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Investigation of Hydrogeological Parameters in the Eastern and Western Catchments of Erbil City, Northern Iraq

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ABSTRACT

In Kurdistan Region-Iraq, groundwater uses as one of the significant resources for household, agricultural and industrial purposes have increased rapidly over the last several decades. This study aims to evaluate groundwater aquifers and hydrogeological conditions in the eastern and western sites of Erbil Basin, northern Iraq. The groundwater-bearing beds in the study area belong to the Bakhtiari formations and Recent deposits. From thirty-six groundwater boreholes, in which eighteen (18) water samples for each part of the Erbil Basin, are collected to characterize and compare the hydrogeological parameters of the area. The transmissivity, hydraulic conductivity, and storativity derived from pumping test data are calculated using (Cooper-Jacob and Theis Recovery). On the eastern side, the results of transmissivity, hydraulic conductivity, and storativity by the Cooper-Jacob method are between 0.30 - 28.19 m^2/day, 0.001 -0.116 m/day, and 0.03 - 0.98, respectively. On the western side, the transmissivity, hydraulic conductivity, and storativity are between 0.42 - 141.6 m^2/day, 0.001 - 0.701 m/day, and 0.01- 0.92 respectively. Using the recovery method, the results of transmissivity and hydraulic conductivity on the eastern side are between 0.28 - 52.52 m^2/day and 0.001 - 0.217 m/day, respectively, while on the western side, the transmissivity and hydraulic conductivity were between 2.64 - 161.33 m^2/day, 0.011 - 0.798 m/day respectively. Generally, the results of the pumping test by both methods show that the transmissivity and hydraulic conductivity rate on the western side are higher than on the eastern side. The pumping test method is a successful method for identifying hydrogeological parameters of aquifers, highlighting its potential to monitor aquifers and groundwater resource management in the Erbil basin.

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تحديد المعاملات الهيدروجيولوجية في حوض المياه الشرقية والغربية لمدينة أربيل، شمالي العراق

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الملخص

ازداد حفر الآبار واستخراج المياه الجوفية في إقليم كردستان العراق بسرعة خلال العقود الماضية للأسباب الزراعية والمنزلية والصناعية، كون أن المياه الجوفية تعد مصدرًا أساسيًا للمياه. تهدف هذه الدراسة إلى تقييم الظروف الهيدروجيولوجية لخزانات المياه الجوفية وخصائصها الهيدروليكية في المواقع الشرقية والغربية لحوض أربيل، شمالي العراق. الطبقات الحاملة للمياه الجوفية في منطقة الدراسة تعود الى تكوينبختياري والرواسب الحديثة. تم جمع النماذج من ستة وثلاثون (36) بئراً للمياه الجوفية تم فيها أخذ ثمانية عشر (18) نموذجا لكل جزء من حوض أربيل (شرقي وغربي) لوصف ومقارنة المقاييس الهيدروجيولوجية للمنطقة. تم حساب الناقلية المائية والتوصيل الهيدروليكي ومعامل الخزن المستمدة من بيانات الضخ الاختباري باستخدام طريقتي (Cooper-Jacob and Theis Recovery). في الجانب الشرقي، كانت نتائج الناقلية المائية، والتوصيل الهيدروليكي، ومعامل الخزن بطريقة Cooper-Jacob بين 0.30 – 28.19 م^2/ يوم، 0.001 – 0.116 م/ يوم، 0.03 – 0.98، على التوالي. اما في الجانب الغربي، كانت الناقلية المائية والتوصيل الهيدروليكي ومعامل الخزن بين 0.42 – 141.6 م^2/ يوم، 0.001 – 0.701 م / يوم، 0.01- 0.92 على التوالي. اما باستخدام طريقة الاسترداد، كانت نتائج النفاذية والتوصيل الهيدروليكي على الجانب الشرقي بين 0.28 – 52.52 م^2/ يوم و0.001 – 0.217 م/ يوم على التوالي، بينما في الجانب الغربي، كانت النفاذية والتوصيل الهيدروليكي بين 2.64 – 161.33 م^2/ يوم. م^2/ يوم، 0.011 – 0.798 م / يوم على التوالي. بشكل عام، تظهر نتيجة اختبار الضخ بكلتا الطريقتين، على أن النفاذية ومعدل التوصيل الهيدروليكي على الجانب الغربي كان أعلى من الجانب الشرقي. أثبتت طريقة الضخ الاختباري أنها طريقة ناجحة لتحديد المعايير الهيدروجيولوجية لخزانات المياه الجوفية، وإبراز قدرتها على مراقبة طبقات المياه الجوفية وإدارة موارد المياه الجوفية في حوض أربيل.

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Introduction

Water scarcity, which may be caused by global climate change, and the growth of the world's population, has made it harder to use and manage water resources) Alley, et al., 2002; Conama, 2006). Groundwater resources are often thought to be considerably less vulnerable to climate change than other types of water resources (Berghuijs, et al., 2016; Lin and Yeh, 2011). However, the demand for groundwater resources has been continuously rising due to population expansion and socioeconomic development. Groundwater is the primary water source in arid and semi-arid areas. This shows how important it is to improve planning, put in place policies for water resource management and allocation, and have a good understanding of the parts and features of the catchment hydrological cycle, which makes it easier to evaluate the sustainability of groundwater use and management (Huang and Yeh, 2018). In the last 30 years, there have been a lot of changes to Iraq's hydrological conditions. This is because of the stress caused by the growing demand for water resources and the continuous decrease in the amount of water available. In general, the unusually low levels of lakes, rivers, and water reservoirs throughout these three decades are reflected in the fall in precipitation rates and surface water running amounts. Thus, throughout much of areas in Iraq, groundwater resources have become the most dependable water source (Saleh, et al, 2020).

Groundwater is the primary water source in Erbil City, northern Iraq. However, this source is at risk of depletion due to the major developments that have happened over the last 20 years at all levels in the city. In the last decade, Erbil City witnessed rapid development in construction projects due to the city's increase in population, leading to an increase in water consumption. 40% of the city's water supply comes from private wells (Ministry of Municipality, Directorate of water in Erbil City). Although Erbil has an average annual rainfall of 400 mm, most of which falls during the winter and spring, an issue of water scarcity arises during the dry seasons, which are represented by summer and autumn with little to no precipitation. Additionally, aquifer protection regulations and groundwater management knowledge gaps will have a detrimental impact in the future (Ali and Hamamin, 2011).

