 |  | 246 |
| 7 | E44$^{o}$ 37' 0.51'' | N30$^{o}$ 46' 7.5'' | 95 | 70 | 198 |
| 8 | E44$^{o}$ 54' 50.7'' | N30$^{o}$ 48' 58.6'' | 94 | 70 | 150 |
| 9 | E44$^{o}$ 57' 51.8'' | N30$^{o}$ 48' 35.9'' | 90 | 58 | 136 |
| 10 | E45$^{o}$ 02' 57.44'' | N30$^{o}$ 49' 9.54'' | 92 | 63 | 129 |
| 11 | E44$^{o}$ 55' 12.7'' | N31$^{o}$ 9' 7.7'' | 80 | 45 | 61 |
| 12 | E44$^{o}$ 56' 46.21'' | N31$^{o}$ 10' 5.8'' | 94 | 37 | 50 |
| 13 | E44$^{o}$ 58' 49.49'' | N31$^{o}$ 9' 55.7'' | 80 | 35 | 50 |
| 14 | E45$^{o}$ 0' 52.7'' | N31$^{o}$ 8' 52'' | 80 | 31.7 | 50 |
| 15 | E45$^{o}$ 6' 13.50'' | N31$^{o}$ 0' 35'' | 88 | 56 | 81 |
| 16 | E45$^{o}$ 5' 21.6'' | N30$^{o}$ 58' 3.29'' | 90 | 59 | 91 |
| 17 | E45$^{o}$ 4' 3.9'' | N30$^{o}$ 55' 23'' | 100 | 64 | 109 |
| 18 | E45$^{o}$ 3' 57.27'' | N31$^{o}$ 12' 50.54'' | 80 | 8 | 22 |
| 19 | E45$^{o}$ 2' 36.7'' | N31$^{o}$ 13' 18.7'' | 35 | 6 | 20 |
| 20 | E45$^{o}$ 01' 6.0'' | N31$^{o}$ 13' 56.55'' | 40 | 5.2 | 20 |

## 2- Location of the study area:

The study area having an areal extent (9484) km$^2$ located southwest Al-Samawa city and Southwest of the Euphrates River, in the stable zone of Iraq. It extends from E44º1'20" to E45º15'25" longitude and N30°1'50" to N31°15'51" latitude (Figure-1).

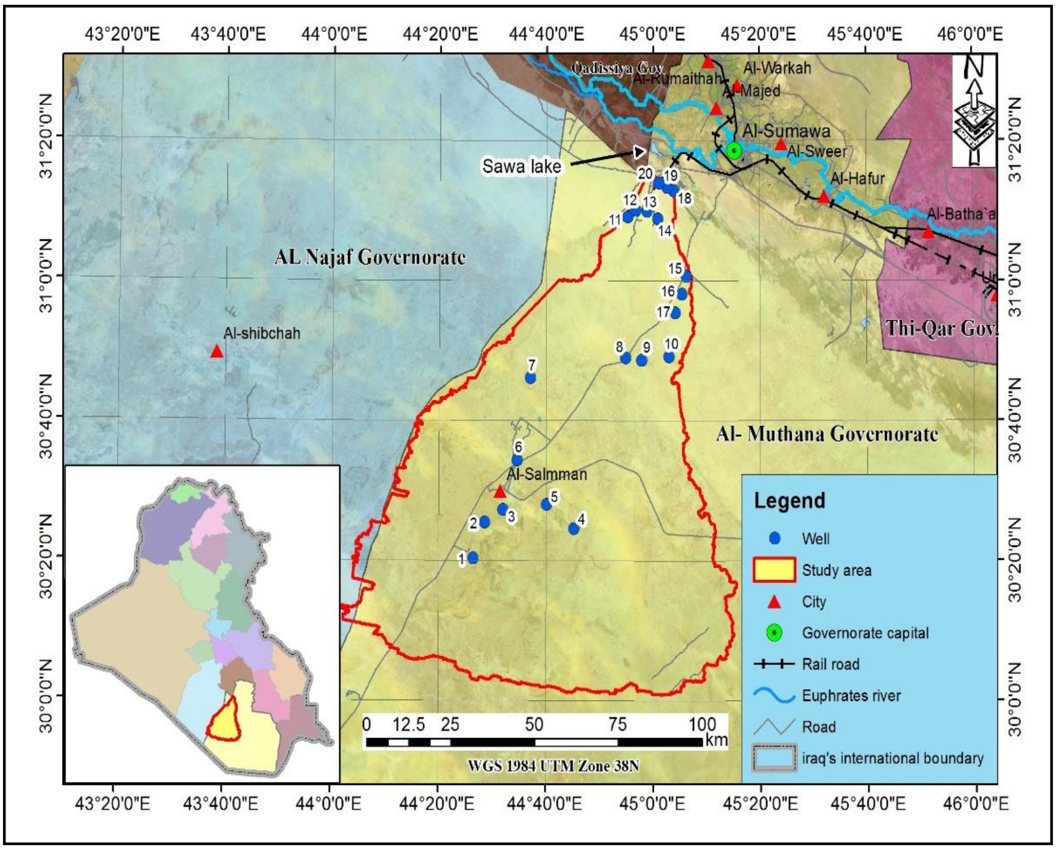

**Figure 1-**Location map digitized from Administrative map of Iraq (2007) General Commission of Surveying, and Distribution of water wells samples map in the study area.

## 3- Geology of the study area

The geological description for the study area (Figure-2) is listed from oldest to the youngest as below [3] and Key Holes-3[4], Key Holes-5[5], Key Holes-4 and Abu lum Bore Hole were used to draw the cross section within the study area (Figure-3):

**3-1** Rus Formation (Early Eocene)

The Formation consists predominantly of anhydrite.

**3-2** Al-Dammam Formation in the southern desert has been sub-divided into three members based on the lithological, physical and faunal variation.

a. Lower member (Jil Formation) (Early Eocene): it is composed mainly of marl, chalk to chalky limestone, and recrystallized limestone.

b. Middle member (Middle Eocene): it is composed mainly of breccia or conglomerate at the base followed upwards by whitish grey fresh water Limestone, light grey, chalky, fossiliferous dolostone, grey lithographic limestone with some phosphatic pellets, and massive recrystallized Nummulites limestone.

c. Upper member (Upper Eocene): it is composed of recrystallized limestone and thin horizons of chalky to marly limestone at the middle part, and marl and marly limestone, rich with chert nodules at the upper part.

**3-3** Euphrates Formation (Lower Miocene)

It is composed of claystone or by basal breccia at the base, overlain by greenish grey marl alternated with highly fossiliferous limestone to coquina. The Euphrates Formation in the study area is interfinger with deltaic deposits of the Ghar Formation or it is replaced completely by the latter.

3-4 Ghar Formation (Lower Miocene)

It is composed of (2-3) meters basal breccia or red claystone at the base and then followed upwards by the alternation of pebbly sandstone, calcareous sandstone and sandy limestone.

