HYDRAULIC PARAMTERS OF GROUNDWATER AQUIFERS IN KHANAQIN BASIN

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ABSTRACT

Estimating the physical properties of water-bearing layers is an essential part of groundwater studies. One of the most effective ways of determining these properties is to conduct and analyze aquifer tests. The aim of this research is to carry out hydrogeological investigation in Khanaqin basin within Diyala Governorate in the east of Iraq to calculate hydraulic parameters of the most important product groundwater aquifers. Cooper-Jacob and Theis Recovery test methods were used to calculate transmissivity and storage coefficient after field investigation of aquifers extended in the basin. The geographical position, elevations, static water levels, depths, thicknesses and maximum yields were carried out during field work. The results showed that Khanaqin basin has two geological units represented by unconfined and confined aquifers, where (4) wells were used in pumping test. The average transmissivity parameter was ranged between (273-4590 m^2/day) in unconfined aquifer while this range was (14.97-249.35 m^2/day) in confined aquifer. Transmissivity contour map indicated increasing value of this parameter towards northern west direction of the Khanaqin basin. Storage coefficient ranged between $(3.5*10^{-5})$ to $(1.14*10^{-3})$. The increasing of transmissivity parameter as groundwater movement generally flow towards the northern west leading to increase groundwater discharge from wells penetrate unconfined and confined aquifers.

Keywords: *Groundwater Aquifers, Hydraulic Parameters, Khanaqin Basin.*

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1. INTRODUCTION

Worldwide, more than a third of all water used by humans comes from ground water. In rural areas the percentage is even higher: more than half of all drinking water worldwide is supplied from ground water [1]. The continuing of groundwater extraction from the aquifers for all purposes is contributing to groundwater depletion in many parts of world [2]. Estimating the physical properties of water-bearing layers is an essential part of groundwater studies. One of the most effective ways of determining these properties is to conduct and analyze changing, with time, water levels (or total heads) of aquifers caused by withdrawals through wells [2]. This type of study is referred to as an aquifer test and, in most cases, includes pumping a well at a constant rate for a period ranging from several hours to several days and measuring the change in water level in observation wells located at different distances from the pumped well [3].

Analyzing and evaluating aquifer test data is as much an art as a science. It is a science because it is based on theoretical models that the geologist or engineer must understand and on thorough investigations that he must conduct into the geological formations in the area of the test. It is an art because different types of aquifers can exhibit similar drawdown behaviors, which demand interpretational skills on the part of the geologist or engineer [4].

The study area is located in Diyala Governorate in the east of Iraq and bordered by Iraqi - Iranian borders from the east and Diyala river from the west while Nadoman anticline fold and Bernand mountain chain surrounding the basin from south and north respectively. The area covers 1920 km^2 within (45º 10'- 45 º 45') E and (34 º 10 ' - 34 º 45') N, figure (1).

The work plan in the studied area included the following items:
1- Office work including preparing data and preliminary information of the area (wells stratigraphic columns, maps, literature reviews, scientific references, hydrogeological data bank).
2- Field work including:
- Inventory of water wells and measuring water levels in the wells as well as determine geographical positions and levels of (43) water points.
- Drilling of (4) wells of (190-300) meters depths and (4) monitoring wells with (30-50) meters distance to pumping wells respectively to evaluate hydraulics properties through pumping test process. These wells were drilled in cooperation with general commission of groundwater and the farmers owning these wells.
- Pumping test in (4) wells.

The aim of this research is to carry out hydrogeological investigation in Khanaqin basin within Diyala Governorate in the east of Iraq to calculate hydraulic parameters of the most important product groundwater aquifers in order to achieve optimum use of groundwater in term of sustainable water management.

2. GEOLOGICAL SETTING:

Khanaqin basin is built up by geological formations ranging in age from upper Jurassic up to Recent. Main ridges provide long wide water sheds to the internal plains and also of second order sheds, figure (2) [6]. The main Stratigraphic sequence in the basin consists of Avanah, Oligocene group, Euphrates-Jerebi, Fatha, Injana, Mukdadiyah, Bai Hassan, Bamu Conglomerate formations and Quaternary deposits as shown in figure (3) [6].
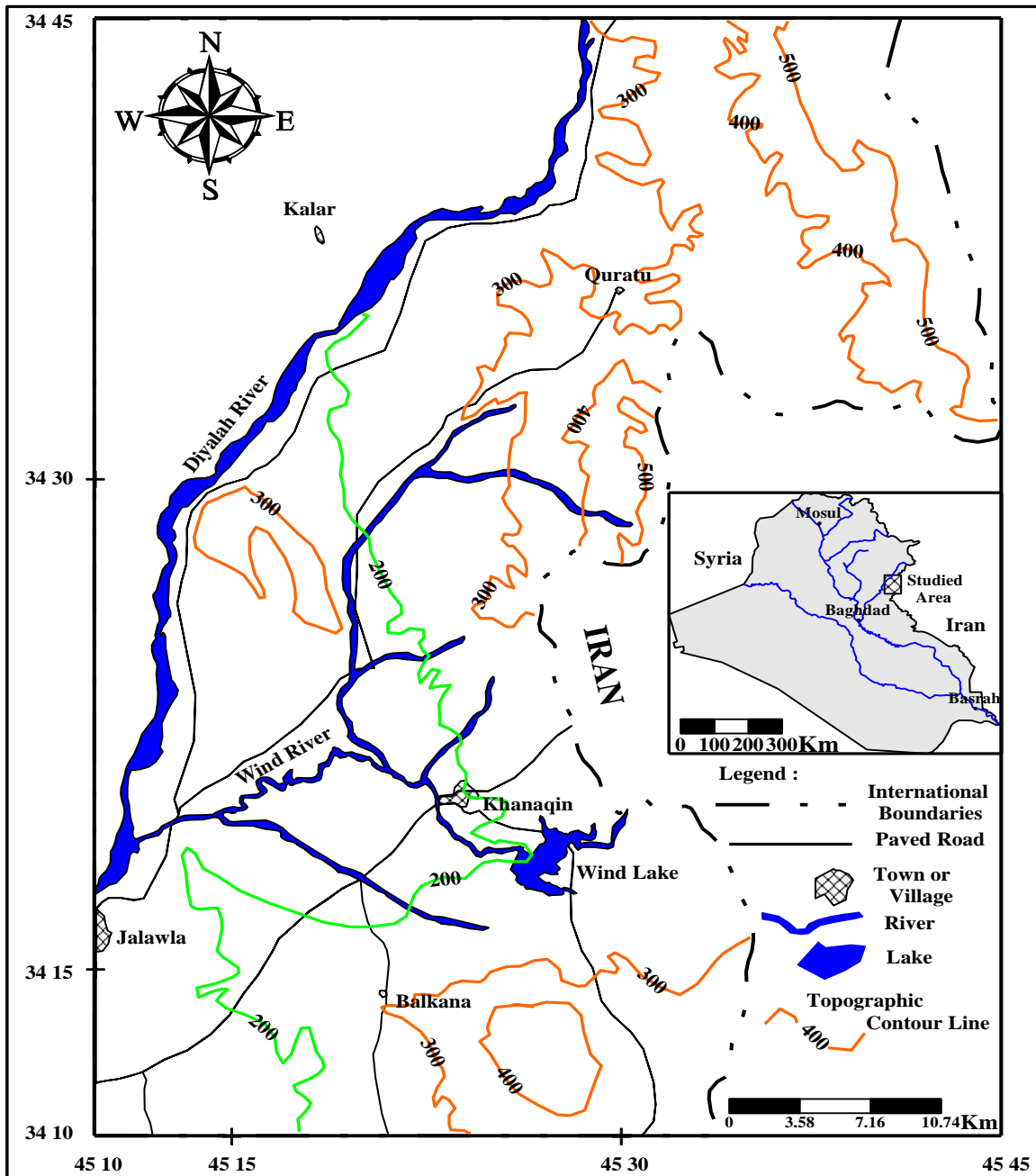
Figure 1: Location and Topography Map of Khanaqin Basin [5]

