



Hydrogeological Assessment of The Aquifers in Kirkuk City, Iraq

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Article information

Received: 00- May -20**

Revised: 00- June -20**

Accepted: 00- Aug -20**

Available online: 00- Dec – 20**

Keywords:

Pumping test
Groundwater
Hydraulic properties
Observation well
Iraq
Kirkuk

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ABSTRACT

Groundwater has been considered one of the most important sources of water for agricultural, household, and industrial operations in the Kirkuk City. The current study intends to investigate groundwater storage and estimating the hydraulic characteristics of the primary aquifers within the study area. Pumping tests are carried out in (5) water wells using the main observation wells dug in the Bai-Hassan Formation and Quaternary deposits. The aquifer types are confined to semi-confined and unconfined based on the diagrams of the drilling wells and the results of the hydraulic characteristics. The saturation thickness of the studied aquifers ranges from 22 to 66 m. The hydraulic conductivity values vary from (19.29 to 70.79 m/d), while the highest transitivity value is 1758.58 m²/day. The storage coefficient values range between (0.0002059 - 0.074). The flow net map is generated by monitoring groundwater depths from 22 wells drilled within the region of interest. The water table depths range from (1.5 m) to (31 m) below the ground surface. According to the groundwater flow map, groundwater in the region flows mostly from the north and northeast to the southwest and moves parallel to the Kassa River.

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التقييم الهيدروجيولوجي للخرانات المائية الجوفية في مدينة كركوك، العراق

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المخلص	معلومات الارشفة
تعتبر المياه الجوفية من أهم مصادر المياه للعمليات الزراعية والمنزلية والصناعية في مدينة كركوك. تهدف الدراسة الحالية إلى التحقق من تخزين المياه الجوفية وتقدير الخصائص الهيدروليكية لخرانات المياه الجوفية الأولية داخل منطقة الدراسة. أجريت اختبارات الضخ في (5) آبار مياه باستخدام آبار المراقبة الرئيسية المحفورة في تكوين باي حسن وترسبات العصر الرباعي. ان أنواع الخرنات الجوفية الموجودة هي محصورة الى شبه محصورة اضافة الى خزان غير محصور بناءً على مقاطع آبار الحفر ونتائج الخصائص الهيدروليكية. يتراوح سمك التشبع للخرانات الجوفية المدروسة من 22 إلى 66 متراً. اختلفت قيم التوصيل الهيدروليكي من (19.29 إلى 70.79 متر/يوم)، بينما كانت أعلى قيمة للنقلية هي 1758.58 متر ² /يوم. وكان معامل التخزين في حدود (0.0002059 - 0.074). تم إنشاء خريطة شبكة التدفق من خلال مراقبة أعماق المياه الجوفية من 22 بئراً تم حفرها داخل منطقة الدراسة. تتراوح أعماق منسوب المياه الجوفية من (1.5 متراً) إلى (31 متراً) تحت سطح الأرض. وفقاً لخريطة تدفق المياه الجوفية، غالباً ما تتدفق المياه الجوفية في المنطقة من الشمال والشمال الشرقي إلى الجنوب الغربي وتتحرك موازية لنهر الخاصة.	تاريخ الاستلام: 00-مايو-20** تاريخ المراجعة: 00-يونيو-20** تاريخ القبول: 00-أغسطس-20** تاريخ النشر الالكتروني: 00-ديسمبر-20** الكلمات المفتاحية: مياه الجوفية بئر المراقبة ضخ التجريبي خصائص الهيدروليكية العراق كركوك المراسلة: الاسم: سردار عمر محمدصالح Email: sardar.omar455@gmail.com

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Introduction

Hydrogeological assessments are crucial for the development and management of groundwater resources, as well as their utilization (Agha and Al-Tamimi, 2021). Groundwater is one of the world's primary sources of fresh water used for drinking, irrigation, and other purposes (Al-Hayali and Al-Tamimi, 2021). The Mediterranean climate (including Iraq) has an impact on the region's meteorology, which is defined as a hot, dry, and long summer as well as cold and rainy winter (Hamamin, 2018). As a result, groundwater management and quality should be the primary tasks to be addressed in the studies of groundwater (Sinha et al., 2016).

The demands on Iraq's groundwater supplies have risen, particularly in recent decades due to rising population and other demands (Al-Madhlom and Hussain, 2016). Due to a limitation of freshwater resources, particularly surface water in some Iraqi regions, they have been forced to rely on groundwater to support their household, agricultural, and industrial needs. Groundwater in the study area is recharged as a result of irrigation return, rainfall infiltration, and riverbed floods (Tizro and Kamali, 2014). In this research, the depth and

directions of groundwater flows as well as the hydraulic parameters of the water-bearing units within Kirkuk City have been studied due to the relevance and sustainable management of the primary aquifers. Groundwater in its normal form travels gradually and being influenced by various fixed hydraulic parameters such as hydraulic conduction, transmissivity, and storage coefficient (Todd, 1980). Rainfall is among the most important climatic parameter in the hydrological process; it is regarded as one of the main climatic factors in hydrogeological research, and it is the primary factor in water balance and groundwater recharges (Al-Tamimi, 2007).

This study aims to determine hydrogeological characteristics, which include hydraulic conductivity (K), Transmissivity (T) and Storage coefficient (Sc), for the required aquifer based on pumping test data.

Location of the study area

Kirkuk Governorate is located 250 km north of Baghdad (capital of Iraq). The area of the study is located between latitudes $35^{\circ}23'5.95''$ - $35^{\circ}30'24.94''$ N and longitudes $44^{\circ}19'41.28''$ - $44^{\circ}26'17.33''$ E, distributed over an area of 117 km². The elevation ranges between (391- 257) meters (a.s.l), where the highest elevation is about 391 m (a.s.l) in the northern part, and the lowest elevation is 254 m (a.s.l) in the southern part of the city.

