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

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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; SO4-2, Cl-, HCO3-, and major cations; Ca+2, Mg+2, Na+, and K+, in addition to the minor element (NO3-). 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 µs/cm. The predominant cation was Mg+2, and Na+, while the predominant anions were SO4-2, and Cl-. The prevalent cation in the aquifer Na+ of 49%, followed by Ca+2 of 30%, Mg+2 of 17%, and K+ of 4%, while the prevalent anion was SO4-2 of 48%, Cl- of 31%, and HCO3- of 21%. Groundwater is classified as unsuitable for drinking, while it is suitable for irrigation. The water type is Na-SO4 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 32º 20`-32º 40` North and longitudes 43º19`- 43º 50` East (Fig. 1).

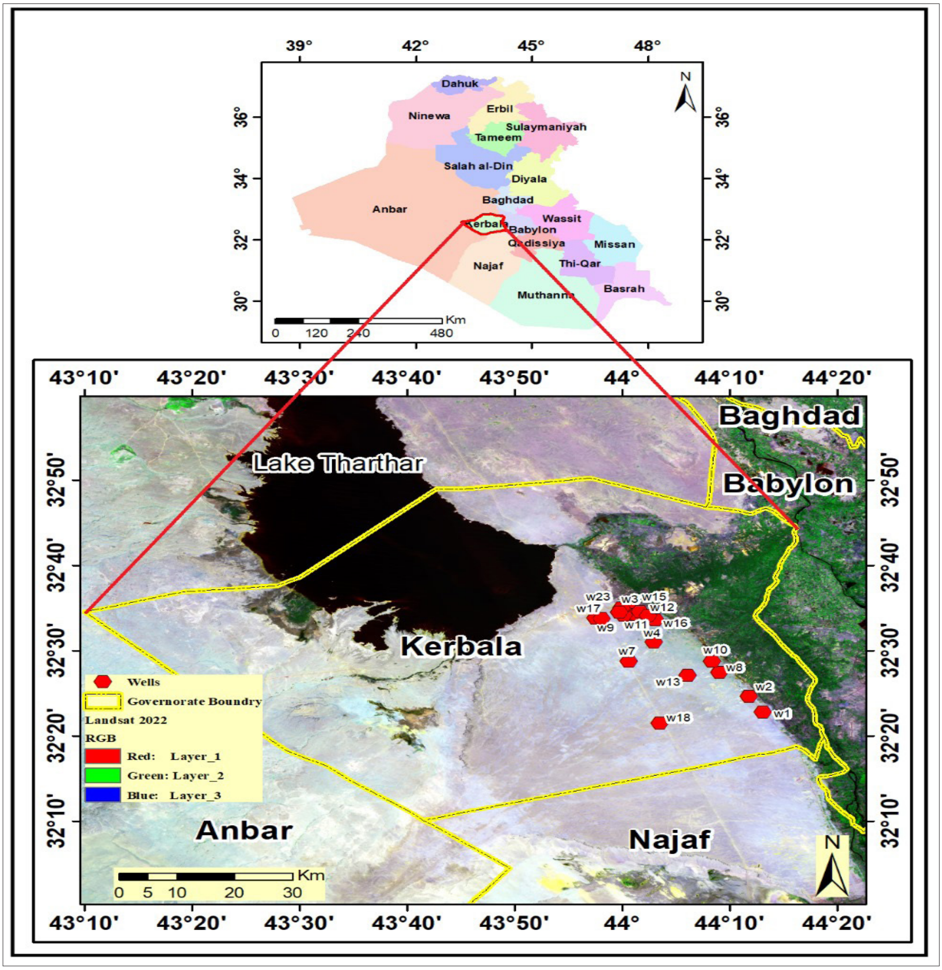


Fig.1: Karbala Governorate with groundwater sampling sites

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), 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+, K+, Ca++, SO4--, Mg++, HCO3-, Cl- and minor element(NO3-), 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

Sample No.	Latitude North	Longitude East	depth	pH	Mg+2	Ca+2	Na+	K+	Cl-	SO4-2	HCO3-	NO3	EC µs/cm	TDS ppm
W.1	43 58 3.4	32 33 45.5	48	7.25	155	175	606	90	536	938	596	0.6	4890	3125

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	

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

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), Atloviski, (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 μs/cm, with a mean value of 4310 μs/cm (Table 1), which classified as slightly mineralized water to moderately mineralized water (Detay, 1997). The concentration of major ions indicated that Na+ is the prevalent cation in the aquifer, with a percentage of 49%, followed by Ca+2 with a percentage of 30%, while Mg+2 occupies 17%, and K+ percentage 4%, while the prevalent anion was SO4-2 with a percentage of 48%, followed by Cl- with a percentage of 31%, and HCO3- with a percentage of 21%. The concentration of NO3- in the groundwater sample ranges between

