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Hydrogeological Assessment of The Aquifers in Chamchamal Sub-Basin / Iraq

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ABSTRACT

Chamchamal sub-basin is located in the northeastern part of Iraq, within the Sulaimani governorate. The study area covers about (285) Km^2. Most of the study area is an elevated area, ranging between (511-1216) m above sea level. Fatha, Injana, Mukdadiya, Bai Hassan, and Quaternary deposits are the main geological units in the Chamchamal sub-basin. The current study intends to investigate groundwater storage and estimate the hydraulic characteristics of the primary aquifers within the study area. A pumping test was conducted in five wells distributed to cover the study area. The saturation thickness of the studied aquifers ranges from (7 to 64) m. The hydraulic conductivity values varied from (0.0326-16.890) m/day, while the transmissivity value ranged between (0.3-337.8) m^2/day. The storage coefficient values were ranged between (0.001-0.1272). The aquifer types are semi-confined, semi-unconfined, and unconfined based on the results of the hydraulic characteristics (T, K, Sc), and the study area has been classified as heterogeneous and anisotropy. The flow net map was generated by monitoring groundwater depths from 50 wells within the study area. The water table depths range from (8 to 140) m below the ground surface. The groundwater flow map for the study area indicates that the water moves from the northwest and northeast of the sub-basin to the south basin similar to the relief of the study area, then drains for the Shiwasoor stream. Chamchamal sub-basin is one of the secondary hydrogeological basins of the Al- Adhaim Basin, which is one of the main tributaries of the Tigris River.

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التقييم الهايدرولوجي للخزانات المائية في حوض جمجمال الثانوي / العراق

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الملخص

يقع حوض جمجمال الثانوي في الجزء الشمالي الشرقي من العراق ضمن محافظة السليمانية. تغطي منطقة الدراسة (285.5) كم^2. معضم منطقة الدراسة عبارة عن مناطق مرتفعة يتراوح ارتفاعها بين (511–1216) م، فوق مستوى سطح البحر. التكاوين الجيولوجية الرئيسية في حوض جمجمال الثانوي هي انجانه، المقدادية، باي حسن، وترسبات العصر الرباعي. تهدف الدراسة الحالية إلى التحقق من تخزين المياه الجوفية وتقدير الخصائص الهيدروليكية لخزانات المياه الجوفية داخل منطقة الدراسة. أجريت اختبارات الضخ في خمسة آبار موزعة في منطقة الدراسة. يتراوح السمك المشبع للخزانات الجوفية المدروسة من 7 إلى 64 متر. اختلفت قيم التوصيل الهيدروليكي من (16,890–0,0326) متر/ يوم، بينما تراوحت قيم الناقلية (337,809–0,294) متر^2/ يوم. وكان معامل التخزين في حدود (0.1272–0.001). ان أنواع خزانات المياه الجوفية الموجودة في المنطقة هي شبه محصورة، شبه غير محصورة، و غير محصور بناءً على نتائج الخصائص الهيدروليكية (الناقلية، التوصيل الهيدروليكي، ومعامل الخزن) وقد صنفت منطقة الدراسة غير متجانسة ومتباينة الخواص. تم إنشاء خريطة شبكة التدفق من خلال مراقبة أعماق المياه الجوفية من (50) بئراً داخل منطقة الدراسة . تتراوح أعماق منسوب المياه الجوفية من (8 إلى 140) متر تحت سطح الأرض. وفقًا لخريطة تدفق المياه الجوفية ، غالباً تتدفق المياه الجوفية في المنطقة من الشمال والشمال الشرقي إلى الجنوب الغربي وتتحرك بأتجاه وادي شيواسور . حوض جمجمال الثانوي احد الاحواض الهايدروجيولوجية الثانوية لحوض رافد العظيم وهو احد الروافد الرئيسية لنهر دجلة.

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Introduction

The shortage of water resources, especially surface water, in Iraq, has led to the tendency to exploit groundwater to meet domestic, agricultural, and industrial needs (Al-Hayali and Al-Tamimi, 2021). Groundwater plays an important role in a geographical area where surface water is insufficient to meet daily needs (Mohammed et al, 2021). The importance of any aquifer depends on main characteristics such as permeability, extension, and thickness (Jassim and Goff, 2006). Hydrogeological conditions are determined by geological, morphological, climatic, and hydrological factors, and their degree of influence differs from one place to another place. Hydrogeological methods are considered one of the important foundations for the development and management of groundwater resources and their exploitation (Agha and AL-Tamimi, 2021). An aquifer is defined as a permeable and porous geological formation or formations that allow free movement of water at varying speeds, bounded from the bottom or the top, or together, by layers or solid sediments that are impermeable to water (Walton, 1970). Chamchamal region is generally located under a continental climatic region that is hot and dry during the summer and cold, rainy, and snowy during the winter (Mohammed, 2017). Rainfall is the most effective climatic parameter in the hydrological cycle, it is considered one of the most important climatic elements in hydrogeological studies and it represents the main factor in the water balance and groundwater recharge (Al-Tamimi, 2007). In this research, the depth and directions of groundwater flows, as well as the hydraulic parameters of the water-bearing units within the Chamchamal have been studied due to the relevance and sustainable management of the primary aquifers. The current study aims to determine hydrogeological characteristics, which include Transmissivity (T), Hydraulic conductivity (K), and Storage coefficient (Sc) for the required aquifer based on the pumping test data.

Location of the study area

Chamchamal sub-basin is located in the North Eastern part of Iraq, within Sulaimani governorate, it is about (60) Km to the SW of Sulaimani City. Geographically, it extends between the coordinates (35°26′00″, 35°38′00″) N, (44°46′00″, 44°59′00″) E, which lies in Zone 38N in (UTM), covering about (285.5) Km2, most of the study area is an elevated area, ranging between (511 - 1216) m above sea level, (Fig.1). The study area is located in northeastern Iraq within a semi-mountainous area, it is bordered on the west by the Bani Maqan plateau.

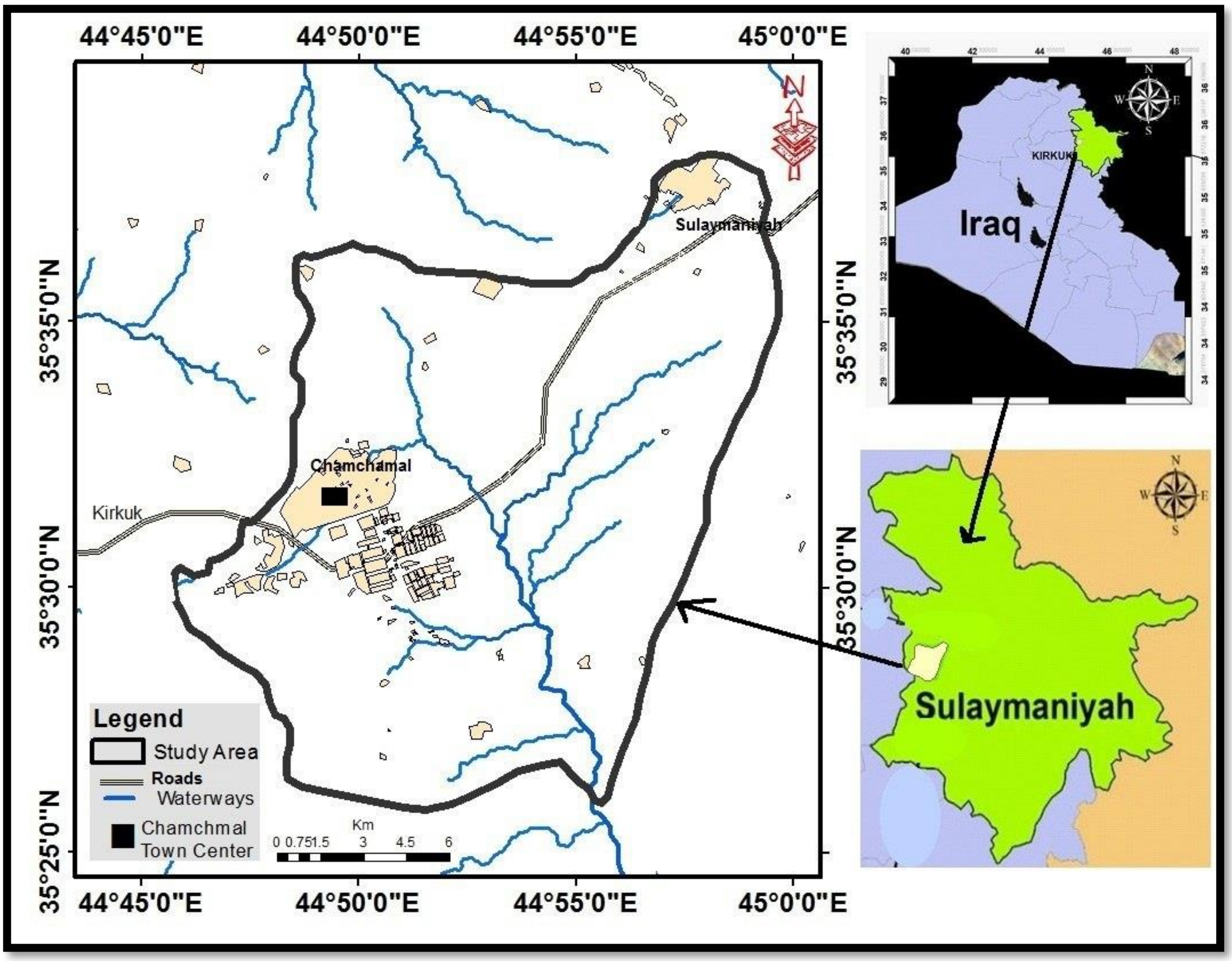

Fig. 1. Location Map of the Study area

Geological and hydrogeological setting

Generally, the study area consists of sedimentary rock units and sediments belonging to the Cenozoic era, and their ages range from the Tertiary (Middle-Upper Miocene) to the Quaternary (Pleistocene-Holocene). Many geological formations Fatha, Injana, Muqdadiyia, Bai Hassan formations, and Quaternary sediments are outcrops within the study area (Sultan et al, 2022), (Fig. 2). All these units belong to the Tertiary and Quaternary periods (Abo-Khomra et al., 2022). The importance of any aquifer depends on main characteristics like permeability, extension, and thickness (Jassim and Goff, 2006). The exposed Formations in the study area are Fatha, Injana, Mukdadiya, and Bai Hassan Formations, and Quaternary deposits that include floodplain sediments, riverine sediments, and valley-filling deposits (Jassim and Goff, 2006). The climate is an important factor and affects the hydrological situation and the amount of groundwater and surface water through temperatures and the amount of precipitation, which varies from year to year and season to season (Al-Tamimi, 2002). The general climate of Iraq is characterized by hot dry in summer, and cold rainy in winter (Jassim and Goff, 2006). The region is influenced by the Mediterranean climate, which is characterized by hot, dry summers and cool, wet winters (Mohammed, 2017). In recent years, it has been noted that the dry periods have become longer than the wet periods.

