Tikrit Journal of Pure Science (2023) 28 (6): 84-95
Doi:

TJPS

Tikrit Journal of Pure Science
ISSN: 1813 – 1662 (Print) --- E-ISSN: 2415 – 1726 (Online)
Journal Homepage: http://tjps.tu.edu.iq/index.php/j

The hydrogeological condition of Dibdibba aquifer between Karbala and Najaf in the middle of Iraq

Ahmed I. Abood[1], Sabar A. Salih[1], Ahmed N. Qwair[2]
[1]Department of Applied Geology, College of Science, Tikrit university, Tikrit, Iraq
[2]Ministry of Water Resources, National Center for Water Resources Management

Keywords: Hydrogeology; Water stream; Pumping test; Hydraulic properties; Depth of water.

ARTICLE INFO.

Article history:

-Received: 05 Sep. 2023

-Received in revised form: 09 Oct. 2023

-Accepted: 10 Oct. 2023

-Final Proofreading: 24 Dec. 2023

-Available online: 25 Dec. 2023

Corresponding Author*:
Ahmed I. Abood

ABSTRACT

The study area is located on the Dibdibba plateau in the middle of Iraq, particularly between the governorates of Karbala and Najaf. Given that the Dibdibba hydrogeological aquifer is thought to be the main source of water in this region, this site is chosen for performing the hydrogeological assessment. The study included 60 wells located on the west of the study area in Najaf Governorate. In these wells, the groundwater depths were measured in the field at the beginning of December 2021. The water stream was between 7.8 and 37.7 meters above the sea level, while the well depths ranged from 2.83 to 34 meters. Then, the spatial distribution of depths and water streams was mapped. Many wells were left by farmers because the water stream had gone down and the depth of the water had increased. The flow net of groundwater was determined to have two directions. The first direction was from the west to the east, and the second one was from the west and northwest to the southeast. The hydraulic properties of the Dibdibba aquifer in this study area were extracted by pumping tests. The experiments were carried out for five wells distributed over the area. The data was replaced with input into software for pumping tests, then analyzed by Newman's and Jacob's corrected methods for unconfined aquifers. Transmissivity values in experiments (T) ranged between 348 and 596 square meters/day, while hydraulic conductivity ranged between 14.1-22.5 m/day. The specific yield (Sy) equivalent to the storage coefficient in a confined aquifer was between 0.006 and 0.0302. The results of pumping test showed that the aquifer was of unconfined type according to the Neuman's and Jacob's corrected curves. In addition, the hydraulic property values were similar in all experiments with a slight difference, which may be related to the differences in saturated thickness, total depths, hydraulic gradient, and properties of rocks and sediments.

Tikrit Journal of Pure Science (2023) 28 (6): 84-95
Doi:

الوضع الهيدروجيولوجي لخزان دبدبة الجوفي بين كربلاء والنجف وسط العراق

أحمد اسماعيل عبود [1]، صبار عبدالله صالح [1]، أحمد ناظم كوير [2]

[1] قسم الجيولوجيا التطبيقية، كلية العلوم، جامعة تكريت، تكريت، العراق

[2] وزارة الموارد المائية، المركز الوطني لإدارة الموارد المائية.

الملخص

تقع منطقة الدراسة في جزء من هضبة دبدبة في وسط العراق بين محافظتي كربلاء والنجف، تم اختيار الموقع للتقييم الهيدروجيولوجي نظرا لأهمية خزان دبدبة في المنطقة. والذي يعتبر المصدر الرئيسي للمياه، شملت الدراسة 60 بئراً موزعة على المنطقة، حيث قيست اعماق المياه الجوفية في الحقل في ديسمبر 2021 م، وتراوحت بين (2.83 – 34) مترًا، بينما تراوح منسوب المياه الجوفية فيها بين (7.8 - 37.7) مترًا فوق مستوى سطح البحر، ومثلت الأعماق والمناسيب مكانيا بواسطة الخرائط، كما وجدت عدد كبير من الابار متروكة بسبب انخفاض مناسيب المياه الجوفية وزيادة الاعماق غرب منطقة الدراسة في محافظة النجف، ورسمت اتجاهات الجريان للمياه الجوفية في المنطقة، حيث وجد اتجاهين سائدين للجريان الاول الى الشرق والثاني الى الجنوب الشرقي، واستخرجت قيم الخواص الهيدروليكية المتمثلة بالتوصيلية الهيدروليكية ومعامل الناقلية والعطاء النوعي من خلال اجراء تجارب الضخ الاختباري لخمس ابار منتخبة في المنطقة، وحللت بياناتها بطريقتي نيومان وجاكوب المصححة للخزان غير المحصور، حيث تراوحت قيم معامل الناقلية في الابار Transmissivity (T) من (348-596) متر مربع/ يوم بينما التوصيلية الهيدروليكية (K) Hydraulic conductivity بين (14.1-22.5) متر/ يوم اما العطاء النوعي Specific Yield (Sy) فقد تراوحت قيمه بين (0.006-0.032)، وقد بينت هذه النتائج ان المكمن من النوع غير المحصور حسب منحنيات نيومان وجاكوب المصححة المتطابقة معه، وان المعاملات الهيدروليكية متقاربة نوعا ما في جميع التجارب، ولوحظ تفاوت طفيف بسبب السمك المشبع والاعماق المحفورة والانحدار الهيدروليكي، اما التقارب في النتائج فهو دليل على تجانس طبقات المكمن.

