

The Quantitative and Qualitative Assessment of Groundwater in Karbala Governorate, Iraq

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ABSTRACT

Karbala governorate, however, neighborhood the western desert, which bounded by longitudes ($43^{\circ} 09' 41'' - 44^{\circ} 18' 56''$) and latitudes ($32^{\circ} 10' 15'' - 32^{\circ} 50' 15''$) with total area study of 4987 km², represents part of sedimentary plain belongs to the unstable shelf and Salman zone belongs to the stable shelf. The main geological formations that exposed in the studied area represented by Al-Fatha Fn. (M. Miocene), Injana Fn. (U. Miocene), Dibdiba Fn. (Pliocene – pliestocene) and Quaternary Fn. (Pliostocene – Holocene). Two main underground reservoirs were distinguished based on the sedimentary facies and (four water reservoirs) as well. Quantitatively, the assessment was based on the climatic information (rainfall, temperature and humidity) for (39 years) for the period (1980 - 2019), so, by using Thornorite equation the water surplus was calculated representing the renewable storage of the unconfined aquifer which amounted to ($110.9 * 10^6$ m³/year), while the fixed storage for both systems (unconfined and confined) were calculated as ($7.68 * 10^9$ m³) and ($6.16 * 10^9$ m³) respectively, with total equivalent to ($13.84 * 10^9$ m³). While qualitatively, the assessment was based on utilizing the data bank information (151 wells) belongs to the general commission for ground water (2013) in addition to some available field data. The results reveal that there some wells are within the permissible limits to be used for drinking purposes, which can be used for municipal after conducting biological tests on them, although they should not be used for agriculture. In general, it can be said that most of the water from the wells in the study area is suitable for agricultural use, with the exception of small scattered areas.

Key ward: Water Resources Groundwater Assessment Karbala Governorate Iraq

INTRODUCTION

With increase in dry and semi-arid conditions that led to the emergence of a shortage of water and to the increase the demand for it on the other hand, which led to the existence and occurrence of shortages as a result of the pressure of the increase in the population at the present time, so all countries of the world (especially the countries in the Arab region, which suffers from a shortage of its water resources) seeks to increase and preserve its water resources and search for different sources to obtain fresh water, including water extracted from the ground by advanced means and techniques.

Karbala Governorate is considered as one of the important areas in terms of religious, historical, touristic and agricultural aspects, Fig 1. In addition to what is available from surface water in the rivers running in the area and irrigation channels, the groundwater resources, on the other hand, have been exploited in a large and main way for the purpose of planting many crops, in addition to the abundance of palms in it, especially in the western and southwestern region of the governorate, where the Shethatha district, which is famous for the cultivation of crops and palms, and the large number of palms called it the Ain -Altamur. On the other hand, the district is considered one of the very important tourist areas for the presence of historical springs in it, but because of the exploitation of groundwater in this area in a large and random manner, especially after drilling a fair number of flowing wells after 2003, which led to the depletion of groundwater and thus to the drying up of many those springs that were running for many years irrigate the orchards and areas located in the vicinity of the district and a few of them remained with little drainage until 2015, which then led to a partial drying of the five large springs namely, (Ain Al-Zarka Al-Kabeer, Al-Zarka Al-Saghira, Al-Hamra, Umm Al-Kawani and Ain Al Seeb). The main objective of this study is Conducting a quantitative and qualitative assessment of the groundwater in the study area.

