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# Hydrogeochemical Assessment of Groundwater Quality and its Suitability for Irrigation and Domestic Purposes in Rural Areas, North of Baiji City-Iraq

**Mahmood F. Abed[1]*, Ghazi A. Zarraq[1], Salwa H. Ahmed[2]**
[1]Department of Applied Geology, College of Sciences, Tikrit University, Tikrit. Iraq.
[2]Department of Environmental Engineering, College of Engineering, Tikrit University, Tikrit. Iraq.

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**Abstract**
**Background:** The present study was conducted to highlight the importance of environmental pollution and its negative impacts on aquatic, plants and animals lives, especially in industrial areas.
**Objective**: This research involved studying the hydrogeochemistry of the groundwater and assessing its quality for irrigation and domestic purposes using quality parameters. In this study, 33 groundwater samples were collected from wells during May 2013 and were analyzed for major ions and TDS.
**Results:** The hydrogeochemical facies of groundwater were identified using the Gibbs model and Chloro – alkaline indices. The results of the Gibbs graph suggest that groundwater chemistry is controlled by evaporation factors. It was found that the values of chloro – alkaline indices were positive, indicating ionic exchange between Na+ in groundwater with Ca2+ and Mg2+ in the aquifer material.
**Conclusion:** The current study of corrosivity ratio showed that groundwater wells are unsuitable for domestic uses.

**Keywords: Hydrogeochemical, Groundwater, Baiji City.**

# تقييم هيدروجيوكيميائي لنوعية المياه الجوفية ومدى ملاءمتها لأغراض الري والاستخدام المنزلي في مناطق ريفية, شمال بيجي, العراق

**محمود فاضل عبد[1], غازي عطية زراك*[2], سلوى هادي أحمد[3]**
[1] قسم علوم الارض التطبيقية, كلية العلوم, جامعة تكريت, صلاح الدين, العراق
[2] قسم هندسة البيئة, كلية الهندسة, جامعة تكريت, صلاح الدين, العراق

**الخلاصة**
تهدف الدراسة الحالية إلى إبراز أهمية التلوث البيئي وتأثيره السلبي على الاستخدامات المنزلية والحياة المائية والنباتات والحيوانات على حد سواء وخاصة في المناطق الصناعية. يشمل هذا البحث دراسة هيدروجيوكيميائية المياه الجوفية وتقييم جودتها للري وتقييمها للأغراض المنزلية باستخدام معايير الجودة ، تشير الدراسة إلى أن جميع آبار المياه الجوفية مناسبة للري. في منطقة الدراسة. تم جمع 33 عينة من المياه الجوفية من الآبار خلال شهر مايو 2013 وتم تحليلها للأيونات الرئيسية والمواد الصلبة الذائبة. تم التعرف

* Email: ghazi.zarraq@tu.edu.iq

على نوعية للمياه الجوفية الهيدروجيوكيميائية باستخدام نموذج Gibbs ومؤشرات Chloro Alkaline. تشير نتائج الرسم البياني لمؤشر Gibbs إلى أن كيمياء المياه الجوفية تتحكم فيها عوامل التبخر. وجد أن قيم مؤشرات Chloro−Alkaline كانت موجبة ، مما يشير إلى التبادل الأيوني بين Na + في المياه الجوفية مع Ca2 +و Mg2 + في مياه الخزان الجوفي. أظهرت نتائج نسبة التآكل أن آبار المياه الجوفية غير صالحة للاستعمالات المنزلية.

## 1. Introduction

Groundwater is considered as an important natural resource that helps the growth of cultivation and manufacturing in any country, besides its drinking and domestic usages [1]. Groundwater, which moves through aquifers, interacts with the aquifer material in the subsurface environment, leading to an alteration in its chemical composition due to a variety of hydro-geochemical processes. [2]. Generally, groundwater quality entirely depends on the physiochemical parameters present, which are mostly derived from geogenic and anthropogenic activities of a particular area. Geogenic factors that have to dominate over water chemistry comprise the amount and pattern of atmospheric precipitation, quality of recharge area, and subsurface geochemical processes, including rock–water interaction processes in the aquifer. Anthropogenic activities which influence the water chemistry include mining and agricultural activities, domestic and industrial waste, and dumping of solid waste. The hydrogeochemical processes and hydrogeochemistry of the groundwater differ in space and time. Therefore, it is important to investigate and perceive the different hydrogeochemical attributes of water quality parameters [3-4].

In the present study, an attempt has been made to assess the groundwater quality via determining its suitability for agricultural and domestic purposes through applying hydrogeochemical models and diagrams. Those include Gibbs's model, chloro-alkaline indices, sodium percentage (Na%), residual sodium bicarbonate (RSBC), permeability index (PI), magnesium hazard (MR), Kelly's ratio (Kr), potential salinity (PS), and corrosivity ratio (CR).