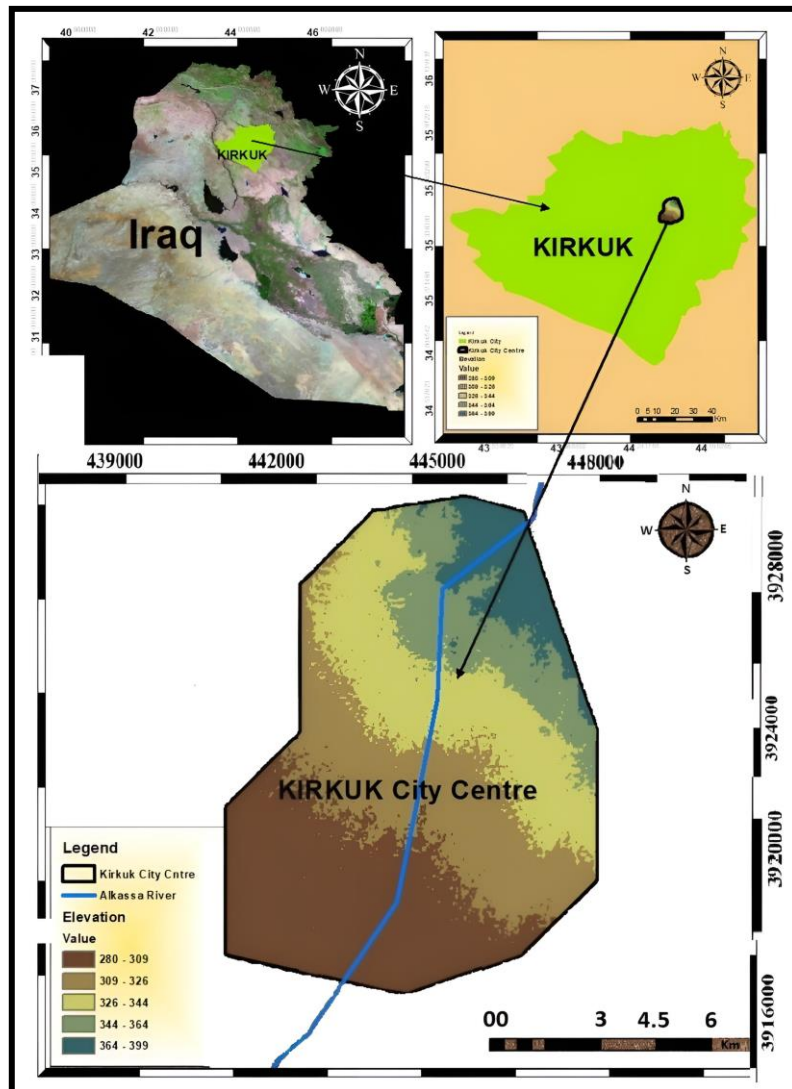


Fig. 1. Location Map of the Study area

Geological and hydrogeological setting

The study area is on the unstable shelf, particularly in Iraq's Foothill zone. The unstable shelf has been considered the strongest part of the Arab plate before its emergence in the Late Jurassic in the southern Neo-Tethys. Maximum subsidence of the Arab plate occurred in the Late Cretaceous (Jassim and Goff, 2006). The formation outcrops in the research region extend in age from Pleistocene to Holocene, as evidenced by the Bi-Hassan Formation and Quaternary deposits (Fig. 2). The research region is located in the foothill zone aquifers (Al-Jiburi and Al-Basrawi, 2012). The Bi-Hassan Formation consists of terrigenous clastics ranging from silt to boulder conglomerates; the grain size of clastics often rises vertically upward (Buday, 1980). As for Quaternary deposits, it is mainly comprised of gravels and clays. The origin of its sedimentation goes back to river sediments, delta sediments, aeolian sediments, and lake sediments (Jassim and Goff, 2006).

Materials and Methods

Any hydrological investigation must first determine the groundwater level and flow direction. Groundwater flows from the zone of the larger hydraulic head to the zone of the lower hydraulic head, according to Darcy's law. The final flow direction map is generated by measuring the groundwater levels at 22 wells during the field work in the research region as shown in Table (1) and Figure (4). Groundwater depths are measured in this study using a groundwater level sensor (sounder device) and GPS to determine the locations of measured wells. Identifying the hydraulic parameters of aquifers is carried out using pumping test activities to determine (K, T, Sc).

