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Hydrogeological Assessment of Aquifers in Al-Hawija City, Kirkuk, Northern Iraq

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ABSTRACT

Groundwater is a significant source of fresh water for drinking, agriculture, and various other uses worldwide. The current study intends to determine groundwater aquifer types and estimate the hydraulic properties of the aquifers within the study area. The pumping test process was applied on five pumping wells with monitoring wells where the hydraulic conductivity values varied (22.02-65.5) m/day, while the transmissivity values ranged between (695-3413) m2/day. The storage coefficient ranges between (0.00074-0.0037). The aquifer type is a semi-confined aquifer based on the results of the hydraulic properties (transmissivity, T; hydraulic conductivity, K; and storage coefficient, S). The study area has been classified as heterogeneous and anisotropic, and the main groundwater movements are from south to west and northwest, recharged from the Bai Hassan Formation (the lower aquifer in the study area) exposed in the away regions. When the precipitation occurs on the mountaintops, it infiltrates into the formation and continues to move toward the study area.

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التقييم الهيدروجيولوجي للخزانات المائية في مدينة الحويجة، جنوب غربي كركوك، شمالي العراق

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الملخص

المياه الجوفية هي مصدر مهم للمياه العذبة للشرب والزراعة واستخدامات أخرى مختلفة في جميع أنحاء العالم. تهدف الدراسة الحالية إلى تحديد أنواع خزانات المياه الجوفية وتقدير الخصائص الهيدروليكية للخزانات المائية داخل منطقة الدراسة. تم تطبيق عملية اختبار الضخ على خمسة آبار ضخ مع آبار مراقبة حيث تراوحت قيم التوصيلية الهيدروليكية (22.02-65.5) م / يوم، بينما تراوحت قيمة النفاذية بين (695-3413) م 2 / يوم. وتراوحت قيمة معامل التخزين ما بين (0.00074-0.0037). الخزان المائي الجوفي هو من النوع شبه المحصور. بناءً على نتائج الخصائص الهيدروليكية (الانتقالية T، التوصيلية الهيدروليكية K، معامل التخزين S)، فقد تم تصنيف منطقة الدراسة على أنها غير متجانسة ومتباينة الخواص وحركة المياه الجوفية الرئيسة من الجنوب إلى الغرب والشمال الغربي وأن المصدر الرئيس لتغذية المياه الجوفية هو تكوين باي حسن وهو الخزان المائي السفلي في منطقة الدراسة وهو مكشوف في المناطق البعيدة. عندما تحدث الأمطار على قمم الجبال فإنها تتسرب إلى التكوين وتستمر في التحرك نحو منطقة الدراسة.

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Introduction

Groundwater represents all water located below the Earth's surface (Schwartz and Zhang, 2024). In Iraq, the scarcity of water resources, particularly surface water, has resulted in the inclination to utilize groundwater for domestic, agricultural, and industrial requirements (Al-Hayali et al., 2021). Groundwater is vital in regions where surface water is insufficient to fulfill daily requirements (Mohammed et al., 2021). The significance of an aquifer is determined by its primary attributes, including permeability, extent, and thickness (Jassim and Goff, 2006). Hydrogeological approaches are crucial for the development and management of groundwater resources and their exploitation (Agha and Al-Tamimi, 2022). An aquifer is a geological structure or formation that is permeable and porous, allowing water to move freely at different rates. It is bordered either from the bottom, top, or both, by layers of solid sediments that do not allow water to pass through (Maliva, 2016). The area is characterized by a semi-arid climate (Soran, 2008). This study focuses on investigating the depth and flow directions of groundwater, as well as determining the hydraulic properties such as transmissivity (T), hydraulic conductivity (K), and storage coefficient (S) of the aquifer in question using data obtained from pumping tests of the water-bearing units in the study area. The aim is to understand and effectively manage aquifers for long-term sustainability.

Location of the study area

Al-Hawija City is located in Kirkuk Province in northern Iraq. It is located within the geographical coordinates between longitudes 43°44'0"E to 43°49'0"E and latitudes 35°18'30"N to 35°21'30"N. Additionally, it has an elevation of 179-210 m above sea level. The location is situated 65 kilometers southwest of Kirkuk City. It represents the largest and most significant town in Kirkuk Province and Iraq (Al-Jumaily, 2007) (Fig. 1).

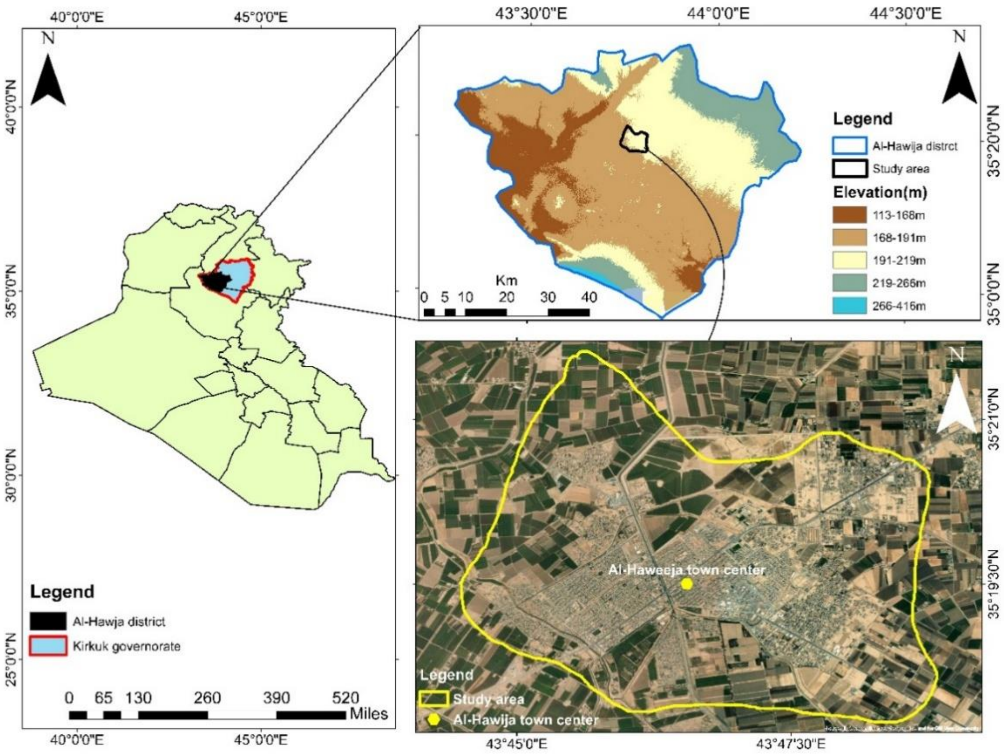

Fig. 1. Location map of the study area.