الكلمات المفتاحية: هيدروجيولوجي، منسوب الماء، الضخ الاختباري، المعاملات الهيدروليكية، العمق للمياه

Introduction

The last 60 years have seen unprecedented groundwater extraction and overdraft in all of the world [1]. By 2025, 1.4 billion people in about 48 countries will suffer from the water scarcity [2]. Iraq is going through an unprecedented severe water crisis for many reasons, including climate changes, lack of rain, and the policies of neighboring countries, in addition to the increase in requests due to the population growth [3]. The study area is located to the East of the Western Desert and includes 1114 square kilometers between Karbala in the north and Najaf in the south, along the Euphrates River in the west, within longitudes (43°90 -44°25́) and latitudes (31°95 -32°40). Its interior and the exposed geological formations are of Tertiary and Quaternary age (middle Eocene–Pleistocene). They are listed from the oldest to the newest: Dammam, Euphrates, Fat'ha, Injana, and Dibdibba [4]. Hydrogeologically, the study area is located within Mesopotamia and the Western Desert Zone, and the main aquifers of groundwater are Miocene carbonate and Mesopotamian plain silt [5] (see Fig. 1). The Dibdibba aquifer is the main aquifer in the study area. Since the population has grown on both sides of the road between Karbala and Najaf, it has also reduced the rate of groundwater recharge due to the change of the basin or watershed from natural land to an urban area. For this reason, the area requires studies and continuous monitoring of groundwater levels due to such processes as over-pumping, pollution, little recharge, and re-evaluation of developments in it. The study objectives include identifying the hydraulic head of groundwater in the Dibdibba aquifer, the sources of its recharge, as well as the direction of flow, and estimating the hydraulic parameter by pumping-test experiments and data analysis, thus determining the aquifer's natural drainage. The study area gradually elevates above the sea level as it flows from the west to the east. According to the data from DEM-30 and the US Geological Survey, its height is between 12 and 90 meters above the sea level (Fig. 2)

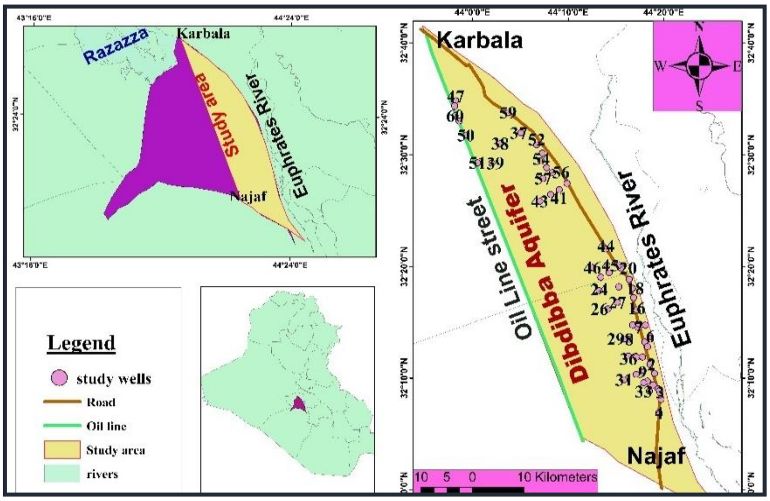

Fig.1. Location of the study area and wells

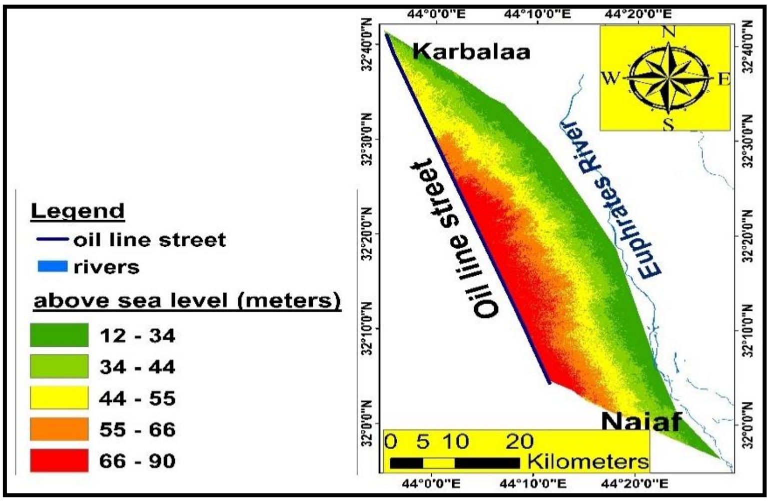

Fig.2. Topography of the study area

Methodology:

In this study, (60) wells from different locations in the area studied were monitored and the groundwater depth was measured by a sounder device, and then the spatial distribution of depths was drawn. After that, the water stream was determined by subtracting the depths of water from the elevation taken from a digital elevation model of the USGS (DEM-30) and dropped from the global mapper program because it was more accurate than the readings taken in the field by GPS. The spatial distribution of the water stream (a.s.l. meters) was drawn. In addition, the direction of groundwater movement was determined and crossed vertically with the water stream in order to draw the flow net. The hydraulic gradient was calculated according to Darcy's law in the northern, southern, and middle parts of the study area. The hydraulic properties of the Dibdibba aquifer were calculated by conducting five pumping experiments distributed in the study area and analyzing the data using Neuman's and Jacob's correct methods for the unconfined aquifer.

Many software applications were used to process and analyze the data as follows:

1. A location map of the research region was created with highlighting the location of wells. Then, a map of the test pumping wells' position, and spatial distribution maps for water dept, water level, hydraulic gra dient, and flow net) was created using the ArcGIS software.
2. The Global Mapper (22.1) was used for the corrected elevations by projecting well points on the Digital Elevation Model (DEM-30).
3. Aquifer Test (2011.1) was used to analyze the pumping test data with observing wells (multi-well), because it gave accurate analysis in this way in (PW1) (Fig. 8).
4. AQTESOLV was used to analyze the pumping test data of single-well pumping because of its high accuracy.

