Hydraulic Properties of Ground Water Aquifers Within Badra Area Northeastern Part of Wassit Governorate/East of Iraq

Al-Kubaisi Y. Qusai
Geology department, College of science, University of Baghdad
Al-Shammary H. Sarteel
College of science, Wassit University
Al-Khafaji K. Ahmed
Geology department, College of science, Uni. of Baghdad

Abstract

Hydraulic analyses were carried out on the region located between latitude 32° 55′N to 33° 20′N, and longitude 45° 50′E to 46° 15′ covered an area about 1868 Km^2.The climate of study area is semi arid to arid. Euphrates, Fatha, Injana, and Mukdadiya Formations rocks are exposed in the study area overlaying by Quaternary deposits. The geomorphologic features of study area are of structural, denudation, fluvial, and flood plain origins. Ground water occurred in two main types of aquifers; the first one is confined aquifer represented by Mukdadiya Formation, the second is unconfined aquifer represented by Quaternary deposits. The direction of ground water flow had been determined from previous study depending on the data of static and dynamic water level gathered from 32 wells represented confined and unconfined aquifers. These data shows that ground water flows from east to west and from north east to south west. Depending on three wells (well 1, well 3, and well 10) and using Theis &Jacob's methods, well test analysis results referred that the transmissivity and storage coefficient ranged between 90.38 to 3208.5 m^2 /day and $1.5*10^{-4}$ to $5.5*10^{-3}$ respectively. The mean value of transmissivity by approximation method for confined aquifer is 72.28 m^2 /day and for unconfined aquifer is 135.41 m^2 /day. Hydraulic conductivity ranged between 1.07 to 11.45 m/day for confined aquifer and 0.103 to 11.34 m/day for unconfined aquifer. Specific capacity ranged between 1.5 to 90.53 for confined aquifer and 2.34 to 240.1 for unconfined aquifer. Specific yield average for unconfined aquifer is 0.0428.Encouraging productivity of the wells requires study the chemical properties of water to be used for many purposes.

Key terms: Aquifer; transmissivity; storage coefficient; hydraulic conductivity; specific yield; specific capacity.

المستخلص

نفذت عملية التحليل الهيدروليكي لمنطقة الدراسة الواقعة بين الإحداثيات الجغرافية 32° 55′شمالا الى 33° 20′ شمالا و45° 50′الى 46° 15′وتغطي مساحة مقدارها 1868 كيلومترا مربعا.مناخ منطقة الدراسة قاحل الى شبه قاحل. تتكشف في منطقة الدراسة صخور اربع تكاوين جيولوجية هي تكوين الفرات والفتحة وإنجانة والمقدادية وهذه التكاوين تكون مغطاة بترسبات العصر الرباعي.الأشكال الجيومورفولوجية للمنطقة ذات اصل تركيبي او فيضي . تتواجد المياه الجوفية في تكوين محصور متمثل بتكوين المقدادية وتكوين غير محصور متمثل بترسبات العصر الرباعي .اتجاه حركة المياه الجوفية حددت من دراسات سابقة إذ أن الإتجاه العام يكون الى الجنوب او الجنوب الغربي. بالإعتماد على البئر رقم 1 و3 و10 وبإستخدام طريقة ثايس و جاكوب فقد اشارت نتائج اختبار الآبار الى ان قيمة الناقلية المائية تتراوح بين 90.38 الى 3208.5متر مربع في اليوم ومعامل الخزن بين 1.5 $*10^{-4}$ الى 5.5 $*10^{-3}$. معدل قيمة الناقلية المائية بإستخدام الطريقة التقريبية للمكمن المائي المحصورهي 72.28 مترا مربعا في اليوم وللمكمن المائي غير المحصور كانت 135.41 مترا مربعا في اليوم.التوصيلية الهيدروليكية تراوحت بين 1.07 الى 11.45 متر في اليوم للتكوين المائي المحصور و0.103 اى 11.34 متر في اليوم للتكوين غير المحصور.السعة النوعية تروحت بين 1.5 الى 90.53 للمكمن المحصور و2.34 الى 240.1 للمكمن غير المحصور . العطاء النوعي للتكوين غير المحصور هو 0.0428 . الإنتاجية العالية لآبار منطقة الدراسة تتطلب دراسة الخصائص الكيميائية لمياه هذه الأبار لغرض ملاحظة ملائمتها للإستخدامات المختلفة.

الكلمات الدالة: التكوين المائي,الناقلية,معامل الخزن,التوصيلية الهيدروليكية,العطاء النوعي , السعة النوعية.

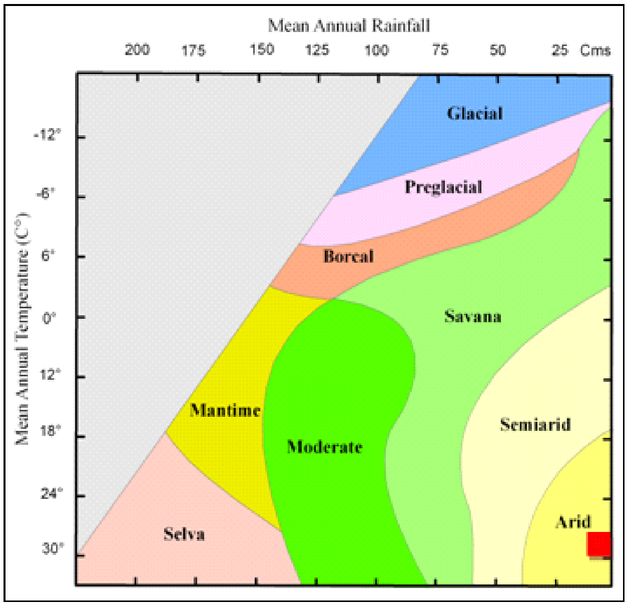
Introduction

Aquifer parameters are used to quantify pumping interference effects and to assist the management of the resource. The purpose of any aquifer test is to determine the hydrogeological parameters. Among the basic parameters are the storativity, transmissivity and leakage coefficient. Evaluation of aquifer parameters, namely, transmissivity T, and storage coefficient S, from aquifer test data has been a continual field research (Birpinar, 2003) .Pumping test may serve two main objectives. Firstly, a pumping test may be performed in order to determine the hydraulic characteristic of the aquifers or water bearing layers. This is called an aquifer test. Secondly, a pumping test may provide information about the yield and drawdown of the well .These data can be used for determining the specific capacity or the discharge-drawdown ratio of the well, such a pumping test called well test (Kruseman and De Ridder, 1991).Because of decreasing in surface water the demand on ground water rising day after day for many purposes whether drinking, agricultural, livestock, and poultry. This study aims to determine the productivity of the wells in the study area by examine hydraulic properties of these wells to see if productivity equivalent to the consumption of water in the region under study.