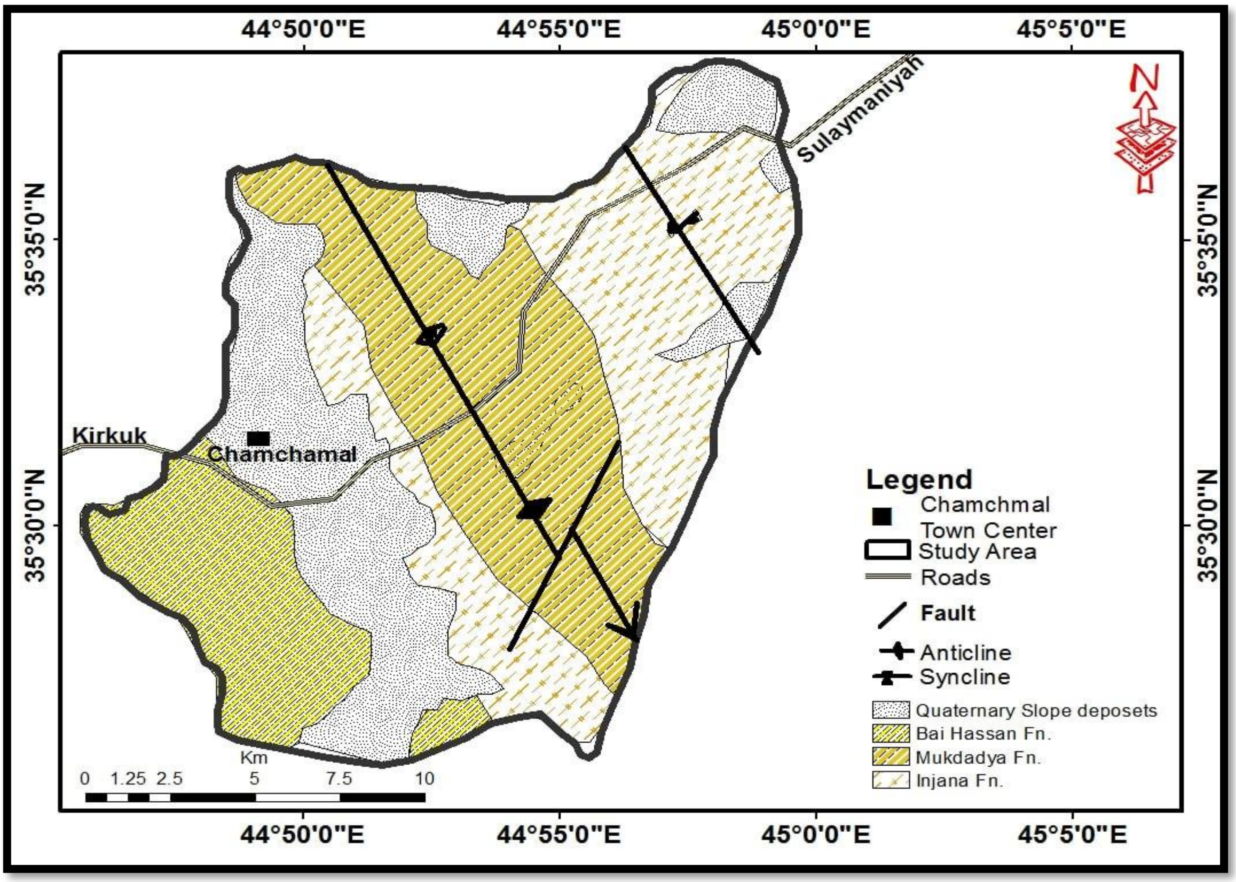

Fig. 2. Geological map of the study area (Modified from Sissakian, 1992)

Materials and Methods

The flow of groundwater takes different directions throughout the region depending on topographic, geological, and structural features (Al Jiburi and Al Basrawi, 2012). Groundwater moves from locations of higher pressure to lower pressure and from higher elevation areas to lower elevation. Groundwater flow pattern in the aquifer is affected by the permeability, hydraulic gradient, and fractured density of the rock units (Al-Azawi and Al-Shamma'a, 2016). The final flow direction map was created by measuring the depths of the groundwater for (50) wells in the study area, (Table 1), and (Fig. 3). (Fig. 4) shows the groundwater flow direction map for the study area indicating that the water moves from the northwest and northeast of the sub-basin to the south basin similar to the relief of the study area, then drains for Shiwasoor stream. Groundwater flows from the zone of the larger hydraulic head to the zone of the lower hydraulic head, according to Darcy's law. Groundwater depths were measured in this study using a groundwater level sensor (sounder device) and AndroiTS GPS program to determine the locations of measured wells. Identifying the hydraulic parameters of aquifers using pumping test activities to determine (K, T, Sc) (Fig. 11), (Fig. 12), (Fig.13), and (Fig. 14). The pumping test was performed in (5) wells as shown in (Fig. 3), and the borehole lithology of selected wells in the study area (Fig.5). The drawdown with time in (Fig. 6 a,b), (Fig. 7 a,b), (Fig. 8 a,b), (Fig. 9 a,b), (Fig.10 a,b), and Tables (2, 3, 4, 5, and 6). The variation in these values is because of the sewer water which is not discharged with proper systems, in fact from most of the study areas the sewer water from households and industrial locations is recharged into the groundwater directly beside the heterogenic and the porosity of the formations is the reason for the values' differences (Al-Tamimi and Shwani, 2019). The pumping test was carried out for at least several hours until reached steady-state conditions. There are several methods available for data analysis, including (Theis, Walton, Cooper-Jacob, Hantush, and Neuman). This method is considered more accurate for calculating the conductivity due to the absence of the potential effect of pumping fluctuations (Al-Tamimi, 2002). Cooper-Jacob methods for analysis were employed in the current as shown in equation (a) as follows (Todd, 2007), and Theis recovery test the water level rise is measured through what is called the residual drawdown as shown in equation (b) by using the equation below is applied (Kruseman and De Ridder, 1979) as follows:

$$\mathbf{T} = \frac{2.3\,Q}{4\pi\Delta s} \quad \ldots\ldots\ldots (a)$$

Where,

T = Transmissivity (m^2 /day).

Q = Discharge (m^3/day.)

S = Drawdown (m).

$$\mathbf{T} = \frac{2.3Q}{4\pi\Delta s'} \quad \ldots\ldots\ldots (b)$$

Where,

T: Transmissivity (m^2/day).

$\Delta s'$: Residual drawdown (m), (s_2-s_1).

Q: The constant Discharge from the well in (m^3/day).

Table 1: Water wells basic data of the study area.

Wells Symbol	Location name	well Depth (m)	water Depth (m)	Elevation (m) a.s.l	Latitude (N)	Longitude (E)	W.t. (m) a.s.l.
W1	Khaled Noury	160	130	870	35° 29′ 55″	44° 49′ 34″	740
W2	Asu Mohammed	200	120	870	35° 30′ 02″	44° 46′ 16″	750
W3	Ayoub Hussein	200	74	865	35° 30′ 00″	44° 45′ 52″	791
W4	Dawood Hussein	70	18	909	35° 37′ 38″	44° 58′ 21″	891
W5	Fadel Mohammed	20	16	897	35° 37′ 29″	44° 57′ 56″	881
W6	Hendren Station	105	15	842	35° 36′ 49″	44° 56′ 53″	827
W7	Jamal Mohammed	80	8	872	35° 37′ 11″	44° 57′ 19″	864
W8	Jawhar Saadallah	75	24	685	35° 29′ 23″	44° 51′ 40″	661
W9	Ibrahim Mohamed	90	22	680	35° 28′ 09″	44° 52′ 24″	658
W10	Ibrahim Mohamed	90	23	685	35° 28′ 04″	44° 52′ 26″	662
W11	Nozad Mohamed	131	18	674	35° 28′ 31″	44° 52′ 22″	656
W12	Nozad Mohamed	121	60	685	35° 28′ 29″	44° 52′ 16″	625
W13	Asu Mohammed	131	24	687	35° 29′ 00″	44° 51′ 23″	663
W14	Nozad Mohamed	110	49	687	35° 28′ 28″	44° 52′ 13″	638
W15	Ahmed Yadgar	160	80	709	35° 29′ 45″	44° 51′ 05″	621
W16	Asu Mohammed	61	21	689	35° 28′ 58″	44° 51′ 27″	668
W17	Ahmed Yadgar	280	50	703	35° 29′ 43″	44° 51′ 03″	659
W18	Sheikhu Ahmed	150	30	689	35° 27′ 34″	44° 52′ 45″	668
W19	Mahmoud Ali	120	80	668	35° 27′ 54″	44° 53′ 01″	588
W20	Aram Najmalddin	110	55	678	35° 27′ 30″	44° 52′ 26″	623
W21	Hewia Ahmed	157	123	690	35° 27′ 33″	44° 52′ 24″	567
W22	Hemin Ahmed	150	30	689	35° 27′ 38″	44° 52′ 30″	659
W23	Muafer 19	250	140	830	35° 29′ 17″	44° 49′ 03″	690
PW24	Muafer 10	168	98	788	35° 29′ 44″	44° 49′ 18″	690
PW25	Faruq Karim Agha	50	19	712	35° 34′ 08″	44° 51′ 38″	693
W26	Faruq Karim Agha	100	21.5	711	35° 34′ 10″	44° 51′ 41″	689.5
W27	Abaas Agha	45	34	729	35° 34′ 17″	44° 52′ 05″	695
W28	Ali Askari Mosque	55	24.5	715	35° 31′ 59″	44° 50′ 18″	690.5
W29	Shorash (Nozad)	57	48	710	35° 30′ 51″	44° 51′ 00″	662
W30	Ban Maqan	66	42	877	35° 29′ 15″	44° 48′ 02″	835
W31	Ban Maqan	70	38	810	35° 30′ 18″	44° 47′ 54″	772
W32	Abdullah Mohamed	100	23	695	35° 32′ 25″	44° 51′ 09″	672
W33	Abdullah Mohamed	75	15	700	35° 32′ 23″	44° 51′ 14″	685
W34	Refaat Ghafoor	120	25	699	35° 32′ 08″	44° 51′ 12″	674
W35	Yassin Yakhi	60	29	695	35° 31′ 56″	44° 51′ 35″	666
W36	Latif Saber	85	18	705	35° 31′ 50″	44° 51′ 07″	687
W37	Waria Anwar	77	41	695	35° 31′ 24″	44° 51′ 44″	654
W38	Omar Hussan	80	32	688	35° 30′ 54″	44° 51′ 57″	656
W39	Sherzad Omar	60	37	696	35° 30′ 03″	44° 52′ 13″	659
PW40	Qara tamur Village	55	16	620	35° 28′ 34″	44° 55′ 13″	604
W41	Payingan Village	40	14	669	35° 30′ 00″	44° 56′ 31″	655
W42	Ramadan Amen	20	11	762	35° 32′ 56″	44° 57′ 02″	751
W43	Likawa Village	60	39	766	35° 34′ 47″	44° 55′ 59″	730
W44	Ali Mansour Village	145	11	647	35° 30′ 50″	44° 54′ 27″	636
W45	Hassan Abdullah	20	4	631	35° 30′ 47″	44° 54′ 18″	627
W46	Jabir Maruf	17	13	757	35° 35′ 12″	44° 50′ 05″	744
W47	Jabir Maruf	30	8	755	35° 35′ 19″	44° 50′ 10″	747
W48	Curki Shamar Mosque	80	37	727	35° 34′ 42″	44° 51′ 27″	690
PW49	Farm	80	6.5	789	35° 35′ 13″	44° 53′ 17″	782.6
PW50	Chak station	100	9.8	780	35° 35′ 02.5″	44° 53′ 00.8″	770,2

