University of Baghdad
College of Engineering
JE
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 29 Number 2 February 2023

Comparison of Groundwater Quality and Quantity between Al-Rahbah and Al-Haydariyah Regions

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ABSTRACT

This study focused on two areas in AL-Najaf city, AL-Ruhbah and Al-Haydariyah regions because of the importance and widespread use of groundwater in these areas. The two areas were compared quantitatively and qualitatively. For the quantitative approach, the GMS software was used in conjunction with the GIS software to simulate the groundwater flow behavior. The solid model for both areas was created, the geological formation was determined, and the hydraulic properties were identified using GMS software. To test the quantity of groundwater in both areas, the wells have been redistributed to a distance of 2000 m between them, and a period of 1000 days was chosen. When a discharge of 10 l/s and operation times of 4, 8, and 12 h/d were chosen for the AL-Ruhbah area, the maximum drawdown for all cases was equal to 18.04 m, whereas for Al-Haydariyah, when 5 l/s was chosen, the maximum drawdown was 0.81, 2.56, and 8.13 m, respectively. Field measurement and experimental laboratory tests were conducted to identify the type of water quality in the study areas. TDS, WQI, and SAR classification were employed to determine the type of groundwater. In both areas, groundwater was slightly to moderately saline. A piper diagram was also employed for the two regions to identify the water quality and it revealed that groundwater in the two studies cannot be used for drinking and can only be used for irrigation of plants that can withstand salty water.

Keywords: Al-Ruhbah, Al-Haydariyah, Groundwater Flow, Quality, Quantity.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2023.02.12

Article received: 11/9/2022
Article accepted: 10/10/2022
Article published: 1/2/2023

المقارنة النوعية والكمية للمياه الجوفية بين منطقتي الرحبة و الحيدرية

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الخلاصة

ركزت هذه الدراسة على منطقتين في مدينة النجف الأشرف هما منطقتي الرُحبة والحيدرية لأهمية وانتشار استخدام المياه الجوفية في هذه المناطق. تم مقارنة المجالين كماً ونوعاً. بالنسبة للنهج الكمي ، تم استخدام برنامج GMS بالاقتران مع برنامج GIS لمحاكاة سلوك تدفق المياه الجوفية. تم إنشاء النموذج الصلب لكلا المنطقتين ، وتحديد التكوين الجيولوجي ، وتحديد الخصائص الهيدروليكية باستخدام برنامج GMS. لاختبار كمية المياه الجوفية في كلا المنطقتين ، تم إعادة توزيع الآبار على مسافة 2000 م بينهما ، وتم اختيار فترة 1000 يوم. عندما تم اختيار تصريف 10 لتر/ ثانية وأوقات تشغيل 4 و 8 و 12 ساعة / يوم لمنطقة الرحبة ، كان الحد الأقصى للتراجع لجميع الحالات يساوي 18.04 مترًا ، بينما بالنسبة للحيدرية ، عندما تم اختيار تصريف 5 لتر/ ثانية ، كان الحد الأقصى للتراجع 0.81 و 2.56 و 8.13 م على التوالي. تم إجراء القياسات الميدانية والاختبارات المعملية التجريبية للتعرف على نوعية المياه في مناطق الدراسة. تم استخدام تصنيف TDS و WQI و SAR لتحديد نوع المياه الجوفية. في كلا المنطقتين ، كانت المياه الجوفية خفيفة إلى متوسطة الملوحة. كما تم استخدام مخطط بايبر للمنطقتين لتحديد جودة المياه وكانت النتيجة أن المياه الجوفية في الدراستين لا يمكن استخدامها للشرب ويمكن استخدامها فقط لري النباتات التي يمكنها تحمل المياه المالحة.

الكلمات الرئيسية: الرحبة, الحيدرية, جريان المياه الجوفية, نوعية, كميه.

1. INTRODUCTION

The hydrological cycle is an endless, looping process that never ends. Rainfall, runoff, evaporation, and storage are the four basic processes that make up the water cycle. Rainfall will be divided into many sections when it reaches the earth. Some of it will fall on the plant's surface and evaporate again, some of it will flow in a water stream until it reaches the sea, and some of it will travel down into the soil and create groundwater, (**Pinder, 2011)**. Rainfall is the main source of a significant portion of the groundwater. When compared to the flow of surface water, the groundwater movement is extremely slow, **(Britannica, 2020**). Groundwater is regarded as one of the most significant freshwater sources because it contains roughly 95% of all freshwater. The usage of this water was restricted to arid and semi-arid regions devoid of surface water due to the insufficient understanding of this source. Groundwater is extremely important, especially in major cities. In many countries, the sole source of water supply was groundwater, for example in Mexico City, which had 1,000 deep wells, **(Chilton, 1996)**. The mathematical model may be used to simulate the physical processes in the groundwater system under different hydrogeological conditions,

(Mustafa, et al, 2017). Due to the adaptability of its simulation technique and capacity for conceptual simulation, the GMS software, also known as the groundwater modeling system, is now the most widely used program in a range of situations to explore groundwater. It may also be used to monitor the movement of contaminants in groundwater, **(Zhao, et al., 2021)**. **(Atiaa and Al-Asadiy, 2007)**, analyzed the drop in groundwater level by creating a conceptual model of the Al-Dibdibba sandy reservoir in the Safwan-Zubair area. The reservoir in this location was made up of two layers, the first being a sandy layer with hydraulic conductivity and a specific yield of about 20 m/day and (0.035-0.4), respectively, and the second being clay, which has a thickness of around 2 meters and a hydraulic conductivity of about 0.38 meters per day. The investigation discovered that the groundwater level has dropped 0.52 m, which might generate a slew of difficulties in terms of groundwater quantity and quality. Four different groundwater conservation plans were presented, including uniformly spreading wells around the study area, building shallow ponds, minimizing cultivated areas, and defining the type of crop. The final and most costly, technique is the artificial recharge of subsurface water. (**Al-Saedy and Abdulhussain, 2013)**, recommended digging five wells to lower the high level of the groundwater in the research zone, each with a depth of 100 m and a discharge of around 161 l/s, spread out throughout the city of Al- Mishkhab. It was discovered that after 250 days of operation, the water level would drop to an appropriate level. The outcomes showed that the groundwater level could be brought down to the target level in a year.