### 1.1 The study area

The study area is located around an industrial district (i.e. North Refineries Company, Detergents plant, Thermal Power Plant, and Gaseous Power Plant) to the north of Baiji city and lies in between northern 351160 to 371087 and eastern 3862912 to 3887201 in UTM units (Figure 1). Villages within the study area are Al-hinshi, Shwaish, and Albojwari villages, located to the east and northeast of North Refineries Company and the detergents plant, as well as to the south- southeast of the Thermal and Gaseous power plants. On the east bank of Tigris River, there is Al-laqlaq village. Baiji city is located in the south of an industrial district. The Al-600 housing area and Baiji-Mousel highway are located to the west of the industrial district.

### 1.2 Geology and hydrogeology of the area

The area is situated within Hemrin – Makhul Subzone or foothill zone which is distinguished by a thick cover of sediments. The older rocks exposed in the study area are Fat'ha Formation (Middle Miocene), which is distinguished by the dominating evaporates facies that consist of halite, gypsum, anhydrite, and limestone facies, which refer to the shallow marine environment [5]. The outcrops of Fat'ha formation are exposed along the Tigris River to the north of the study area. Fat'ha formation is overlaid by Injana formation (Upper Miocene) which consists of silty claystone, siltstone, and sandstone with thin layers of gypsum nodules. This formation is exposed in some places along the Tigris River and in Makhul Anticline [6]. Injana formation is covered by quaternary (Pleistocene and Holocene) deposits which are represented by river terraces, flood plain deposits, slope sediments, valley fillings, and gypseous soil. River terrace deposits consist of sandstone and sand. whereas flood plain deposits consist of gravel, sand, silt, and clay [7].

Hydrogeologically, the study area consists of two aquifers, one belongs to Injana Formation, which is characterized by deep wells and has a confined type [8], and the other belongs to Quaternary deposits which are characterized by shallow wells and of an unconfined type [9].