Structurally, the area is a part of two zones, the High Folded Zone (north eastern part), and the majority of the area belongs to Foot-hill zone of the Unstable Shelf at Nubio-Arabian Platform. Tectonically, the Foot-hill zone here is divided into Hemrin-Makhul and Chemchemal-Butmah subzones. Chia Surakh, Ali Mire, Kiria Pika, Pulkhana, Naodoman are the main structural elements, they are asymmetrical and thrusted anticlines, separated by broad and asymmetrical synclines filled by Tertiary sediments [7].
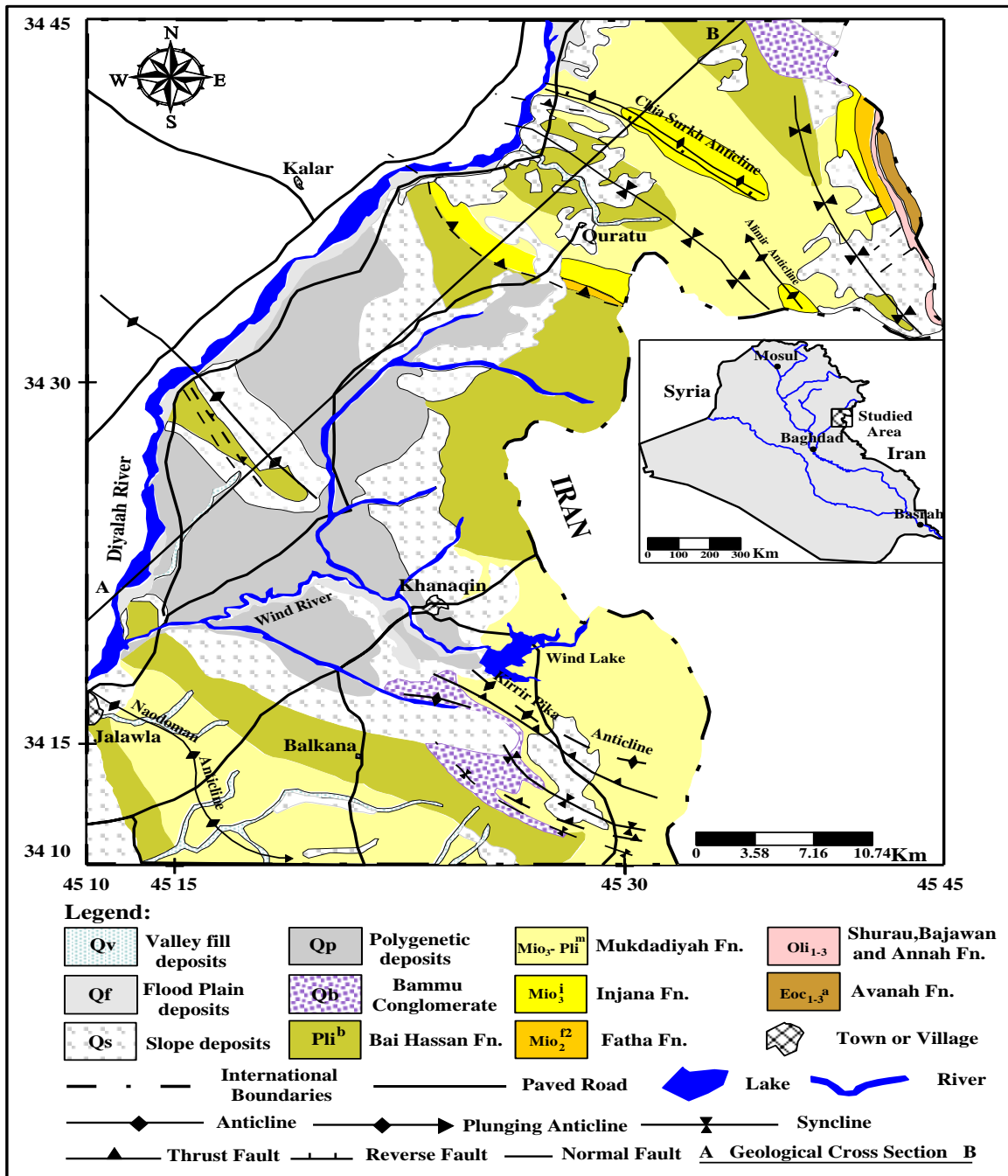
Figure 2: Geological Map of Studied Area [6].

