Diyala Journal of Engineering Sciences Vol. 13, No. 02, June 2020, pages 22-33 ISSN 1999-8716
DOI: 10.24237/djes.2020.13204 eISSN 2616-6909

Estimation of Aquifer Hydraulic Parameters from Pumping Test Data Analysis: A Case Study of Baquba Shallow Unconfined Aquifer

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Abstract

The groundwater resources are an important component of arid and semi-arid countries such as the Baquba area under this study. The pumping tests have conducted in the shallow unconfined aquifer (Quaternary sediments) within Baquba Local Government Area, Diyala, Iraq, for estimating of the aquifer properties as there is limited information on aquifer parameters. Drawdown and recovery data have recorded in seventeen single pumping wells and two monitoring wells locates at distances of 4 and 20 m from the pumping well in Abu-Khamis and Al-Othmania sites respectively. Type-curve matching of the drawdown and recovery data have analyzed using Cooper-Jacob's Straight-line and Thies recovery methods through computer software (Aqtesolv4.5). The ranges of the drilling borehole depth are 15m to 38.4m. The aquifer saturated thickness ranges from 8m to 26m. The outcomes of the pumping test data analysis showed that the transmissivity values ranged between 124 to 541 m^2/day with an average value of 245.3m2/day. The hydraulic conductivity ranged from 7.5 to 25.6 m/day with an average value of 14.5 m/day. The specific yield ranges from 0.05 to 0.28 with an average value of 0.12. The specific capacity of the wells have ranged from 0.86 to 7.07 l/s with an average value of 2.46 l/s. The transmissivity values have analyzed according to Krasny classification system (KCS) for identifying the transmissivity variations as well as the supply potential of the groundwater within the study area. The transmissivity classification results have showed that the study area classifies as a high groundwater supply potential with slightly heterogeneous aquifer soil.

Keywords: Estimation aquifer parameter; Shallow unconfined; Single well test; Pumping test.

Paper History: (Received: 4-7-2019; Accepted: 19-11-2019)

Introduction

In many areas of the world, the increasing requesting for water has laid expansion pressure on subsurface water resources [1]. In the arid and semi-arid region, climate change is a major factor affecting both surface and groundwater sources. These changes led to a sharp decrease in surface water sources, which led to the creation of other sources of water and development the method of exploitation [2].

The problem of severe and increasing drought in Iraq is one of the most serious environmental issues. Diyala governorate has suffered hard drought in 2008, as known the drought have a direct effect in descending the level of water in reservoirs and dams like Hamreen that is consider the vital source of water in the city where is located. However, in Diyala governorate drought has started in the governorate in 2000 and continued up to 2011 indicating that Diyala is currently considered a drought susceptible region (region with probable effects ensuing from a lacking water balance) [3].

In order to mitigate the water shortage, the governorate of Iraq through the General Authority for Groundwater drilled a lot of boreholes in many areas in Baquba district. The Boreholes drilling in Baquba area are geared toward increasing due to the huge demand to the water that has been used for different purposes including agricultural, domestic and industrial as well as other purposes [4].

Cognition of aquifer parameters is fundamental and significant for management of subsurface water resources. There are many techniques used to identify the influx characteristics of aquifers involve pumping test, geophysical well logging, and electrical resistivity. Traditional, the pumping tests are widely used to estimates of hydraulic parameters characterizing influx and conveyance operations in the underground, because of simplicity field processes and effective low cost. Virtually, the pumping water from the pumping wells with a specific rate of flow in order the drawdown has observed as well as the residual drawdown within the pumping well (single well test) or in observation wells that have located at a specified distance from the pumping well [5].

The aim of the study is to estimate the hydraulic aquifer parameters of the Baquba district zone. This will be carried out by conducting several pumping tests within the study area.

Description of the study area

The The area has been proposed in the present study is located in Diyala province with coordinates latitude (33° 25′ 26″- 33° 53′ 24″) North and longitude (44° 23′ 17″- 44° 57′ 47″) East as demonstrated in Figure 1, it consists of five administrative units includes Baquba Centre, Kanan, Beni Saad, Buhriz (Ashnouna) and Abbara. The area of the study is equal to (1630 km2) and the population estimation according to 2017 has approximate equal to (664,830). The main source of the water resources in the past that have been used for different purposes domestic, industrial and agriculture is Diyala river that is cross it from the north to the south in the middle part of it, now the use of it is limited because of the poor of the water quality, as well as three binary streams (Sarria, Kanan, and Al-Khalis), used mainly for domestic purposes that take its water from Himreen reservoir [6]. The agriculture areas spend along the sides of this river and streams that play an important role for the province economy, at the recent years these lands subject to destruction due to the lack of water supply, so the groundwater importance stands between the other resources to substitute the deficiency in the water supply. The climate condition of this area is classified as an arid area with annual precipitation value equal to 148.5mm/year [7].

From a topographical perspective, the area that is the focus of the present investigation is predominantly flat plain in character. The elevation above sea level in the study area ranges between (26 – 54 m) a.s.l., where the highest elevation lies in the northern part and decreases towards east and southern so that it can be appropriated for the agricultural activity Figure 2. The digital elevation model (DEM) has employed for the purposes of representation of the topography of the area in question; this representation is illustrated in Figure 2 with a resolution of 25 meters. The DEM has downloaded from the website of the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/) [8].

The location of the study area is laid at the part of the northern Mesopotamia Plain as shown in Figure 3. The quaternary sediment is the mastered cover of the plain of Mesopotamia. The distributions of the sediment types consist from clay, silty clay, clayey silt, silt, sand and gravel [9]. The flood plains, as well as, the deposits of Tigris River and Diyala River, are the main cover component of the study area through the Quaternary age. The largest part of the study area has been consisting from the sediment with types of clay, silt, and sand while the gravel is the dominant type at the north part Figure 4.