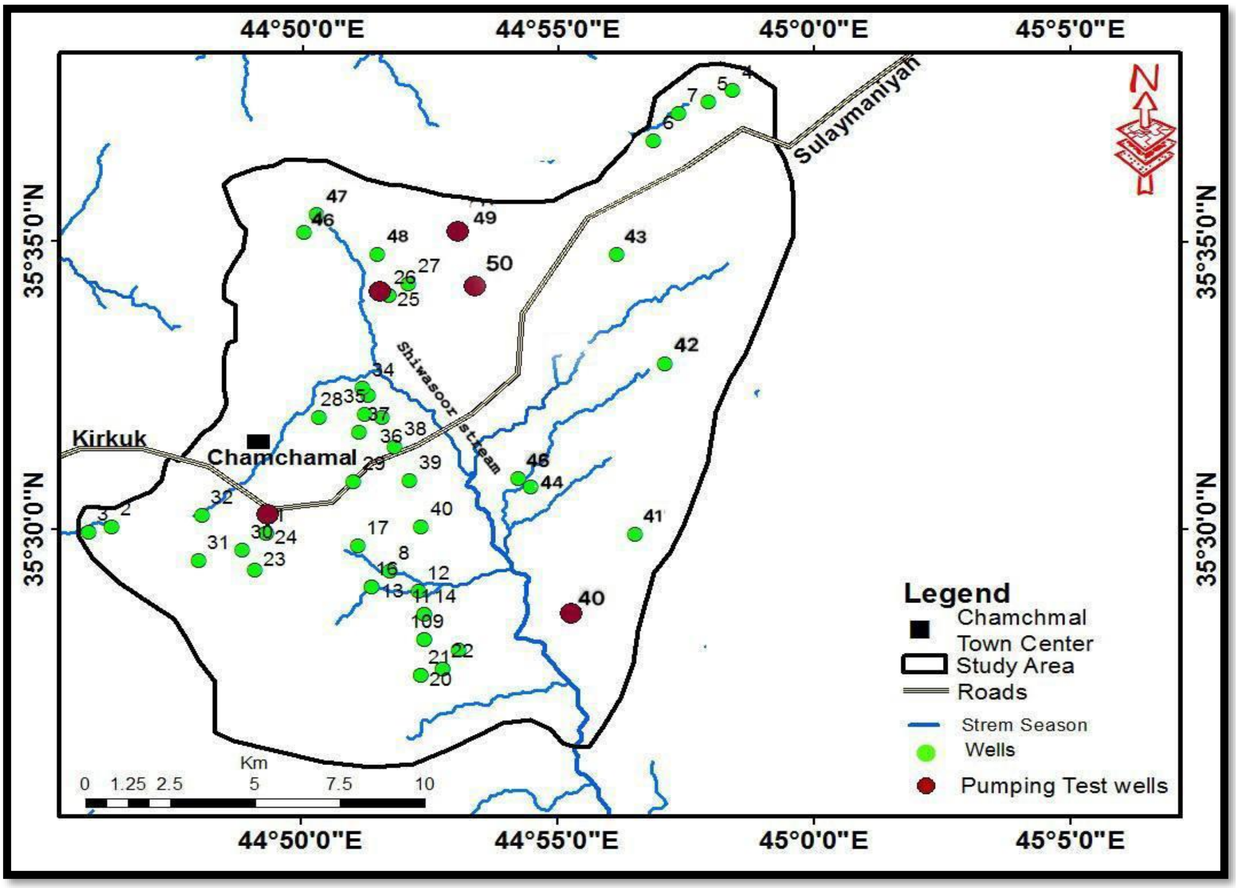

Fig. 3. Well sites of the study area.

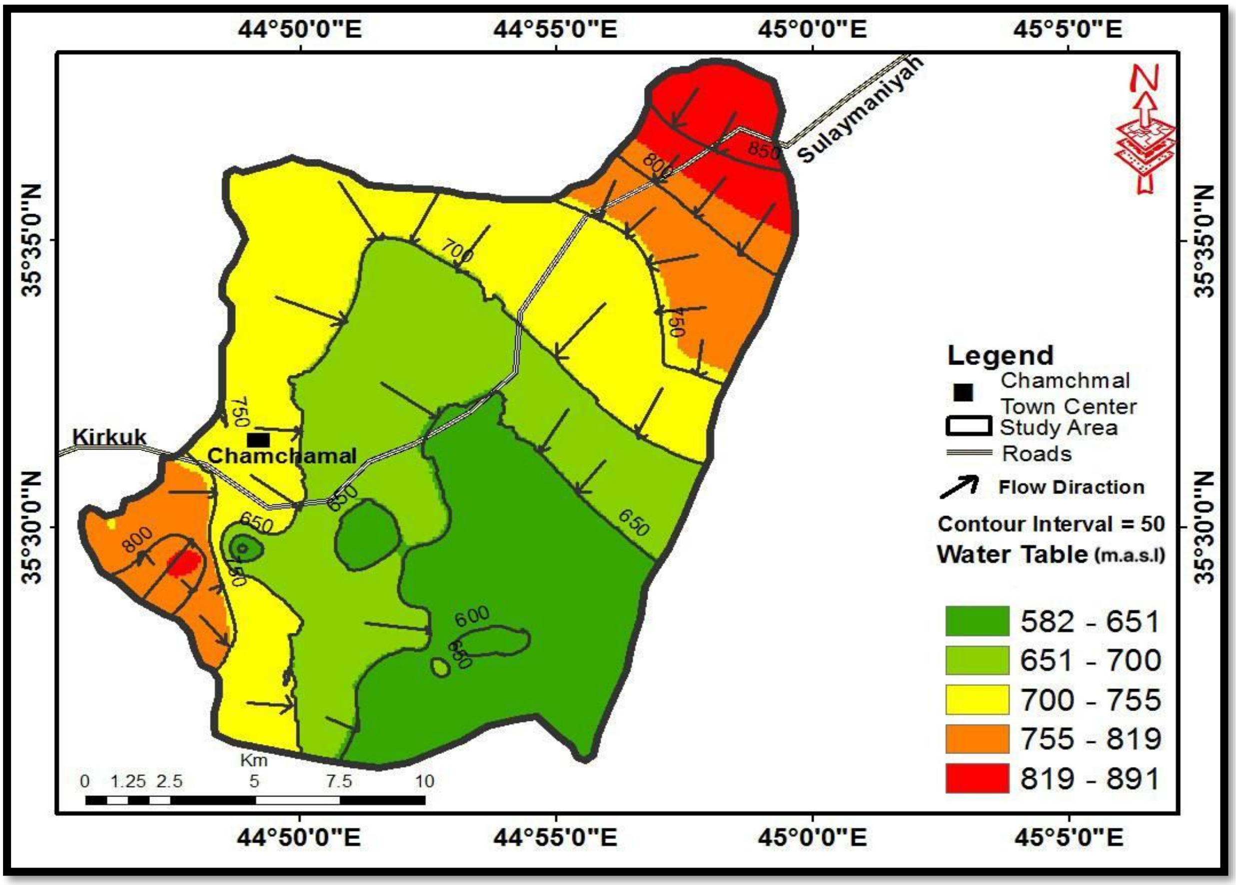

Fig. 4. The groundwater flow map of the study area.

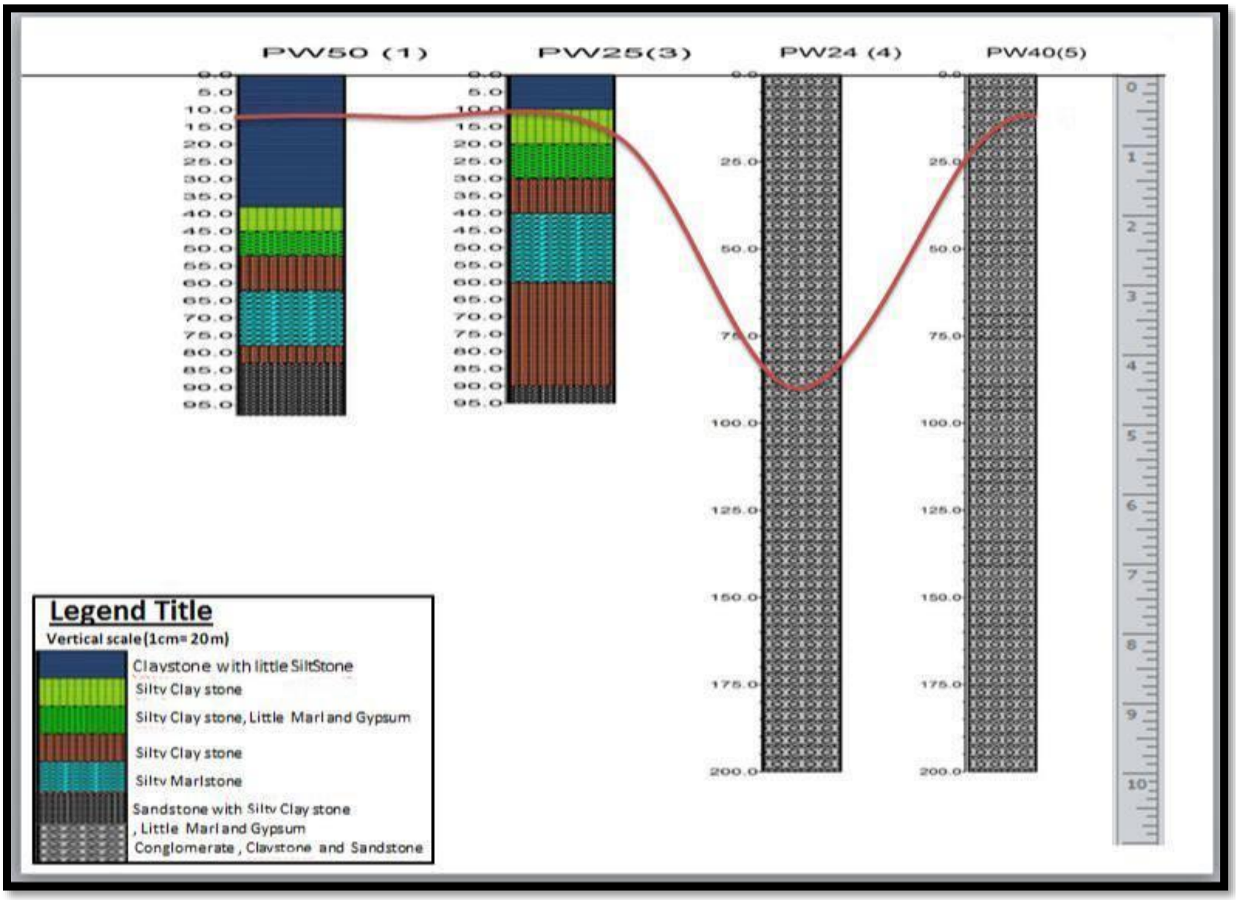

Fig. 5. Borehole lithology of selected wells in the study area.