Erbil City receives its water from two main sources: 35% from surface water and 65% from groundwater. The depth of groundwater wells has remarkably increased with time; for example, in 1996, the depth of the water table was 120 meters; in 2003, it was 200 meters; in 2010 was 300 meters; in 2020 was 500 meters, and now (2022) in some areas it reached 700 meters (Kurdistan Regional Governorate, Department of Media and Information, 2022). Therefore, investigating hydraulic parameters in the region is important to monitor aquifer characterizations and thus helps to facilitate groundwater resource management in the basin.

The main goal of this study is to describe the hydrogeological system and type of groundwater aquifers in the region. Also, estimation of the aquifer's hydraulic parameters using pumping test studies, and identifying the water-bearing layers and formations by describing the lithology of the wells.

Study Area

Erbil City in northern Iraq is in the central basin of the Erbil plain, whose area is about 1400 km^2. The area of Erbil City is about 70 km^2. It is between 36^o 08' 30" and 36^o 14' 15" north; and 43^o 57' 30" and 44^o 03' 20" east. There are two bodies of water on either side of the Erbil Basin. It is bounded by the Greater Zab to the north and the Lesser Zab to the south. The water flow in the Erbil Basin runs from the northeast to the southwest (Al-Kubaisi, et al., 2019). Figure (1) shows the location of 36 wells, both east and west (red dots indicate those wells that conducted the pumping test).

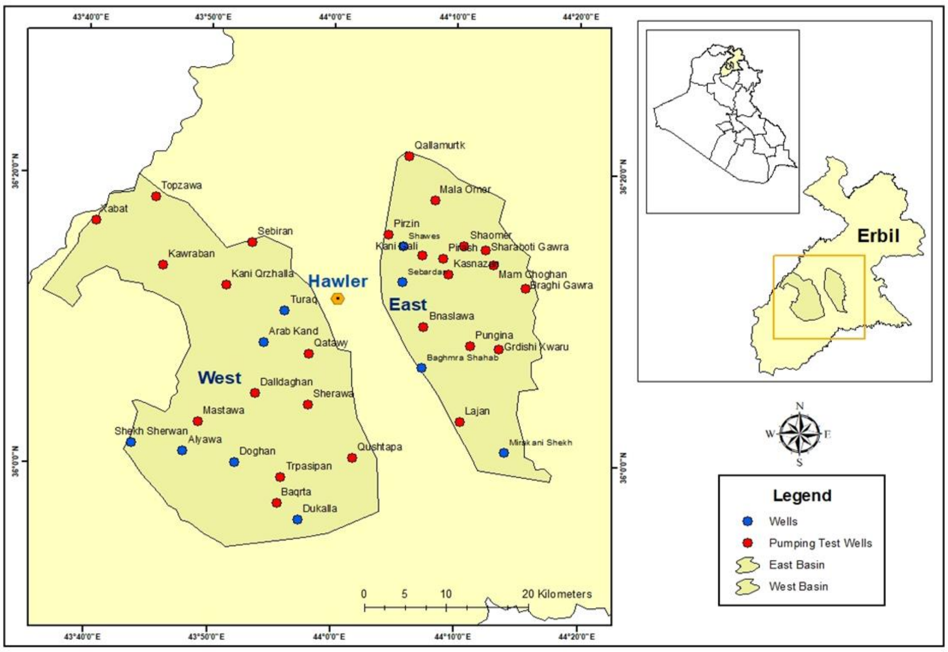


Fig. 1. Location map of the study area

Materials and Methods

The depth of wells, lithological geological formations, and pumping test data of wells are obtained from the Directorate of Groundwater in Erbil. A Global Positioning System (Garmin® GPS of UTM unit) is employed to establish the existing wells' locations (Table 1)

Table 1. The coordinates and depths of the wells that have been studied from both parts (East and West) of the Erbil Basin

No.	Name of wells (East)	X (UTM)	Y (UTM)	Depth (m)	No.	Name of wells (West)	X (UTM)	Y (UTM)	Depth (m)
1	Bnaslawa	421,126	4,001,927	391	19	Kawraban	389,342	4,009,874	350
2	Shawes	418,627	4,012,212	400	20	Sebiran	400,267	4,012,698	380
3	Kasnazan	424,144	4,008,618	450	21	Qushtapa	412,357	3,985,341	540
4	Pirzin	416,841	4,013,677	350	22	Xabat	381,149	4,015,609	250
5	Braghi Gawra	433,526	4,006,754	400	23	Kani Qrzhalla	397,075	4,007,287	400
6	Qallamurtk	419,422	4,023,648	280	24	Dalldaghan	400,523	3,993,521	350
7	Mam Choghan	429,648	4,009,734	390	25	Arab Kand	401,402	4,000,313	180
8	Pungina	426,738	3,999,453	350	26	Alyawa	391,689	3,986,278	218
9	Shaomer	426,078	4,012,128	380	27	Qatawy	407,123	3,998,497	350
10	Sharaboti Gawra	428,669	4,011,671	420	28	Shekh Sherwan	385,405	3,987,276	250
11	Baghmra Shahab	420,885	3,996,730	350	29	Trpaspian	403,644	3,982,850	300
12	Pirash	423,548	4,010,588	325	30	Mastawa	393,521	3,989,951	250
13	Kani Gani	420,992	4,010,992	380	31	Sherawa	406,961	3,991,863	450
14	Sebardan	418,527	4,007,660	300	32	Doghan	398,056	3,984,813	233
15	Mala Omer	422,519	4,018,023	320	33	Turaq	404,159	4,004,031	330
16	Grdishi Xwaru	430,298	3,999,039	206	34	Dukalla	405,730	3,977,465	300
17	Lajan	425,547	3,985,940	305	35	Topzawa	388,479	4,018,519	320
18	Mirakani Shekh	430,946	3,985,868	330	36	Baqrta	403,163	3,979,538	315

The lithological sections of wells are drawn by the AutoCAD program. The location map of the study area is drawn by the Arc GIS (version 10.8) program, while the contour map of the groundwater flow direction is drawn by the Surfer program.