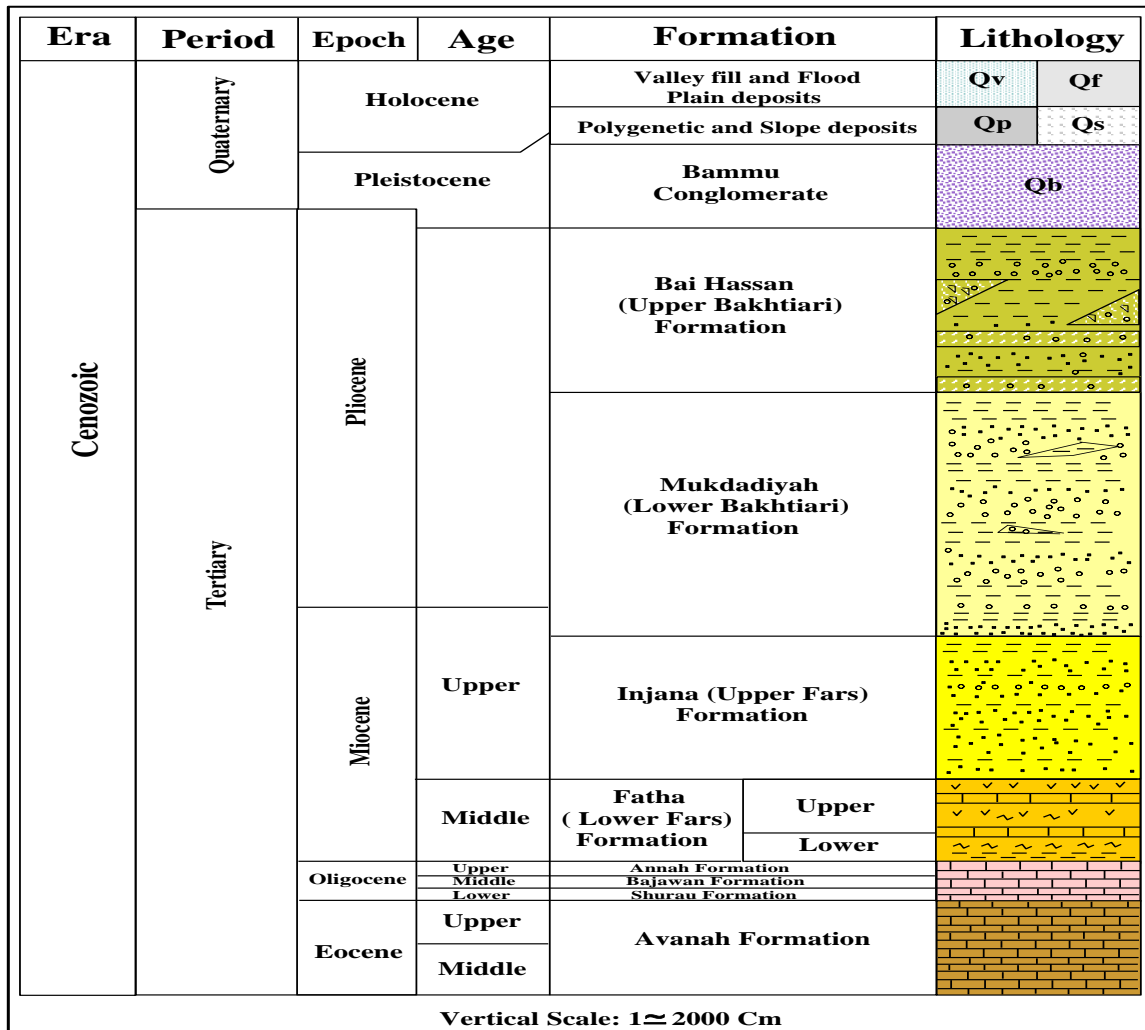| Era	Period	Epoch	Age	Formation		Lithology	
Cenozoic	Quaternary	Holocene		Valley fill and Flood Plain deposits		Qv	Qf
				Polygenetic and Slope deposits		Qp	Qs
		Pleistocene		Bammu Conglomerate		Qb	
	Tertiary	Pliocene		Bai Hassan (Upper Bakhtiari) Formation			
				Mukdadiyah (Lower Bakhtiari) Formation			
		Miocene	Upper	Injana (Upper Fars) Formation			
			Middle	Fatha (Lower Fars) Formation	Upper		
					Lower		
		Oligocene	Upper	Annah Formation			
			Middle	Bajawan Formation			
			Lower	Shurau Formation			
		Eocene	Upper	Avanah Formation			
			Middle				

Vertical Scale: 1 ≅ 2000 Cm

Figure 3: Geological Formations Sequence in Study Area [6].

3. MATERIALS:

1- Topographic maps at a scale of 1:250000 used in field investigation.

2- GPS device to determine wells locations and elevations of wells.

3- Stratigraphic sheets and hydrogeological data bank [8].

4- Cooper - Jacob and Theis Recovery Test equations.

5- Mathematical programs (Grapher and Surfer) in analyzing data and information obtained from pumping test and draw contour map.

4. METHODOLOGY:

Depending on (43) inventoried wells and (65) wells obtained from hydrogeological data bank, the stratigraphic sheets of these wells had been compared with figure (3), and taking into consideration the groundwater levels measured in these wells as well as types of water bearing layers; the geological units were divided into unconfined and confined aquifers. The aquifers were investigated during field work where geographical position, elevations, static water levels, depths, thicknesses and maximum yields. The methodology depends on using (Cooper-Jacob, 1946) [9], and Theis

Recovery Test (Theis, 1935) [10] methods to calculate hydraulics parameters of groundwater aquifers. The mathematical programs (Grapher and Surfer) were used to demonstrate the calculated results and draw contour map.

5. RESULTS AND DISCUSSION:

Depending on (43) inventoried wells and (65) wells obtained from hydrogeological data bank, only (90) wells were used according to available information in each well. The results showed that (38) wells belongs to unconfined aquifer while (52) wells belong to confined aquifer, figure (4).

5.1 Hydrogeological Properties of Unconfined Aquifer:

The geological formations distributed and exposed in Khanaqin basin as shown in figure (2) determined the types of aquifers where unconfined aquifer composite of Quaternary deposits, Bai Hassan and Mukdadiyah formations according to their exposure on surface.

Both Bai Hassan and Mukdadiyah formations exposed in specific locations within the basin, producing the unconfined aquifer. in another hand, whenever Bai-Hassan formation overlying Mukdadiyah formation turned the last one into confined aquifer combined with Injana formation. Table (1) shows the statistical data of hydrogeological properties of unconfined aquifers.

5.2 Hydrogeological Properties of Confined Aquifer:

Table (2) shows the statistical data of hydrogeological properties of confined aquifer which mainly consist of Mukdadiyah (in specific locations) and Injana formations according to lithological columns of wells investigated in area.

5.3 Hydraulic Parameters Calculation:

The principle of an aquifer test is simple: water is pumped from a well tapping the aquifer, and the discharge of the well and the changes in water levels in the well and in piezometers at known distances from the well are measured. The change in water level induced by the pumping is known as the drawdown. In the literature, aquifer tests based on the analysis of drawdowns during pumping are commonly referred to as pumping tests [11;12]. Determining the yield of groundwater systems require, among other information, knowledge of:
1. The position and thickness of aquifers and confining beds.
2. The transmissivity and storage coefficient of the aquifers.
3. The position and nature of the aquifer boundaries.
4. The location and amounts of ground-water withdrawals.
Acquiring knowledge on these factors requires both geologic and hydrologic investigations [13;14]

Pumping test operations start by discharge water from the well drilled in aquifer, which reduces the water level (either water table or piezometric level) around the pumping well. This operation creates cone of depression rapidly due to discharge of the water stored in aquifer [15]. Continuous discharge of water causing the cone of depression becomes wider and deeper with time as the compensation of the discharged quantity of water becomes lesser due to the resistance of porous media to the water movement towards the well leading to decrease the water storage in aquifer. This situation will cause increasing cost of pumping operations, decreased well productivity and depletion of groundwater aquifers [16]. Hydraulic conductivity, transmissivity and storage coefficient are most important parameters that controlling aquifers ability on storage and

productivity, where number of mathematical methods and equations are used to obtain the values of these parameters, such as the (Cooper-Jacob, 1946) [9] method and Theis Recovery Test (Theis, 1935) [10] in the case of unsteady flow, using following equations [17;18]:

$$T = \frac{2.3Q}{4\pi\Delta S} \quad (1) \quad \text{Cooper – Jacob}$$

Solution (1946) [9]

$$Sc = \frac{2.25Tt\circ}{r^2} \quad (2)$$

$$T = \frac{2.3Q}{4\pi\Delta S'} \quad (3) \quad \text{Theis Recovery}$$

Solution (1935) [10]

where:

ΔS‘ ΔS': Drawdown in one logarithmic cycle (m).

t_o: Time at zero drawdown (Day).

r = Radius between pumping well and observation well (m).