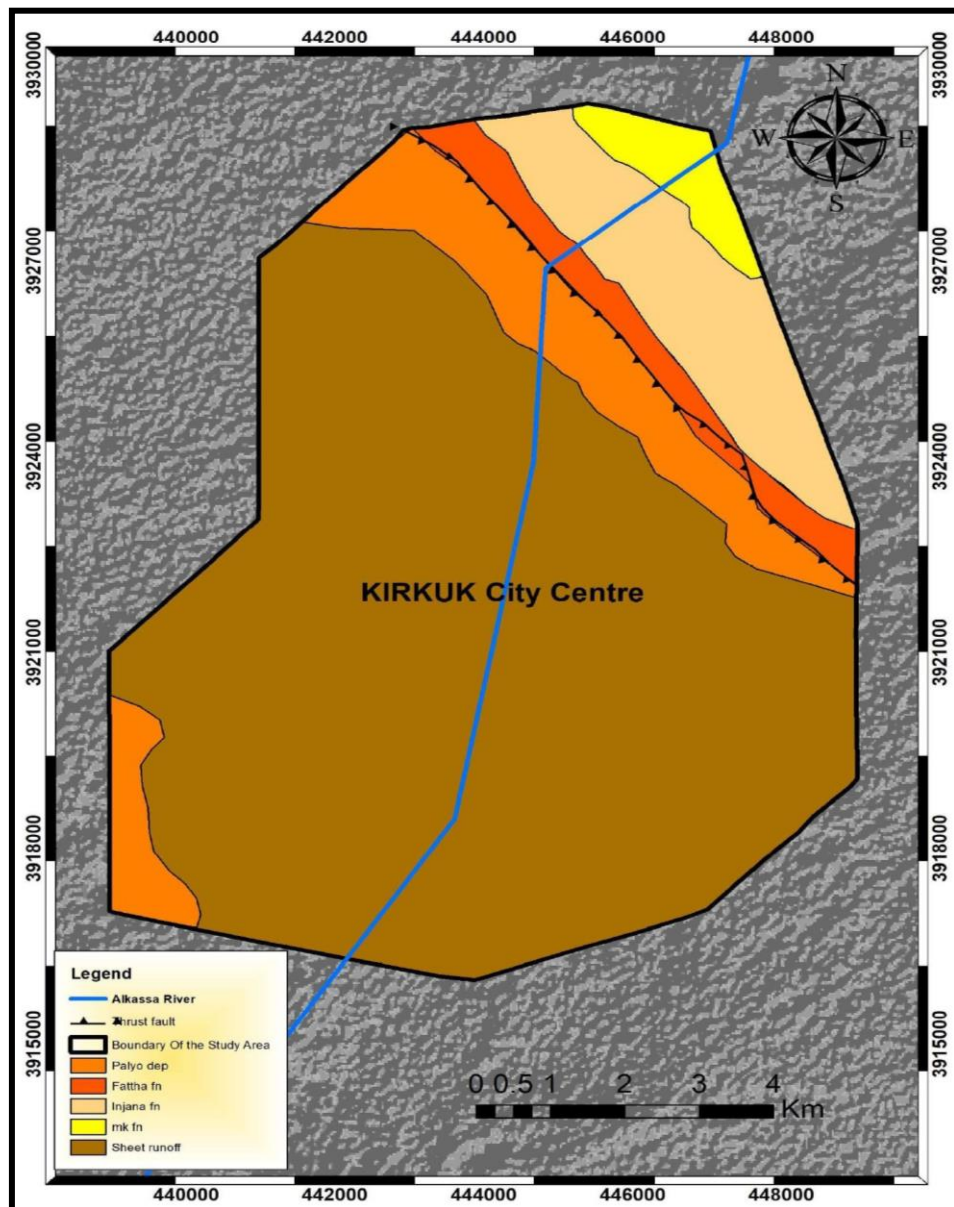
The pumping test is performed in (5) wells using the main observation wells that penetrated both the Bai-Hassan and Quaternary deposits as shown in Figure (5). The pumping test is carried out for at least several hours until reaching the steady-state conditions. There are several methods available for data analysis, including (Theis, Walton, Cooper- Jacob, Hantush, and Neuman) (Kruseman and Ridder, 1979). Cooper- Jacob methods for analysis are employed in the current study (equation a). The profile data and geological cross-sections of the wells drilled in the research region are obtained from the Governorate of Kirkuk's Water Drilling Department and created using Starter 5 Golden software as shown in Figure (3).

$$T = \frac{2.3Q}{4\pi\Delta s} \text{ -----(a)}$$

Where, T = Transmissivity (m² /day); Q = Discharge (m³/day); S = Drawdown (m).

Table 1: Wells basic data for the study area.

Well No	Name	Coordinates		Elevation (m a.s.l)	Depth to water (m)	MSL (m a.s.l)
		Easting	Northing			
W 01	Rahimawa	445436.2	3929245.21	391	3.1	387.9
W 02	Ikhwan	445324.34	3927428.16	373	2	371
W 03	Qishla	444556.84	3925553.49	360	11.3	348.7
W 04	Mall Kirkuk	443487.26	3923804.11	350	16	334
W 05	Tisin bridge	443283.29	3923435.74	334	23.6	310.4
W 06	Failaq	442143.21	3926462.26	349	31	318
W 07	Train station	442217.58	3922364.26	334	25.2	308.8
W 08	Shorija	446712.11	3923507.08	343	1.6	341.4
W 09	Ashti garden	446475.5	3921998.89	339	12.3	326.7
W 10	Qadsia	446742.17	3920087.22	327	25.1	301.9
W 11	Khadra bridge	439610.71	3920871.71	308	13.9	294.1
W 12	Zaitun St.	441982.51	3921102.61	316	19.7	296.3
W 13	Vet. Hospital	441916.98	3918761.6	304	12.6	291.4
W 14	Smileland	443406.97	3919060.08	308	14.6	293.4
W 15	Laylan bridge	446983.44	3918237.26	318	27.2	290.8
W 16	4th bridge	443892.44	3920073.75	322	17.6	304.4
W 17	Askary	446344.65	3916854.68	317	21.8	295.2
W 18	Kirkuk Univ.	440315.78	3916923.55	257	6.7	250.3
W 19	Wasti	439996.7	3918250.39	301	10.8	290.2
W 20	Al-huzairan	438561.28	3918599.05	297	6.7	290.3
W 21	Al-nidaa	443268.79	3917150.86	308	11.2	296.8
W 22	Panjaali	448170.88	3918569.26	329	25.2	303.8

**Fig. 2. Geological map of the study area.**

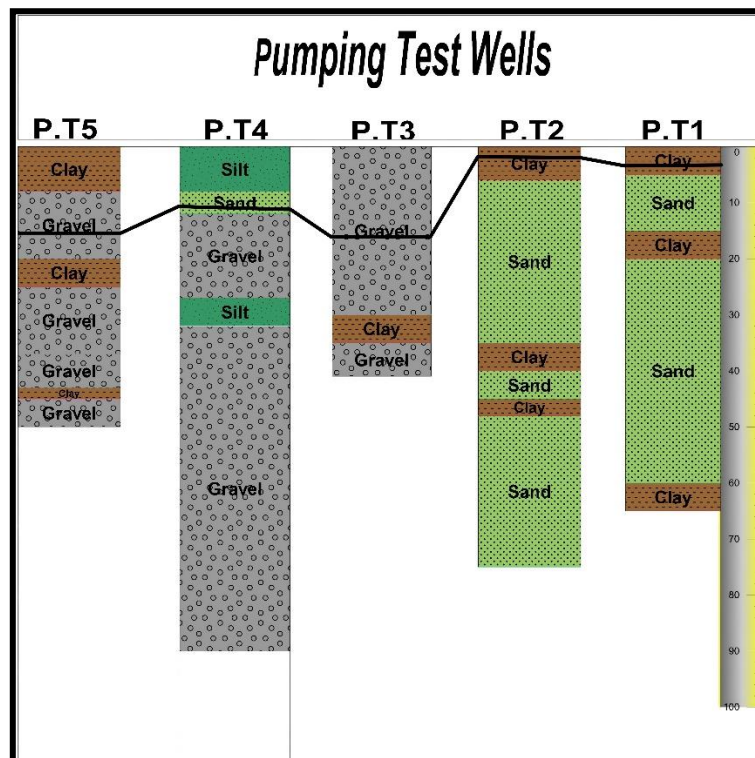


Fig. 3. Cross-section map showing the pumping test wells and water table levels.