The hydraulic conductivity, transmissivity, and storativity of wells are calculated using Jacob and Theis recovery methods. In the Jacob method, the drawdown is plotted by the AQTESOLV program, while in Theis's recovery method, the residual drawdown is plotted on semi-logarithmic paper using an Excel program.

Hydraulic Properties of Groundwater Aquifers

The aquifer's depth, aerial expansion, number of water-bearing formations exposed to the well, and hydraulic characteristics are aquifer parameters that affect well performance. An aquifer's characteristics may be described in terms of its transmissivity, storage coefficient, hydraulic conductivity, and specific yield (Michael and Khepar, 1989).

Hydraulic Conductivity (K)

Hydraulic conductivity is defined as the flow rate of water through a horizontal cross-section of one square meter of the aquifer under a hydraulic gradient area, and hydraulic conductivity is the measure of the water transmitting capability of an aquifer. High hydraulic conductivity indicates an aquifer can readily transmit water, while low values indicate poor transmission (Shwani, 2008).

Coarse-grained sands and gravels have high hydraulic conductivities (in the range of 50 to 1000 m/day) and rapidly convey water. Fine-grained silts and clays have low hydraulic conductivities (in the range of 0.001-0.1 m/day) and limited water transmission.

Transmissivity (T)

It is defined as the amount of water transmitted through a unit width of the aquifer by the saturated aquifer thickness under a unit hydraulic gradient. Thus, transmissivity calculates how much water will move through the water-bearing formation (Dara, 2011). High values of transmissivity are associated with highly permeable or thick aquifers. Conversely, low transmissivity is characteristic of thin aquifers or those of low permeability (Kruseman and de Ridder, 1994).

Coefficient of Storage (Storativity, S)

The amount of water that the aquifer gives up or stores per unit of the aquifer's surface area per unit change in the component of the head is normal to the surface. When water enters or out of an aquifer, the amount of water stored in the aquifer changes (Shwani, 2008).

Groundwater Pumping Tests

Pumping tests could give information about the rocks that hold water and the well. The pumping test results are evaluated to determine the aquifer's hydraulic characteristics, such as hydraulic conductivity, transmissibility, storage coefficient, specific yield leakage factor, and hydraulic resistance. A pumping test will also provide information regarding the hydrogeological parameters of the well site, including the kind of aquifer, its size and thickness, the gradient of the water table, and the recharge limits (Michael and Khepar, 1989).

In the study region, the Jacob technique is used to calculate the data from twelve selected wells in the western section and fourteen selected wells from the eastern part. While the Theis Recovery method is used to calculate eight chosen wells from both the eastern and western parts of the basin.

Period of the Pumping Test

The duration of the pumping test is determined by the kind of aquifer, its hydraulic qualities, and how the data from the pumping test will be processed. You can get reliable information if you keep pumping until you almost reach a steady state. In a semi-confined aquifer, this state is reached in about 15 to 20 hours (Michael and Khepar, 1989).

Jacob Straight Line Method

The Jacob method is used to look at the results of well-pump tests. Jacob noticed in 1948 that the values of transmissivity could be found by noting that $t/t_o = 10$ (one logarithmic cycle), so $\log t/t_o = 1$. If s is the difference in drawdown per log cycle of t, then the following equation can be used to find transmissivity (Todd, 2005)

$$T = 0.183 \frac{Q}{\Delta s}$$

$$K = T / b$$

Where: T - Transmissivity (m^2/day)
Q - Pumps constant rate discharge from the well (m^3/day)
Δs - Difference of drawdown per log cycle t.K - Hydraulic conductivity (m/day)
b - Saturated thickness (m)

Theis Recovery Method

Theis recovery technique is utilized to calculate the transmissivity of semi-logarithmic paper, and a straight line is fit between the spots. Then, the following equation calculates the transmissivity and hydraulic conductivity:

$$T = 0.183\, Q / \Delta s` \qquad K = T / b$$

where: T - Transmissivity (m^2/day)
Q - Discharge from the well (m^3/day)
$\Delta s`$ - Difference of drawdown per log cycle t
K - Hydraulic conductivity (m/day)
b - Saturated thickness (m)

Results and Discussion

Aquifers and Confining Beds

An aquifer is a saturated geologic formation that may provide a well with sufficient water. A geologic unit known as a confining bed is generally impermeable and does not produce significant amounts of water. There are two main types of groundwater conditions in aquifers: confined and unconfined. An unconfined aquifer lacks an above-confining layer and is often susceptible to infiltration from the surface. An unconfined aquifer or water table aquifer is one in which the top surface of the zone of saturation is the water table. A confined aquifer, also called an artesian aquifer, is one where groundwater is held back by layers of rock that don't let much water through (Punmia and Jain, 1995). If a well is dug into a confined aquifer, the extra fluid pressure can cause the water to rise above its level in the aquifer. This is called an artesian system. The water in an artesian system may or may not rise all the water to the ground surface; some pumping may still be necessary to bring it to the surface for use (Shwani, 2008).

In the study area, the types of aquifers are intergranular aquifers (confined and unconfined); generally, most selected aquifers from the eastern part are confined, while those from the western part are unconfined. The formations of wells in the study area have been identified, represented by the Bakhtiari Formation and Recent deposits. Generally, most of the selected wells in the eastern part are represented by the Bakhtiari Formation, while most of the western part wells are represented by the Recent deposits. It is found that most of the sediments from both parts are composed of sequences of clay, gravel, pebble, sandstone, and siltstone (Fig. 2. A and B).