The study area located in the east part of Iraq between latitude $32^{\circ}\ 55'$ N to $33^{\circ}\ 20'$ N, and longitude $45^{\circ}\ 50'$ E to $46^{\circ}\ 15'$ E, covered an area about 1868 Km^2 as shown in figure 1.Using climate parameters obtained from Badra meteorological station from 1994 to 2005 as shown in table 1 and depending on Al-Kubaisi, 2004 classification the value of aridity index claas1 is equal to 0.75 and the value of aridity index class 2 is equal to 1.18 that means the climate type of the study area is semi arid to arid, this classification depends on precipitation and temperature that measured directly in the field therefore the results of this classification is more reliable. Depending on mean annual temperature and mean annual rainfall the research area lies in the arid region (figure 2).

Table 1: monthly mean climate parameters for Badra area from 1994 to 2005(Enaad.2007).

Monthly mean from 1994 to 2005												Parameters
Sep.	**Aug.**	**Jul.**	**Jun.**	**May**	**Apr.**	**Mar.**	**Feb.**	**Jan.**	**Des.**	**Nov.**	**Oct.**	
0	**0**	**0**	**0.6**	**1.36**	**13.16**	**32.0**	**25.65**	**50.74**	**34.87**	**40.07**	**13.47**	**Rainfall/mm**
32.12	**36.95**	**37.67**	**35.44**	**31.09**	**23.79**	**17.45**	**13.04**	**10.65**	**12.40**	**17.78**	**26.37**	**Temperature/C°**
27.4	**22.7**	**22.4**	**24.1**	**29.9**	**54.8**	**53.1**	**63.8**	**75.7**	**69.9**	**57.7**	**35.7**	**Relative humidity %**
377.85	**484.54**	**511.85**	**470.7**	**370.10**	**242.47**	**169.33**	**91.25**	**60.6**	**67.82**	**122.92**	**252.10**	**Evaporation/mm**
3.18	**3.79**	**3.99**	**3.58**	**3.09**	**3.37**	**3.12**	**2.39**	**2.35**	**1.97**	**2.09**	**2.32**	**Wind speed m/s**


Mean Annual Rainfall
200 175 150 125 100 75 50 25 Cms
Mean Annual Temperature (C°)
-12° -6° 6° 0° 12° 18° 24° 30°
Glacial
Preglacial
Boreal
Savana
Mantime
Moderate
Semiarid
Selva
Arid

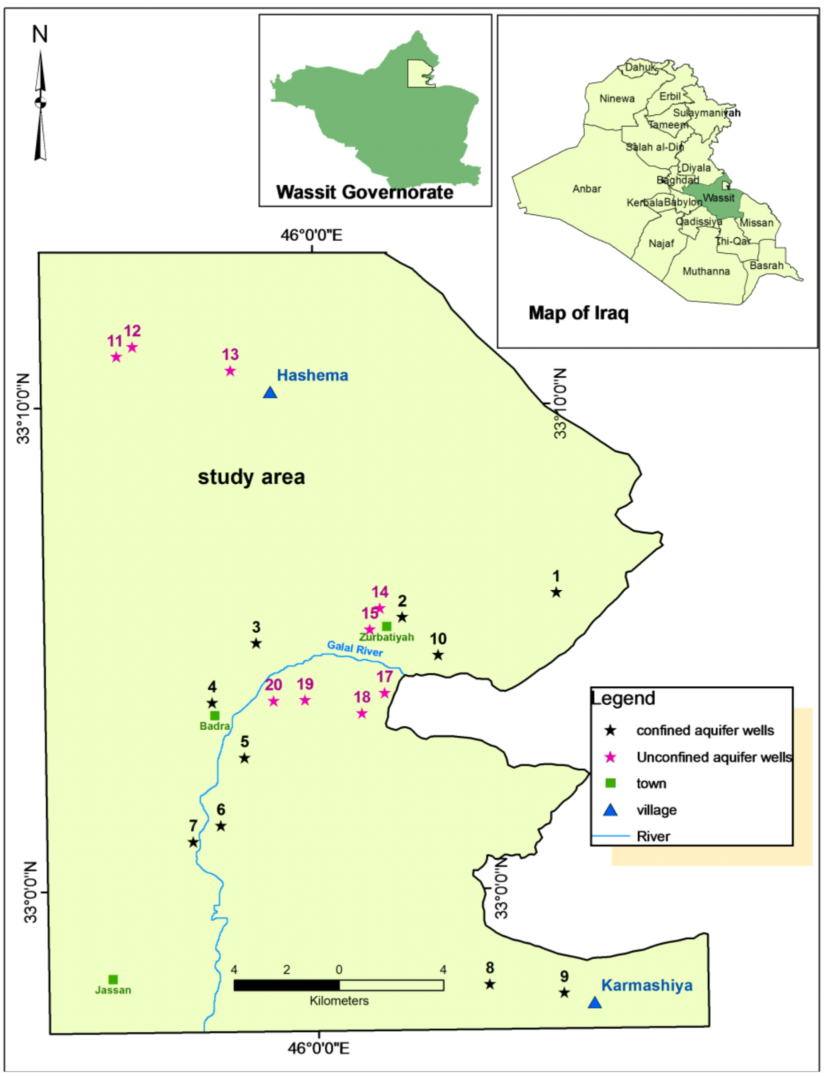

N
Wassit Governorate
Map of Iraq
Dahuk
Ninewa
Erbil
Sulaymaniyah
Tameem
Salah al-Din
Diyala
Anbar
Baghdad
Kerbala
Babylon
Wassit
Qadissiya
Missan
Najaf
Thi-Qar
Basrah
Muthanna
46°0'0"E
33°10'0"N
33°0'0"N
Hashema
study area
Zurbatiyah
Galal River
Badra
Jassan
Karmashiya
Kilometers
4 2 0 4
Legend
confined aquifer wells
Unconfined aquifer wells
town
village
River

