

**Hydro-chemical Study for Selected Wells in the  
Holy city of Karbala/ Central Iraq**

**Iman A. Al-Ali  
College of Science, University of Baghdad**

**Najah A. Abd  
College of Science, University of Baghdad**

**Hasan j. Alatta  
College of Science, University of Baghdad  
[iman.ali@sc.uobaghdad.edu.iq](mailto:iman.ali@sc.uobaghdad.edu.iq)**



## Abstract

Twenty-four groundwater samples were collected at different depths within the Dammam aquifer and Quaternary deposits. A detailed hydro-chemical study of water samples was conducted, including physical properties; Hydrogen number (pH), total dissolved solids (TDS), and electrical conductivity (EC), while the chemical analysis included the major anions;  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ , and major cations;  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , and  $\text{K}^+$ , in addition to the minor element ( $\text{NO}_3^-$ ). The results indicate a neutral to slightly alkaline water with pH of 7.17 which characterized by hard water that is neutral- slightly alkaline water. The TDS exceeds the permissible limits for drinking, with an average of 2787 ppm, which represents slightly brackish water. Conductivity EC indicates heavily mineralized water with EC of 4310.8  $\mu\text{S}/\text{cm}$ . The predominant cation was  $\text{Mg}^{2+}$ , and  $\text{Na}^+$ , while the predominant anions were  $\text{SO}_4^{2-}$ , and  $\text{Cl}^-$ . The prevalent cation in the aquifer  $\text{Na}^+$  of 49%, followed by  $\text{Ca}^{2+}$  of 30%,  $\text{Mg}^{2+}$  of 17%, and  $\text{K}^+$  of 4%, while the prevalent anion was  $\text{SO}_4^{2-}$  of 48%,  $\text{Cl}^-$  of 31%, and  $\text{HCO}_3^-$  of 21%. Groundwater is classified as unsuitable for drinking, while it is suitable for irrigation. The water type is  $\text{Na-SO}_4$  affected by the interaction between aquifer material (Halite, dolomite, and calcite), and the groundwater in contact.

**Keywords:** Holy city of Karbala, Hydro-chemical analysis, Water- rock interaction, water type, water suitability

## Introduction:

The Holy city of Karbala is a major religious and commercial center characterized by high population density, where visitors from all over the world flock to it, making use of its facilities and putting pressure on its surface and groundwater. Groundwater is the best alternative source of water due to the rareness of surface water which is affected by many natural and anthropogenic factors. Water resources deterioration, by the effect of any pollution, causes risks to the environment, human health, and damage to natural resources (Al-Mayyahi and Al-Ali, 2024). Also, the interaction between groundwater and ambient aquifer in contact is a major issue (Al-Dabbas, 2017).

Like other arid and semi-arid countries, Iraq has suffered from climate change and political factors related to the policies of neighboring countries, a severe water crisis that affected its quantity and quality, so groundwater was the safest solution to meet the requirements of life. The issue of water pollution, especially in areas that witness long periods of drought and high population density, receives great international attention because of its direct impact on the population, especially those that have a religious status and sacred rituals, such as Karbala Governorate, which receives millions of visitors to visit its two major shrines. The two holy sites put pressure on water resources, which may cause many health and environmental problems if controls are not put in place according to serious studies through which groundwater is evaluated for its suitability for various purposes, and the effect of rock-water interaction on water quality. In terms of climate conditions, the region suffers from aridness with hot dry summers and cold dry winters, while the mean annual rainfall does not exceed 85-90 mm between the months of January and April. The mean annual temperature is 24.1 oC, with evaporation of 2984 mm, relative humidity of 47.9%, the speed of wind

is 3.0 m/sec. The percentage of water surplus was 27.7 mm, and water deficit of 69.13 for the period 1980-2015. The climate classification of the Karbala area is continental and a dry climate, as well as the region having a significant water deficit of up to 93 % of the total rainfall values, with high rates of evaporation of 2993 mm yearly (Kadum and Al-Ali, 2022). The study area is restricted between latitudes 32° 20' -32° 40' North and longitudes 43°19' - 43° 50' East (Fig. 1).

