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Climatic Water Balance and Hydrogeological characteristics of Lailan Basin, Southeast Kirkuk - North of Iraq

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Abstract

This paper examined the climatic water balance and hydrogeological conditions of the water bearing layers within Lailan basin. To achieve the water balance the meteorological data from Kirkuk station for the period (1970 to 2016) was used to calculate the water surplus and water deficit. Based on Mehta's model the water surplus (Ws) is equal to (127.86 mm/ year) representing 36.87 % of the total rainfall, while 63.13% of the total rainfall are water deficit. The study area is characterized by two main aquifer types, unconfined and semi-confined. Generally, groundwater recharge occurs from both sides of the basin toward the center and the general flow direction is from northeast to southwest. To determine the hydraulic properties of semi-confined aquifer, pumping and recovery tests data from seven wells in the study area were analyzed based on the Hantush-Jacob's (1955) and Theis recovery (1935) methods.The values of T, K ,Sc and S ranged from (79.63 – 753.8 m^2/day),(2.01 – 16.75 m/day),(0.42 – 5.95 m^2/day) and (0.0068 - 6.134E-16) respectively . Due to the aquifer lithology heterogeneity the hydraulic properties varied from one location to another, reflecting the change of both porosity and permeability.

Keywords: water balance, hydrogeological conditions, pumping test, Lailan basin.

الموازنة المائية المناخية والخصائص الهيدروجيولوجية لحوض ليلان جنوب شرق كركوك– شمال العراق

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الخلاصة

تم في هذا البحث دراسة الموازنة المائية المناخية والظروف الهيدروجيولوجية للطبقات الجوفية الحاملة للمياه في حوض ليلان . ولتحقيق الموازنة المائية ، تم استخدام بيانات الأرصاد الجوية من محطة كركوك للفترة (1970 – 2016) لحساب الزيادة والنقصان المائي . بتطبيق موديل مهتا تم حساب الزيادة المائية الذي يساوي (127.86 ملم /سنة) ويمثل 36.87 ٪ من مجموع الأمطار الكلي بينما 63.13 ٪ من مجموع الأمطار الكلي هو عجز مائي . تتميز منطقة الدراسة بوجود نوعين رئيسيين من الخزانات الجوفية، خزانات غيرمحصورة وشبه محصورة. وبشكل عام تحدث التغذية للمياه الجوفية من جانبي الحوض باتجاه مركز الحوض واتجاه الجريان العام للمياه الجوفية من الشمال الشرقي باتجاه الجنوب الغربي. لتحديد الخواص

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الهيدروليكية لخزانات المياه الجوفية الشبه المحصورة تم تحليل بيانات ضخ وعودة المنسوب لسبعة آبار في منطقة الدراسة استنادا على طريقة حنتوش – جاكوب وطريقة ثايس لعودة المنسوب . تراوحت قيم الناقلية من (9.63 – 753.8 m^2/day) ، والتوصيلية الهيدروليكية (2.01 – 16.75 m/day) ، والسعة النوعية (0.42 – 5.95 m^2/day)، ومعامل الخزن (0.0068 – 6.134E−16) . بسبب عدم تجانس صخارية الخزان الجوفي المحصور تتفاوت الخواص الهيدروليكية من موقع إلى آخر، وهذا ما يعكس تفاوت المسامية والنفاذية للخزان.

Introduction

Iraq is experiencing a shortage in water resources, particularly in surface water, therefore there is an orientation to exploitation of groundwater to meet the requirements for industrial, agricultural and domestic sectors. The selected area to study "Lailan basin", located in the southeastern part of Kirkuk city, is an important agricultural and industrial area. Groundwater is a significant source of water resources in the basin, where the Lailan district and most of the villages in the basin are depend on the groundwater as a main source of water in their supply systems. Recently, due to population and economic growth, the use of groundwater has increased dramatically, and excessive groundwater withdrawal has become a serious problem in the basin. There are many studies included the study area such as, Sogiria [1], studied the hydrology of Kirkuk and northern part of Al Adhaim Basin. Araim [2], studied the hydrogeological basins of Iraq. Al-Nakash et al. [3], they designed an operational program for wells in Kirkuk. The State Company of Geological Survey and Mining studied the hydrogeology and hydrochemistry of groundwater of Kirkuk quadrangle sheet (NI-38-2)[4]. Saud [5], studied the Hydrogeology and hydrochemistry of groundwater of Kirkuk governorate. The General Commission for Groundwater / Branch of Kirkuk, studied the hydrochemistry of groundwater of Lailan sub-basin [6]. The aim of this paper is to determine the hydraulic characteristics of the aquifer and create a water balance for the Lialan basin.

The Study Area

Lailan basin which covers an area of 436 km^2 is situated within the southeast part of Kirkuk governorate, north of Iraq, between longitudes (44° 21' 00" E - 44° 42' 00" E) and latitudes (35° 7' 30" N - 35° 28' 30" N) , approximately 255 km north of Baghdad Figure-1. The study area climate characterized by two seasons, the wet and the dry. The wet season begins in October and ends in April. The dry season lasts between May and September. Generally, the mean annual precipitation reaches 346.7 mm while annual evaporation exceeds 2000 mm (Table-1). In this basin, groundwater is the only source of water for both agricultural and municipal uses. Geologically, The most important geological formations that are exposed in the basin are Bai Hassan and Mukdadiyah Formations in addition to Quaternary deposits Figure-2 [7]. Bai- Hassan Formation is characterized by thick layers of conglomerates interbedded with sandstone, siltstone, and claystone. While Quaternary deposits are characterized by layers of gravel, sand, silt and clay [3] [8] . The basin is located between two structures; Kirkuk structure from the northeast side and Jambur Anticline from the southwest side, where the basin is confined between two thrust faults.