## 3- Physical Analysis

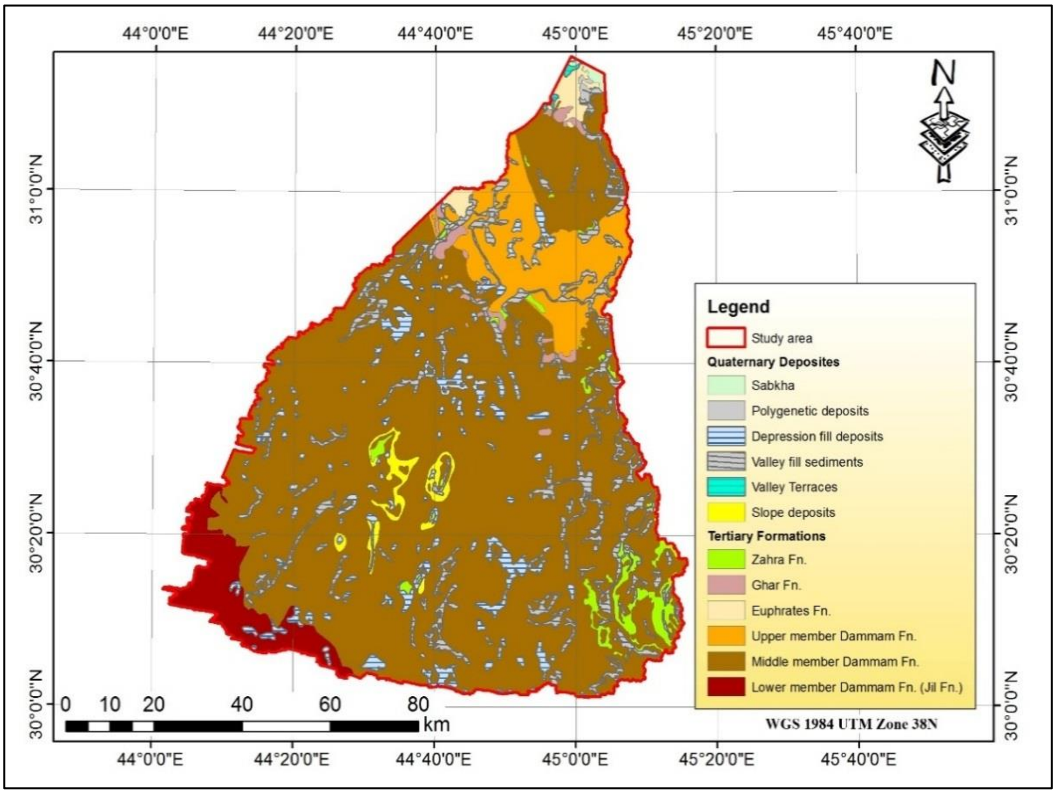

**Figure 2-**Geological map of the study area digitized from GEOSURV. 1996 (NH-38-6), (NH-38-7) and (NH-38-2)

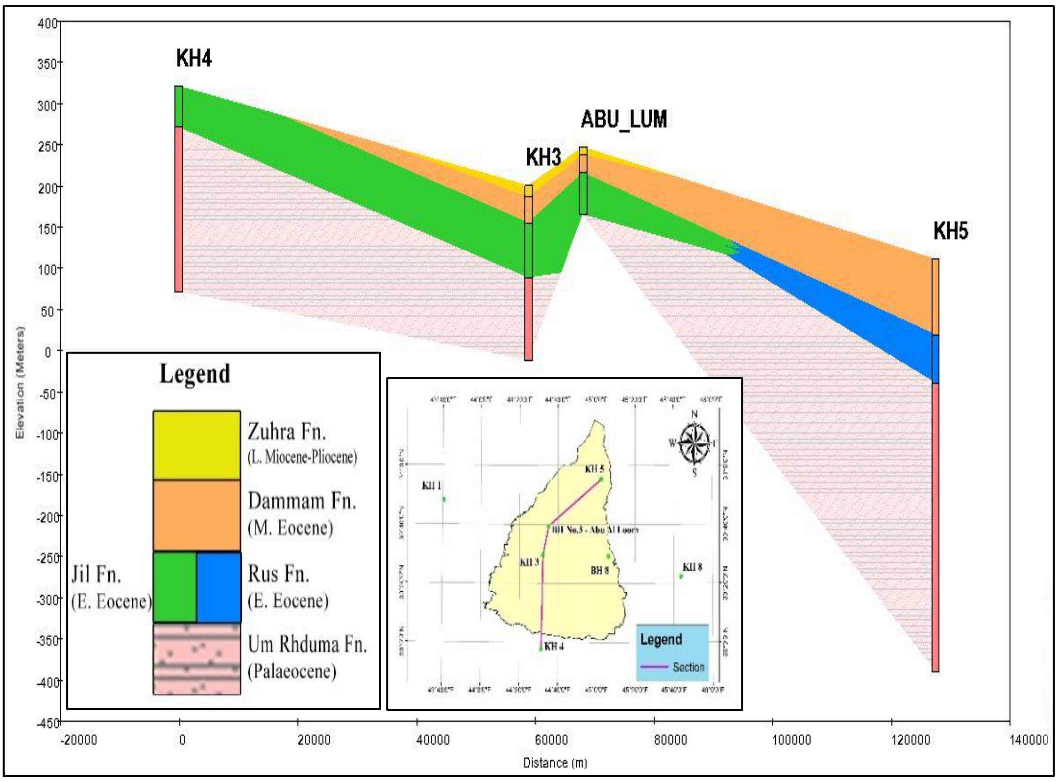

**Figure 3-**Cross section in the study area between KH4, KH3, BH Abu lum and KH5.

### 3-1 Electrical Conductivity (EC)

The aqueous solution can measure their ability to carry an electric current by using the conductivity. This ability depends on the presence of ions; on their total concentration, mobility, and valence; and on the temperature of measurement. Solutions of most inorganic compounds are relatively good conductors. Conductivity is customarily reported in micromhos per centimetre (μmho/cm) [6]. The Electrical Conductivity (EC) values for the two seasons (dry and wet) are shown in (Table-2) and (Figure-4) showed the distribution of EC in both dry and wet seasons in the study area.

**Table 2-**The EC values of water wells samples in the study area

| Well No. | EC (µS/cm) of dry season | EC (µS/cm) of wet season | Well No. | EC (µS/cm) of dry season | EC (µS/cm) of wet season |
|---|---|---|---|---|---|
| 1 | 2810 | 2880 | 11 | 2550 | 2640 |
| 2 | 2260 | 2550 | 12 | 2850 | 2990 |
| 3 | 2500 | 2540 | 13 | 3760 | 3800 |
| 4 | 2862 | 3220 | 14 | 3460 | 3480 |
| 5 | 2310 | 3000 | 15 | 4220 | 4690 |
| 6 | 2680 | 2800 | 16 | 4590 | 4940 |
| 7 | 5050 | 5130 | 17 | 4790 | 5000 |
| 8 | 4890 | 4970 | 18 | 4800 | 2660 |
| 9 | 5500 | 5630 | 19 | 4580 | 2610 |
| 10 | 4870 | 5070 | 20 | 4220 | 4730 |