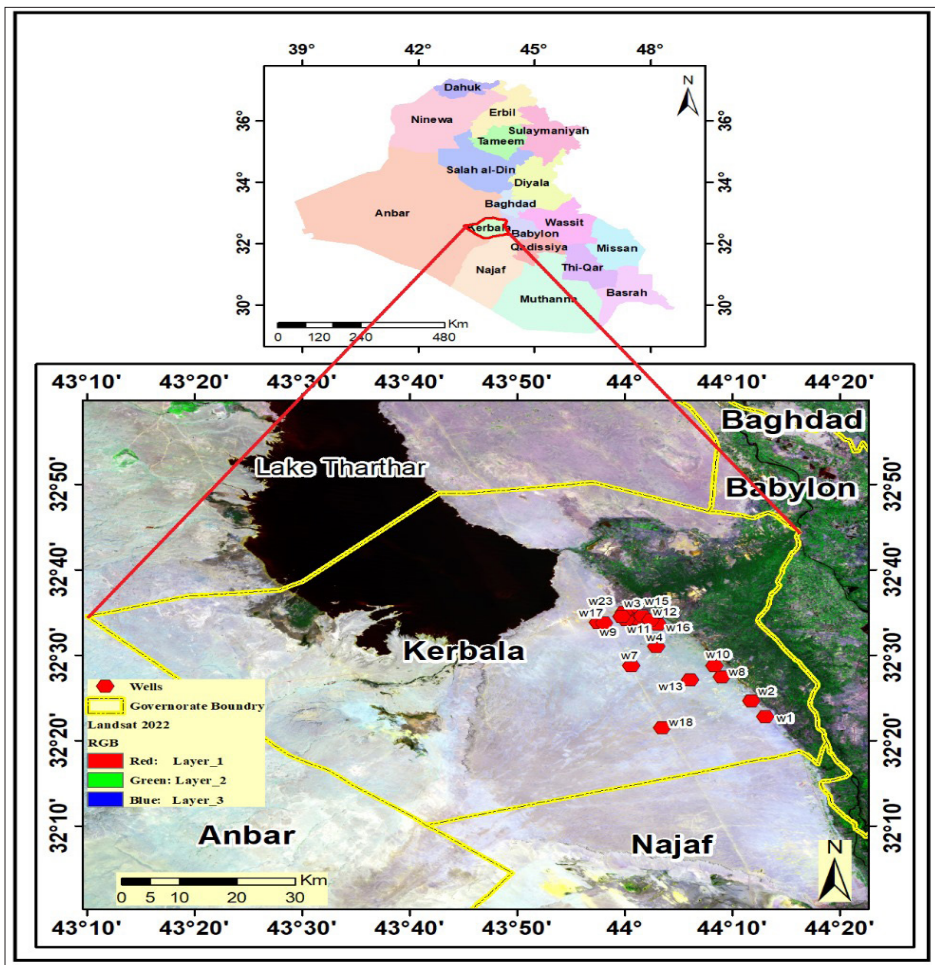


Fig.1: Karbala Governorate with groundwater sampling sites

Geologically, the quaternary sediment prevails in different areas in addition to the ambience of groundwater as transboundary aquifers, which clearly affected the quality of water by rock- water interactions, such as Al-Dammam, Euphrates, and Injana formations (Al- Mubarak and Amin, 1983, Sissakian, et al. 2000), (Figure 1).

The water resources in Karbala Governorate urgently need to be evaluated via water quality assessment due to the pollution factors they are exposed to, in addition to over- drafting as a result of the lack of drainage coming into Iraq and consequently salinization of both water and soil. In this field, many studies have tried to cover the hydrology and the geology of the city of Karbala, with a few of them covering the details of groundwater and its relationship with the aquifers and the reservoirs containing it, as it directly impacts the water quality and suitability for different uses (Al-Kubaisi, 2020, Noori, et al, 2017). Tectonically, the study area occurs within the stable shelf (Rutba-Jezira Zone), that with a large basement and no anticlines (Jassim and Buday, 2006). The geological formations arranged are as follows; Injana Formation (Upper Miocene), Fatha Formation (Middle Miocene), and Quaternary deposits which include; Pleistocene and Holocene sediments (Dawood, 2000). Evaluating the groundwater quality ensures the best investment in it, and prepares a hydro-geochemical study and optimal management of groundwater.

