

HYDROGEOLOGICAL CHARACTERIZATION OF QUSHTAPA AND SHAMAMIK AREA IN ERBIL BASIN, USING PUMPING TEST DATA

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ABSTRACT

This study investigates the hydrogeological parameters through detailed pumping test analysis in the Qushtapa and Shamamik areas within the Erbil Basin. This study aims to assess key aquifer parameters, including hydraulic conductivity, transmissivity, and storage coefficient, which are substantial for sustainable groundwater management. Data from 10 groundwater pumping tests were analyzed using established analytical approaches, such as the Cooper-Jacob straight-line method, and the Theis recovery method using AQTESOLV and the Microsoft Excel program to derive hydrogeological parameters of the aquifer. The results show significant spatial variability in aquifer properties impacted by lithological variability and the rate of groundwater recharge. The average hydraulic conductivity ranges between 0.0245 mday^{-1} and 0.191 mday^{-1} . The average Transmissivity value ranges from $8.62 \text{ m}^2\text{day}^{-1}$ to $47.725 \text{ m}^2\text{day}^{-1}$. The Storage Coefficient ranges between 0.071 and 0.323. Based on the Krasny (1993) classification for Transmissivity, the studied area is classified as an area with a Low-Intermediate class of Transmissivity. Pumping tests play a crucial role in ensuring long-term water security and informing sustainable development policies in the study area.

Key words: AQTESOLV, aquifer, Hydraulic conductivity, saturated thickness, single well test



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INTRODUCTION

Globally, groundwater is the most valuable natural resource. It is a non-renewable resource that should be preserved in a robust quantitative and qualitative manner for future generations (Llamas & Martínez-Santos, 2005a; Llamas & Martínez-Santos, 2005b). The global proportion of water consumed by people from groundwater sources exceeds one-third, with rural regions relying heavily on groundwater for the majority of their drinking water (Al-Ansari et al., 2014; Al-Sudani, 2019). It supplies around forty percent of the water required for all purposes, excluding hydropower production and energy supply facilities (Heath, 1998). Global climate change and population expansion have contributed to water shortages, posing challenges in effectively using and managing water resources (Alley et al., 2002; CONAMA,

2006; Jalut, 2020; Tran et al., 2023a; Tran et al., 2023b). These changes have resulted in a significant reduction in surface water supplies, promoting the emergence of alternative water sources and the advancement of exploitation methods (Kubba, 1998). In 2021-2022, the government formally declared a drought in the Kurdistan region due to a lack of precipitation, which particularly affected aquifer recharge and the agricultural sector, and its implications persist. To address the water deficit, the government of the Kurdistan Region of Iraq drilled numerous deep wells across the Erbil basin, and the study area is no exception. This led to the depth of groundwater wells being increased dramatically year by year due to the region's high groundwater extraction. It is anticipated that urbanization and development also obstruct the Infiltration of water into the soil and the replenishment of this essential

resource. Understanding the spatial distribution of groundwater is essential for efficient water resource management and ensuring its sustainability (Arshad et al., 2024; Paswan et al., 2024; Waseem et al., 2020). Extensive knowledge of aquifer characteristics is essential for effectively managing and sustainable utilization of water resources (Jasim & Jalut, 2020; Mustafa & Mawlood, 2023). Mustafa (2017) applied several practical methods for estimating hydraulic parameters of unconfined aquifers in the Kawargosk area. The results show that the Cooper-Jacob (1946) method and Theis (1935) recovery method are among the more reliable applicable methods for analyzing pumping test data. Mawlood (2019) aimed to investigate the effects of groundwater exploitation on the aquifer's sustainability, using climate data, soil, the number of wells, and the hydrogeology of the Erbil aquifer to recognize the current and future conditions of the aquifer. The results show that there is an irresponsible use of GW, and there is a decrease in the water table of about 1.24 m/year in the Erbil basin. Jasim and Jalut (2020) analyzed pumping test data from 17 productive wells and 2 observation wells in the shallow unconfined aquifer in Baquba City, central Iraq. The results indicated that the area is classified as a high groundwater supply potential and slightly heterogeneous aquifer soil. This research implements multi-measurement techniques, including AQUTESOLV software, to investigate aquifer properties using pumping test and recovery test data, which will help us to evaluate aquifer efficiency better and enhance our comprehension of aquifer parameters, as well as using ArcGIS to show groundwater flow direction. Numerous methods are used for assessing the aquifers' hydraulic parameters of

the aquifers, but the Cooper-Jacob and Theis method remains prominent (Calvache et al., 2016; Tumlinson et al., 2006). While advanced models facilitate simulation, they cannot replace field data and may result in inaccurate evaluations. The absence of observation wells further limits the application of other models. In this research, the Cooper-Jacob and Theis Recovery method is applied to evaluate the hydraulic parameters of the aquifers to promote the efficient management of groundwater resources, especially in the study area that faces water scarcity and is threatened by over-extraction, and will inform decision-makers about sustainable extraction practices that guarantee this resource's long-term availability. Previous studies have thoroughly investigated the hydrogeological properties of the Erbil Basin. Despite ongoing water scarcity, particularly due to extensive agricultural and industrial usage, the hydrogeological conditions in certain regions of the Erbil Basin are poorly understood. This research aims to investigate the groundwater flow direction to assess the ease with which water flows through the aquifers, and to determine the hydrogeological parameters of the aquifers in the study area by using intensive well data in areas suffering from water shortage.

MATERIALS AND METHODS

Study area: The study area is located in the Erbil basin, which is a part of the Erbil Plain. It covers an area of about 1,302 km², located between 35° 43' 50" to 36° 14' 01" N latitude and 43° 40' 42" to 44° 17' 55" E longitude (Figure 1). Its climate is categorized as dry to semi-arid. The average annual precipitation in the Erbil basin over the previous 20 years (2000–2020) was approximately 467 mm (Hamad, 2022).

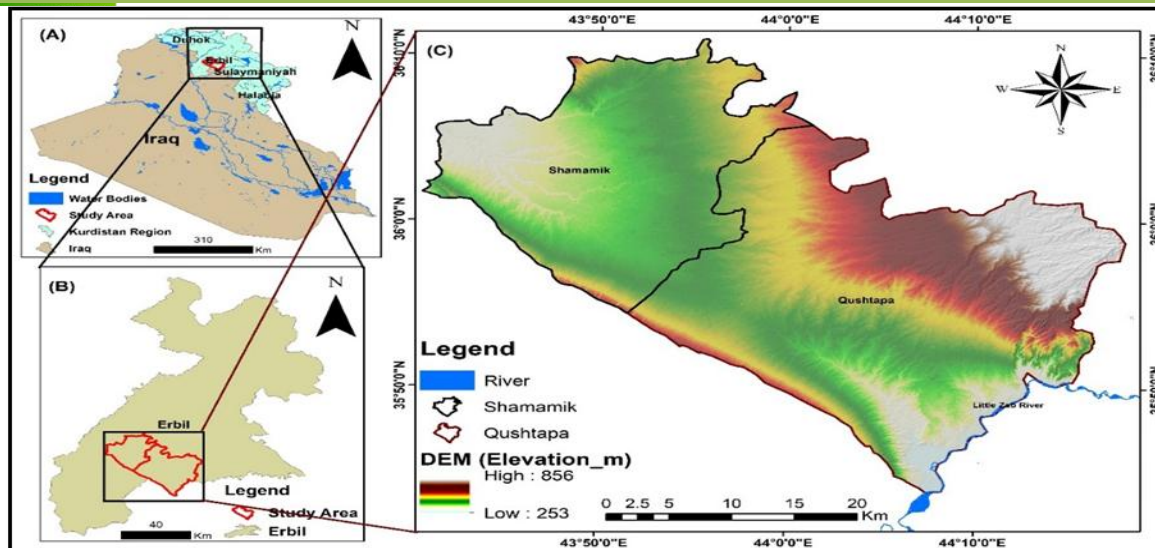


Figure 1. Location maps of the study area

Because of its fertile soil and abundant, high-quality groundwater, the Erbil basin is among the most significant basins in the Kurdistan Region/Northern Iraq. From river valleys to flat alluvial plains, gravel hills, and the Zagros foothill zones, the Erbil basin contains a wide variety of geomorphological and geological features (Dizayee, 2014). The Erbil Basin features many anticlines and synclines. Such structural formations resulting from the

bending of the Earth's crust owing to tectonic pressures. Hydrogeologically, the basin is located in the low folded zone, significantly affected by its geological context, with the Erbil region predominantly consisting of conglomerate aquifers (Sissakian and Fouad, 2015). Toward the south, it is delineated by the Demirdagh anticline; to the north, it is delineated by the Pirmam anticline and the Bastora Stream (Figure 2).

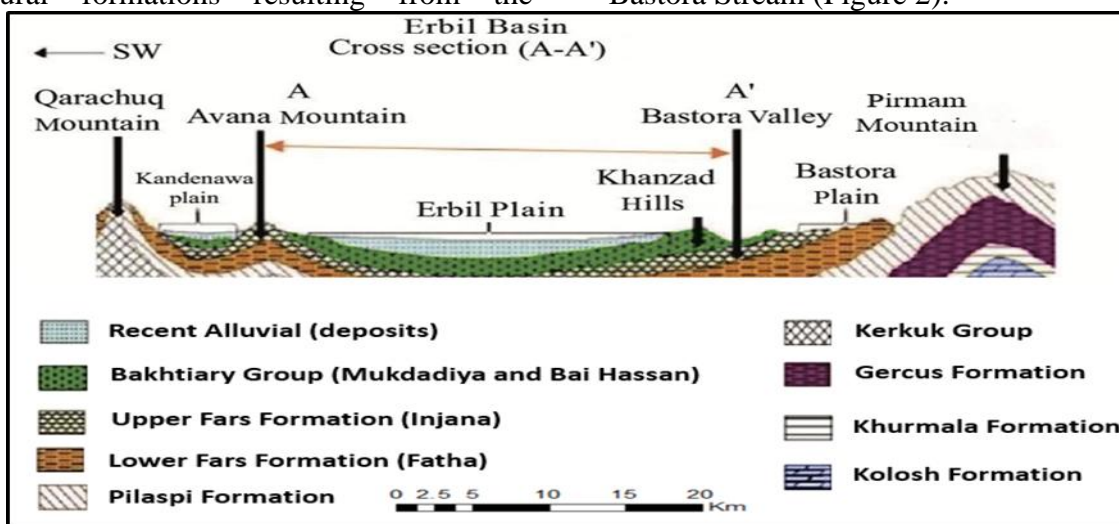


Figure 2. Geological Cross Section of Erbil Basin modified from Mustafa and Mawlood (2024).

Data Set : The coordination of the wells for the groundwater flow map is recorded during the fieldwork. The data used are from 10 wells obtained in coordination with the Ministry of Municipality and Tourism, General Directorate of Erbil surrounding water, five from the Qushtapa area, and five from Shammaik, spatially distributed across the

area. The data was recorded from 2016 to 2024.

Groundwater Flow Direction

Thirty-six wells were studied to determine the groundwater flow direction. The coordinates recorded and the static water level are subtracted from the surface elevation to represent the water table above sea level (W.T. a.s.l), Table 1 and Figure 3.