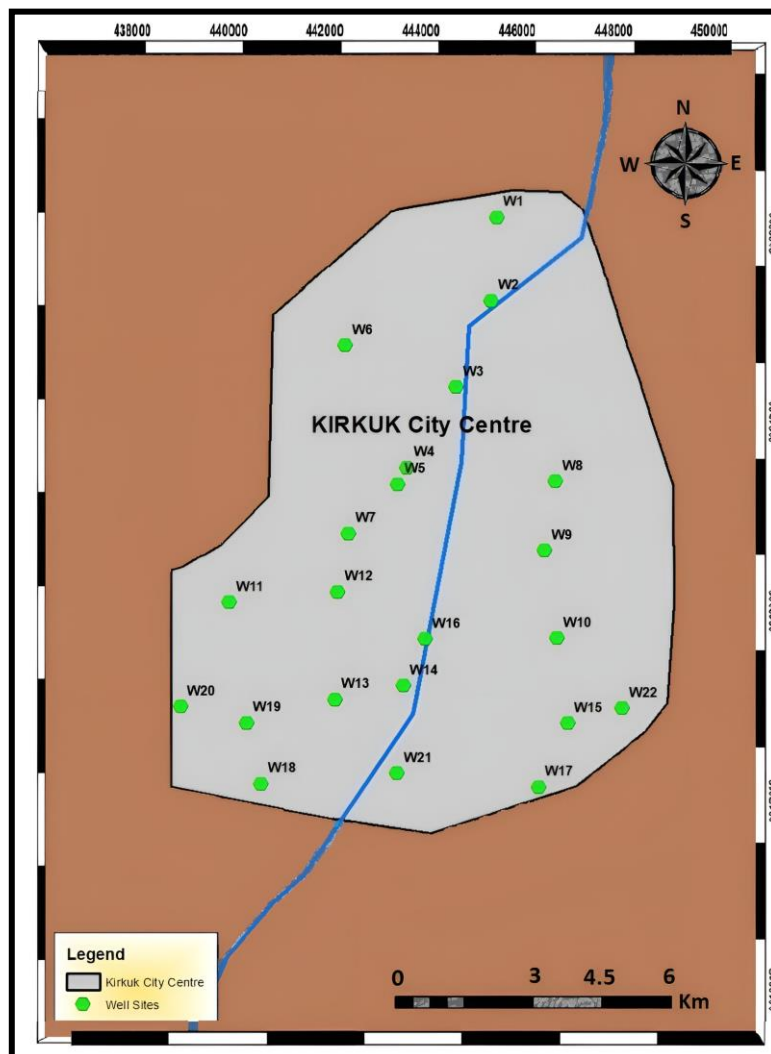


Fig. 4. Wells' sites of the study area.

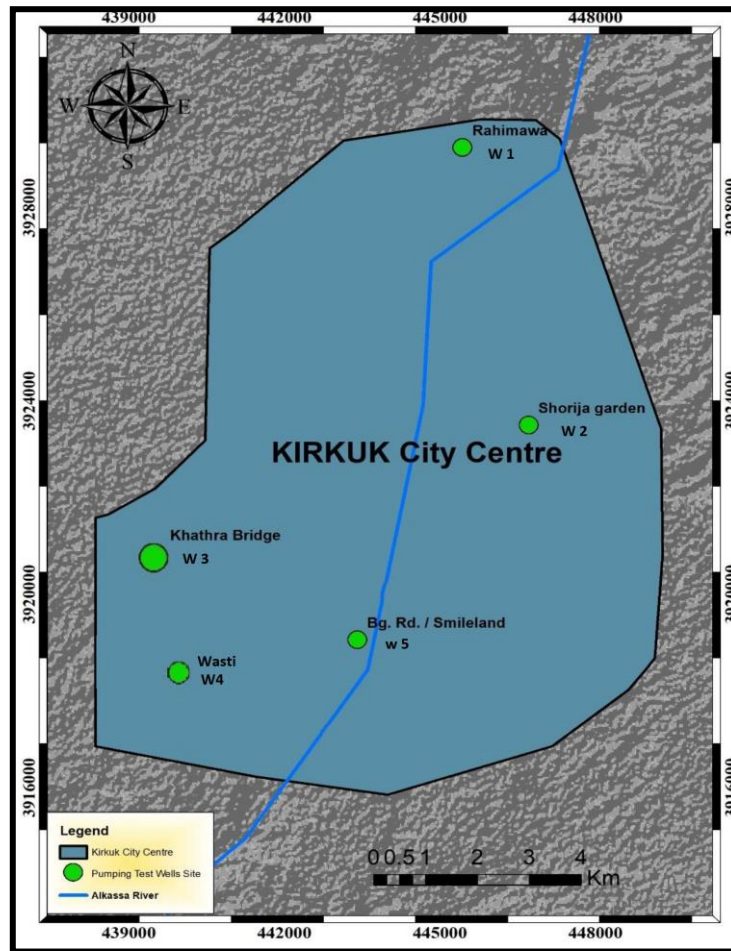


Fig. 5. Selected wells' sites for pumping test.

Results and discussion

The flow direction map is created by measuring the groundwater depths in the measured wells distributed in the study area. The groundwater depths range from (1.5 - 31) m as shown in Figure (6). Equipotential lines have been drawn, and the overflow directions of the water in the region have been described. The directions of groundwater flow are not in one particular movement although some of movements are parallel to Al-Khassa River especially toward the north and northeast of the city where it is of higher topography (Fig. 6).