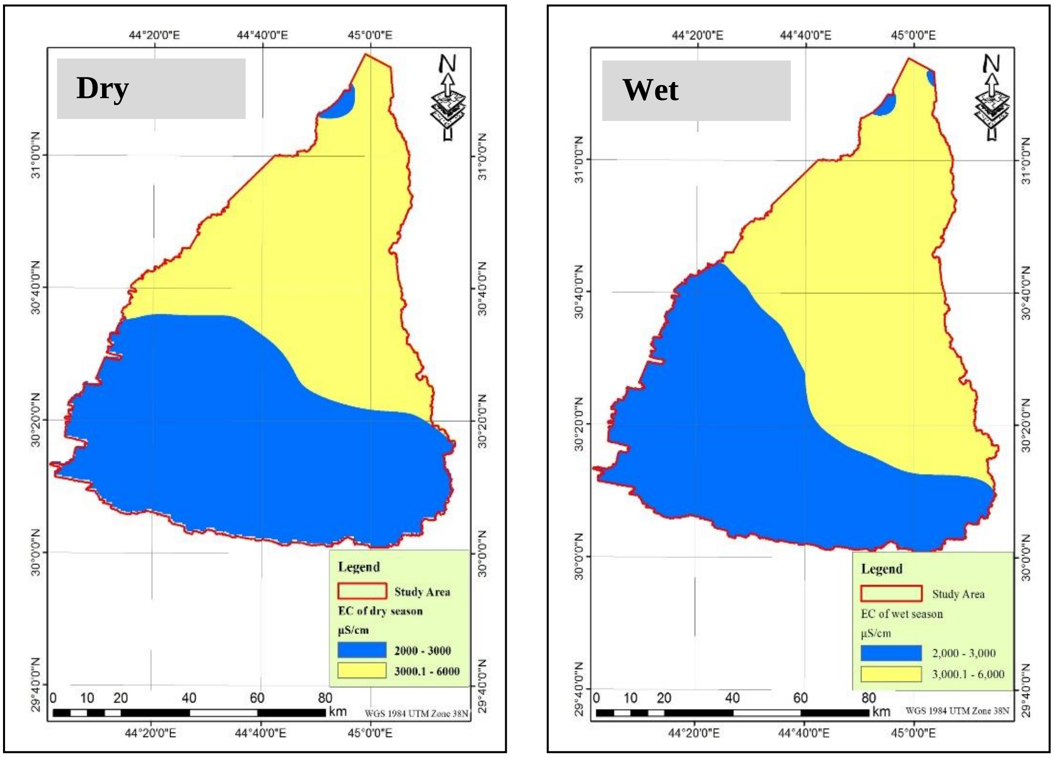

**Figure 4-**Spatial distribution of EC in the study area during the dry and wet seasons.

### 3-2 Total Dissolved Solids (TDS)

The concentration of total dissolved solids (TDS) in groundwater is determined by weighing the solid residue obtained by evaporating a measured volume of filtered sample to dryness [7]. The concentration of the dissolved ions within natural water depends on the type of soil and rocks that are in contact with it and the period of tangency process and climate [8]. The TDS represents a total summation of ionic concentrations of cations and anions. It is measured by the (ppm) or (mg/l) units

[9]. Total dissolved solids (TDS) values for the two seasons (dry and wet) are shown in (Table-3); the distribution of TDS in both dry and wet seasons in the study area is shown in (Figure-5).

**Table 3-**The TDS values of water wells samples in the study area.

| Well No. | TDS (ppm) of dry season | TDS (ppm) of wet season | Well No. | TDS (ppm) of dry season | TDS (ppm) of wet season |
|---|---|---|---|---|---|
| 1 | 1960 | 1990 | 11 | 1770 | 1710 |
| 2 | 1480 | 1790 | 12 | 1974 | 2000 |
| 3 | 1760 | 1760 | 13 | 2480 | 2500 |
| 4 | 1860 | 2150 | 14 | 2340 | 2340 |
| 5 | 1289 | 2020 | 15 | 2720 | 3270 |
| 6 | 1800 | 1960 | 16 | 2980 | 3450 |
| 7 | 3360 | 3580 | 17 | 3080 | 3512 |
| 8 | 3160 | 3470 | 18 | 3100 | 1770 |
| 9 | 3582 | 3960 | 19 | 2960 | 1720 |
| 10 | 3140 | 3563 | 20 | 2725 | 3280 |

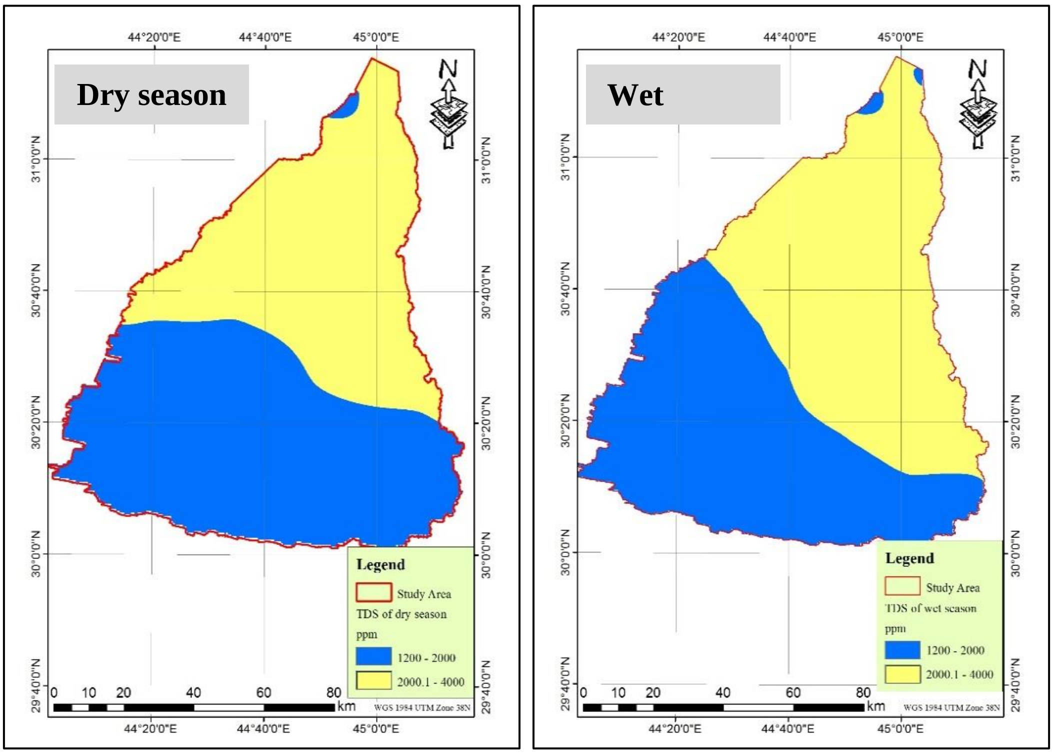

**Figure 5-**Spatial distribution of TDS in the study area during dry and wet seasons.

## TDS to EC Ratio

If the ratio of calculated TDS to conductivity falls below 0.55, the lower ion sum is suspect. If the ratio is above 0.7, the higher ion sum is suspect. If reanalysis causes no change in the lower ion sum, an unmeasured constituent, such as ammonia or nitrite, may be present at a significant concentration. If poorly dissociated calcium and sulphate ions are present, the TDS may be as high as 0.8 times the EC. The acceptable criterion is calculated TDS/conductivity = 0.55 –0.7 [6]. The calculated values for TDS to EC Ratio for the two seasons (dry and wet) are acceptable as shown in (Table-4).

**Table 4-**The TDS/conductivity values of water wells samples in the study area

| Well No. | TDS/conductivity of dry season | TDS/conductivity of wet season |
|---|---|---|
| 1 | 0.7 | 0.69 |
| 2 | 0.65 | 0.7 |
| 3 | 0.7 | 0.69 |
| 4 | 0.65 | 0.67 |
| 5 | 0.56 | 0.67 |
| 6 | 0.67 | 0.7 |
| 7 | 0.67 | 0.7 |
| 8 | 0.65 | 0.7 |
| 9 | 0.65 | 0.7 |
| 10 | 0.65 | 0.7 |
| 11 | 0.69 | 0.65 |
| 12 | 0.69 | 0.69 |
| 13 | 0.66 | 0.66 |
| 14 | 0.68 | 0.67 |
| 15 | 0.65 | 0.7 |
| 16 | 0.65 | 0.7 |
| 17 | 0.64 | 0.7 |
| 18 | 0.65 | 0.67 |
| 19 | 0.65 | 0.66 |
| 20 | 0.65 | 0.69 |

### 3-3 Hydrogen ion concentration (pH)

Pure water defines the condition of acid-base neutrality. So, equal concentrations of $H^+$ and $OH^-$, or $[H^+] = [OH^-]$ which represents acid-base neutral water. In neutral water at 25°C, $[H^+] = [OH^-] = 1 * 10^{-7}$ mol/L. The logarithmic units for expressing $[H^+]$ as a positive decimal number called the pH, shown in Equation (1), has been developed by the chemists which range between 0 to 14. The pH is the negative of the base$_{10}$ logarithm of the hydrogen ion concentration in moles per liter [10]:

$$pH = -\log_{10}[H^+] \qquad \ldots\ldots (1)$$

The pH values for the two seasons (dry and wet) are shown in (Table-5).