Water quality is equally as necessary as water quantity. An increase in human activity and water extraction associated with the industry are regarded as the main contributors to the deterioration of water quality. Groundwater can be polluted naturally by the soil or artificially by people since the quality of groundwater varies from place to place depending on the climate and type of soil it travels through. As a result, some types of soil may react with water when it passes through them, causing the soil to dissolve and flow with the water and pollute groundwater, **(Shekhar, 2017)**. The best approach to assess the water's quality is to examine its physical and chemical properties, compare them to standards, and then make a decision. Due to the significance of this phrase in determining whether a source is suitable for a certain purpose, several studies have examined this term to assess it. **(Ebrahimi, et al., 2016)**, examined the amount and quality of groundwater in Iran's Damghan aquifer. Based on information from the observation wells for the years 1966 to 2010, the amount of groundwater was examined. The study of the groundwater head data revealed that the groundwater level decreased by around 7.4 m throughout these years, which is related to an increase in groundwater extraction. The appropriateness of groundwater for irrigation and consumption has also been researched. The groundwater was classified using the Chadha and Piper diagrams, which fell into the Na-Cl classification. Compared to WHO standards, the water was unfit for human consumption. Additionally, because of the high salinity content in the groundwater, it is bad for agriculture. **(Mustafa, et al., 2017)**, evaluated the water quality of the branch of Al Gharraf stream in Al-Nasiriya city before the Al-Kut dam was evaluated using a CCME (Council of the Minister of the Environment) indicator. This inducer was used to condense the numerous tests and transform them into a single result that could be compared and assessed. In 2017, 17 factors were used to evaluate it and decide whether it met the standards or not. All of the water's metrics, except stations 7, 11, 12, and 15, were within acceptable ranges, including alkalinity, Cl, Ec, Ca, So4, K, Na, TDS, TH, and pH. **(Dawood, et al., 2018),** collected 41 groundwater samples in 2014 from various locations in Basrah City to assess their suitability for irrigation. The analysis revealed that the sodium percentage was from 8.87 to 51.03 meq/l, the permeability indicator was between 5.44 and 84.32 meq/l, and the SAR ranged from 0.11 to 39.33 meq/l. The water was determined to be suitable for irrigation purposes when the results were compared to the criteria, but there were certain spots where it could not be used for irrigation. The TDS was also looked at, and it was discovered that its value was over 3000 mg/l, which reduced the effectiveness of using irrigation. **(Alwaeli, et al., 2021)**, employed WQI and GIS to evaluate the quality of groundwater in the 900 km^2 area of Baghdad. 97 water samples were collected from various locations. For the year 2019, they were tested for a variety of parameters, including NO_3, HCO_3, Cl, Ca, Mg, SO_4, TDS, EC, pH, Na, and K. The groundwater quality distribution was determined using the kriging technique with the GIS, and a WQI map was also constructed. The outcome revealed that the WQI was between 50 and 300, meaning that 30% of the region was considered to be good and 70% was considered to be poor. In terms of the entire region, 3 % were usually excellent, 30 % were good, 33 % were poor, 12 % were extremely poor, and 20 % were unfit for human use. The goal of this study is to compare the quantity of groundwater in two different Al-Najaf City regions and to discuss the effects of adding more pumping wells to each area. Additionally, various techniques were used to examine the quality of the groundwater to be compared too.

2. THE STUDY AREA

Two separate areas of Al-Najaf city were chosen for research as shown in **Fig.1**. AL-Ruhbah region is a village located in the southwest of the governorate of AL-Najaf, with an area of 132 km^2 and a perimeter of 49 km. It is a desert region with no surface water supply and is fully reliant on groundwater from wells for agriculture, irrigation, and daily needs. Al-Haydariyah region, with an area of 309 km^2 and a perimeter of 72 km, is located in the northeastern section of the governorate center of AL-Najaf. This area has the Euphrates River, a surface water resource that borders this region and is regarded as an important source of water for the governorate's population. Because the river is insufficient to supply those people's demands, the move toward groundwater has increased. Because of the different geological formations and construction of the two research regions, this study has studied them independently to demonstrate the differences between the two study areas. In terms of the quantity and quality of groundwater available in the two regions, as well as the impact of drilling a set of wells scattered around the region on the quantity of groundwater.

3. THE QUANTITY STUDY

For the quantity section analysis, GMS V 10.6.1 was used, and a vast amount of data was prepared and gathered.

3.1 The Geological Formation and Solid Model

AL-Ruhbah area geological formation consists of the AL-Dammam aquifer, which is a confined aquifer with a large average thickness of 175 m, and it was discovered using 6 borehole cross sections that this region consists of five layers of mix, gravel, sand, clay, and limestone, each layer with a variable thickness. While Al-Dibdibba aquifer, which can be found in the Al-Haydariyah area and was investigated using 25 boreholes, only has two layers: a thin layer of clay in the bed that ranges in thickness from 10 to 2 meters, and sand. The average thickness of the unconfined aquifer in this area is 85 meters. With the aid of the usage of the GMS (Groundwater Modeling System) V 10.6.1 software, the geological formation for the two locations has been built and is depicted in **Figs. 2** and **3.**

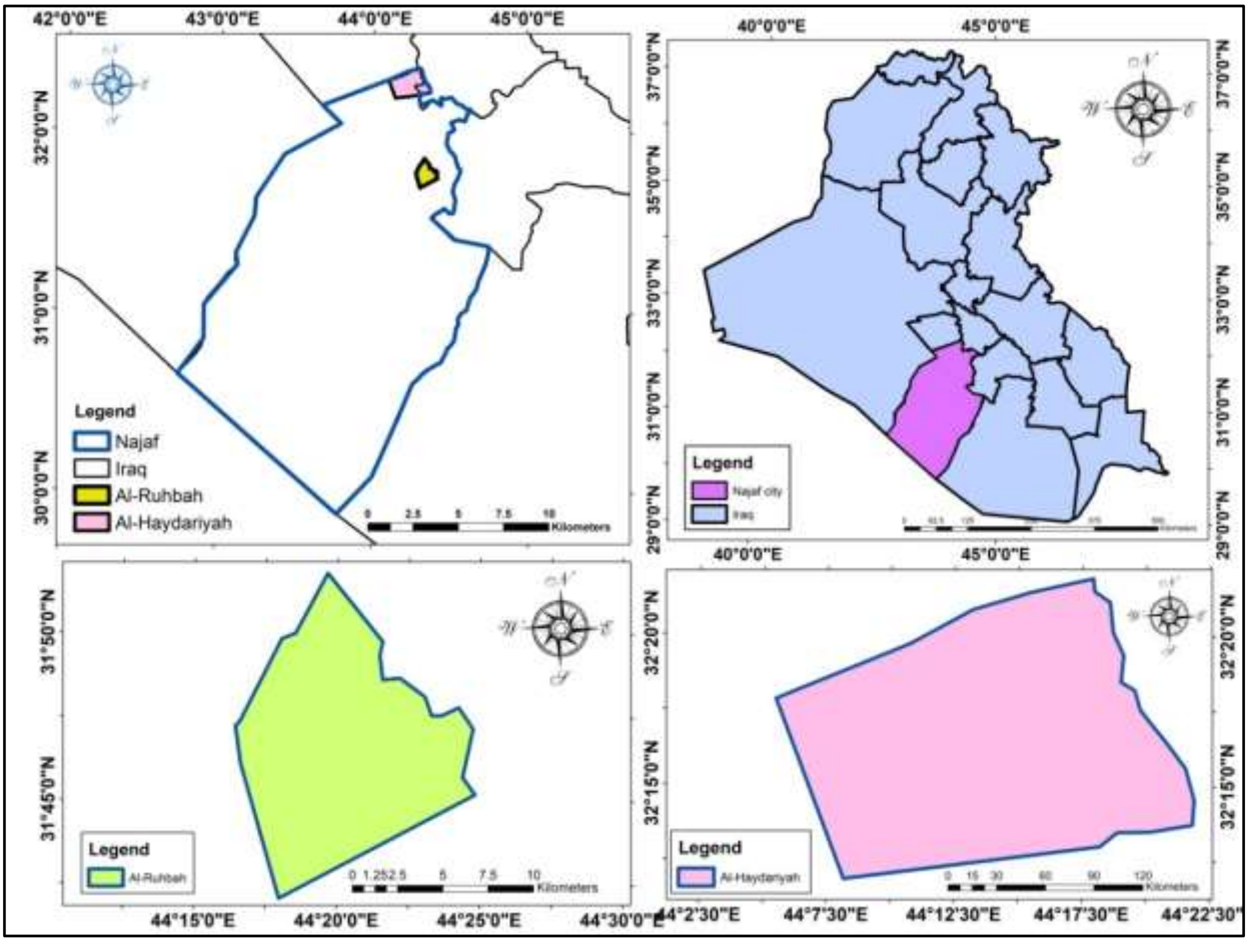

Figure 1. The location of the study areas by GIS software.