Using Copper-Jacob method, which is a simplification of the Theis method, as depicted in the figures (13, 14, 15 and 16), and deals with the wells pumped at a constant rate, is applied.

The hydraulic characteristics indicate variation in hydraulic conductivity from one location to the next, where it is in the Khadhra bridge location having the greatest value (70.79 m/d), while in Shorija, the lowest value is (19.29 m/d). Highest transmissivity value within the study area is (1758.584 m² /d). The storage coefficient values range from the lowest value of (0.0002059) in Rahimawa to the maximum value of (0.074) at Khadhra Bridge.

The variation in these values is because of the sewer water, which is not discharged with proper system; in fact, from most of the study area, the sewer water from households and industrial locations are recharged into the groundwater directly beside the heterogenic and porosity of the formations of Bai-Hassan and the Quaternary deposits are the reasons for the values' differences (Al-Tamimi and Shwani, 2019). The aquifer types include (confined, semi-

confined and unconfined). Based on table (8), it is heterogenic and anisotropic according to the results of the pumping tests performed on the chosen wells within the study region.

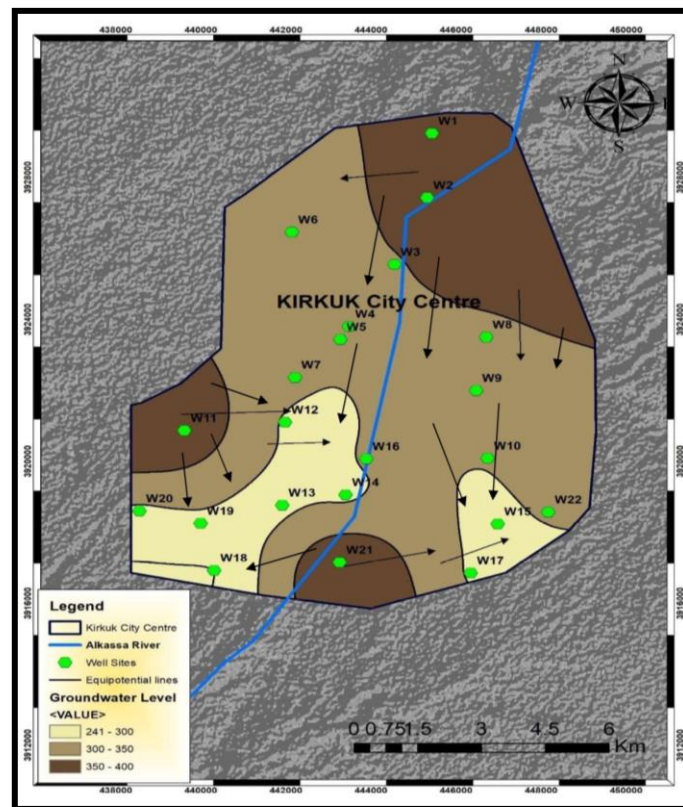


Fig. 6. Groundwater flow direction map of the study area.

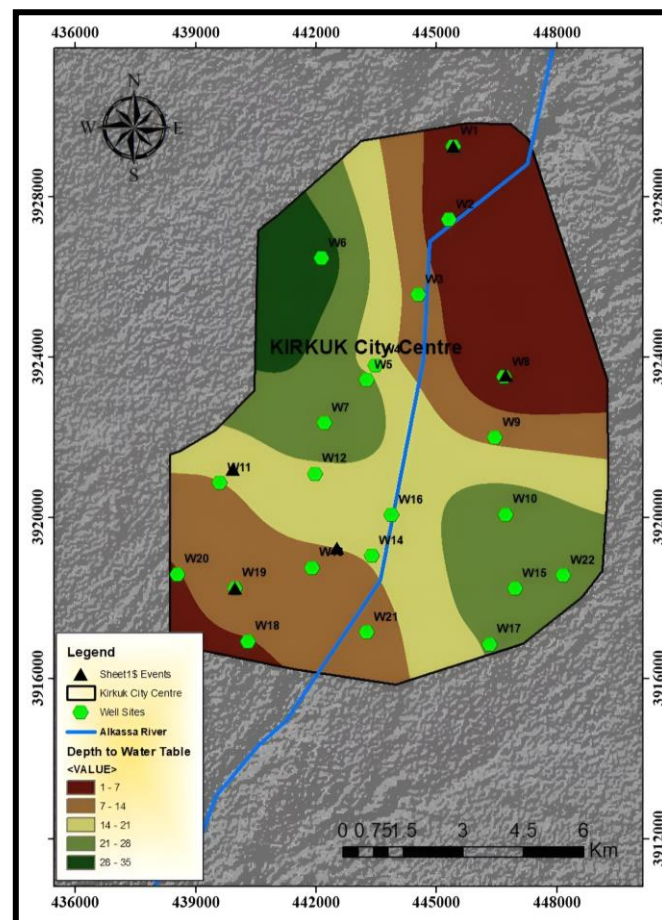
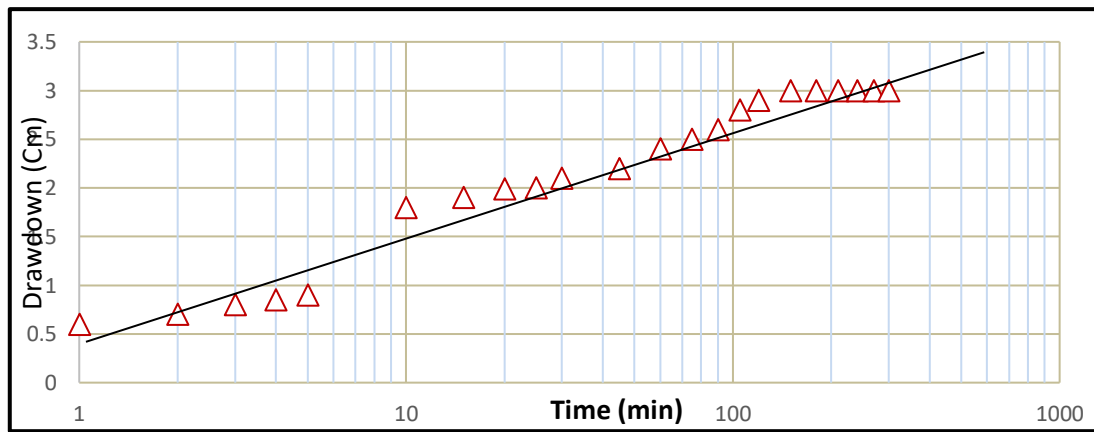


Fig. 7. Groundwater level map of the study area.