## Materials and Methods

Twenty-four groundwater samples were collected from different depths in April 2022 (Table 1). The collecting samples has been done by a team of specialized and professional hydrologists in clean bottles, that were washed with the water sample and filled to the neck. Stickers were also placed on which the sample number, its location, and well

depth were written. The analyses were carried out in the laboratories of the General Commission of Groundwater (GCGW). The water samples were tested for accuracy (A%), and relative difference (R. D%), as the following (Hem, 1985):

$$R.D \% = ....(Equ. 1)$$

$$A\% = 100 - R. D.....(Equ. 2), \text{ Where:}$$

R.D: Relative differences, A: Accuracy

If  $R.D \leq 5$ :the result could be accepted.

If  $5 < R.D \leq 10$ :the result will be accepted with risk.

$R.D > 10\%$ : the result is uncertain, and cannot be depended on in the interpretations. All the water samples were accepted, with A% of 99.2- 97.8%. Eleven parameters of water quality were analyzed, includes; TDS, pH, EC, Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>++</sup>, SO<sub>4</sub><sup>--</sup>, Mg<sup>++</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup> and minor element(NO<sub>3</sub><sup>-</sup>), APHA, (2005). The location coordinate and water samples were listed in (Table 1).

**Table 1: Water quality parameters  
(physical and chemical) of Karbala wells in (ppm) units**

|                    |            |
|--------------------|------------|
| TDS ppm            | 3125       |
| EC µs/cm           | 4890       |
| NO <sub>3</sub>    | 0.6        |
| HCO <sub>3</sub> - | 596        |
| SO <sub>4</sub> -2 | 938        |
| Cl-                | 536        |
| K+                 | 90         |
| Na+                | 606        |
| Ca+2               | 175        |
| Mg+2               | 155        |
| pH                 | 7.25       |
| depth              | 48         |
| Longitude East     | 32 33 45.5 |
| Latitude North     | 43 58 3.4  |
| Sample No.         | W.1        |

|            |            |            |            |            |            |            |            |
|------------|------------|------------|------------|------------|------------|------------|------------|
| 2523       | 4270       | 2427       | 4270       | 1690       | 2100       | 2518       | 2720       |
| 3920       | 6530       | 3750       | 6540       | 2640       | 3250       | 3900       | 4200       |
| 1.2        | 1.4        | 1.2        | 1.3        | 1.3        | 0.3        | 1.1        | 1.2        |
| 435        | 523        | 102        | 517        | 180        | 371        | 338        | 497        |
| 736        | 1585       | 982        | 1584       | 598        | 678        | 797        | 660        |
| 571        | 791        | 568        | 788        | 323        | 392        | 559        | 624        |
| 16         | 128        | 35         | 128        | 5          | 12         | 3          | 29         |
| 403        | 475        | 423        | 485        | 267        | 352        | 407        | 418        |
| 251        | 409        | 177        | 415        | 204        | 181        | 253        | 308        |
| 94         | 263        | 110        | 265        | 89         | 92         | 135        | 149        |
| 7.15       | 7.12       | 7.12       | 7.18       | 7.15       | 7.14       | 7.17       | 7.2        |
| 24         | 22         | 24         | 18         | 44         | 65         | 42         | 24         |
| 32 34 30.1 | 32 35 00.4 | 32 34 07.0 | 32 34 36.4 | 32 34 11.4 | 32 21 29.9 | 32 33 48.6 | 32 33 35.0 |
| 43 59 43.5 | 43 59 54.6 | 44 02 25.8 | 44 01 48.9 | 44 00 09.0 | 44 03 28.8 | 43 57 33.5 | 44 03 05.0 |
| W.2        | w.3        | w.4        | w.5        | w.6        | w.7        | W.8        | W.9        |