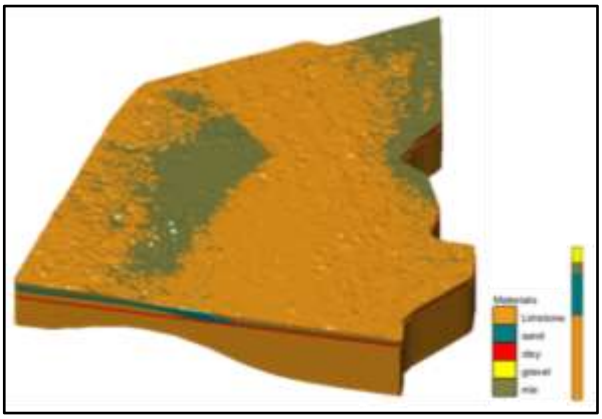

Figure 2. The solid model of the AL-Ruhbah model

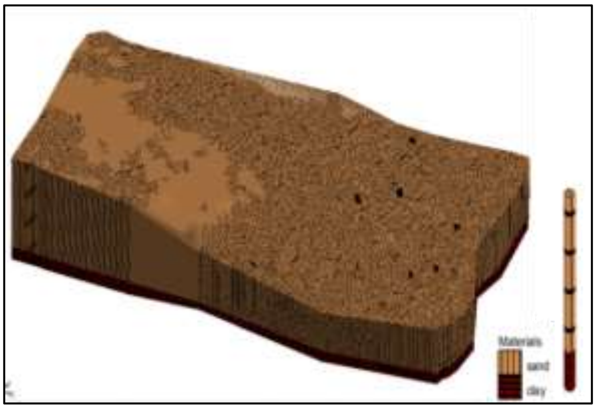

Figure 3. The solid model of the Al-Haydariyah model

As indicated in **Figs. 4** and **5**, which illustrate the ground surface elevation in the locations, the elevation of the ground surface in the AL-Ruhbah area ranges from 55 to 10 m, while in the Al-Haydariyah area ranges from 87 to 15 m. The ground elevation for the two research regions was estimated by converting the DEM created in GIS V 10.6.1 to TIN (Triangle Integration Network) in GMS V 10.6.1.

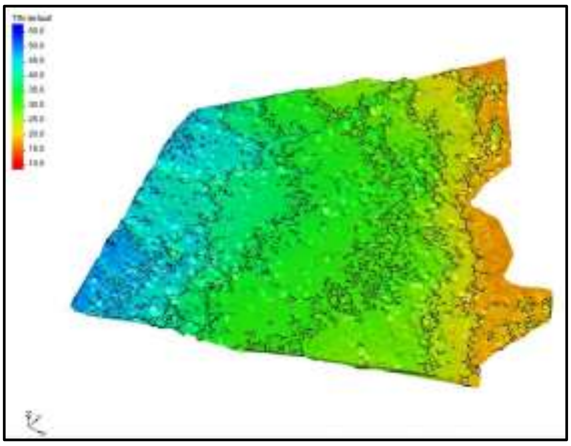

Figure 4. The elevation of the ground surface for the AL-Ruhbah model

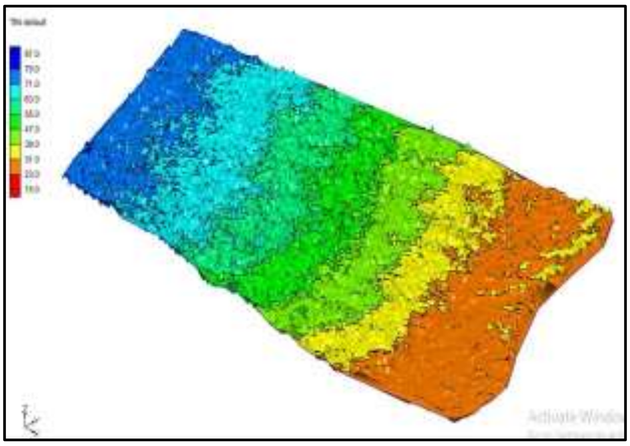

Figure 5. The elevation of the ground surface Al-Haydariyah model

3.2 The Fieldwork

A group of wells was chosen from the study areas for groundwater flow simulation, with 19 wells selected from the Al-Ruhbah area and 33 wells picked from the Al-Haydariyah area. The General Authority for Groundwater/Najaf collected data for drilled wells from 2013 to 2021, and the sites were visited to measure groundwater levels and collect samples for laboratory analysis. The following was the fieldwork:

3.2.1 Collecting Modeling Data

Field measurements in the two research sites were taken from 3/12/2021 to 4/1/2022. Data for six Al-Ruhbah monitoring wells and six Al-Haydariyah monitoring wells were obtained during that time. Their coordinates were determined using a GPS (Global Positioning System) gadget. The groundwater level in these wells was measured with a depth-measuring instrument (water sounder), as indicated in **Fig. 6**.
The water level indicator device provides the most accurate device for measuring the level of water in the well; it can reach a depth of 300 m and has a sensor that emits a specific sound when it comes into contact with the surface of the water in the well. It is a very important device used to monitor groundwater in aquifers. The groundwater head can be calculated after determining the groundwater elevation and ground surface elevation for each well. It should be emphasized that the wells are not operating but must be at rest while measuring groundwater elevation, thus monitoring groundwater elevation in the morning before the farmers activate the well is best.

3.2.2 Collecting Water Samples for Quality Management

Moreover, water samples were collected using plastic bottles with a capacity of 1 liter (preparing the bottles before use by washing them with distilled water first and then with the same water as the sample) **Fig 7**.

Figure 6. The device that use to measure the groundwater head

Figure 7. The laboratory measuring for the quality of the groundwater

3.3 The MODFLOW Model

The GMS V 10.6.1 was used in conjunction with the GIS V 10.6.1 to investigate the amount of groundwater in both regions. The processes for creating a conceptual model are outlined in **Fig. 8** and are followed by the GMS program when developing a model. There are five coverages in the conceptual model: Boundary coverage is a term used to describe the border of an area that has been generated using GIS software**, (Hussein and Abed, 2020).** It depends on the topography and the distribution of wells in the area. Coverage of sinks and sources: This coverage refers to the boundary conditions of the regions; all of the boundary conditions for the AL-Ruhbah area were constant head types, while all of the boundary conditions for the Al-Haydariyah region except the east side, which is a general head type due to the presence of the Euphrates River, were constant head types too. This coverage also records the wells, along with their coordinates and discharge. The third coverage is the recharge coverage: in this coverage, 5% of the annual rainfall for AL-Najaf city was used as an initial value for the recharge, which is equivalent to 91.3 mm/day, and it was corrected by calibration. The hydraulic conductivity coverage is the fourth coverage; the initial value of hydraulic conductivity for each stratum was determined **(Todd, 1980)**, and then corrected by calibration. The fifth and final coverage is the observation coverage, which consists of six observation wells for both regions as shown in **Tables 1** and **2**, and illustrated in **Figs. 9** and **10**.