Table 2: Pumping test data of well No. 1 (Rahimawa).

Time (min)	Drawdown (cm)	Time (min)	Drawdown (cm)
1	0.6	60	2.4
2	0.7	75	2.5
3	0.8	90	2.6
4	0.85	105	2.8
5	0.9	120	2.9
10	1.8	150	3
15	1.9	180	3
20	1.99	210	3
25	2	240	3
30	2.1	270	3
45	2.2	300	3

**Fig. 8. Pumping test data analysis of W1 (Rahimawa) using Copper-Jacob method.****Table 3: Pumping test data of well No. 2 (Shorija).**

Time (min)	Drawdown (cm)	Time (min)	Drawdown (cm)
1	0.01	60	0.5
2	0.04	75	0.58
3	0.05	90	0.63
4	0.07	105	0.72
5	0.08	120	0.73
10	0.1	150	0.77
15	0.18	185	0.8
20	0.2	200	0.9
25	0.3	240	1
30	0.38	250	1
45	0.45	300	1

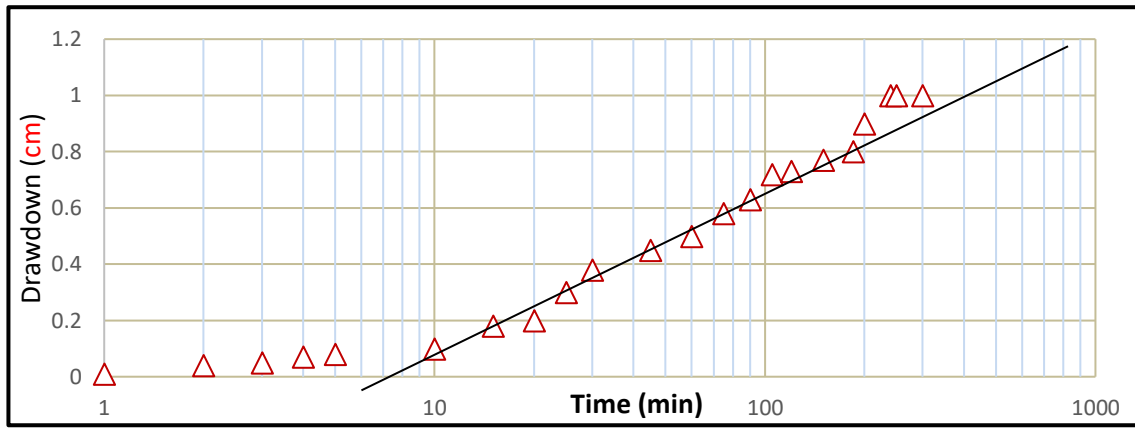


Fig. 9. Pumping test data analysis of W2 (Shorija) using Copper-Jacob method.

Table 4: Pumping test data of well No. 3 (Khadra bridge)

Time (min)	Drawdown (cm)	Time (min)	Drawdown (cm)
1	0.2	45	0.585
2	0.34	60	0.85
3	0.38	75	1.65
4	0.39	90	2
5	0.39	105	2.25
10	0.45	120	2.35
15	0.46	150	2.65
20	0.48	180	3
25	0.5	210	3
30	0.52	240	3

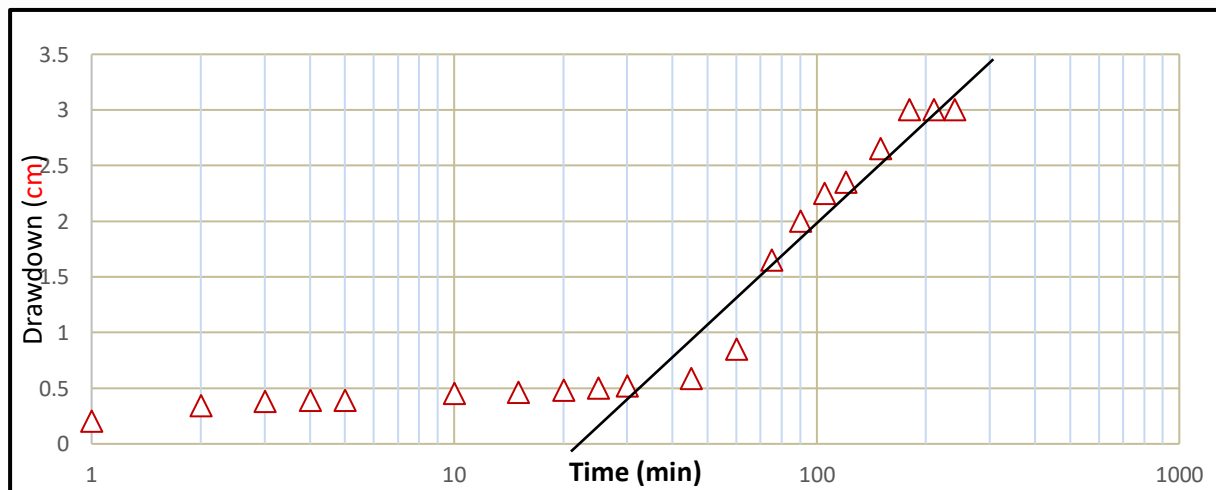
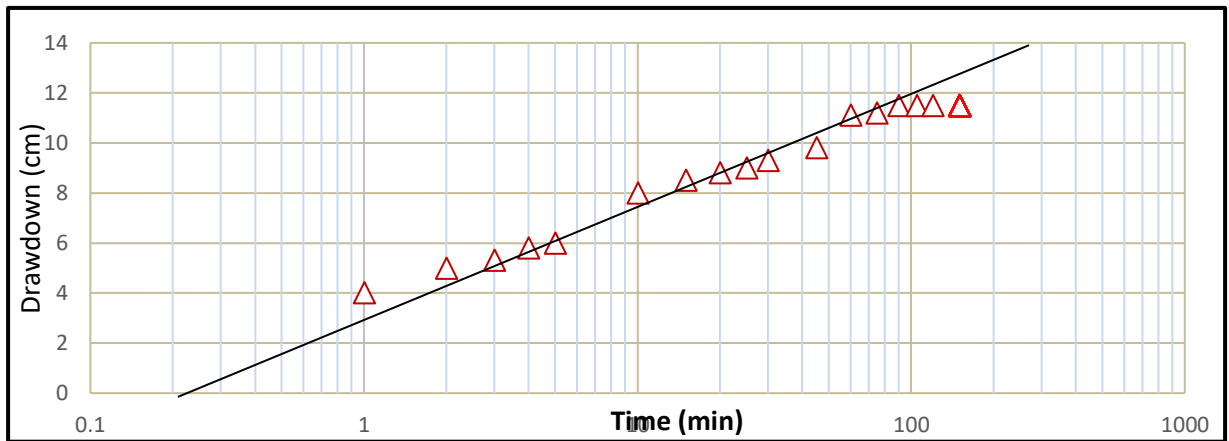