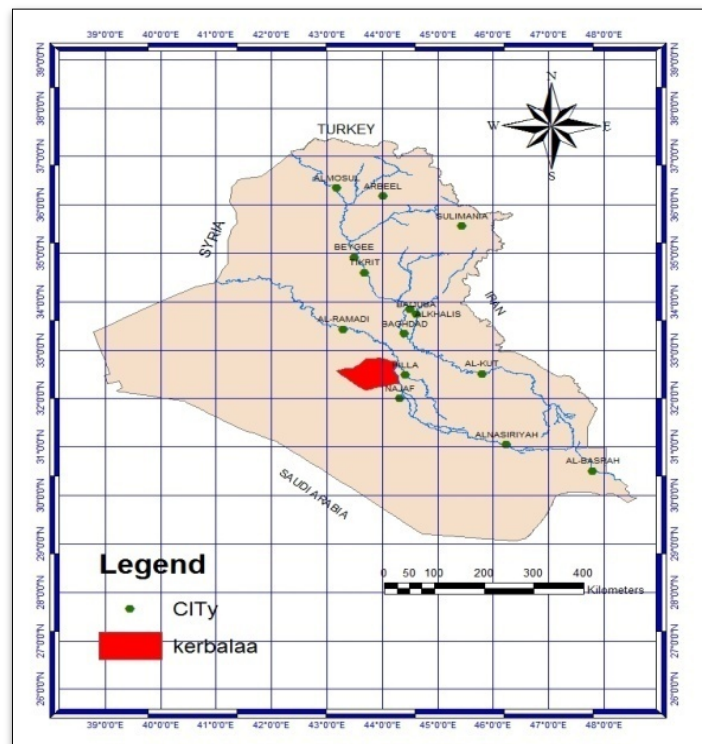


Fig (1) location of the study area

GEOLOGY AND TECTONIC OF THE AREA

The main Geological formations revealed in the study area are belong to the Tertiary period and Quaternary one, which represented by Al-Fatha, Injana and Dibdiba (Middle Miocene, Upper Miocene and Pliocene-Pleistocene) respectively, while the Recent deposits are belongs to the Pleistocene-Holocene. Karbala Governorate is located within two geological plates of a

scale (1/250,000), Fig 2 shows the geology of study area. Tectonically, these plates are part of the north-eastern part of the African-Arabian Platform which belongs to the Unstable Shelf.

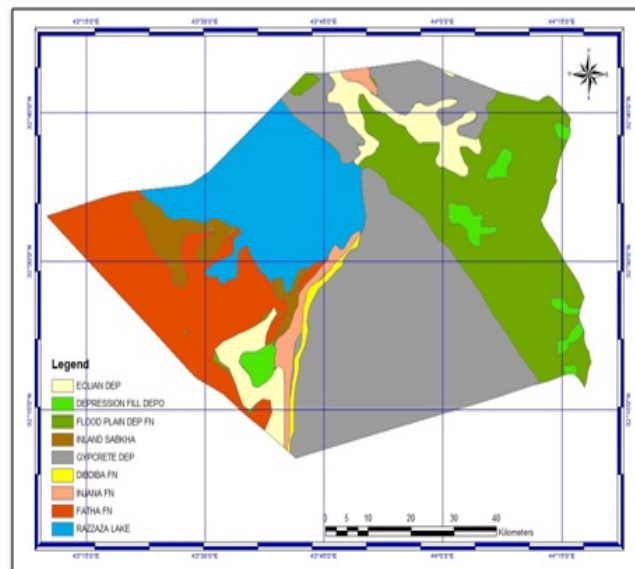


Fig (2) geology of the study area

HYDROGEOLOGY

Among the most important characteristics on which the hydro-geological conditions depend are the geological and structural nature, the type of the rock formations, the nature of the water-bearing rocks, so the presence of groundwater in the rocks and the layers bearing them will be determined and depend on the aforementioned conditions. The study indicated that the groundwater resides in two important aquifers, one of which belongs to the Tertiary period, represented by the formations of Umm Al-Radhuma, Dammam and Injana, while the other to the Quaternary age represented by the formations of the Pliocene – Pliocene (Dibdiba) and Recent Alluvium. These two aquifers differ from each other in the conditions of deposition, the environment, the rock texture and the physical properties of the rocks containing them, as well as their thickness, hydraulic and hydro-chemical properties. There are a number of springs that spread in the western and southwestern parts of the Karbala plate - Shathatha area towards northwest - southeast along the eastern edge of the desert, west of the Euphrates River, where this area is known as the zone of springs. The presence of these springs is determined by the presence of water-bearing aquifers represented by the Dammam and Umm Al-Radhuma formations mainly within the areas of the Karbala-Shathatha plate in addition to the geological and structural nature of the area. (Abdul-Razzaq et al. 2012) indicated that the number of springs had reached, after being counted, (24) with varying drainage, but most of them were dry while another part of them was filled in.

GROUNDWATER LEVEL AND MOVEMENT SYSTEM

The spongy nature of geological formations or containing voids and cracks of secondary porosity allows them to keep water inside or pass through them. Thus, these water have energy levels that represent saturated zones at different depths. The shape of these energy levels depends, in general, on the porosity of the rocks, their permeability, the conditions of recharge

and the nature of the areas towards which the groundwater flows, as well as on the thickness of the water-bearing layers even the nature of the impermeable layers located above and below them, (Al Neif et al. 2016, Abdul Razzaq et al. 2019). (Fig 3&4) show the Ground water levels and their movement in unconfined and confined aquifers.