Table 1. Coordinates of the wells and depth to water table in Qushtapa and Shamamik

Wells	X	Y	Z(m)	S.W.L	W.T. (m.a.s.l)
Qucha Blbas	408913	3990217	368	88	280
Mirkhuzar	405515	3986741	352	123	229
Grd Mala	414735	3985171	413	109	304
Kardiz	420020	3983714	451	63	388
Dushiwan	426944	3982055	517	76	441
Shaqazi	426618	3977944	456	52	404
Dola Bakra	416459	3977831	396	96	300
Sebiran Ado	409443	3981912	369	101	268
Dugrdkan	405330	3981529	348	127	221
Dukala	406712	3977227	351	90	261
Qurshaqflu	403642	3975802	337	101	236
Qazi khana	408701	3973982	344	94	250
Dolaza	412990	3972720	332	50	282
Aazyana	427601	3974853	444	46	398
Grda Sor	423326	3971715	356	65	291
Umarawa	417477	3965530	300	52	248
Grd Lanka	415486	3967464	305	80	225
Sherawa	420346	3960714	277	52	225
Bnberz	396853	4001768	345	61	284
Yarmja	394850	3999441	330	88	242
Dustapa	399166	3999441	331	52	279
Beryat	404017	3996474	355	55	300
Daldaghan	399595	3992680	338	132	206
Dhemat	391627	3995093	305	61	244
Awena	383004	3991476	282	51	231
Shekh Sherwan	385654	3988512	296	89	207
Mastawa	393537	3989965	309	86	223
Sorbash Hawez	399127	3990622	330	93	237
Pirdawd	403319	3986780	340	128	212
Dusara Fatah	402128	3986780	336	83	253
Grd Azaban	394911	3985195	308	99	209
Helawa	391150	3984201	309	41	268
Awdalok	393624	3980931	321	107	214
Jdida lak	396969	3981366	318	70	248
Trpa Spiyan	403752	3983088	340	85	255
Ashaba Lak	395748	3978500	335	75	260

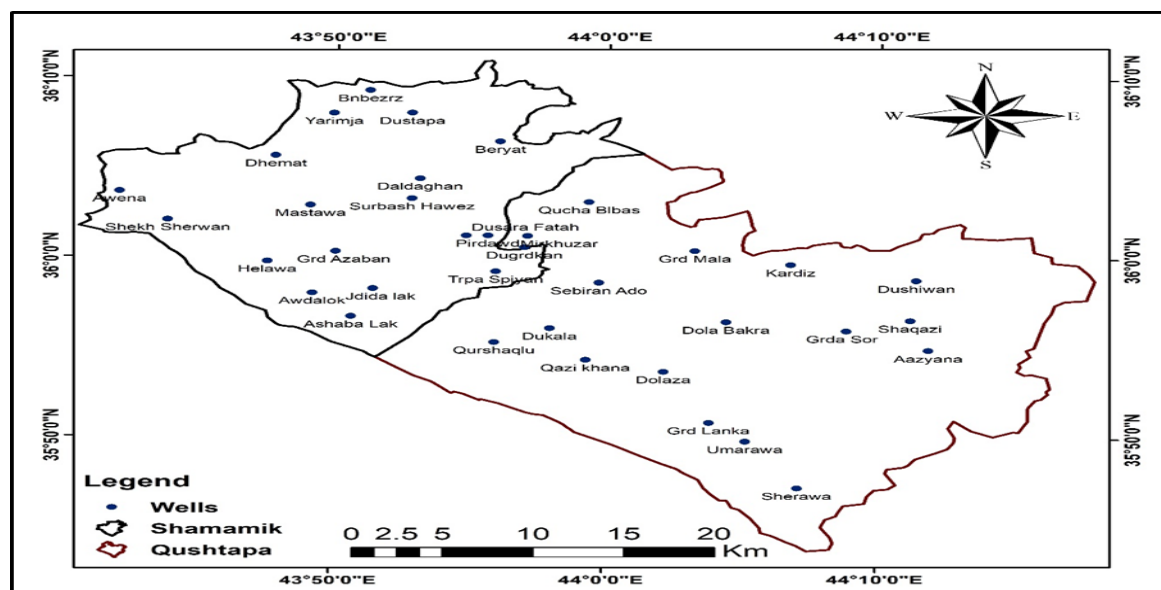


Figure 3. Spatial Distribution of the wells in the study area

Pumping Test Data Analysis

The pumping test theory entails extracting groundwater from a well at a steady pace while monitoring the water levels in the pumped or adjacent wells over time. The collected data is then applied to relevant well flow equations to estimate the aquifer hydraulic characteristics, especially Transmissivity and Storage Coefficient. In the study area, all the monitored drawdowns were obtained from pumped wells, not monitoring

wells, which is referred to as Single-well testing. Ten wells with unconfined aquifers were chosen regarding their spatial distribution for evaluating their hydraulic parameters (Table 2). The wells were pumped for 120 minutes, and the recovery test took 60 minutes. According to Mustafa (2017), the Cooper-Jacob (1946) Straight-line method and Theis (1935) Recovery method are the most reliable methods for such aquifer conditions.

Table 2. Name and Coordinates (UTM) of the wells in Qushtapa and Shamamik

ID	Wells	X	Y	Z(m)
1	Daldaghan	399595	3992680	338
2	Grda Sor	423326	3971715	356
3	Helawa	391150	3984201	309
4	Mastawa	393537	3989965	309
5	Mirkhuzar	405515	3986741	352
6	Qazikhana	408701	3973982	344
7	Qurshaghlu	402862	3975896	350
8	Sorbash Hawez	399127	3990622	330
9	Sorbash Khidr	406078	3975327	346
10	Trpa Spiyan	403752	3983088	340

Cooper-Jacob (1946) Straight Line Method

This Solution method has been applied to calculate the Transmissivity and Storage Coefficient of the aquifers for a specific period. The Cooper and Jacob (1946) equation for calculating hydrogeological parameters in a single well test will be conducted by applying Eq. (1) and Eq. (2), respectively.

$$T = \frac{2.3Q}{4\pi\Delta s} \quad \dots\dots\dots (1) \quad S = \frac{2.25Tt_0}{r^2} \quad \dots\dots\dots (2) \quad \text{Where:}$$

- T= Transmissivity (m²day⁻¹)
- Q= Constant Discharge Rate (m³day⁻¹)
- Δs=Difference in drawdown per one log cycle of time (m)
- S= Storage Coefficient (Unit-less)
- t₀ = extend of the straight line, where drawdown = 0
- r = distance between observation well and pumped well (m)

Due to the absence of observation wells, the r value is represented by the wells' casing radius.

Theis (1935) Recovery Method

After the pump is stopped, the groundwater level commences to increase and return nearly to its static level, which refers to its level before pumping. The rise in the water level during the recovery period is termed as

residual drawdown (s'). It is applied for measuring the Transmissivity of the aquifers, Eq. (3).

$$T = \frac{2.3Q}{4\pi\Delta s'} \quad \dots\dots\dots (3)$$

- Where;
- T= Transmissivity (m²day⁻¹)
- Q = Constant Discharge Rate (m³day⁻¹)
- Δs'=Difference in residual drawdown per one log cycle of time (m)

Applied Software

The ArcGIS 10.8 version is applied for mapping groundwater flow direction. For analyzing Pumping test data Aquifer Test Solver Program (AQTESOLV) Version 4.5 was selected which is applicable for such aquifer conditions within the study area, the concept of the software as the theoretical concept of Cooper-Jacob (1946), the collected data entered to the program with some modification, as the rate of discharge in the field was recorded in Gallonmin⁻¹, should be converted into m³day⁻¹, and the recorded drawdown should be corrected then be plotted, the corrected drawdown is done by applying Eq. (4).

$$s^* = s - \frac{s^2}{2b} \quad \dots\dots\dots (4)$$

- Where;
- s*=Corrected Drawdown (m)

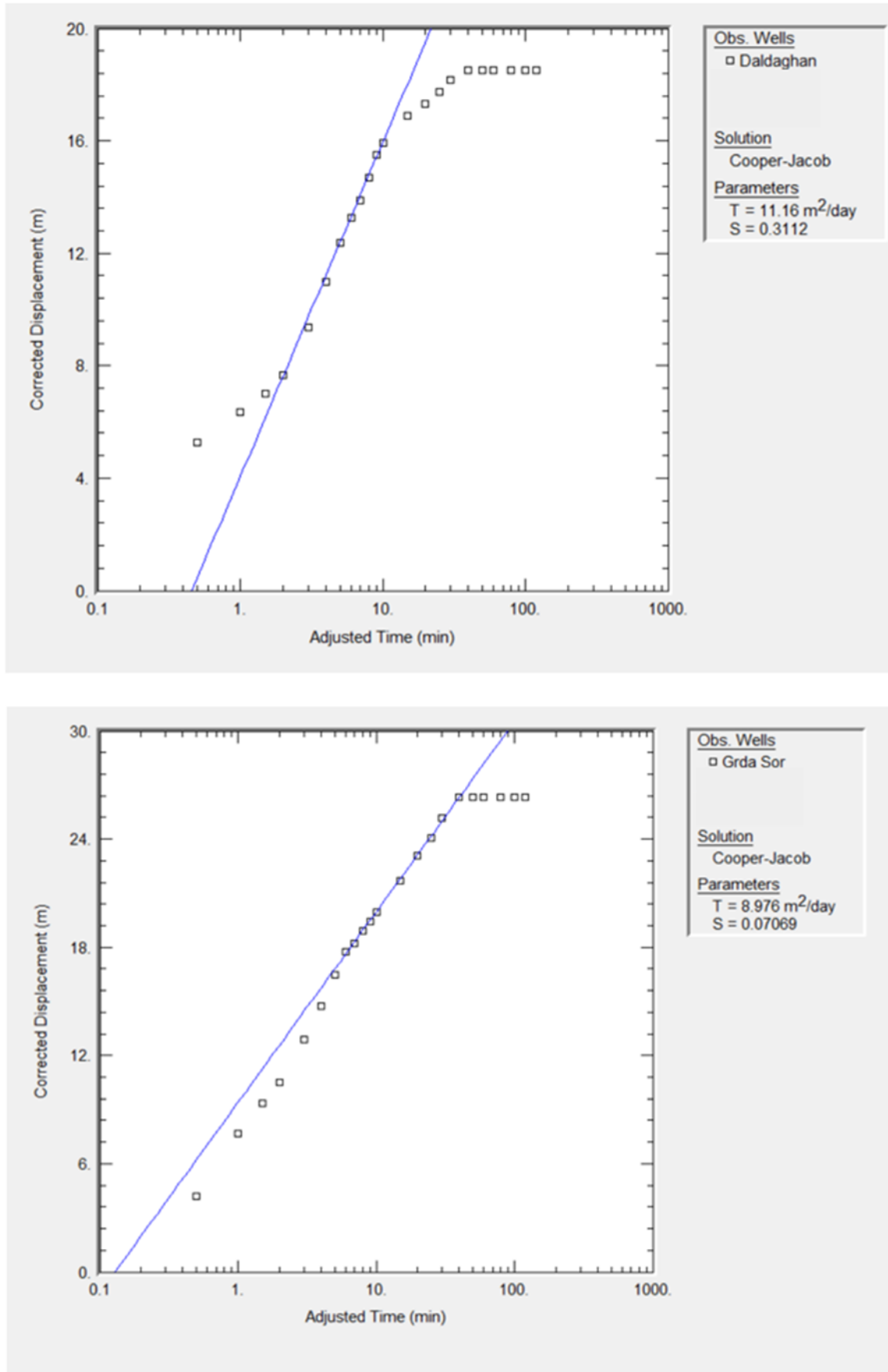


Figure 5. Cooper-Jacob Straight line plot of pumping tests in Daldaghan and Grda Sor well