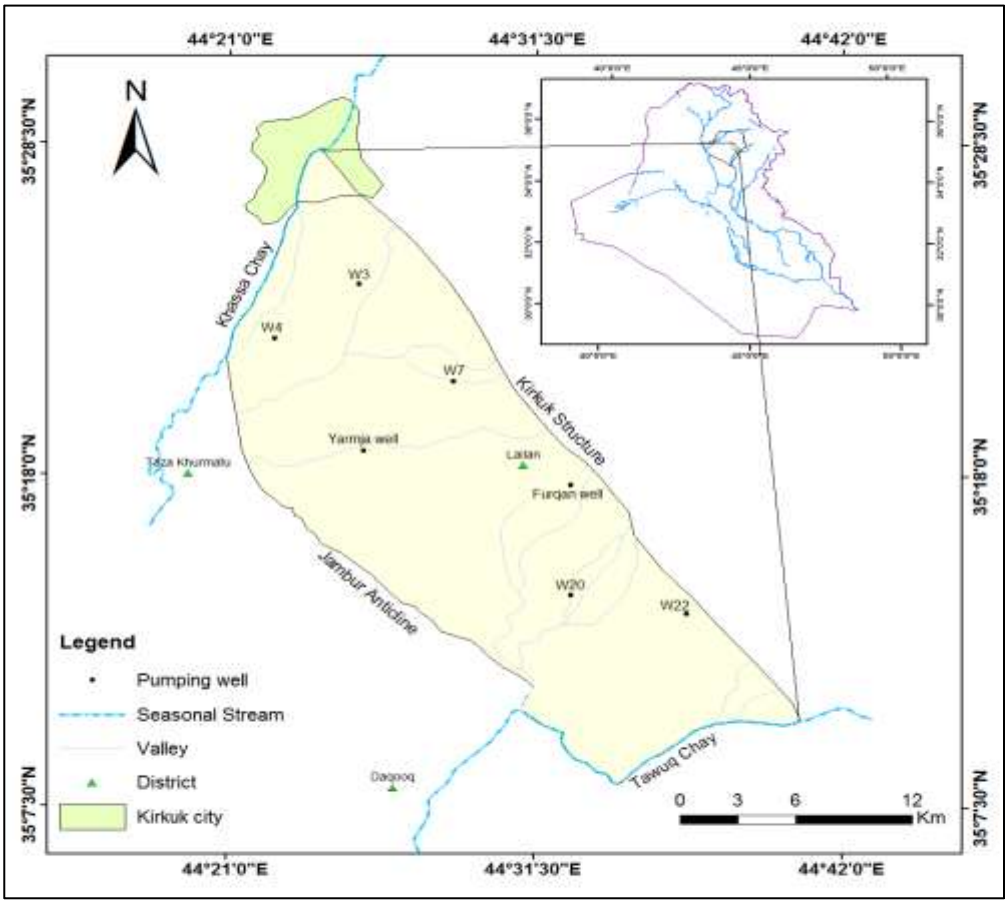

Figure 1-Location of the study area showing the pumping wells locations [7].

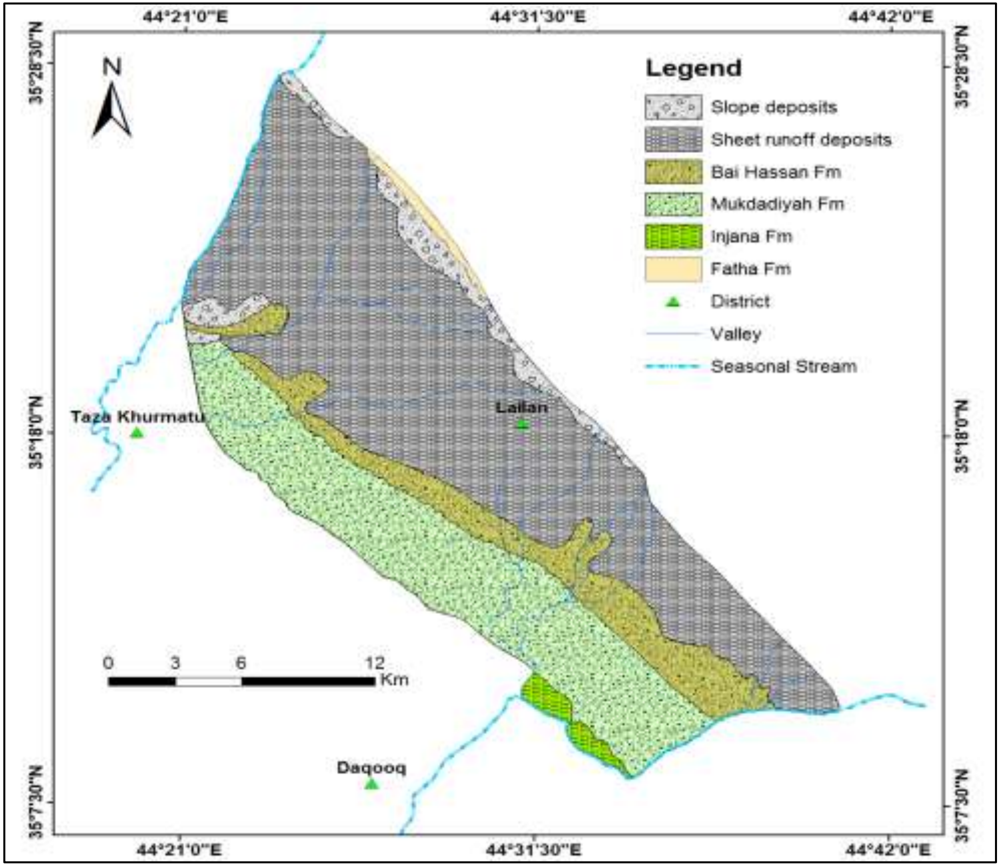

Figure 2- Geologic map of the study area, after [7].

Groundwater Aquifer Description

An aquifer is defined as a geological material that is capable of storing and transmitting water to wells placed in them in sufficient quantities to be considered economically. Groundwater in the study area is extracted from layers of gravel, sand and silt which returns to the older Quaternary deposits and Bai Hassan Formation, which its thickness is estimated about 300 m [3]. Bai-Hassan formation is an important aquifer because it contains water in good quantities and qualities within thick layers of gravel and conglomerate. While Quaternary deposits are divided into younger unconsolidated alluvium deposits and the older deposits. The older Quaternary deposits have good permeability and the ability to store water in layers of gravel, sand, silt where it is difficult to determine its boundary with the Bai Hassan formation due to similarities of rock quality [3]. The groundwater levels in the basin extends from 10 m to 54 m, whereas the wells depths ranges from 90 m to 150 m. The average discharge of these wells is more than 9 L/Sec. From study the lithologic logs of drilled wells in the study area obtained from [9], the study area is characterized by rapid variation of subsurface sediment sequence, in the form of multi aquifers interceded with clay layers. These aquifers are classified into two main aquifers, unconfined and semi-confined or leaky aquifer. Unconfined aquifers occur at depths of between 10 and 40 m, whereas the semi-confined aquifers occur at depths more than 40 m. The thickness of these aquifers and the clay layers are different spatially from place to place in the basin. Correlation between lithologic logs of some drilled wells in the study area are shown in Figure-3.

Groundwater Flow System

Groundwater in its natural state is invariably moving, this movement is governed by established hydraulic characteristics such as (hydraulic conductivity and hydraulic gradient). It moves in the direction of the steepest hydraulic gradient [10] . According to Figure-4 that show the flow map of Lialan basin, the high levels of groundwater occurs on both sides of the basin, towards Kirkuk structure in northeast side and Jambur Anticline in southwest side. The general flow direction as inferred from flow map is from northeast to southwest similar to the direction of regional groundwater flows in the region. However, there is another local flow from the southwest side toward the middle of the basin unlike the general direction. The flow net map reveals recharge occurrence from both sides of the basin toward the center.