|            |            |            |            |            |            |            |            |
|------------|------------|------------|------------|------------|------------|------------|------------|
| 1978       | 1932       | 2194       | 2293       | 2076       | 2650       | 3970       | 2644       |
| 3060       | 3000       | 3400       | 3550       | 3210       | 4100       | 6130       | 4090       |
| 1.1        | 0.8        | 1.8        | 2          | 0.3        | 1.2        | 1.1        | 1.2        |
| 210        | 204        | 460        | 221        | 367        | 486        | 611        | 129        |
| 555        | 547        | 714        | 811        | 672        | 649        | 1231       | 1026       |
| 597        | 590        | 346        | 560        | 388        | 613        | 738        | 595        |
| 13         | 12         | 7          | 10         | 12         | 29         | 62         | 35         |
| 266        | 261        | 344        | 232        | 348        | 407        | 659        | 485        |
| 191        | 186        | 200        | 274        | 177        | 297        | 361        | 205        |
| 123        | 118        | 97         | 161        | 88         | 138        | 256        | 140        |
| 7.14       | 7.2        | 7.24       | 7.18       | 7.16       | 7.2        | 7.16       | 7.2        |
| 28         | 29         | 42         | 24         | 18         | 42         | 22         | 38         |
| 32 34 35.1 | 32 34 13.2 | 32 27 05.4 | 32 34 07.0 | 32 34 13.4 | 32 28 44.3 | 32 33 48.6 | 32 27 27.7 |
| 44 01 39.0 | 44 01 16.8 | 44 06 05.3 | 44 02 25.8 | 44 01 01.2 | 44 08 21.1 | 43 57 33.5 | 44 09 01.6 |
| w.10       | w.11       | w.12       | w.13       | w.14       | W.15       | W.16       | w.17       |

|            |            |            |            |            |            |            |      |
|------------|------------|------------|------------|------------|------------|------------|------|
| 3665       | 1895       | 2102       | 3968       | 4160       | 2830       | 3986       | 1690 |
| 5680       | 2930       | 3250       | 6120       | 6430       | 4380       | 6180       | 2640 |
| 1.4        | 1.1        | 0.4        | 1.2        | 2          | 1.3        | 0.6        | 0.3  |
| 517        | 199        | 370        | 610        | 638        | 508        | 526        | 102  |
| 1246       | 548        | 675        | 1230       | 1271       | 818        | 1449       | 547  |
| 720        | 583        | 393        | 737        | 777        | 635        | 708        | 323  |
| 11         | 10         | 12         | 63         | 62         | 18         | 93         | 3    |
| 610        | 253        | 353        | 658        | 668        | 428        | 601        | 232  |
| 347        | 169        | 182        | 360        | 400        | 280        | 372        | 169  |
| 181        | 110        | 93         | 256        | 295        | 112        | 202        | 88   |
| 7.25       | 7.22       | 7.19       | 7.12       | 7.19       | 7.2        | 7.17       | 7.12 |
| 70         | 18         | 18         | 22         | 18         | 36         | 26         | Min. |
| 32 28 46.1 | 32 34 47.4 | 32 34 41.8 | 32 31 01.2 | 32 34 44.8 | 32 24 38   | 32 22 45.9 |      |
| 44 00 39.1 | 44 00 42.1 | 44 00 26.5 | 44 02 57.9 | 44 00 46.0 | 44 11 47.1 | 44 13 07.6 |      |
| w.18       | w.19       | w.20       | w.21       | w.22       | w.23       | w.24       |      |

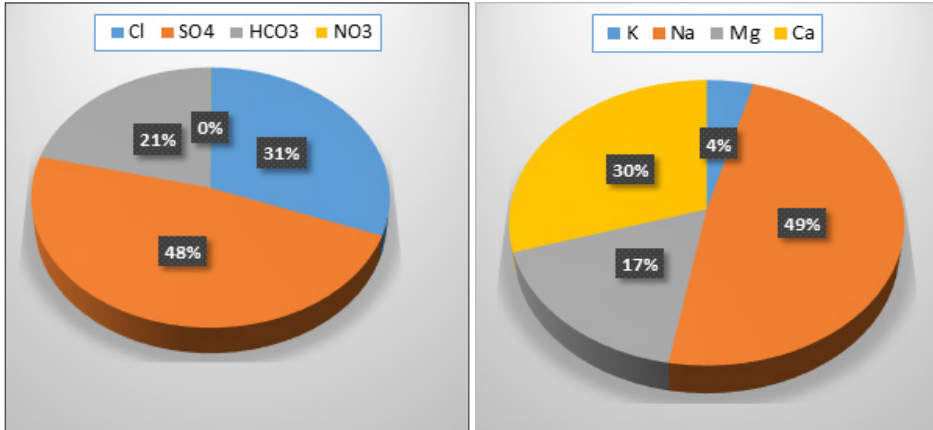
|      |         |
|------|---------|
| 4270 | 2787    |
| 6540 | 4310    |
| 2    | 1       |
| 638  | 388     |
| 1585 | 902     |
| 791  | 578     |
| 128  | 36      |
| 668  | 425     |
| 415  | 261     |
| 295  | 152     |
| 7.25 | 7.17    |
| Max. | Average |

