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HYDROGEOLOGICAL CHARACTERISTICS OF RABIA SUB-BASIN NORTHWEST, IRAQ

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ABSTRACT

At the procedural level and according to climate factors, the study area has an arid climate. About 12.4% of the total rainfall was observed as excess water in the study area over 30 years. The amount of groundwater recharge, measured in millimeters per year at a rate of 16.7 mm/year, was 5.37% of the total rainfall. The main direction of the flow net in the studied area was from west to east, and the water table levels ranged from 321 to 409 m above sea level. The values of a saturated thickness (b) for the Rabia sub-basin were between (73 and 127 m).

Depending on the results of pumping test analysis from eight wells, the hydraulic conductivity values (K) of the Rabia sub-basin aquifer ranged between (2.91 to 5.55) m/day. The Transmissivity (T) values ranged from (235.3 to 704.2) m²/day, while the storage coefficient (Sc) values ranged between (1.16×10^{-4} to $3.98 \times 10^{-}$). This value indicates that the aquifer is confined.

INTRODUCTION

Water is one of the greatest gifts that God Almighty has given His servants. It is the source of life for all living things and the reason that life is possible on the surface of the earth, demonstrating the significance of water's presence wherever it occurs. No living thing can ever survive without it. Groundwater is significant not only on a local level but also globally, as more than 2 billion people depend on it on a daily basis (Kemper, 2004) Therefore, groundwater must be understood and investigated groundwater as a suitable substitute for surface water if it is not available.

Aquifer studies are crucial in order to understand its hydraulic properties, movement, and course, which are particularly significant in the study area in terms of investing in groundwater, such as in agriculture and groundwater management (Walton, 1970). According to hydrogeological, the aquifer system in the Low Folded Zone has recently been divided into thirteen parts, (Al-Jiburi and Al-Basrawi, 2012; Figure 1). The Rabia sub-basin is located in the spatial distribution of the aquifer systems in the Low Folded Zone.

The location of the study area is in the northwest of Nineveh Governorate, extending from longitude (42º 04' 19.102" – 42º 40' 37.471") and latitude (36º 29' 18.135" – 36º 56' 24.471"). The area of the sub-basin has been determined using GIS, which is 1679.94 Km².

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Part of the sub-basin is located outside the borders of Iraq (Syria), covering an area of 58.7 Km² (Figure 2), Through fieldwork, the study area contains 54 villages distributed over most of the sub-basin areas. The sub-basin is surrounded by folds, the largest of which is the Sinjar Anticline and the Ain Zala Anticline. The study area is characterized by sediments and geological formations extending from Miocene to the Quaternary (Figure 3; Sissakian, 1995). Based on the above, the study aims to determine the hydrogeological characteristics of the Rabia Sub-Basin.