Geological setting

Tectonically, the city is located within the range of a low folded zone in the Hemrin-Makhul subzone (Jassim and Goff, 2006).

Stratigraphically, it is covered with Quaternary deposits that consist of river deposits forming floodplains, and there is no formation exposed on the surface (Buringh, 1960). Where Al-Hawija district consists of the Fatha Formation (Middle Miocene), Injana Formation (Upper Miocene), Mukdadyia Formation (Late Pliocene), Bai-Hassan Formation (Upper Pliocene), and Quaternary deposits, as shown in Figure 2 (Awadh et al., 2016; Gharib et al., 2024).

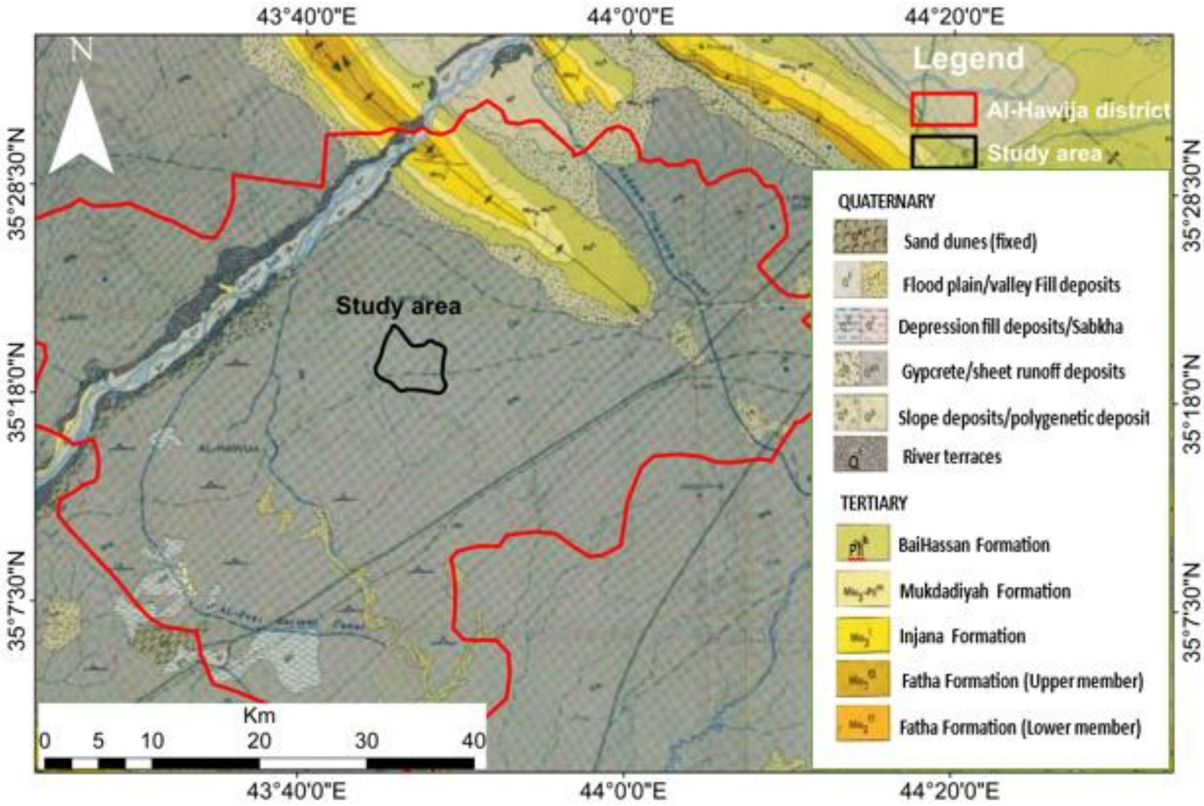

Fig 2. Geological map of the Al-Hawija district (Sissakian, 1992).

Materials and Methods

According to Darcy's law, the groundwater moves from the higher hydraulic head area to the lower hydraulic head area (Wang et al., 2022). The flow direction map is created by measuring the groundwater depths of 20 wells in the study area, as shown in Table 1 and Figure 3. The depths of groundwater were measured by a groundwater level meter (sounder device). The hydraulic properties of the aquifer were determined by performing a pumping test to determine (K, T, and S). Pumping tests were conducted in five pumping wells with monitoring wells (W10 with OW-1, W17 with OW-2, W18 with OW-3, W19 with OW-4, and W20 with OW-5) (Table 2 and Fig. 4). The pumping test was performed for at least 3 to 4 hours to reach a steady state condition. There are many methods for data analysis used for this purpose, such as Theis, Cooper-Jacob, Hantush, Walton, and Neuman (Kruseman and Ridder, 1979). (Theis, Hantush) methods are used in the current study for data analysis (Figs. 7-11; Tables 3-6). Because the aquifer is located in semi-confined conditions. The data for drawing the pumping wells correlation in the study area were taken from the Water Drilling Department, Governorate of Kirkuk, and drawn using the Starter software package, version 3 (Fig. 6).

Table 1: Water wells basic data of the study area (SWL is defined).