**Table 5-**The pH values of water wells samples

| Well No. | pH of dry season | pH of wet season | Well No. | pH of dry season | pH of wet season |
|---|---|---|---|---|---|
| 1 | 7.19 | 7.13 | 11 | 7.25 | 7.11 |
| 2 | 7.2 | 7.22 | 12 | 7.14 | 7.14 |
| 3 | 7.3 | 7.3 | 13 | 7.22 | 7.2 |
| 4 | 7.18 | 7.15 | 14 | 7.17 | 7.17 |
| 5 | 7.17 | 7.17 | 15 | 7.3 | 7.25 |
| 6 | 7.11 | 7.19 | 16 | 7.19 | 7.2 |
| 7 | 7.16 | 7.15 | 17 | 7.25 | 7.2 |
| 8 | 7.13 | 7.14 | 18 | 7.17 | 7.2 |
| 9 | 7.24 | 7.19 | 19 | 7.18 | 7.2 |
| 10 | 7.3 | 7.18 | 20 | 7.28 | 7.17 |

## 4- Chemical Analysis

### Major Cations

### 1- Calcium ion ($Ca^{2+}$)

Calcium is an essential component of many rock minerals and is the most plentiful of the alkaline-earth metals. Calcium ions have an ionic radius near 1 angstrom, which represents to some extent large ions. The charged field around the ion is therefore not as intense as the fields of smaller divalent ions. Calcium ions have a less strongly retained shell of oriented water molecules surrounding them in solution [8].Groundwater in contact with sedimentary rocks of marine origin derives most of their calcium from the solution of calcite, aragonite, dolomite and limestone, anhydrite, and gypsum [11]. The concentration values of Calcium ion ($Ca^{2+}$) for the two seasons dry and wet range (128-287) ppm, and (160-350) ppm respectively Tables-(6, 7).

**2- Magnesium ion ($Mg^{2+}$)**

Magnesium is an alkaline-earth metal. The geochemical behavior of magnesium shows that, magnesium ions are smaller than sodium or calcium ions. It is found in the dolomite mineral, which is considered as the second most important carbonate mineral after calcite. Clay minerals are the other source of magnesium ion in water as well as in the ferromagnetic igneous rocks and minerals such as olivine, pyroxene and amphibole [8]. The concentration values of Magnesium ion ($Mg^{2+}$) for the two seasons dry and wet range (73-139) ppm, and (92-190) ppm respectively Tables-(6, 7).

**3- Sodium ion ($Na^{+}$)**

The primary source of sodium ion in the areas of evaporate deposits is the halite and clay minerals. Sodium ions are not strongly hydrated because it is having an ionic radius to some extent larger than (1) angstrom [8], [11]. The concentration values of Sodium ion ($Na^{+}$) for the two seasons dry and wet range (133-532) ppm, and (220-540) ppm respectively Tables-(6, 7).

**4- Potassium ($K^{+}$)**

The potassium ion is substantially larger than the sodium ion, and it would normally be expected to be adsorbed less strongly than sodium in ion-exchange reactions. Groundwater that percolate through evaporate deposits contain very large quantities of potassium derived from the dissolution of sulfate. The solubilities of potassium salts are all high and generally, similar in magnitude to the solubilities of sodium salts [8],[11]. The concentration values of Potassium ion ($K^{+}$) for the two seasons dry and wet range (8-90) ppm, and (22-123) ppm respectively Tables-(6, 7).

**Major anions**

**1- Chloride ion ($Cl^{-}$)**

Chloride is the most plentiful of the halogens. The sedimentary rocks represent the major sources of chloride, especially evaporates. [8],[11]. The concentration values of Chloride ion ($Cl^{-}$) for the two seasons dry and wet range (243-650) ppm, and (340-763) ppm respectively Tables-(6, 7).

**2- Bicarbonates ion ($HCO_3^{-}$)**

Bicarbonates are considered the most important component that affects the pH of a solution. The process of $HCO_3$ depletion to $CO_3$ in solution becomes high when the pH is more than 8.2, but when the pH is less than 8.2 the hydrogen ions are added to the carbonate and become dissolved bicarbonate [8],[11]. The concentration values of Bicarbonates ion ($HCO_3^{-}$) for the two seasons dry and wet (65-473) ppm, and (63-610) ppm respectively Tables-(6, 7).

**3- Sulfates ion ($SO_4^{2-}$)**

In the aqueous systems the redox properties is strongly control chemical behavior of sulfur. In the most highly oxidized form, the effective radius of the sulfur ion is only 0.20 angstrom and it forms a stable. The gypsum represents the most common source of sulfates. The source of sulfate in groundwater is gypsum crystals which occur in many sedimentary rocks. The most important of these in natural-water chemistry are associations of the type $Na_2SO_4$ and $CaSO_4$ [8]. The concentration values of sulfates ion ($SO_4^{2-}$) for the two seasons dry and wet range (416-1180) ppm, and (725-1353) ppm respectively Tables-(6, 7).

**Minor compounds of nitrate ($NO_3^{-}$)**

Nitrate forms through several chemical alterations to nitrogen oxides in the atmosphere. The large concentrations of nitrite are rarely occuring to affect the ionic balance to large extent. There is considerable evidence that a significant amount of reduced nitrogen is present in many groundwater. The groundwater considered risky polluted when nitrate concentrations reach or exceed 10 mg/L [8]. The concentration values of Nitrogen oxides ($NO_3^{-}$) for the two seasons dry and wet range (1.1-2.4) ppm, and (1.1-2.0) ppm respectively Tables (6, 7).