The first site of the pumping test operation was performed in the (farm), the well depths (60) m with an elevation (789) m a.s.l, and the saturation thickness (b) is 7.09 m. The static water level in the pumping well was (6.50) m. The pumping process occurred between two wells. The first was employed as pumped, and the second was observation. The observation well has a depth of (80) m, and the static water level in an observation well was (5) m. Groundwater depth was measure by use (Sounder device). The distance between the pumping well and the observation well (r) was 35 m. With the experimental pumping test, the results were analyzed according to the Jacob method for the level (Fig. 6 a, b). The amount of well discharge value of the pumping well was (1.052) L/sec. equivalent (90.947) m3/day. Table (2) shows the drawdown in the level with time. The average of transmissivity is (36.885) m2/day, the storage coefficient is (0.001 or 1×10-3), and the hydraulic conductivity is (5.202) m/day.

Table 2: Pumping test data of well (PW49).

Time (min.)	Drawdown(m)	Time (min.)	Drawdown(m)
1	0	30	0.2
5	0.02	45	0.25
10	0.05	60	0.3
15	0.1	75	0.3
20	0.12	90	0.3
25	0.15	105	0.3

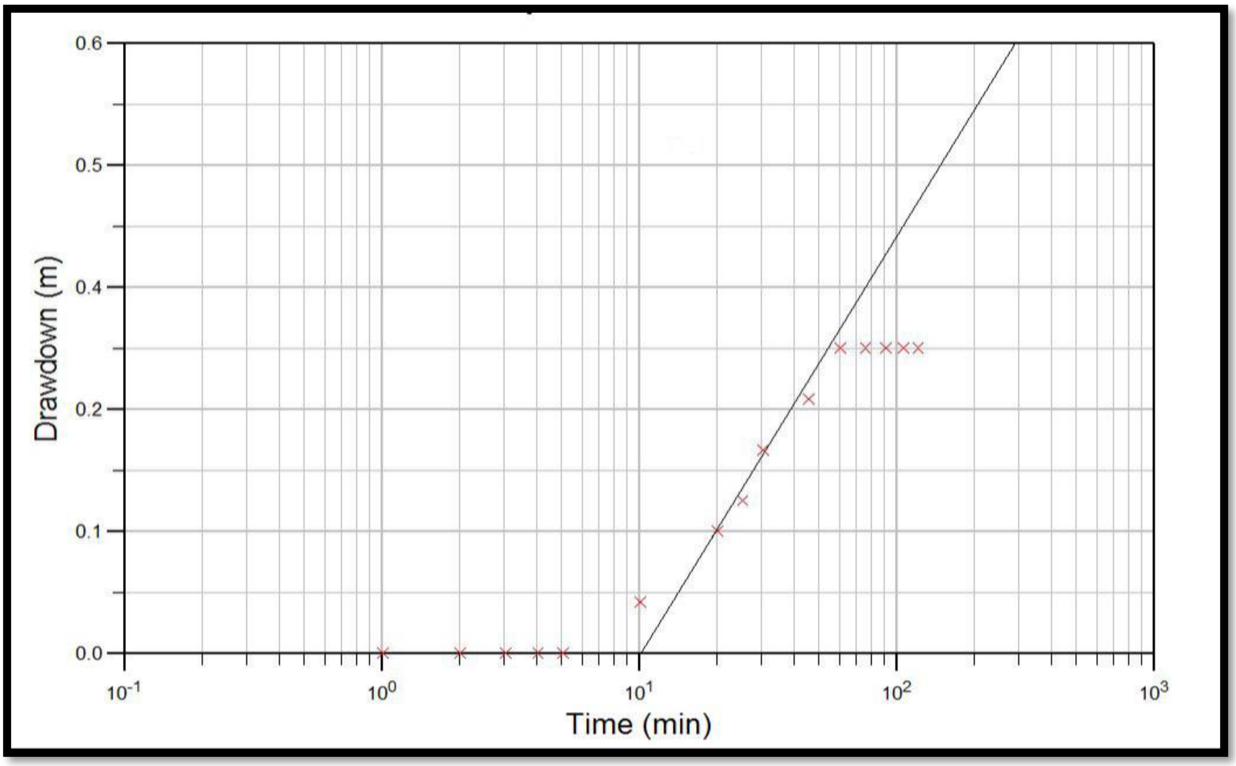

Fig. 6.a. Time- drawdown curve (Cooper and Jacob method) for well (PW49).

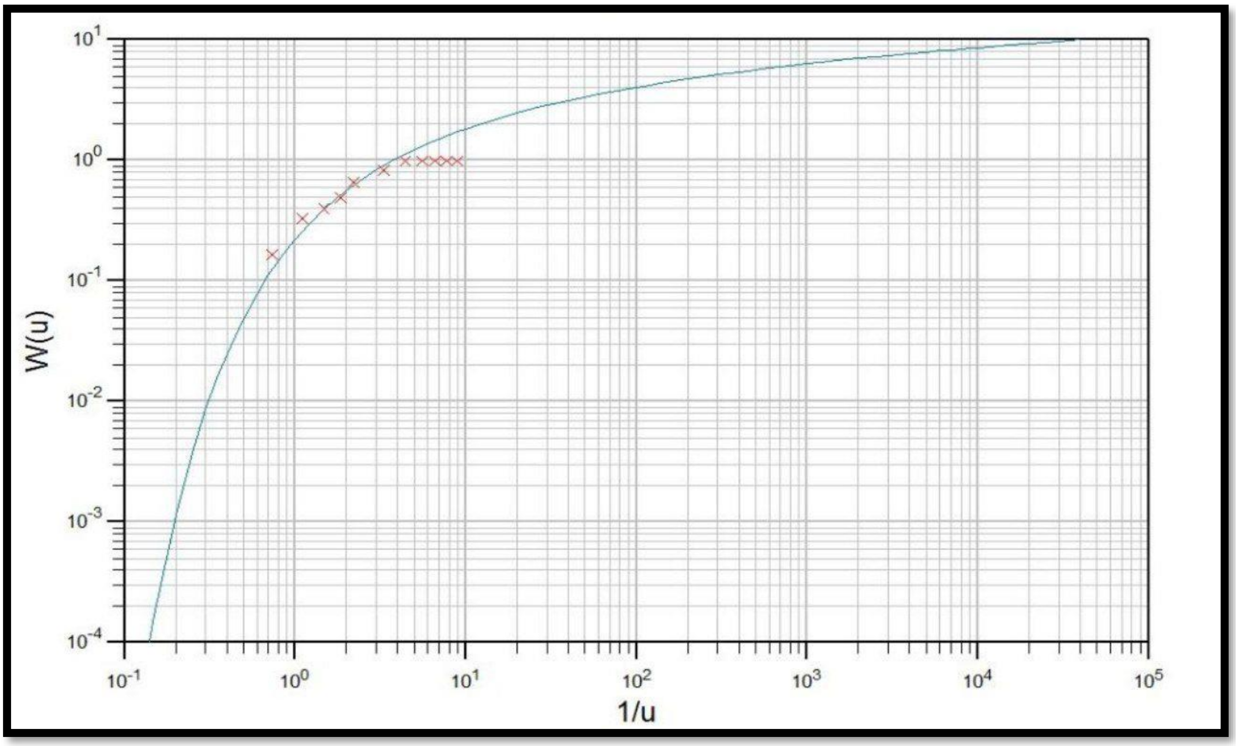

Fig. 6.b. t/t'- residual drawdown curve (Theis method) for well (PW49).

The second site of the pumping test operation was performed in the Chak station, drilled in 2007, The well depth (100) m with an elevation (780) m a.s.l, and the saturation thickness (b) is 58 m. The static water level in the pumping well was (9.80) m. The experimental pumping test and the return of the level were conducted on it, and the results were analyzed according to the Cooper-Jacob and Theis method for the level (Fig. 7 a, b, c). The amount of well discharge value of the pumping well was (1) L/sec. equivalent (86.40) m^3/day. Table (3) shows the drawdown in the level and the residual drawdown with time. The average of transmissivity is (0.2945) m^2/day, the storage coefficient is (0.00363 or 3×10^{-3}), and the hydraulic conductivity is (3.29×10^{-2}) m/day.

Table 3: Pumping test data of well (PW50).