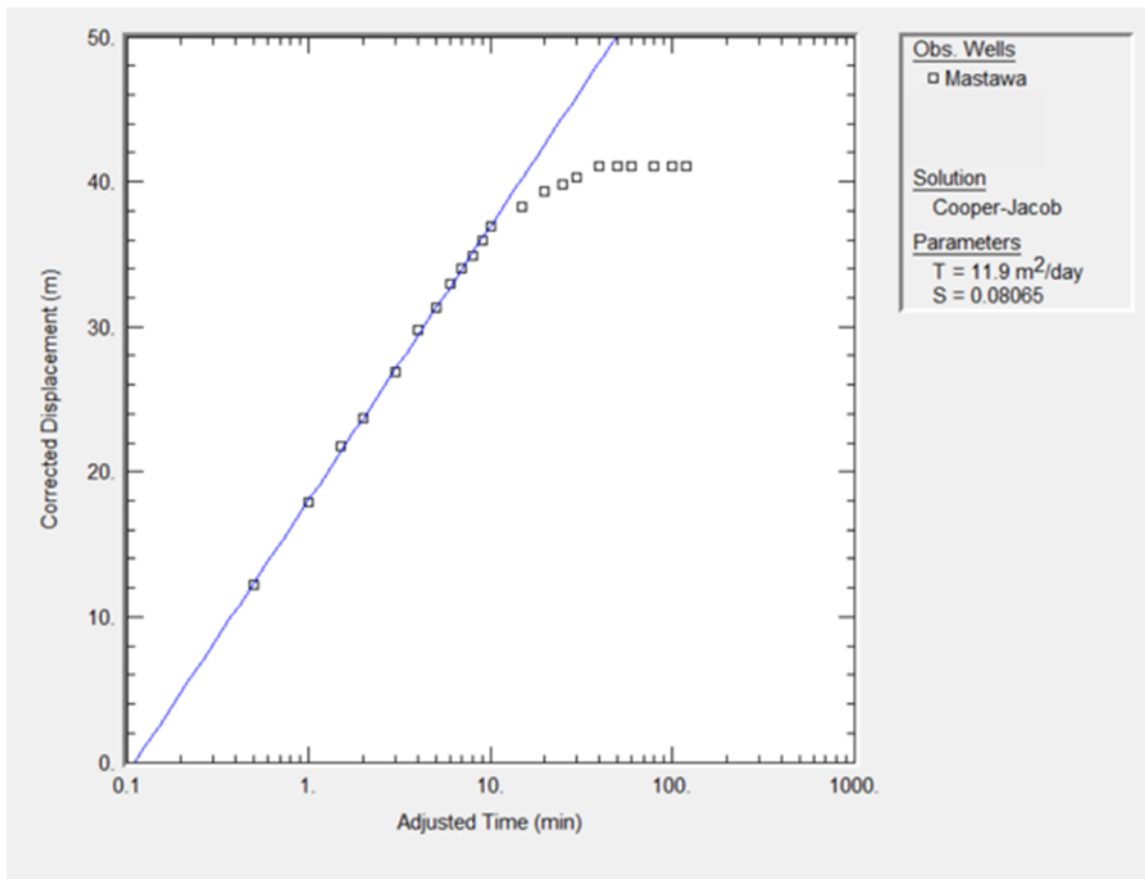
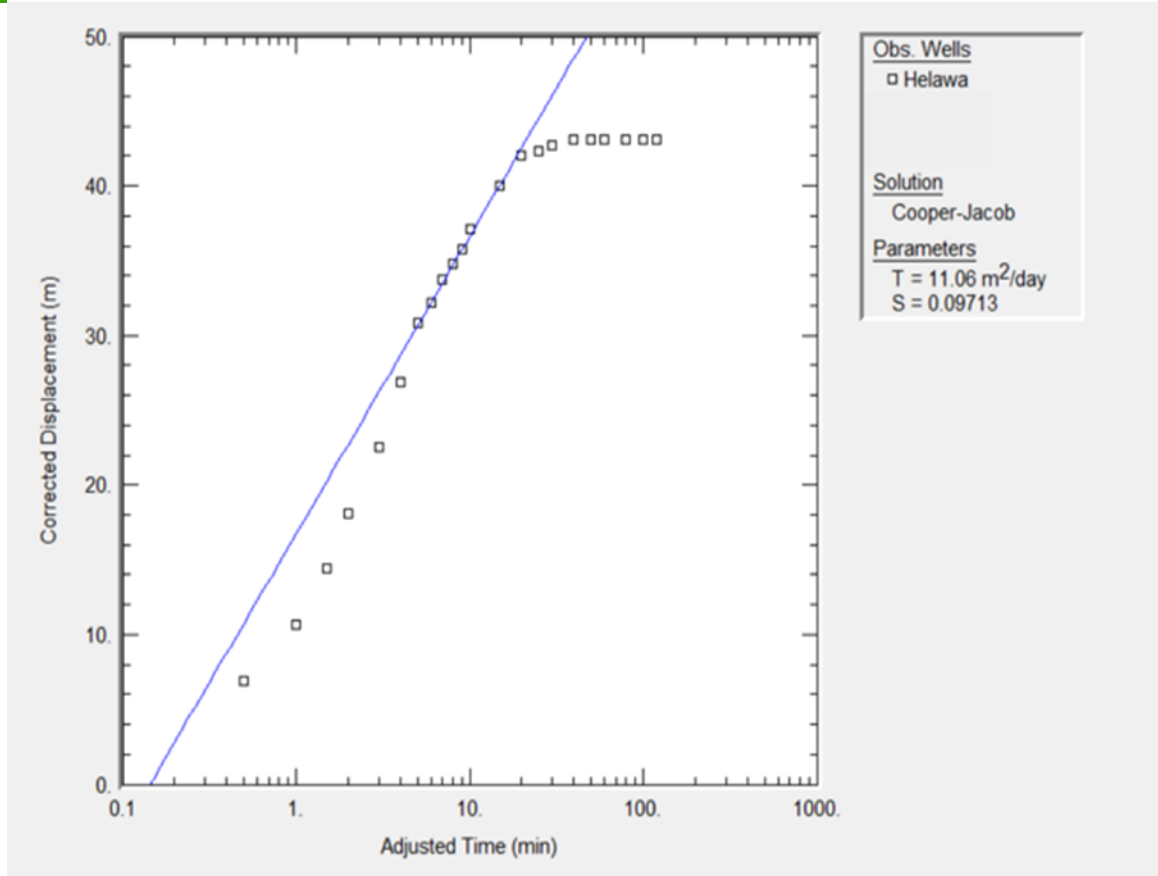


Figure 6. Cooper-Jacob Straight line plot of pumping tests in Helawa and Mastawa well

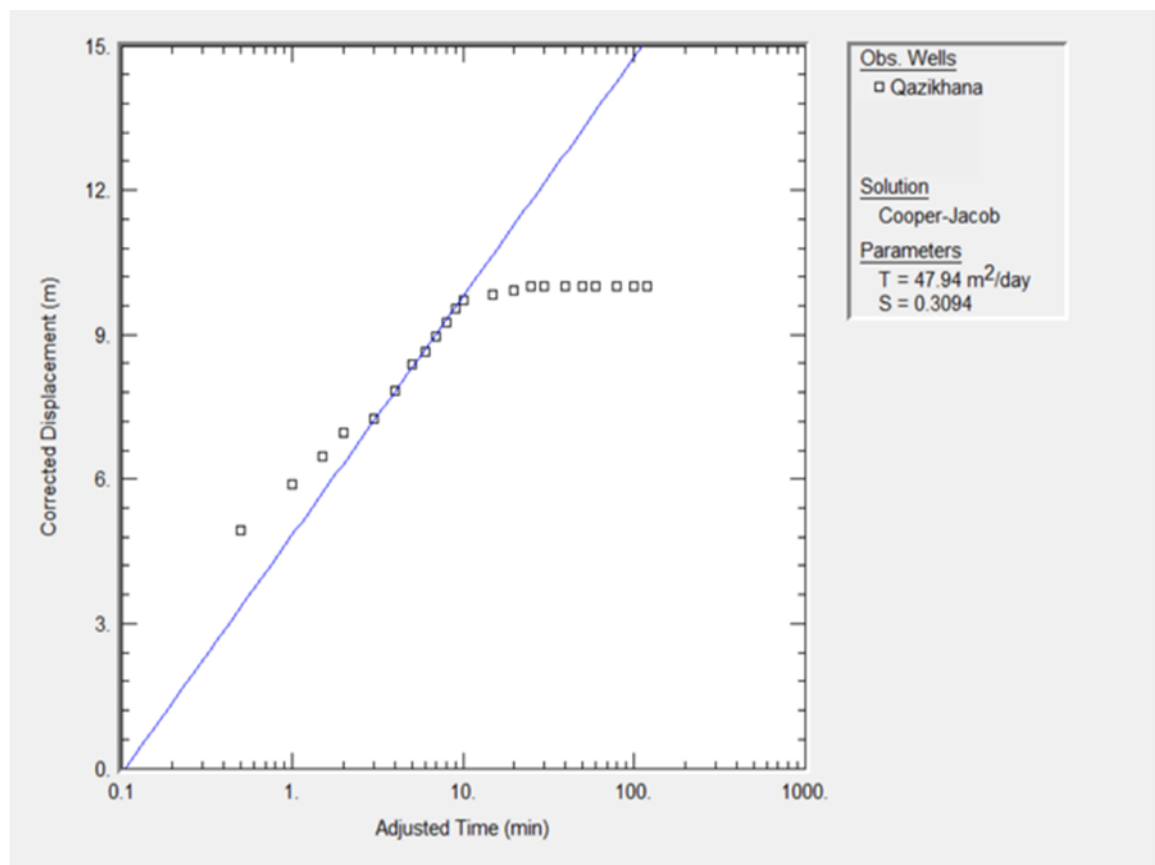
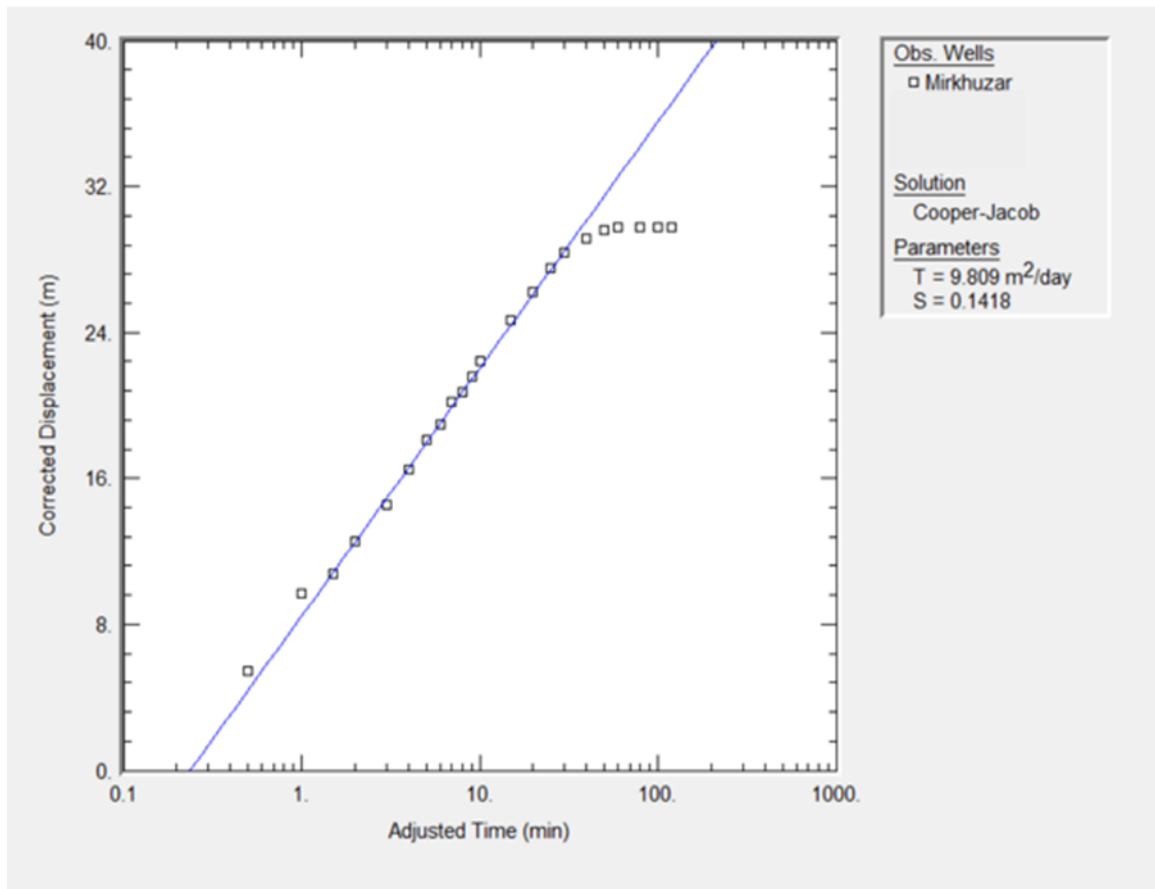