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

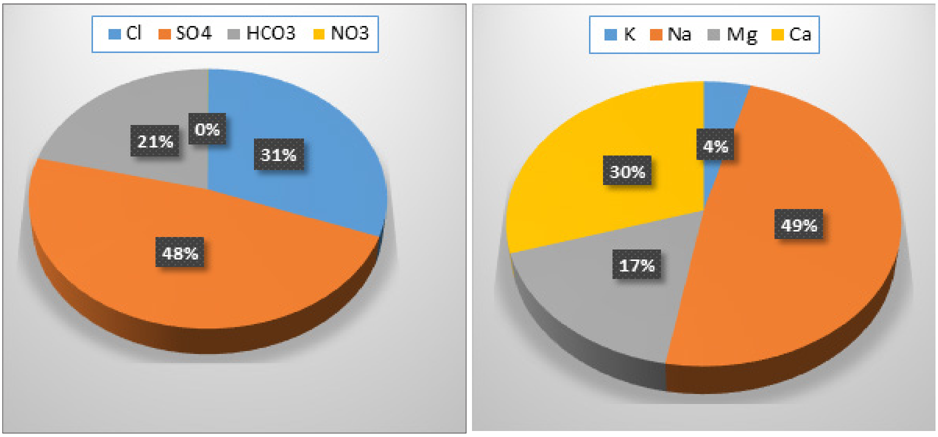
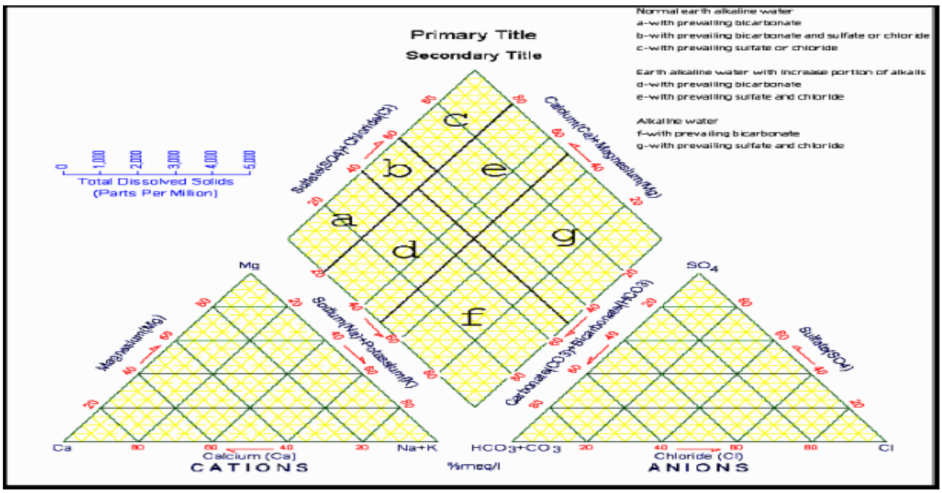


Fig. 2: Percentage of major ions, a: Cations, b: Anions

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).



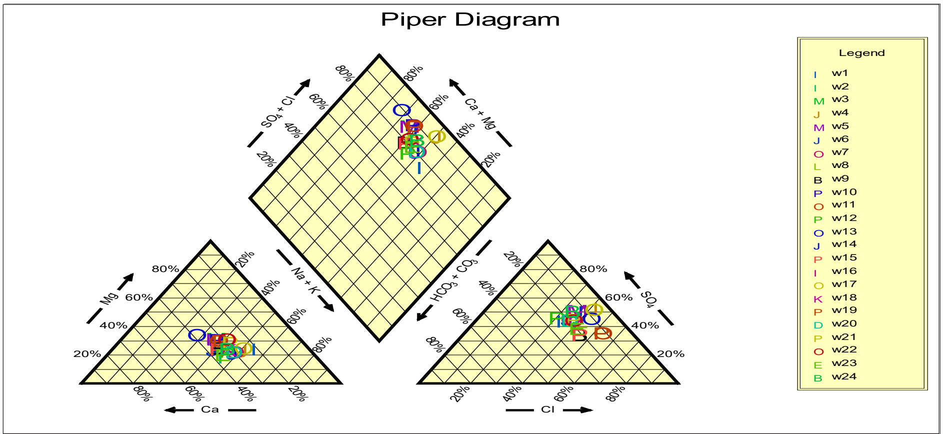


Figure 3. Piper diagram (1944),

show the groundwater type of Karbala City

Al-Dammam aquifer in Karbala Governorate is characterized by water type as $Na-SO_4$ which is represented in Korlof classification as the following:

TDS (2787) SO_4^{-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.

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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+ SO4) 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+ SO4) 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	rCa2+/ rMg2+	rNa/rCl	rCa/rCa+ SO4	rMg/rCa+ SO4
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 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):

SAR=rNa /

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 Na–SO4, 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).

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