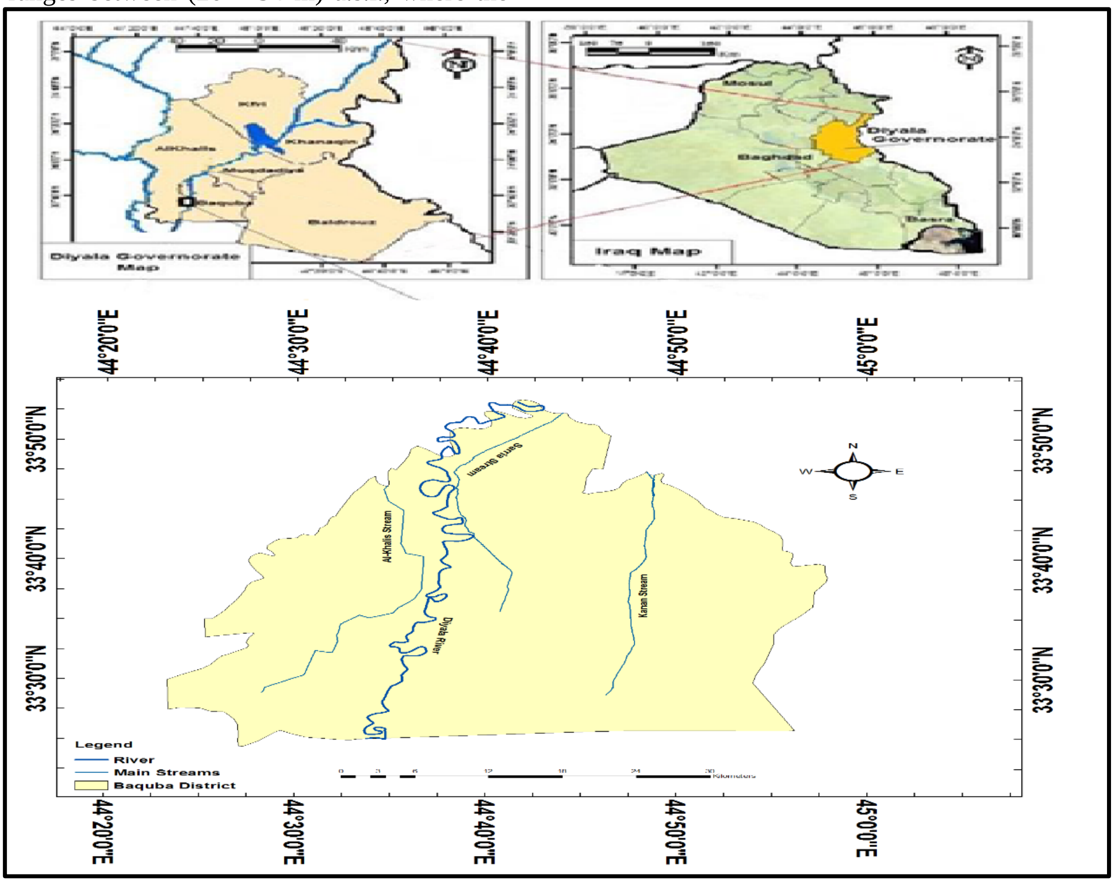

Fig (1) location map of the Baquba study area

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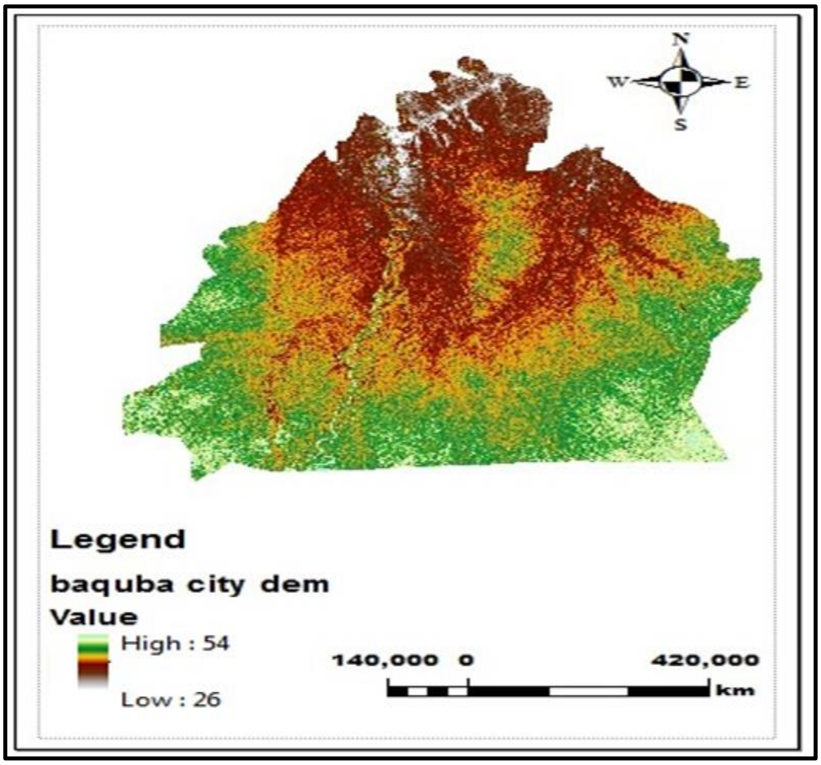

Fig (2) DEM of the study area [6]