Results and Discussion

The values of water depths in the study area ranged between 2.83 and 34 meters below the earth's surface. The shallow depth was located in the eastern and northeastern regions, most possibly as a result of artificial groundwater recharge by the human activities in the suburban areas. Depths increased in the western and northern-west areas of the study area. It was also noted that farmers had left many wells, due to the drop in their water levels, and thus they had to drill another deeper well. The left wells and the water depth are shown in Fig. (3) and Table (1).

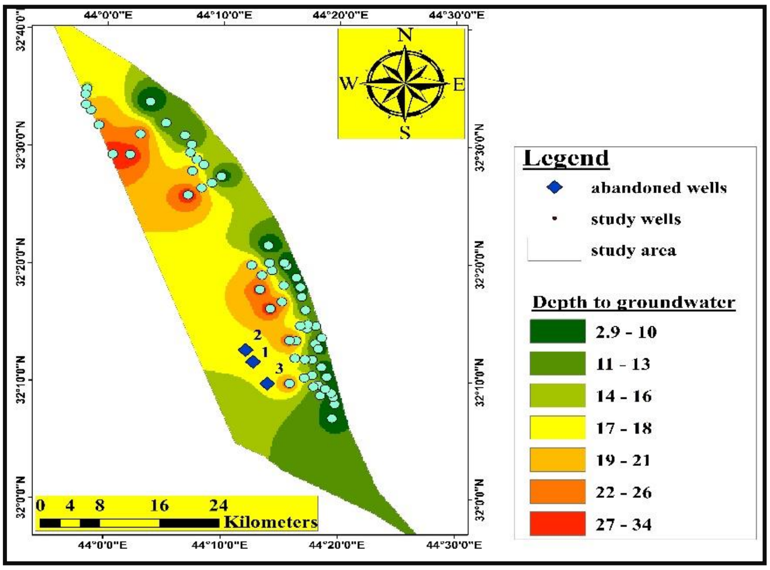

Fig.3. Depth of water (meter)

The levels of groundwater ranged between 7.8 and 37.7 meters above the sea level. The deeper levels were recorded in the west and northwest of the study area and the shallower depths were in the east and southeast parts of the study area, especially in Najaf Governorate. The water stream level is shown in Fig. (4) and Table (1).

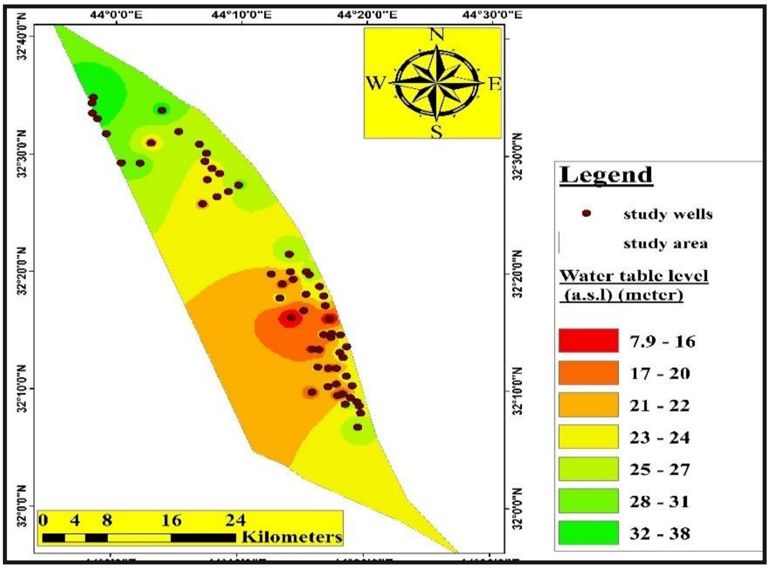

Fig. 4. Water stream level (a.s.l.) meter

The movement of groundwater flow was in two directions. The first direction was from the west towards the east, while the second one was from the west and northwest towards the southeast from Karbala to Najaf (Fig. 5).