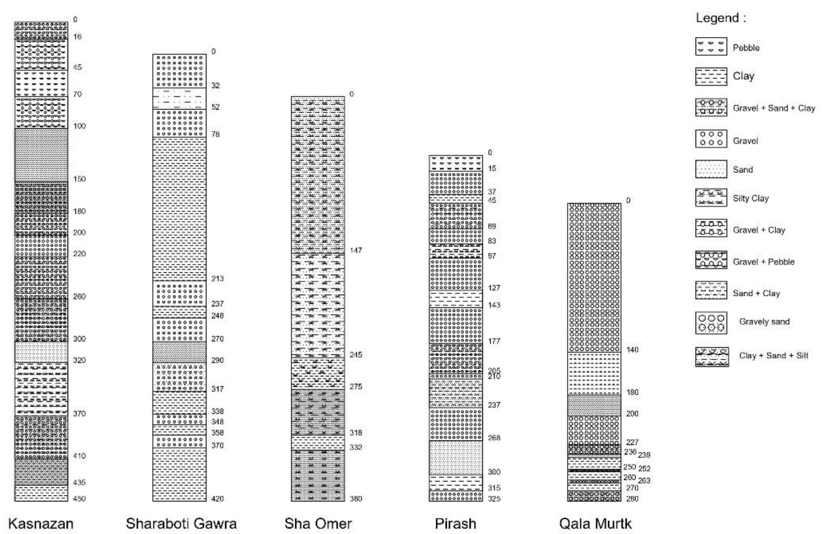


Fig. 2.A Lithological Column of five wells from the Eastern part of the study area

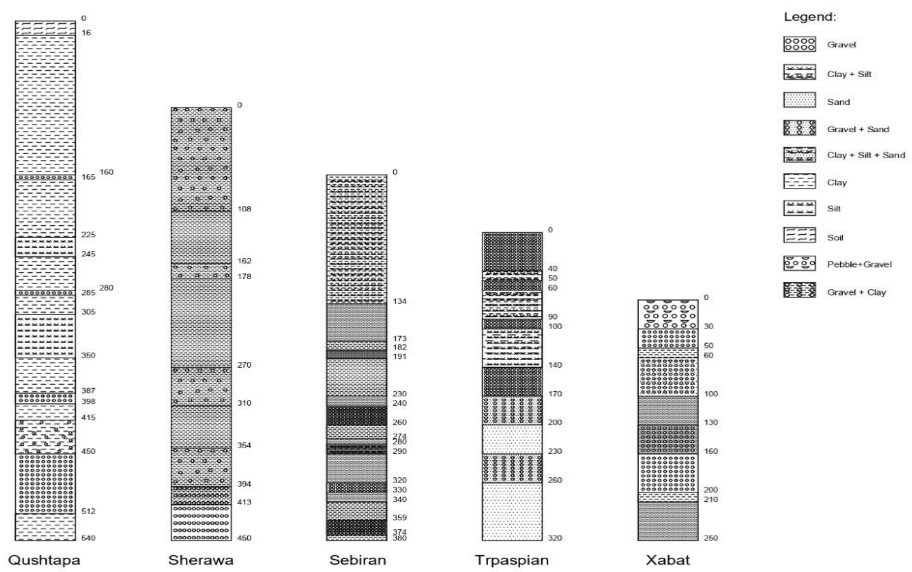


Fig. 2.B. Lithological Column of five wells from the Western part of the study area

Depth to Groundwater

The geography of the region and human activities, which are reflected by groundwater extraction, have an impact on depths. The depth is one of the determining elements affecting the drilling techniques, the type of pumps used, and the size of wells (Najeeb, et al., 2021).

In the study area, the groundwater level is measured; in the eastern part, it ranges between 0 - 159 meters, while in the western part it ranges between 9 -174 meters. In the eastern part, the wells (Pungina and Sharaboti Gawra) are artesian wells, meaning that the well's water level equals zero, while the Kasnazan well has the highest water level reaching 159 meters. In the western part, the Arab Kand well has the lowest water level reaching 9 meters, while the Kani Qrzhalla well has the highest water level reaching 174 meters (Table 2).

The static water level of the eastern wells has decreased significantly with time because the selected wells in the eastern part are located in the recharge zone. The recharge zone area is higher than the sea level datum; for that reason, the direction of groundwater movement in the Erbil basin is from east to west. Also, in the eastern part, in some of the wells, the extra fluid pressure can cause the water to rise above its level in the aquifer; this is called an artesian system, which makes the water flow to the up wells.

Table 2. Depths to Groundwater (groundwater level) from the Eastern and the Western part of Erbil Basin

No. of Wells	Well Names (East)	Groundwater Level (m)	No. of Wells	Well Names (West)	Groundwater Level (m)
1	Bnaslawa	147	1	Kawraban	114
2	Shawes	70	2	Sebiran	101
3	Kasnazan	159	3	Qushtapa	100
4	Pirzin	47	4	Xabat	50
5	Braghi Gawra	89	5	Kani Qrzhalla	174
6	Qallamurtk	38	6	Dalldaghan	90
7	Mam Choghan	54	7	Arab Kand	9
8	Pungina	42	8	Alyawa	20
9	Shaomer	0	9	Qatawy	50
10	Sharaboti Gawra	0	10	Shekh Sherwan	53
11	Baghmra Shahab	101	11	Trpaspian	60
12	Pirash	53	12	Mastawa	48
13	Kani Gani	56	13	Sherawa	89
14	Sebardan	99	14	Doghan	18
15	Mala Omer	76	15	Turaq	33
16	Grdishi Xwaru	17	16	Dukalla	40
17	Lajan	34	17	Topzawa	68
18	Mirakani Shekh	102	18	Baqrta	53

Groundwater Table and Flow Direction

The groundwater table is a very important part of studying groundwater because it controls how much water can be taken out of the ground and where it moves and drains naturally. The elevation of the groundwater table above sea level is measured from the Eastern part ranging between 308 and - 910 meters, while the western part ranges between 181.2 - 342 meters (Table 3).