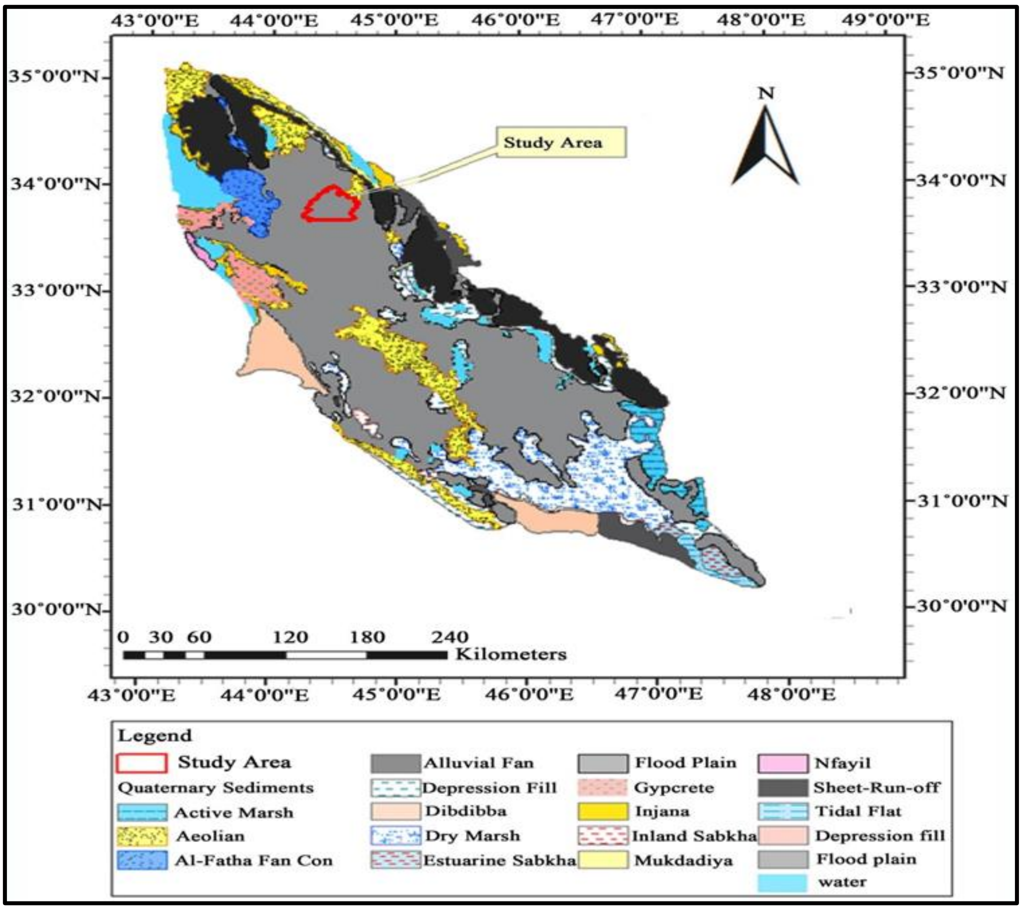

Fig (3) Geological map of the Mesopotamia plain [8]

Diyala Journal of Engineering Sciences Vol. 13, No. 02, June 2020, pages 22-33 ISSN 1999-8716
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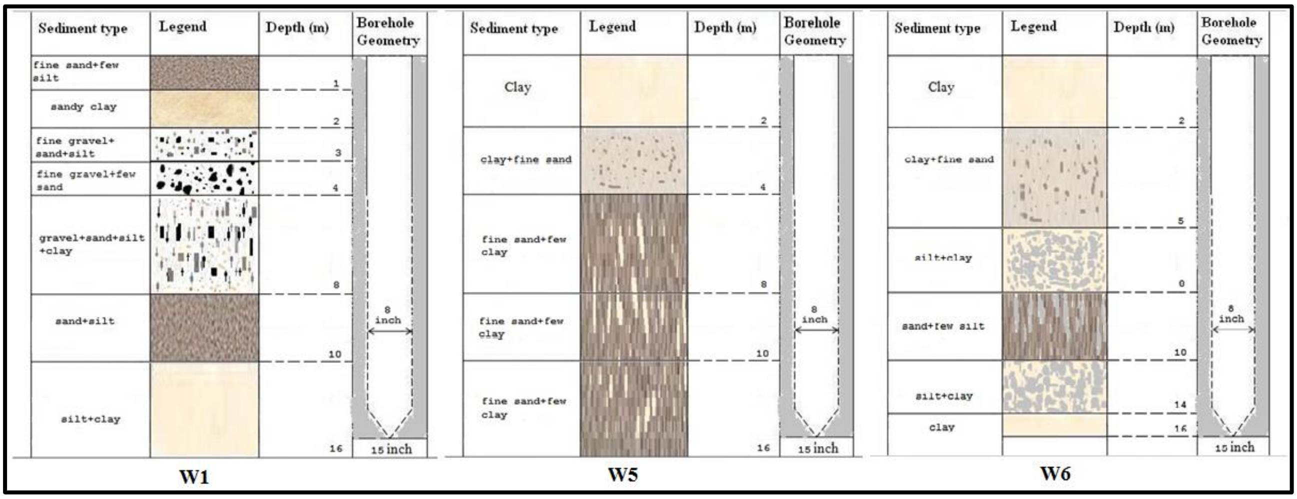

Fig (4) lithology of the boreholes (W1, W5, W6)

Field works

Hydraulic Aquifer Properties

The hydraulic properties of the aquifer have been divided according to the degree of importance into two types, significant and less significant. The significant properties that can be estimated from the result of pumping test include transmissivity, hydraulic conductivity, coefficient of storage, specific yield and specific capacity. Transmissivity defined as the aquifer hydraulic characteristic that represents the rate of flow at dominated field temperature through a vertical strip of the aquifer under hydraulic gradient for the unit-width and stretches to the whole entire aquifer thickness. For that, it represents the product of the average hydraulic conductivity and aquifer thickness, and it's measured by a meter per day [10].

The hydraulic conductivity value change from one place to another according to the way of formed geological formation deposit [11]. The common

ranges of hydraulic conductivity vary according to the type of sediment and have value (0.02-40 m/day)for unconsolidated sediment, for sandstone below 0.5 m/day and for clays or shale becomes less than 0.0001 m/day [12].