**Table 6-**Concentrations of cations and anions for water wells samples (dry season) in the study area.

| Well No. | Cations | | | | | | | | ΣCations | Anions | | | | | | | | ΣAnions | % difference | A % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Ca^{+2}$ | | $Mg^{+2}$ | | $Na^{+}$ | | $K^{+}$ | | | $Cl^{-}$ | | $SO_4^{-2}$ | | $HCO_3^{-}$ | | $NO_3^{-}$ | | | | |
| | ppm | epm | ppm | epm | ppm | epm | ppm | epm | epm | ppm | epm | ppm | epm | ppm | epm | ppm | epm | epm | | |
| 1 | 183 | 9.13 | 123 | 10.12 | 250 | 10.87 | 30 | 0.8 | 30.89 | 404 | 11.40 | 844 | 17.57 | 115 | 1.89 | 1.7 | 0.03 | 30.88 | 0.03 | 99.97 |
| 2 | 128 | 6.39 | 92 | 7.57 | 133 | 5.78 | 8 | 0.2 | 19.95 | 243 | 6.85 | 576 | 11.99 | 65 | 1.07 | 1.2 | 0.02 | 19.93 | 0.04 | 99.95 |
| 3 | 165 | 8.23 | 112 | 9.22 | 220 | 9.56 | 24 | 0.6 | 27.63 | 369 | 10.41 | 758 | 15.78 | 80 | 1.31 | 1.3 | 0.02 | 27.52 | 0.20 | 99.80 |
| 4 | 152 | 7.58 | 95 | 7.82 | 185 | 8.05 | 8.2 | 0.2 | 23.66 | 430 | 12.13 | 416 | 8.66 | 156 | 2.56 | 2 | 0.03 | 23.38 | 0.60 | 99.40 |
| 5 | 132 | 6.59 | 100 | 8.23 | 146 | 6.35 | 10 | 0.3 | 21.42 | 250 | 7.05 | 622 | 12.95 | 68 | 1.12 | 1.1 | 0.02 | 21.13 | 0.68 | 99.32 |
| 6 | 170 | 8.48 | 115 | 9.46 | 232 | 10.09 | 28 | 0.72 | 28.75 | 376 | 10.61 | 792 | 16.49 | 82 | 1.34 | 1.2 | 0.02 | 28.46 | 0.51 | 99.49 |
| 7 | 280 | 13.97 | 135 | 11.11 | 525 | 22.83 | 88 | 2.25 | 50.17 | 644 | 18.17 | 1160 | 24.15 | 470 | 7.70 | 2 | 0.03 | 50.05 | 0.12 | 99.88 |
| 8 | 260 | 12.98 | 126 | 10.37 | 408 | 17.74 | 78 | 1.99 | 43.09 | 545 | 15.37 | 1002 | 20.86 | 408 | 6.69 | 2.3 | 0.04 | 42.96 | 0.15 | 99.85 |
| 9 | 287 | 14.32 | 139 | 11.44 | 532 | 23.14 | 90 | 2.30 | 51.20 | 650 | 18.33 | 1180 | 24.57 | 473 | 7.75 | 2.2 | 0.04 | 50.69 | 0.50 | 99.50 |
| 10 | 250 | 12.48 | 122 | 10.04 | 404 | 17.57 | 74 | 1.89 | 41.98 | 540 | 15.23 | 966 | 20.11 | 402 | 6.59 | 2.3 | 0.04 | 41.97 | 0.01 | 99.99 |
| 11 | 166 | 8.28 | 113 | 9.3 | 221 | 9.61 | 25 | 0.64 | 27.84 | 370 | 10.44 | 760 | 15.82 | 80 | 1.31 | 2.1 | 0.03 | 27.60 | 0.43 | 99.57 |
| 12 | 185 | 9.23 | 124 | 10.2 | 252 | 10.96 | 31 | 0.79 | 31.19 | 405 | 11.42 | 846 | 17.61 | 116 | 1.90 | 1.6 | 0.03 | 30.96 | 0.37 | 99.63 |
| 13 | 172 | 8.58 | 115 | 9.46 | 452 | 19.66 | 38 | 0.97 | 38.68 | 564 | 15.91 | 993 | 20.67 | 108 | 1.77 | 1.2 | 0.02 | 38.37 | 0.40 | 99.60 |
| 14 | 227 | 11.33 | 111 | 9.13 | 342 | 14.87 | 37 | 0.95 | 36.28 | 467 | 13.17 | 880 | 18.32 | 251 | 4.11 | 1.7 | 0.03 | 35.64 | 0.89 | 99.11 |
| 15 | 200 | 9.98 | 73 | 6.01 | 280 | 12.17 | 42 | 1.07 | 29.24 | 358 | 10.10 | 785 | 16.34 | 165 | 2.70 | 2 | 0.03 | 29.18 | 0.10 | 99.90 |
| 16 | 227 | 11.33 | 94 | 7.74 | 350 | 15.22 | 61 | 1.56 | 35.85 | 447 | 12.61 | 888 | 18.49 | 281 | 4.61 | 1.7 | 0.03 | 35.73 | 0.17 | 99.83 |
| 17 | 238 | 11.88 | 119 | 9.79 | 397 | 17.26 | 73 | 1.87 | 40.81 | 537 | 15.15 | 910 | 18.95 | 405 | 6.62 | 2.4 | 0.04 | 40.77 | 0.05 | 99.95 |
| 18 | 240 | 11.98 | 120 | 9.87 | 400 | 17.40 | 74 | 1.89 | 41.14 | 540 | 15.23 | 923 | 19.22 | 406 | 6.65 | 2.3 | 0.04 | 41.14 | 0 | 100 |
| 19 | 226 | 11.28 | 93 | 7.65 | 348 | 15.14 | 60 | 1.54 | 35.60 | 446 | 12.58 | 882 | 18.36 | 280 | 4.59 | 1.8 | 0.03 | 35.56 | 0.06 | 99.94 |
| 20 | 201 | 10.03 | 73 | 6.01 | 282 | 12.27 | 43 | 1.1 | 29.40 | 359 | 10.13 | 793 | 16.51 | 166 | 2.72 | 2 | 0.03 | 29.39 | 0.02 | 99.98 |

**Table 7-**Concentrations of cations and anions for water wells samples (wet season) in the study area.

| **Well No.** | **Cations** | | | | | | | | **ΣCations** | **Anions** | | | | | | | | **ΣAnions** | **% difference** | **A %** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **$Ca^{+2}$** | | **$Mg^{+2}$** | | **$Na^{+}$** | | **$K^{+}$** | | | **$Cl^{-}$** | | **$SO_4^{-2}$** | | **$HCO_3^{-}$** | | **$NO_3^{-}$** | | | | |
| | **ppm** | **epm** | **ppm** | **epm** | **ppm** | **epm** | **ppm** | **epm** | **epm** | **ppm** | **epm** | **ppm** | **epm** | **ppm** | **epm** | **ppm** | **epm** | **epm** | | |
| 1 | 188 | 9.38 | 126 | 10.37 | 254 | 11.05 | 32 | 0.82 | 31.62 | 408 | 11.51 | 850 | 17.7 | 117 | 1.92 | 1.2 | 0.019 | 31.14 | 0.76 | 99.2 |
| 2 | 168 | 8.38 | 114 | 9.38 | 225 | 9.79 | 25 | 0.64 | 28.19 | 390 | 11 | 760 | 15.82 | 81 | 1.33 | 1.2 | 0.019 | 28.17 | 0.04 | 99.96 |
| 3 | 165 | 8.23 | 112 | 9.216 | 220 | 9.57 | 24 | 0.61 | 27.63 | 369 | 10.41 | 758 | 15.78 | 80 | 1.31 | 1.3 | 0.02 | 27.52 | 0.2 | 99.8 |
| 4 | 182 | 9.08 | 130 | 10.70 | 290 | 12.61 | 38 | 0.97 | 33.36 | 428 | 12.07 | 912 | 18.99 | 125 | 2.05 | 1.2 | 0.02 | 33.13 | 0.35 | 99.65 |
| 5 | 191 | 9.53 | 128 | 10.53 | 259 | 11.27 | 34 | 0.87 | 32.20 | 415 | 11.71 | 864 | 17.99 | 118 | 1.93 | 1.1 | 0.017 | 31.65 | 0.87 | 99.1 |
| 6 | 183 | 9.13 | 123 | 10.12 | 250 | 10.87 | 30 | 0.77 | 30.90 | 404 | 11.4 | 844 | 17.57 | 115 | 1.89 | 1.2 | 0.019 | 30.87 | 0.05 | 99.95 |
| 7 | 334 | 16.67 | 152 | 12.51 | 498 | 21.66 | 118 | 3.02 | 53.86 | 714 | 20.14 | 1243 | 25.88 | 479 | 7.85 | 1.1 | 0.018 | 53.89 | 0 | 100 |
| 8 | 322 | 16.07 | 147 | 12.1 | 486 | 21.14 | 114 | 2.92 | 52.22 | 677 | 19.1 | 1210 | 25.19 | 475 | 7.79 | 1.3 | 0.021 | 52.1 | 0.12 | 99.9 |
| 9 | 350 | 17.47 | 190 | 15.64 | 540 | 23.49 | 123 | 3.15 | 59.74 | 763 | 21.52 | 1353 | 28.17 | 610 | 10 | 1.2 | 0.019 | 59.72 | 0.02 | 99.98 |
| 10 | 332 | 16.57 | 150 | 12.34 | 496 | 21.58 | 116 | 2.97 | 53.45 | 712 | 20.08 | 1225 | 25.50 | 478 | 7.83 | 1.2 | 0.019 | 53.44 | 0.01 | 99.99 |
| 11 | 160 | 7.98 | 92 | 7.57 | 220 | 9.57 | 24 | 0.61 | 25.74 | 340 | 9.60 | 725 | 15.09 | 63 | 1.03 | 1.3 | 0.02 | 25.74 | 0 | 100 |
| 12 | 190 | 9.48 | 127 | 10.45 | 258 | 11.22 | 33 | 0.84 | 32 | 410 | 11.57 | 855 | 17.8 | 118 | 1.93 | 1.1 | 0.018 | 31.32 | 1.07 | 98.93 |
| 13 | 170 | 8.48 | 117 | 9.63 | 450 | 19.57 | 38 | 0.97 | 38.66 | 564 | 15.91 | 993 | 20.67 | 105 | 1.72 | 1.2 | 0.019 | 38.32 | 0.44 | 99.56 |
| 14 | 227 | 11.33 | 111 | 9.13 | 342 | 14.88 | 37 | 0.95 | 36.28 | 467 | 13.17 | 880 | 18.32 | 251 | 4.11 | 1.7 | 0.027 | 35.64 | 0.9 | 99.1 |
| 15 | 296 | 14.77 | 137 | 11.27 | 459 | 19.97 | 100 | 2.56 | 48.57 | 620 | 17.49 | 1122 | 23.36 | 470 | 7.7 | 2 | 0.032 | 48.58 | 0 | 100 |
| 16 | 320 | 15.97 | 145 | 11.93 | 482 | 20.97 | 112 | 2.87 | 51.73 | 674 | 19.01 | 1200 | 24.98 | 474 | 7.77 | 1.7 | 0.027 | 51.8 | 0 | 100 |
| 17 | 325 | 16.22 | 149 | 12.26 | 488 | 21.23 | 115 | 2.94 | 52.65 | 680 | 19.18 | 1230 | 25.61 | 477 | 7.82 | 1.4 | 0.022 | 52.63 | 0.02 | 99.98 |
| 18 | 165 | 8.23 | 110 | 9.05 | 227 | 9.87 | 26 | 0.67 | 27.82 | 364 | 10.27 | 781 | 16.26 | 71 | 1.16 | 1.1 | 0.018 | 27.71 | 0.2 | 99.8 |
| 19 | 162 | 8.08 | 112 | 9.22 | 222 | 9.66 | 22 | 0.56 | 27.52 | 344 | 9.70 | 760 | 15.82 | 70 | 1.14 | 1.3 | 0.02 | 26.69 | 1.52 | 98.48 |
| 20 | 301 | 15.02 | 138 | 11.36 | 463 | 20.14 | 105 | 2.69 | 49.20 | 624 | 17.6 | 1150 | 23.94 | 472 | 7.74 | 1.4 | 0.023 | 49.3 | 0 | 100 |