Wells Symbol	Longitude (E)	Latitude (N)	Elevation (m)	Depth to water table (m a.s.l)	SWL (m a.s.l)
W1	43°47'35.00"E	35°19'58.60"N	196	26.43	169.57
W2	43°46'48.70"E	35°19'23.60"N	193	20.5	172.5
W3	43°47'50.10"E	35°19'18.38"N	192	21.65	170.35
W4	43°45'42.40"E	35°19'35.20"N	189	17.9	171.1
W5	43°45'44.40"E	35°19'35.40"N	189	17.9	171.1
W6	43°45'32.20"E	35°19'17.70"N	187	16.9	170.1
W7	43°45'34.70"E	35°19'18.70"N	187	16.9	170.1
W8	43°45'57.40"E	35°19'7.30"N	190	16.2	173.8
W9	43°45'44.50"E	35°19'5.90"N	189	15.8	173.2
W10	43°47'16.80"E	35°19'15.60"N	193	20	173

W11	43°47'23.80"E	35°19'9.10"N	194	20.28	173.72
W12	43°47'21.30"E	35°20'0.90"N	196	25.15	170.85
W13	43°46'7.10"E	35°19'54.70"N	191	19.24	171.76
W14	43°45'13.90"E	35°19'21.40"N	186	16.7	169.3
W15	43°47'1.90"E	35°19'52.50"N	197	25.05	171.95
W16	43°47'15.40"E	35°19'35.90"N	193	21.65	171.35
W17	43°48'25.80"E	35°18'20.80"N	192.12	19.95	172.17
W18	43°48'12.00"E	35°19'57.00"N	198.12	27	171.12
W19	43°45'15.40"E	35°21'14.50"N	188	18.9	169.1
W20	43°44'54.40"E	35°18'57.30"N	184	13.32	170.68

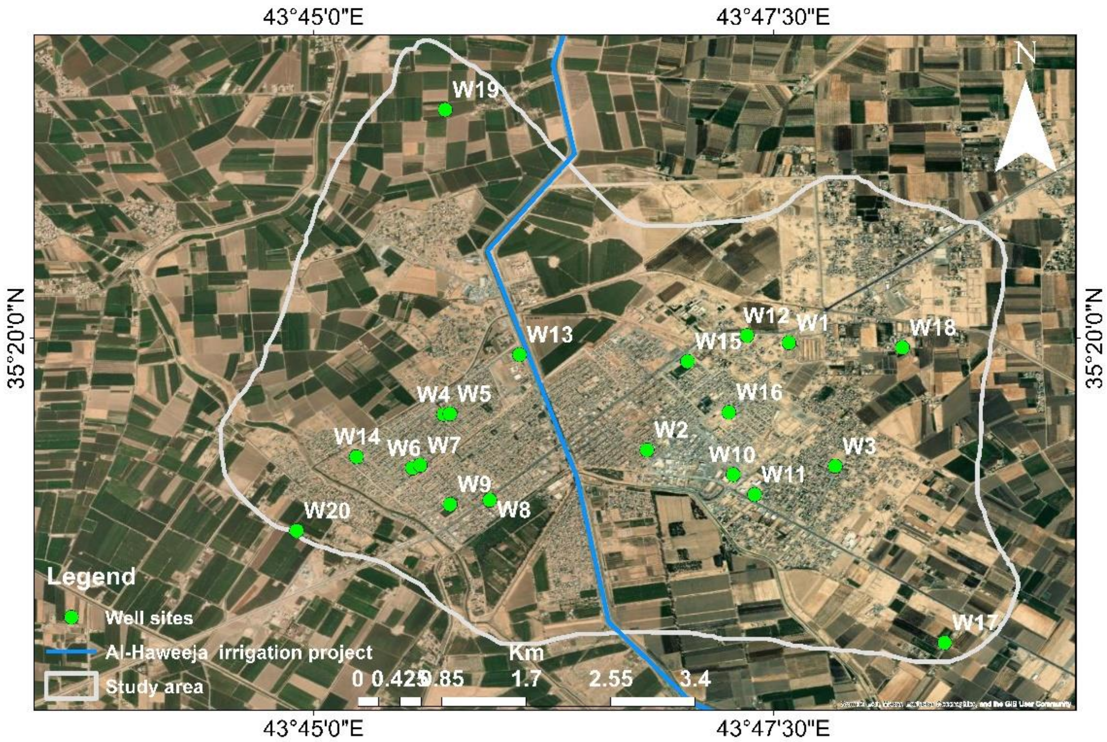

Fig. 3. Well sites of the study area.

Table 2: Observation and pumping wells basic data of the study area.

Wells Name	Wells Symbol	Longitude (E)	Latitude (N)	Discharge L/Sec	Elevation (m)	Depth to water table (m a.s.l)	SWL (m a.s.l)
Observation well-1	OW-1	43°47'16.37"E	35°19'12.23"N		192	19.9	172.1
Pumping well-1	W 10	43°47'16.80"E	35°19'15.60"N	7	193	20	173
Observation well-2	OW-2	43°48'26.77"E	35°18'21.70"N		192	19.97	172.03
Pumping well-2	W 17	43°48'25.80"E	35°18'20.80"N	23	192.12	19.95	172.17
Observation well-3	OW-3	43°48'11.74"E	35°19'56.35"N		198	27	171
Pumping well-3	W 18	43°48'12.00"E	35°19'57.00"N	17	198.12	27	171.12
Observation well-4	OW-4	43°45'42.82"E	35°21'13.4"N		188	18.95	169.05
Pumping well-4	W 19	43°45'15.40"E	35°21'14.50"N	24	188	18.9	169.1
Observation well-5	OW-5	43°44'54.40"E	35°18'57.30"N		184	13.4	170.6
Pumping well-5	W 20	43°44'54.40"E	35°18'57.30"N	23	184	13.32	170.68