In the practical purposes, the specific yields equal the effective porosity due to the negligible of the aquifer elasticity and the fluid. In spite of the specific storage of the unconfined aquifer negligible, the specific yield became more significant through the process of pumping as the aquifer is gradually dewatered under gravity drainage when the water table is lowered. Thereupon, the storativity is equal only to the specific yield, such that:

$$s = s_y \ \ for\, unconfined\, aquifer \qquad (1)$$

Where:

s: storativity (dimentionless)

s_y: specific yield (dimentionless)

The effectiveness of both aquifer and well characteristics (T and S) measured according to Specific capacity. It's defined as the ratio of the pumping rate and the drawdown and is usually expressed in liters per minute per meter of drawdown for a specific period of pumping. It has been represented by the following equation:

$$S_c = \frac{Q}{sw} \qquad (2)$$

In the above equation the Specific capacity in (m² /day), discharge rate in (m³/day) and the drawdown in (m), denoted by S_C, Q and S_w respectively [11].

Pumping Tests Analysis Method

According to the concept of pumping test that has been represented by pumping water from the aquifer with a constant value at a specific time, the treatment of these process is conducted by the help of the analytical method [5] as described in the following:

Cooper and Jacob's Solution Method, this method has been used for determination the derived parameters of the aquifer represented by specific capacity and transmissivity for a specific time of pumping (specific period). The plotting that has been represented by the relation between the drawdown and the time period of pumping on the semi-log diagram. The time takes place the logarithmic x-axis while the y-axis represents the linear drawdown. The straight line of Jacob's has been located at the middle and ignoring the early measured point due to the effect of these data by the volume of the water already stored in the borehole. The rate of pumping (Q) measured by the cubic meter per day for the period of the test and the slope (drawdown change along the logarithmic axis with one cycle (Δs)) appointed and the flow cooper-Jacob equations incorporated for single well for the purpose of transmissivity (T) computation.

Diyala Journal of Engineering Sciences Vol. 13, No. 02, June 2020, pages 22-33 **ISSN 1999-8716**
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$$T = \frac{2.3Q}{4\pi \Delta S} or\ 0.183 \left(\frac{Q}{\Delta S}\right) \qquad (3)$$

In the above equation the measured transmissivity in square meter per day, and the discharge measured by the cubic meter per day have been represented by the T and Q respectively, as well as the relation of the drawdown and the time for one cycle is represented by ΔS [5].

Theis Recovery Equation, in this method the plot is adopted on semi-logarithmic paper including the relation between (t / t') and residual drawdown (Δs') and the fitted straight line pass through the plotted points.

Where:

t: time in a minute including totally pumping period and recovery time period**.**

t': time measured when the pumping process stop (time of recovery) (min).

The transmissivity determines by the equation below:

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

In the above equation the residual drawdown difference measured in meter per log- cycle of (t / t') is represented by Δs', and the other terms have the same descriptions of (Cooper-Jacob equation) parameters except using residual drawdown instead of drawdown [5]. This method reflects accuracy for calculating the hydraulic properties due to the level of water became normal to avoid in fluctuation problem of the groundwater through pumping work. Since it has assumed that the aquifer is unconfined the drawdown data has corrected by means of:

$$s' = s - \frac{s^2}{2h} \qquad (5)$$

Where:

s is the recorded drawdown and h is the saturated thickness of the aquifer. The reason for the correction of the above equation is based on the assumption that the aquifer is confined and to account for the transmissivity change that occurs in an unconfined aquifer the drawdown has to be corrected [13].

Software Selected for Pumping Test Data Analysis

AQTESOLV is major universal software for the analysis and design of the aquifer tests such as slug test, pumping test, and constant head test. The AQTESOLV has created by Glenn M. Duffield, HydroSOLVE, Inc. AQTESOLV has a high ability to use it for analyzed different aquifer types ranged from semi-confined, water-table, artesian, and fractured aquifers [14]. In the present study, the pumping test data obtained from the area under investigation were analyzed by AQTESOLV software version 4.5.

Results and Discussions

In the present study, twenty wells have used for conducted pumping tests, ten wells in each river side as shown in Figure 5. The two observation wells are available in the studied area. The information's of the wells were demonstrating in Table 1. Typical plots of time versus drawdown and time versus residual drawdown are shown in Figures 6 to 11. The results obtained from pumping tests data are presented in Tables 2, and 3.

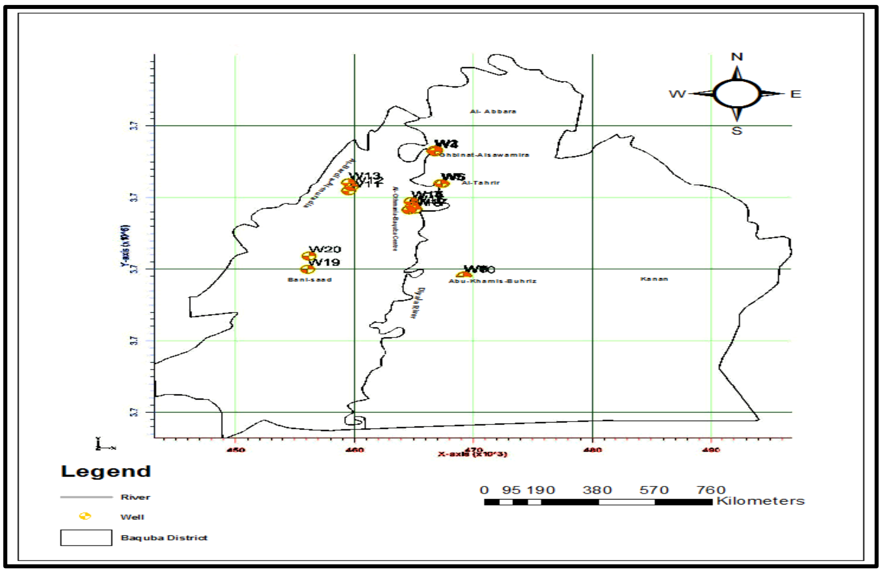

Fig (5) Location of pumping tests

Diyala Journal of Engineering Sciences Vol. 13, No. 02, June 2020, pages 22-33 ISSN 1999-8716
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Table 1: Field data for the wells of study area (W1-W20)