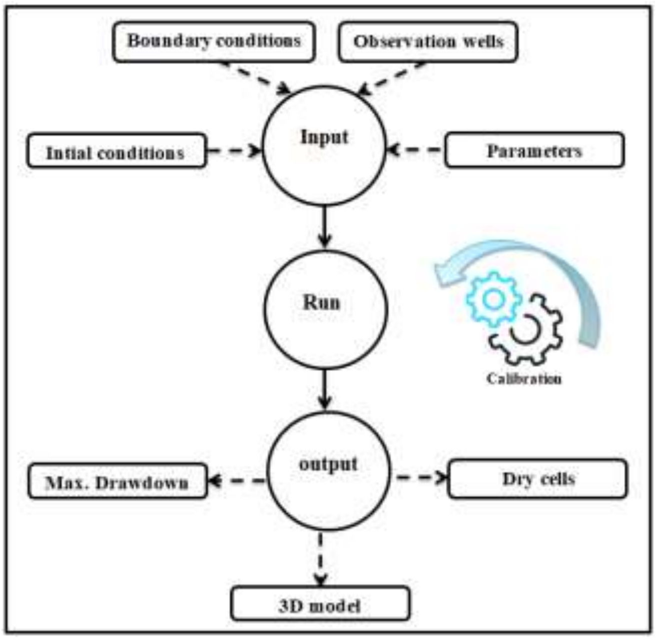

Figure 8. The processes to create the conceptual model by using GMS software, **(GMS Tutorials)**.

Table 1. The Observed and computed head of the monitoring wells for the AL-Ruhbah model by GMS software.

Well No.	Observed Head (m)	Observed head interval	Observed Head conf. %	Computed head (m)	Residual head (m)
W3	18.14	0.5	95	17.721	0.418
W23	12.0	0.5	95	12.500	-0.500
W25	12.5	0.5	95	12.500	0.000
W26	19.5	0.5	95	19.882	-0.382
W29	15.0	0.5	95	15.828	-0.828
W31	17.66	0.5	95	17.441	0.218

* conf. refers to confidence, **(GMS Tutorials)**.

Table 2. The Observed and computed head of the monitoring wells for the Al-Haydariyah model.

Well No.	Observed Head (m)	Observed head interval	Observed Head conf. %	Computed head (m)	Residual head (m)
W1	18.5	0.5	95	18.298	0.5019
W5	27.2	0.5	95	26.629	0.570
W11	33.8	0.5	95	34.236	-0.436
W14	20.0	0.5	95	19.774	0.325
W15	30.9	0.5	95	31.447	-0.497
W18	25.35	0.5	95	25.825	-0.475

After building the conceptual model the two regions have been run under a steady and unsteady state to prepare the two models for the prediction under different scenarios to test the quantity of the two models. The hydraulic characteristics of the aquifers have been determined by using the PEST package in the GMS software and with the aid of the observation wells and they are as indicated in **Table 3**.

Table 3. The hydraulic properties for AL-Ruhbah and Al-Haydariyah models.

Layers	Hydraulic conductivity (m/day)	Specific yield	Specific storage (1/m)	Vert. anisotropy (Kh/kv)
AL-Ruhbah model				
Limestone	10.0	0.010	0.0000477	3.0
Sand	8.121	0.126	0.00001	3.0
clay	0.240	0.012	0.00001	3.0
gravel	30.0	0.2	2.0 *10-6	3.0
mix	11.029	0.15	0.00001	3.0
The recharge rate		0.000039 m/day		
Al-Haydariyah model				
sand	17.490	0.3	0.00001	3.0
clay	1.042	0.012	5.251× 10-7	3.0
The recharge rate		0.00007 (m/day)		

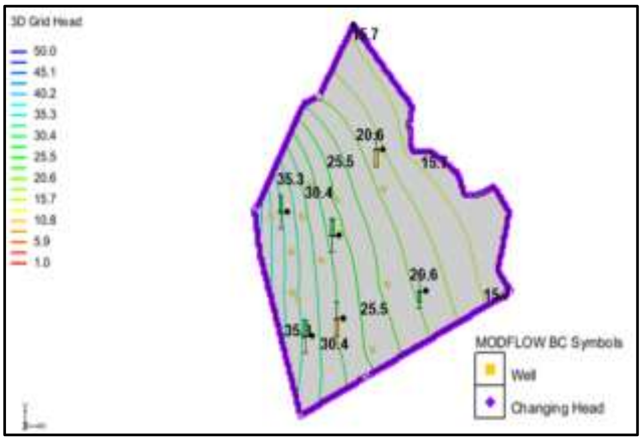

Figure 9. The calibration target for the AL-Ruhbah model.

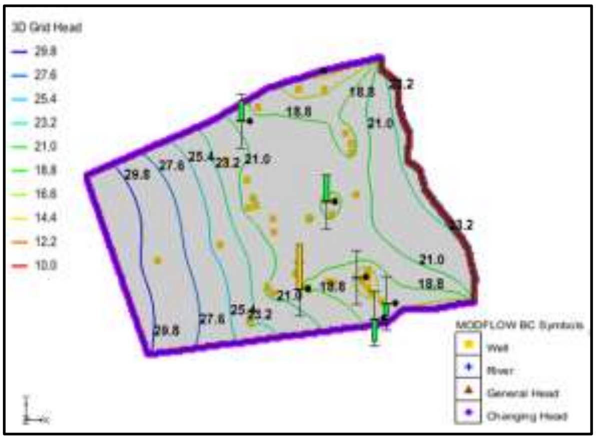

Figure 10. The calibration target for the Al-Haydariyah model.

3.4 The Scenarios of the Model

The wells were redistributed at particular and equal distances and operated under various pumping circumstances to determine the best and safest pumping scenario. A distance of 2000 m between the wells was chosen and three periods were chosen 4, 8, and 12 hours each day, and the wells were run for different scenarios for 1000 days.

3.4.1 AL-Ruhbah area

The distance between the wells in this scenario was 2000 meters, with 37 pumping wells operating at 4, 8, and 12 hours each day, respectively, and the highest fall in groundwater level was still constant and it was equal to 18.04 m. The pumping wells in this scenario and for all operation periods did not cause drying, so they are considered appropriate and as seen in **Fig. 11**.