Figure 2: Climatic boundaries of the morphogenetic Regions (Peltier, 1950 in Fookes1971)

Figure 1: map showing well sits and the position of study area within Iraq

Geology & Geomorphology of studied area

There are four formations exposed in the study area from tertiary period in addition to Quaternary deposits as they are shown in figure 3: **Euphrates Formation** -late-early Miocene (Burdigalian) was deposited under shallow marine, reef and lagoon conditions with local and lithophyllid reefs and with intermittently occurring fore-reef conditions on one side, and lagoonal conditions on the other side. The formation consist mainly of limestone with texture ranging from oolitic to chalky which locally contain coral and shell coquinas; they are often recrystallized and siliceous. Beds of green marl, argillaceous sandstone, breccias, and conglomerate in addition to conglomeritic limestone also occurs (Al-Mubarek, 1971 and Al-Jumaily, 1974; in Jassim et al., 1984). The thickness of formation in type locality is 8 m but it is increased to 100 meter (Al-Sayab, et al, 1982) the formation exposed at the core of south Hemrin structure at north east of studied area. **Fatha Formation -**Early Miocene composes of anhydrite, Gypsum, and salt interbedded with limestone and marl, it is deposited in evaporite lagoon environment. The thickness of formation in studied area is 237 meter Al-Harbood, 2000), the formation exposed at the core and limbs of south Hemrin anticline at the north east part of studied area. **Injana Formation** -M. Miocene (Tortonian) is essentially composed of mostly red or gray color silty marl or clay stone, the thickness is variable due to the original differences and the erosion (Buday &Jassim, 1980). The thickness of formation in studied area is 618 m (Al- Harbood, 2000).**Mukdadiya Formation** -Late Miocene (messinian) is composed principally of clasitcs, mainly pebbly sandstone, sandstone and red mudstone. The sandstone is often strongly cross bedded. The formation was deposited in fluvial environment (Basi and Jassim, 1973); in Jassim et al 2006. The formation consists of cyclic deposits of clastic materials coarsening upwards. The thickness of the formation reaches (300-1200 m) in studied area, (Enad, 2007).**Quaternary deposits** is comprised of Pleistocene and recent deposits these include alluvium deposits, which consist of a mixture of gravel, sand, silt, clay, and conglomerates of post Pliocene deposits, they show no sign of bedding or stratification (Hamza et al., 1989).

Topographically, the area understudy slopes towards the southwest, where the highest point reaches as much as 95m above sea level and the lowest point is 28m above sea level. The observed geomorphological features seem to be affected by many factors some of which are structural like: Meza, Questa, hogback, the other morphological features come from differential weathering like: pseudo karsts, seasonal river, strike valley and strike hills.

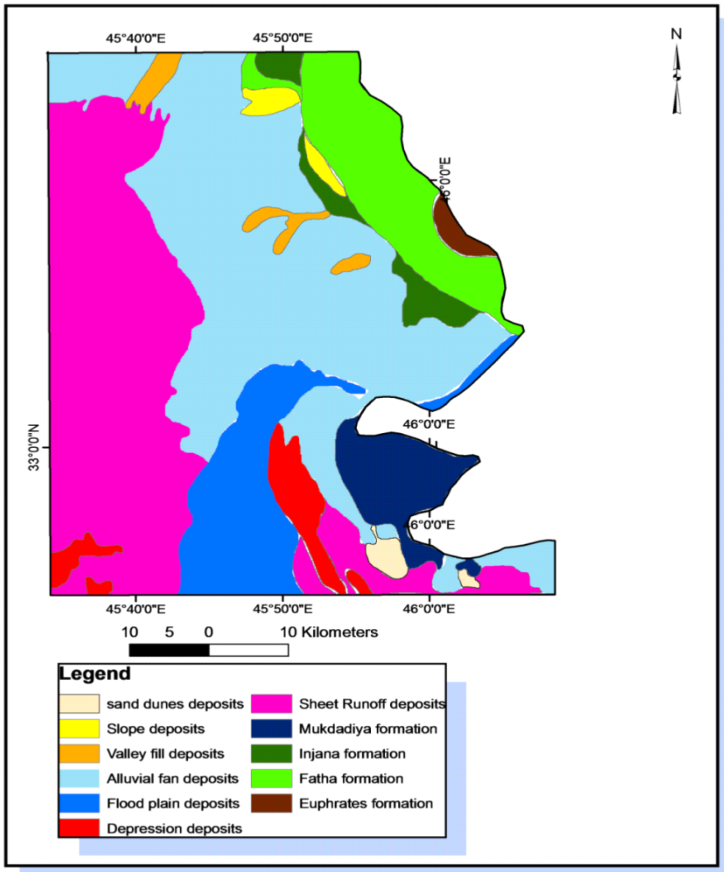


Figure 3: geological map of study area.

Methodology:

Well test data for most of the wells in the study area are available from the field work performed by the staff of the wells drilling company. By analyzed these data hydraulic properties of the main aquifers had calculated using more than one method for data analyses to calculate Transmissivity, storativity, specific yield, hydraulic conductivity, and specific capacity. Depending on the data obtained from Badra meteorological station the type of climate was detected in addition to calculate water surplus and water deficit for the study area.