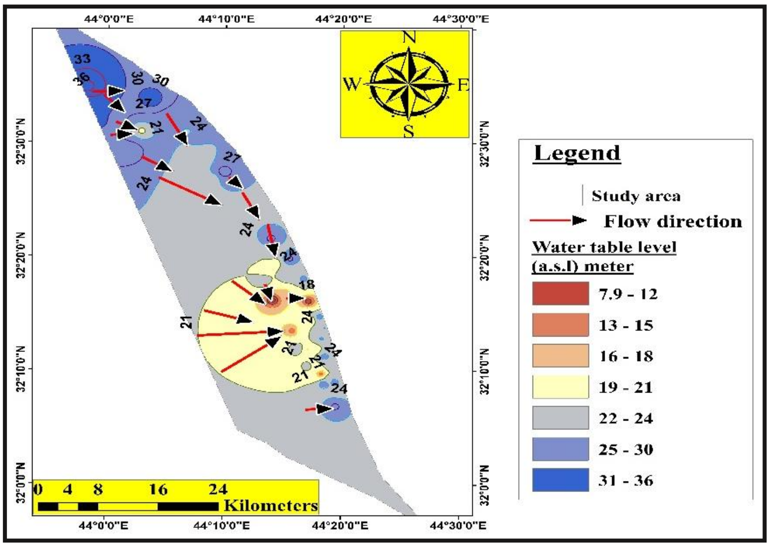

Fig.5. Groundwater flow-net of study area

Table (1). Depths and head levels of groundwater in the study area

Well N0.	Eastern	Northern	Elevation DEM	Depth of water	head	Well N0.	Eastern	Northern	Elevation DEM	Depth of water	head
BH-O1	436678.83	3555600	30.61	7.16	23.45	BH-31	430622.6	3558882.04	44.78	26.4	18.38
BH-O2	434905.74	3561427.93	31	5.31	25.69	BH-32	434434.55	3558616.51	31.44	18	13.44
BH-O3	436513.01	3556737.27	29.5	5.5	24	BH-33	433825.18	3558358.73	31.45	13.32	18.13
BH-O4	436326.93	3553378.99	36	8.21	27.79	BH-34	433667.17	3562633.8	31.08	12.3	18.78
BH-O5	434076.07	3565116.12	34.48	10.9	23.58	BH-35	432688.06	3562652.57	32.7	14.9	17.8
BH-O6	434935.33	3566034.35	30.4	6.34	24.06	BH-36	431346.05	3562827.86	43.3	20.03	23.27
BH-O7	432971.28	3567525.35	34.2	17.12	17.08	BH-37	414018.07	3599880.54	35.52	9.73	25.79
BH-O8	431497.56	3565587.76	41.09	22.17	18.92	BH-38	410584.74	3598115.21	45.26	24.9	20.36
BH-O9	433655.62	3560157.35	34.85	14.41	20.44	BH-39	409196.23	3594909.48	60.46	30.8	29.66
BH-10	434767.52	3556987.11	38.41	12.14	26.27	BH-40	421478.38	3591458.29	34.83	5.55	29.28
BH-11	436207.72	3557348.88	29.76	4.7	25.06	BH-41	420206.52	3590430.52	36.46	13.65	22.81
BH-12	435623.98	3559896.03	26.4	3.7	22.7	BH-42	418805.79	3589647.24	44.2	21.4	22.8
BH-13	434505.59	3564340.43	30.5	6.1	24.4	BH-43	416986.8	3588525.77	53.3	32.22	21.08
BH-14	434170.07	3567896.11	33.57	8	25.57	BH-44	427786.53	3580580.53	32.3	4.35	27.95
BH-15	433072.56	3568137.34	34.7	12.5	22.2	BH-45	427936.86	3577844.94	33.32	11.6	21.72
BH-16	432771.02	3570408.8	20.04	10.3	9.74	BH-46	425549.84	3577483.52	42.32	20.75	21.57
BH-17	432279.91	3572472.16	30.92	9.8	21.12	BH-47	403389.58	3605277.75	52.2	14.5	37.7
BH-18	432094.11	3574016.16	29.92	4.8	25.12	BH-48	403211.69	3604410.98	52.55	16.6	35.95
BH-19	431560.35	3575525.57	26.04	3.6	22.44	BH-49	403915.41	3601931.17	52.8	20.6	32.2
BH-20	430276.18	3577385.06	33.6	4.6	29	BH-50	405004.13	3599567.87	53	22.55	30.45
BH-21	429926.38	3577840.16	31.3	7.6	23.7	BH-51	406868.57	3594973.96	61.5	33.5	28
BH-22	428296.95	3576644.49	35.3	16.85	18.45	BH-52	416571.27	3597906.47	32.92	9.1	23.82
BH-23	426913.65	3575906.13	42.8	24.5	18.3	BH-53	417485.94	3596494.6	34.2	8.9	25.3
BH-24	426635.98	3573681.75	55.12	31.8	23.32	BH-54	417292.72	3595218.18	41	18.37	22.63
BH-25	429859.91	3574296.26	38.82	16.4	22.42	BH-55	418176.25	3594105.36	40.6	17.2	23.4
BH-26	428045.02	3570644.58	41.8	34	7.8	BH-56	419114.67	3593300.15	37.08	13.5	23.58
BH-27	429601.33	3571717.55	41	24.6	16.4	BH-57	417569.03	3592318.04	42.7	21.35	21.35
BH-28	432084.69	3567943.77	40.2	19.5	20.7	BH-58	435399.88	3558016.02	30.79	8.9	21.89
BH-29	430634.87	3565647.19	43.4	30.1	13.3	BH-59	411917.43	3603230.61	35.21	2.83	32.38
BH-30	432595	3559758	41	19.03	21.97	BH-60	403266.56	3602805.91	51.36	21.83	29.53

The hydraulic gradient was calculated according to Darcy's law, which represented the difference between the water stream level at two wells divided by the difference between their horizontal distances on the earth surface [6]. It calculated the north, middle, and south parts of the study area for wells using (equation 1):

$i = dh / dl$ ………………………….(1)

i: hydraulic gradient.
dh: the difference between the water stream level at two wells (meters).
dl: the difference between the horizontal distance of the two wells (meters). Where the value of the hydraulic gradient to the north of the study area was (0.0005), the middle was (0.00041) and the south was (0.0012) (Fig. 6).