The hydraulic gradient and hydraulic conductivity within the groundwater aquifer control the movement of groundwater. Other things, like porosity, the type of aquifer (confined or unconfined), and the recharge and discharge area, can also affect the movement of groundwater. Groundwater flows from areas with a higher elevation or higher pressure (hydraulic head-recharge areas) to areas with a lower elevation or lower pressure. Two important groundwater flow characteristics are specific yield and specific retention (Najeeb, et al., 2021). Most groundwater moves from pore to pore quite slowly. A few millimeters every day is the average pace. The force of gravity supplies the energy that causes the water to flow. Gravity causes water to flow from locations with a high water table to others with a lower water table (Shwani, 2008). In the study area, the groundwater movement is from the east to the west (Fig. 3).

Table 3. Elevation and Water Table above sea level from the Eastern and the Western part of Erbil Basin

East Wells	Elevation (m)	S.W.L (m)	Water Table above Sea Level (m)	West Wells	Elevation (m)	S.W.L (m)	Water Table above Sea Level (m)
Bnaslawa	524	147	377	Kawraban	295	114	181.2
Shawes	538	70	468	Sebiran	359	101	258
Kasnazan	678	159	519	Qushtapa	398	100	298
Pirzin	510	47	463	Xabat	273	50	223
Braghi Gawra	625	89	536	Kani Qrzhalla	444	174	270
Qallamurtk	555	38	517	Dalldaghan	317	90	227
Mam Choghan	866	54	812	Arab Kand	346	9	337
Pungina	644	42	602	Alyawa	309	20	289
Shaomer	778	0	778	Qatawy	374	50	324
Sharaboti Gawra	910	0	910	Shekh Sherwan	317	53	264
Baghmra Shahab	510	101	409	Trpaspian	343	60	283
Pirash	652	53	599	Mastawa	305	48	257
Kani Gani	701	56	645	Sherawa	310	89	221
Sebardan	410	99	311	Doghan	324	18	306.4
Mala Omer	641	76	565	Turaq	375	33	342
Grdishi Xwaru	769	17	752	Dukalla	346	40	306
Lajan	575	34	541	Topzawa	283	68	215
Mirakani Shekh	410	102	308	Baqrta	325	53	272

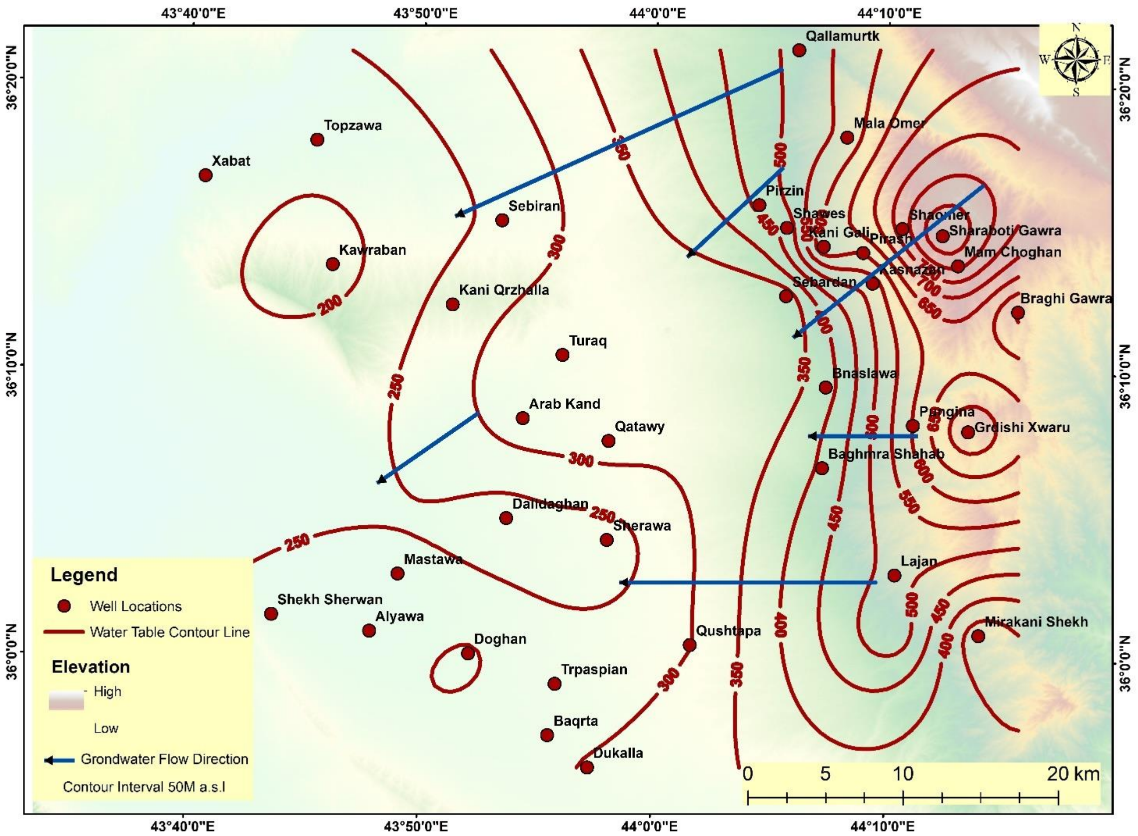


Fig. 3. Water Table Contour Map and Groundwater Movement of Study Area

The result of the Pumping Test by Copper-Jacob Method

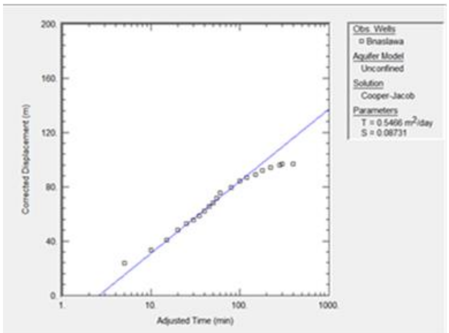
In the Jacob method, the relationship is between correction drawdown and time. According to this relationship, the transmissivity, hydraulic conductivity, and storativity are calculated by the AQTESOLV program; from the Eastern part, the transmissivity, hydraulic conductivity, and storativity were between 0.30 - 28.19 m^2/day, 0.001 -0.116 m/day, 0.03 - 0.98 respectively, while from western part the transmissivity, hydraulic conductivity, and storativity are between 0.42 - 141.6 m^2/day, 0.001 - 0.701 m/day, 0.01- 0.92 respectively (Table 4.A and B), (Fig.4.A and B).