Results and discussion

Thiem method:

To analyze the data obtained from water wells drilling company the steady state flow condition assumed, hence Thiem equation can be used to calculate transmissivity according the equation bellow (Walton, 1970).

T=K*D=1.22Q/s................................**(1)**

Where:

T = aquifer Transmissivity in (m^2/day), Q = the constant well discharge (m^3/day).

s= the stabilized drawdown (m), D= the saturated thickness of the aquifer (m).

K = hydraulic conductivity of the aquifer (m/day).

Equation (1) expresses that Transmissivity approximately equals the specific yield of the well, i.e. the yield of the well per meter drawdown. A well test can be applied to both confined and unconfined aquifers, but for unconfined aquifers, the corrected draw down $\mathbf{s}^{-}$ must be used (Boonstra and De Ridder, 1981). This phenomenon is called (skin effect), the equation is:

$$\mathbf{T = KD = 1.22Q/ s^{-}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \mathbf{(2)}$$

$$\mathbf{s^{-} = s - (s)^{2}/2D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \mathbf{(3)}$$

Where:

$\mathbf{s}^{-}$ = the corrected drawdown (m)

Transmissivity calculations according to thiem equation are listed in the table 2. average Transmissivity value of approximation method for confined aquifer is 81.07 m^2/day while the average Transmissivity values of approximation method for unconfined aquifer is (228.43) m^2/day as it shows in table 2.

Table 2a: Transmissivity values by approximation method for confined aquifer in the study area.

Confined aquifer				
Transmissivity m^2/day	**Discharge m^3/day**	**Drawdown (s) m**	**Depth to Static water level (m)**	**Well number**
67.32	596.0	10.8	29.0	1
20.38	518.0	31.0	6.0	2
69.03	679.0	12.0	3.0	4
263.5	864.0	4.0	2.0	5
40.15	691.0	21.0	4.0	6
56.75	604.8	13.0	9.0	7
30.20	594.0	24.0	12.0	8
30.96	792.0	31.2	3.0	9

Unconfined aquifer						
Transmissivity m^2/day	**Corrected drawdown (s^{-})**	**Saturated thickness (m)**	**Discharge m^3/day**	**Drawdown (s) m**	**Depth to Static water level (m)**	**Well number**
34.78	17.78	39.5	238.0	52.0	13	11
220.3	5.36	38.5	968.0	5.8	9.2	12
362.88	3.92	32.0	1166.0	4.2	6.0	13
163.01	5.83	14.5	779.0	20.9	2.1	14
147.74	3.27	11.0	396.0	4.0	6.0	15
64.46	9.81	51.0	518.4	11.0	9.0	17
100.83	8.99	40.5	743.0	10.3	5.0	18
117.41	8.08	44.0	777.6	9.0	6.0	19
7.57	27.37	73.4	170.0	36.4	3.6	20

Table 2b: Transmissivity values by approximation method for unconfined aquifer in the study area.

Theis method:

Before starting pumping test operation many things should be prepared like: the depth of pumping and observations well and the distance between tested well and the pizometers, the rate of pump. The characteristic of the wells of study area are listed in table 3.

Table 3: characters of pumped and observed wells in the study area.

Distance between pumped and observed well r (m)	Discharge(m^3/day)	Pumping time (min)	Total drawdown (m)	Observation well water depth (m)	Pumping well water depth (m) (Static)	Observation well depth (m)	Pumping well depth (m)	Well Name
21.5	604.8	180	0.13	27.2	29	45	60	Daraji(W.No. 1)
25	432	165	0.081	0.0	0.0	60	60	Dahnook(W.No.3)
26.5	950.4	180	3.55	2.71	3	48	60	Karmashiya(W. No.10)

By using the data of pumping test performed in three selected wells 1, 3, and 10 (Al-Furat Center, 2002). The data that listed in table 4 were plotted on logarithmic paper(with the same scale as that used for the type curve, drawdown versus time (or drawdown versus t/r^2) then this plot was superimposed on thies type curve of W(u) versus 1/u which is plotted on a double logarithmic paper as in figure 4. The values of drawdown, time, W (u), and 1/u were substituted in the equations 4 and 5 to solve transmissivity and storage coefficient.

$$\mathbf{T = Q\,W(u) / 4\pi s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(4)}$$

$$\mathbf{S_c = (4\,T\,t\,u) / r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(5)}$$

Where:

T = transmissivity (m^2/day), S_c = storage coefficient (unit less).

Q = the pumping rate (m^3/day), s = drawdown (m).

t = the time (day), r = the distance from the pumping well to observation well in (m).

W (u) = the well function of u, u = $(r^2/S)/ (4* T* t)$.

The low values of drawdown in table 4 due to the high productivity of the wells as well as to the narrow diameters of the pipes that supplied by the wells in order to regulate the amount of water used by the farmers or any other users in the study area.

Table 4: pumping test data for the wells 1, 3, and 10 (Al-Furat Center, 2002).