Q= Well discharge (m^3/day).

T: Transmissivity (m^2/day).
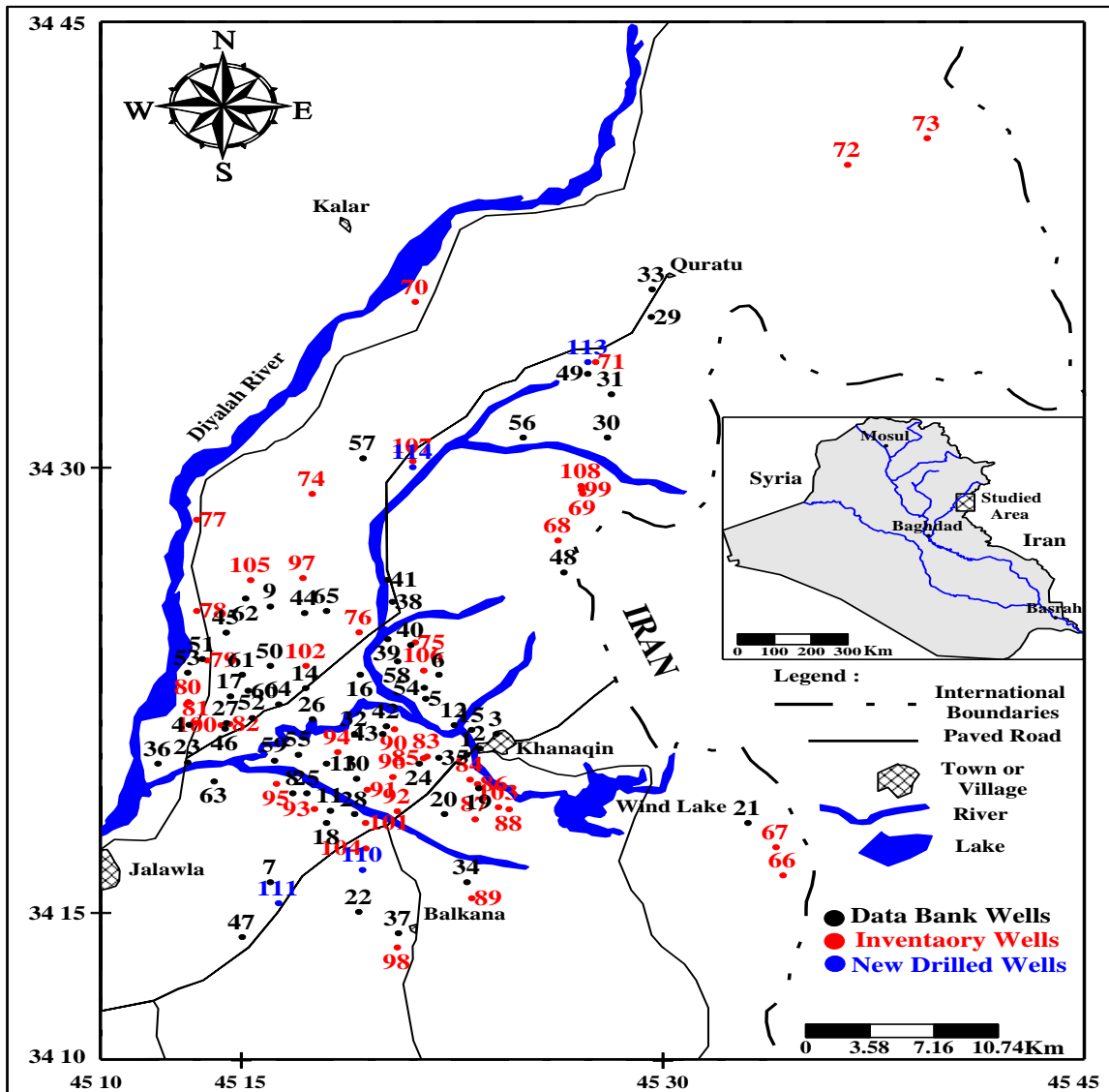
Sc: Storage coefficient.

Figure 4: Inventory, Data Bank and Drilled Wells in Khanaqin Basin

Table 1: Statistical Data Shows Hydrogeological Properties of Unconfined Aquifer in the Study Area

Statistic	Number of values	Minimum	Maximum	Mean	Standard deviation
Elevation (m)	38	124.2	300	183.94	42.702
Static water level (m.)	38	2	27	10.99	6.282
Water Table (m.a.s.l.)	38	97.2	293	172.94	42.742
Total depth (m)	38	16.7	148	48.039	31.921
Depth to water (m)	34	2	26	11	5.82
Thickness (m.)	34	9	130	36.11	28.01
Maximum yield (m*3/day)	37	92	743	338.9	207.6

Table 2: Statistical Data Shows Hydrogeological Properties of Confined Aquifer in the Study Area

Statistic	Number of values	Minimum	Maximum	Mean	Standard deviation
Elevation (m)	52	139	350	183.89	53.72
Static water level (m.)	52	0	40	14.28	10.14
Water Table (m.a.s.l.)	52	113	343.4	169.609	55.08
Total depth (m)	52	20	157	58.06	27.03
Depth to water (m)	27	7	63	22.3	11.4
Thickness (m.)	27	6	123	23.74	22.64
Maximum yield (m*3/day)	50	99	792	475.3	191.7

Table (3) shows the data of the pumping wells drilled in the Khanaqin basin, which were used to obtain the values of the hydraulic parameters of groundwater aquifers. The pumping test operations were carried out in two stages:

1- Pumped water and measuring water levels and recovery in observations wells.

2- Pumped water and measuring the water levels decreasing and recovery in pumping wells.

Table (4) shows time- drawdown data observed in pumping wells, while table (5) shows calculated hydraulics parameters of groundwater aquifers in Khanaqin basin. Figures (5,6,7,8) illustrate (Cooper-Jacob and Recovery) of wells (110,111,113 and114) drawings respectively.