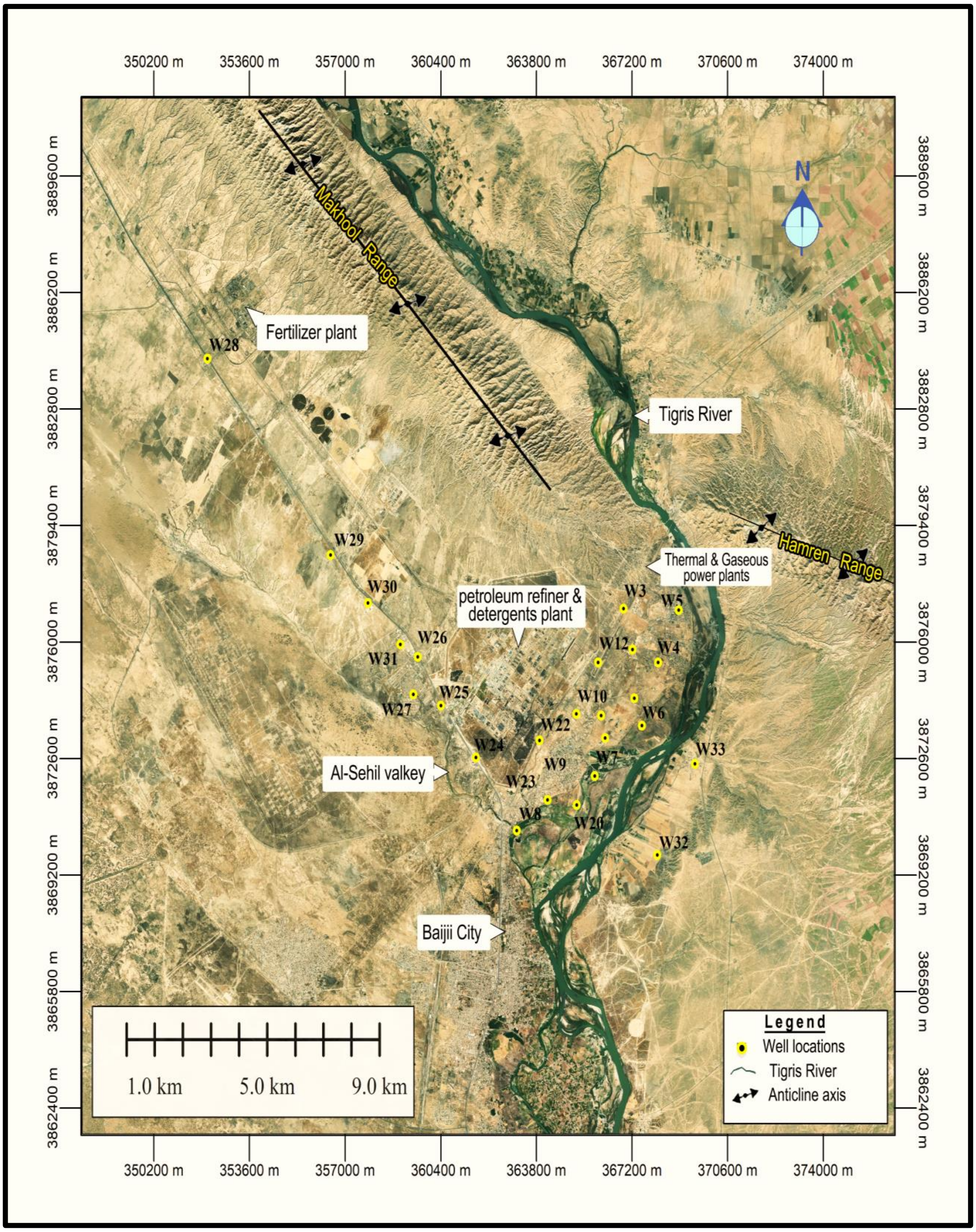


**Figure 1-** Satellite Image of Groundwater Sampling Locations

## 2. Materials and Methods

For groundwater assessment, 33 well samples were collected within the study area in May 2013, as shown in Table- 1 and Figure 1. The Groundwater samples were collected using 1.5-liter polyethylene bottles for physiochemical tests. The bottles were rinsed with water samples three times and filled to the neck. All of the collected samples were kept in a cool box in the field and then stored in a refrigerator (4 – 6 °C) before being sent to the laboratory.

**Table 1-** The ground water samples of wells

| Well No. | Location | Easting | Northing | Well No. | Location | Easting | Northing |
|---|---|---|---|---|---|---|---|
| W1 | Shwaish village | 368255 | 3874477 | W18 | Shwaish village | 367136 | 3875200 |
| W2 | Al-bojwari village | 364502 | 3870045 | W19 | Al-bojwari village | 366070 | 3873853 |
| W3 | Al-hinshi village | 366864 | 3877000 | W20 | Al-bojwari village | 365098 | 3871237 |
| W4 | Shwaish village | 368028 | 3875350 | W21 | Al-bojwari village | 364256 | 3871347 |
| W5 | Al-hinshi village | 368127 | 3876689 | W22 | Al-bojwari village | 363891 | 3873087 |
| W6 | Al-bojwari village | 367478 | 3873474 | W23 | Al-bojwari village | 362650 | 3871417 |
| W7 | Al-bojwari village | 365861 | 3872147 | W24 | Hana Khalil farm | 361547 | 3872471 |
| W8 | Al-bojwari village | 363131 | 3870461 | W25 | Campus of detergents factory | 360278 | 3874042 |
| W9 | Al-bojwari village | 365028 | 3872987 | W26 | Al-Nesrain fuel station | 359493 | 3875638 |
| W10 | Al-bojwari village | 365198 | 3873907 | W27 | Firas Almuhsin crusher factory | 359507 | 3874551 |
| W11 | Al-bojwari village | 367326 | 3874203 | W28 | Mohammed Alqadori farm | 352114 | 3884144 |
| W12 | Shwaish village | 365966 | 3875450 | W29 | Jazerat Alarab fuel station | 356547 | 3878497 |
| W13 | Al-bojwari village | 364211 | 3872439 | W30 | Al-Baraka block factory | 357736 | 3877112 |
| W14 | Al-bojwari village | 366268 | 3873069 | W31 | Al-Saafi block factory | 359055 | 3876042 |
| W15 | Shwaish village | 368830 | 3875779 | W32 | Al-Laqlaq village | 368085 | 3869665 |
| W16 | Al-hinshi village | 368759 | 3877010 | W33 | Al-Laqlaq village | 369405 | 3872354 |
| W17 | Shwaish village | 367084 | 3875740 | | | | |

Physiochemical characteristics of the water samples were analyzed in the laboratories of Tikrit University and the methods used are presented in Table-2.

**Table 2-** Techniques and Equipment Used for the Physiochemical Analysis.

| Parameter | Techniques and equipment |
|---|---|
| TDS | Gravimetric method (Standard Methods 2540 D) |
| $Ca^{2+}$ and $Mg^{2+}$ | EDTA titrimetric method |
| $Na^+$, $K^+$ | Flame photometric method |
| $HCO_3^-$ | Titration method (Standard Methods 2320 A) |
| $SO_4^{2-}$ | Turbidmetric method (Standard Methods 4500 E) |
| $Cl^-$ | Argenometric method (Standard Methods 4500) |
| $NO_3^-$ | U-V spectrophotometer with wave length 220nm |

The analytical accuracy for major ions in all water samples was computed according to [10], by the equation below:

$$U\ \% = \frac{\sum cations - \sum anions}{\sum cations + \sum anions}\ x\ 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

where U is the uncertainty. Levels of anions and cations are expressed in meq/l. All groundwater analyses were compatible with the accepted value of uncertainty, which is less than 10%.