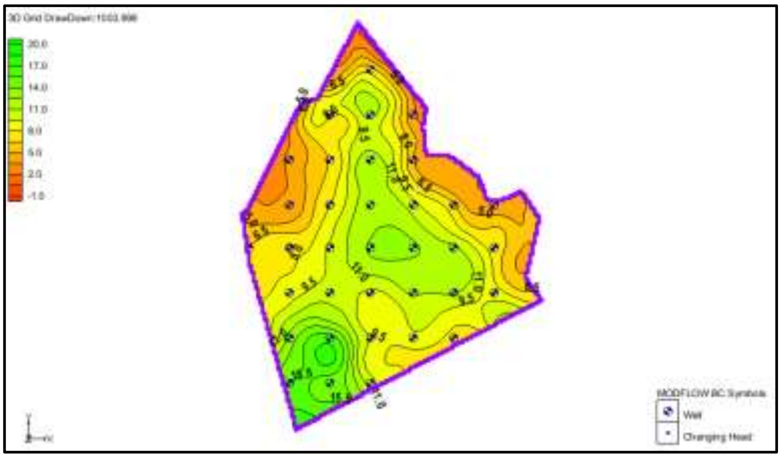

Figure 11. The drawdown of the piezometric head for the AL-Ruhbah model by GMS software.

3.4.2 Al-Haydariyah area

In this area, a distance of 2000 m was imposed between the wells, and thus the number of wells, depending on the chosen distance, was 87 well, and when it was operated with a period of 4 h/day and discharge 5 l/s and for 1000 days, the maximum drawdown in groundwater was equal to 0.81 m, it can be considered a safety scenario and can be adopted because it did not dry out the area. The maximum drawdown in groundwater was equal to 2.56 m when the operation period was equal to 8 h/d as illustrated in **Fig. 12**, this case also did not cause dry cells. However, when the model is run under the same previous conditions, but with an operation time of 12 hours per day, the maximum drawdown increases to 8.13 m, and this drawdown in the water level leads to the drying out of the area as shown in **Fig. 13**.

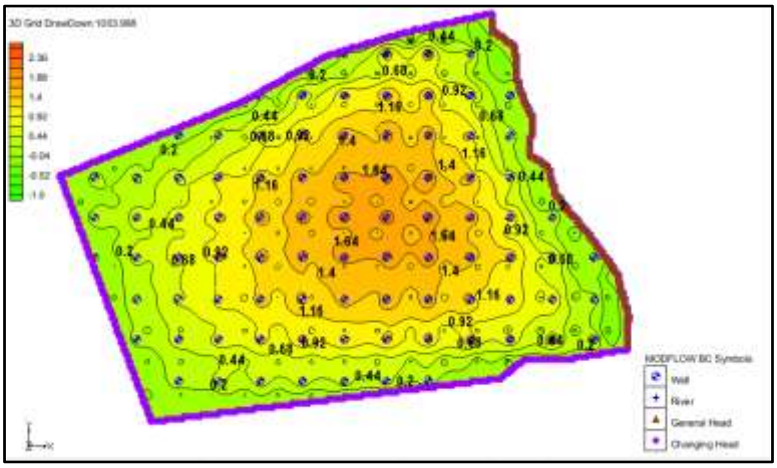

Figure 12. The drawdown of the water level, with 8 h/day, Q=5 l/s, and distance of 2000 m by GMS software.

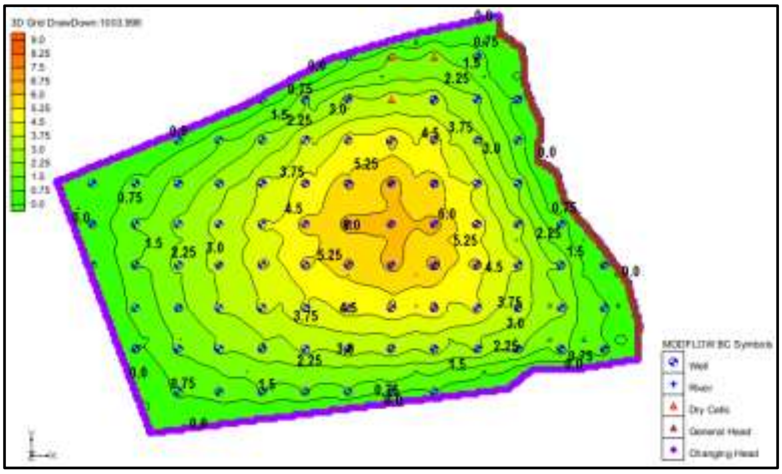

Figure 13. The drawdown of the water level, with 12 h/day, Q=5 l/s, and distance of 2000 m by GMS software.

4. THE QUALITY COMPREHENSION

For the quality determination 19 wells in AL-Ruhbah have been tested and 25 wells in Al-Haydariyah. The samples have been collected in the period 3/12/2021 to 4/1/2022 and have been tested in the laboratories of the Faculty of Engineering / University of Kufa using a set of devices. The TDS classification, WQI classification, and SAR classification have been used to determine the quality of the groundwater, also piper diagram has been used as follows:

4.1 TDS Classification

The results of the TDS for the AL-Ruhbah area revealed that the TDS was variable, with a range of 2180 - 4900 ppm and an average value of roughly 2806 ppm. Except for W2, W5, W8, W14, and W17, which were moderately salty, all the wells were somewhat slightly saline. As shown in **Table 4** and **Fig. 14**. While the TDS value for the Al-Haydariyah area varied from 2593.00 to 4777 with an average of 3112.61 mg/l. **Fig. 15** illustrates how much TDS is present in most of the wells of the Al-Haydariyah area and how this is classified. It indicates that the majority of the region is moderately saline to slightly.

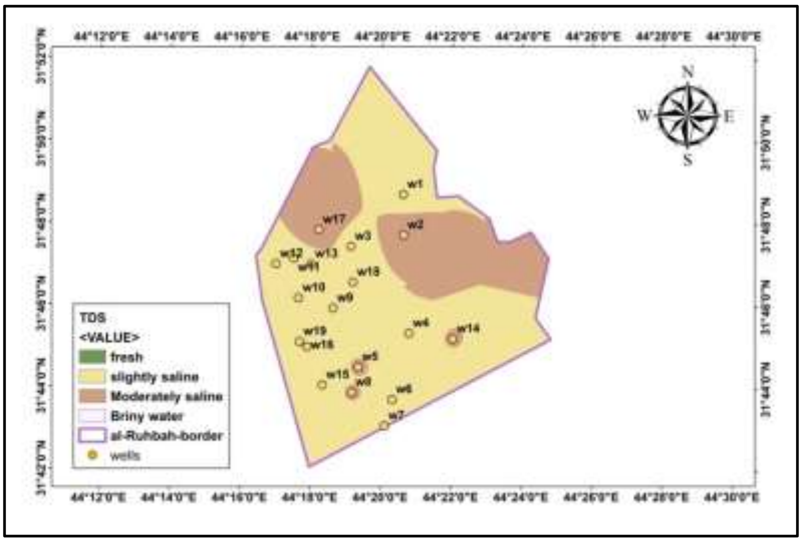

Figure 14. The distribution of the TDS concentration of the Al-Ruhbah area by GIS software.