Time (min)	Drawdown (m)	t' (min.)	Residual Drawdown(m)	t/t'
1	2.2	1	44.6	91
2	2.4	2	44	46
3	2.6	3	43.2	31
4	3	4	42.6	23.5
5	5.8	5	41.8	19
10	6.8	10	38.6	10
15	9.4	15	34.8	7
20	12.6	20	32.8	5.5
25	16.2	25	28.6	4.6
30	19	30	25.2	4
45	29.2	45	16.6	3
60	37.6	60	11	2.5
75	45.6	75	7.8	2.2
90	45.6	90	6	2
105	45.6	105	5.5	1.8

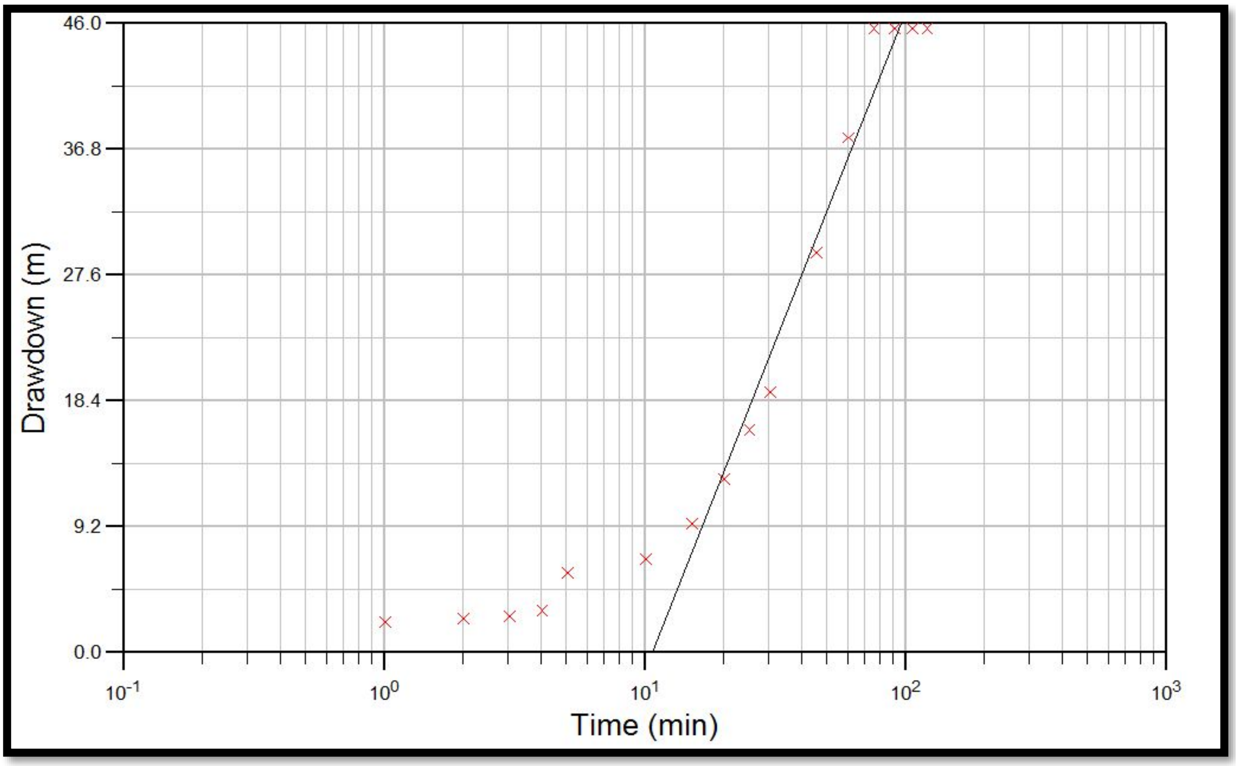

Fig. 7.a. Time- drawdown curve (Cooper and Jacob method) for well (PW50).

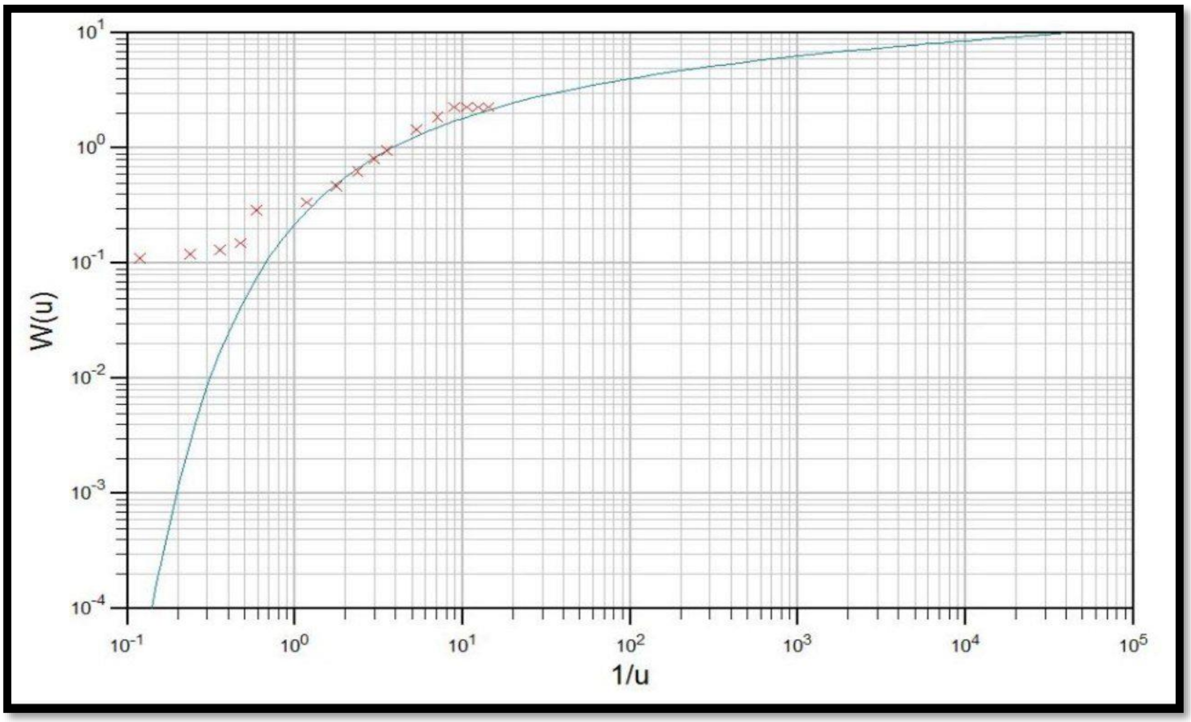

Fig. 7.b. Time- drawdown curve (Theis method) for well (PW50).

The third site of the pumping test operation was performed in the Faruq Karim well, drilled in (2007) with an elevation (712) m a.s.l. The well depth (50) m and the saturation thickness (b) is 13 m. The static water level in the pumping well was (17.60) m. The experimental pumping test and the return of the level were conducted on it, and the results were analyzed according to the Cooper-Jacob and Theis method for the level (Fig. 8 a, b, c). The amount of well discharge value of pumping well was (1.66 L/sec.) equivalent (143.42) m^3/day. Table (4) show the drawdown in the level and the residual drawdown with time. The average of transmissivity is (70.0318) m^2/day, the storage coefficient is (0.06118 or 6×10^{-2}), and the hydraulic conductivity (5.387) m/day.

Table 4: Pumping test data of well (PW25).

Time (min.)	Drawdown (m)	t' (min.)	Residual Drawdown (m)	t/t'
1	0.4	1	0.59	61
2	0.5	2	0.55	31
3	0.55	3	0.4	21
4	0.58	4	0.1	16
5	0.6	5	0	13
10	0.61	10	0	7
15	0.61	15	0	5
20	0.62			
25	0.63			
30	0.63			
45	0.63			
60	0.63			

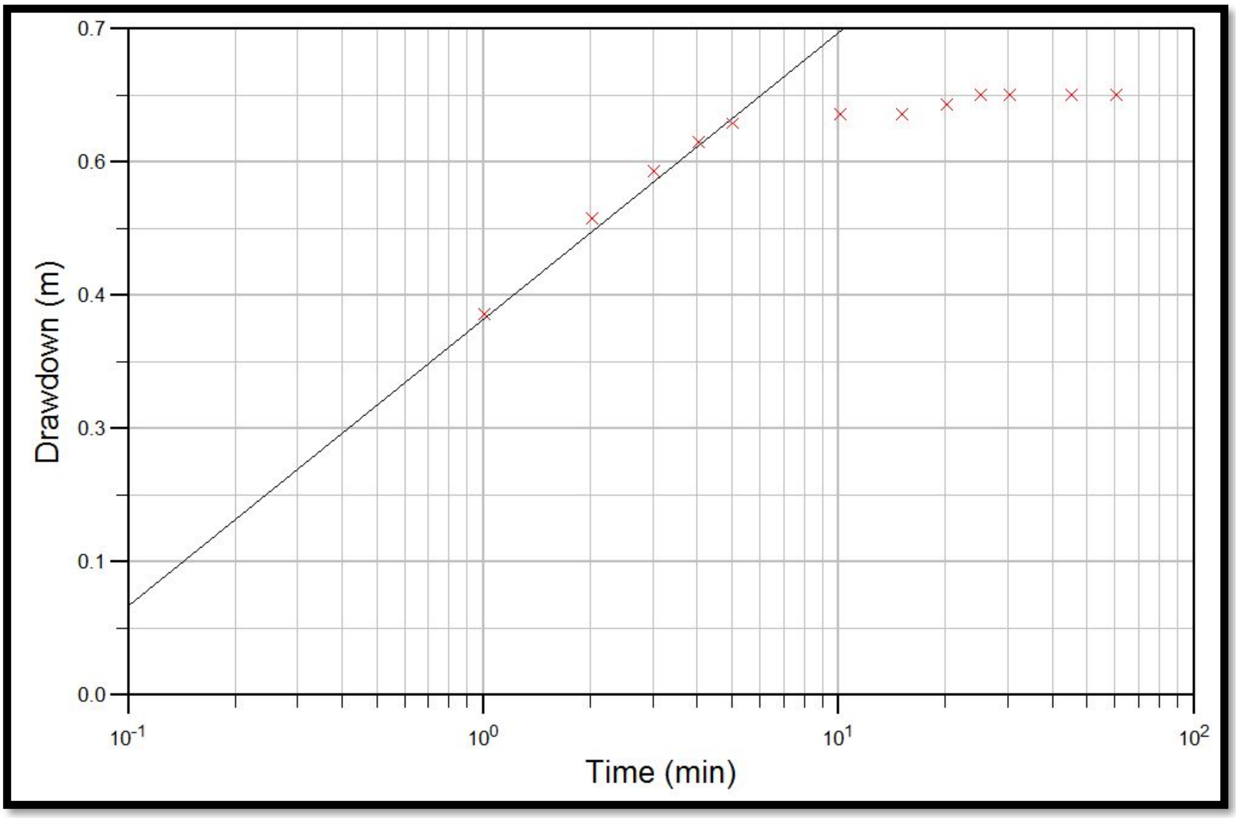

Fig. 8.a. Time- drawdown curve (Cooper and Jacob method) for well (PW25).