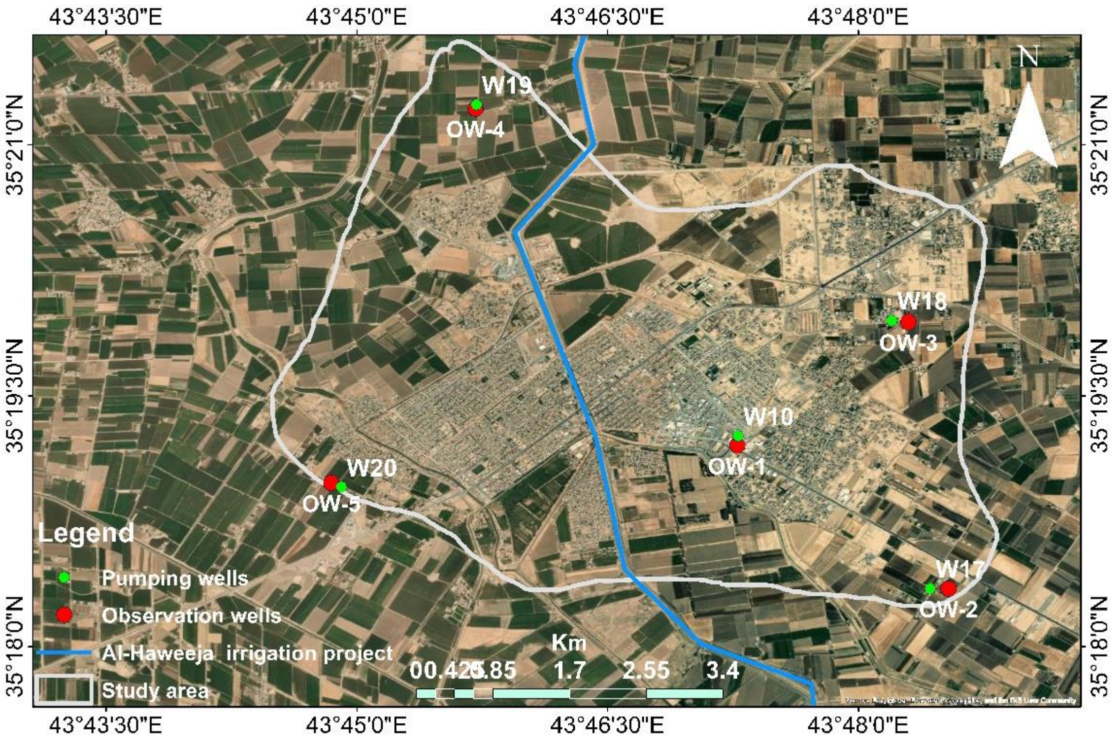

Fig. 4. Pumping and observation well sites of the study area.

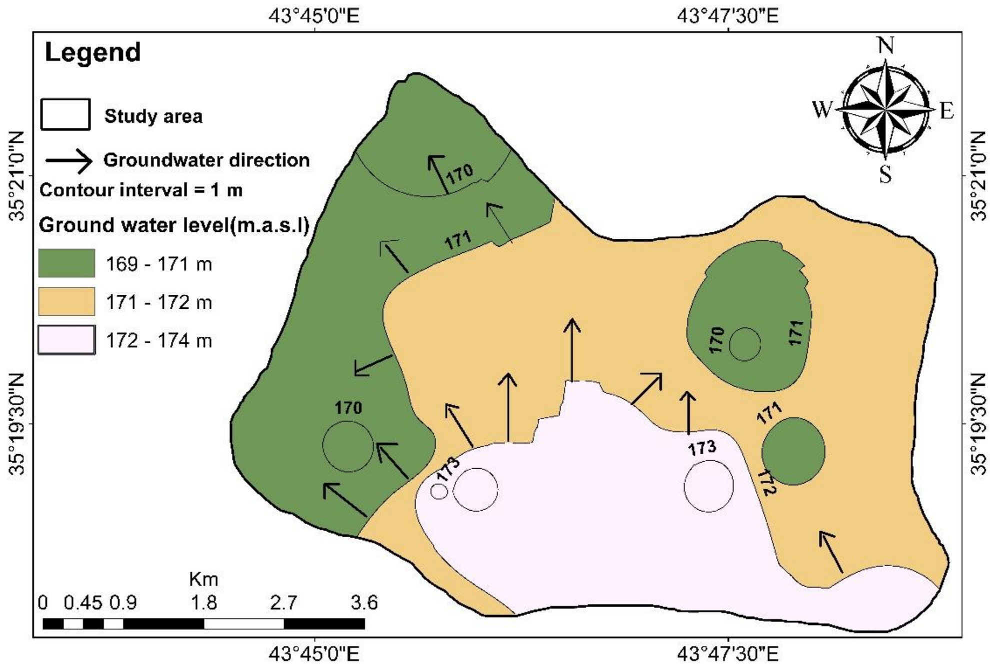

Fig. 5. Spatial distribution and movement direction of groundwater in the study area