Daraji well(No.1)			**Dahnook well(No.3)**			**Kirmashiya well(No.10)**		
Drawdown in observation well (m)	**Water depth in observation well (m)**	**Time (min)**	**Drawdown in observation well (m)**	**Water depth in observation well (m)**	**Time (min)**	**Drawdown in observation well (m)**	**Water depth in observation well (m)**	**Time (min)**
0.07	**27.27**	**1**	**0.0**	**0.0**	**0**	**0.33**	**3.04**	**1**
0.087	**27.287**	**2**	**0.02**	**0.02**	**1**	**0.58**	**3.29**	**2**
0.092	**27.292**	**3**	**0.025**	**0.025**	**2**	**0.79**	**3.5**	**3**
0.095	**27.295**	**4**	**0.03**	**0.03**	**3**	**0.95**	**3.66**	**4**
0.1	**27.3**	**6**	**0.04**	**0.04**	**4**	**1.08**	**3.79**	**5**
0.11	**27.306**	**10**	**0.045**	**0.045**	**5**	**1.3**	**4.01**	**7**
0.11	**27.31**	**15**	**0.05**	**0.05**	**10**	**1.54**	**4.25**	**10**
0.115	**27.315**	**20**	**0.05**	**0.05**	**17**	**1.71**	**4.42**	**12**
0.117	**27.317**	**25**	**0.055**	**0.055**	**20**	**1.88**	**4.59**	**15**
0.12	**27.42**	**30**	**0.058**	**0.058**	**25**	**2.1**	**4.81**	**20**
0.125	**27.427**	**45**	**0.062**	**0.062**	**30**	**2.2**	**4.91**	**25**
0.127	**27.429**	**60**	**0.065**	**0.065**	**35**	**2.41**	**5.13**	**30**
0.129	**27.43**	**75**	**0.065**	**0.065**	**45**	**2.52**	**5.23**	**35**
0.13	**27.43**	**90**	**0.07**	**0.07**	**60**	**2.62**	**5.33**	**40**
0.13	**27.43**	**120**	**0.075**	**0.075**	**75**	**2.69**	**5.4**	**45**
0.13	**27.43**	**150**	**0.078**	**0.078**	**90**	**2.78**	**5.49**	**50**
0.13	**27.43**	**180**	**0.08**	**0.08**	**105**	**2.89**	**5.6**	**60**
			0.081	**0.081**	**120**	**2.99**	**5.7**	**70**
			0.081	**0.081**	**135**	**3.09**	**5.8**	**80**
			0.081	**0.081**	**150**	**3.16**	**5.87**	**90**
			0.081	**0.081**	**165**	**3.21**	**5.92**	**100**
						3.29	**5.98**	**110**
						3.32	**6.03**	**120**
						3.39	**6.1**	**135**
						3.46	**6.17**	**150**
						3.51	**6.22**	**165**
						3.55	**6.26**	**180**

After matching operation (figure 4) and extraction the required parameters from the plots which are the draw down, time, and well functions (Wu, 1/u) transmissivity and storage coefficient can be determined as shown in table 5.

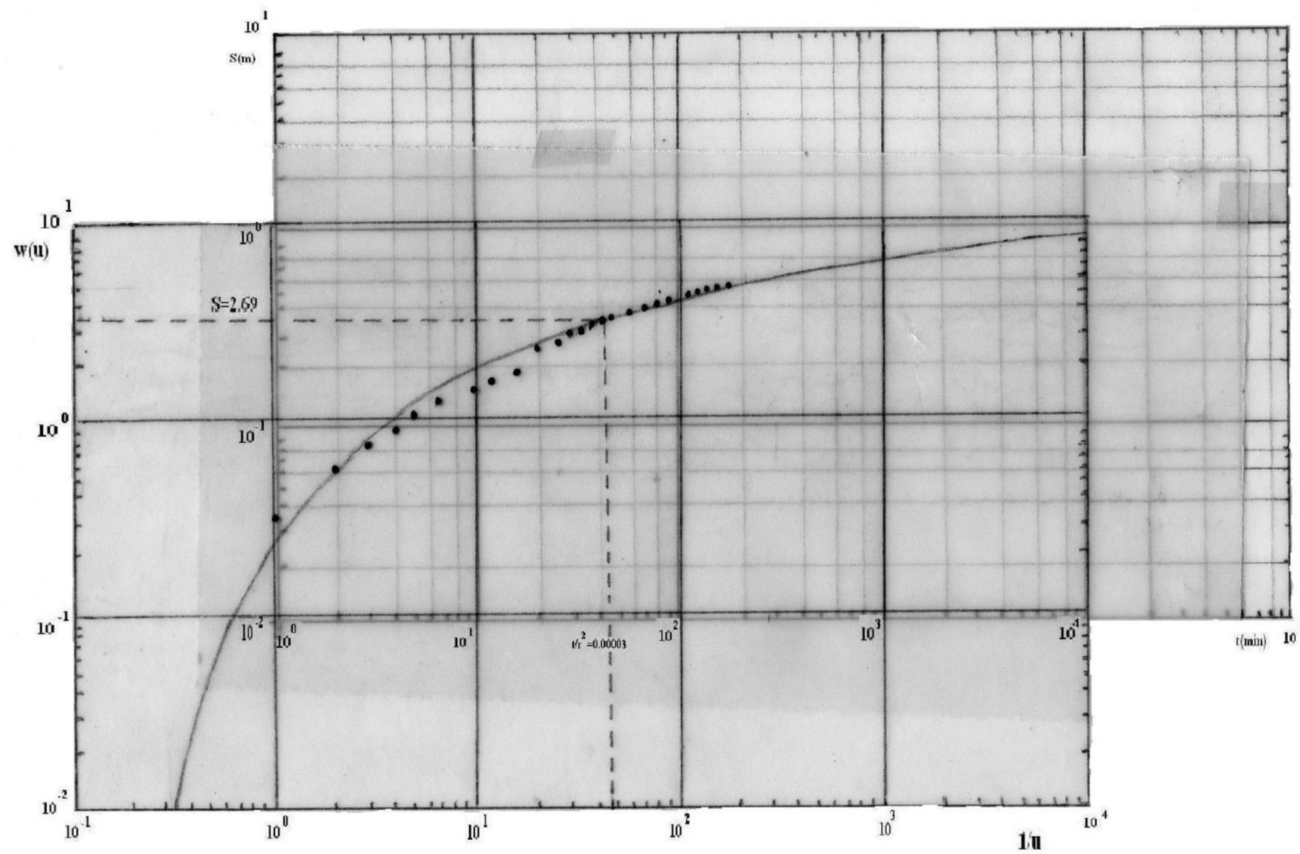


Figure 4: Analysis of data from pumping test well 10 (Karmashiya) with the Theis method

Table 5: Hydraulic parameters value for wells (1, 3, 10) using Theis method.