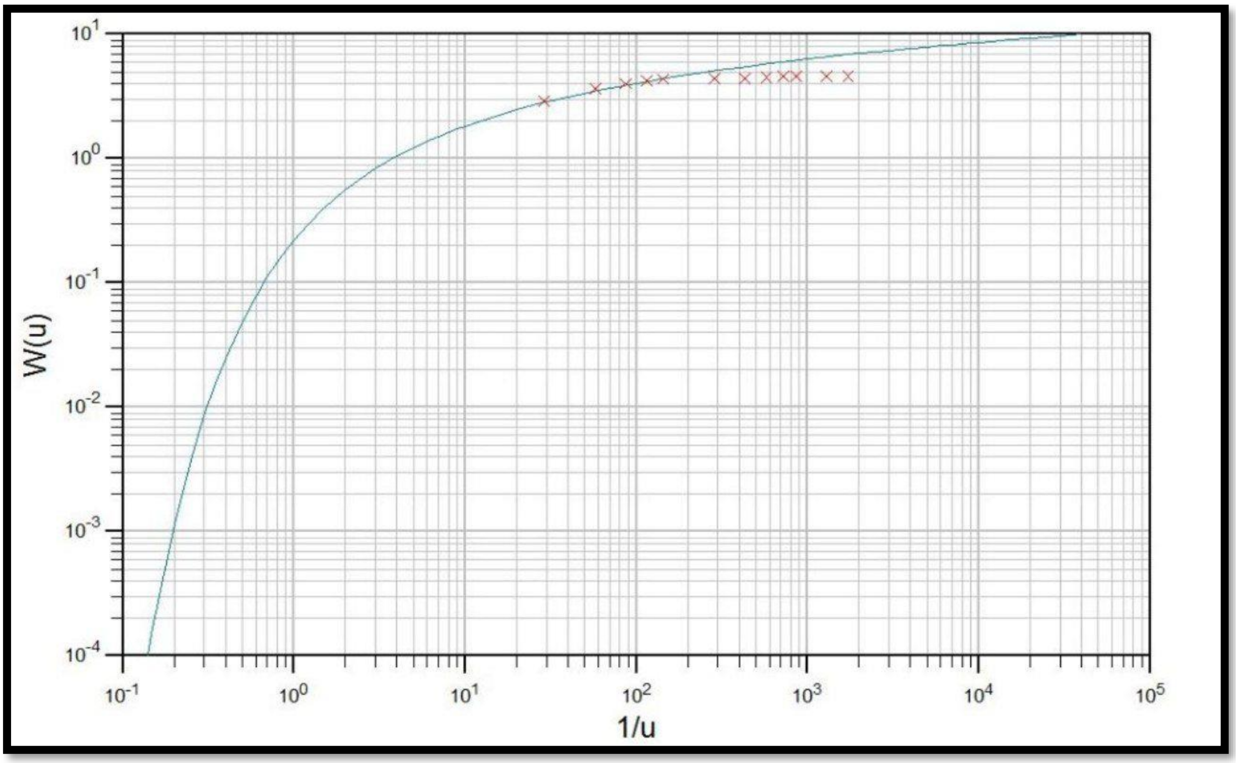

Fig. 8.b. Time- drawdown curve (Theis method) for well (PW25).

The fourth site of the pumping test operation was performed in the Muafer village, drilled in (2010). The village is located in an agricultural area and elevation (785) m a.s.l. The well depth (168) m and the saturation thickness (b) is 64 m. The static water level was (89.50)

m. The experimental pumping test and the return of the level were conducted on it, and the results were analyzed according to the Cooper-Jacob and Theis method for the level (Fig. 9 a, b, c). The amount of well discharge value of the pumping well was (3) L/sec. equivalent (259.2) m^3/day. Table (5) show the decrease in the level and the residual drawdown with time. The average of transmissivity is (8.7996) m^2/day, the storage coefficient (0.1272 or 1×10^{-1}), and the hydraulic conductivity (0.137) m/day.

Table 5: Pumping test data of well (PW24).

Time (min)	Drawdown (m)	t' (min.)	Residual Drawdown(m)	t/t'
1	0.5	1	7.9	121
2	1	2	7.6	61
3	1.9	3	7.2	41
4	2.5	4	6.7	31
5	2.7	5	4.5	25
10	4.5	10	3.5	13
15	6.3	15	2.7	9
20	7.1	20	2.1	7
25	7.5	25	0.5	5.8
30	7.9			
45	8.4			
60	9.1			
75	9.3			
90	9.3			
105	9.3			
120	9.3			

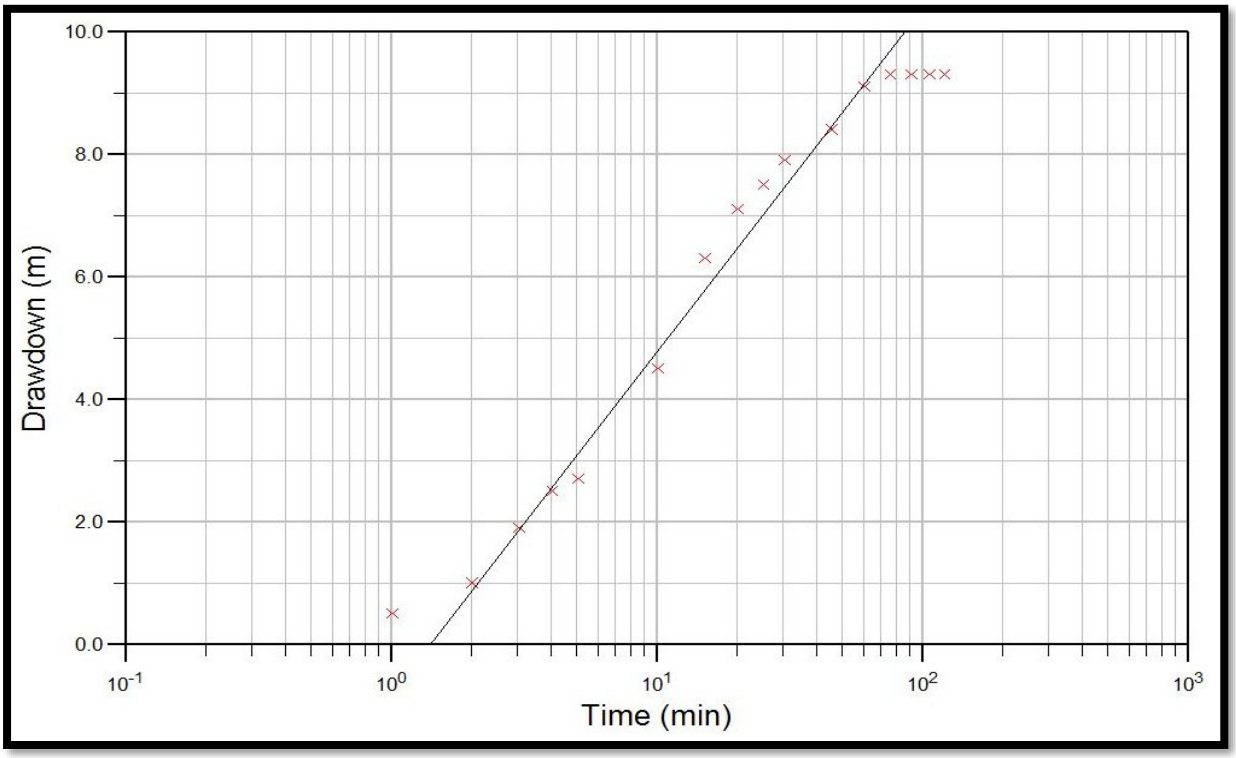

Fig. 9.a. Time- drawdown curve (Cooper and Jacob method) for well (PW24).

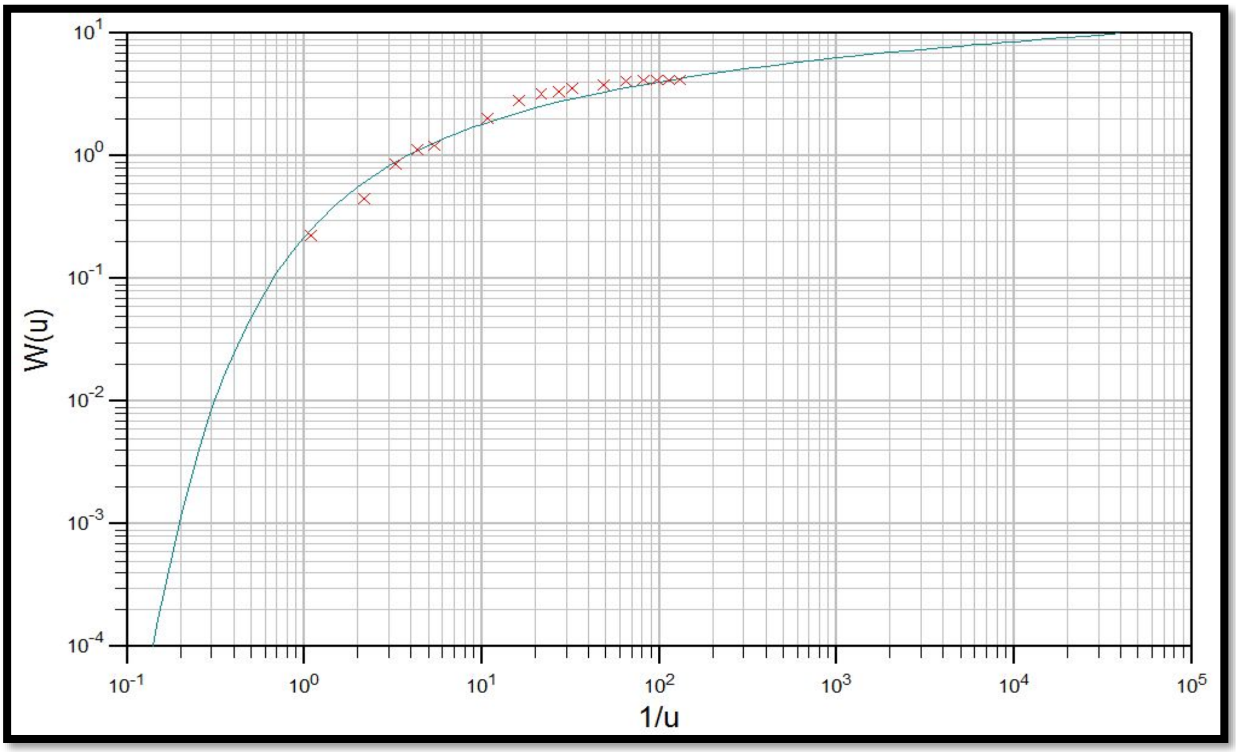

Fig. 9.b. Time- drawdown curve (Theis method) for well (PW24).

The fifth site of the pumping test was performed in Qara Tamur village in the south of the basin, drilled in (2013), with an elevation (615) m a.s.l. The well's depths (55) m and the saturation thickness (b) (20) m. The static water level in the pumping well was (10.80). The experimental pumping test and the return of the level were conducted on it, and the results were analyzed according to the Cooper-Jacob and Theis method for the level (Fig. 10 a, b, c). The amount of well discharge value of the pumping well was (1.5 L/sec.) equivalent (129.6 m^3/day). Table (6) shows the decrease in the level and the residual drawdown with time. The average of transmissivity is (337.809) m^2/day, the storage coefficient is (0.0338 or 3×10^{-2}), and the hydraulic conductivity is (16.890) m/day.

Table 6: Pumping test data of well (PW40).