## 5- Hydrochemical Classification

### 5-1 Piper's Diagram:

The Piper's diagram is a representative method to plot the proportions of cations and anions, expressed in meq/L, which used to classify and study the chemical composition of groundwater [2]. The plotted water samples for dry season divided for two groups first one 1,2,3,4,5,6,11 and 12 having water sulphate type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^{-}$ which resulting of permanent hardness while second group 7,8,9,10,14,15,16,17,18,19, and 20 having water sulphate type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^{-}$ - $SO_4^{-2}$ mixed. Only Sample No. 13 having water type NaCl , all water samples plotted in strong acids part (Figure-6). The plotted water samples for wet season divided for two groups first one 1,2,3,4,5,6,11,12,18, and 19 having water sulphate type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^{-}$ which resulting of permanent hardness while second group 7,8,9,10,14,15,16,17, and 20 having water sulphate type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^{-}$ - $SO_4^{-2}$ mixed. Only Sample No. 13 having water type NaCl , all water samples plotted in strong acids part (Figure-6)

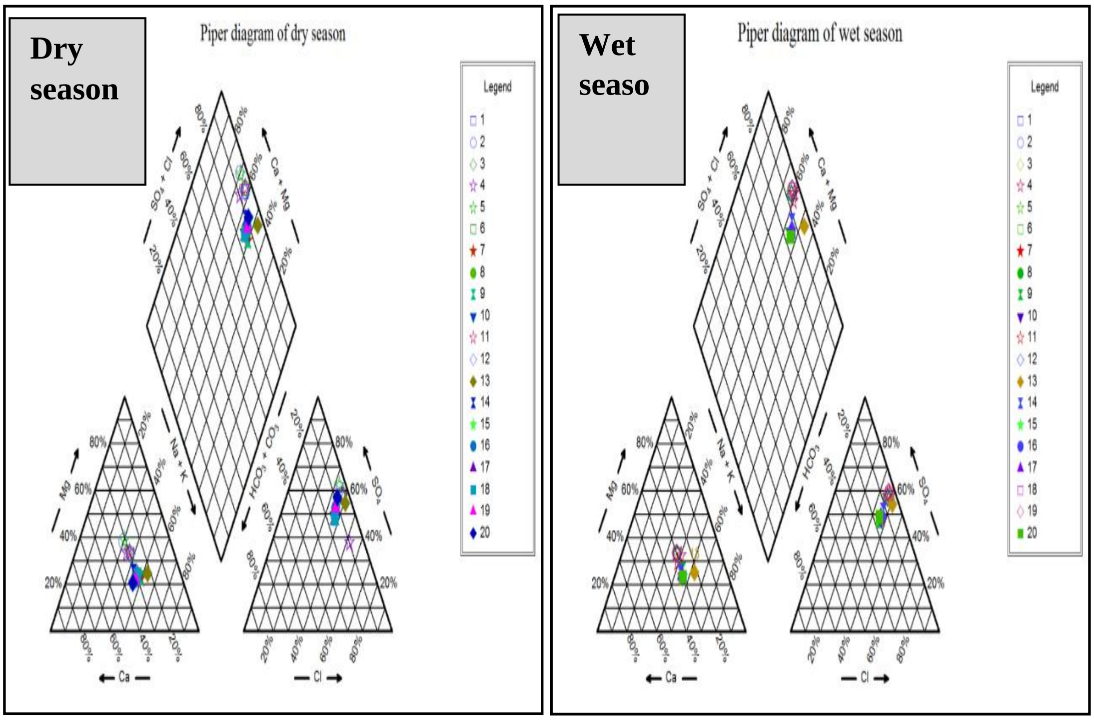

**Figure 6-**Piper's diagram of the water wells samples for the dry and wet seasons in the study area.

### 5-2 Chadha's diagram

A diagram published in 1999 which plotted the difference in milliequivalent percentage between alkaline earth (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis, and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle, depending upon the size of the scales chosen for X and Y co-ordinates. The plotted points would be in one of the four possible sub-fields of the diagram. The square or rectangular field describes the overall character of the water [12].

In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows:

1- Alkaline earth exceed alkali metals.
2- Alkali metals exceed alkaline earth.
3- Weak acidic anions exceed strong acidic anions.
4- Strong acidic anions exceed weak acidic anions.
5- Alkaline earth and weak acidic anions exceed both alkali metals and strong acidic anions, respectively.
6- Alkaline earth exceed alkali metals and strong acidic anions exceed weak acidic anions.
7- Alkali metals exceed alkaline earth and strong acidic anions exceed weak acidic anions.
8- Alkali metals exceed alkaline earth and weak acidic anions exceed strong acidic anions.