Well No.	UTM coordinates		Well Elevation (m)	Well Depth (m)	Static water level (m)	Aquifer Thickness (m)	Discharge L/sec	Well radius (m)	Casing radius (m)
	X(m)	Y(m)							
W-1	466822	3736659	51	16	4.73	11.27	3.38	0.1095	0.1905
W-2	466747	3736595	50	16	3.4	12.6	3.82	0.1095	0.1905
W-3	466713	3736521	50	16	3.53	12.47	4.01	0.1095	0.2159
W-4	466790	3736416	50	16	3.55	12.45	3.89	0.1095	0.2159
W-5	467263	3731990	47	16	3	13	4.21	0.1095	0.1905
W-6	467400	3731957	47	16	3	13	4.5	0.1095	0.1905
W-7	469211	3719041	45	25	2.54	22.46	5	0.1095	0.1905
W-8	469233	3719036	45	21	2.47	18.53	5	0.1095	0.1905
W-9	469234	3719033	45	18	2.47	15.53	5	0.127	0.2286
W-10	469142	3718940	45	19	2.72	16.28	4.68	0.0762	0.217
W-11	459503	3730927	45	24	2.835	21.165	7.189	0.0762	0.1016
W-12	459721	3731503	46	23	3.28	19.72	6.58	0.1016	0.1524
W-13	459492	3732120	45	21	2.415	18.585	6.72	0.1016	0.1524
W-14	464799	3729423	45	19	2.72	16.28	4.35	0.0762	0.127
W-15	464818	3729423	45	15	2.04	12.96	4.35	0.0508	0.1016
W-16	464912	3728799	45	18	2.495	15.505	4.043	0.0762	0.1524
W-17	465117	3728370	46	28	3.06	24.94	4.2	0.1016	0.1905
W-18	464639	3728283	46	28	3.38	24.62	4.15	0.0508	0.1016
W-19	456089	3719961	43	25	1.32	23.68	5.46	0.0762	0.127
W-20	456203	3721793	43	18	1.51	16.49	5.21	0.1016	0.1524

For well (W1) to well (W4), which are located in a village namely Ghbinat-Alsawamira, the average values of transmissivity, hydraulic conductivity, specific yield, and specific capacity that have been computed from the time-drawdown/recovery curves of the pumping well itself are equal to (182.89m^2/day, 15.01m/day, 0.09, and 1.02m^2/day) respectively. An acceptable value for the pumping well itself measured during the recovery phases.

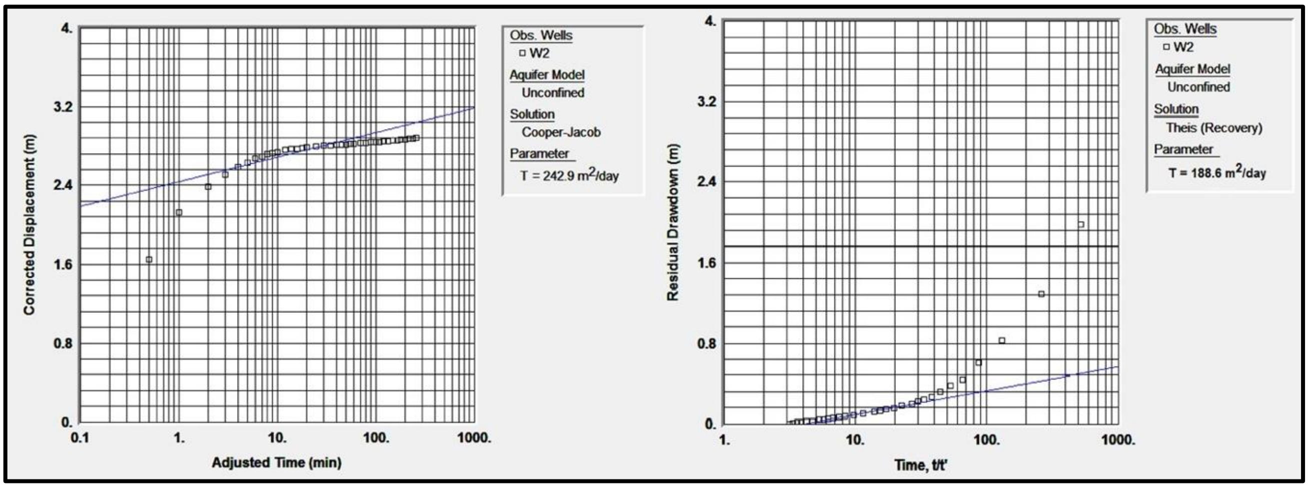

Fig (6) Analysis of pumping test data for pumping well W2

For the wells, W5 and W6, which are located in Al-Tahrir area, the time-drawdown curves showed greater drawdown values compared with the other wells drawdown data, these values result from the presence of fine materials significantly in the upper layers and this leads to the low efficiency of the well and increase the value of the drawdown. The average values of transmissivity, hydraulic conductivity, specific yield, and specific capacity have been computed in these two wells

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are equal to (175.55m^2/day, 13.50m/day, 0.09 and 0.98m^2/day) respectively.