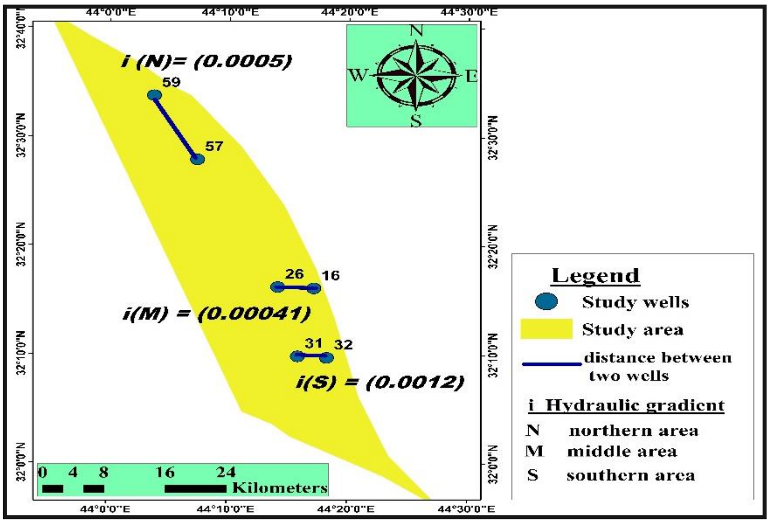

Fig.6. Hydraulic gradient of the study area

For evaluating the hydraulic properties of the Dibdibba aquifer, five pumping test experiments were conducted in the area. The locations of the wells used in the pumping test experiments shown in Fig. (7) were then analyzed by the correct methods of Neuman (1979) [7] and Cooper Jacob (1946) [8] for the unconfined aquifer [9].

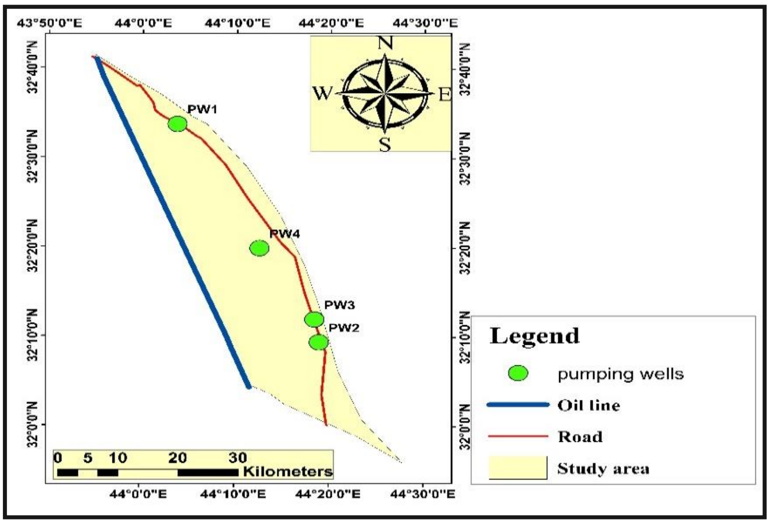

Fig.7. Locations of Test Pumping Wells in the study area

Pumping-Test Experiments

1. Authority for Groundwater / Karbala (PW1)

The total depth of the pumping well was (30) meters, the observing well was (82.26) meters away from it, and the depths of the water were measured in the pumping well (2.83) and the observing well (2.98) meters. The saturated thickness of the aquifer in that well was (27.1) meters, so the pumping rate was (8.0) L/sec (Table 2).

Table.2. Drawdown with time and depth of water for the Authority for Groundwater / Karbala (PW1)

Time(min)	Drawdown(m)	Depth to water(m)	Time(min)	Drawdown(m)	Depth to water(m)	Time(min)	Drawdown(m)	Depth to water(m)
0	0	2.98	9	0.11	3.09	35	0.2	3.18
1	0.05	3.03	10	0.12	3.1	40	0.2	3.18
2	0.05	3.03	12	0.12	3.1	50	0.2	3.18
3	0.07	3.05	14	0.13	3.11	60	0.21	3.19
4	0.08	3.06	16	0.14	3.12	70	0.21	3.19
5	0.09	3.07	18	0.15	3.13	85	0.23	3.21
6	0.1	3.08	20	0.15	3.13	100	0.23	3.21
7	0.11	3.09	25	0.18	3.16	115	0.23	3.21
8	0.11	3.09	30	0.18	3.16			

The data from experiment (1) was analyzed in the aquifer test program by using Neuman's method for an unconfined aquifer (Fig. 8). It was found that the transmissivity by Newman's method is equal to 415 square meters per day, the hydraulic conductivity is 15.3 meters per day, and the specific yield is 0.026 (Table 6).

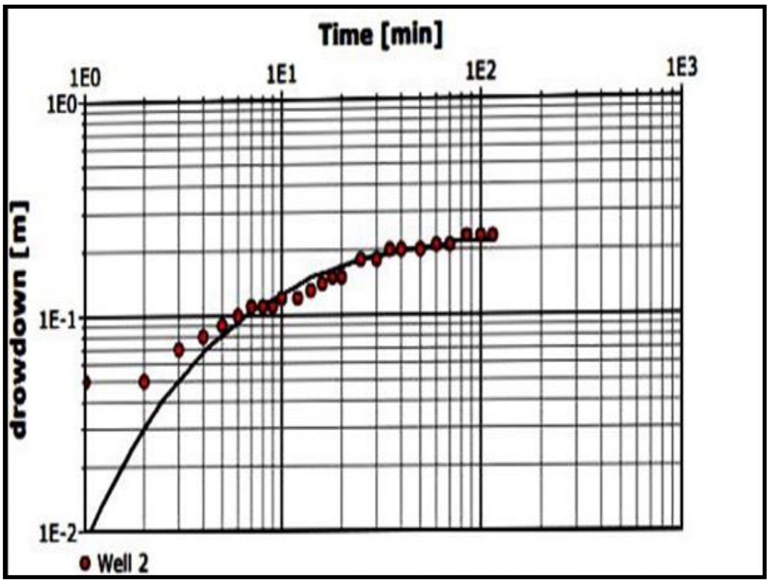

Fig.8. The Authority of Groundwater / Karbala by Newman curve Method

2- Ibrahim's Khalil Well/Najaf (PW2)

The drawdown levels were recorded with time through the pumping well itself (single well test), with a total depth of (30) meter (Table 3). The depth of water was 8.9 meters and the discharge rate was 8 L/sec. Then, the data was analyzed using the program AQTESOLV by Neuman's and Jacob's correct methods for the unconfined aquifer. The two methods and curves are represented in Fig. (10) and the results of the analysis are shown in Table (6).