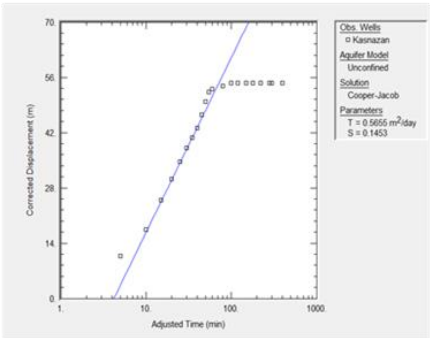
Table 4.A. Transmissivity, Hydraulic Conductivity, and Storativity from the Eastern part of Erbil Basin according to the Copper-Jacob Method

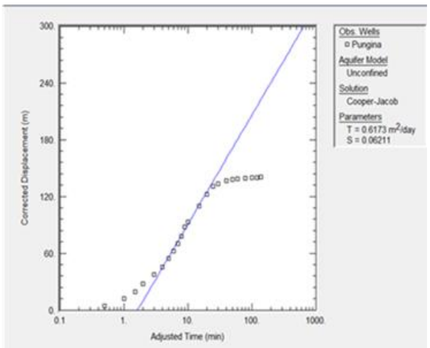
Wells Name	Q (m^3/day)	Transmissivity (T) (m^2/day)	Hydraulic Conductivity (K) (m/day)	Storativity (S)
Mala Omer	453.6	0.91	0.004	0.06
Bragh	712.8	1.72	0.005	0.12
Shaomer	1555.2	6.69	0.018	0.1
Kani Gani	803.5	2.74	0.008	0.09
Sharaboti Gawra	809.3	1.63	0.004	0.09
Mam Choghan	213.1	0.30	0.001	0.03
Qallamurtk	2066.4	28.19	0.116	0.33
Pungina	388.8	0.62	0.002	0.06
Pirzin	1166.4	2.93	0.009	0.96
Grdishi Xwaru	485.3	3.45	0.018	0.03
Lajan	524.16	1.09	0.004	0.25
Pirash	777.6	1.95	0.007	0.98
Kasnazan	136.8	0.56	0.002	0.14
Bnaslawa	158.4	0.54	0.002	0.08

Table 4.B. Transmissivity, Hydraulic Conductivity, and Storativity from the Western part of Erbil Basin according to the Copper-Jacob Method

Wells Name (West)	Q (m^3/day)	Transmissivity (T) (m^2/day)	Hydraulic Conductivity(K) (m/day)	Storativity (S)
Qushtapa	1133.3	4.19	0.009	0.12
Xabat	1697.8	45.99	0.23	0.55
Kawraban	635.0	1.48	0.006	0.12
Sebiran	1457.3	1.52	0.005	0.01
Daldaghan	874.1	8.74	0.034	0.17
Tirpaspian	1153.4	8.99	0.037	0.42
Mastawa	1586.9	141.6	0.701	0.87
Topzawa	1262.9	22.71	0.09	0.29
Baqrta	1568.2	14.3	0.057	0.92
Kani Qrzhalla	583.2	1.99	0.009	0.68
Qatawy	388.8	0.42	0.001	0.40
Sherawa	648	0.69	0.002	0.82

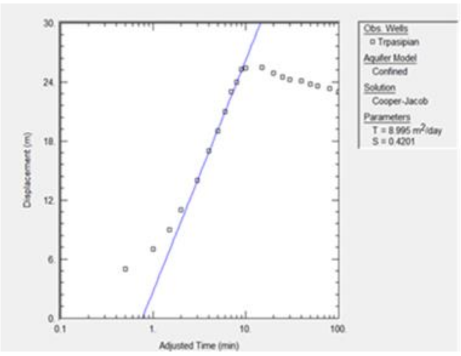


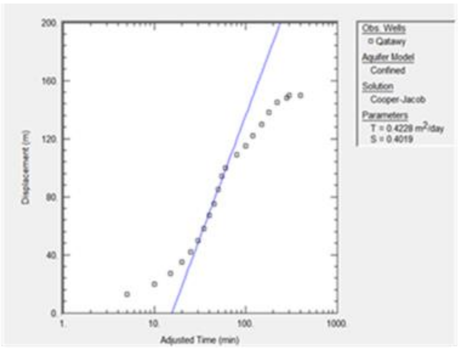


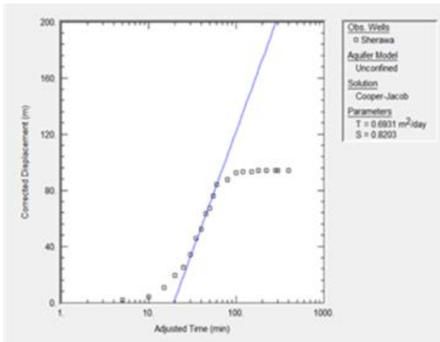


A - Bnaslawa **B - Kasnazan** **C - Pungina**

Fig. 4.A. The results of the pumping test by the Cooper-Jacob method for three wells within the study area from the Eastern part of Erbil Basin.







A - Trpaspian **B - Qatawy** **C - Sherawa**

Fig. 4.B. The results of the pumping test by the Cooper-Jacob method for three wells within the study area from the Western part of Erbil Basin

Theis Recovery Method

In the Theis recovery method, the relationship is between residual drawdown and time drawing on semi-logarithmic paper by Excel program; according to this relationship, the transmissivity and hydraulic conductivity are calculated. From the Eastern part, the Transmissivity and hydraulic conductivity were between 0.28 - 52.52 m^2/day, and 0.001 - 0.217 m/day, respectively, while from the Western part, the Transmissivity and hydraulic conductivity are between 2.64 - 161.33 m^2/day, 0.011 - 0.798 m/day respectively (Table 5.A and B), (Fig. 5.A and B).