## Results and Discussion

### 3.1. Physical and Chemical Analysis

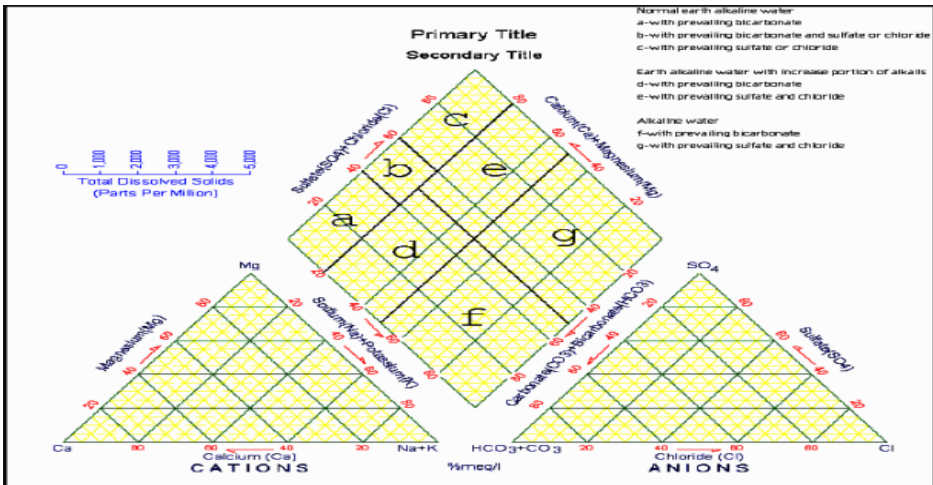
The standard value of pH recommended by WHO (2007) IQS (2009) ranges between 6.5 and 8.5, while the value of pH in Karbala wells range between 7.12 and 7.25, with a mean value of 7.17, and was classified as neutral with low alkaline. The salinity (TDS) varied highly in groundwater samples, as it ranged between 1690-4270 ppm, with a mean value of 2787 ppm, which was classified as slight water to slightly brackish water according to Drever (1997), Atlovski, (1962), and Todd (2007) (Table 1). The high salinity values of TDS were obviously in wells of low depths (w.3, w.5, W16, w21, w22, and w24), which reflect the leaching of salts and the infiltration via the soil structure to the groundwater, which reinforces the idea of water-rock interaction. The electrical conductivity (EC) ranged between 2640 and 6540  $\mu\text{s}/\text{cm}$ , with a mean value of 4310  $\mu\text{s}/\text{cm}$  (Table 1), which classified as slightly mineralized water to moderately mineralized water (Detay, 1997). The concentration of major ions indicated that  $\text{Na}^+$  is the prevalent cation in the aquifer, with a percentage of 49%, followed by  $\text{Ca}^{+2}$  with a percentage of 30%, while  $\text{Mg}^{+2}$  occupies 17%, and  $\text{K}^+$  percentage 4%, while the prevalent anion was  $\text{SO}_4^{-2}$  with a percentage of 48%, followed by  $\text{Cl}^-$  with a percentage of 31%, and  $\text{HCO}_3^-$  with a percentage of 21%. The concentration of  $\text{NO}_3^-$  in the groundwater sample ranges between