Figure 7. Cooper-Jacob Straight line plot of pumping tests in Mirkhuzar and Qazikhana well

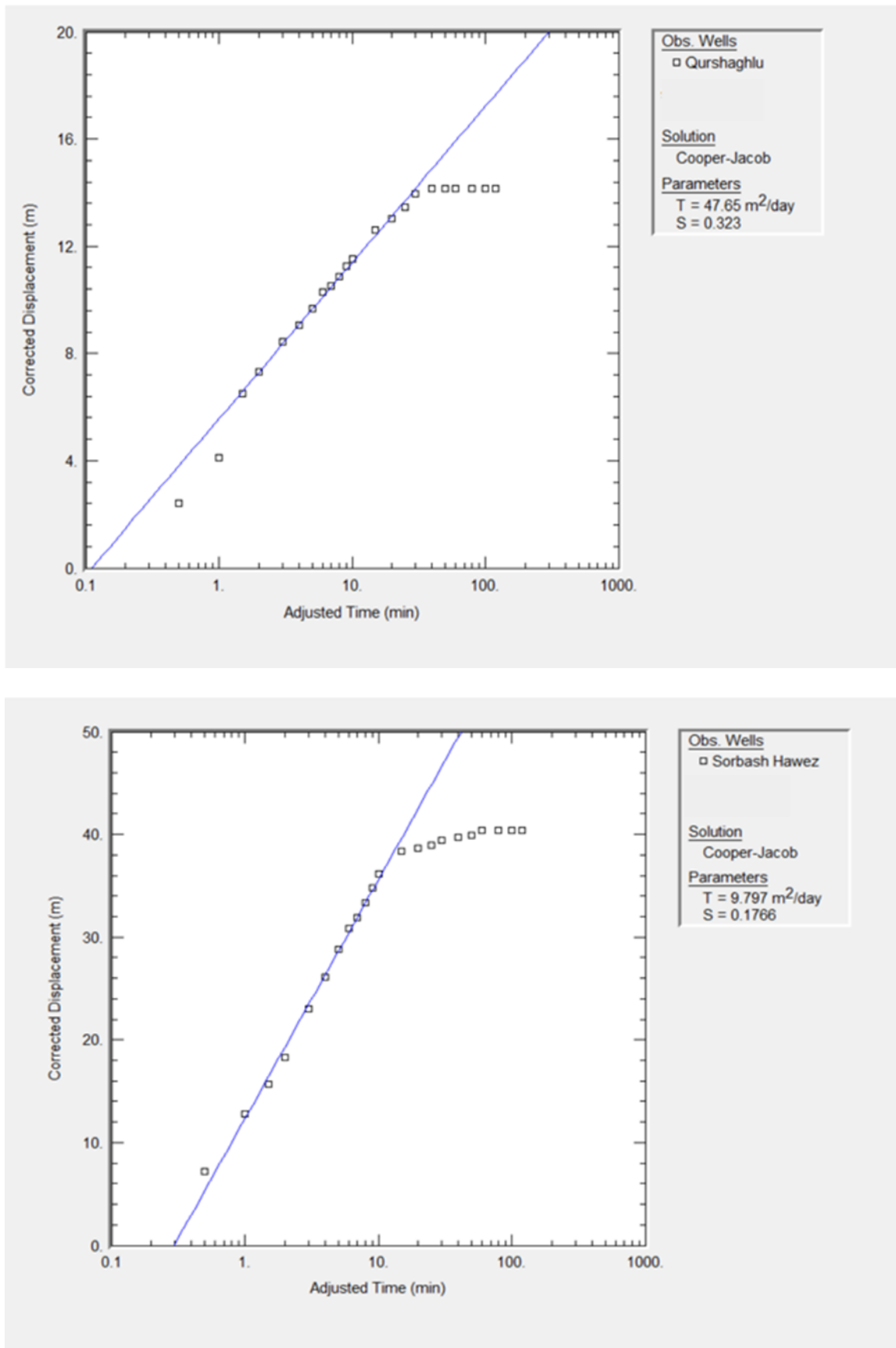


Figure 8. Cooper-Jacob Straight line plot of pumping tests in Qurshaghlu and Sorbash Hawez well

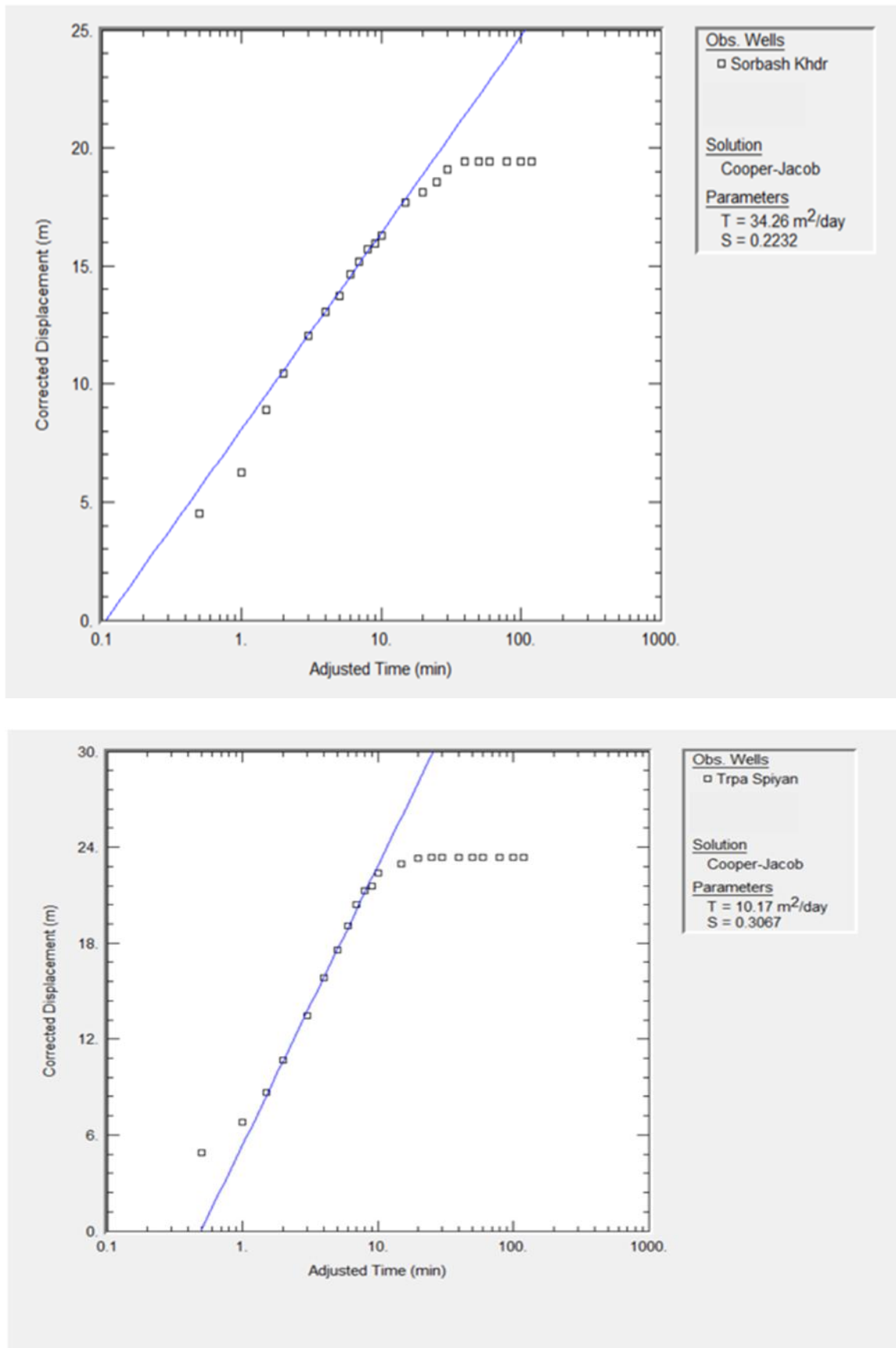


Figure 9. Cooper-Jacob Straight line plot of pumping tests in Sorbash Khdr and Trpa Spiyan Well

The Recovery data was analyzed with the Microsoft Excel program using Theis (1935)

equation. Figures 10-14 show the Their recovery curve for all tested wells.