Table.3. Drawdown with time and depth of water for Ibrahim's Khalil well/Najaf (PW2)

Time(min)	Drawdown(m)	Depth of water(m)	Time(min)	Drawdown(m)	Depth of water(m)	Time(min)	Drawdown(m)	Depth of water(m)
0	0	8.9	10	0.96	9.86	45	1.18	10.08
1	0.7	9.6	12	0.99	9.89	60	1.22	10.12
2	0.82	9.72	14	1.01	9.91	75	1.25	10.15
3	0.85	9.75	16	1.03	9.93	90	1.27	10.17
4	0.88	9.78	18	1.05	9.95	105	1.28	10.18
5	0.9	9.8	20	1.09	9.99	120	1.29	10.19
6	0.92	9.82	25	1.1	10	135	1.3	10.2
7	0.93	9.83	30	1.12	10.02	150	1.31	10.21
8	0.94	9.84	35	1.15	10.05	165	1.31	10.21
9	0.95	9.85	40	1.16	10.06	180	1.31	10.21

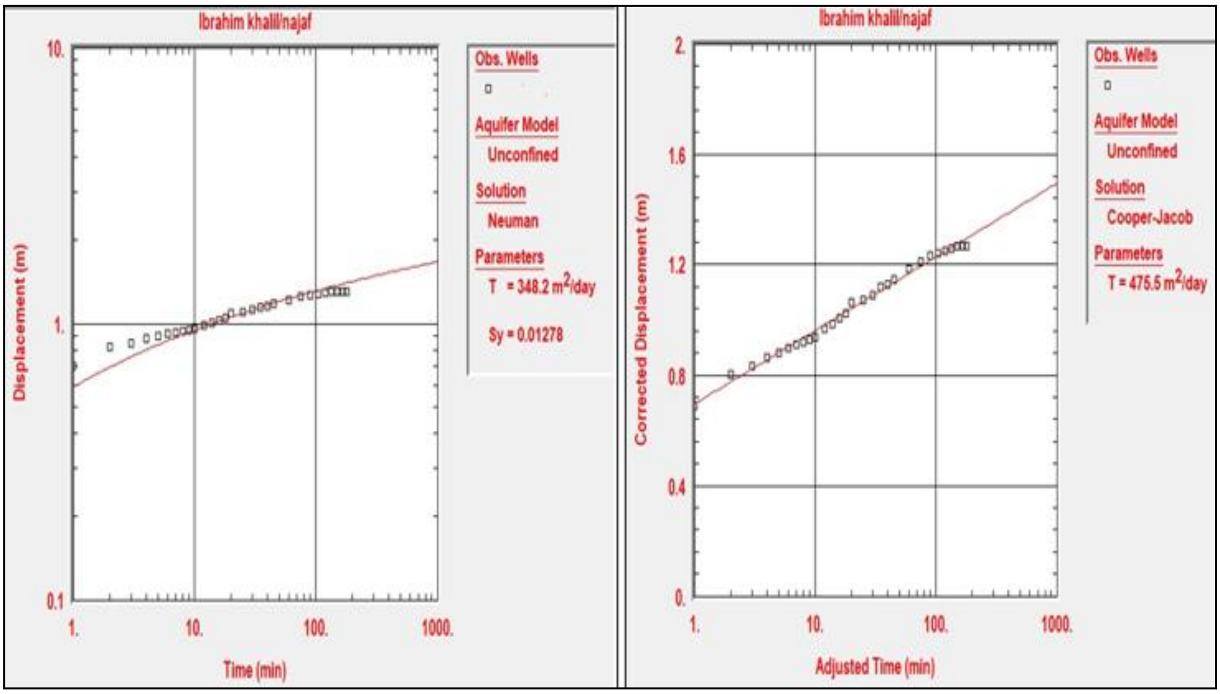

Fig.9. Ibrahim's Khalil well/Najaf (PW2) by using Neuman's and Jacob's correct methods

3- Sheaee Waqef Well (PW3)

The drawdown levels were monitored with time through the pumping well (single well test). The total depth of the well was 50 meters, and the water depth was 5 meters. When the pumping process began, the discharge was 8 L/sec, and the pumping continued for 105 minutes (Table 4). After that, the data was inserted in the AQTESOLV program and analyzed by using the methods of Neuman and Jacob for an unconfined aquifer (Fig. 10). The results are shown in Table (6).

Table.4. Drawdown with time and depth of water for Sheaee Waqef well (PW3)

Time(min)	Drawdown(m)	Depth of water(m)	Time(min)	Drawdown(m)	Depth of water(m)	Time(min)	Drawdown(m)	Depth of water(m)
0	0	5	10	0.89	5.89	50	1.02	6.02
1	0.76	5.76	12	0.9	5.9	60	1.03	6.03
2	0.81	5.81	14	0.91	5.91	75	1.04	6.04
3	0.83	5.83	16	0.92	5.92	90	1.05	6.05
4	0.84	5.84	18	0.93	5.93	105	1.05	6.05
5	0.85	5.85	20	0.94	5.94			
6	0.86	5.86	25	0.96	5.96			
7	0.87	5.87	30	0.98	5.98			
8	0.88	5.88	35	0.99	5.99			
9	0.88	5.88	40	1	6			