Fig. 10. Pumping test data analysis of W3 (Khadra bridge) using Copper-Jacob method.

Table 5: Pumping test data of well No. 4 (Wasti).

Time (min)	Drawdown (cm)	Time (min)	Drawdown (cm)
1	4	30	9.3
2	5	45	9.8
3	5.3	60	11.1
4	5.8	75	11.2
5	6	90	11.5
10	8	105	11.5
15	8.5	120	11.5
20	8.8	150	11.5
25	9		

**Fig. 11. Pumping test data analysis of W4 (Wasti) using Copper-Jacob method.****Table 6: Pumping test data of well No. 5 (Baghdad Rd).**

Time (min)	Drawdown (cm)	Time (min)	Drawdown (cm)
1	0.098	60	1.2
2	0.196	75	1.5
3	0.295	90	1.56
4	0.392	105	1.8
5	0.491	120	2
10	0.499	150	2.2
15	0.499	175	2.5
20	0.75	180	2.5
25	0.9	210	2.5
30	1	240	2.5
45	1		

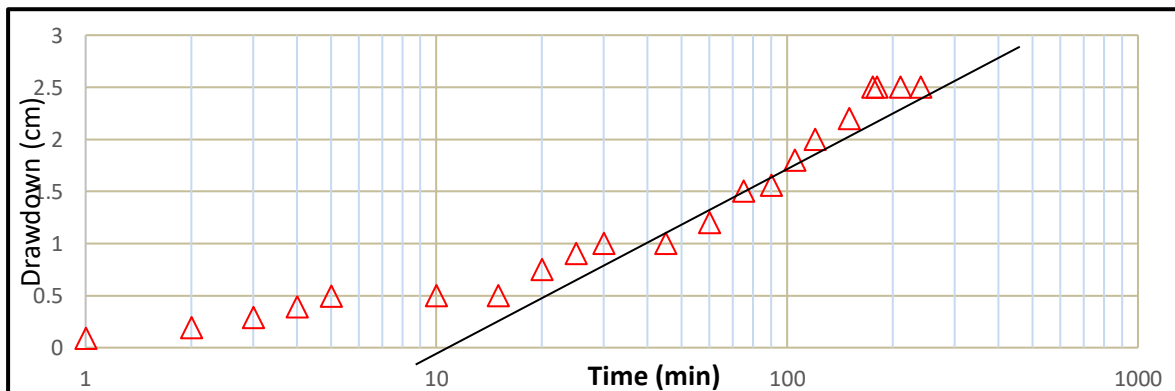
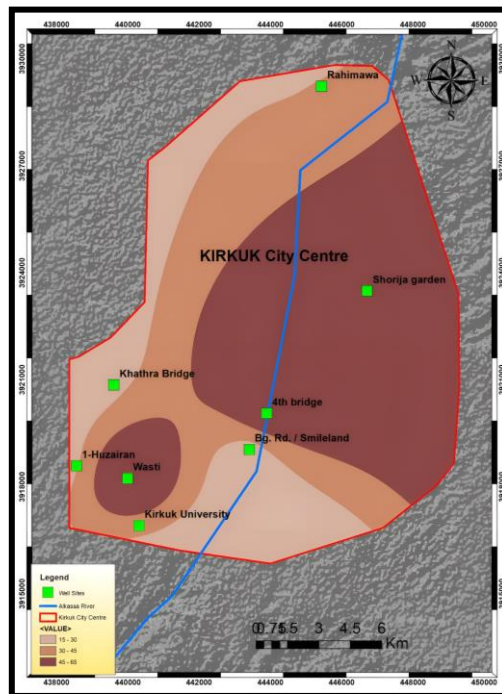
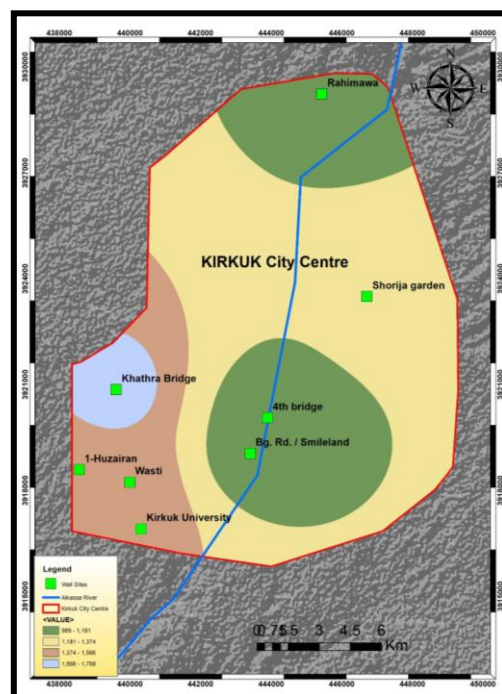
**Fig. 12. Pumping test data analysis of W5 (Baghdad Rd) using Copper-Jacob method.**

Table 7: Values of (T, K, S) for the wells of the study area and types of aquifers.