**2.1 Hydrogeochemical facies**

In this study, two graphical diagrams were used to illustrate the development, classification, and distribution of groundwater chemical components. The first is Gibbs diagram, proposed by an earlier work [11], which is used to explain the impact of hydrogeochemical processes, such as rock-water interaction mechanism, precipitation, and evaporation, on groundwater geochemistry. The second involves the chloro – alkaline indices (CA-I and CA-II) , as shown in Table- 3, which are used to indicate the ion exchanges between groundwater and its aquifer [12].

**2.2 Hydrogeochemical indices**

To assess the suitability of groundwater quality for irrigation and domestic uses, various indices and models were applied depending on the formulas introduced by some researchers (Table- 3).

**Table 3-** Methodology for determining various indices

| Index | Mathematical formula | Researchers |
|---|---|---|
| Sodium percentage | $Na\% = \frac{Na^{+} + K^{+}}{(Ca^{+2} + Mg^{+2} + Na^{+} + K^{+})}\ X\ 100$ | [13] |
| Potential salinity | $PS = Cl^{-} + (0.5\ x\ SO_4^{-2})$ | [14] |
| Residual sodium bicarbonate | $RSBC = HCO_3^{-} - Ca^{+2}$ | [14-15] |
| Permeability Index | $PI = \frac{Na + \sqrt{HCO3}}{Ca + Mg + Na}\ X\ 100$ | [16] |
| Magnesium Hazard | $MH = \frac{Mg}{Ca + Mg}\ X\ 100$ | [17] |
| Kelly's ratio | $KR = \frac{Na}{(Ca + Mg)}$ | [18] |
| Corrosivity ratio | $CR = \frac{\left\{\left(\frac{Cl^{-}}{35.5}\right) + \left(\frac{SO_4^{-2}}{96}\right)\right\}}{\frac{2(HCO_3^{-})}{100}}$ | [19] |
| Chloro-alkaline indices | $CA - I = \frac{Cl^{-} - (Na^{+} + K^{+})}{Cl^{-}}$ <br> $CA - II = \frac{Cl^{-} - (Na^{+} + K^{+})}{SO_4^{2} + HCO_3^{-} + NO_3^{-}}$ | [20] |

Note: all ions are expressed in meq/l , except upon calculating CR where ions are in mg/l.

**3. Results and Discussion**

Several models and indices were used to illustrate the hydrogeochemical of groundwater and its suitability for irrigation and domestic uses. Concentrations of major ions are listed in Table-4.