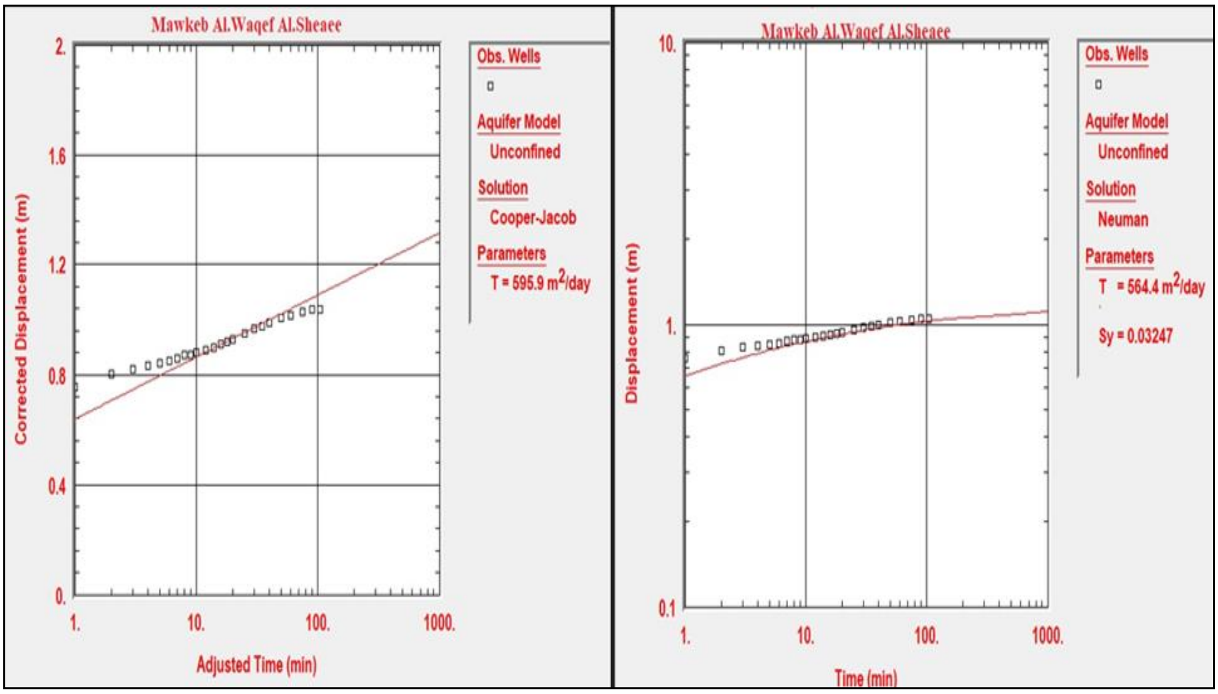

Fig.10. Sheaee waqef well (PW3) by using Neuman's and Jacob's correct methods

4- Mohammed Hussain Farm (PW4)

The total depth of the well was 54 meters, the readings of the drawdown were recorded with time in the pumping well (single well test) with a discharge of 7 L/sec. The depth of the water before the start of the pumping process was 31.8 meters, and the pumping lasted for 105 minutes until the level stabilized (Table 5). Then, the data was inserted in the AQTESOLV program for analysis by using Neuman's and Jacob's correct methods for an unconfined aquifer. The curve of drawdown in the two methods is shown in Fig. (11); the results of hydraulic properties are shown in Table (6).

Table.5. Drawdown with time and depth of water for Mohammed Hussain Farm (PW4)

Time(min)	Drawdown(m)	Depth of water(m)	Time(min)	Drawdown(m)	Depth of water(m)	Time(min)	Drawdown(m)	Depth of water(m)
0	0	31.8	10	0.92	32.72	45	1.14	32.94
1	0.65	32.45	12	0.95	32.75	60	1.18	32.98
2	0.78	32.58	14	0.97	32.77	75	1.21	33.01
3	0.81	32.61	16	0.99	32.79	90	1.23	33.03
4	0.84	32.64	18	1.01	32.81	105	1.24	33.04
5	0.86	32.66	20	1.05	32.85	120	1.25	33.05
6	0.88	32.68	25	1.06	32.86	135	1.26	33.06
7	0.89	32.69	30	1.08	32.88	150	1.27	33.07
8	0.9	32.7	35	1.11	32.91	165	1.27	33.07
9	0.91	32.71	40	1.12	32.92			