Well No.	Well Sites	Cooper and Jacob method			Type of aquifer
		T (m ² /d)	K (m/d)	Sc	
W1	Rahimawa	1067.2	34.48	0.0002059	Confined
W2	Shorija	1254.328	19.29	0.0009678	Confined
W3	Khadhra bridge	1758.584	70.79	0.074	Unconfined
W4	Wasti	1484.462	22.25	0.00927	Leaky/Semi Confined
W5	Baghdad Rd.	989.641	44.12	0.027448	Leaky/Semi Confined

Table 8: Values of storage based on aquifer layer types (Suprapti and Pongmanda, 2020)

Aquifer Type	Storage Coefficient
Confined	0.00005 – 0.005
Leaky / Semi Confined	0.005 – 0.05
Unconfined	0.05 – 0.3

**Fig. 13. Spatial distribution of saturated thickness of the aquifer in the study area.****Fig. 14. Spatial distribution of Transmissivity values in the study area.**

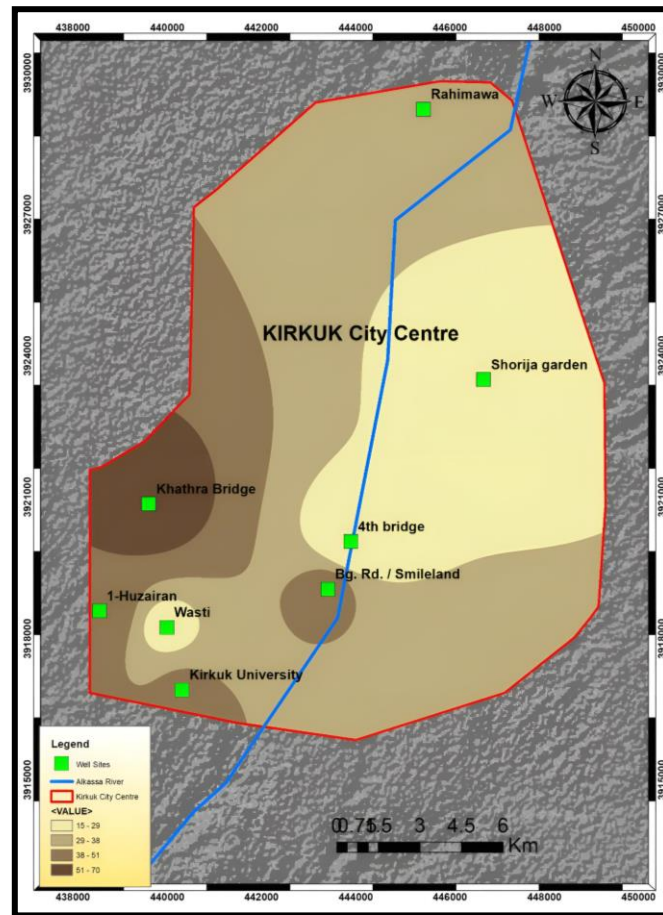


Fig. 15. Spatial distribution of hydraulic conductivity values in the study area.

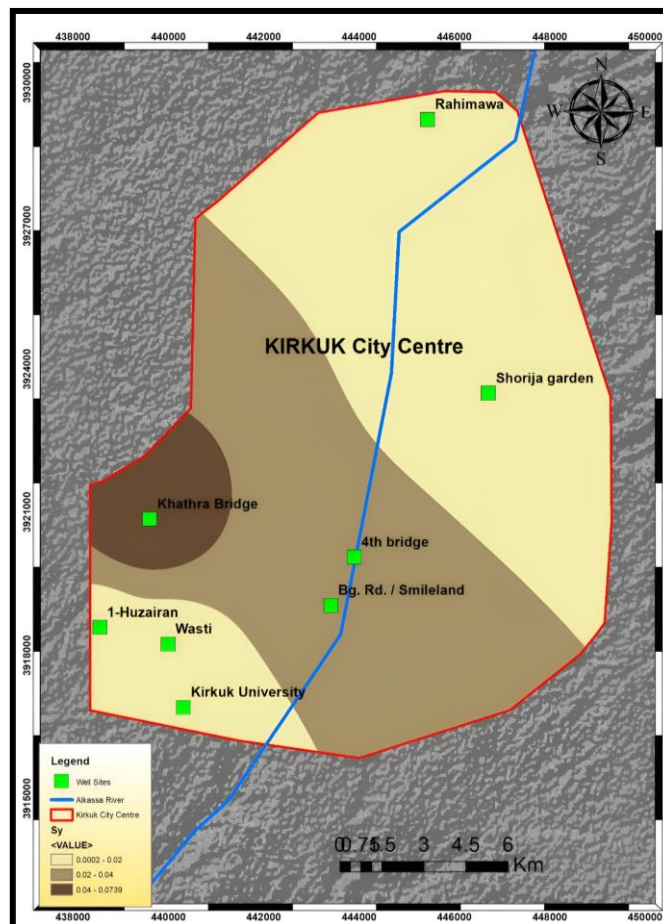


Fig. 16. Spatial distribution of Storage Coefficient values in the study area.

Conclusion

Based on the previous results, it is found that the water depths in Kirkuk City change from one location to the next and the levels of water, in general, are not very high.

The quantity of water is estimated as plenty and used for various purposes in the region, where groundwater is held in confined to semi-confined aquifers, the overall direction is not in one particular direction, while some of the movements are from the north and northeastern regions of the basin (recharge areas) to the discharge areas at southwest.

Acknowledgements

The authors would like to express their gratitude to the University of Kirkuk, College of Science for providing all of the required facilities, which contributed in the improvement of the quality of this work.

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