Table 3: Pumping Wells Data Drilled in Khanaqin Basin

Well No.	Geographic Coordinates		Elevation (m)	S.W.L. (m)	D.W.L. (m)	Total Depth (m)	Discharge (m^3/Day)
	Longitude	Latitude					
W110	451929	341642	192	25.18	50.4	192	604
W111	451630	341530	160	16.56	44.25	190	691
W113	452754	343356	335	11.50	15.5	210	691
W114	452047	343020	227	17	20	120	691

Table 4: Time- Drawdown Data Observed in Pumping Wells in Khanaqin Basin

Well No.	Cooper-Jacob Solution		Theis Recovery Solution	Drilling Starting Date	Drilling Ending Date
	Time (min)	Drawdown (m)	Residual drawdown (m)		
W110	1	0.25	2.03	16/6/2013	2/7/2013
	5	0.89	0.96		
	30	1.48	0.36		
	60	1.65	0.25		
	120	1.78	0.15		
	240	1.89	0.095		
	420	1.96	0.055		
W111	1	0.21	39.26	21/9/2013	12/10/2013
	5	1.8	32.03		
	30	7.84	22		
	60	10.99	14.21		
	120	14.63	7.65		
	240	18.56	4.88		
	420	21.19	1.54		
	540	22.2	1.02		
W113	1	0.02	59.91	16/5/2013	21/5/2013
	5	0.12	52.22		
	30	0.63	0.635		
	60	0.75	0.41		
	120	0.84	0.275		
	240	0.96	0.185		
W114	1	0.05	4.2	11/11/2015	30/11/2015
	5	0.075	4.8		
	30	0.09	5.45		
	60	0.095	6.13		
	120	0.095	7.08		
	240	0.1	8.05		

Table 5: Hydraulics Parameters of Groundwater Aquifers in Khanaqin Basin.

Well No.		W110	W111	W113	W114
Cooper-Jacob Solution	t_0 (min)	0.34	1.73	4.9	0.25
	$\triangle S_1$ (m)	0.0235	0.465	9.75	0.7
	$\triangle S_2$ (m)	0.088	-	10	0.6
	T_1 (m²/Day)	8073	169.9	17	237
	T_2 (m²/Day)	2156	-	16.6	276.5
	Sc	$3.7*10^{-3}$	$1.14*10^{-3}$	$1.2*10^{-4}$	$3.5*10^{-5}$
Theis Recovery Solution	$\triangle S'_1$ (m)	0.07	0.21	9	0.8
	$\triangle S'_2$ (m)	0.035	-	21	0.6
	T_1 (m²/Day)	2710	376.3	18.4	276.5
	T_2 (m²/Day)	5420	-	7.9	207.4
Average T (m²/Day)		4590	273	14.97	249.35
Radius (m)		34	20	32	51
Total pumping Time (min)		420	540	240	240

$\triangle S_1$: Drawdown in a one logarithmic cycle in observation well (m).
$\triangle S_2$: Drawdown in a one logarithmic cycle in pumping well (m).
$\triangle S'_1$: Residual drawdown in a one logarithmic cycle in observation well (m).
$\triangle S'_2$: Residual drawdown in a one logarithmic cycle in pumping well (m).
T_1: Transmissivity obtained in observation well (m²/day).
T_2: Transmissivity obtained in pumping well (m²/day).

During pumping test operation, the drawdown in well (113) was recorded (52) m. which highly affected on transmissivity value obtained by Cooper-Jacob and Recovery methods. This drawdown caused by inappropriate wells compilation where we used drawdown recorded in observation well only in calculating transmissivity coefficient. The results of hydraulics parameters shown in table (5) indicate that wells (110) and (113) has a as moderate values of transmissivity while

well (111) has a low value and well (114) recorded high value of this parameter. The lowest value of transmissivity recorded in well (111) caused by highly resistant on groundwater movement towards this well which penetrate Quaternary deposits represented by slope deposit, composed of sandy, silty, clayey soils as shown in figures (2 and 3). On the other hand well (114) located in the upper part of basin penetrated polygenetic deposits of Quaternary which composed of sandy, silty clay admixture and contain gravels at basal parts accompanied with Bai Hassan formation which composed of conglomerate, claystone and sandstones with occasional siltstones causing by increasing transmissivity value