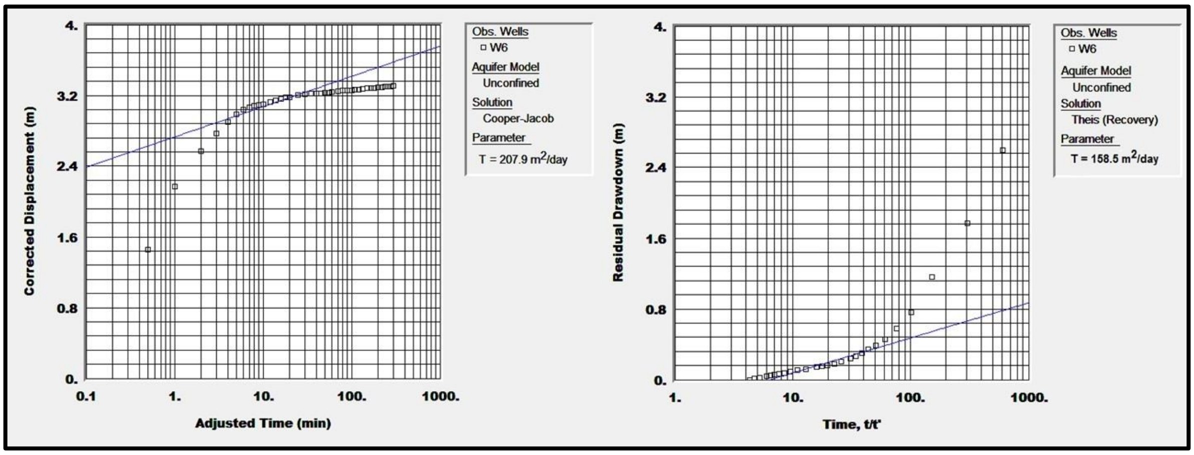

Figure (7) Analysis of pumping test data for pumping well W6

For wells (W7 to W10), these wells have located in a village namely Abo-Khamis within Buhriz sub-district near the Tourist Baghdad Street. The average values of (T, K, S_y, and S_c) that have been computed from the time-drawdown/recovery curves of the pumping well itself (w7 and w10) and observation well for (w9) are equal to (228.25m^2/day, 12.66m/day, 0.08, and 4.71m^2/day) respectively. The maximum drawdown value has recorded within this area equal to 2.01m. A good matching has been getting from these wells in both phases (pumping and recovery), the reason of that when the drawdown values smaller the curves slop also smaller.

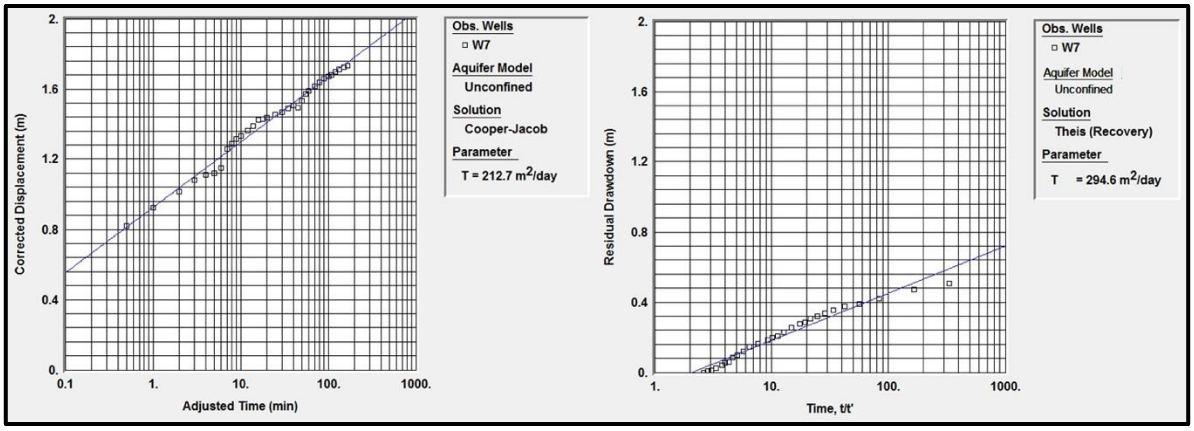

Figure (8) Analysis of pumping test data for pumping well W7

For W11 to W13, these wells have located in a village named as AL-Bardia which fallow Beni Saad sub-district. The average values of (T, K, S_c, and S_y) have been computed from the time-drawdown/recovery curves of the pumping well itself are equal to (480.72m^2/day, 24.24m/day, 4.71m^2/day, and 0.28) respectively. The smaller drawdown values have been recorded in this area compared with the other place within the study area. These curves have showed the best fit for these points in the two phases pumping and recovery. This area has high values of transmissivity and specific capacity; this indicates the groundwater supply is high; therefore this location is a suitable place to study the possibility of the build a water supply project within it.

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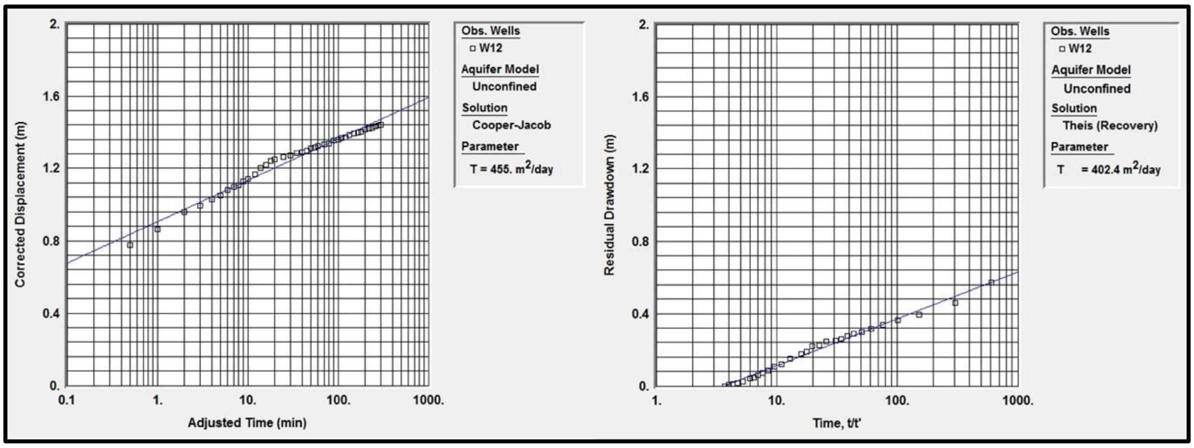