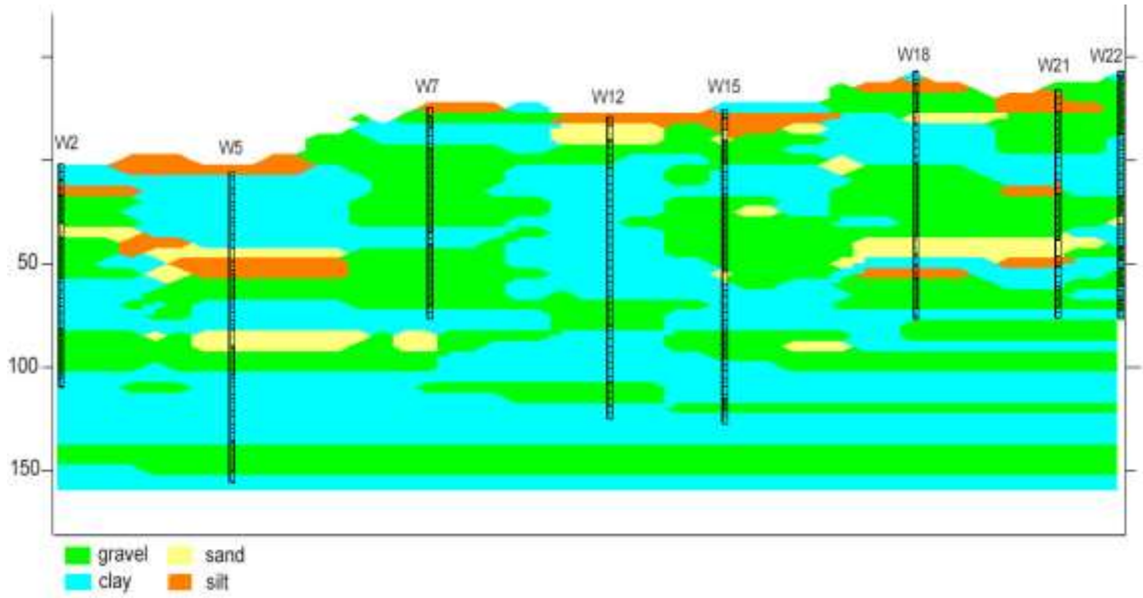

Figure 3- The lithologic correlation between the wells in the study area [9].

Groundwater Hydrograph

Groundwater hydrograph shows the changes in groundwater levels over time and are often the most important source of information about the hydrological and hydrogeological conditions of aquifers [11]. Figure-5 briefly presents the hydrograph of groundwater levels in Lailan basin depending on three piezometers which used to monitor groundwater level fluctuation monthly over the period (August /2011 to April /2017) by the General Commission of Groundwater / Kirkuk. Although, the number of the piezometers does not cover the basin, but there is clearly drawdown of groundwater levels in basin in last six years, where it reaches more than 10 meters in the piezometers 1 and 3. Reflecting an increasing in groundwater exploitation within the last years, because of lack of precipitation and increase land investment as well as the random drilling of wells and excessive withdrawal of groundwater.

Materials and methods

Climate parameters of the Kirkuk meteorological station for the period (1970 to 2016) have been used to calculate the water balance of Lialan basin [12]. These parameters Includes (precipitation, temperature, evaporation, relative humidity, wind speed and sunshine), their monthly averages are shown in Table-1. Calculation of the water balance is the basis of the assessment of climate, soil, and plant conditions that are very useful for planning the development of agricultural production and water sustainability in any region. It is intended to provide important information on the amount of water that can be obtained, the value of the surplus water and deficit water [13]. In this study , Mehta's model [14] was used to calculate the water balance by determining the water surplus and water deficit. This model based on [15], where the basic concepts of the model are shown in Figure-6, and includes:

P	*monthly precipitation*
PET_{crop}	*crop potential evapotranspiration*
SW	*soil water content*
AWC	*available water capacity*
S_t	*watershed storage*
$APWL$	*accumulated potential water loss*

Determination of hydraulic properties of aquifers is an essential to assess the hydrogeological conditions in any region. One of the common methods to determine aquifer properties is the use of pumping test. A pumping test procedure involves extracting groundwater from a pumping well and measuring the aquifer response by monitoring drawdown as a function of time. These data are included in the equations to calculate the hydraulic properties of the aquifer.

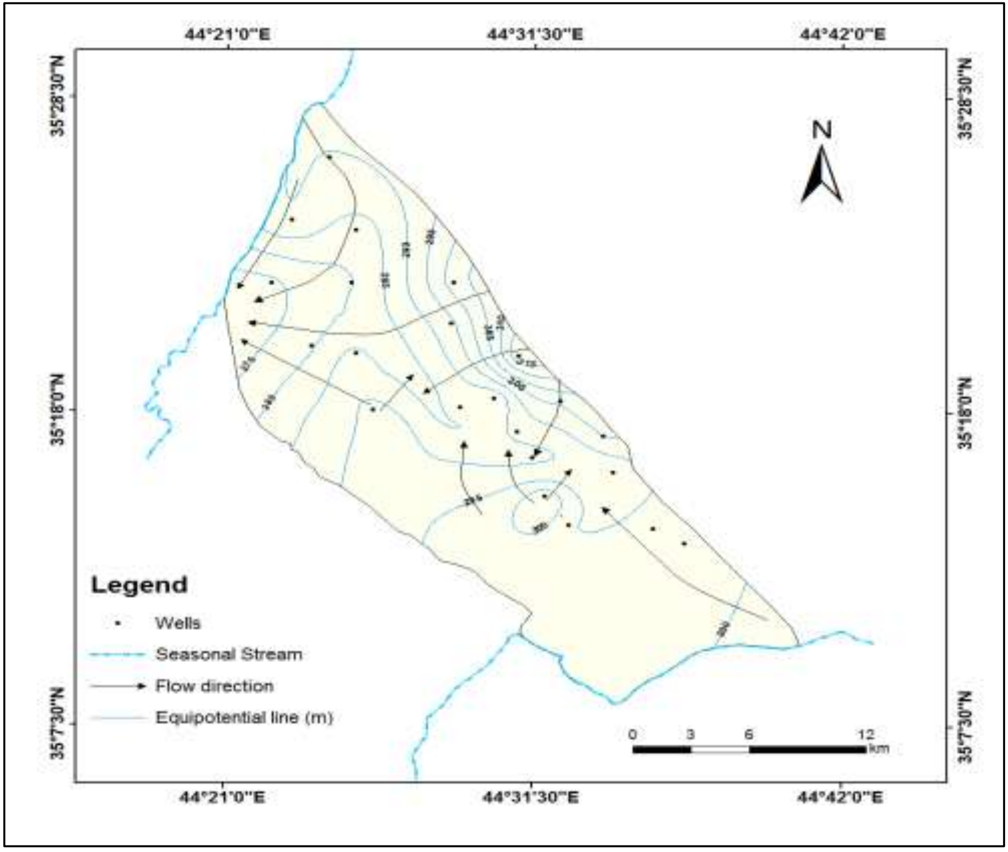

Figure 4- Groundwater flow map in the study area.