As we can see from figure (4), the wells (110 and111) which located in the south of the basin with (192 and 190 m). depth respectively penetrated full Quaternary deposits and Bai Hassan and partially penetrated Mukdadiyah formation which making storage coefficient reflect confined aquifer. In the north part of the basin, well (113) with (210 m) depth penetrated Quaternary deposits, Bai Hassan with a limited thickness of aquifers affected by Thrust fault making Injana formation the main aquifer in this location which composed of monotonous sequence of sandstones and claystone which are reddish brown, calcareous, fractured silty and contain thin beds of fine sandstones and siltstones. This geological sequence representing unconfined to semi-confined aquifer as reflected by storage coefficient. On the other hand, well (114) of (120 m). depth which located to south of well (113) the storage coefficient represented by unconfined to semi-confined as aquifer formed of Quaternary deposits and Bai Hassan formation only. Transmissivity contour map as shown in figure (9) indicated increasing value of this parameter towards north west direction of the basin. This increasing of transimissivity as groundwater movement generally flow towards the same direction leading to increase groundwater discharge from wells penetrate unconfined and confined aquifers.
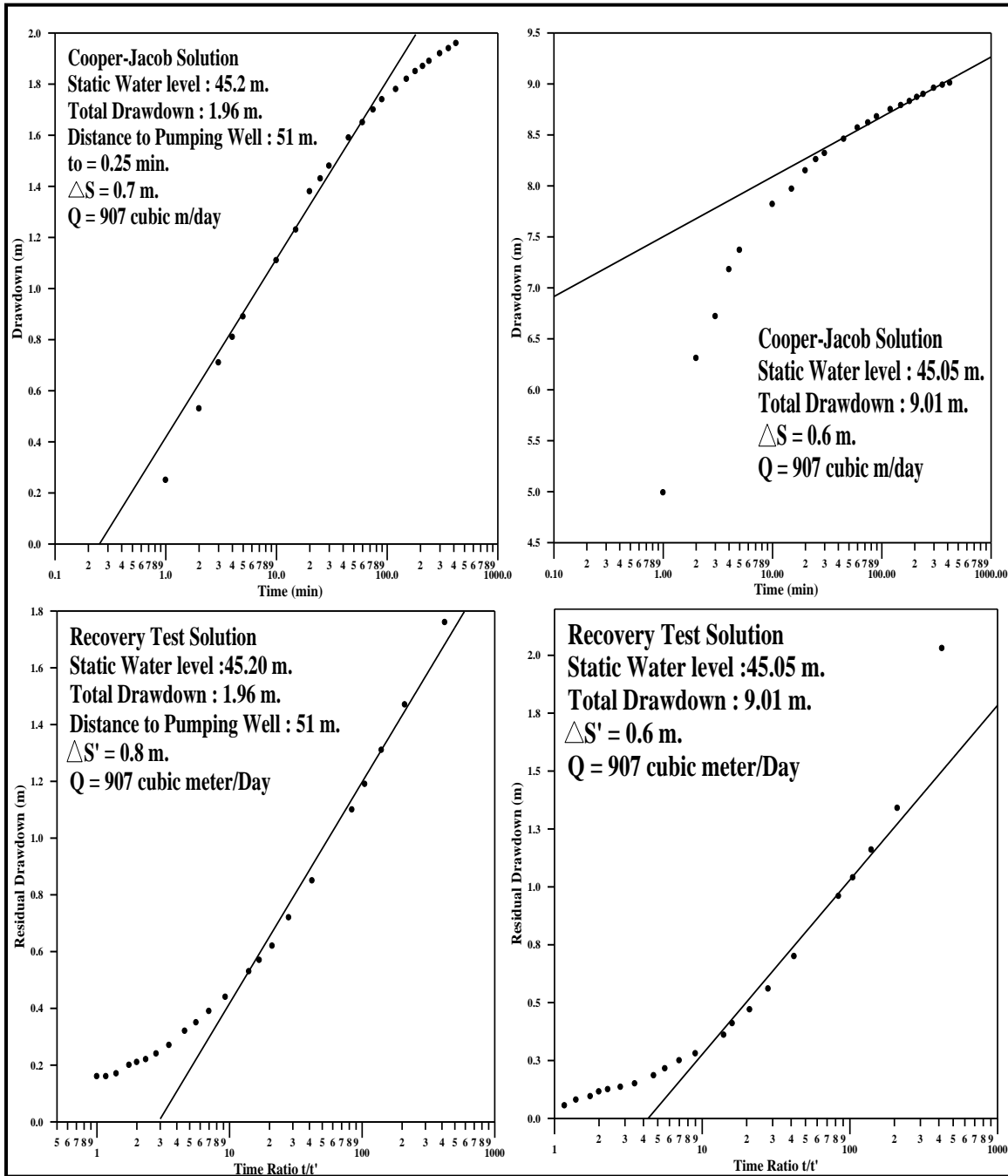
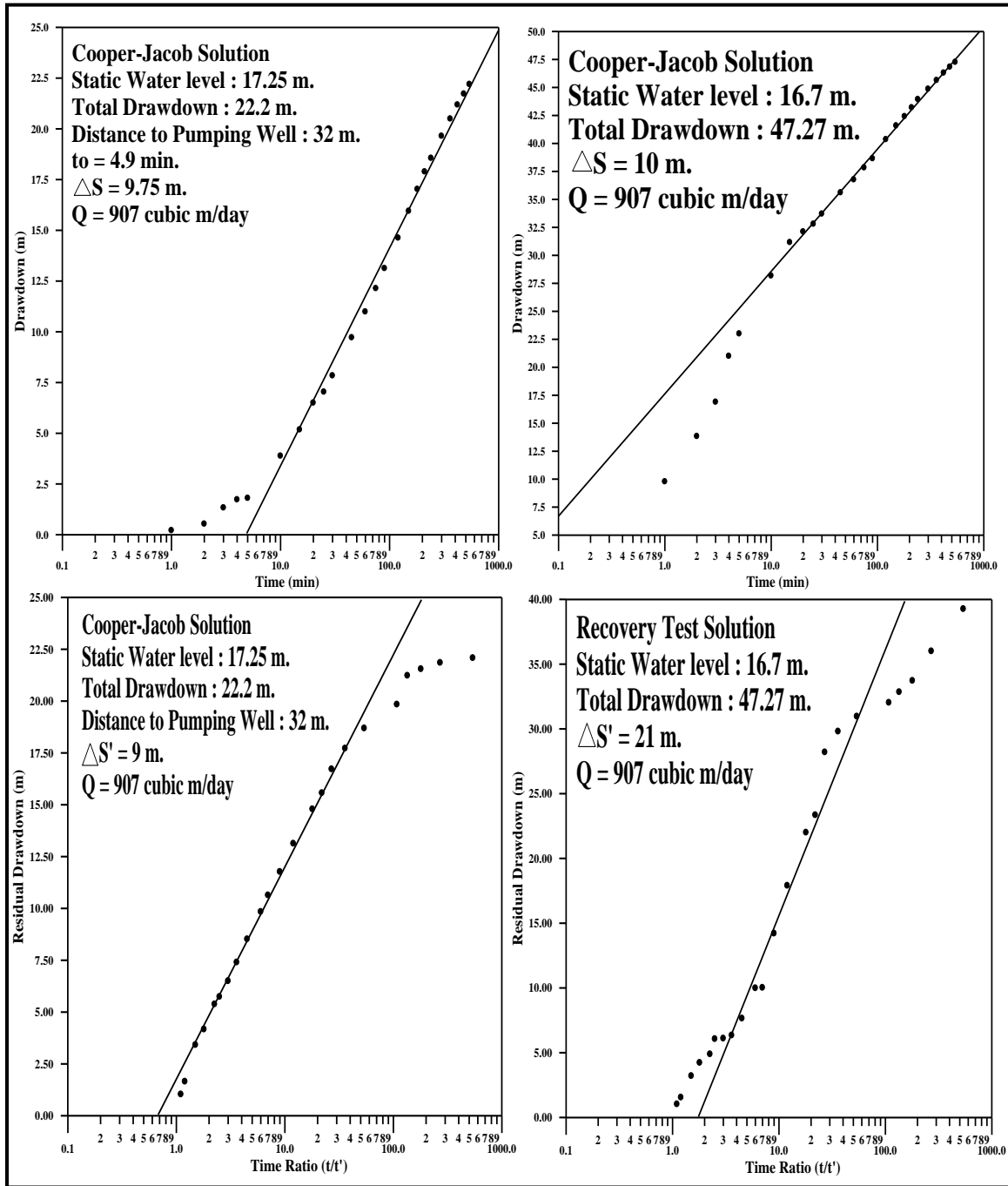*Figure (5): Pumping Test (Cooper-Jacob and Recovery Solution) Results of Well (110).*