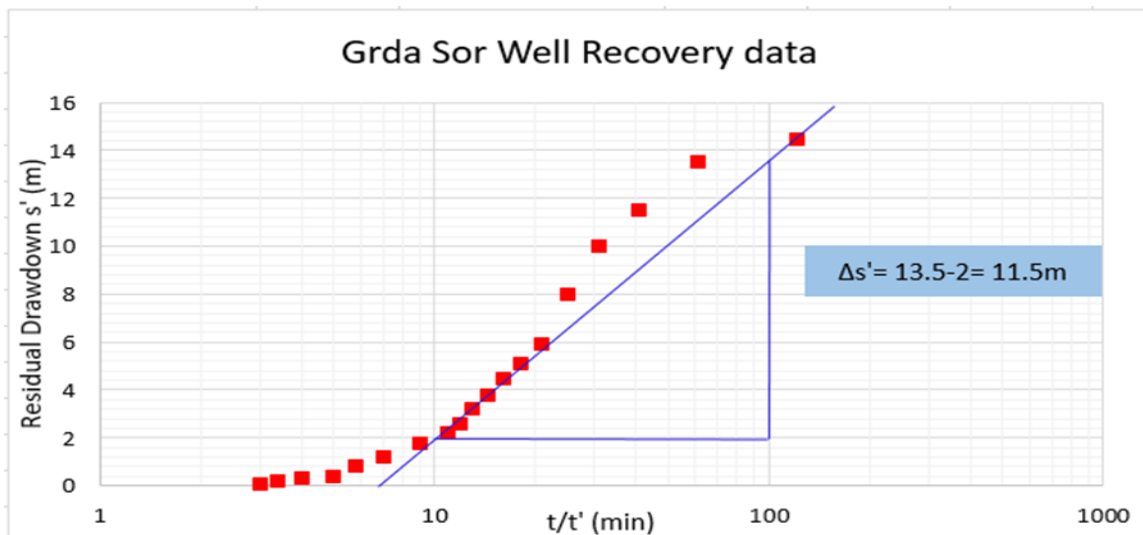
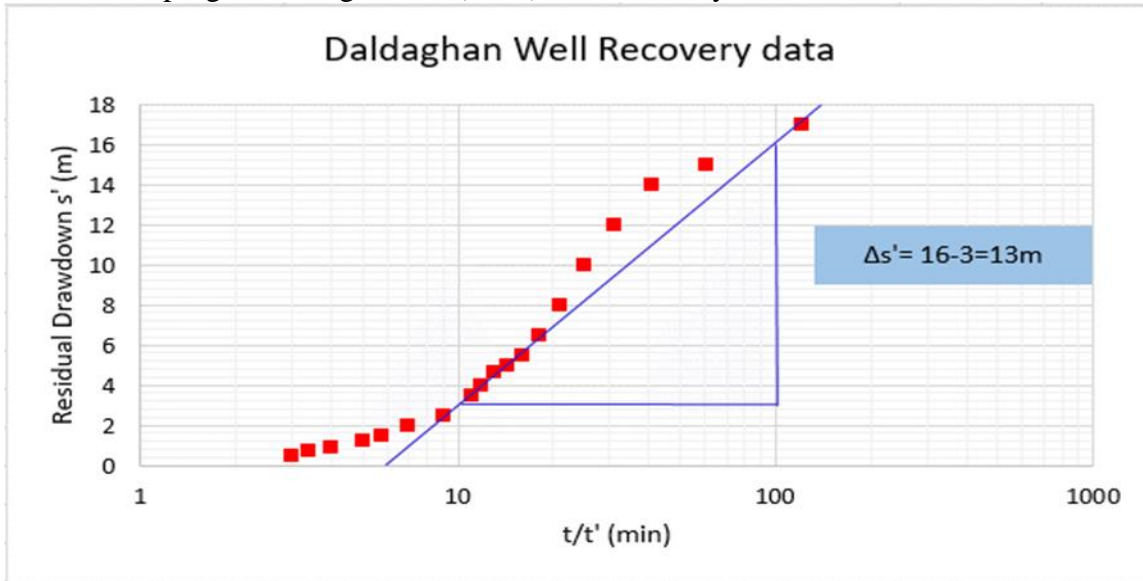
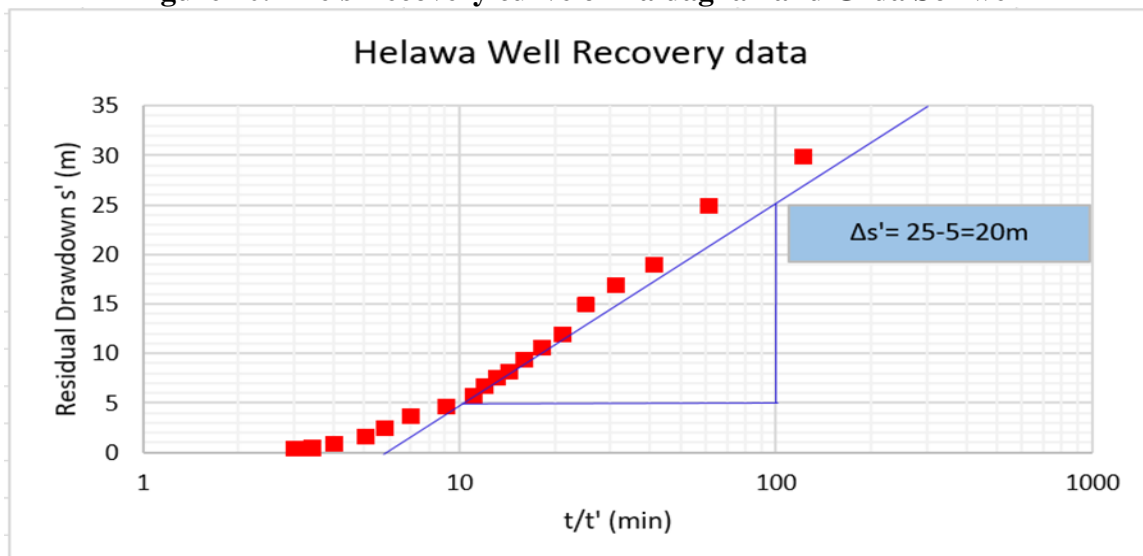


Figure 10. Theis Recovery curve of Daldaghan and Grda Sor well



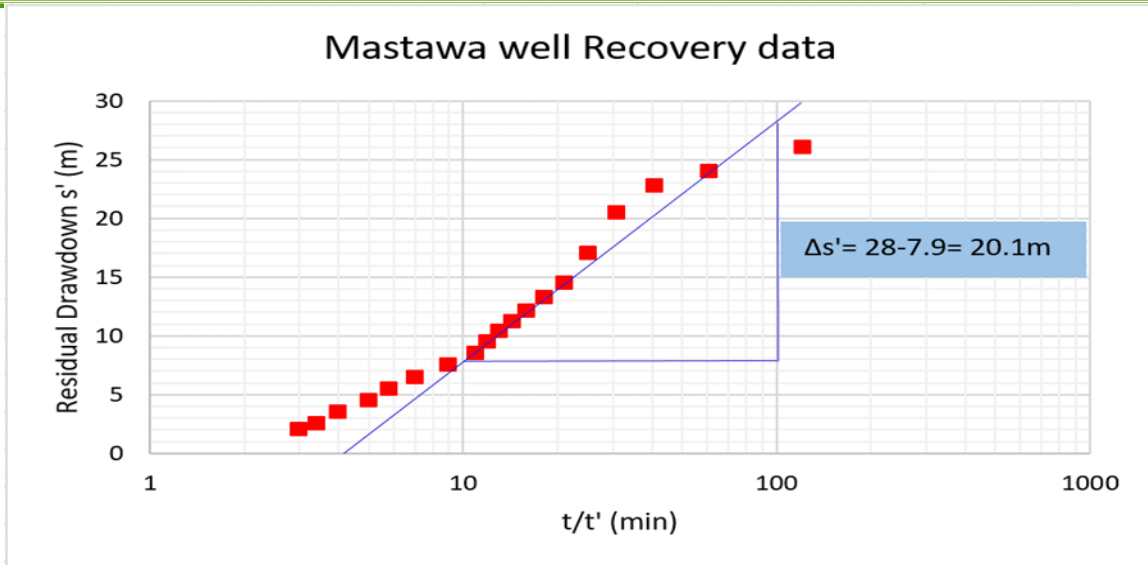


Figure 11. This Recovery curve of Helawa and Mastawa well

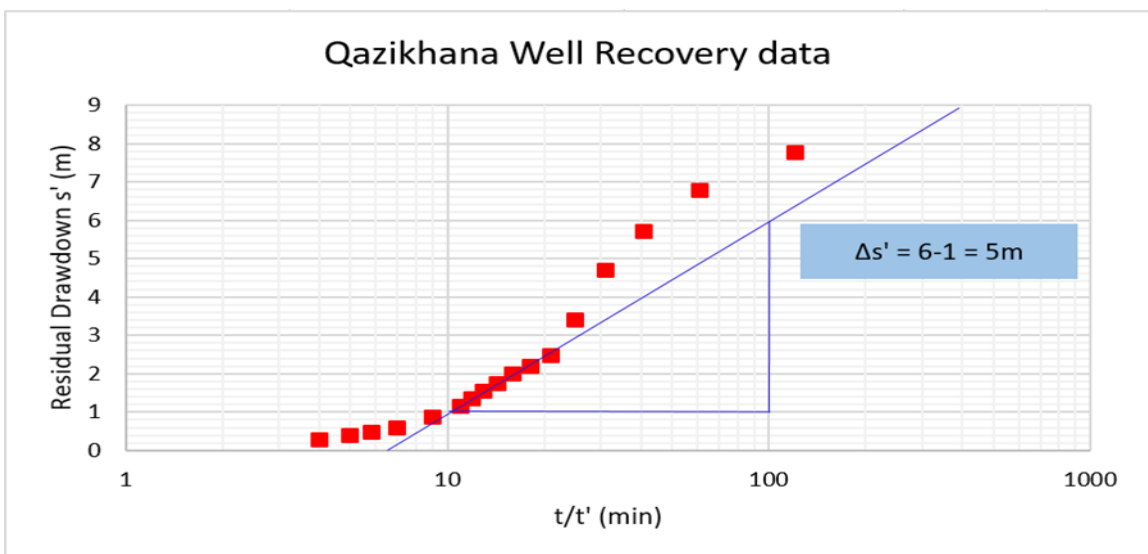
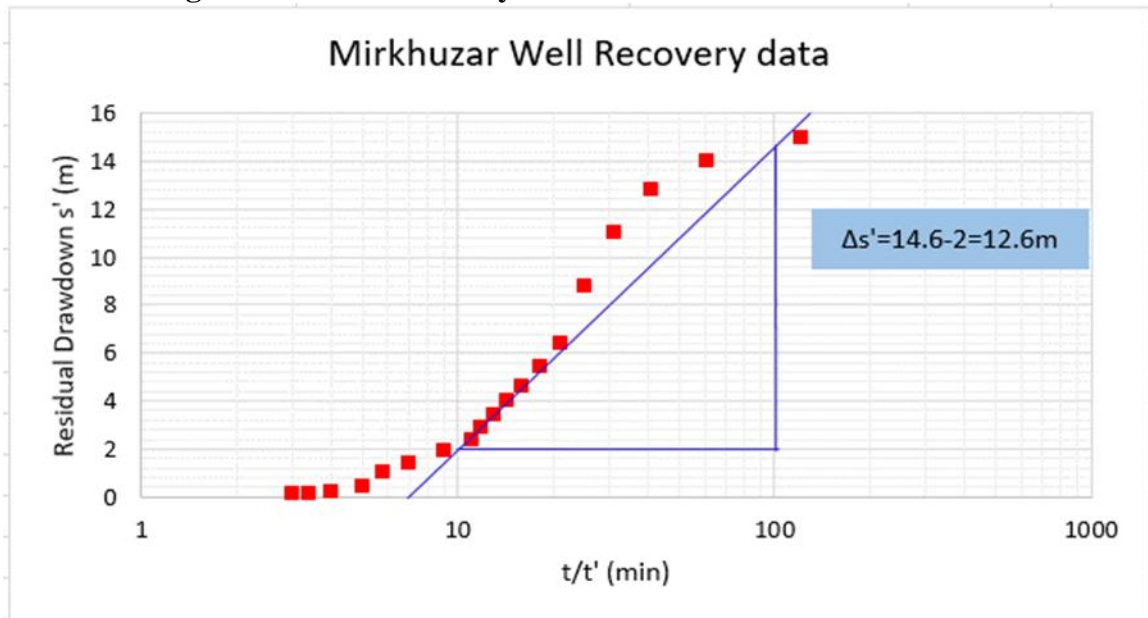