Figure (9) Analysis of pumping test data for pumping well W12

For wells (W14, W15, W16, W17, and W18) which are located in a village namely (AL-Othmania) fallow Baquba Centre. The average values of (T, K, and S_c) that have been computed from the time-drawdown/recovery curves of the pumping well itself and from one observation well (W15) are equal to (214.38m2/day, 12.08m/day, and 2.42m2/day) respectively. An acceptable matching for the pumping well itself field data and observation well field data curves have been getting. The maximum has recorded drawdown values for these wells equal to 3.55m. The average specific yield value that computed in this area depended on the aquifer characteristic is equal to 0.1, and this value is acceptable for unconfined aquifer which is fall in range (0.01-0.3).

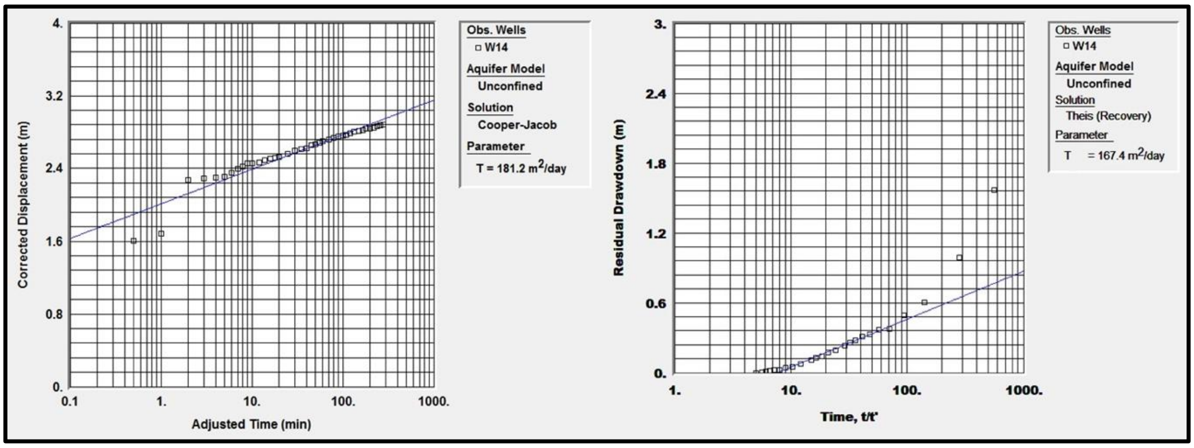

Figure (10) Analysis of pumping test data for pumping well W14

For W19 and W20, these two wells have located in a village namely Mohammed Sakraan which fallow Beni Saad sub-district. The average values of (T, K, S_c, and S_y) have been computed from the time-drawdown/recovery curves of the pumping well itself are equal to (197.97m^2/day, 9.5m/day , 2.8m2/day and 0.055) respectively. These two curves have showed the best fit for these points in the two phases pumping and recovery.

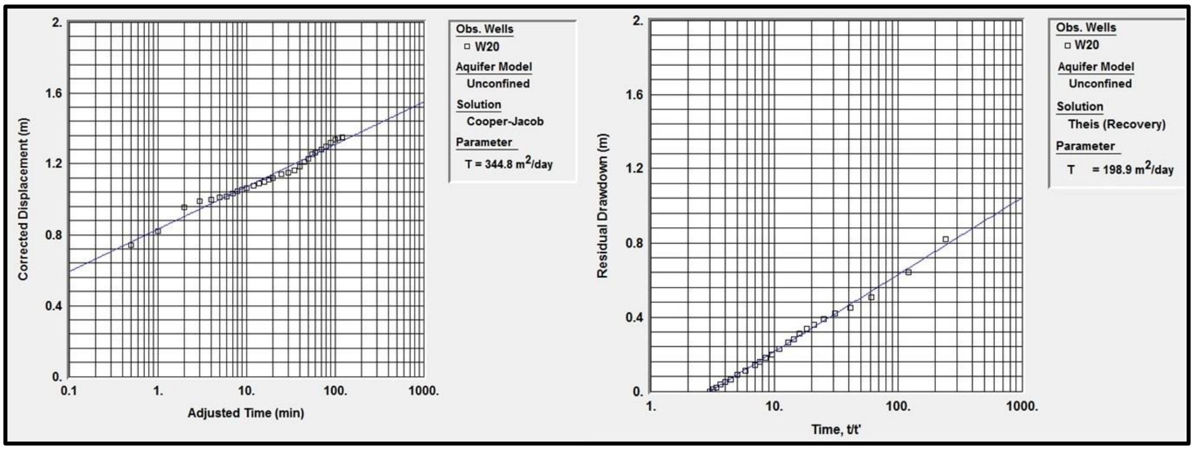

Figure (11) Analysis of pumping test data for pumping well W20

Table 2: Summary of the calculation results of the wells data

Well No	Analysis method	T(m^2/day)	Average T(m^2/day)	Aquifer Thickness (m)	K (m/day)	S.C (L/sec)
W1	Cooper-Jacob	192.7	177.7	11.27	15.77	0.86
	Theis Recovery	162.7				
W2	Cooper-Jacob	242.9	215.75	12.6	17.12	1.03
	Theis Recovery	188.6				
W3	Cooper-Jacob	215.3	201.55	12.47	16.16	1.09
	Theis Recovery	187.8				
W4	Cooper-Jacob	110	136.55	12.45	10.97	1.11
	Theis Recovery	163.1				
W5	Cooper-Jacob	188.9	167.9	13	12.92	0.95
	Theis Recovery	146.9				
W6	Cooper-Jacob	207.9	183.2	13	14.09	1.01
	Theis Recovery	158.5				
W7	Cooper-Jacob	212.7	253.65	22.46	11.29	2.77
	Theis Recovery	294.6				
W8	Cooper-Jacob	216.8	254.45	18.53	13.73	3.45
	Theis Recovery	292.1				
W9-OBS	Cooper-Jacob	216.8	254.45	15.53	16.38	2.77
	Theis Recovery	292.1				
W10	Cooper-Jacob	142.6	150.45	16.28	9.24	2.33
	Theis Recovery	158.3				
W11	Cooper-Jacob	536	541.35	21.165	25.58	4.42
	Theis Recovery	546.7				
W12	Cooper-Jacob	455	428.7	19.72	21.74	4.40