**Table 4-** Concentration values of major ions and TDS in mg/l.

| Well No. | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{2-}$ | $HCO_3^{-}$ | $NO_3^{-}$ | TDS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 299.00 | 107.80 | 163.70 | 5.66 | 332.00 | 1020.00 | 21.80 | 12.1 | 1980 |
| 2 | 168.67 | 56.35 | 377.60 | 5.80 | 85.00 | 1267.00 | 13.70 | 10.8 | 1990 |
| 3 | 156.27 | 43.29 | 116.07 | 2.79 | 93.00 | 576.00 | 39.00 | 10.8 | 1050 |
| 4 | 270.03 | 92.97 | 368.94 | 4.47 | 270.00 | 1358.00 | 11.00 | 13.6 | 2400 |
| 5 | 378.09 | 147.48 | 197.16 | 4.80 | 75.00 | 1571.00 | 11.00 | 9.9 | 2425 |
| 6 | 394.02 | 87.51 | 117.63 | 2.16 | 63.00 | 1355.00 | 7.80 | 10.5 | 2075 |
| 7 | 241.35 | 106.05 | 357.75 | 3.18 | 438.00 | 1035.00 | 23.00 | 8.7 | 2250 |
| 8 | 375.51 | 100.29 | 181.35 | 2.79 | 192.00 | 1269.00 | 16.70 | 9.3 | 2150 |
| 9 | 266.00 | 111.77 | 374.00 | 5.21 | 198.50 | 1501.00 | 22.60 | 10.3 | 2500 |
| 10 | 311.00 | 199.00 | 299.00 | 5.61 | 511.00 | 1400.00 | 25.00 | 11.9 | 2770 |
| 11 | 245.00 | 105.00 | 331.44 | 9.33 | 350.00 | 1100.00 | 22.00 | 10.5 | 2190 |
| 12 | 278.60 | 89.35 | 205.70 | 11.00 | 160.00 | 1080.00 | 16.00 | 15.7 | 1875 |
| 13 | 208.00 | 78.64 | 356.00 | 4.35 | 145.00 | 1300.00 | 34.00 | 7.2 | 2150 |
| 14 | 411.26 | 137.60 | 381.00 | 3.44 | 206.00 | 2016.00 | 28.00 | 10.9 | 3200 |
| 15 | 199.00 | 57.25 | 157.00 | 8.00 | 99.00 | 867.00 | 9.30 | 9.35 | 1410 |
| 16 | 145.00 | 67.00 | 115.00 | 9.70 | 98.70 | 687.00 | 47.00 | 11.2 | 1188 |
| 17 | 315.33 | 145.83 | 198.40 | 7.60 | 115.00 | 1519.00 | 17.80 | 14.8 | 2330 |
| 18 | 287.00 | 177.00 | 355.00 | 4.70 | 499.80 | 1220.00 | 30.70 | 10.3 | 2600 |
| 19 | 300.00 | 160.70 | 231.30 | 6.10 | 295.00 | 1196.00 | 17.80 | 12.3 | 2230 |
| 20 | 301.45 | 94.83 | 198.00 | 8.60 | 355.70 | 900.80 | 11.00 | 11.2 | 1885 |
| 21 | 243.70 | 109.30 | 367.63 | 4.30 | 341.00 | 1124.00 | 8.10 | 17.2 | 2220 |
| 22 | 367.00 | 97.20 | 298.00 | 2.60 | 481.00 | 1050.00 | 26.60 | 10.2 | 2340 |
| 23 | 301.00 | 125.44 | 233.76 | 4.60 | 368.00 | 1113.80 | 36.40 | 9.6 | 2200 |
| 24 | 355.05 | 209.25 | 500.10 | 4.68 | 231.00 | 2313.00 | 21.00 | 11.8 | 3680 |
| 25 | 196.23 | 99.30 | 290.00 | 2.90 | 246.00 | 1112.00 | 17.60 | 9.34 | 1975 |
| 26 | 356.25 | 154.98 | 361.56 | 4.05 | 198.00 | 1941.00 | 16.60 | 10.7 | 3100 |
| 27 | 390.00 | 201.00 | 456.93 | 4.72 | 556.00 | 1562.00 | 19.50 | 10.1 | 3220 |
| 28 | 288.60 | 127.85 | 202.60 | 9.30 | 255.00 | 1131.00 | 22.10 | 19.3 | 2050 |
| 29 | 220.33 | 103.67 | 391.00 | 7.55 | 165.00 | 1450.00 | 39.00 | 8.34 | 2390 |
| 30 | 433.00 | 144.00 | 399.60 | 5.83 | 634.00 | 1450.00 | 22.00 | 10.9 | 3110 |
| 31 | 297.00 | 120.43 | 320.00 | 3.20 | 122.00 | 1565.00 | 13.80 | 10.3 | 2455 |
| 32 | 177.25 | 61.52 | 129.44 | 4.92 | 107.00 | 741.00 | 15.77 | 11.5 | 1245 |
| 33 | 323.66 | 134.65 | 178.63 | 2.88 | 173.00 | 1346.00 | 23.75 | 15.4 | 2200 |

**3.1 Hydrogeochemical facies**

**a) Gibbs plot**

The relation between the composition of water and lithological characteristics of an aquifer can be confirmed by using the Gibbs diagram [21]. Gibbs I was plotted between anions ($Cl^-$/ $Cl^-$ + $HCO_3^-$) against TDS, while Gibbs II was plotted between cations ($Na^+$ + $K^+$ / $Na^+$ + $K^+$ + $Ca^{2+}$) against TDS [22], as illustrated in Figure 2.