S_c	T M^2/day	Q m^3/day	W(u)	u	1/u	r (m)	t (day)	t(min)	s (m)	Well Name	Well no.
$1.5x10^{-4}$	3208.5	604.8	8.0	0.00035	3100	21.5	0.02	30	0.12	Daraji /2	1
$1.5x10^{-3}$	2643.5	432	5.0	0.003	280	25	0.031	45	0.065	Dahnook/1	3
$3.3x10^{-4}$	90.0	950.4	3.2	0.023	42	26.5	0.031	45	2.69	Karmashiya/ 1	10

Jacob method:

In this method the same condition as for Thies method will be considered in addition to the value of u is that will be satisfied in confined aquifer for small distance of r then small value of t but fro unconfined conditions the time mat take large value (Kruseman and De Ridder, 1991).By plotting the information in table 4 on a single logarithmic paper (t on a logarithmic scale). To determined T and S the required parameters are t, s, $t_{o,}$ and Δs are extracted from plots as they shown in figure 5 and substituted in the equations 6 &7.

$$T= 2.30\ Q/ 4\pi\Delta s \quad =0.183\ Q/\Delta s \ \ldots\ldots\ldots\ldots\ldots\ (6)$$
$$S_c= 2.25\ T\ t_o/ r^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

Where:
Q = rate of discharge measured in (m^3/day), Δs= difference of drawdown per log cycle (t) measured in (m).
t_o= the intercept of the straight line extend with the time axis, S_c= storage coefficient.
After plotting field data on cooper- Jacob's graph (figure 5) the value of transmissivity and storativity are listed in table 6.

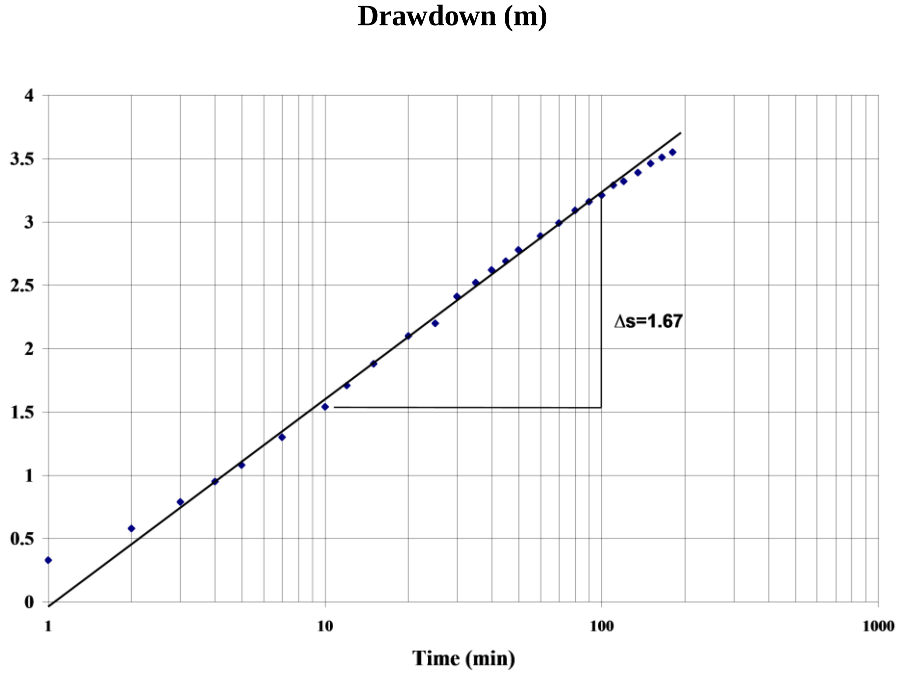


Figure 5: Analysis of pumping test data for the well 10 (Karmashiya) using Cooper - Jacob method

Table 6: Hydraulic parameter values for (well 1), (well 3) and (well 10) using Cooper -Jacob method.

S_c	T(m^2/d	Q(m^3/d)	r (m)	t_o (day)	t_o(min)	Δs (m)	Well Name	Well No.
$5.5x10^{-3}$	2768.78	604.8	21.5	0.00041	0.6	0.04	Daraji/2	1
$1.7x10^{-3}$	2400	432.0	25.0	0.0002	0.35	0.033	Dahnook/1	3
$2.4x10^{-4}$	104.77	950.4	26.5	0.00069	1.0	1.6	Karmashiya/1	10

8The values of hydraulic parameters obtained from Jacob's method are more reliable than of Thies's method because the practical approach is in using Jacob straight line method which is a graphical method using semi logarithmic paper and Theis equation. This is from the fact that under ideal conditions the plot of data is along a straight line rather than along a curve shape when evaluating the results of an aquifer test (Moore, 2002).

Van der Van method:

The storage coefficient is a function of the depth and thickness of the aquifer, its order of magnitude can also be estimated, using the following equation, for confined aquifer (Van der Van, 1979) in (Boonstra and De Ridder, 1981):

$$\mathbf{S_c = 1.8 \times 10^{-6} (d_2-d_1) + 8.6 \times 10^{-4} (d_2^{0.3} - d_1^{0.3})}\text{………}\mathbf{(8)}$$

Where:

S_c= storage coefficient (unit less), d_1= depth of the upper surface of the aquifer in meter.
d_2= depth of the lower surface of the aquifer in meter.
The values of storage coefficient by Van der Van formula is showing in table (7).

Table 7: Storage coefficient by using Van der Van (1979) formula:

Storage coefficient	d(2)in meter	d(1) in meter	well number
$4.75X10^{-4}$	30	15	1
$1.17X10^{-4}$	85	77	2
$1.04X10^{-4}$	59	16	3
$4.37X10^{-4}$	64	40	4
$4.91X10^{-4}$	46	25	5
$3.17X10^{-4}$	80	59	6
$3.81X10^{-4}$	54	35	7
$4.4X10^{-4}$	56	34	8
$4.4X10^{-4}$	56.5	34	9

Storage coefficient values that determined by (Van der Van) formula and those determined by Theis and Cooper-Jacob methods for the wells (1, 2, 3, 4, 5, 6, 7, 8, and 9) are closed to each other.