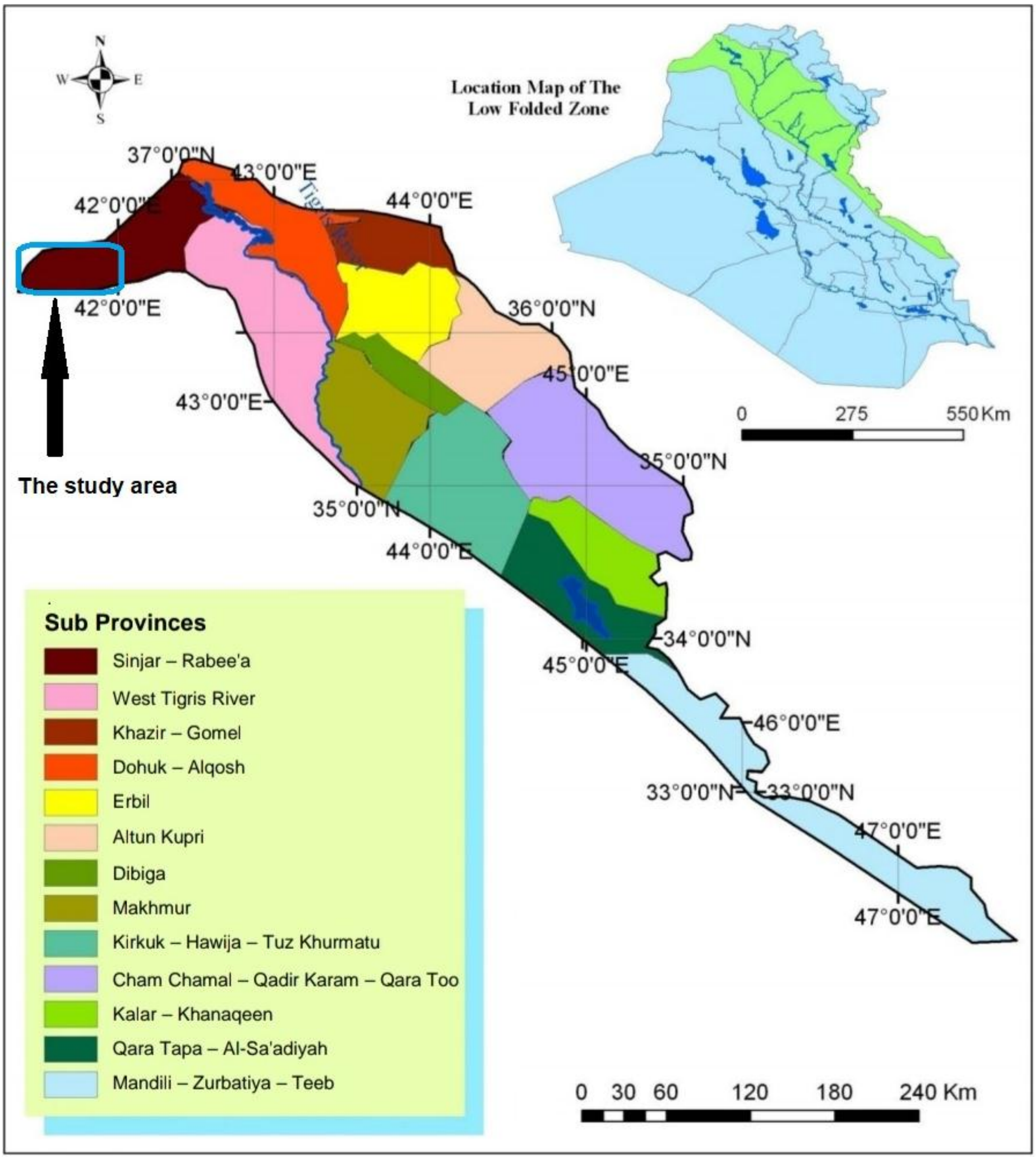


Figure 1: Spatial distribution of the aquifer systems in the Low Folded Zone modified from (Al-Jiburi and Al-Basrawi, 2012).