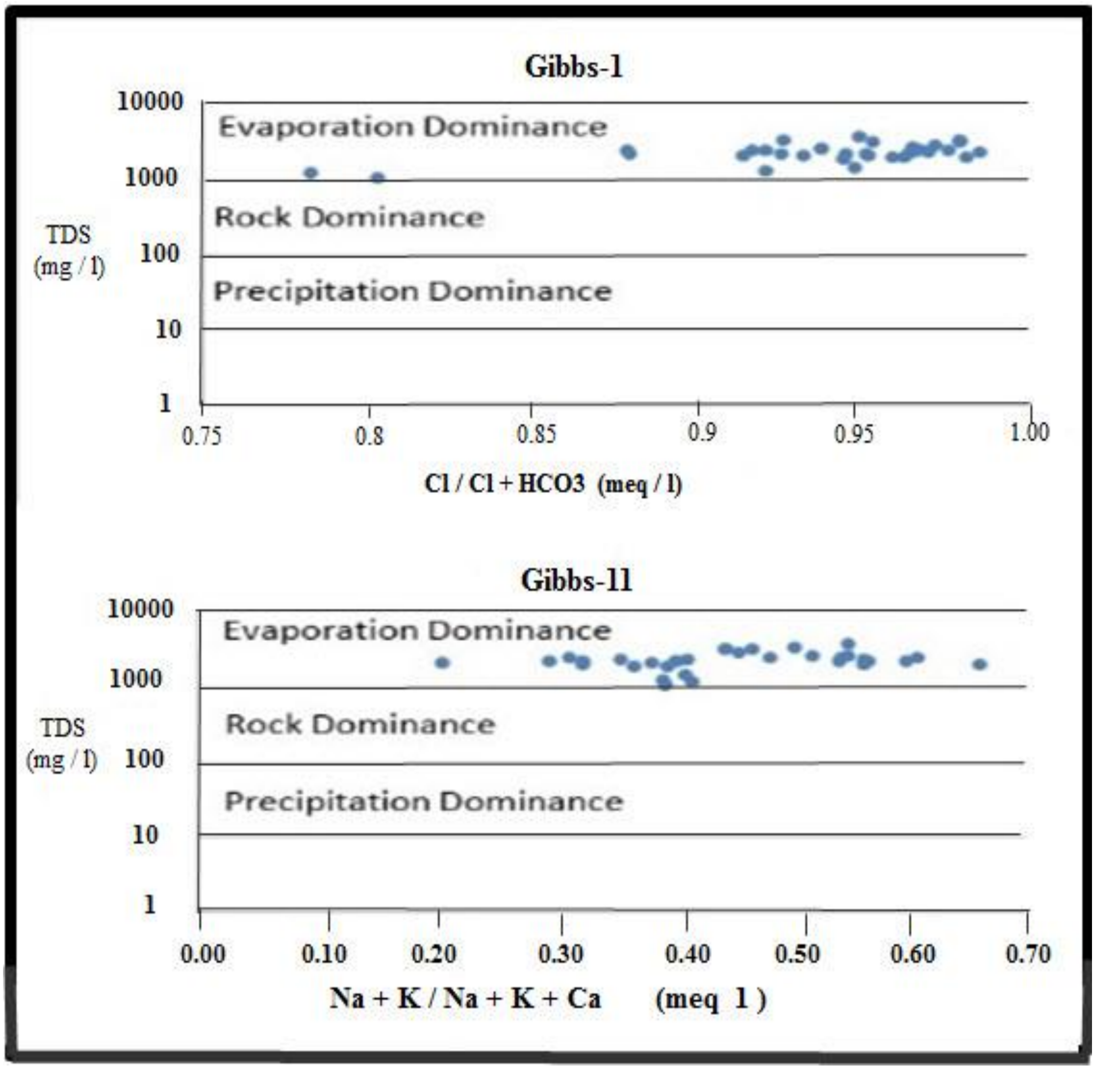


**Figure 2-** Gibbs diagrams of groundwater using anions (Gibbs I) and cations (Gibbs II)

The anion ratio varied from 0.78 to 0.99, whereas the cation ratio varied from 0.21 to 0.66 (Table- 5). The plotting of data pointed on diagrams suggests that the evaporation is the dominant factor controlling the groundwater chemistry in the study area. All samples fall in an evaporation dominance category, indicating that the aquifer of the study area is affected by evaporation, leading to salt accumulation in the soils. The main processes in the natural and gradual development of groundwater composition are the moisturing in the vadose zone and the evaporation of surface water. The remaining water is concentrated by evaporation and results in deposition of the evaporate that is finally percolated into the zone of saturation [23].