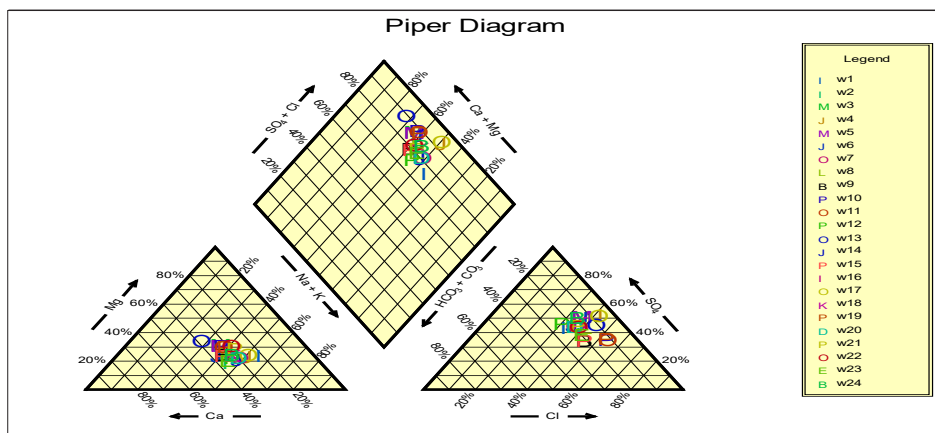
0.3 and 2 ppm, indicating high agricultural activities in the study area (Fig. 2).



**Fig. 2: Percentage of major ions, a: Cations, b: Anions**

Applying Piper Diagram for determining the water quality of Al-Dammam aquifer, indicated all the water samples lied within 'e' field which indicated water type of " Normal earth alkaline water with prevailing sulfate and chloride " (Fig. 3).





**Figure 3. Piper diagram (1944),**

**show the groundwater type of Karbala City**

Al-Dammam aquifer in Karbala Governorate is characterized by water type as Na-SO<sub>4</sub> which is represented in Korlof classification as the following:

TDS (2787) SO<sub>4</sub>-2 (18.78) Cl- (16.52) PH (7.17)

Na+ (25.13) Ca+2 (13.08)

### 3.2 Water- Rock Interaction

The interaction between groundwater and the ambient aquifer rocks were determined by applying the hydro-chemical functions; the value of  $rCa^{2+}/rMg^{2+}$  is of 1.08, as the ratio  $> 1$  reflects a calcite rocks contribution (Awadh et al, 2016). This means that the origin of Al- Dammam groundwater is between rain-water, and sea-water, and reflects the interaction between rocks (Halite, Calcite and Dolomite) and the water. According to the pH value, the median is of acidic rainwater.

According to (Maya and Lockus, 1995), if ratio of  $rCa^{2+}/rMg^{2+}$  is equal to 1, it reflects the dissolution of dolomite and limestone rocks in water. Since the groundwater samples of Karbala was located between 0.68 to less than 1.61, it indicates the contribution of calcite rocks to groundwater of Al-Dammam aquifer are greater than the dolomite.

The hydro-chemical function of  $rCa^{2+}/rMg^{2+}$  indicates the calcareous nature of the aquifer rocks, while the increase in the TDS concentration and  $Ca^{2+}$ , and  $Mg^{2+}$  indicate the chemical weathering of the dolomite, gypsum, and calcite rocks of Al-Dammam aquifer.

The second hydro-chemical ration is  $rNa/rCl$  and is used to determine the groundwater origin of the water, if it is meteoric ( $rNa/rCl > 1$ ) or marine ( $rNa/rCl < 1$ ). As a result, the groundwater of Al-Dammam aquifer in Karbala city is of meteoric origin for all water samples (Table 2) (Hounslow, 1995)

The hydro-chemical function of  $rNa/r (Na + Cl)$ , ranges between 0.38- 2.31, which indicates the distribution of halite rocks in the area, in addition to the occurrence of another source of excessive sodium amounts into the groundwater.

The ratio of  $rCa/r (Ca + SO_4)$  were less than 0.5, which indicates ion exchange of dolomite and calcite deposit occurred. In the studied area, the ratio is exceeding 0.5 in all the wells which reflects the dissolution of gypsum rocks and contribution of Al-Nfayil formation in to the groundwater system as recharged water during rainfall in addition to the excessive amounts comes of

leaching the agriculture lands.

The values represented by the ratio of  $rMg/r(Ca+SO_4)$  were more than 0.5 in all of the wells, reflecting the contribution of dolomite rocks more than calcite in the Al-Dammam aquifer (Table 2).