Hydraulic Conductivity:

Hydraulic conductivity considered as a function of the properties of the medium and properties of the fluid (Genetti, 1999). It depends on a variety of physical factors, including porosity, (size distribution, shape, and arrangement) of particles. It determined from the equation bellow.

$$\mathbf{K= T / D}\text{…………………………………}\mathbf{(9)}$$

Where:

K= hydraulic conductivity of the aquifer (m/day), T= Transmissivity in (m^2/day)
D = saturated thickness of the aquifer which is penetrated by the well in (m)
Table 8 showing the values of hydraulic conductivity of the aquifers in the study area using equation 9 .The mean hydraulic conductivity for the confined aquifer is 3.5 (m/day) and the mean hydraulic conductivity for unconfined aquifer is 6.3 (m/day). The low values of hydraulic conductivity in some locations (wells), caused by the clay content within the lithology of the aquifer which consists of mixture of gravel, sand, silt and clay.

Table 8: Hydraulic conductivity values for aquifers in the study area.

Hydraulic Conductivity (m/day)	Saturated thickness (m)	Transmissivity (m^2/day)	Well No.
Confined aquifer			
2.171	31.0	67.32	1
2.547	8.0	20.38	2
2.876	24.0	69.03	4
11.45	23.0	263.5	5
1.912	21.0	40.15	6
2.986	19.0	56.75	7
1.078	28.0	30.20	8
1.407	22.5	30.96	9
Unconfined aquifer			
0.413	39.5	16.33	11
4.326	50.0	216.3	12
11.34	32.0	362.88	13
11.24	14.5	163.01	14
13.43	11.0	147.74	15
1.264	51.0	64.46	17
2.52	40.5	100.83	18
2.668	44.0	117.41	19
0.103	73.4	7.57	20

Specific Capacity:

The specific capacity values are not constant for wells in unconfined aquifers, because an increase in drawdown at the same time decreases the effective thickness of the aquifer. Thus even discounting energy losses at the well, the specific capacity would decrease with discharge for the water table case (Soliman, 1984). Specific capacity expresses the productivity of the productive well and decreases with the period of pumping because the drawdown continually increases with time (Walton, 1970).

Specific capacity is the ratio of the obtained rate of the discharge to the drawdown (Fetter, 1994):

$$\mathbf{SC = Q / s} \quad \text{..} \quad \mathbf{(10)}$$

Where:

SC= specific capacity measured in (m^3/day/m), Q= constant discharge measured in (m^3/day)

s= total drawdown in the well measured in meter

According to Alsawaf (1977), the specific capacity depends on the saturated thickness of aquifer:

$$\mathbf{SC = DQ / [(TD\text{-}SWL)s\ ]} \quad \text{..................................} \quad \mathbf{(11)}$$

Where:

SC= specific capacity of well measured in (m^2/day)

D = saturated thickness of the aquifer which is penetrated by the well and measured in meter

Q= constant rate discharge from the well, measured in (m^3/day)
TD= total depth of the well penetrated the aquifer, measured in meter
SWL= static water level measured in meter, S_w= total drawdown in the well, measured in meter.
According to the equations 10 and 11 specific capacity values are calculated and listed in the table 9.

Specific Yield:

The specific yield refers to the unconfined parts of an aquifer .The storage coefficient for an unconfined aquifer corresponds to its specific yield (Todd, 2005). Estimation of specific yield depending on the saturated thickness can be found by Johnson equation (Johnson, 1955):

$$S_Y = D / 1000 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Where:
S_Y= specific yield (unit less), D= saturated thickness measured in meter.
Equation (12) was used to determine S_Y values for the unconfined selected wells in the study area, the results shown in table (10). The mean specific yield for the area of study is about (0.041).

Table 9: specific capacity values for aquifers in the study area.

SC= DQ / [(TD-SWL)s_w]	SC by(Q/ s_w) in(m^2/d)	(TD-SWL)	s (m)	SWL (m)	TD (m)	D (m)	Q m^3/day	Well No.
Confined aquifer								
55.18	55.18	31	10	29	60	31	551.8	1
1.5	16.71	89	31	6	95	8	518	2
20.26	56.58	67	12	3	70	24	679	4
95.53	216	52	4	2	54	23	864	5
8.64	32.91	80	21	4	84	21	691.2	6
17.33	46.52	51	13	9	60	19	604.8	7
11.94	24.75	58	24	12	70	28	594	8
10.02	25.54	57	31	3	60	22.5	792	9
Unconfined aquifer								
2.34	4.57	77	52	13	90	39.5	238	11
113.12	166.9	56.8	5.8	9.2	66	38.5	968	12
240.1	277.62	37	4.2	6	43	32	1166	13
22.78	37.27	22.9	20.9	2.1	25	14.5	779	14
45.37	99	24	4	6	30	11	396	15
42.13	47.12	57	11	9	66	51	518.4	17
60.65	60.65	74.3	10	5	54	40.5	743	18
79.2	86.4	48	9	6	54	44	777.6	19
3.92	4.72	88.4	36	3.6	92	73.4	170	20

Table 10: Specific yield values of the unconfined aquifer for studied area

S_Y Specific yield	D Saturated thickness (m)	Well No.	S_Y Specific yield	D Saturated thickness (m)	Well No.
0.041	41.0	23	0.039	39.5	11
0.051	51.0	25	0.038	38.5	12
0.040	40.5	26	0.032	32.0	13
0.044	44.0	27	0.014	14.5	14
0.038	38.0	28	0.011	11.0	15

Water Surplus (Ws) and Water Deficit (WD):

Water surplus means that the values of rainfall are greater than the potential evapotranspiration during a given period, while the water deficit means that potential evapotranspiration is greater than the rainfall. The actual evapotranspiration (AE) could be derived from the potential evapotranspiration (PE) and rainfall (P) (Lerner et al, 1990), as follows:

$$AE = PE \quad \text{when} \quad P>PE, \quad AE = P \quad \text{when} \quad P<PE$$

By using the Thornthwait method for determined (PE), the values of water surplus were determined for the period (1994 – 2006).Water surplus period (November – March) and water deficit period (April – October).