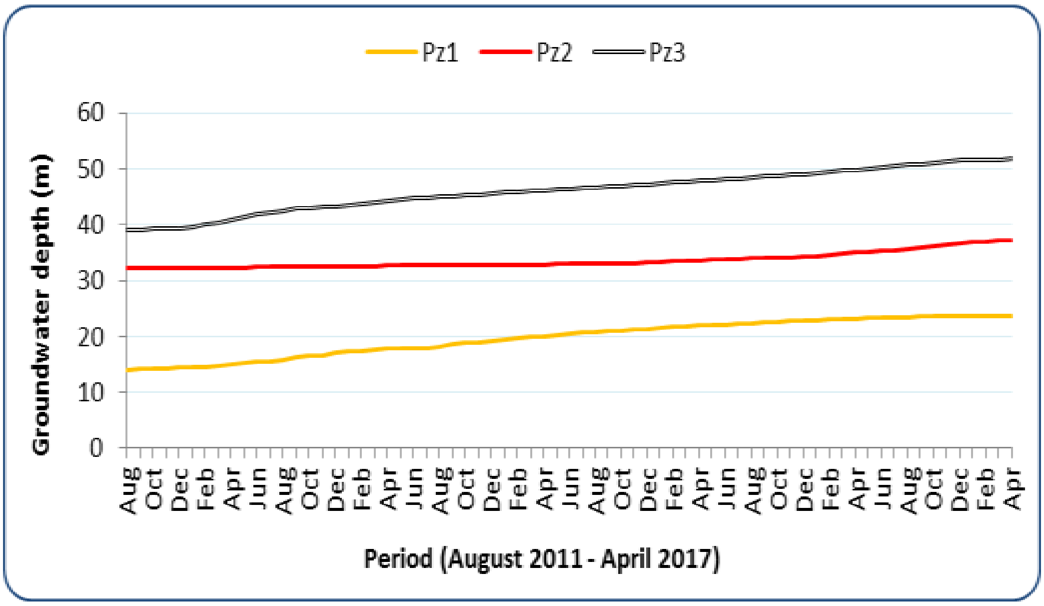

Figure 5- Monthly groundwater levels fluctuation in three piezometers (Pz_1, Pz_2, Pz_3) for the period (August 2011- April 2017).

Table 1-The monthly means of climatic data for the period (1970-2016) [12]

Element	Precipitation mm	Air Temperature (°C)	Evaporation mm	Relative humidity %	Wind speed (m/ sec)	Sunshine hour/day
Jan.	66.2	9.1	52.2	71.08	1.3	5.3
Feb.	59.4	10.9	38.3	65.47	1.6	6.3
Mar.	55.8	15	110.8	57.51	1.7	7.2
Apr.	40.8	20.8	164.7	49.71	1.9	7.7
May	13.5	27.6	268.5	33.52	2	9.2
Jun.	0.1	33.3	361.9	23.11	2	11.1
July	0.1	36.2	415.0	21.68	1.9	10.9
Aug.	0.0	35.7	400.2	23.04	1.8	10.9
Sep.	0.6	31.4	309.2	25.91	1.4	10.1
Oct.	13.7	24.9	205.1	37.24	1.4	7.9
Nov.	40.4	16.4	93.3	56.75	1.2	6.7
Dec.	56.1	10.8	55.8	69.31	1.2	5.6
Sum.	346.7		2475			

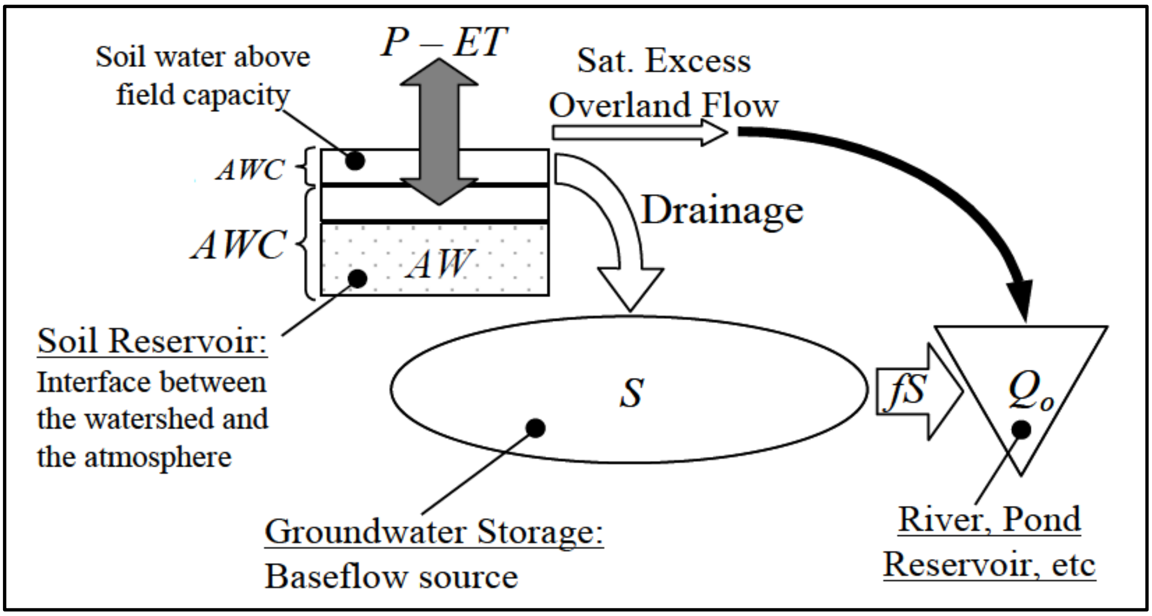

Figure 6 -Mehta's Model concepts [14].