Table 5.A. Transmissivity and Hydraulic Conductivity from the Eastern part of Erbil Basin according to Theis Recovery method

Well Name	Q (m3/day)	ΔS (m)	b (m)	Transmissivity (T) (m^2/day)	Hydraulic Conductivity (K) (m/day)
Mala Omer	453.6	120	244	0.69	0.003
Bragh	712.8	68	311	2.61	0.008
Shaomer	1555.2	80	380	3.56	0.009
Kani Gani	803.5	64	324	2.29	0.007
Sharaboti Gawra	809.3	84	420	1.76	0.004
Mam Choghan	213.1	140	336	0.28	0.001
Qallamurtk	2066.4	7.2	242	52.52	0.217
Pungina	388.8	120	308	0.59	0.002

Table 5.B. Transmissivity and Hydraulic Conductivity from the Western part of Erbil Basin according to Theis Recovery method

Well Name	Q (m3/day)	ΔS (m)	b (m)	Transmissivity (T) (m^2/day)	Hydraulic Conductivity (K) (m/day)
Qushtapa	1133.3	28	440	7.41	0.016
Xabat	1697.8	4.6	200	67.54	0.337
Kawraban	635.0	44	236.2	2.64	0.011
Sebiran	1457.3	3.4	276	78.44	0.284
Daldaghan	874.1	7.2	260	22.22	0.085
Tirpaspian	1153.4	8.4	240	25.13	0.105
Mastawa	1586.9	1.8	202	161.33	0.798
Topzawa	1262.9	6.4	252	36.11	0.143

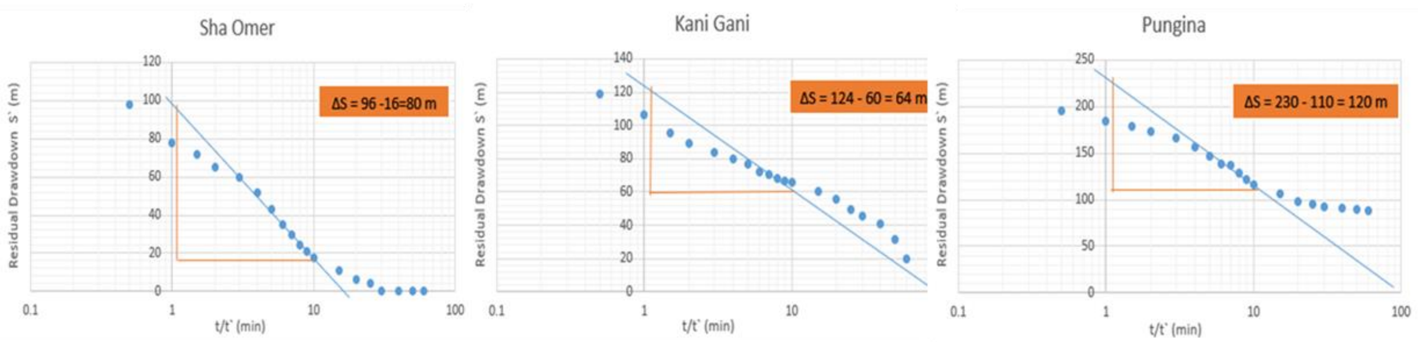


Fig. 5.A. The results of the pumping test by Theis recovery method for three wells within the study area from the Eastern part of Erbil Basin

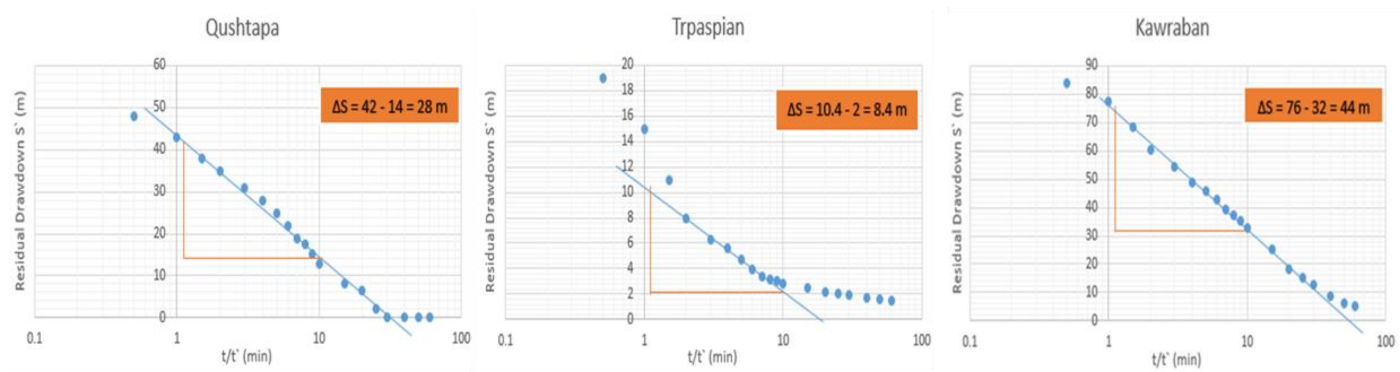


Fig. 5.B. The results of the pumping test by Theis recovery method for three wells within the study area from the Western part of Erbil Basin

These findings demonstrate that hydraulic conductivity in the research area varies between (0.001-0.8 m/day) using both Jacob and Recovery techniques, indicating that it is typically low. Due to the majority of the sediments in the area being made up of fine-grained silts and clays, they indicate poor water transmission because of the type of soils present there.

In general, the pumping test result shows that the transmissivity and hydraulic conductivity by both Jacob and Recovery techniques are higher in the western part than in the eastern part, which may be related to the kind of aquifers and geological formation of the beds, because the result of low transmissivity and hydraulic conductivity of a well means that the majority of the lithology of this well is composed of clay and silty materials, which cause less permeable and high porous patterns in geologic units. Thus, this well is characterized by low water discharge and less storativity. Moreover, the water level in this well is low due to the high distance difference between static and dynamic water levels. While the result of high transmissivity and hydraulic conductivity of a well means that the majority of the lithology of this well is composed of gravel and sand materials. Also, this well is characterized by high water discharge and is thus considered to be a high storage well. Moreover, the water level in this well is high due to the less distance difference between static and dynamic water levels. (Fig.6.A and B).