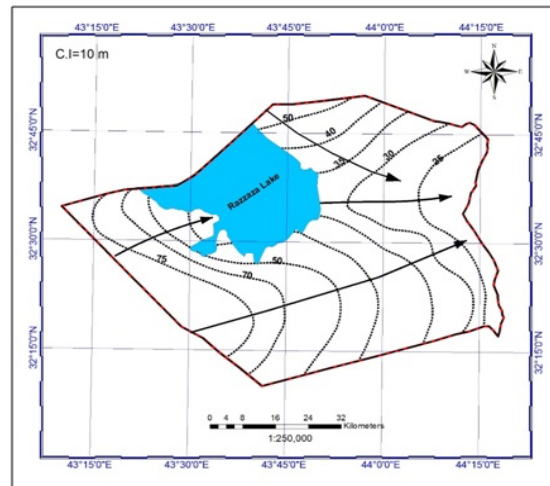


Fig (3) level and movem. (Unconf.)

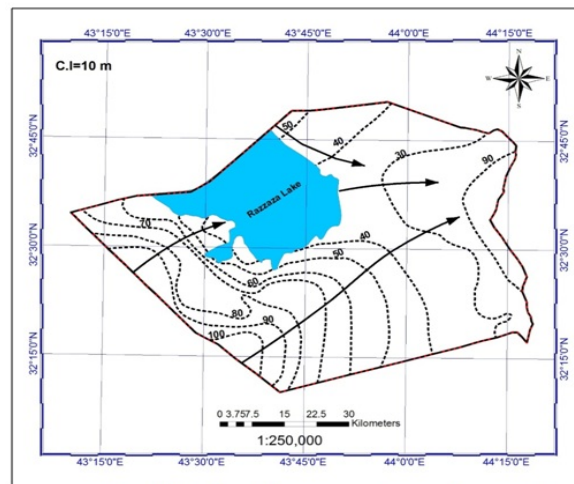


Fig (4) level and movem. (Conf.)

DATA, METHOD AND RESULTS

Quantitative Assessment

For the purpose of calculating the volume of recharge water to the unconfined aquifer, (Thornorite equation, 1948) was used for a period of time (39 years) from the year (1980 - 2019) as shown below:

$$PE = 16 \left[\frac{10 \ln}{J} \right]^a$$

$$J = \sum_{j=1}^{12} j$$

$$j = \left[\frac{\ln}{5} \right]^{1.514}$$

$$a = 0.016 J + 0.5$$

$$Ws = P - Eta$$

$$Ws = Ro + Re + SM$$

Where, P(Rain), PE(Potential Evaporation), Eta(True Evaporation), Ws(Water Surplus), Ro(Runoff), RE(Groundwater Recharge), SM(Soil Moisture) and WD(Water Loss), according to the availability of the climatic information, Table 1 show the coefficients for Karbala climatic station (1980-2019) as below:

Table (1) the coefficients for Karbala climatic station (1980 – 2019)

Month	P(mm)	T℃	J℃	PE(mm)	K	PEc(mm)	Eta(mm)	SM(mm)	WS(mm)	WD(mm)
Oct.	5.02	26.77	12.68	88.08	0.97	85.43	8.02	0.00	0.00	77.41
Nov.	14.08	18.23	7.08	29.58	0.87	25.73	17.08	0.00	0.00	8.65
Dec.	18.81	12.58	4.04	10.31	0.86	8.86	8.86	95.00	9.95	0.00
Jan.	20.75	9.19	2.51	4.23	0.88	3.72	3.72	95.00	17.03	0.00
Feb.	17.42	13.59	4.54	12.84	0.85	10.91	10.91	95.00	6.51	0.00
Mar.	16.85	18.42	7.20	30.46	1.03	31.37	16.85	0.00	0.00	9.52
Apr.	12.63	25.28	11.63	78.86	1.09	85.95	12.63	0.00	0.00	73.32
May	3.10	31.34	16.10	137.81	1.20	165.37	3.10	0.00	0.00	162.27
Jun.	0.09	35.91	19.78	202.85	1.20	243.42	0.09	0.00	0.00	243.33
Jul.	0.00	38.45	21.94	246.30	1.22	300.46	0.00	0.00	0.00	300.46
Aug.	0.08	37.61	21.22	231.33	1.16	268.34	0.00	0.00	0.00	268.26
Sep.	2.61	33.88	18.11	171.95	1.03	177.10	2.61	0.00	0.00	174.49
Total	114.44		146.83	1244.6		1406.66	88.87	95.00	33.49	1317.71

To calculate the surface runoff in the study area, the equation prepared by (Abdul-Razzak & Al-Shahrabaly 2012, 2017) was used, as given below:

$$SR = 0.234 (P - 106.42) = 1.87 \text{ (mm)}, \text{ then}$$

$$WS = SR + GW$$

$$GW = WS - SR$$

$$GW = 33.49 - 1.87 = 31.62 \text{ (mm)}$$

So, the renewable recharge to the ground water = $3509 \times 10^6 \times 31.62 \times 10^{-3} = 110.9 \times 10^6 \text{ m}^3/\text{year}$.