In the present study , Aquifer hydraulic properties have been calculated using pumping and recovery test analysis for 7 wells their locations are shown in Fig. (1). These properties includes (Hydraulic conductivity (k), Transmissivity (T), Storage coefficient (S) and Specific capacity) . Hantush - Jacob method [16] and Theis recovery method [17] were used to analysis the pumping and recovery test results.In this methods, the transmissivity (T) is given by [18]:

$$T = \frac{2.3\,Q}{4\pi\Delta s} \qquad (1)$$

Where:

T Transmissivity (m² /day)

Δs Difference of the drawdown (m) per one log-cycle

Q Discharge (m³/day)

The hydraulic conductivity (K) was calculated from:

$$K = \frac{T}{b} \qquad (2)$$

Where:

T Transmissivity (m²/day)

b Saturated thickness of the aquifer (m)

The specific capacity (Sc), a measure of well productivity, was computed from:

$$Sc = \frac{Q}{S_t} \qquad (3)$$

Where:

Q discharge rate (m³/day)

S_t *Total drawdown (m)*

Although these tests have been conducted without observation wells, the storage coefficient is determined according to Theis Solution method [17] based on the effective radius of the single well which replaced the value of (r) by the following equation:

$$S = \frac{4uTt}{r^2} \qquad (4)$$

Where:

T Transmissivity (m² /day)

r Distance from pumping well to observe well (m)

u Theis function (dimensionless unit)

t Time of pumping (minute)

Results and discussion

1- Mehta's Model

In order to applying Mehta's model, evapotranspiration ETo was calculated according to Penman-Monteith method using CropWat V.8 Software developed by USDA (U.S. department of agriculture) as shown in Table-2. The equation is expressed as follows [19]:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 \, (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\, u_2)} \qquad \textbf{(5)}$$

Where :

ET_o	*Evapotranspiration (mm day $^{-1}$)*
R_n	*Net radiation at the crop surface (MJ m^{-2}day^{-1})*
G	*Soil heat flux density (MJ m^{-2}day^{-1})*
T	*Mean daily air temperature at 2 m height (^{o}C)*
u_2	*Wind speed at 2 m height (ms^{-1})*
e_s	*Saturation vapor pressure (kPa)*
e_a	*Actual vapor pressure (kPa)*
Δ	*Slope vapor pressure curve (kPa ^{o}C^{-1})*
γ	*Psychrometric constant (kPa ^{o}C^{-1})*

Thus, Crop potential evapotranspiration (PET_{crop}) can be calculated using equation (6) as shown in Table (2) [20] :

$$PET_{crop} = ET_o \times K_c \qquad \textbf{(6)}$$

Where:

ET_o	*Evapotranspiration*
K_c	*Crop coefficient*

Crop coefficient varies according to crop characteristics, stage of growth and climatic conditions. It ranges from 0.3 to 0.4 at the starter of the growing season and reaches to maximum water consumption during June, July, August and September, then K_c value can be 1.2 [21]. Table-3 below summarizes the equations to calculate SW and APWL based on net precipitation (ΔP) which calculated as follow:

$$\Delta P = P - PET_{crop} \qquad \textbf{(7)}$$

The AWC value is estimated to be (50 mm) based on tables developed by [15] regarding the soil texture, crop type and field capacity. According to the model results which indicated in Table-2, the total water surplus (Ws) is equal to (127.86 mm/ year) representing 36.87 % of the total rainfall. While the water deficit is representing 63.13% of the total rainfall.

Table 2-Monthly Water Balance for Lailan basin

Elements	P	ETo	PET_{crop}	APWL	ΔP	SW	dSW	AET	Deficit	Surplus
Jan.	66.2	38.2	13.3	0	52.8	50	0	13.3	0	52.8
Feb.	59.4	52.1	18.2	0	41.1	50	0	18.2	0	41.1
Mar.	55.8	89.8	31.4	0	24.3	50	0	31.4	0	24.3
Apr.	40.8	131	45.8	-5	-5	45.18	-4.8	35.9	0.2	0
May	13.5	196.9	68.9	-60.4	-55.4	14.9	-30.2	-16.7	25.1	0
Jun.	0.1	237.7	285.2	-345.6	-285.1	0.049	-14.8	-14.7	270.3	0
July	0.1	253.7	304.4	-650	-304.3	0	-0.04	0.05	304.3	0
Aug.	0	238	285.6	-935.6	-285.6	0	0	0	285.6	0
Sep.	0.6	172.8	207.3	-1142.3	-206.7	0	0	0.6	206.7	0
Oct.	13.7	124.5	149.4	0	-135.7	0	0	13.7	135.7	0
Nov.	40.4	65.2	22.8	0	17.5	17.5	17.5	22.8	0	0
Dec.	56.1	40.4	14.1	0	41.9	50	32.4	14.1	0	9.5
Total	346.7									127.86

Table 3-Equations of the Model [14]

Situation in the watershed	*SW*	*APWL*	*Excess*
$\frac{\textbf{Soil is drying}}{\Delta P < 0}$	$= AWC \exp\left(\frac{APWL_t}{AWC}\right)$	$= APWL_{t-1} + \Delta P$	$= 0$
$\frac{\textbf{Soil is wetting}}{\Delta P > 0 \text{ but } AW_{t-1} + \Delta P \leq AWC}$	$= AW_{t-1} + \Delta P$	$= AWC\ In\ (\frac{SW_t}{AWC})$	$= 0$
$\frac{\textbf{Soil is wetting above capacity}}{\Delta P > 0,\ AW_{t-1} + \Delta P > AWC}$	$= AWC$	$= 0$	$= SW_{t-1} + \Delta P - AWC$

When P > PET, AET = PET . When P < PET, AET = dSW + P

Where : AET = Actual Evapotranspiration.

dSW = Change in soil water over the time step

2- Aquifer hydraulic properties

Seven pumping and recovery tests were performed on seven wells scattered in Lailan basin as shown in Figure-1. The test results incorporated into (AQTESOLV 4.5) software to calculate the hydraulic properties of semi-confined aquifer at the basin ,i.e, Transmissivity, hydraulic conductivity and specific capacity. Wells properties in terms of depth, static water level , saturated thickness, discharge and drawdown are presented in Table-4. Figures-(7-13)show the curves of time-drawdown and time - residual drawdown for each well that was analyzed. Tests results are presented in Table-5. The spatial distribution of transmissivity and hydraulic conductivity are shown in Figures-(14, 15) respectively. Clearly, the results of test analysis indicate variable values ranges for both transmissivity from (79.63 to 753.8 m^2/day) and hydraulic conductivities from (2.01 to 16.75 m/day). The specific capacity is ranged from (0.42 to 5.95 m^2/day) . There is a variation in the hydraulic properties of the study area because of the aquifer heterogeneity due to lithological variation reflecting the change of both porosity and permeability. In general, results from the recovery method see more reliable since the recovery data represent the aquifer conditions on site, and they are free from the effects of pumping and interference (mainly human errors).