	Theis Recovery	**402.4**				
W13	**Cooper-Jacob**	**448.1**	**472.1**	**18.585**	**25.40**	**5.31**
	Theis Rec	**496.1**				
W14	**Cooper-Jacob**	**181.2**	**174.3**	**16.28**	**10.71**	**1.36**
	Theis Recovery	**167.4**				
W15-OBS	**Cooper-Jacob**	**169.6**	**221.7**	**12.96**	**17.11**	**7.07**
	Theis Recovery	**273.8**				
W16	**Cooper-Jacob**	**252.2**	**219**	**15.505**	**14.12**	**1.23**
	Theis Recovery	**185.8**				
W17	**Cooper-Jacob**	**203.4**	**220.15**	**24.94**	**8.83**	**1.18**
	Theis Recovery	**236.9**				
W18	Cooper-Jacob	226.8	236.75	24.62	9.62	1.27
	Theis Recovery	**246.7**				
W19	**Cooper-Jacob**	**133.7**	**124**	**16.49**	**7.52**	**3.67**
	Theis Recovery	**114.3**				
W20	**Cooper-Jacob**	**344.8**	**271.85**	**23.68**	**11.48**	**1.93**
	Theis Recovery	**198.9**				

Table 3: Average of the hydraulic parameter according to the area of the wells locations

Name of Location	**Average $T(m^2/day)$**	**Average K(m/day)**	**Average S_c(L/sec)**	**Average S_y**
Ghbinat-Alsawamira	**182.89**	**15.01**	**1.02**	**0.09**
Al-Tahrir	**175.55**	**13.50**	**0.98**	**0.09**
Abu-Khamis-Buhriz	**228.25**	**12.66**	**2.83**	**0.08**
Al-Bardia-Al-muradia	**480.72**	**24.24**	**4.71**	**0.28**
Al- Othmania-Baquba	**214.38**	**12.08**	**2.42**	**0.10**
Bani-saad	**197.97**	**9.5**	**2.80**	**0.05**

Transmissivity Classification

Transmissivity analysis is determined based on Krasny (1993) [15] for estimating the potential of the groundwater. Jiri Krasny [1993] proposed classification between the transmissivity and variation according to the magnitude of the transmissivity and standard deviation of the transmissivity-index; these are demonstrated in Table 4 and Table 5 respectively.

The transmissivity-index (Y) that has been related to transmissivity according to the following equation:

$$T\,(\frac{m^2}{day}) = 10^{Y-8.96} \times 86400 \qquad (6)$$

The transmissivity –index calculated by rearrange the above equation thus:

$$Y = \log(\frac{T}{86400}) \times 8.96 \qquad (7)$$

Table 4: Transmissivity Analysis based on Transmissivity magnitude classification

Magnitude of Transmissivity (m2/day)	Class of Transmissivity Magnitude	Designation of Transmissivity Magnitude	Specific Capacity (m2/day)	Groundwater Supply Potential
>1000	I	Very high	>864	Regional importance
100 - 1000	II	High	86.4 – 864	Lesser regional importance
10 - 100	III	Intermediate	8.64 - 86.4	Local water supply
1–10	IV	Low	8.64 – 0.864	Private consumption
0.1 – 1	V	Very low	0.0864 – 0.864	Limited consumption
<0.1	VI	Imperceptible	<0.0864	Very difficult to utilize for local water supply

Table 5: Krasny Classification of Transmissivity Variation

Standard Deviation of Transmissivity Index (Y)	Class of Transmissivity Variation	Designation of Transmissivity Variation	Hydrogeological Environment
< 0.2	A	Insignificant	Homogeneous
0.2 – 0.4	B	Small	Slightly heterogeneous
0.4 – 0.6	C	Moderate	Fairly Heterogeneous
0.6 – 0.8	D	Large	Considerably Heterogeneous
0.8 – 1.0	E	V. large	Very Heterogeneous
> 1.0	F	Extremely large	Extremely Heterogeneous

The values of transmissivity for the study area range between (175.55- 480.72) m^2/day, compared these value with the Krasny transmissivity range values, finding the transmissivity values measuring from Baquba District fall between (100-1000) m^2/day, therefore the study area classifies as a high transmissivity area with groundwater Potential Supply namely (Lesser regional importance). Also, the Large transmissivity variation range between (6.12- 6.76), these values indicated by the standard deviation of the transmissivity index of the studied area which is equal (0.2), this value located with the range (0.2-0.4) Table (5-5), that reflects the aquifer condition varies (slightly heterogeneous) over the study area.

Conclusion

From the present study the following conclusions are derived:

1. The pumping test results showed that the transmissivity (T) values ranged between 124 to 541.35m2/day. The hydraulic conductivity (K) ranged from 7.5 to 25.6 m/day. The specific yield (Sy) ranged from 0.05 to 0.28. The specific capacity (Sc) of the wells ranged from 0.86 to 7.07 l/s with an average of 2.46 l/s.
2. According to transmissivity values and specific capacity the aquifer classify as a high production with slightly heterogeneous.
3. The outcomes of this study have revealed that the Baquba shallow unconfined aquifer has the potential to product effectiveness amounts of water to meet the needs of the population in this region.

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DOI: 10.24237/djes.2020.13204 **eISSN 2616-6909**

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