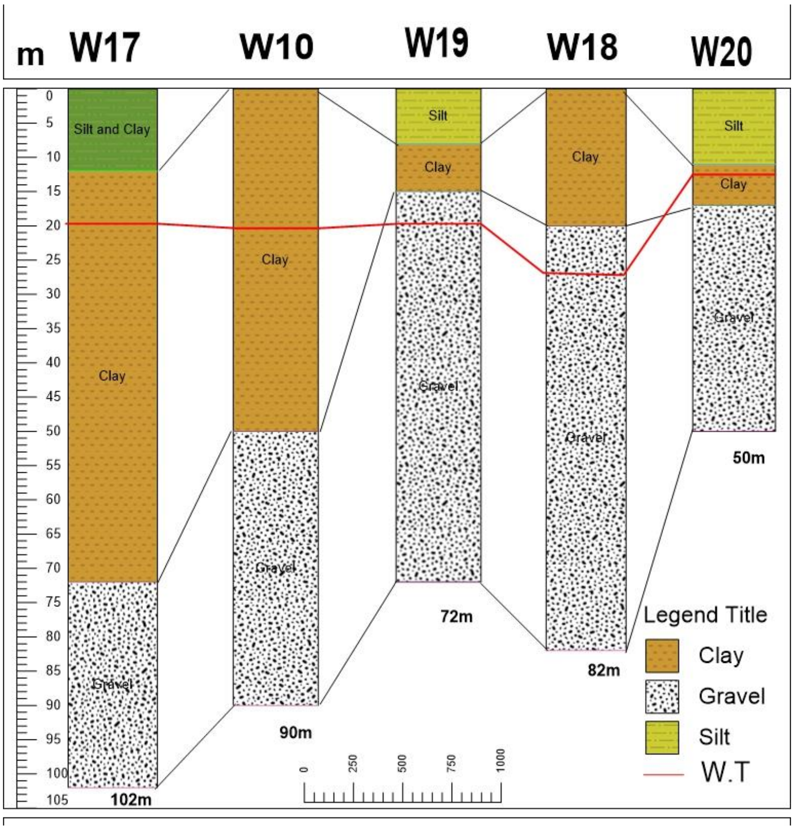

Fig. 6. Pumping wells correlation.

Pumping test No.1.

Table 3: Data of pumping test No.1.

Time (min.)	Drawdown (cm)	Time (min.)	Drawdown (cm)
1	01	30	12
2	1	45	13
3	3	60	14
4	4	75	15
5	6	90	15
10	6	105	16
15	7	120	18
20	8	150	18
25	10	180	18

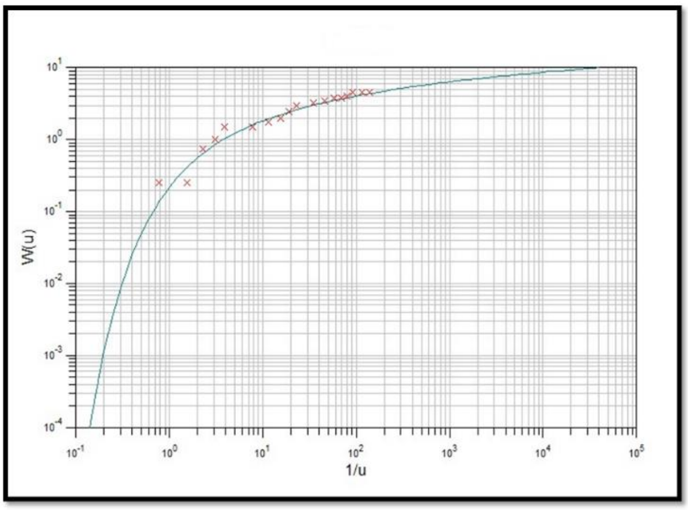

Fig. (7a). Time-drawdown curve (Theis's method) for pumping test No.1.

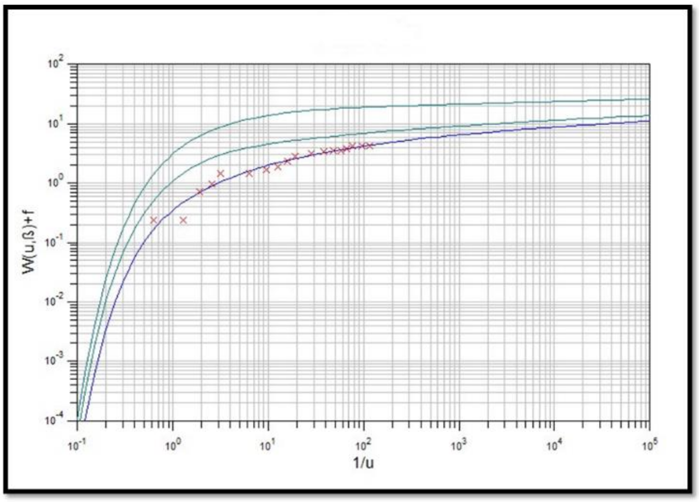

Fig. (7b). Time-drawdown curve (Hantush method) for pumping test No.1.

Pumping test No.2.

Table 4: Data of pumping test No.2.

Time (min.)	Drawdown (cm)	Time (min.)	Drawdown (cm)
1	1	30	72
2	15	45	83
3	22	60	91
4	30	75	97
5	37	90	100
10	43	105	101
15	49	120	105
20	57	150	108
25	64	180	108

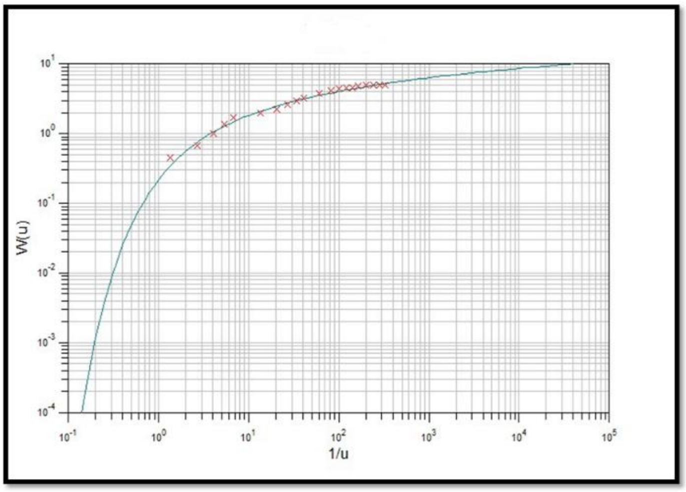

Fig. (8 a). Time-drawdown curve (Theis's method) for Pumping test No.2.