Conclusion

By applying Mehta's model the water balance of Lailan basin was calculated. The result showed that the total water surplus (Ws) is equal to (127.86 mm/ year) representing 36.87 % of the total rainfall. While 63.13% of the total rainfall are water deficit. Lailan basin was characterized by rapid variation of subsurface sediment, in the form of multi aquifers interceded with clay layers under unconfined and semi-confined conditions. Generally, groundwater recharge occurs from both sides of the basin toward the center and the general flow direction is from northeast to southwest. Groundwater hydrograph revealed a decline in the groundwater level at basin to more than 10 meters in the last six years because of random drilling , squandering and the absence of the law. Pumping and recovery tests data from seven wells scattered in the basin were analyzed based on the Hantush -Jacob's (1955) and Theis recovery methods to determine the hydraulic properties of confined aquifers. The values of T, K ,Sc and S ranged from (79.63 - 753.8 m^2/day),(2.01 - 16.75 m/day),(0.42 to 5.95 m^2/day) and (0.0068 - 6.134E-16) respectively. The hydraulic properties change from one location to another because of the aquifer lithology heterogeneity which reflect the change of both porosity and permeability.

Table 4- Summary of pumping wells properties in Lailan basin

Well	Coordinates		Well Depth	Static Water level	Saturated thickness	Discharge	Drawdown
	longitudes	latitudes	(m)	(m)	b (m)	Q (l/s)	(m)
W3	44°25'25.53"	35°24'3.70"	156	26.1	59	10	7.69
W4	44°28'40.65"	35°20'58.38"	150	22.18	47	10	6.78
W7	44°32'42.54"	35°14'13.56"	102	31.22	58	10	6.45
W20	44°22'33.73"	35°22'16.06"	96	10.55	33	11	4.79
W22	44°36'38.95"	35°13'38.23"	120	44.32	44	10	7.83
Yarmja	44°25'37.29"	35°18'47.08"	108	23.7	45	11	1.85
Furqan	44°32'41.61"	35°17'41.78"	120	51.79	25	8	18.84

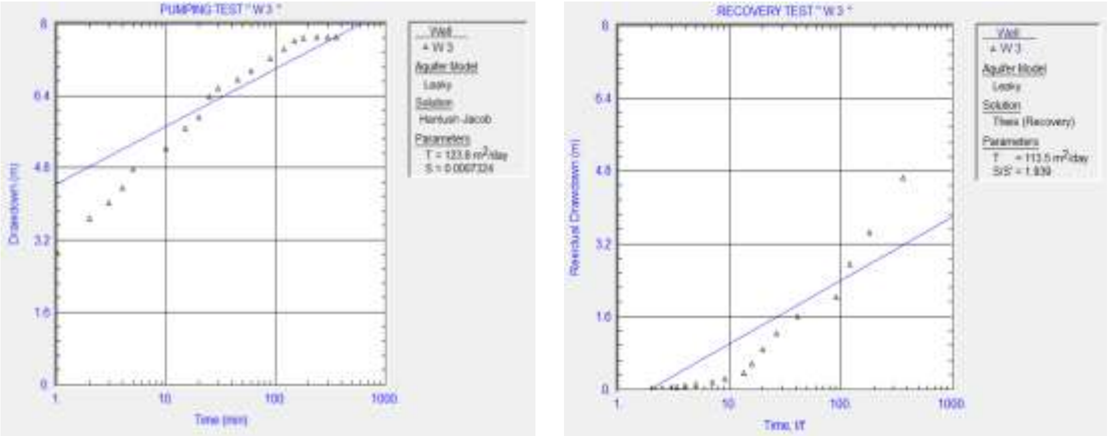

Figure 7 -Time-drawdown and time - residual drawdown curves of well "W3".

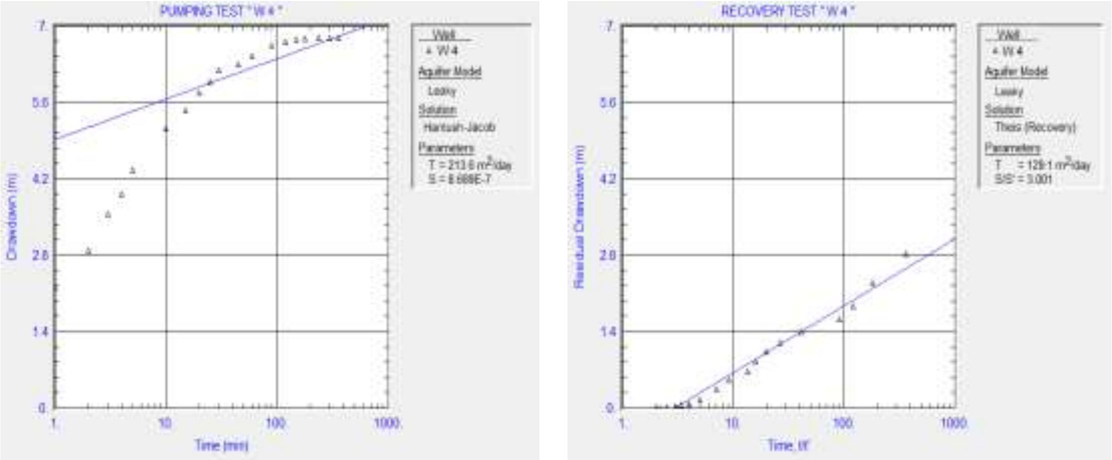

Figure 8 - Time-drawdown and time - residual drawdown curves of well "W4".

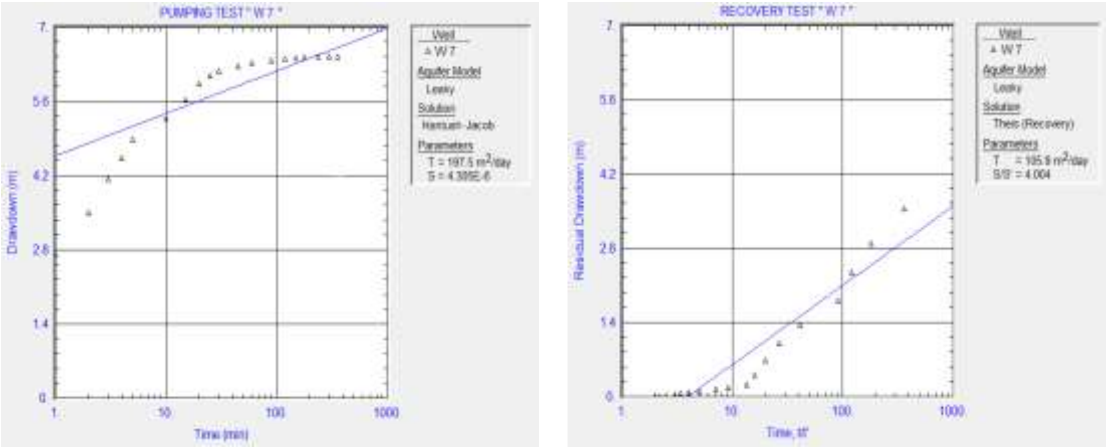

Figure 9 - Time-drawdown and time - residual drawdown curves of well "W7".