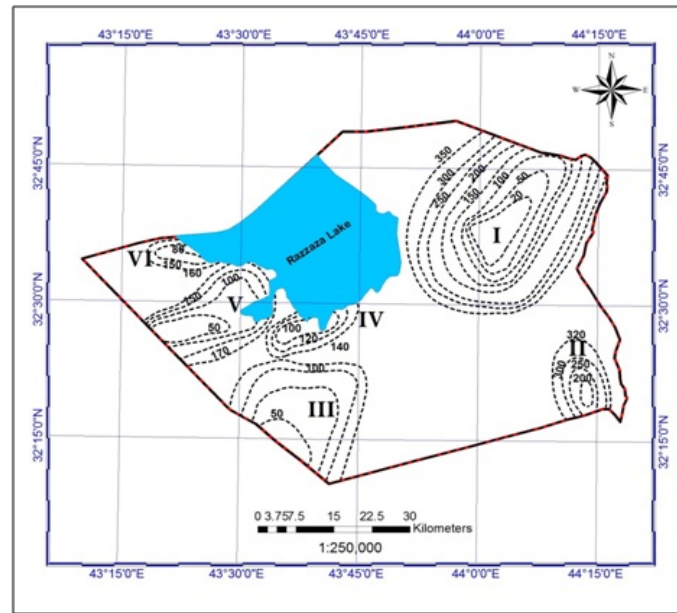


Fig (5) Show water-saturated thickness, unconfined aquifer

Well, to calculate the fixed volume of water for unconfined. This can be achieved by drawing a map of the saturated thickness of the aquifer, which represents the status of the secondary basins of the unconfined water system in the study area, Fig (5).

For the purpose of calculating the volume of water for unconfined aquifer, the following equation was used, which represents the volume of the cone, as:

$$Vol_{Un} = \{((a1 + a2) + \sqrt{a1 * a2}) h/3\} \Phi$$

Where, $a1 \& a2$ (area of vertical and horizontal diameter, m^2), h (The difference between the highest and lowest value of the thickness contour line (m) and Φ (effective porosity). Six zones were obtained which can be invested throughout the study area, where drilled wells are available. Table (2) show the computed parameters of these zones.

Table (2) the computed parameter values of the unconfined aquifer with the fixed volume.

Sub-basin	A1($^{\circ}10$)	A2($^{\circ}10$)	h/3(m)	Eff. Por(Φ)	Vol ($^{\circ}10$) m^3
I	1.90	0.175	110	0.02	5.85
II	0.25	0.03	40	0.02	0.29
III	0.90	0.09	23.3	0.02	0.59
IV	0.27	0.04	13.3	0.02	0.11
V	0.54	0.10	40.0	0.02	0.70
VI	0.18	0.02	26.6	0.02	0.14
Total Vol.					7.68

The net volume was calculated as ($7.68 \times 10^9 m^3$). With regard to calculate the volume of fixed water in the confined aquifer (Dammam Fn.) in the area under study, where the drilled wells

information is available. Well, according to the sketch, Fig 6, and use the equation given below as:

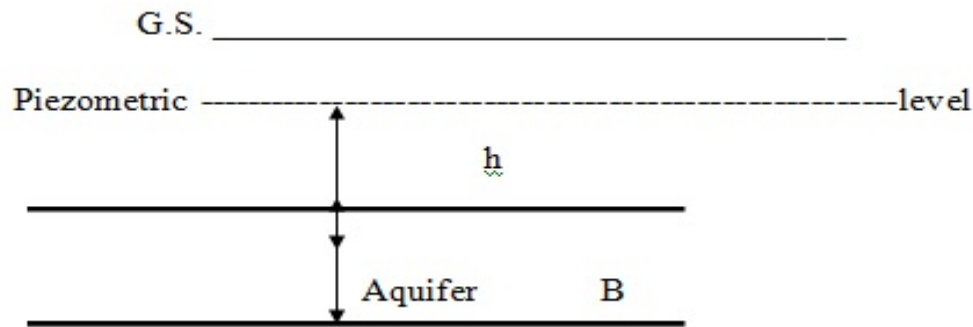


Fig (6) Sketch explains the situation to how calculate the fixed volume (Conf.)