**Table 5-** Statistics of each index

| Well No. | Na% | RSBC | PI | MH | KR | PS | CR | Gibbs I | Gibbs II | CA-I | CA-II |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 23.39 | -14.56 | 24.97 | 37.29 | 0.30 | 19.98 | 11.67 | 0.96 | 0.33 | 8.59 | 9.58 |
| 2 | 55.94 | -8.19 | 57.32 | 35.53 | 1.26 | 15.59 | 4.20 | 0.91 | 0.66 | -4.51 | 2.17 |
| 3 | 31.07 | -7.16 | 35.64 | 31.36 | 0.44 | 8.62 | 4.96 | 0.80 | 0.40 | 0.67 | 3.01 |
| 4 | 43.34 | -13.29 | 44.31 | 36.22 | 0.76 | 21.75 | 9.16 | 0.98 | 0.55 | 5.49 | 7.44 |
| 5 | 21.91 | -18.69 | 22.74 | 39.15 | 0.28 | 18.47 | 3.91 | 0.92 | 0.32 | -2.00 | 2.19 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 16.14 | -19.53 | 17.12 | 26.81 | 0.19 | 15.88 | 2.88 | 0.93 | 0.21 | -1.13 | 1.89 |
| 7 | 42.96 | -11.67 | 44.52 | 42.02 | 0.75 | 23.13 | 14.82 | 0.97 | 0.56 | 11.09 | 12.15 |
| 8 | 22.77 | -18.46 | 24.11 | 30.58 | 0.29 | 18.63 | 7.62 | 0.95 | 0.30 | 3.95 | 5.54 |
| 9 | 42.19 | -12.90 | 43.56 | 40.94 | 0.72 | 21.23 | 9.13 | 0.94 | 0.55 | 2.67 | 5.61 |
| 10 | 29.19 | -15.11 | 30.39 | 51.35 | 0.41 | 28.99 | 18.04 | 0.97 | 0.46 | 13.50 | 14.57 |
| 11 | 41.26 | -11.86 | 42.56 | 41.41 | 0.69 | 21.32 | 12.38 | 0.96 | 0.55 | 8.39 | 9.76 |
| 12 | 30.27 | -13.64 | 31.32 | 34.60 | 0.42 | 15.76 | 6.31 | 0.95 | 0.40 | 2.47 | 4.62 |
| 13 | 48.07 | -9.82 | 50.20 | 38.41 | 0.92 | 17.62 | 8.69 | 0.88 | 0.60 | 0.28 | 4.19 |
| 14 | 34.35 | -20.06 | 35.63 | 35.56 | 0.52 | 26.80 | 11.68 | 0.93 | 0.45 | 2.94 | 6.05 |
| 15 | 32.45 | -9.78 | 33.62 | 32.18 | 0.47 | 11.82 | 3.63 | 0.95 | 0.41 | 0.27 | 2.71 |
| 16 | 29.17 | -6.47 | 33.12 | 43.25 | 0.39 | 9.94 | 6.14 | 0.78 | 0.42 | 0.90 | 3.37 |
| 17 | 24.14 | -15.44 | 25.21 | 43.27 | 0.31 | 19.06 | 6.06 | 0.92 | 0.36 | 0.52 | 3.50 |
| 18 | 35.01 | -13.82 | 36.43 | 50.43 | 0.53 | 26.80 | 17.98 | 0.97 | 0.52 | 12.99 | 14.16 |
| 19 | 26.60 | -14.68 | 27.71 | 46.91 | 0.36 | 20.77 | 10.53 | 0.97 | 0.41 | 7.09 | 8.40 |
| 20 | 27.88 | -14.86 | 28.73 | 34.16 | 0.38 | 19.41 | 11.05 | 0.98 | 0.37 | 9.15 | 9.92 |
| 21 | 43.22 | -12.03 | 44.03 | 42.52 | 0.76 | 21.32 | 10.55 | 0.99 | 0.57 | 7.95 | 9.34 |
| 22 | 33.12 | -17.88 | 34.68 | 30.40 | 0.49 | 24.50 | 16.46 | 0.97 | 0.42 | 12.61 | 13.57 |
| 23 | 28.87 | -14.42 | 30.81 | 40.74 | 0.40 | 21.98 | 14.59 | 0.95 | 0.41 | 9.39 | 10.69 |
| 24 | 38.50 | -17.37 | 39.41 | 49.29 | 0.62 | 30.59 | 11.57 | 0.95 | 0.55 | 3.16 | 6.60 |
| 25 | 41.39 | -9.50 | 43.01 | 45.49 | 0.70 | 18.52 | 8.97 | 0.96 | 0.56 | 5.11 | 6.83 |
| 26 | 34.14 | -17.50 | 35.12 | 41.78 | 0.52 | 25.79 | 8.93 | 0.95 | 0.47 | 2.75 | 5.64 |
| 27 | 35.71 | -19.14 | 36.58 | 45.95 | 0.55 | 31.94 | 18.83 | 0.98 | 0.51 | 14.41 | 15.55 |
| 28 | 26.64 | -14.04 | 27.91 | 42.22 | 0.35 | 18.97 | 9.79 | 0.95 | 0.39 | 5.94 | 7.48 |
| 29 | 46.83 | -10.36 | 48.74 | 43.70 | 0.87 | 19.75 | 10.54 | 0.88 | 0.61 | 0.96 | 4.86 |
| 30 | 34.38 | -21.25 | 35.37 | 35.42 | 0.52 | 32.98 | 21.18 | 0.98 | 0.45 | 16.90 | 17.84 |
| 31 | 36.15 | -14.59 | 37.24 | 40.08 | 0.56 | 19.73 | 5.69 | 0.94 | 0.49 | -0.63 | 3.40 |
| 32 | 29.27 | -8.59 | 31.42 | 36.41 | 0.40 | 10.73 | 4.23 | 0.92 | 0.39 | 1.11 | 3.09 |
| 33 | 22.36 | -15.76 | 23.98 | 40.69 | 0.29 | 18.89 | 8.20 | 0.93 | 0.33 | 3.27 | 5.24 |