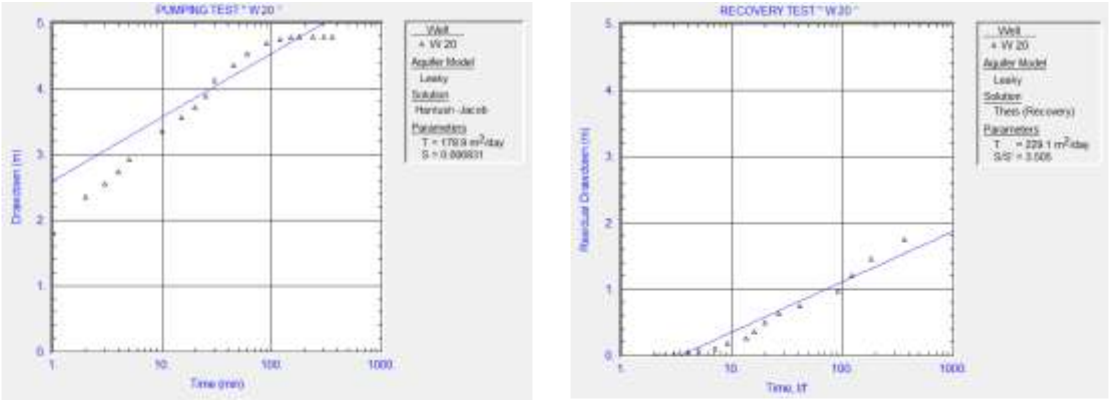

Figure 10 -Time-drawdown and time - residual drawdown curves of well "W20".

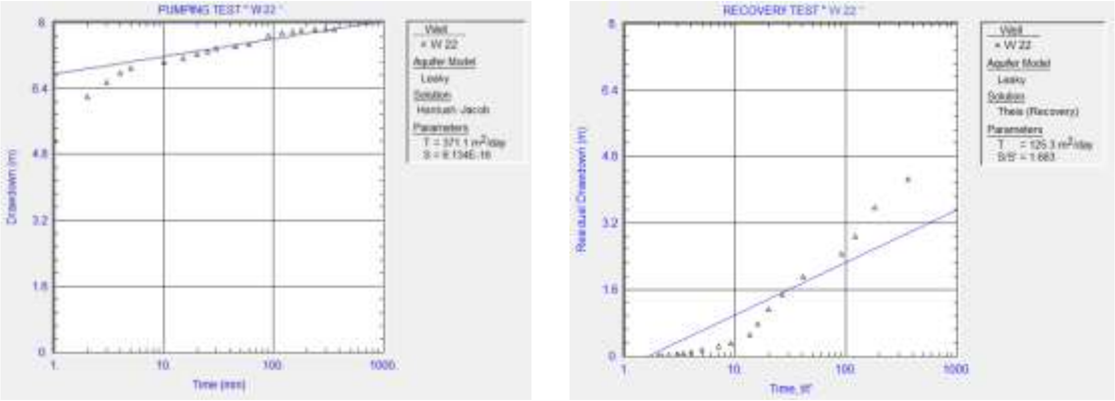

Figure 11-Time-drawdown and time - residual drawdown curves of well "W22".

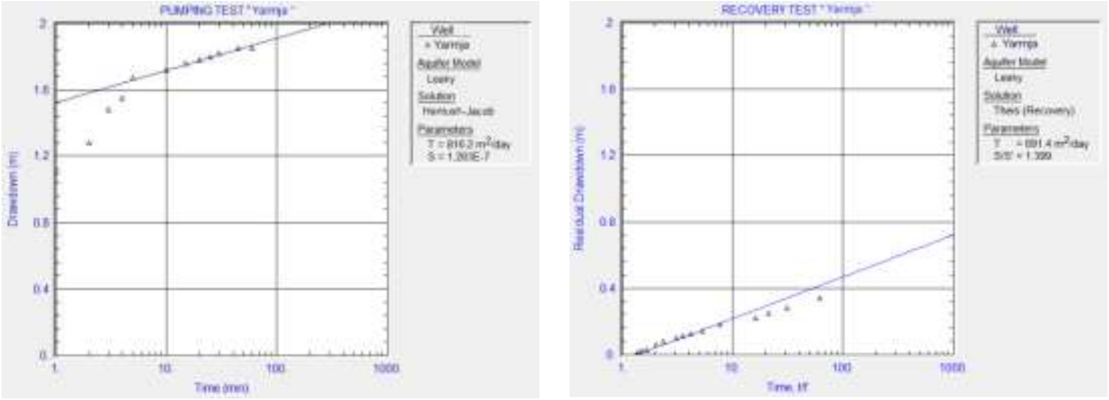

Figure 12 -Time-drawdown and time - residual drawdown curves of well " Yarmja ".

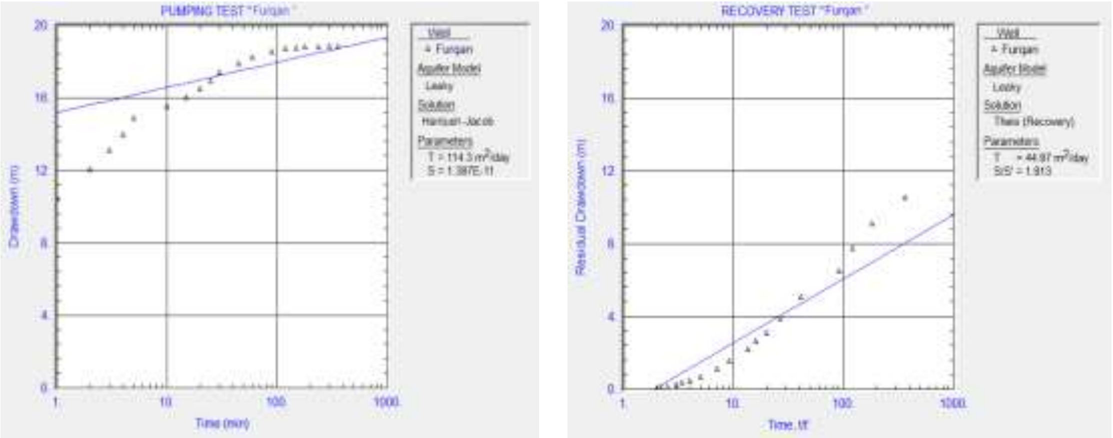

Figure 13 - Time-drawdown and time - residual drawdown curves of well " Furqan ".