**Table 2. Hydro-chemical function of water samples (epm)**

| Well NO. | $rNa/rNa+Cl$ | $rCa^{2+}/rMg^{2+}$ | $rNa/rCl$ | $rCa/rCa+SO_4$ | $rMg/rCa+SO_4$ |
|----------|--------------|---------------------|-----------|----------------|----------------|
| W1       | 0.63         | 0.68                | 1.74      | 0.3            | 0.69           |
| W2       | 1.08         | 1.61                | 1.08      | 0.44           | 0.55           |
| W3       | 0.92         | 0.94                | 1.21      | 0.38           | 0.61           |
| W4       | 0.53         | 0.97                | 1.14      | 0.3            | 0.69           |
| W5       | 2.31         | 0.94                | 0.95      | 0.38           | 0.61           |
| W6       | 0.56         | 1.38                | 1.3       | 0.44           | 0.55           |
| W7       | 0.58         | 1.19                | 1.38      | 0.39           | 0.6            |
| W8       | 0.52         | 1.13                | 1.12      | 0.43           | 0.56           |
| W9       | 0.5          | 1.25                | 1.03      | 0.52           | 0.51           |
| W10      | 0.4          | 0.94                | 0.93      | 0.45           | 0.54           |
| W11      | 0.41         | 0.95                | 0.98      | 0.44           | 0.55           |
| W12      | 0.45         | 1.25                | 1.53      | 0.4            | 0.59           |
| W13      | 0.38         | 1.03                | 0.65      | 0.44           | 0.55           |

|      |      |      |      |      |      |
|------|------|------|------|------|------|
| W14  | 0.58 | 1.21 | 1.38 | 0.38 | 0.61 |
| W15  | 0.5  | 1.3  | 1.02 | 0.52 | 0.47 |
| W16  | 0.57 | 0.85 | 1.37 | 0.41 | 0.58 |
| W17  | 0.55 | 0.88 | 1.25 | 0.32 | 0.67 |
| W18  | 0.56 | 1.16 | 1.3  | 0.4  | 0.59 |
| W19  | 0.4  | 0.93 | 0.96 | 0.42 | 0.57 |
| W20  | 0.58 | 1.18 | 1.38 | 0.39 | 0.6  |
| W21  | 0.57 | 0.85 | 1.38 | 0.41 | 0.58 |
| W22  | 0.57 | 0.82 | 1.32 | 0.42 | 0.57 |
| W23  | 0.58 | 1.51 | 1.03 | 0.45 | 0.54 |
| W24  | 0.56 | 1.11 | 1.3  | 0.38 | 0.61 |
| Min. | 0.38 | 0.68 | 0.63 | 0.3  | 0.51 |
| Max  | 2.31 | 1.61 | 1.74 | 0.52 | 0.69 |
| Ave. | 0.62 | 1.07 | 1.16 | 0.40 | 0.57 |

## Suitability for Irrigation

According to the previous results, and the analyses of TDS in groundwater samples, for the Holy city of Karbala, it was concluded that it is not suitable for drinking, and it is recommended to treat and sterilize it before use.

Therefore, it was necessary to test the suitability of groundwater



for agriculture as it has an important role in the study area. The Sodium Absorption Ratio (SAR), is one of the important tests that express the risk of  $\text{Na}^+$  absorbed from the soil, increasing its percentage harms the soil structure and decreases the porosity of the soil, (Ayres and Westcot, 1989). It is calculated as in the following equation (Todd, 2007):

$$\text{SAR} = \frac{\text{rNa}}{\text{rCa} + \text{rMg}}$$

### **All the concentration was in meq/l**

Wilcox (1948), developed a classification of the suitability of water for irrigation, which included four groups according to the value of SAR, and ranked them from least dangerous to the most as the following; S1, S2, S3, and S4. Based on this, the wells of Karbala were classified as S1 as the least dangerous, with an SAR value of 3.25. Therefore, it can be valid for irrigating the sodium- sensitive crops.

## **5. Conclusion**

The groundwater of Karbala Governorate occurs mainly within Al-Dammam aquifer; shallow wells were within the quaternary deposits which record a high salinity concentration. The origin of the groundwater is mainly of meteoric water origin, with a neutral pH, the EC values indicate Karbala groundwater is excessively mineralized and slightly brackish water. Chemical weathering is the prevalent processing affecting on water quality and ions concentration of water, the ion exchange occurs between clay minerals and groundwater.