**b) Chloro Alkaline Index**

We can understand the ion exchange among the groundwater and the host environment during transport through studying the chloro - alkaline indices. When there are ionic exchanges between sodium or potassium in ground waters and calcium or magnesium in the material of aquifer (weathered layer/ rock) [24], both of the indices are positive, suggesting an ionic exchange of calcium or magnesium in the weathered material with sodium in groundwater [25]. Nearly all groundwater samples had positive values (Table- 5), indicating an ion exchange of sodium in groundwater with calcium or magnesium in the aquifer material.

### 3.2 Hydrogeochemical indices

**a) Sodium percentage (Na %)**

Surplus sodium in waters results in undesirable impacts on soil structure and growth of plants. In the case of irrigation water enriched by sodium, the clay minerals in the soil absorb sodium, replacing the calcium and magnesium ions in the lattice. This replacement affects the permeability and decreases the internal drainage inside the soil. Consequently, air and water circulations become limited under wet conditions, and when dries, such soil becomes firm. Based on Na % values, the irrigation water can be classified as excellent (< 20%), good (20–40%), permissible (40–60%), doubtful (60–80%) and unsuitable (>80%) [26]. Depending on this classification, groundwater samples of the study area are classified into 3% excellent, 70% good, and 27% permissible (Table- 5).

**b) Kelly's ratio (KR)**

This factor is used to evaluate the quality and rating of water for irrigation purposes depending on the concentration of sodium versus calcium and magnesium ions. If Kelly's ratio is higher than 1, this indicates an excess amount of sodium in water, and therefore the ratio for irrigation water should not exceed 1 [27]. Only one sample (w2) exceeded such standard and thus is not safe for irrigation (Table- 5).

**c) Residual sodium bicarbonate (RSBC)**

Residual sodium bicarbonate refers to the excess concentration of bicarbonate over calcium. The irrigation water containing RSBC < 5 is safe, 5–10 is marginal, and > 10 meq/L should be considered as unsatisfactory [27-28]. According to this index, all groundwater samples are less than 5, indicating that the water is safe (Table- 5).

**d) Permeability index (PI)**

The irrigation for a long time impacts soil permeability due to the presence of $Na^+$, $Ca^{2+}$, $Mg^{2+}$, and $HCO_3^-$ ions in water. Thus, the PI values can provide an effective index which can be used to determine the suitability of groundwater for irrigation purpose. According to a previous study [29], PI can be classified into three types: type I (>75%, suitable), type II (25–75%, good), and type III (<25%, unsuitable). Water under type I and type II is suggested for irrigation. In the present study, 85% of groundwater samples are under type II (good), whereas 15 % of samples are considered under type III (unsuitable), as shown in Table- 5.

**e) Magnesium hazard (MH)**

According to agriculturists, the surplus amount of magnesium ions in water harms the soil quality, which brings about low yield production [30]. For irrigation purposes, MH > 50 is not recommended [31]. The current results show that 6 % of wells (i.e. w10 and w18) have values higher than 50 and therefore they are not recommended for irrigation. However, 94 % of groundwater samples are recommended for irrigation purposes (Table- 5).

**f) Corrosivity ratio (CR)**

The corrosivity ratio gives an information about water supply. Any source of water with corrosivity ratio <1 will be recommended to transported in any type of pipes, while CR >1 indicates a corrosive nature of water, leading to corrosive effects on metal pipes [32]. According to this ratio, all groundwater samples are not suitable for transporting in metal pipes (Table- 5).

**g) Potential salinity (PS)**

This index is intended for the categorization of water for agriculture use. If potential salinity (PS) is lower than 3 meq/l, this is an indication that the water is suitable for irrigation [33]. According to this index, all groundwater samples are unsuitable for irrigation purposes (Table- 5).

## 4. Conclusions

This study indicates that the chemical composition of groundwater is controlled by evaporation dominance, according to Gibbs diagram. CA-I and CA-II had positive values that suggest an ionic exchange of calcium or magnesium in the weathered material with sodium in groundwater. According to the data gained from the models, we conclude that the groundwater of the study area is unsuitable for irrigation uses. For domestic purposes, the CR value confirmed that groundwater wells are unsuitable to be transported through metal pipes.

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**Conflict of interest**
The authors declare there was no conflict of interest.

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