Fixed storage (Conf) = average rate * studied area * storage coefficient

Or, Fixed storage(Conf) = (B * A * S1 + h * A * S2)

Vol(Con)= 6.16*10⁹ m³

So, the total volume for both fixed water = 13.84 * 10⁹ m³.

Qualitative Assessment

The qualitative assessment, on the other hand, was applied on the data available in the hydro-geological data bank (2013), (151 wells), belongs to the general commission for groundwater by using different approach as: (Todd, 1980), (Ayers&Westcot,1989), (Done, 1995), (IRS, 2009) and (WHO, 2011). The results of chemical analyzes of the water samples were analyzed in terms of calculating the percentages of all variables, as well as calculating the, TDS, Ec, the sodium adsorption rate (SAR), the hardness percentage (TH), the percentage of soluble sodium (NA%) and other variables. In this context, we reveal only the TDS maps and SAR maps in order to show the suitability of ground water for both domestic and agricultural use. Firstly, to determine the extent to which the results of chemical analyzes can be adopted in hydro-geochemical interpretations, the validity of these results was evaluated using the Accuracy

$$U\% = \frac{\text{Sum Cations} - \text{Sum Anions}}{\text{Sum Cations} + \text{Sum Anions}} \times 100$$

method, (Appelo & Postma, 1999), using the following equation:

Where, U% = the relative error difference. When applying the above method, it was found that the validity of the analyzes of the water samples is within the permissible limits.

Classification of Ground Water

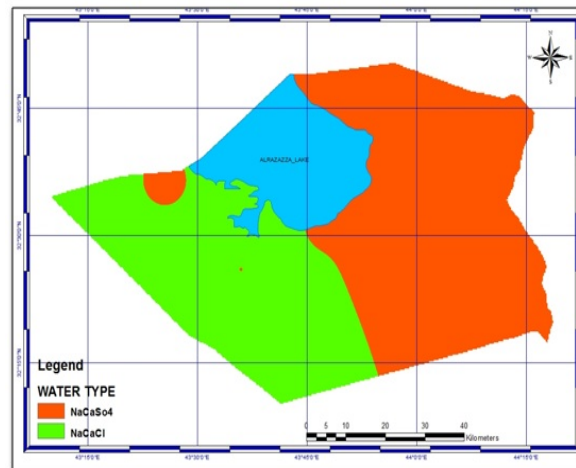
The methods of classifying groundwater hydro-chemically are many and varied, including (Sulin, 1946), (Johns, 1968), (Hem, 1985), (Scholler, 1972), (Ghada, 1999). These methods depend on the value of positive and negative ions in epm% unit. (Johns, 1968) method was used in this classification, Table (3 &4), Figs (7 & 8).

Table (3) Water type (Unconfined)

Anions		Cations		Well No.
Group	Sub Group	Facies	Class	
So ₄	So ₄ > Cl>Hco ₃	Ca	Ca > Mg > Na	17,20,22,
		Na	Na > Ca> Mg	11,
	So ₄ >Hco ₃ > Cl	Ca	Ca > Mg > Na	15,
Cl	Cl>So ₄ >Hco ₃	Na	Na> Ca > Mg	16,23
			Na> Mg > Ca	7,
	Cl> Hco ₃ > So ₄	Ca	Ca > Na> Mg	1,12,
		Na	Na> Ca > Mg	18,

Table (4) Water type (Confined)

Anions		Cations		Well No.
Group	Sub Group	Facies	Class	
So ₄	So ₄ > Cl>Hco ₃	Ca	Ca > Na > Mg	3,5,17,
			Ca > Mg > Na	4,6,14,18,
		Mg	Mg> Ca> Na	24,
		Na	Na> Mg> Ca	27,
	So ₄ >Hco ₃ > Cl	Ca	Na > Ca> Mg	2,8,16,20,
			Ca > Mg > Na	12,
Cl	Cl>So ₄ >Hco ₃	Na	Na> Ca > Mg	1,7,22,
			Na> Mg > Ca	11,
		Ca	Ca > Na > Mg	15,25,
		Mg	Mg> Ca> Na	13,