Time (min.)	Drawdown (m)	t' (min.)	Residual Drawdown(m)	t/t'
1	0.10	1	0.1	21
2	0.11	2	0.06	11
3	0.12	3	0.04	7.66
4	0.13	4	0.03	6
5	0.14	5	0.02	5
10	0.16	10	0.01	3
15	0.16	15	0	2.5
20	0.16	20	0	2
30	0.16			
45	0.16			

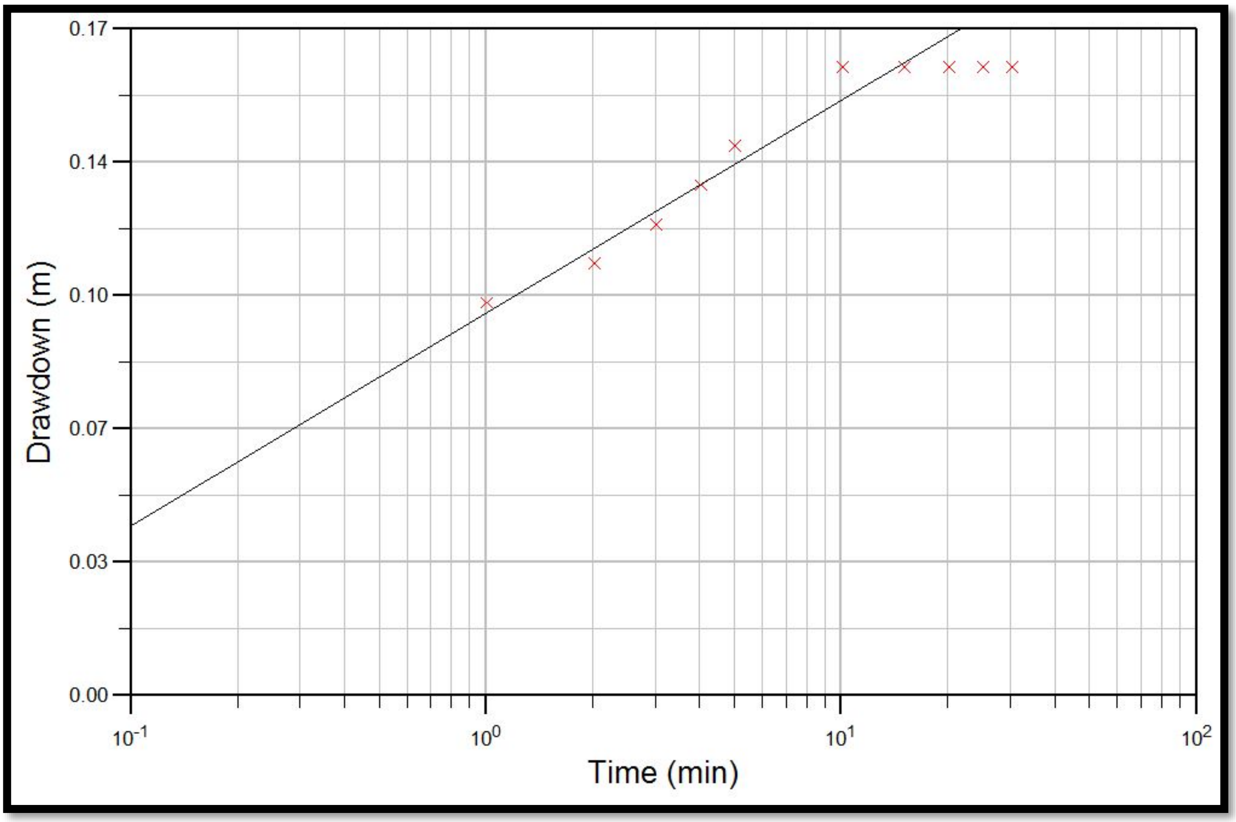

Fig. 10.a. Time- drawdown curve (Cooper and Jacob method) for well (PW40).

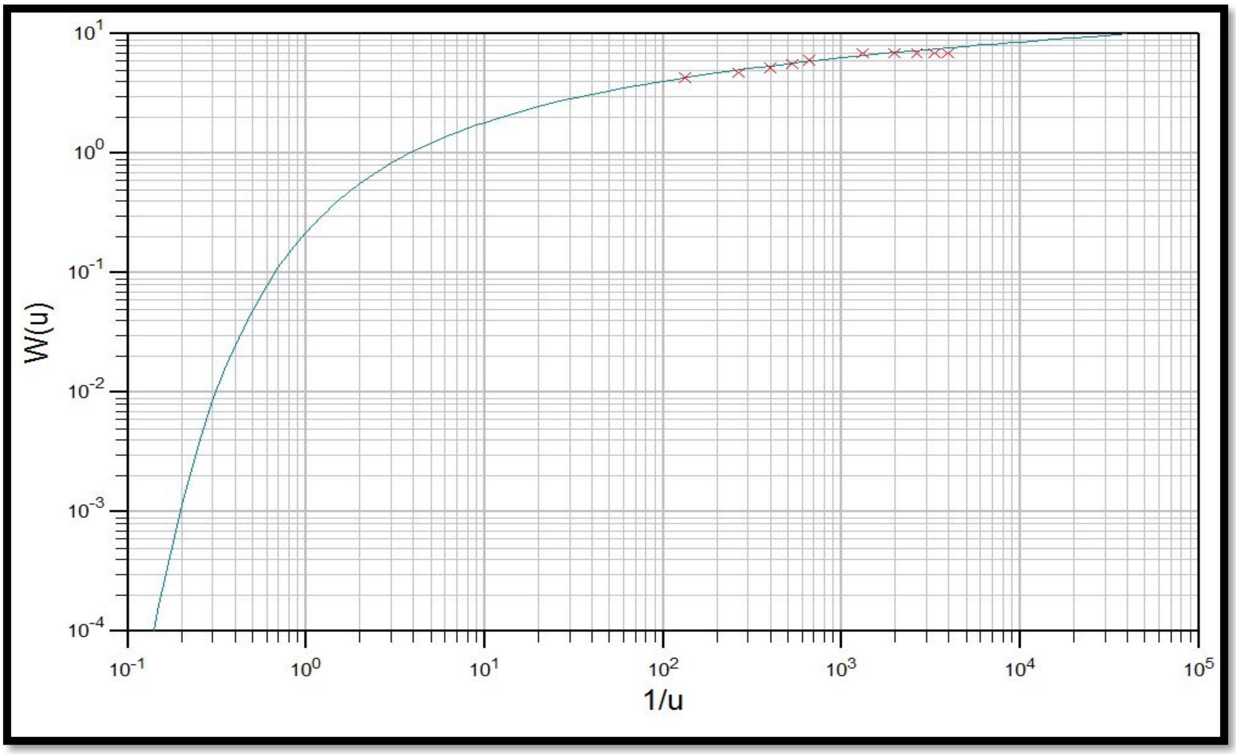

Fig. 10.b. Time- drawdown curve (Theis method) for well (PW40).

Results and discussion

The flow direction map was created by measuring the groundwater depths in the measured wells distributed in the study area. The Groundwater depths range from (8 - 140) m, as shown in Table (1). Equipotential lines have been drawn, and the overflow directions of the water in the region have been described. The groundwater flow direction map for the study area indicates that the water moves from the northwest and northeast of the sub-basin to the south basin similar to the relief of the study area, then drains for the Shiwasoor stream (Fig. 4). Chamchamal sub-basin is one of the secondary hydrogeological basins of the Great River Basin, which is one of the main tributaries of the Tigris River. Using the Copper-Jacob method, which is a simplification of the Theis method, this method deals with the wells pumped at a constant rate. The values of parameters (Transmissivity (T), Hydraulic conductivity (K), and Storage Coefficient (Sc)) and saturation thickness (b) are explained in Tables (7), (8), Figures (11), (12), (13), and (14) respectively. The aquifer types include (semi-confined, semi-unconfined, and confined) based on Table (8), according to the results of the pumping tests performed on the chosen wells within the study region.

Table 7: The coordinates and values of (Q, b) for the wells of the study area.

Wells	Well depth (m)	Latitude (N)	Longitude (E)	Elevation (m)	Discharge (m^3/day)	Saturated Thickness (m)
PW49	80	35° 35′ 13″	44° 53′ 17″	789	90.892	7.09
PW50	100	35° 35′ 02.5″	44° 53′ 00.8″	780	86.4	9.80
PW25	50	35° 34′ 08″	44° 51′ 38″	718	143.424	13
PW24	168	35° 29′ 44″	44° 49′ 18″	785	259.2	64
PW40	55	35° 28′ 34″	44° 55′ 13″	615	129.6	20

Table 8: Value of (T, K, Sc) for the well in the study area.

Wells	T (m^2/day)	K (m/day)	Sc	Type of aquifer
PW49	36.884	5.202	0.001	Semi-Confined
PW50	0.2607	0.0326	0.00363	Semi-Confined
PW25	52.661	5.387	0.06118	Semi-Unconfined
PW24	9.117	0.137	0.1272	Unconfined
PW40	337.8	16.890	0.0338	Semi-Unconfined

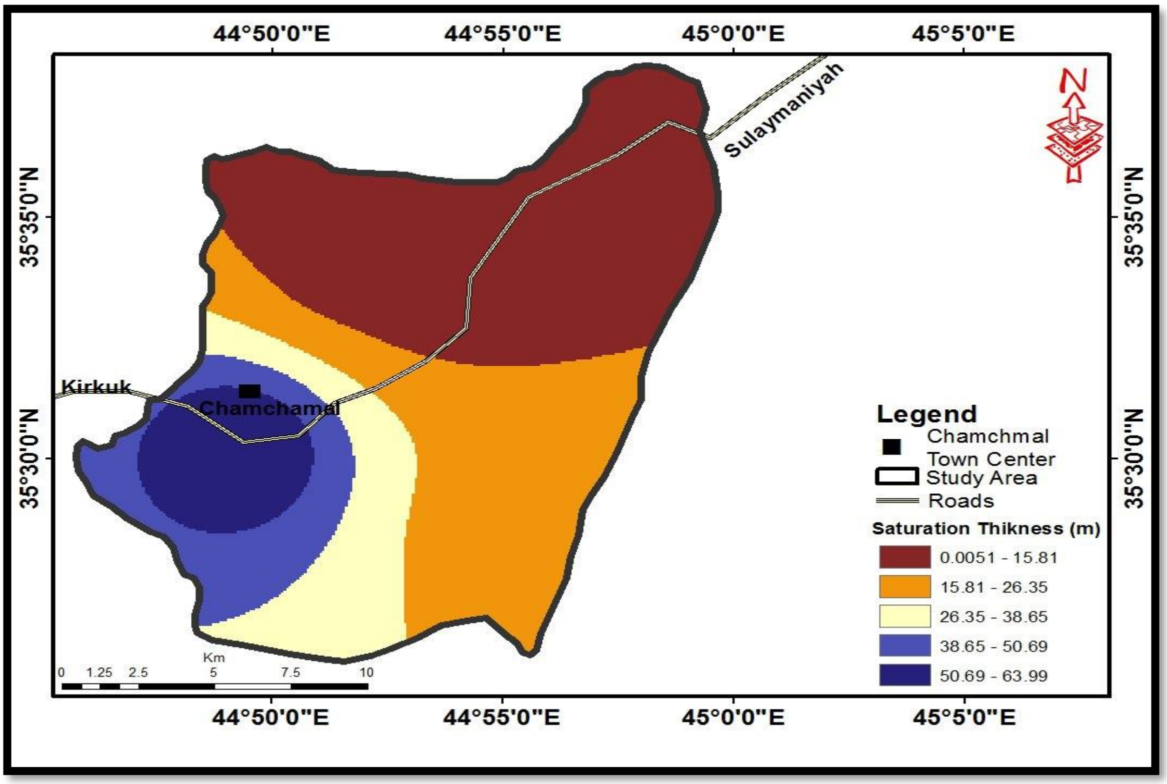

Fig. 11. Spatial distribution of saturated thickness of the aquifer in the study area.