Figure 12. This Recovery curve of Mirkhuzar and Qazikhana well

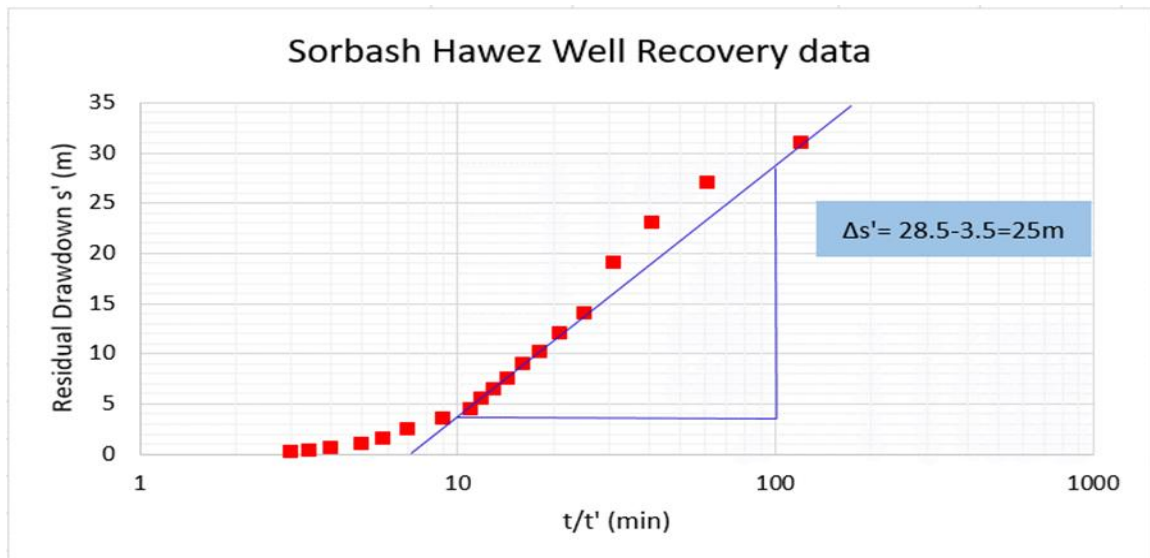
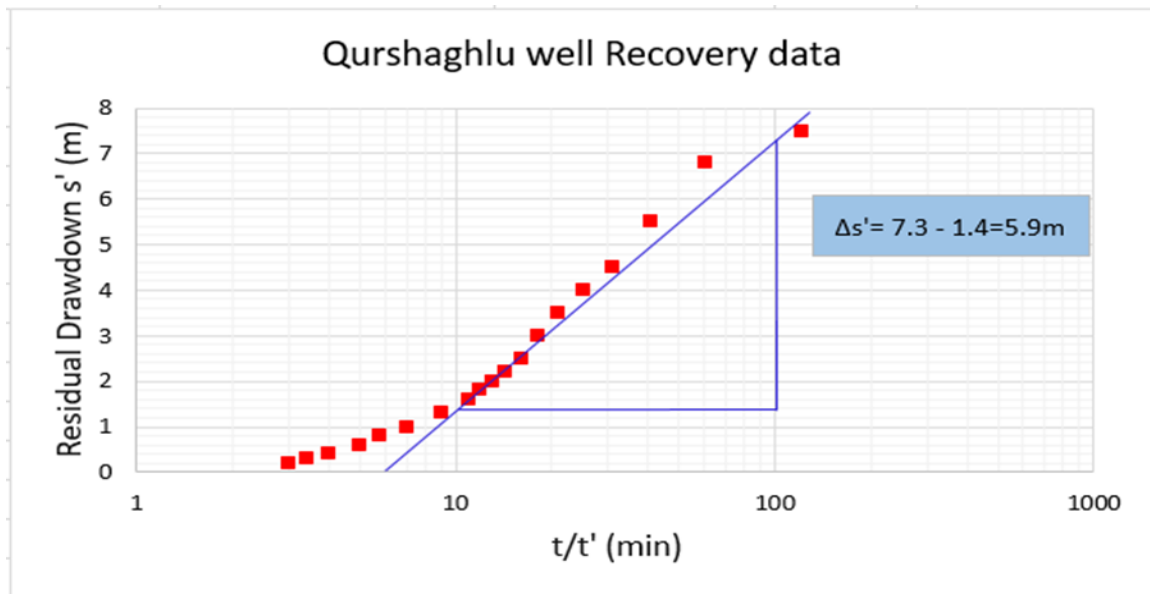
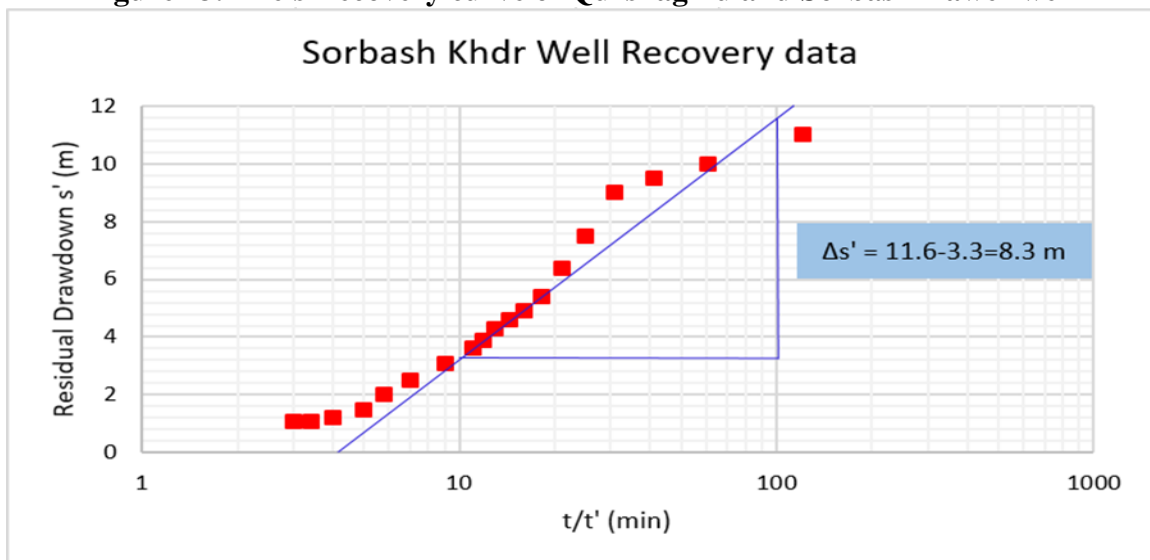


Figure 13. Their Recovery curve of Qurshaghlou and Sorbash Hawez well



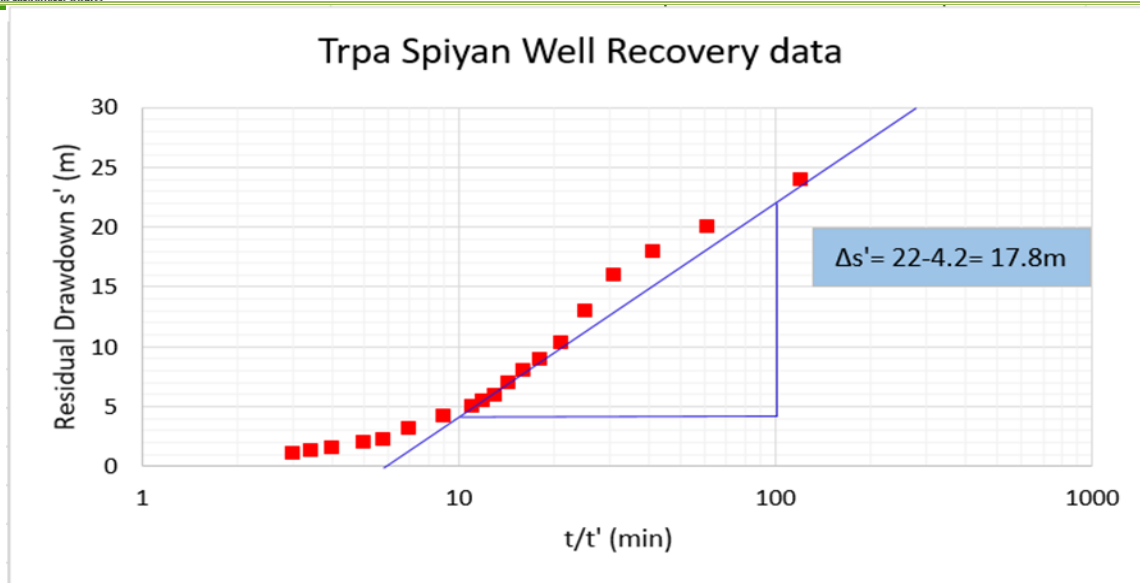


Figure 14. Theis Recovery curve of Sorbash Khdr and Trpa Spiyan well

The determined Transmissivity is close to the estimated value by the Cooper-Jacob method, which was between 8.25 -47.51 $\text{m}^2\text{day}^{-1}$ with a mean of 19.908 $\text{m}^2\text{day}^{-1}$, also hydraulic

conductivity was derived, which was between 0.024-0.19 mday^{-1} with a mean of 0.0684 mday^{-1} . All obtained results from both methods are summarized in the Table. 3.

Table 3. Summary of Hydraulic parameters of the tested wells

Well Name	Analysis Method	T ($\text{m}^2\text{day}^{-1}$)	Average T ($\text{m}^2\text{day}^{-1}$)	b (m)	K (mday^{-1})	Average K (mday^{-1})	S
Daldaghan	Cooper-Jacob	11.16	10.685	260	0.043	0.041	0.312
	Theis Recovery	10.21			0.039		
Grda Sor	Cooper-Jacob	8.98	8.62	205.8	0.044	0.042	0.071
	Theis Recovery	8.25			0.040		
Helawa	Cooper-Jacob	11.06	11.02	383	0.029	0.029	0.097
	Theis Recovery	10.98			0.029		
Mastawa	Cooper-Jacob	11.9	11.535	404	0.029	0.0285	0.081
	Theis Recovery	11.17			0.028		
Mirkhuzar	Cooper-Jacob	9.81	10.175	347	0.028	0.029	0.142
	Theis Recovery	10.54			0.030		
Qazikhana	Cooper-Jacob	47.94	47.725	355.1	0.135	0.1345	0.309
	Theis Recovery	47.51			0.134		
Qurshaghlu	Cooper-Jacob	47.65	47.34	248	0.192	0.191	0.323
	Theis Recovery	47.03			0.190		
Sorbash	Cooper-Jacob	9.79	9.445	385	0.025	0.0245	0.176
Hawez	Theis Recovery	9.10			0.024		
Sorbash Khdr	Cooper-Jacob	34.26	34.285	267	0.128	0.1285	0.223
	Theis Recovery	34.31			0.129		
Trpa Spiyan	Cooper-Jacob	10.17	10.075	245	0.042	0.0415	0.306
	Theis Recovery	9.98			0.041		

The analyzed aquifers are intergranular. From a geological view, the high value of transmissivity is attributed to the porosity and permeability of the rocks, as seen in the Qazikahana well, in the Qushtapa area. It shows the highest transmissivity value and high storativity, which is consistent with a sufficient thickness of permeable layers, such

as the repeated layers of gravel and sand, which are regarded as a highly permeable aquifer material. Additionally, the Qurshaghlu well and Sorbash Khidr well have higher transmissivity and storativity than the other wells. The high transmissivity of the Qurshaghlu well, in addition to the presence of a gravel interbedded layer, could also be due

to a hydraulic connection with the Qazikhana. The wells with high transmissivity and storativity are located in the southwest of the Qushtapa area. Daldaghan well and Trpa Spiyan well in Shamamik area however their geological profile shows a sufficient thickness of permeable layers including gravel, sand, and gravelly sand but their transmissivity is still low this is because the depth to groundwater is sufficiently high which decreased the saturated thickness of the well and directly affected its transmissivity and hydraulic conductivity, but due to their high permeable layers still its storativity is high, and have a good ability to store water between the pore spaces, that's why yield a sufficient amount of water in a constant rate. The hydraulic conductivity could be varying from place to another based on the way in which geological formation deposits formed (McPherson, 2003). The geological profile of all the wells is shown in Figures 15-19. Based on the Krásný (1993) classification for the Transmissivity, the studied area is classified as an area with Low-Intermediate Transmissivity (Table 4). The findings conflict with the study conducted by Shwani (2008) nearly in the same study area. This can be attributed to such groundwater level decline during this period

and inadequate groundwater extraction results in the reduction of the saturated thickness of the aquifers, and a major portion of the aquifers' most permeable layers have been depleted of water, thereby reducing the Transmissivity. The storage coefficient ranges between 0.071 and 0.323. According to Kasenow (1997) and Kruseman et al. (1970), the storage coefficient of unconfined aquifers varies between 0.01 and 0.3, which proves the acceptable result of the data analyzed by the chosen method. The findings are closely within the standard range. This result aligns with the Mustafa (2017) study on the same aquifer condition in Kawargosk Area-Erbil. The study shows that the results of hydraulic parameters measured by Cooper-Jacob (1946) method fall within the standard range, hence this method is recommended for determining the hydraulic parameters in unconfined aquifer types. Low T and K are noted in the wells with a great drawdown during testing of about 20-49m, while the wells with higher T and K have a total drawdown of 10-21m. The decrease of highly permeable layers and increased dependence on lower permeable geological formations have further diminished aquifer output.