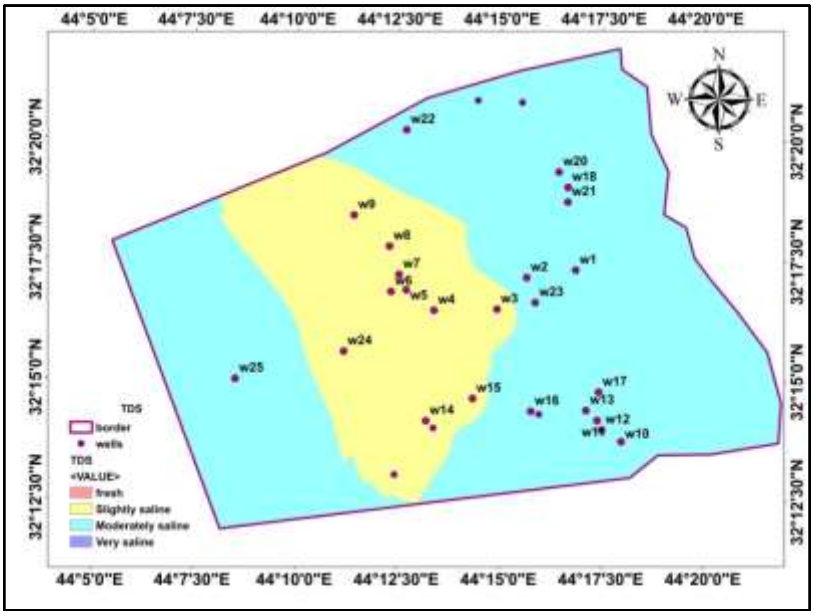

Figure 15. The distribution of the TDS concentration of the Al-Haydariyah area by GIS software.

4.2 WQI Classification

By using the water quality index, it is possible to categorize each well and determine whether or not it is suitable for drinking, the wells that fall under the good class in the AL-Ruhbah area are (w2, w3, w18, and w19), those that fall under the very poor category are (w9, w11, w12, w13 and w17), while all other wells are considered to be of the poor type, as illustrated in **Fig. 16**. The majority of the wells were deemed unfit for drinking, except the (W15, W24, W25, W26, and W27), which were of a very poor type, and the W18 and W21, which were of a poor category, according to the results of using the WQI index to more accurately classify human drinking sources. **Table 5** demonstrates the WQI estimates for the Al-Haydariyah region. **Fig. 17** depicts how the WQI of the research region is distributed.

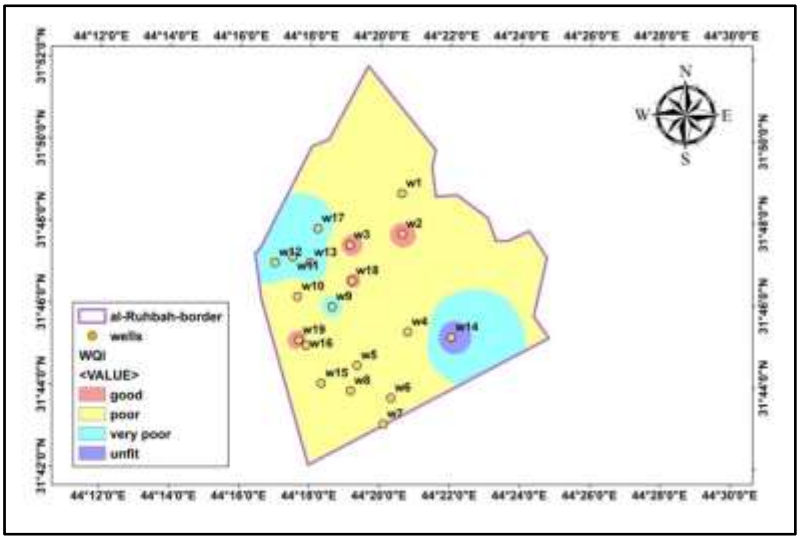

Figure 16. The distribution of the WQI for the AL-Ruhbah area by GIS software.

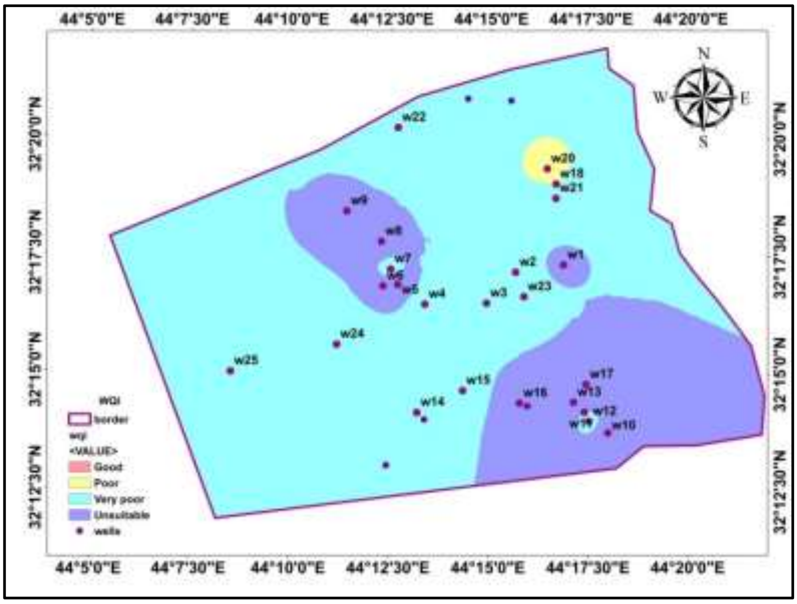

Figure 17. The distribution of the WQI for the Al-Haydariyah area by GIS software.

4.3 SAR Classification

When the SAR classification is applied to the wells in the research area of AL-Ruhbah, it is discovered that (W1 and W17) are good classes, (W15 and W16) are excellent, (W6, W7, and W14) are doubtful, while the remaining wells are unsuitable for irrigation based on the SAR classification (Table 2.6) and as shown in **Fig. 18**. When applying the SAR classification to the wells of the Al-Haydariyah study area, it is found that (W23, W24, W25, W26, and W27) are good class, W18 doubtful, while the others wells are unsuitable for irrigation based on SAR classification, as in **Fig. 19.**

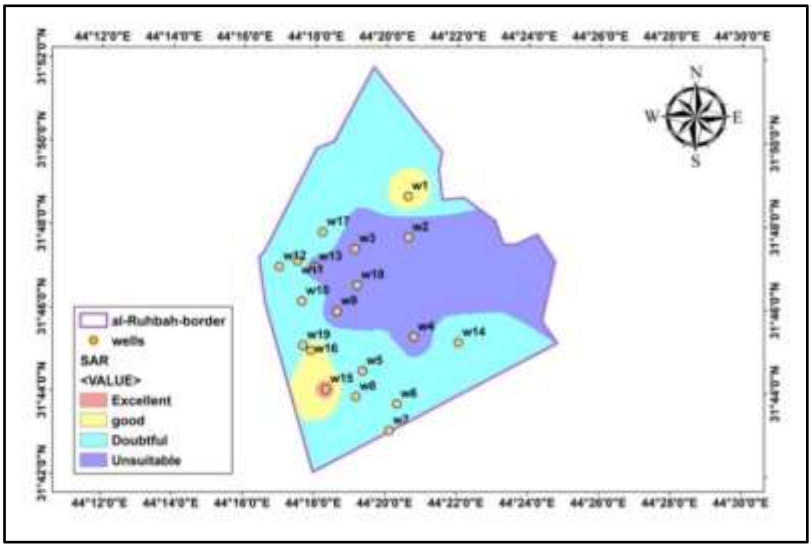

Figure 18. The distribution of the SAR classification for the AL-Ruhbah area by GIS software.