**Table 6-**Characteristics of groundwater samples in different zones derived from Chadha's diagram.

| Field | Water type and chemical facies | Characteristics |
|---|---|---|
| 5 | $Ca^{+2} – Mg^{+2} – HCO_3^-$ -type of recharge waters | water type with temporary hardness. |
| 6 | $Ca^{+2} – Mg^{+2} – Cl^-$ -type of reverse ion-exchange waters | water type with permanent hardness and does not deposit residual sodium carbonate in irrigation use. |
| 7 | $Na^+$ - $Cl^-$ -type end-product waters (seawater) | water type creates salinity problems both in irrigation and drinking uses. |
| 8 | $Na^+$ - $HCO_3^-$ -type of base ion-exchange waters | water type deposit residual sodium carbonate in irrigation use and cause foaming problems. |

The plotted water samples on Chadha's diagram of wells 1,2,3,4,5,6,11,12,14,15,16,17,18,19, and 20 for two season having water sulphate type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^{-}$ which resulting of permanent hardness which plotted in strong acids on field 6, the water sample No.13 is plotted on field 7 for two season having water $Na^{+}$ - $Cl^{-}$ -type (Figure-7), (Figure-8).

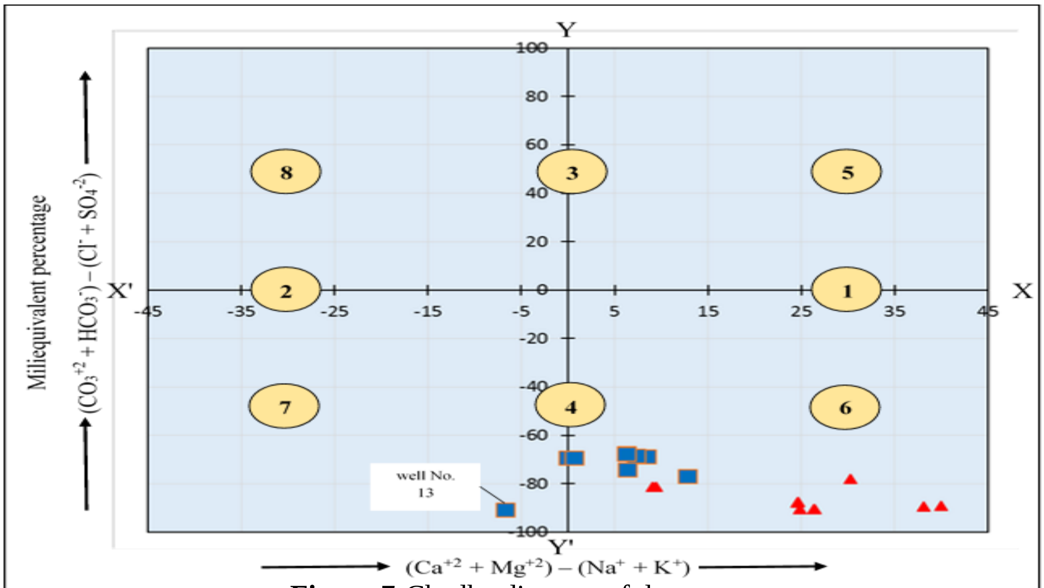

**Figure 7-**Chadha diagram of dry season

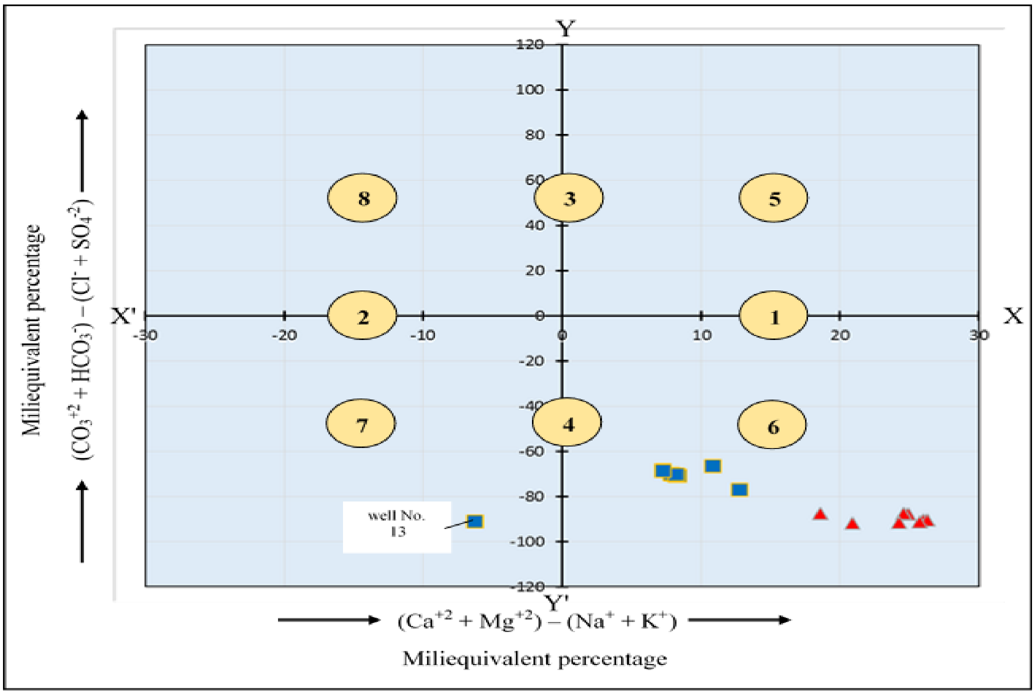

**Figure 8-** Chadha diagram of wet season

## 6- Results discussion

The water samples analysed in the study area revealed an increase in concentrations of $SO_4^{-2}$ ion range between (416 – 1180) ppm with average 848.8 ppm for the dry season and (725-1353) ppm with average 985.8 ppm for the wet season, the increasing trend from southwest to northeast. The concentrations of $Ca^{+2}$ ion range between (128-287) ppm with an average 204.5 ppm for dry season and range between (160-350) ppm with an average 236.6 ppm for wet season (Figure-9). These two ions having the major influence on increasing the Total dissolved solids (TDS) on the study area.

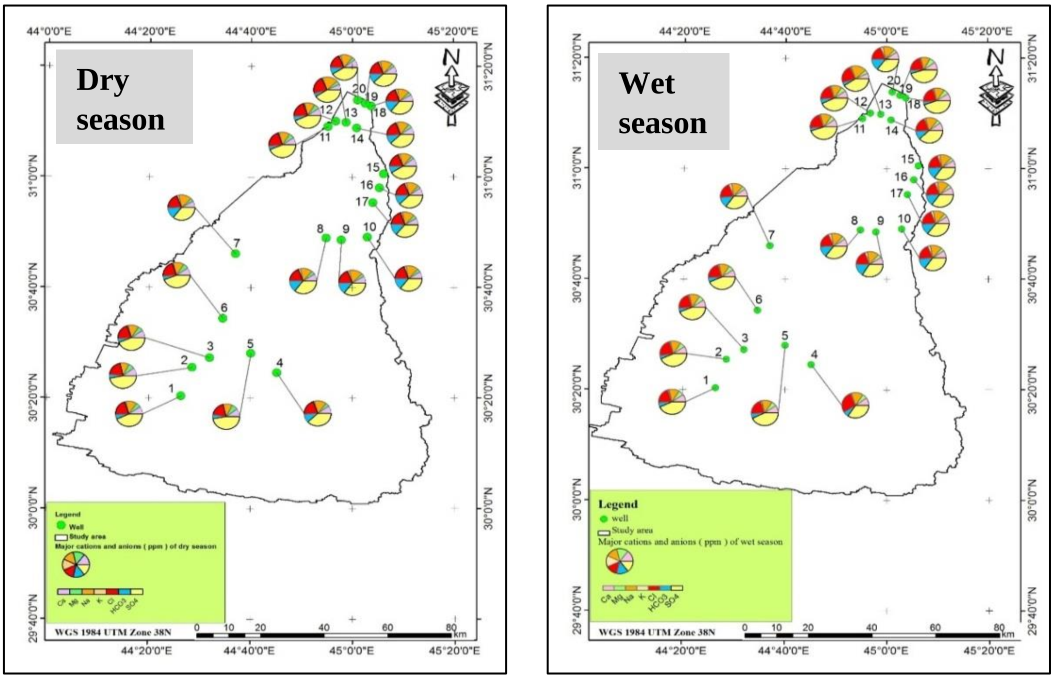

**Figure 9-**Water quality map of main cations and anions in (ppm) for study area during the dry and wet season.

There are strong relation between lithology and structure in the study area. The wells 1,2,3,4,5,6,11,12,18, and 19 with TDS less than 2000 ppm and EC (μS/cm) less than 3000 due to:

1- That all having lithology consist of middle Dammam Formation and lower Dammam Formation (Jil Fn.) which consist of mainly of carbonate rocks.