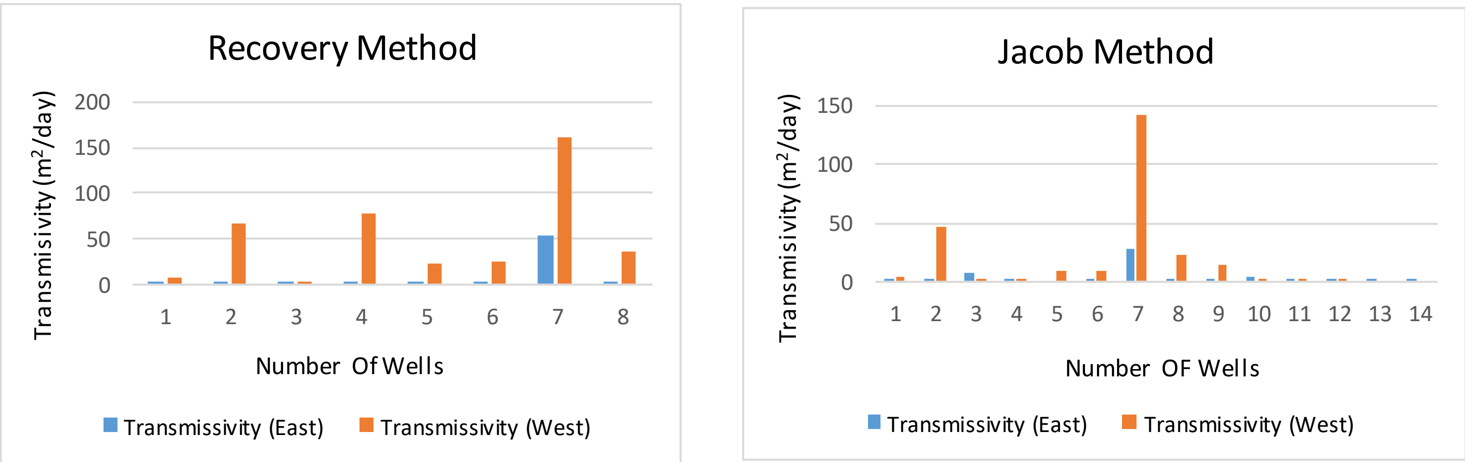


Fig.6. A. Transmissivity by the Jacob and Recovery methods from the Eastern and the Western parts of Erbil Basin

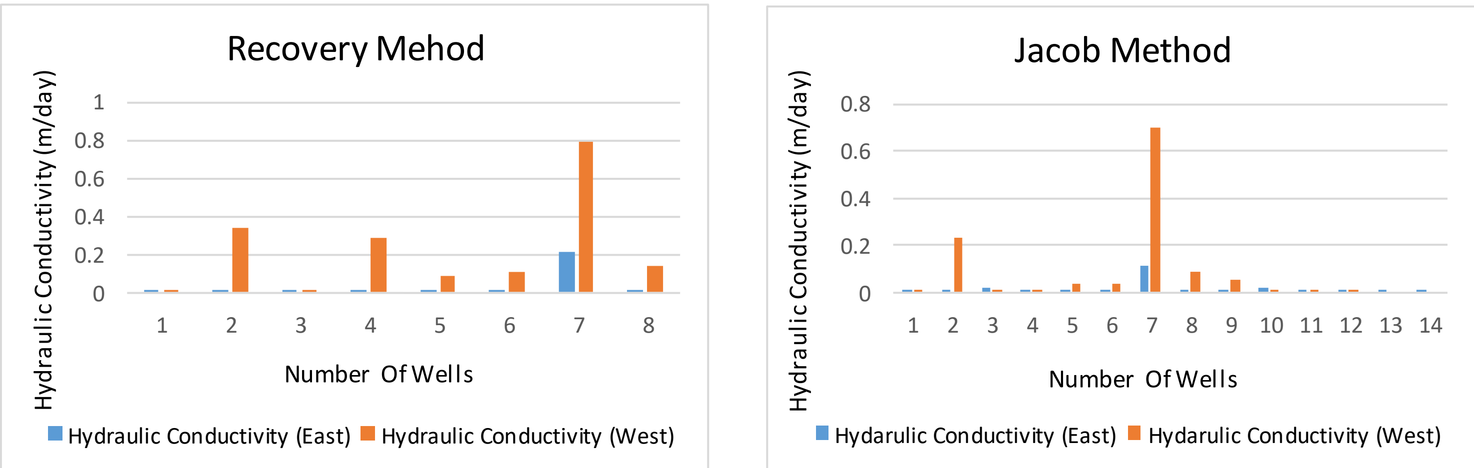


Fig.6. B. Hydraulic Conductivity by the Jacob and Recovery methods from the Eastern and the Western parts of Erbil Basin

Conclusion

In the study area, the types of aquifers are confined and unconfined aquifers. Generally, most selected aquifers from the eastern part are confined, while those from the western part are unconfined

The groundwater-bearing beds in the study area are the Bakhtiari formation and Recent deposits. Most of the sediments from both parts are composed of sequences of clay, gravel, pebble, sandstone, and siltstone

The groundwater movement in the study area is from the east to the west.

In the study area, the groundwater level is measured, so it is found that the static water level of the eastern wells has decreased significantly with time more than the western wells.

On the eastern side, the results of transmissivity, hydraulic conductivity, and storativity by the Cooper-Jacob method are between 0.30 - 28.19 m^2/day, 0.001 -0.116 m/day, and 0.03 - 0.98, respectively. On the western side, the transmissivity, hydraulic conductivity, and storativity are between 0.42 - 141.6 m^2/day, 0.001 - 0.701 m/day, and 0.01- 0.92 respectively.

By using the recovery method, the results of transmissivity and hydraulic conductivity on the eastern side are between 0.28 - 52.52 m^2/day and 0.001 - 0.217 m/day, respectively, while on the western side, the transmissivity and hydraulic conductivity are between 2.64 - 161.33 m^2/day, 0.011 - 0.798 m/day respectively.

The result of the pumping test shows that the transmissivity and hydraulic conductivity from the western part are higher than the eastern part.

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