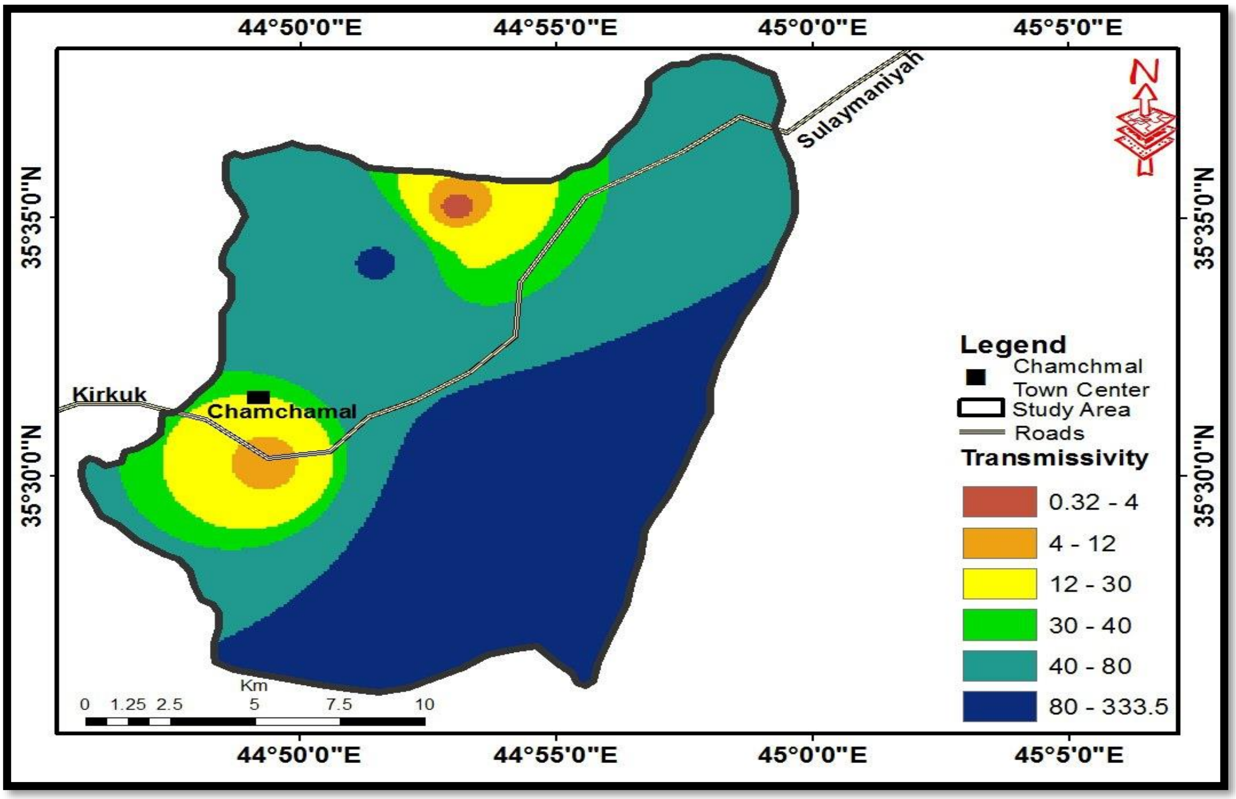

Fig. 12. Spatial distribution of Transmissivity value in the study area.

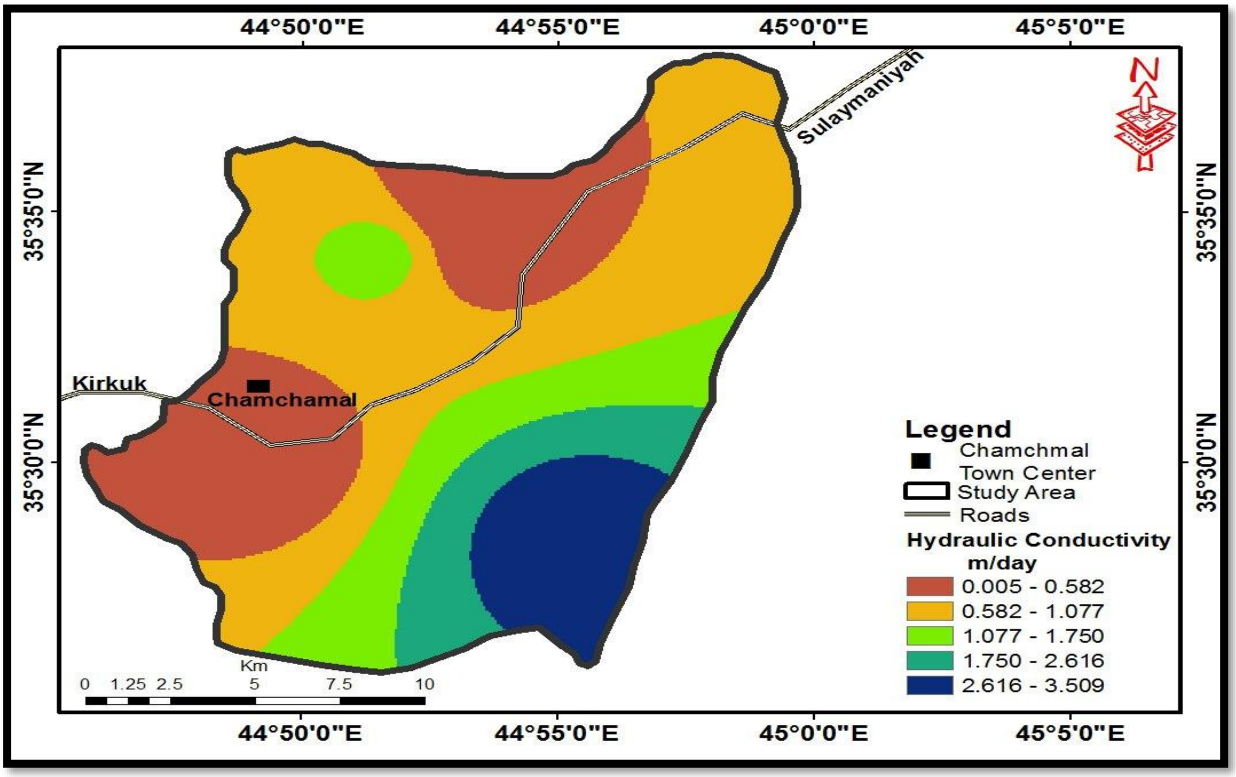

Fig. 13. Spatial distribution of hydraulic conductivity value in the study area.

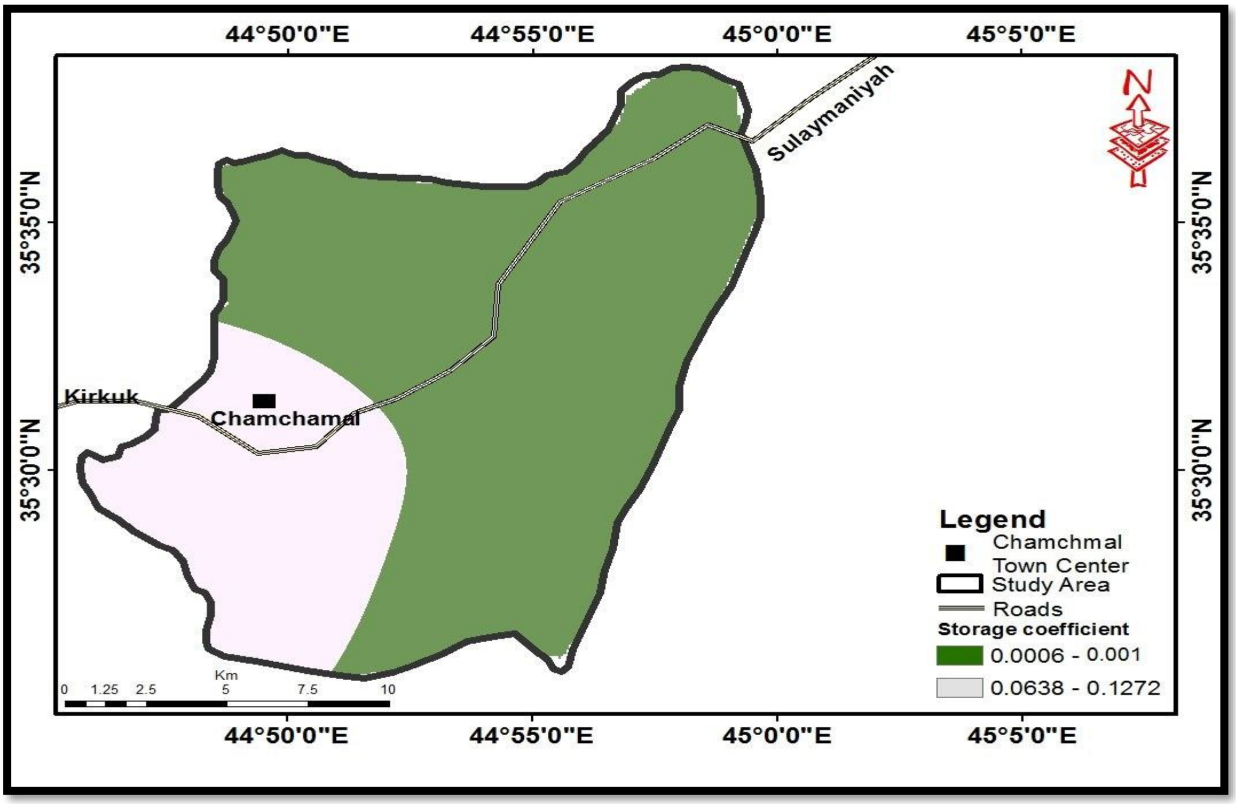

Fig. 14. Spatial distribution of Storage Coefficient values in the study area.

Conclusion

Based on the previous results It was found that the water depths in the Chamchmal sub-basin change from one location to the next and the levels of water, in general, are not very high.

Where the groundwater aquifers are held in semi-confined, semi-unconfined, and unconfined, the study area has classified heterogeneous and anisotropy. The overall direction is not in one direction, while some of the movements are from the north northeastern, and western regions of the basin (recharge areas to the discharge areas) in the south sub-basin similar to the relief of the study area than drains for the Shiwasoor stream.

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