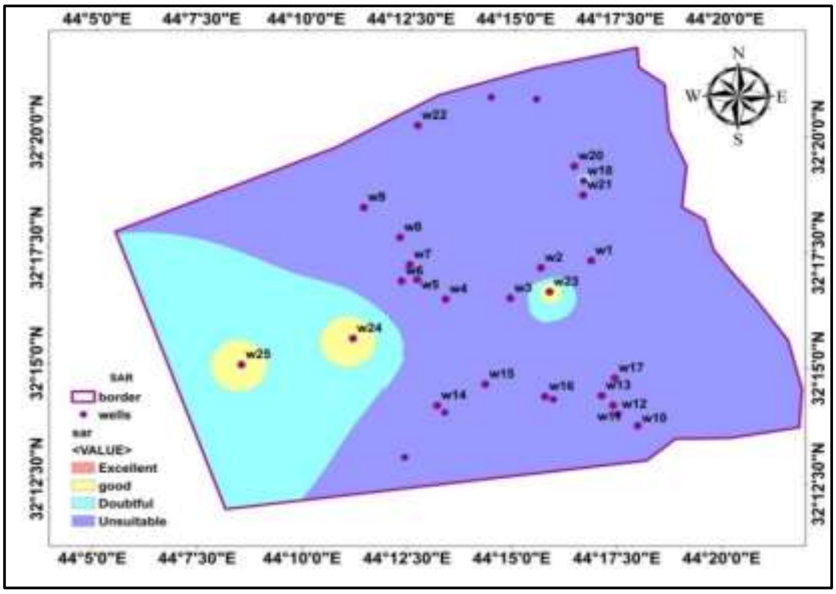

Figure 19. The distribution of the SAR classification for the Al-Haydariyah area.

4.4 Piper Diagram

The Piper diagram is divided into three sections, the first triangle represents cations, the second represents anions, and the composite features in the middle **(Abdulhussein, 2018)**. Software called Aquachem V.9 was used to categorize the groundwater in the AL-Ruhbah region and create the piper diagram For Al-Ruhbah The categorization according to the Piper Diagram yields the following results: Except W15, which is located in the C region and denotes the magnesium type, and (W2, W3) in the D area, which denotes the sodium and potassium type, all of the wells for the cations ions lie in the B area, where there is no dominating type. The wells located in the G, H, and F areas for the anions ions correspond to the Chloride type, No dominating type, and Sulfate type, respectively. Except for W2 and W3, which are located in the 7 area, which refers to Sodium chloride type wells, the type of the wells in the composite domain fall in the areas 6 and 9, respectively, which are Calcium chloride type and Mixed type, Strong acids, therefore, outweigh weak acids, which is where they are placed in the fourth section and as shown in **Fig. 20**.

For Al-Haydariyah, the classification using the Piper Diagram produces the following outcomes: Except for W21 in the D class, all of the wells in the B area for cations ions correspond to potassium and sodium type. The ions in sections F and H, which stand for sulfate type and no dominating type, respectively, are anions. The majority of the wells are situated in the 6 and 9 regions which refer to Calcium chloride type and Mixed type, and only W21 is situated in the 7 area which refers to Sodium chloride type, which causes the groundwater to fall in the fourth area that refers to Strong acids surpass weak acids. and as shown in **Fig. 21**.

Table 4. The quality of the groundwater for the AL-Ruhbah area.

well	TDS mg/l	TDS classification	WQI	Class of WQI	SAR value	Class of SAR
W1	2620	slightly saline	168.77	poor	10.2	Good
W2	3554	Moderately saline	81.05	good	41.4	unsuitable
W3	2268	slightly saline	68.86	good	35.0	unsuitable
W4	2990	slightly saline	99.80	good	26.8	unsuitable
W5	3076	Moderately saline	101.32	poor	26.3	unsuitable
W6	2861	slightly saline	141.51	poor	25.9	Doubtful
W7	2877	slightly saline	168.58	poor	24.8	Doubtful
W8	3076	Moderately saline	101.32	poor	26.3	unsuitable
W9	2967	slightly saline	233.36	very poor	30.5	unsuitable
W10	2370	slightly saline	125.70	poor	18.4	Doubtful
W11	2353	slightly saline	216.18	very poor	18.4	Doubtful
W12	2536	slightly saline	246.55	very poor	24.7	Doubtful
W13	2200	slightly saline	283.04	very poor	29.4	unsuitable
W14	3008	Moderately saline	358.65	unfit	23.7	Doubtful
W15	2260	slightly saline	194.11	poor	6.29	Excellent
W16	2180	slightly saline	110.39	poor	8.8	Excellent
W17	4900	Moderately saline	252.66	very poor	17.6	Good
W18	2940	slightly saline	85.64	good	34.1	unsuitable
W19	2287	slightly saline	77.40	good	27.3	unsuitable

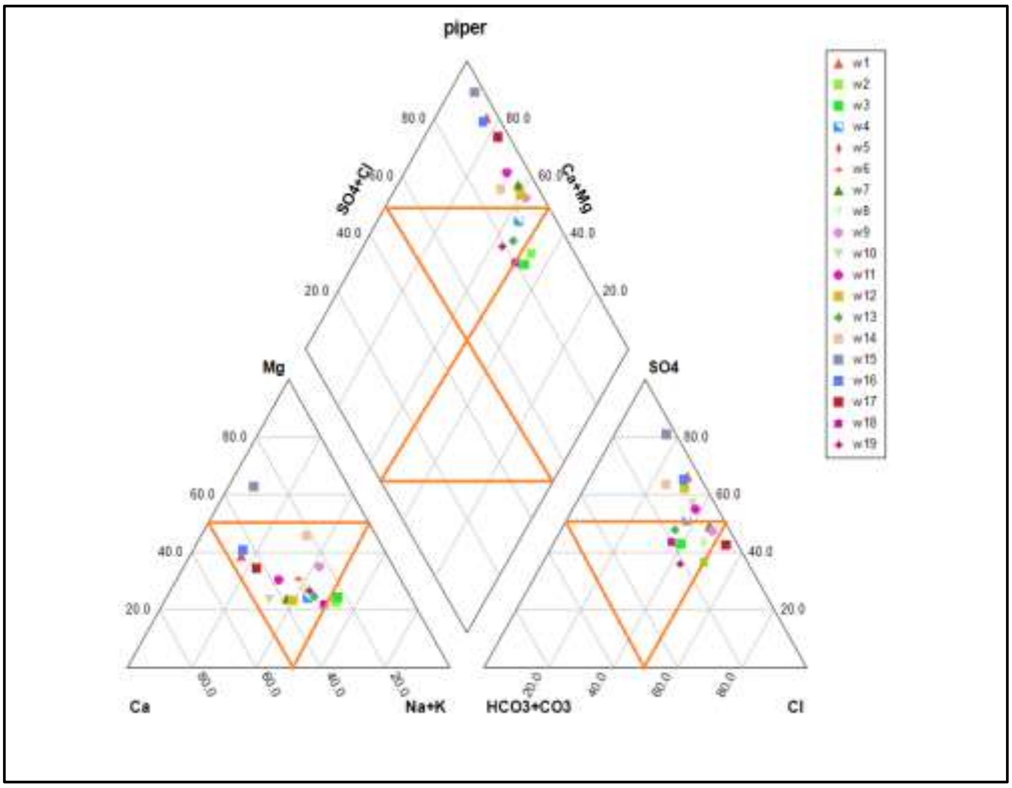

Figure 20. Piper diagram classification of AL-Ruhbah area for groundwater.