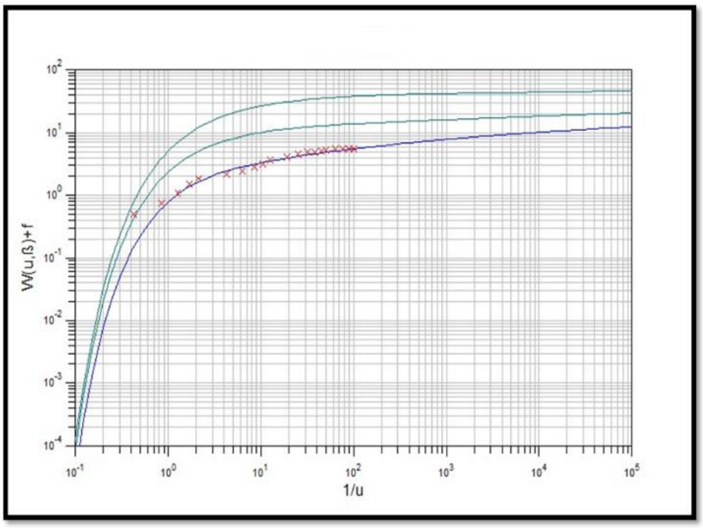

Fig. (8 b). Time-drawdown curve (Hantush method) for pumping test No.2.

Pumping test No.3.

Table 5: Data of pumping test No.3.

Time(min)	drawdown(cm)	Time(min)	drawdown(cm)
1	4	45	23
2	6	60	26
3	8	75	29
4	10	90	33
5	12	105	35
10	13	120	36
15	14	150	37
20	15	180	39
25	17	210	39
30	19		

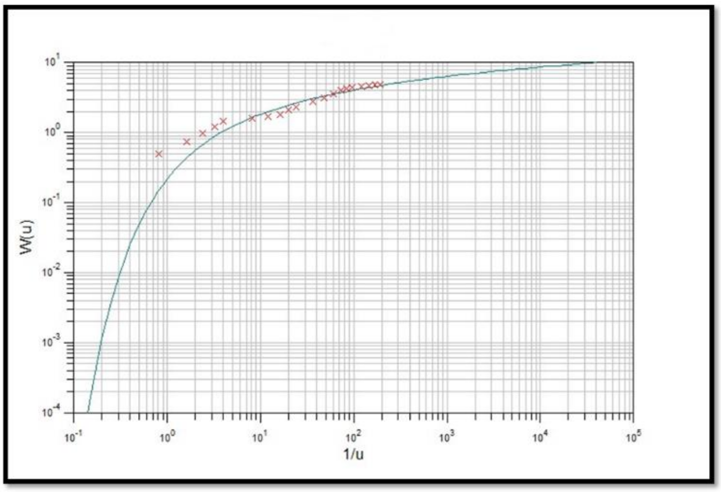

Fig. (9a). Time-drawdown curve (Theis's method) for pumping test No.3.

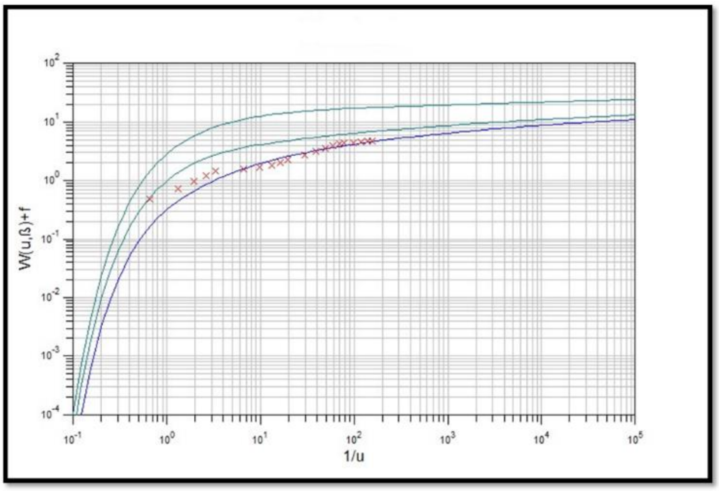

Fig. (9b). Time-drawdown curve (Hantush method) for pumping test No.3.

Pumping test No.4.

Table 6: Data of the pumping test. No.4.

Time(min)	drawdown(cm)	Time(min)	drawdown(cm)
1	5	45	20
2	7	60	21
3	8	75	23
4	1	90	25
5	12	105	26
10	14	120	26
15	15	150	27
20	16	180	28
25	17	210	28
30	18	240	28

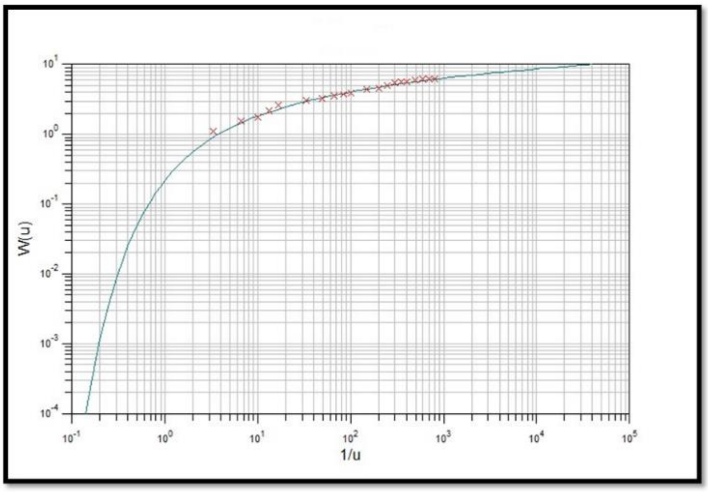

Fig. (10a). Time-drawdown curve (Theis's method) for pumping test No.4.