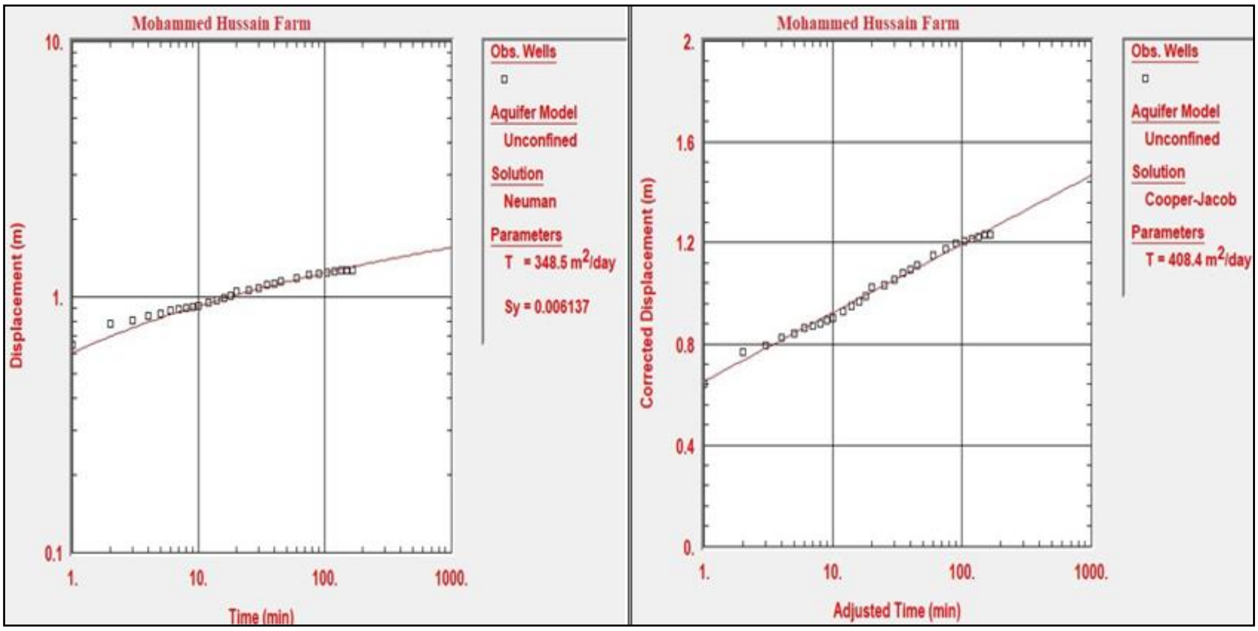

Fig.11. Mohammed Hussain Farm (PW5) by using Neuman's and Jacob's correct methods

Table 6. The hydraulic parameters of pumping test experiments in the study area

Well Id	Total depth (m)	Depth of water (m)	Saturated thickness (m)	Q (L/sec)	T (m^2/day)	K (m/day)	Sy	Type Of Method	Type Of Test	Draw down (meter)
PW1	30	2.83	27.17	8	415	15.3	0.026	Neuman	Observing well	0.23
PW2	30	8.9	21.1	8	348.2	16.5	0.012	Neuman	Single well test	1.31
					475	22.54	--	Jacob correction		
PW3	50	5	45	8	564.4	14.11	0.032	Neuman	Single well test	1.05
					595.9	14.9	--	Jacob correction		
PW4	54	31.8	22.2	7	348	15.7	0.006	Neuman	Single well test	1.27
					408	17.08	--	Jacob correction		

Conclusions and recommendations

1. The depths of the groundwater in the west and northwest areas under study (which represent a recharge area) were much greater than those in the east area near the Euphrates River and the road connecting Karbala and Najaf, representing a discharge area as a result of the current low level.
2. The levels of water stream under study were higher in the west than in the east, where there is a dense population, because of an artificial recharge of groundwater.
3. Due to the lower groundwater levels and deeper water, it was observed that there were numerous abandoned wells in the western part of the study area in Najaf. This caused other wells to be drilled there, but at a greater depth.
4. There were two main groundwater flow directions in the study area: the first one was from the west to the east (from Karbala to Najaf), and the second one was from the northwest to the southeast towards the road between Karbala and Najaf, as it is considered a drainage area due to the large number of wells scattered around it.
5. There were differences in the hydraulic gradient values of the groundwater in the study area. They were lower in the middle of the area towards the east due to the presence of artificial recharge sources, whereas they were higher in the south and north due to over pumping as well as the topography and bed sloping that were inherent to the region.
6. The results of the pumping test analysis for various locations in the study area reported that the Dibdibba aquifer's hydraulic parameter values were the same, with only minor variations in specific yield, transmissivity, and hydraulic conductivity caused by variations in saturated thickness, total depths, and hydraulic gradient.

As for the recommendations, they are presented as follows:

1. Using continuous electronic observation of groundwater levels in specific wells distributed thoughtfully within the study area to enable researchers to get data more easily and accurately without having a hard field work.
2. Farmers and people should be warned about random drilling and the non-governmental drilling companies must obtain permission from the Ministry of Water Resources and the Ground Water Directory before starting to drill new wells under the supervision of a geologist or hydrogeologist.

References

1. Dillon, P., Stuyfzand, P., Grichek, T., LIuria, M., Pyne, R., Jain, R., Bear, J., Schwarz, J., Wang, W., and Fernández, E. (2019). Hydrogeology journal 27, 1-30
2. Saleh, S. A., Abdulrahman, O. R., & Salih, A. M. (2018). Innovated method to estimate the water income in the section of Tharthar Valley near the Site of Hatra Proposed Dam. *Tikrit Journal of Pure Science, 22*(6), 88-102.
3. Al- Ansari, N. (2018). Al Jazeera Center for Studies, The Risks of the Water Crisis in Iraq, Report.
4. Jassim, S. Z. and Goff, J. C. (2006). Geology of Iraq. DOLIN, sro, distributed by Geological Society of London

5. Al-Jiburi, H.K. and Al-Basrawi, N.H. (2015). Hydrogeological map of Iraq, scale 1: 1000 000, 2nd edition, Iraqi Bulletin of Geology and Mining, Vol.11, No.1, p. 17-26.
6. Kresic, N. (2023). Hydrogeology 101, Introduction to Groundwater Science and Engineering, Published by Blue Ridge Press LLC, Book, Lecture 2,3, P27, 32,34.
7. Neuman, S. P. (1979). Perspective on ‘delayed yield’. Water Resources Research, 15(4), 899-908.
8. Cooper Jr, H. H., & Jacob, C. E. (1946). A generalized graphical method for evaluating formation constants and summarizing well-field history. Eos, Transactions American Geophysical Union, 27(4), 526-534.
9. Kruseman, G.P., and de Ridder, N.A. (1990). Analysis and Evaluation of Pumping Test Data. 2nd ed., for Land Reclamation, Wageningen, the Netherlands, 377p.