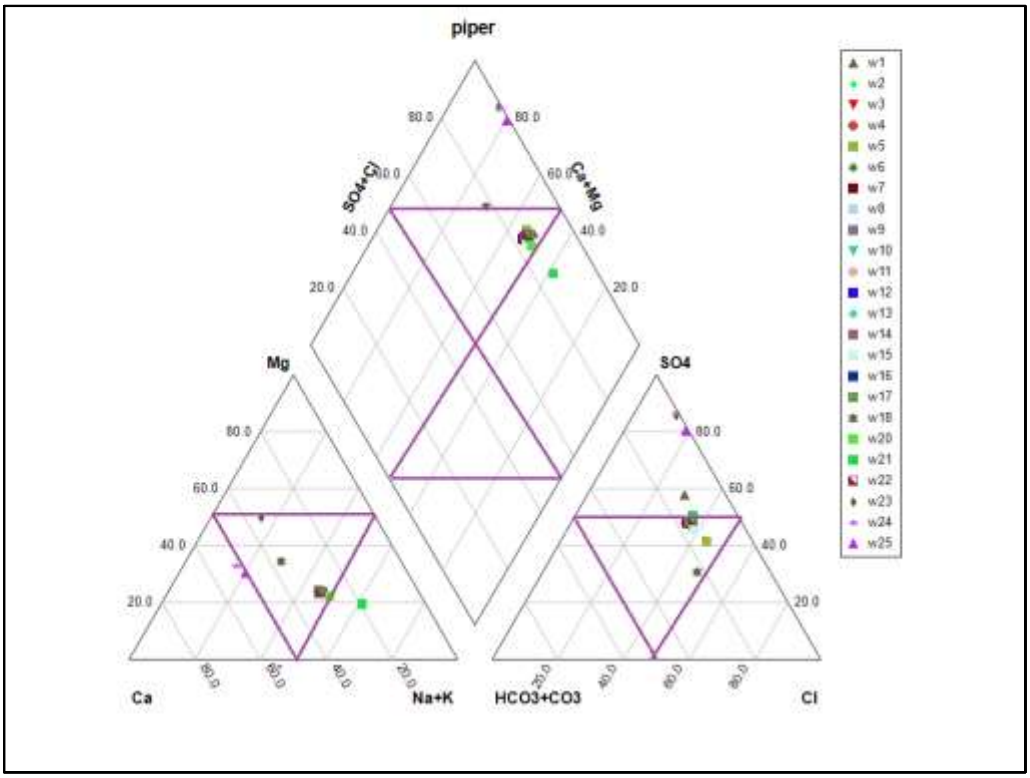

Figure 21. Piper diagram classification of Al-Haydariyah area for groundwater.

Table 5. The quality of the groundwater of the Al-Haydariyah area.

well	TDS mg/l	TDS classification	WQI	Class of WQI	SAR value	Class of SAR
W1	4777	Moderately saline	386.6	unfit	37.9	Unsuitable
W2	3256	slightly saline	319.3	unfit	36.0	Unsuitable
W3	2599	slightly saline	314.6	unfit	29.1	Unsuitable
W4	2675	slightly saline	318.7	unfit	30	Unsuitable
W5	2630	slightly saline	382.3	unfit	30.0	Unsuitable
W6	2593	slightly saline	362.4	unfit	30.1	Unsuitable
W7	2901	slightly saline	324.9	unfit	29.5	Unsuitable
W8	2879	slightly saline	387.02	unfit	32.5	Unsuitable
W9	2663	slightly saline	374.70	unfit	31.0	Unsuitable
W10	3218	slightly saline	412.97	unfit	34.2	Unsuitable
W11	3058	slightly saline	345.65	unfit	33.8	Unsuitable
W12	2981	slightly saline	313.13	unfit	31.9	Unsuitable
W13	3205	slightly saline	412.33	unfit	34.1	Unsuitable
W14	2988	slightly saline	319.10	unfit	32.4	Unsuitable
W15	2949	slightly saline	288.53	very poor	31.79	Unsuitable
W16	3351	slightly saline	411.24	unfit	35.24	Unsuitable
W17	3754	slightly saline	421.02	unfit	35.6	Unsuitable
W18	3550	slightly saline	186.43	poor	19.9	Doubtful
W20	3628	slightly saline	371.20	unfit	36.3	Unsuitable
W21	3506	slightly saline	124.35	poor	55.2	Unsuitable
W22	3888	slightly saline	350.89	unfit	32.3	Unsuitable
W23	3220	Moderately saline	263.27	very poor	12.6	Good
W24	2880	Moderately saline	249.37	very poor	11.01	Good
W25	4070	Moderately saline	281.19	very poor	16.3	Good
W26	3500	Moderately saline	272.98	very poor	14.0	Good
W27	2930	Moderately saline	260.71	very poor	11.4	Good

5. CONCLUSIONS

Following are some conclusions that were gained from the analysis of the results of the current study:

a. The geological formations in the two study areas differ significantly, based on data from borehole cross-sections provided by the General Authority of The Groundwater. The AL-Ruhbah region has five layers, including sand, gravel, limestone, and clay, whereas Al-Haydariyah has only two layers, sand, and clay.

b. In the AL-Ruhbah region, the confined AL-Dammam aquifer, with an average thickness of 175 meters, was investigated. AL-Dibdibba aquifer, in comparison, was studied in the Al-Haydariyah area. It is unconfined and has an average thickness of 85 meters, which is less than the first aquifer.

c. When a 2000 m distance between wells was taken into account, 37 wells were distributed in the AL-Ruhbah area while 87 wells were distributed throughout the entire area of Al-Haydariyah because the second area has a larger area than the first.
d. It was discovered that the maximum drawdown in the AL-Ruhbah area remained constant over 1000 days at three different operation times, 4, 8, and 12 h/day, without causing dry cells in the area and it was equal to 18.04 m. This indicates that the scenario is safe and that it is permissible to add more wells or increase the operation time without affecting the groundwater.
e. While the maximum drawdown for Al-Haydariyah and when operating the wells for 1000 days with 4 h/d and 8 h/d was 0.81 and 2.56 m, respectively, these two cases did not result in dry cells, operating the wells with 12 h/d resulted in a maximum drawdown of equal to 8.13 m and resulted in dry cells.
f. According to the scenarios, the AL-Ruhbah area's confined aquifer is less sensitive than the unconfined aquifer in Al-Haydariyah, even though the first aquifer's discharge was greater when it was equal to 10 l/s than the second, which was equal to 5 l/s. This is because the confined aquifer's thickness is much greater.
g. According to the TDS classification, the two study areas are categorized as slightly to moderately saline.
h. The groundwater quality evaluation for municipal use by using WQI considers that the groundwater in AL-Ruhbah and Al-Haydariyah region is unsuitable for this use, and the water requires extensive treatment to make it fit for this use.
i. In terms of irrigation and agriculture, groundwater in the two study areas could be used to irrigate and cultivate salt-tolerant crops. These plants or crops demand low-quality water according to the SAR classification.

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