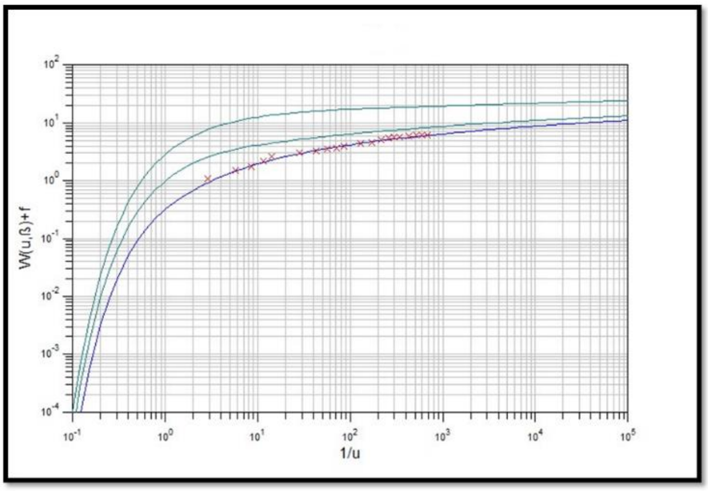

Fig. (10b). Time-drawdown curve (Hantush method) for pumping test No.4.

Pumping test No.5.

Table 7: Data of pumping test No.5.

Time(min)	drawdown(cm)	Time(min)	drawdown(cm)
1	5	45	19
2	6	60	21
3	7	75	20
4	8	90	22
5	9	105	31
10	11	120	33
15	13	150	34
20	14	180	35
25	15	210	36
30	17	240	36

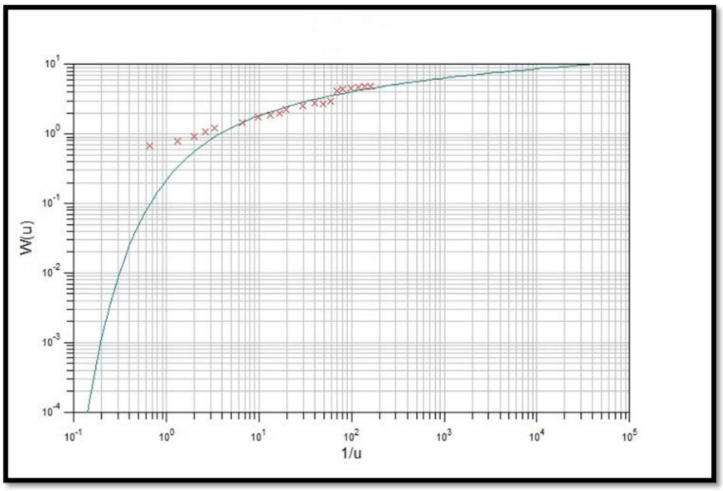

Fig. (11a). Time-drawdown curve (Theis's method) for pumping test No.5.

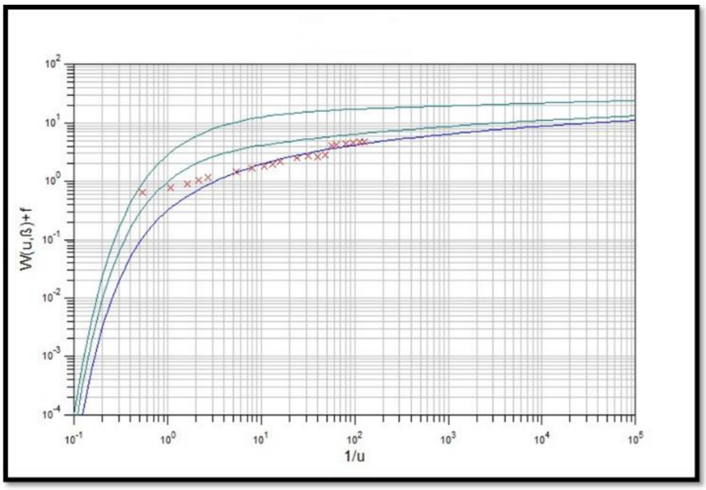

Fig. (11b). Time-drawdown curve (Hantush method) for pumping test No.5.

Results and discussion

Throughout measuring the groundwater depths in 20 wells in the study area, a flow direction map is created where the groundwater depths range from 13.32 to 27m (Table 1 and Fig. 3). Equipotential lines are drawn, and the directions of groundwater in the study area are determined. The direction of groundwater flow indicates that the groundwater movements is from south to the western and northwestern parts as shown in Figure (5). The hydraulic properties show differences in data average, where in pumping test No.1 is (27.7 m/day), the transmissivity value is (1109 m^2/day), and the storage coefficient value is (0.00077). In the pumping test No.2, the hydraulic conductivity is (23.16 m/day), the transmissivity value is (695 m^2/day), and the storage coefficient value is (0.00074). In the pumping test No.3, the hydraulic conductivity is (22.02 m/day), the transmissivity value is (1366.5 m^2/day) and the storage coefficient value is (0.001), In the pumping test No.4, the hydraulic conductivity is (59.54 m/day), the transmissivity value is (3413 m^2/day) and the storage coefficient value is (0.0017); and in the pumping test No.5, the hydraulic conductivity is (62.5 m/day), the transmissivity value is (2062.5 m^2/day) and the storage coefficient value is (0.0037). The parameters as transmissivity (T), hydraulic conductivity (K), and storage coefficient (S), are shown in Table 8, and Figures (12-14).

Table 8: Results of (T, K, S) for the wells in the study area.