2- Structural affect (karst) to wells 1,2,3,4,5 and 6 which made precipitation concentrate in Al-Salman depressions, in the other hand wells 11,12,18 and 19 effect by streams follow faults which in the study area ended with playa (Fayda) which concentrated the precipitation, moreover the thickness of Al-Dammam Formation more than 80m and the wells 11,12,18 and 19 depth less than 80m which reduce the effect of Rus Formation which consist of gypsum on water quality.

The wells 7,8,9,10 ,14,15,16 and 17 which are fully penetration wells, have been affected by the lithology of Rus Formation which laying beneath Al-Dammam Formation causes increasing in TDS more than 2000 and EC (μS/cm) more than 3000 as a result of increase $SO_4^{+2}$ and $Ca^{+2}$. In addition, Piper's diagram and Chadha's diagram showed increasing of $Ca^{+2}$ and sulfate concentrations occur together. The inference is that gypsum (or anhydrite) is dissolved. If ions are added, the TDS would be expected to increase [13]. In addition, the TDS values have been increased during the wet season more than dry season that may due to the high rate of evaporation in the study area, according to the Iraqi Meteorological Organization (IMO, 2017) the evaporation rang between (100.8)mm during January to (765.6)mm during July these would leave considerable amount of salts on the top soil, during the wet season the precipitation wash the top soil and then percolated to groundwater as a recharge which leads to increase the TDS values. The well No.13 (80m. Depth) in Piper's diagram and Chadha's diagram showed addition concentration of $Na^+$ with water type $Na^+$ - $Cl^-$ while all samples having water type $Ca^{+2}$ – $Mg^{+2}$ – $Cl^-$ - $SO_4$ , this is due to Ghar Formation (have thickness 10m -15m) which cover the outcrop of well No.13 area, where percolated precipitation became rich with Sodium due to contact with clay within Ghar Formation (Figure-10). Sodium may be retained by adsorption on mineral surfaces, especially by clays, which have the high cation-exchange capacity. The interactions between surface sites and sodium (monovalent ion) are much weaker than the interactions with divalent ions such as calcium. Cation exchange processes, therefore, tend to extract divalent ions from the solution and to replace them with monovalent ions such as sodium [8].

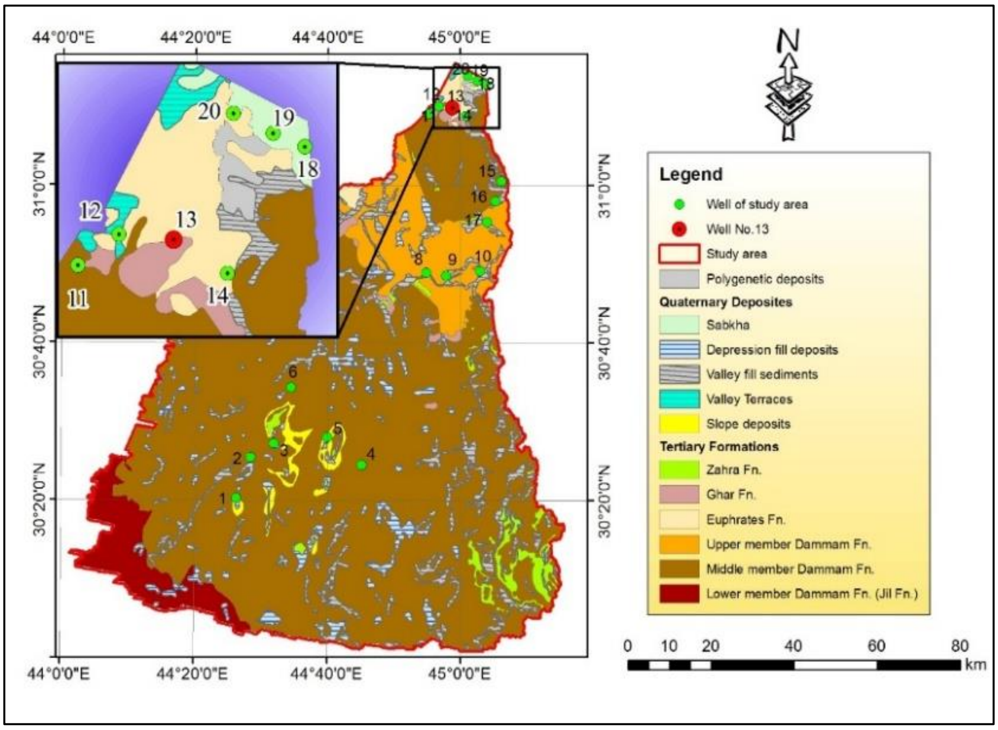

**Figure 10-**Spatial distribution of water well samples on outcrops in the study area.

**References**

1. Fetter, C.W. **2001**. *Applied hydrogeology*. 4th ed. Prentice Hall. Inc., Englewood Cliffs, New Jersey.
2. Appelo, C.A.J. and Postma, D. **2005**. *Geochemistry, groundwater and pollution*. 2$^{nd}$ ed. CRC press, Amsterdam, the Netherlands.
3. Al-Mubarak, M. and Amin, R.M. **1983**. Regional mapping of the south and Western Desert of Iraq. Internal Report. Geosurv. Library. No.1380. Baghdad, Iraq. unpublished.
4. GEOSURV, **1983**. Hydrogeological and hydrotechnical explorations in (Block 1, 2, 3) Final Report on Key well No.3 Al Salman volume No. (8-3). The State Company of Geological Survey and Mining (GEOSURV).Baghdad, Iraq.
5. GEOSURV, **1983**. Hydrogeological and hydrotechnical explorations in (Block 1, 2, 3) Final Report on Key well No.5' Salhubia volume No.(8-5'). The State Company of Geological Survey and Mining (GEOSURV). Baghdad, Iraq.
6. American Public Health Association (APHA), **1999**. Standard methods for the examination of water and waste water. 21th ed. Washington, DC, USA.
7. Freeze, R.A. and Cherry, J.A. **1979**. *Groundwater*. Prentice-Hall, Inc., Englewood Cliffs.
8. Hem, J.D. **1989**. *Study and interpretation of the chemical characteristics of natural water*. 3$^{rd}$ ed. U.S. Geological Survey Water-Supply, Paper 2254.
9. Boyd, C. E. **2000**. *Water quality an introduction*. Kluwer Academic publisher, USA.
10. Weiner, E.R. **2000**. Applications of environmental chemistry: a practical guide for environmental professionals. CRC Press LLC, N.W. Corporate Blvd., Boca Raton, Florida.
11. Davis, S. N. and Dewiest R.J.M. **1966**. Hydrogeology. John Wiley and Sons. Inc., New York.
12. Chadha, D.K. **1999**. A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. Hydrogeology Journal, **7**: 431-439.
13. Hounslow, A.W. **1995**. *Water quality data: analysis and interpretation*. CRC Press LLC, Lewis Publishers, Boca Raton, Florida, USA.