**Fig (7) Water type (Unconfined)**

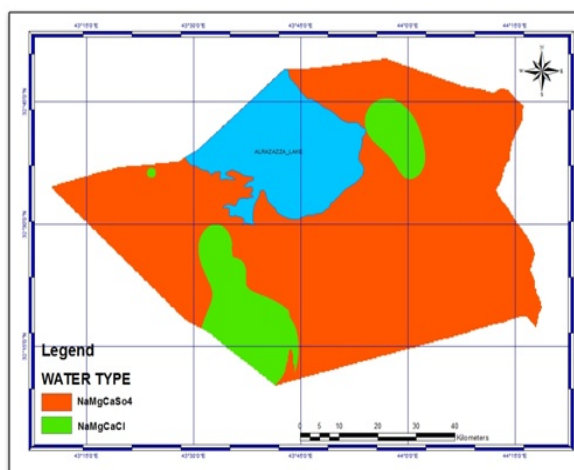


Fig (8) Water type (Confined)

Total Dissolved Salts

The concentrations of total dissolved salts in the water vary depending on the composition of the groundwater types and the speed of movement of this water. The values of salt concentrations for the unconfined wells ranged between (451-5357) mg/l, distributed as follows: 5% less than 1000 mg/l, 48% between (1000-3000) mg/l, and 37% between (3000-5000)) mg/L, and 10% is more than (5000) mg/L, as shown in Figure (9), whereas the TDS values of the confined wells are ranged between (1314-4875) mg/L, distributed as follows: 73% are less than 3000 mg/L, 27% between (3000-5000) mg/L, as shown in Figure (10), respectively.

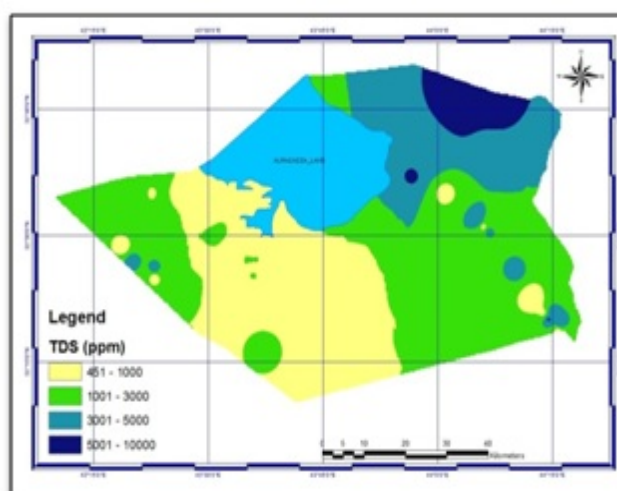


Fig (9) TDS of (Unconfined)

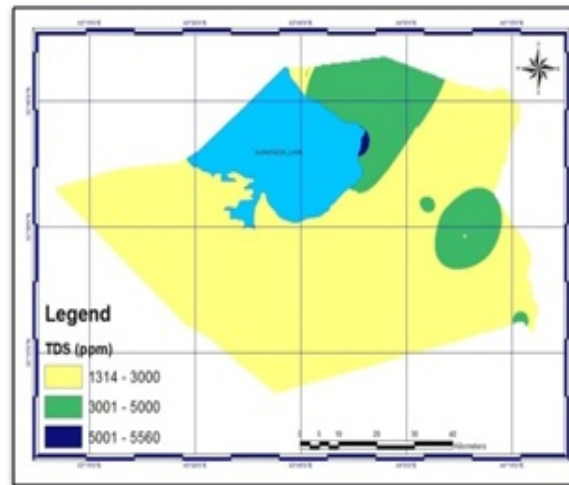


Fig (10) TDS of (Confined)

when comparing the concentrations of total dissolved salts in groundwater, in the study area, with the classifications of Altoviski, 1962, (Gorrel, 1958) and (Drever, 1997), Table (5), shows that 5% of well water falls within (Fresh Water) or about 60% of it falls within Slightly Brackish Water, while 30% falls within Brackish Water or (Salty Water) or (Brine Water).

Table (5) classification of ground water depending on TDS Values

Water Class	Gorrel (1958)	Altoviski (1962)	Drever (1997)
Fresh Water	0 – 1000	0 – 1000	< 1000
Slightly Brackish Water		1000 -3000	
Brackish Water	1000 – 10000	3000 – 10000	1000 – 20000
Salty Water	10000 – 100000	10000 _100000	
Saline Water			35000
Brine Water	100000	> 100000	> 35000

Water Suitability for Drinking Purposes

There are several standard specifications for human drinking water, which include the limits of salinity (TDS) and the limits of concentrations of the main positive and negative ions, which must be free of contaminants.

Two types of specifications have been used in evaluating water validity, they are the specifications of the World Health Organization (WHO, 2011) and the Iraqi specifications (IRS, 2009), as shown in Table (6).