Figure (6): Pumping Test (Cooper-Jacob and Recovery Solution) Results of Well (111).
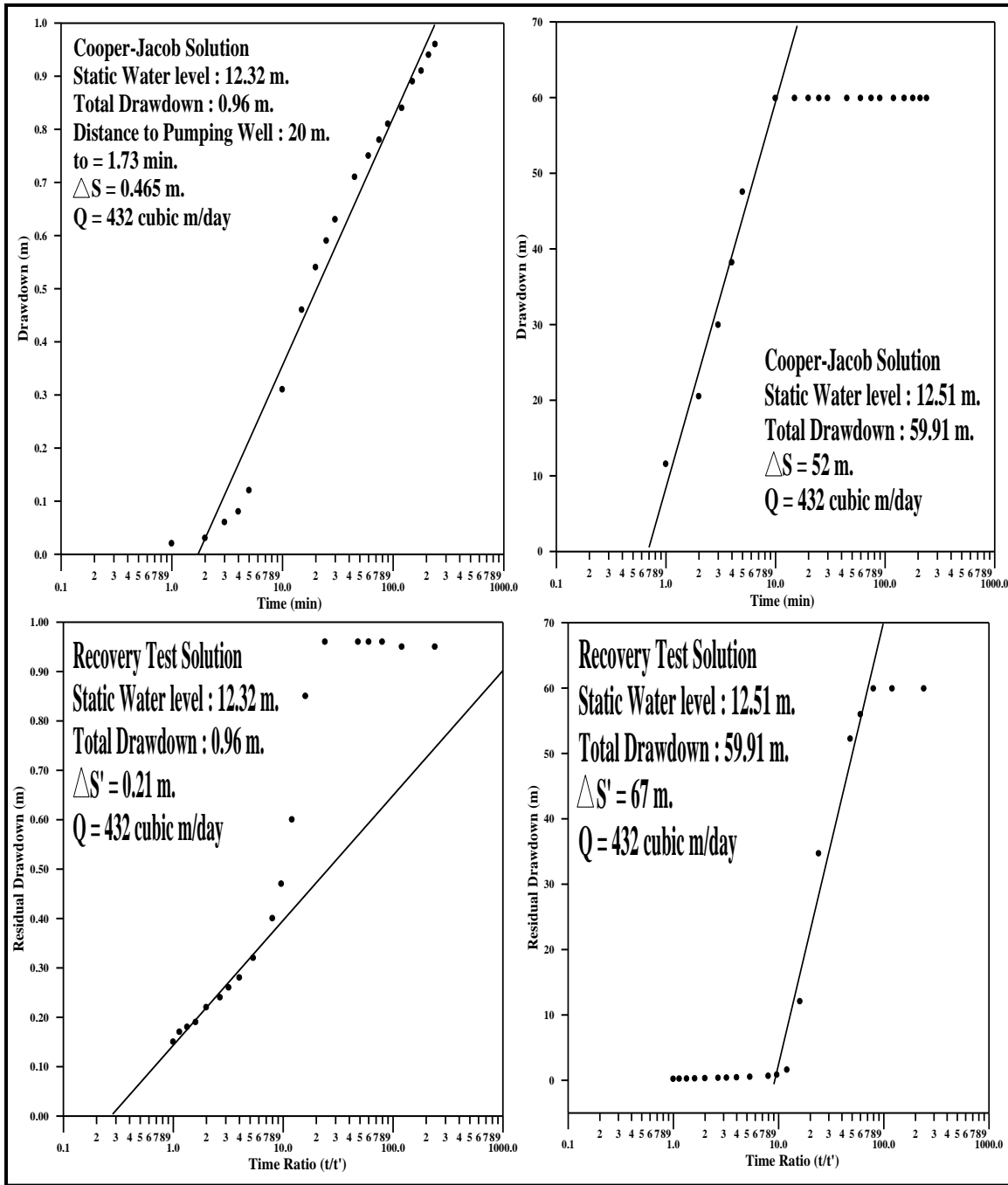
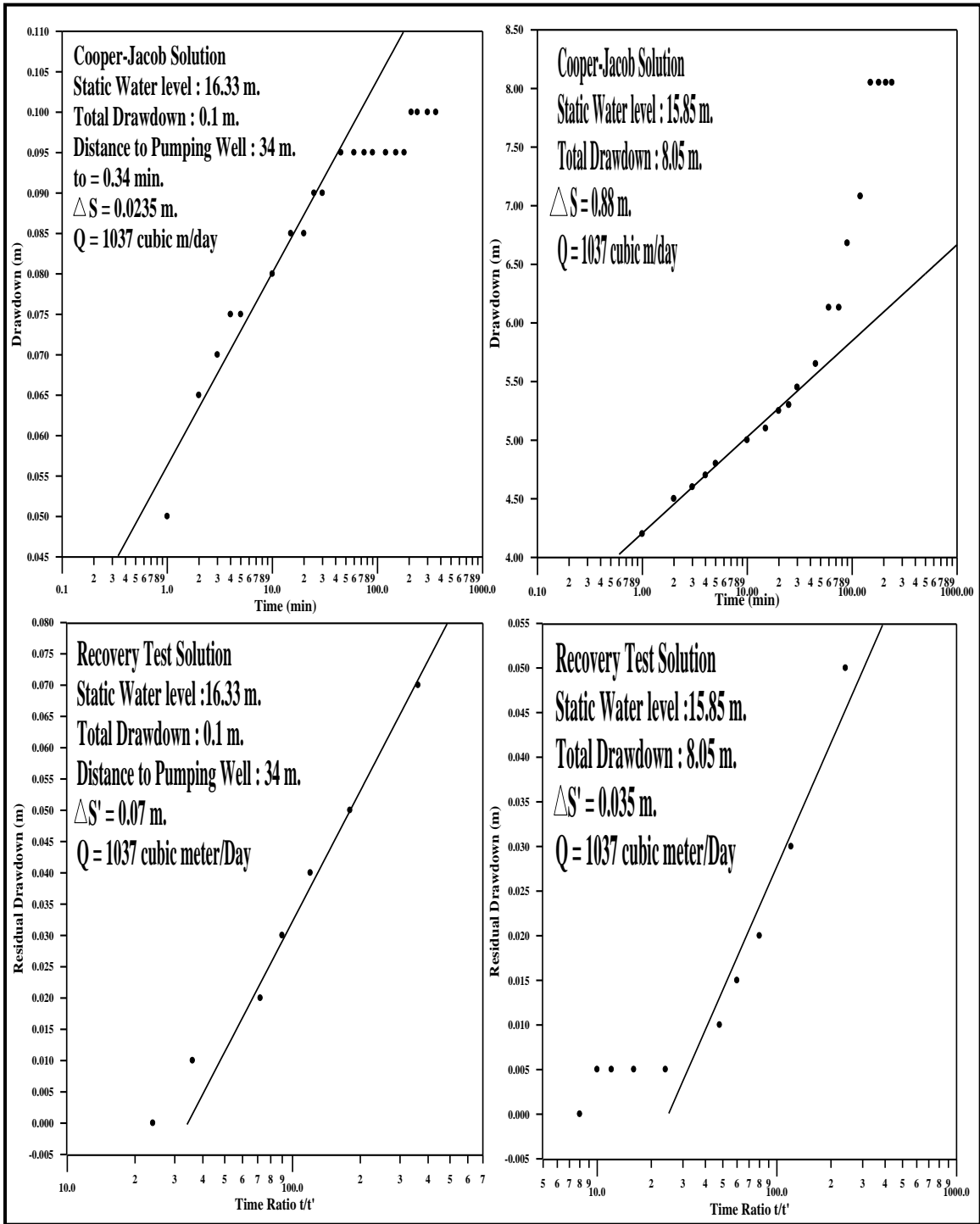*Figure (7): Pumping Test (Cooper-Jacob and Recovery Solution) Results of Well (113).*