Wells	T(m^2/day)	K (m/day)	S	Type of aquifer
W**10**	1109	27.7	0.00077	Semi-confined
W**17**	695	23.16	0.00074	Semi-confined
W**18**	1366.5	22.02	0.001	Semi-confined
W**19**	3413	59.54	0.0017	Semi-confined
W**20**	2062.5	62.5	0.0037	Semi-confined

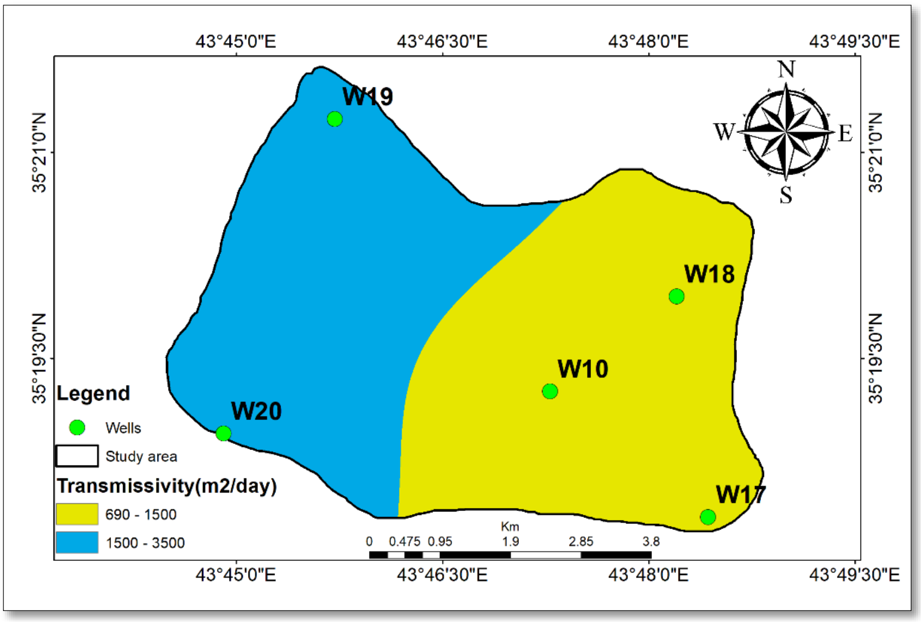

Fig. 12. Spatial distribution of transmissivity values in the study area.

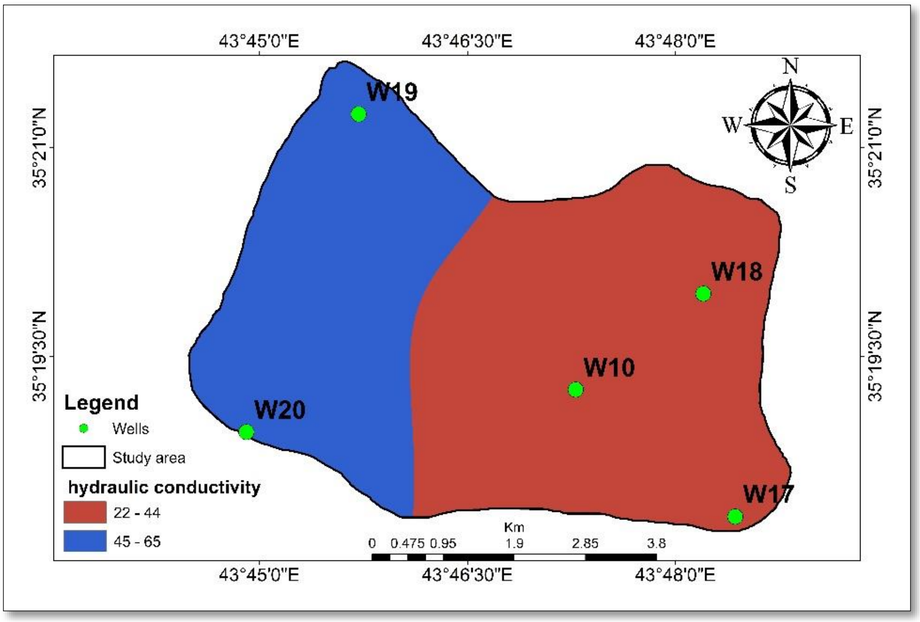

Fig. 13. Spatial distribution of hydraulic conductivity values in the study area.

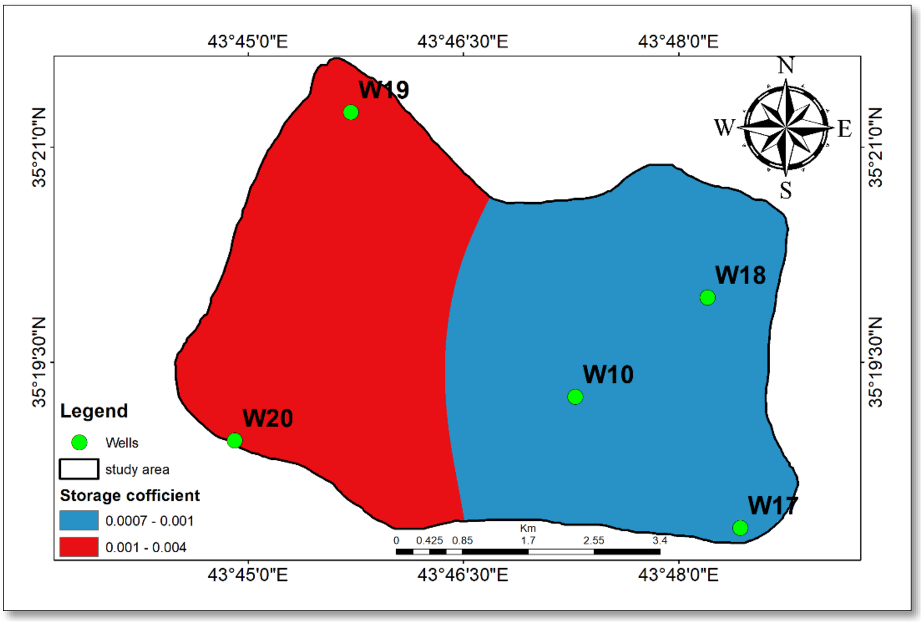

Fig. 14. Spatial distribution of storage coefficient values in the study area.

Conclusion

From the above results, the study area is an area with good groundwater productivity, as groundwater is stored in a semi-confined aquifer and the main groundwater movement is from south to the western and northwestern parts. The aquifer is classified as heterogeneous and anisotropic. The main source of groundwater recharge is from the Bai Hassan Formation, which is the lower aquifer in the study area and is exposed in the surrounding regions. When the precipitation occurs on the mountaintops, it infiltrates into the formation and continues to move toward the study area.

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