Table (6) limits of positive and negative ion concentrations according to the specifications of the World Health Organization (WHO, 2011) and Iraqi Standards (IRS, 2009)

ppm	K	Na	Ca	Mg	Cl	So ₄	No ₃	PH	TDS	Total Hardness
WHO 2011	12	200	100	125	250	250	50	6.5-8.5	1000	500
IRS 2009		200	150	100	350	400	50	6.5-8.5	1000	500

After comparing the (+ve) and (-ve) ions, it was noted that there are only two wells, one for unconfined and other for confined that fall within the permissible limits to be used for drinking status, which can be used for municipal purposes after conducting biological tests on them and not being used for agriculture.

Water Suitability for Agricultural Purposes

The suitability of water for agricultural purposes depends mainly on the salinity of water, soil and the quality of irrigated plants (Ayers & Westcot 1989), and its suitability for these purposes, in addition to salinity, is determined by many criteria, the most important of which are: Sodium adsorption ratio (SAR) and the concentration of some elements such as chlorine, boron, bicarbonate and nitrates. The following equation was used to calculate the rate of adsorption of sodium (Todd, 1980).

$$SAR = \frac{r Na}{\sqrt{r(Ca + Mg) / 2}}$$

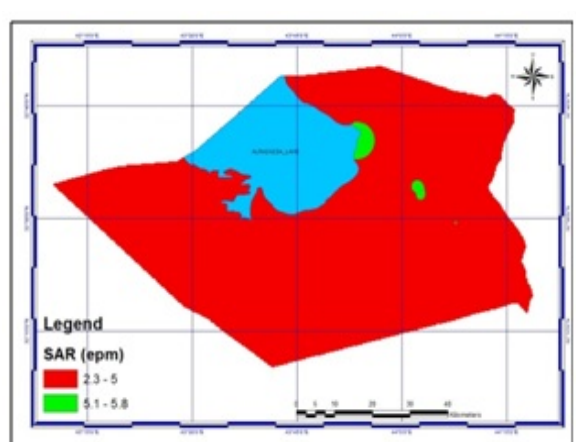


Fig (11) SAR distribution, Unconfined

As for the rate of sodium adsorption, which is one of the basic criteria in determining the suitability of water for agricultural purposes, it was noted that most of the water from both Unconfined and Confined falls within the excellent and good quality of water, as shown in Figures (11&12) respectively.

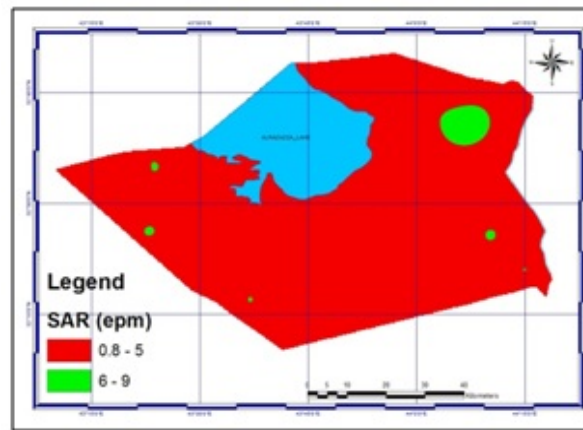


Fig (12) SAR distribution, Confined

In general, it can be said that most of the water from the wells of the study area is suitable for agricultural use, with the exception of small scattered areas.

CONCLUSIONS

Two main underground system were distinguished based on the sedimentary facies and (four water aquifers). Namely, Dammam (U.Eocene), Injana (U.Miocene), Dibdiba (Pliocene-Pleistocene) and Quaternary (Pleistocene-Holocene). The annual renewable recharge to the unconfined system was calculated to be equivalent to $(110.9 \times 10^6 \text{ m}^3/\text{year})$ by using (Thornorite equation) for climatic information comprising (39 years) from the years (1980 - 2019) and that there was an increase in water (recharge) as an average for three years was $(152.03 \times 10^6 \text{ m}^3/\text{year})$ is added to the incoming of the unconfined system, bringing their total to $262.93 \times 10^6 \text{ m}^3/\text{year}$. The fixed storage of both aquifers (unconfined and confined) was calculated as $(7.68 \times 10^9 \text{ m}^3, 6.16 \times 10^9 \text{ m}^3)$ respectively, with a total of $(13.84 \times 10^9 \text{ m}^3)$.

The movement of groundwater for the two hydro-geological systems (Unconfined and Confined) are largely coincided with each other, in terms of direction and with the topography and physiography of the land from the other hand.