Table 11: Water Surplus and Deficit for Badra meteorological station (1994-2006)

WD (mm)	WS(mm)	AE(mm)	PE(mm)	P (mm)	parameters Months
80.24		13.47	93.71	13.47	Oct.
	14.4	26.3	26.3	40.7	Nov.
	25.78	9.09	9.09	34.87	Dec.
	44.77	5.97	5.97	50.74	Jan.
	15.12	10.53	10.53	25.65	Feb.
	2.4	29.60	29.60	32.0	Mar.
64.21		13.16	77.37	13.16	Apr.
184.78		1.36	186.14	1.36	May
265.67		7.0	272.67	7.0	Jun.
331.17		0.06	331.23	0.06	Jul.
365.34		0	365.34	0	Aug.
175.21		0	175.21	0	Sep.
1466.62	102.47	116.54	1583.16	212.61	Total

Conclusion

Pumping test analysis for three wells in three different locations reflected values of transmissivity ranged from 90.03 to 3210.1m^2/day and storage coefficient values ranged from $1.1x10^{-4}$ to $1.5x10^{-3}$. Average transmissivity value of approximation method for confined aquifer is (81.07) m^2/day while the average transmissivity value of approximation method for unconfined aquifer is (228.43) m^2/day. Hydraulic conductivity for confined aquifer ranged from1.078 to 4.80 m/day and 0.103to 45.024 m/day for unconfined aquifer. Specific capacity values ranged from 16.71to 216 m^3/day for confined aquifer and 4.57to1555 m^3/day for unconfined aquifer. Specific yield for unconfined aquifer is (0.01to 0.073), mixture of clay, silt, sand, and gravel in the lithology of aquifers affected and reduced the hydraulic properties of the aquifers. . Both of water surplus and water deficit are forming (46.81 %) and (53.19 %) respectively assuming the soil moisture equal to zero.

References

- Al-Kubaisi, Q.Y., 2004,Annual aridity index of type 1 and type 2 mode option for climate classification , Iraq jour. Sci. 45C, No1, pp32-41.
- Al-Harbood, H. A, 2000, Study of Land Forms, Wassit Government, M. Sc. Thesis, Baghdad University, unpublished.
- Al -Furat Center Company for study and design irrigation projects, 2002, Hydrogeological Investigations, Fifth order, Badra-Jassan Area, Wassit, Iraq, Final Report, 67 p.
- Al-Sayab, A., Al-Ansari, N., Al-Rawi, D. ,Al-Jassim, J., Al-Omari, F., Al-Shaikh, Z, 1982, Geology of Iraq , Mosul University print,277P. (In Arabic).
- Al-Sawaf, F. D.S., 1977, Hydrogeology of South Sinjar Plain, Northwest Iraq. Unpublished Ph. D. thesis, University of London.370 P.
- Boonstra, J. and De Ridder, N.A., 1981, Numerical modeling of groundwater basins, ILRI Publication 29, ILRI, Netherlands, 226p.
- Enad, T. H., 2007, Stratigraphic and sedimentologic study of the Mukdadiya Formation in Badra area Wassit Provenance, M. Sc. Thesis, Baghdad University unpublished, 136p.
- Fetter, C.W., 1994, Applied hydrogeology, 3rd edition prentice-Hall, Inc., New Jersey, 691p.
- Fookes, P. G., Dearman, W.R. and Franklin, J.A., 1971.Some engineering aspects of rock weathering with field examples from datmoor and elsewhere Q.J. Eng Geol., Vol.4, 139-185p.
- Genetti, A. J., 1999, Engineering and Design Groundwater Hydrology, Department of Army, U.S. Army Corps of Engineer, Washington, DC.20314-1000, Manual No. 1110-2-1421, 118p.
- Hamza, N. M. and Domas, J., 1980**,** the Geology of the Adhaim Area, S. Co. G. S.
- Jassim.S.Z. Karim, S.A., Basi, M., Al-Mubarak, M. A. and Munir, J., 1984. Final report on the regional geological survey of Iraq.vol.3, stratigraphy, manuscript report, geologic survey of Iraq.
- Jassim, Saad Z. and Jeremy C. Goff. (2006): Geology of Iraq, published by Dolin, Prague and Moravian Museum, Brno. , 400P.
- Johnson, E. E., 1955, Groundwater and Wells, E. E. Johnson, Inc. Saint Paul. Min.,
- Kruseman, G. P. and De Ridder, N. A., 1991, Analysis of evaluation of pumping test data, int. Inst. For land reclamation and improvement, Nether land 209 p.
- Lerner, N. D., Issar, A. S., Simmers, I., 1990, Groundwater Recharge-A Guide to Understanding and Estimating Natural Recharge, Vol.8, Association of Hydrogeologist, Hanover, ISBN 3-922705-91-X.
- Moore, J. E. (2002) Field Hydrogeology , A Guide for Site Investigations and Report Preparation, by CRC Press LLC / CRC Press Web site at www.crcpress.com
- Mehmet E. Birpinar, 2003, Aquifer parameter identification and interpretation with different analytical methods. Water SA Vol. 29 No. 3.
- Soliman, M. M., 1984, Groundwater management in Arid Regions, Ain Shams University, Egypt, Vol.1, 276 p.
- Todd, D. K., and W.M. Larry, 2005 “Groundwater Hydrology” 3rd Edition. John Wiley &Sons, Inc. USA, 636 p
- Walton, C. W., 1970, Groundwater Resources Evaluation, McGraw Hill Co., 664 p.