Table 4. Transmissivity Classification (Krásný, 1993)

Transmissivity Coefficient (m²/day)	Class of Transmissivity magnitude	Designation of Transmissivity magnitude
>1000	I	Very High
100-1000	II	High
10-100	III	Intermediate
1-10	IV	Low
0.1-1	V	Very Low
<0.1	VI	Imperceptible

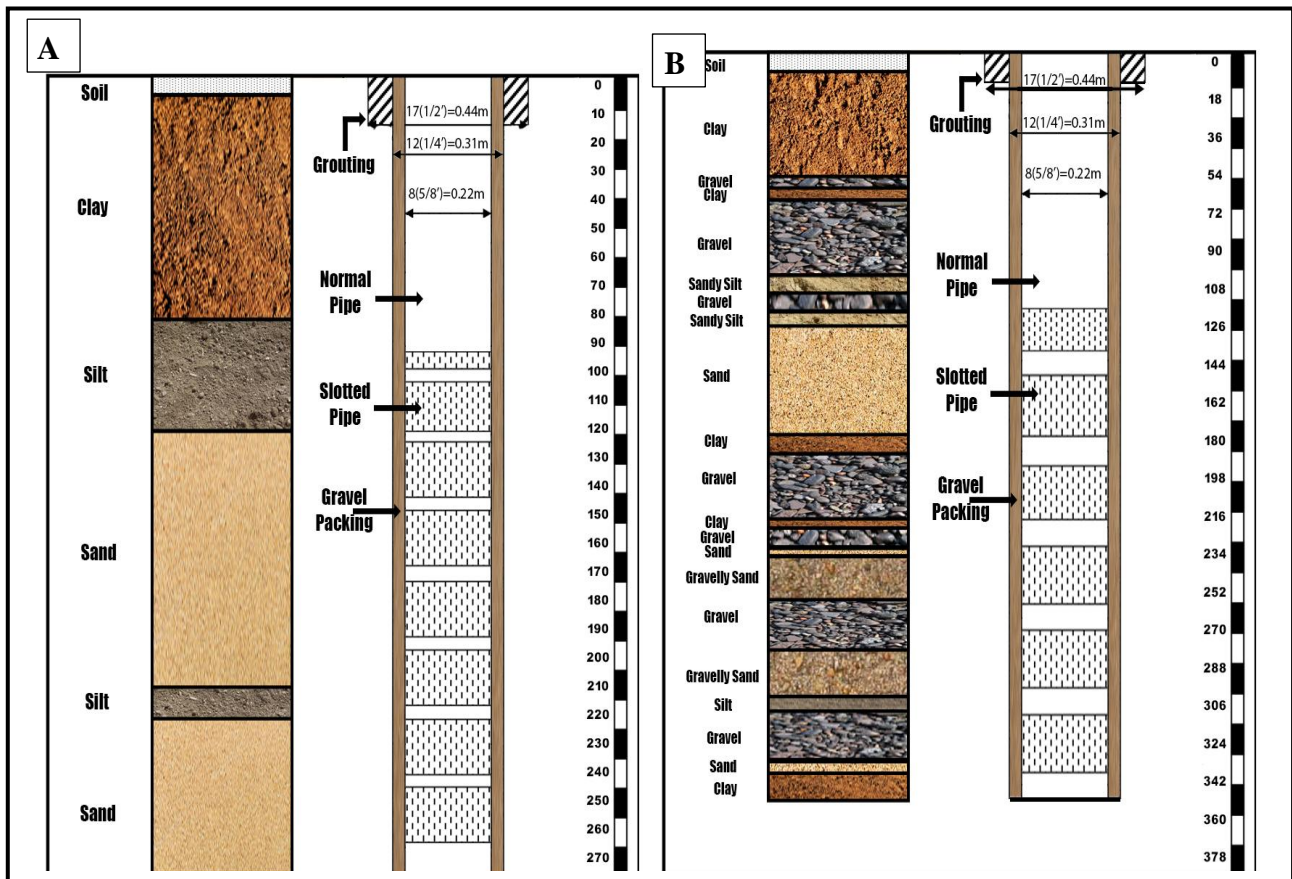


Figure 15. Lithology profile of A: Daladaghan and B: Grda Sor well

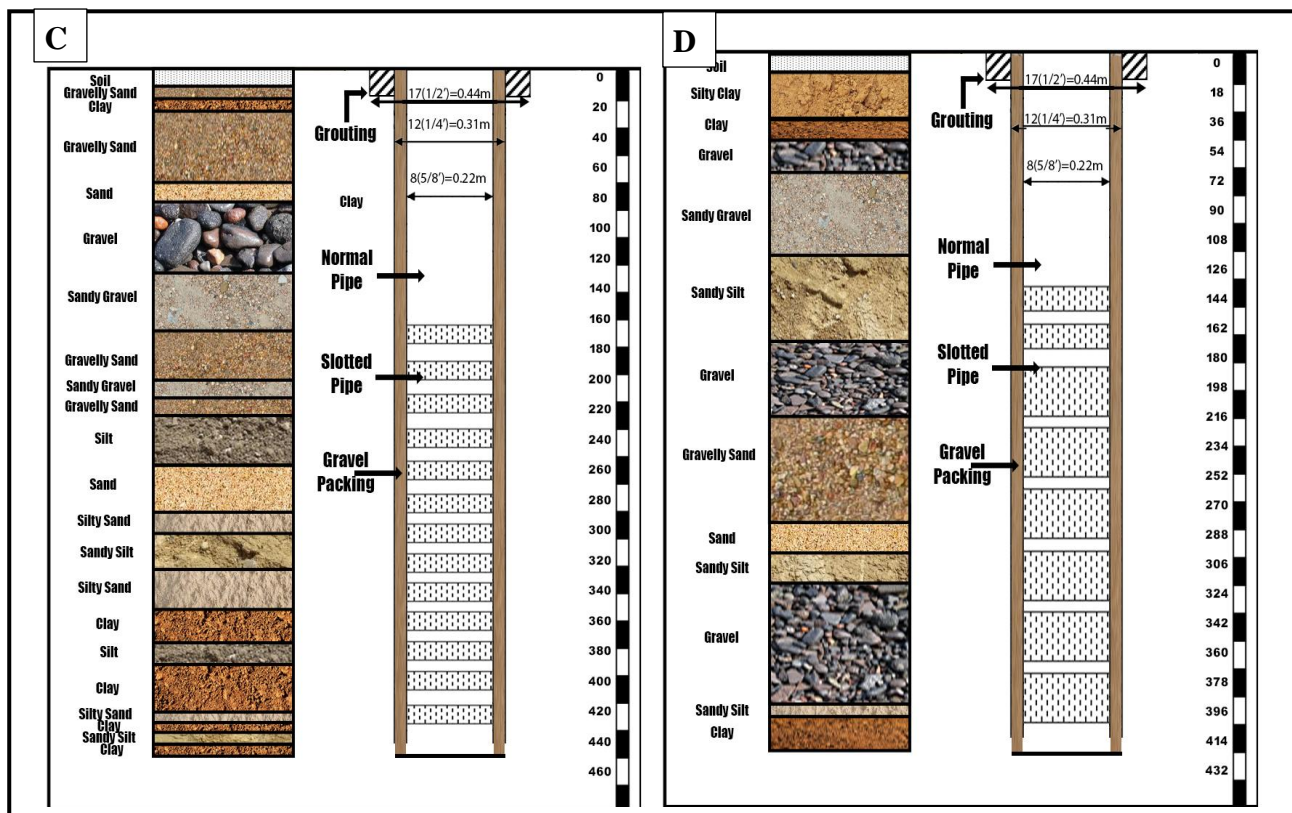


Figure 16. Lithology profile of C: Helawa and D: Mastawa well

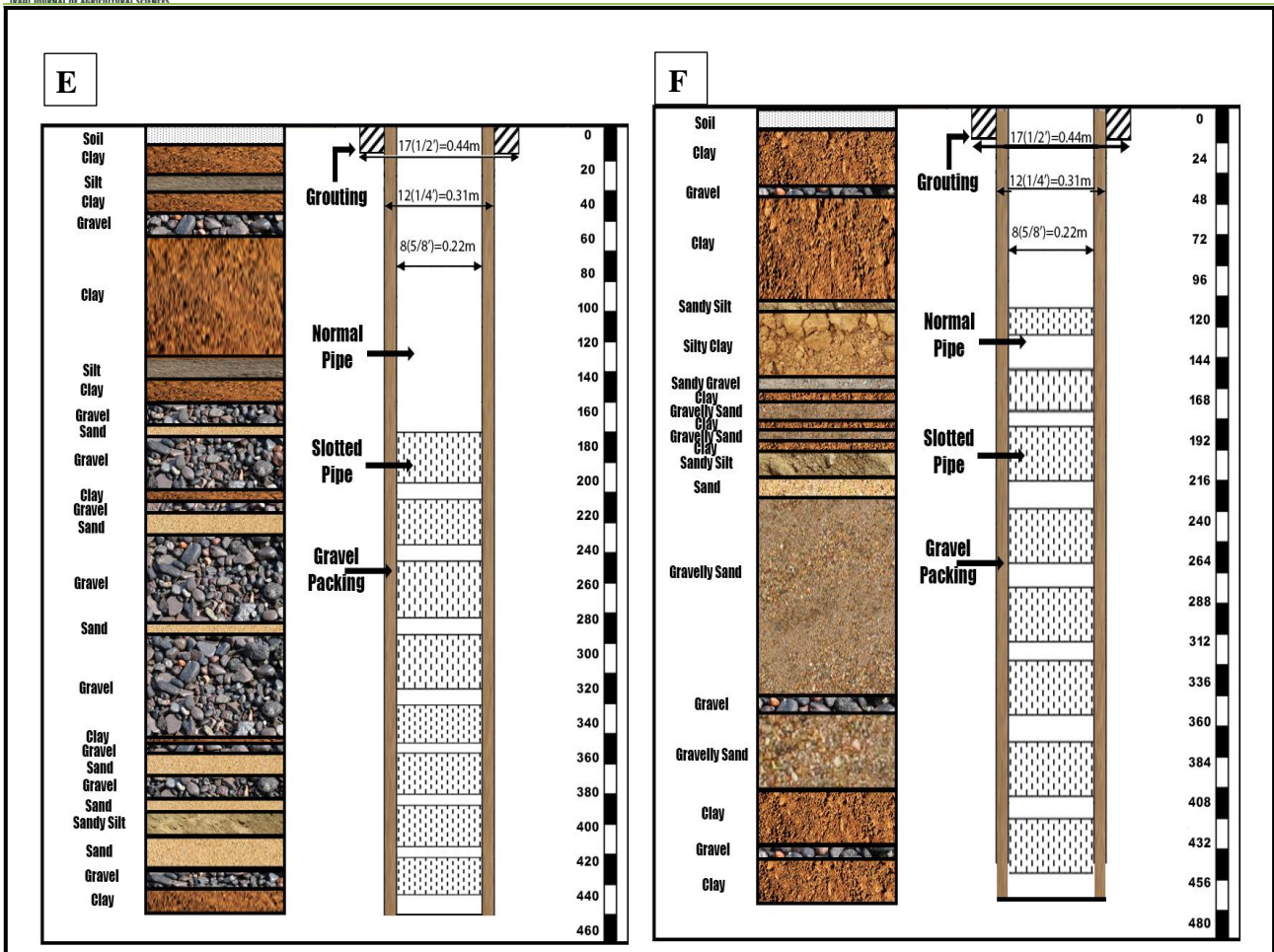


Figure 17. Lithology profile of E: Mirkhuzar and F: Qazikhana well

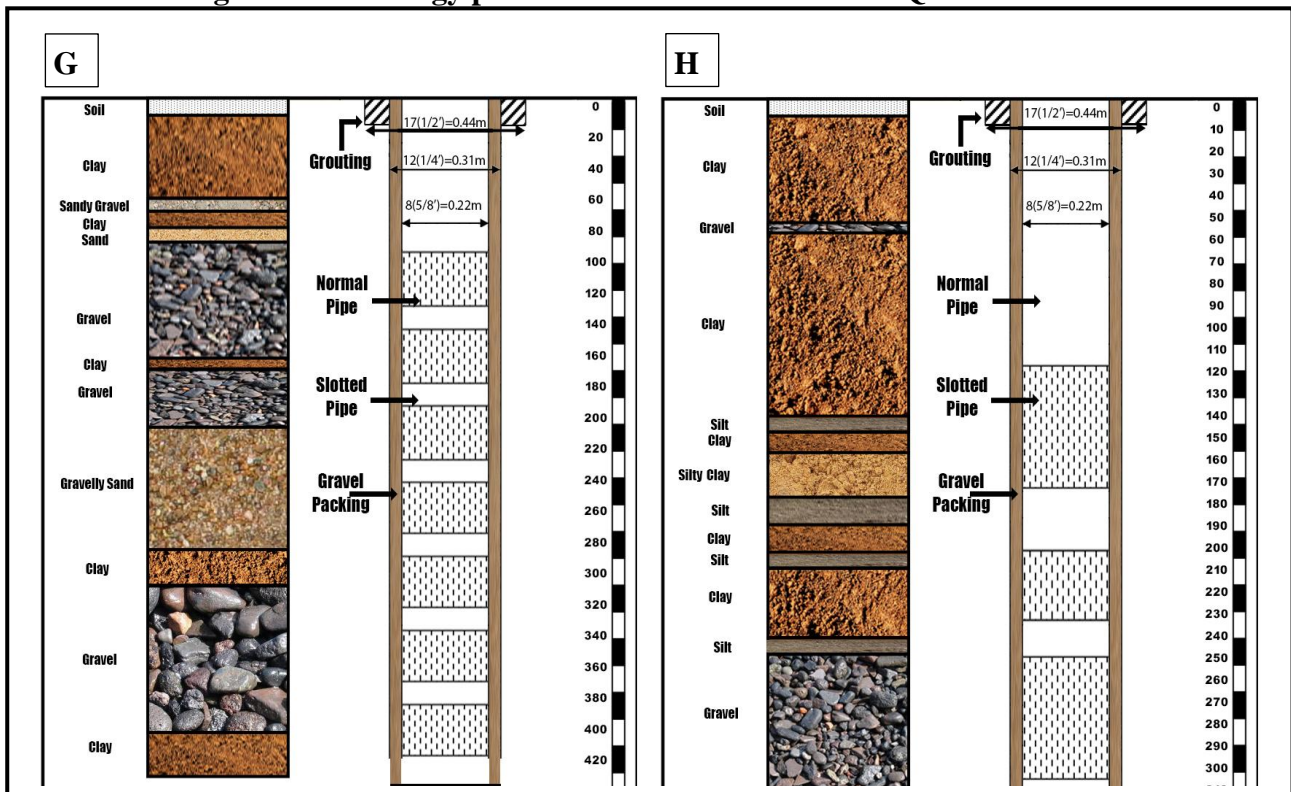


Figure 18. Lithology profile of G: Qurshaghlu and H: Sorbash Hawez well

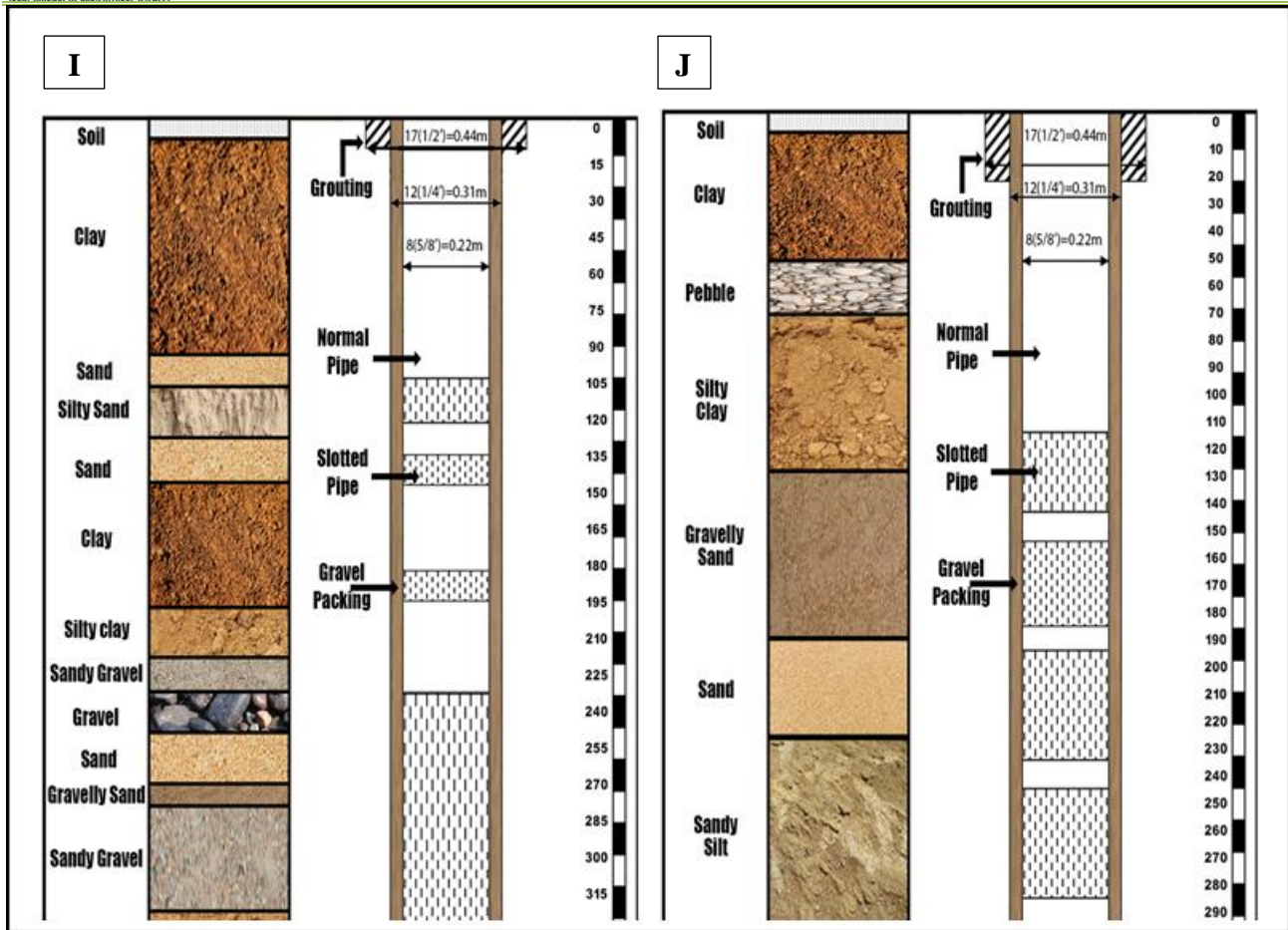


Figure 19. Lithology profile of I: Sorbash Khdr and J: Trpa Spiyan well

CONCLUSION

Pumping and recovery test data were used to determine the hydrogeological parameters of the aquifer in the Qushtapa and Shamamik area. The research concluded that:

1. The groundwater flows to the south-southeast in the Qushtapa area, and in Shamamik moves to south southwest
2. The average value of transmissivity determined by pumping test and recovery data ranged between $8.62 \text{ m}^2\text{day}^{-1}$ and $47.725 \text{ m}^2\text{day}^{-1}$, with a mean of $20.09 \text{ m}^2\text{day}^{-1}$, and the hydraulic conductivity ranged between 0.0245 mday^{-1} and 0.191 mday^{-1} , with a mean of 0.069 mday^{-1}
3. The Storage Coefficient ranges between 0.071 and 0.323
4. Based on the Transmissivity values, the aquifers in the study area are classified as a low to Intermediate transmissivity class.
5. In case of the absence of observation wells, the applied method for estimating the hydraulic parameters of the aquifers is reliable

since the storativity of the aquifers is within the standard range of storativity of the unconfined aquifers type.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHOR/S DECLARATION