After comparing the (+ve) and (-ve) ions, it was noted that there are only two wells, one for old unconfined wells and another of the new confined wells that fall within the permissible limits to be used for drinking purposes, which can be used for municipal after conducting biological tests on them and not being used for agriculture. It was found that the values of sodium adsorption ratio which is one of the basic criteria in determining the suitability of water for agricultural purposes is within the excellent and good water quality for most of the water wells for both unconfined and confined wells. In general, it can be said that most of the water from the wells of the study area is suitable for agricultural use with the exception of small scattered areas.

References

1- Abdul-Razzak, M.I and Al-Shaharably, Q 2012 Impact of Climatic Change on Surface and Ground Water in Adhaim River basin / Iraq (Scientific Paper accepted in the 7th Asian conference, Australia). 2nd Scientific Water Resources Conference, 2017, Al-Umarah, Iraq.

- 2- Abdul-Razzak, Muhammad Ibrahim, Al-Naief, Ayser Abdul-Aziz and Danash, Donia Ibrahim 2019 Quantitative and qualitative assessment of groundwater in the Karbala governorate. Ministry of Water Resources / National Center for Water Resources Management / Department of Groundwater Studies / A scientific-technical study submitted to the Ministry of Water Resources, Baghdad - Iraq.
- 3- Abdul-Razzak, Mohammad Ibrahim, Reda, Souad Abbas and Daoud, Khaled Salman 2012 A hydrogeological and geophysical study of the Ain Al-Tamr district. National Center for Water Resources Management, Department of Groundwater Studies. A scientific study submitted to the Ministry of Water Resources, Baghdad - Iraq.
- 4- Ahmed, Adnan Mahmoud, Hanna, Faris, Jawad, Ali Muhammad, Ali, Batoul Muhammad, Jawad, Sadiq Baqer, Haider, Furat Abdul Sattar, Abdullah, Muhammad Hammoud, Ahmad, Abdullah Ismail, Jawad, Kazem, Abdul Qadir, Shatha Wajbar, Hatem 2000 Al-Ghodari Project - Phase Two (Part One: A hydrogeological study for the western region of the Razzaza Depression). Ministry of Irrigation, General Authority for Operation and Maintenance of Saddam River, Al Furat State Company for Irrigation Studies and Designs, Baghdad - Iraq.
- 5- Al-Naief, Ayser Abdul-Aziz, Abdul-Razzak, Mohammad Ibrahim and Danash, Donia Ibrahim 2016. Quantitative and qualitative assessment of groundwater in Samawah governorate and the possibility of its management and investment.(Ministry of Water Resources / National Center for Water Resources Management / Department Ground water Studies / a scientific-technical study submitted to the Ministry of Water Resources / February.
- 6- Altoviski ' M.E. '1962 : Handbook of hydrogeology .Gosgoelitzdat ' Moscow ' USSR ' 614p.
- 7- Appelo ' C.A.J. and Postma ' D. '1999 : Geochemistry'groundwater and pollution . Rotterdam A.A. Balkama '536p.
- 8- Ayers ' R.S. and Westcot ' D.W. '1989 : Water quality for agriculture . Irrigation and Drainage . Paper 29 ' Rev. 1 'FAO ' Roma' Italy ' 174p.
- 9- Drever, J. I., 1997. The Geochemistry of Natural Water Surface and Ground water Environment Pretice Hall, USA,436p.
- 10- Detay, M., 1997. Water Wells – Implementation, maintenance and Restoration. John Wiley and Sons, London,379p.
- 11- Gorrel, H. A., 1958. Classification of Formation Water Based on Sodium Chloride Content, AAPG Bull 42:2513.
- 12- Hydro-geological database for the year (2013) Ministry of Water Resources / General commission for Ground Water.
- 13- IRS, 2009. Drinking Water Standards, Central Organization for Standardization and Quality Control, Min. of Planning.
- 14- Johns, M. W., 1968. Geochemistry of Ground water from upper Cretaceous-Lower Tertiary Sand Aquifer in South-West Victoria, Australia *Jor. Hydrology* Vol. VI, No.4 ,pp337-357 .
- 15- Scholler, M., 1972. Etude Geochemimque De La Nappe Des"Sables Infericurs" Du Bassin Daquitaine, *Journal ofHydrology* Vol. 15, pp .317-328.
- 16- Thornthwait, C. W., 1948: An approach toward a relation classification of climate, *Geographical, Review*.38, 55-94pp, USA.
- 17- Todd, D.K., 1980. Ground water Hydrology. John Wiley and Sons. Inc. Toppan Printing Co. Ltd., New York, 336p
- 18- WHO ' World Health Organization '2011:
International Standard for Drinking Water ' Geneva.