The common water type is  $\text{Na-SO}_4$ , indicating the dissolution of gypsum, calcite, and halite rocks. Groundwater can be described as earth-alkaline water with prevailing sulfate and chloride. Al-Dammam Aquifer rocks were interacting with the groundwater, and contribute with halite, calcite and dolomite rocks to provide the sodium, calcium, and

magnesium ions, while the source of sulfate is the dissolution of gypsum rocks. Groundwater samples were not suitable for drinking, while they are good for irrigating sensitive crops as the sodium absorption ratio (SAR) did not exceed 10 according to the classification of Wilcox (1948).

## References

1. Al-Dabbas M (2017). Interaction of Rahaliya–Ekhedhur groundwater with the aquifer rock, West Razzaza Lake, Central Iraq. Appl Water Sci 7:3181–3190, DOI 10.1007/s13201-016-0464-16, p 3181-3190.
2. Al-Kubaisi, M. H., (2020). Hydrochemical Facies Description to Assess the Water Quality of Habbaniya Lake, Iraq. Iraqi Geological Journal, Vol. 53, No. 2F, 2020: 94-107.
3. Al-Mayyahi S.O., Al-Ali I.A.,(2024). Assessment of Some Trace Elements in Surface Water and Soil near Al-Ahdab Oil Field, Wasit Governorate, Iraq. IOP Conf. Series: Earth and Environmental Science. doi:10.1088/1755-1315/1300/1/012024.
4. Al-Mubarak, M.A. & Amin, R.M., (1983): Report on the Regional Geological Mapping of the eastern part of the western Desert and western part of the southern Desert, unpublished report geosurv Library No.1 1380, Baghdad – Iraq, (unpublished), 636 p.
5. Altovisiki, M. E., (1962): Hand book of hydrogeology. Geogoe-litzet, Moscow, USSR (In Russian), 614p.
6. APHA, (1999): Standard methods for examination of water and waste water. American Public Health Association. ASTM, 1989: Annual Book of ASTM standards (American Society for Testing materials). Philadelphia, U.S.A. PP. 1110.

7. Awadh SM, Abdulhussein FM, Al-Kilabi JA (2016) Hydrogeochemical processes and water-rock interaction of groundwater in AlDammam aquifer at Bahr Al-Najaf, Central Iraq. Iraqi Bull Geol Mining 12(1):1–15
8. Ayres, R. S. and Westcot, D. W., (1989): Water Quality for Agriculture, Irrigation and Drainage, Paper No. 29, Rev.1, FAO, Roma, Italy, 174pp.
9. Detay M., (1997): Water Wells- implementation, maintenance and restoration, John Wiley and Sons, London, P. 379.
10. Hounslow AW (1995) Water quality data analysis and interpretation. Lewis, New York, pp 45–128
11. Hounslow, A. W. (1995). Water quality data analysis and interpretation. Lewis, New York, pp 45– 128
12. Jassim S Z and Goff G C (2006). Geology of Iraq. Dloin, Prague and Moravian Museum, Brno. Czech Republic, 341p.
13. Jassim, S. Z. and Buday, T., (2006). Tectonic framework, Pub., Dolin, First edition, Ch.4.
14. Kadum W.H., Al-Ali I. A., (2022). Climate parameters analysis as an indication of climate Changes for Diwaniya, Nasiriya, Kut and Karbala meteorological stations - Central and southern Iraq: Karbala climate condition as a case study. Iraqi Journal of Science, 2022, Vol. 63, No. 12, pp: 5295-5308.
15. Maya AL, Loucks MD (1995) Solute and isotopic geochemistry and groundwater flow in the Central Wasatch Range, Utah, USA. J Hydrol 172:31–59
16. Noori, M., Abdulrazzaq K., Mohammed A., and Abbas A. (2017).

International Journal of Science and Nature 8, 741- 756

17. Piper, A. M. (1944). A graphic procedure in the geochemical interpretation of water analyses, Transition, American Geophysical Union. Vol. 25, 914-928p.

18. Sissakian, V.K. (2000). Geological Map of Iraq, scale 1: 1000 000, 3rd edit. GEOSURV. Baghdad, Iraq.

19. Todd, D. K., (2007): Groundwater hydrology third edition, Jhon Wiley and Sons, Third Reprint. Inc. India. 535p.

20. Wilcox, L.V., (1948). Classification and Use of Irrigation Waters. Department of Agriculture, United States, Circular No. 696, Washington D.C., 16p.