Figure (8): Pumping Test (Cooper-Jacob and Recovery Solution) Results of Well (114).
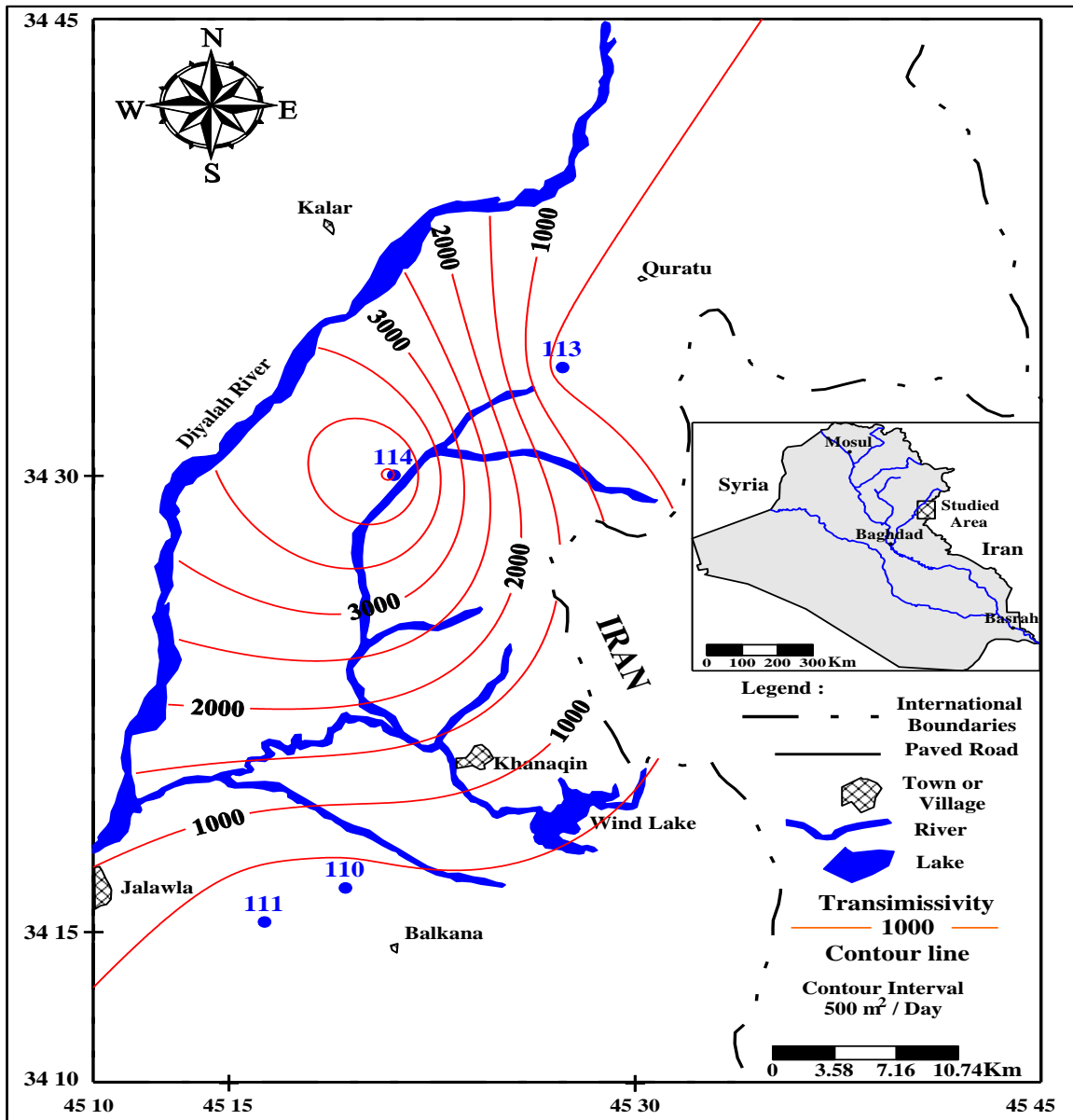
Figure 9: Transmissivity Contour Map in Khanaqin Basin

6. Conclusions:

1- According to (90) wells investigated in the study area, the results showed that (38) wells belongs to unconfined aquifer while (52) wells belong to confined aquifer in Khanaqin basin.

2- The average calculated transmissivity parameter was ranged between (273-4590 m^2/day) in unconfined aquifer while this range was (14.97-249.35 m^2/day) in confined aquifer, while storage coefficient range between $(3.5*10^{-5})$ to $(1.14*10^{-3})$.

3- Transmissivity contour map indicated increasing value of this parameter in both confined and unconfined aquifers towards northern west direction of the Khanaqin basin.

4- Increasing of transimissivity as groundwater movement generally flow towards the northern west leading to increase groundwater discharge from wells penetrate unconfined and confined aquifers.

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المعاملات الهيدروليكية لمكامن المياه الجوفية في حوض خانقين

حسين العيبي زامل السوداني

قسم تكنولوجيا النفط ، الجامعة التكنولوجية ، بغداد ، العراق

المستخلص :

ان تقييم الخصائص الفيزيائية للطبقات الحاملة للمياه احدى اهم الامور في دراسات المياه الجوفية ، وتعتبر اختبارات المكمن الجوفي احدى اهم الطرق لتحديد هذه الخصائص . يهدف البحث الى اجراء التحريات الهيدروجيولوجية لحوض خانقين في محافظة ديالى شرق العراق وحساب المعاملات الهيدروليكية لاهم المكامن الجوفية المنتجة للمياه من خلال تطبيق طريقتي كوبر- جاكوب وثايس لعودة المنسوب لحساب معامل الناقلية والخزن بعد ان تم تحديد المواقع الجغرافية للابار المنتشرة في الحوض بالاضافة الى ارتفاعاتها عن مستوى سطح البحر ومناسيب المياه الجوفية واعماقها وسمك وانتاجية هذه الابار . اظهرت النتائج بان حوض خانقين يتميز بوجود طبقتين للمياه الجوفية متمثلة بالمكمن الجوفي المحصور وغير المحصورة وتم الاعتماد على اربعة ابار اجريت فيها عمليات الضخ الاختباري اذ بلغ معدل الناقلية المحسوب بالطريقتين اعلاه للمكمن غير المحصور (273-4590 م^2/يوم) و (249.35-14.97 م^2/ يوم) للمكمن المحصور فيما بلغ معامل الخزن (3.5* 10^{-5}) الى (1.14*10^{-3}) وبينت خارطة توزيع معامل الناقلية ارتفاع قيم هذا المعامل باتجاه الشمال الغربي من حوض خانقين متوافقة مع اتجاه حركة المياه الجوفية والتي تؤدي الى زيادة كميات المياه الجوفية المستخرجة من الابار المحفورة والمخترقة للمكمنين اعلاه.