We confirm that all Figures and Tables in the manuscript are original to us. Additionally, any Figures and images that do not belong to us have been incorporated with the required permissions for re-publication, which are included with the manuscript.

Author/s signature on Ethical Approval Statement.

Ethical Clearance and Animal Welfare

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AUTHOR'S CONTRIBUTION STATEMENT

Seber M. M. Ameen and Rebwar N. Dara designed the study. Seber M. Ameen was responsible for the data collection, methodology, software application, and formal data analysis, and prepared the original draft of the manuscript. Rebwar N. Dara validated the results and contributed to reviewing and editing the manuscript.

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التوصيف الهيدروجيولوجي لمنطقة قوشتبة وشمامك في حوض أربيل باستخدام بيانات اختبار الضخ

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المستخلص

تبحث هذه الدراسة في المعايير الهيدروجيولوجية من خلال تحليل مفصل لاختبار ضخ المياه من ابار منطقتي قوشتبة وشمامك ضمن حوض أربيل. تهدف هذه الدراسة إلى تقييم معايير الرئيسية لخزان المياه الجوفية، بما في ذلك الأيصالية المائية، والنفاذية، ومعامل التخزين، والتي تعد مهمة لإدارة المياه الجوفية المستدامة. تم تحليل ضخ المياه الجوفية لـ 10 ابار باستخدام مناهج تحليلية، مثل طريقة الخط المستقيم (Cooper-Jacob) و طريقة استرداد ((Theis باستخدام برنامج AQTESOLV و Microsoft Excel لاشتقاق المعايير الهيدروجيولوجية للخزان الجوفي. تظهر النتائج تبايناً مكانياً كبيراً في خصائص الخزان الجوفي المتأثرة بالتباين الصخري ومعدل تغذية المياه الجوفية. يتراوح متوسط الأيصالية المائية بين 0.0245 م يوم-1 و 0.191 م يوم-1. يتراوح متوسط قيمة النفاذية بين 8.62 م يوم-1 و 47.725 م يوم-1. يتراوح معامل التخزين بين 0.071 و 0.323. بناءً على تصنيف كريسني (1993) للنفاذية، تم تصنيف المنطقة المدروسة كمنطقة ذات فئة نفاذية منخفضة إلى متوسطة. تلعب اختبارات الضخ دوراً حاسماً في ضمان الأمن المائي على المدى الطويل وتوجيه سياسات التنمية المستدامة في منطقة الدراسة.

الكلمات المفتاحية: AQTESOLV، الخزان الجوفي، الإيصالية المائية، الطبقة المشبعة، اختبار البئر الفردي