Table 5- Summary of results of pumping and recovery tests analysis based on Cooper-Jacob's and Theis recovery methods.

Well	Cooper-Jacob		Theis recovery		T (m^2/day) Av.	K (m/day) Av.	S	Sc (m^2/day)
	T (m^2/day)	K (m/day)	T (m^2/day)	K (m/day)				
W3	123.8	2.10	113.5	1.92	118.65	2.01	0.000732	1.30
W4	213.6	4.54	129.1	2.75	171.35	3.65	8.689E-7	1.47
W7	197.5	3.41	105.9	1.83	151.7	2.62	4.305E-6	1.55
W20	178.9	5.42	229.1	6.94	204	6.18	0.00683	2.30
W22	371.1	8.43	125.3	2.85	248.2	5.64	6.134E-16	1.28
Yarmja	816.2	18.14	691.4	15.37	753.8	16.75	1.263E-7	5.95
Furqan	114.3	4.57	44.97	1.80	79.635	3.19	1.387E-11	0.42

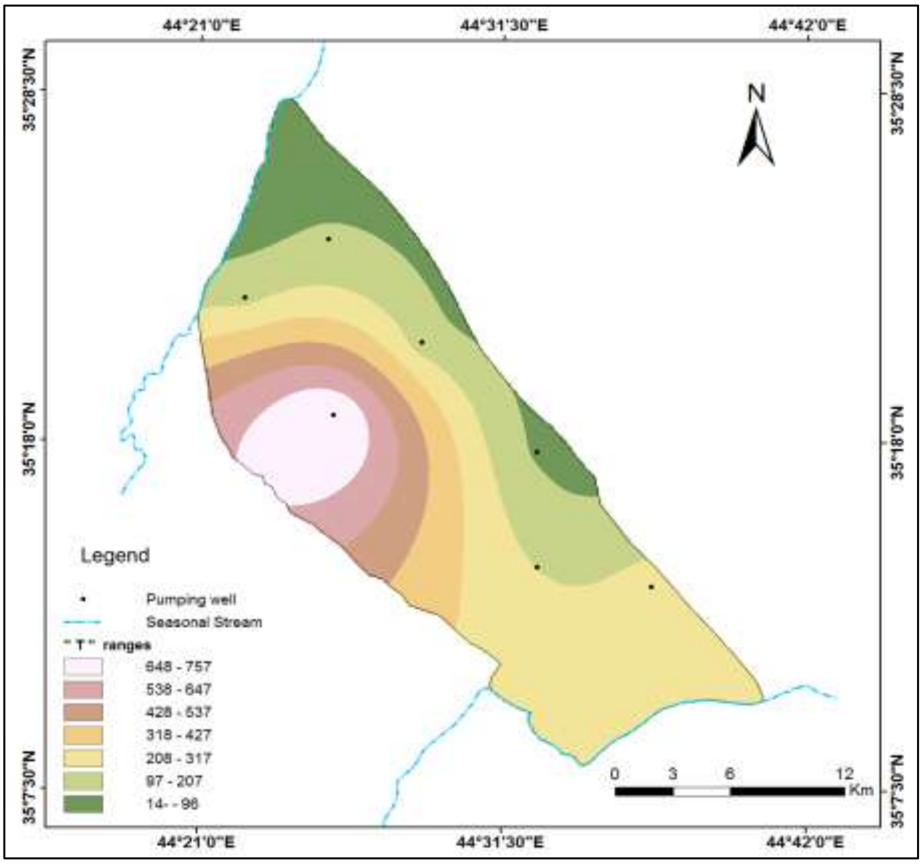

Figure 14-Spatial distribution of the transmissivity values in the study area (m^2/day).

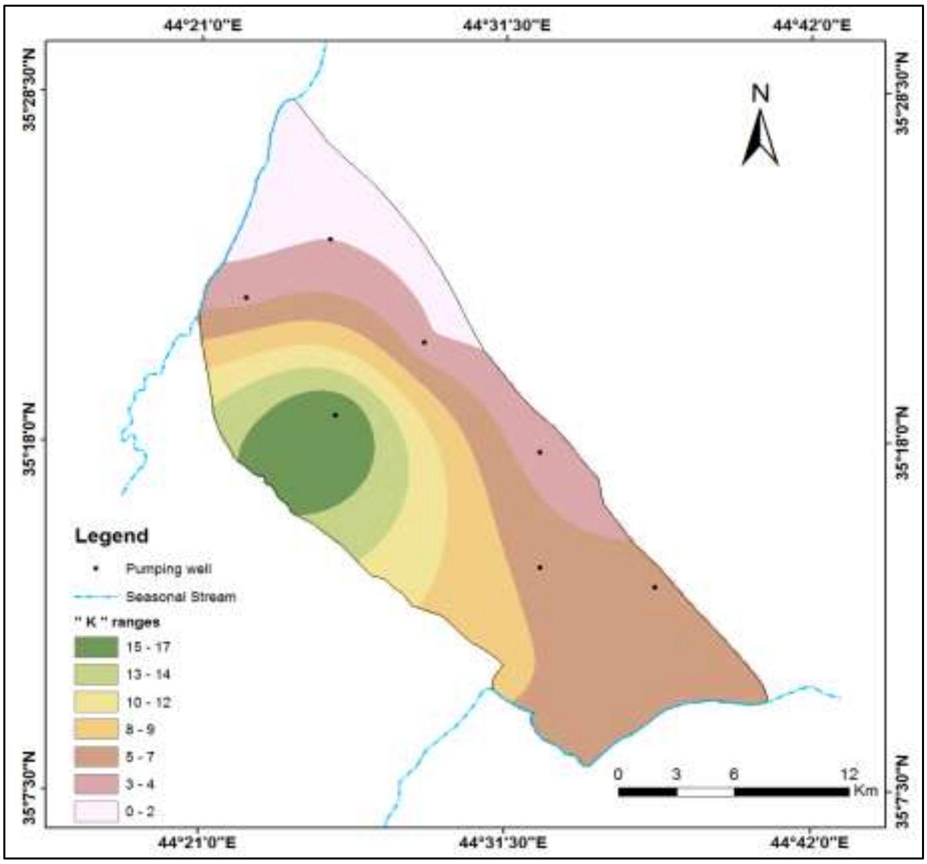

Figure15 -Spatial distribution of the hydraulic conductivity values in the study area (m /day).

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