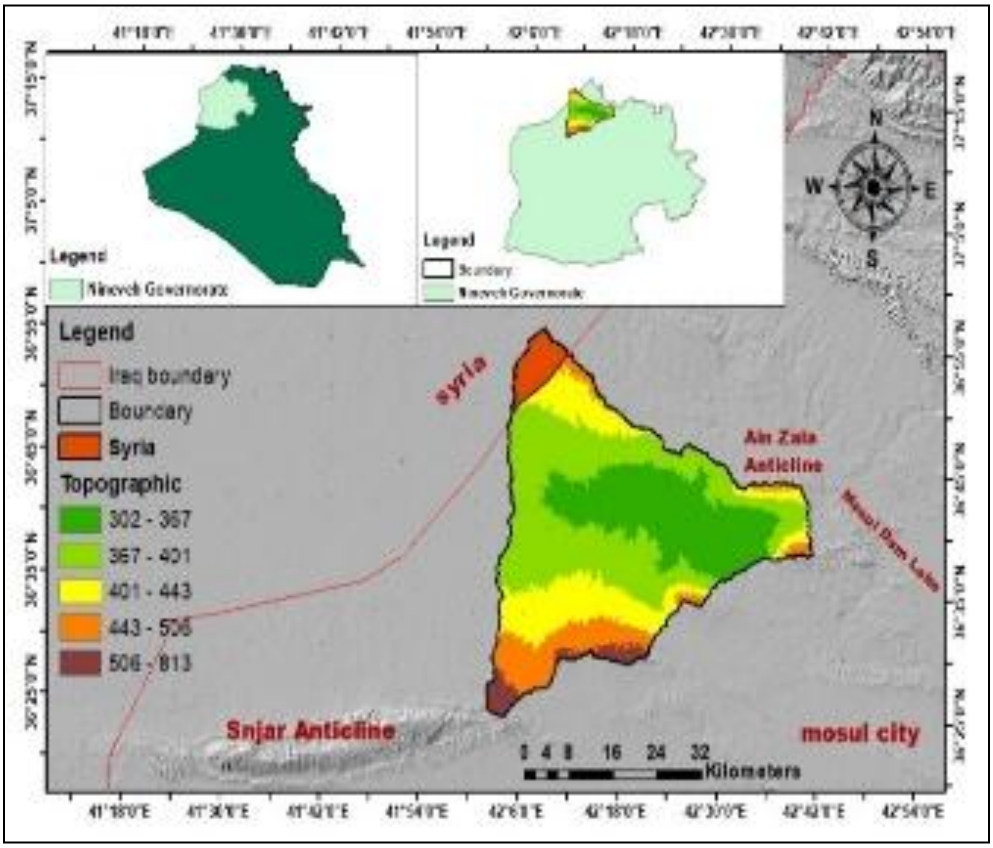


Figure 2: Location of the study area.

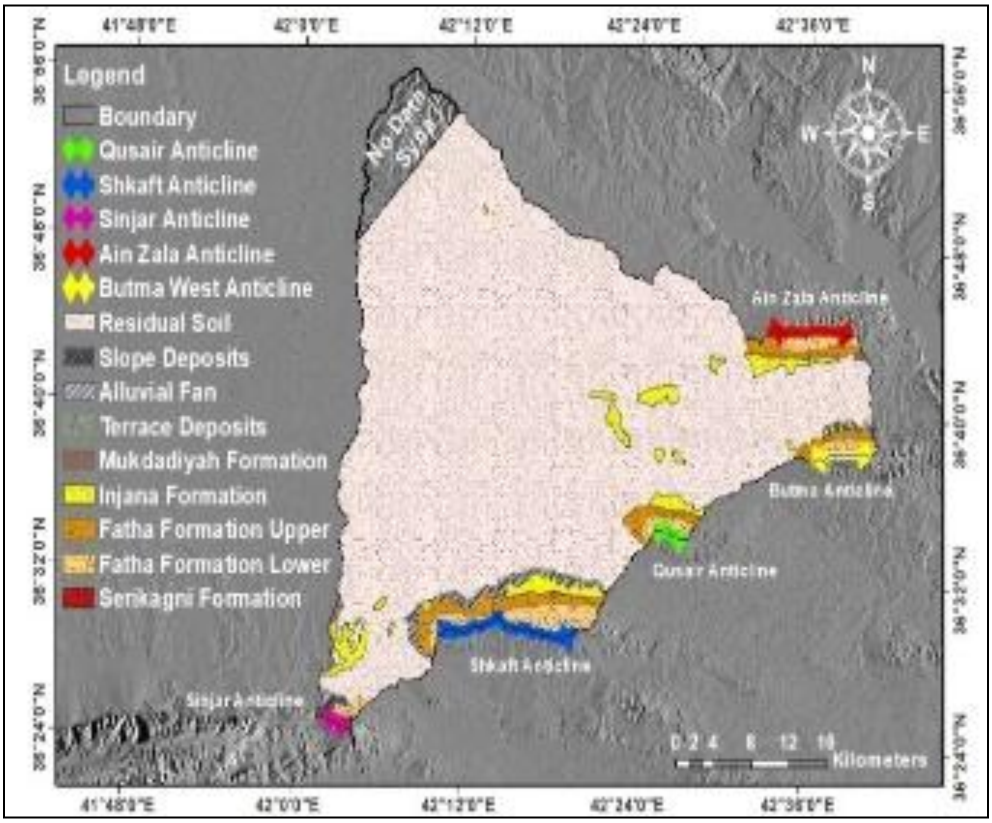


Figure 3: Geological map of the studied area modified from (Sissakian, 1995).

MATERIALS AND METHODS

- **Climate**

The climate is defined as weather variations across a large region and over a long enough duration of time to determine all statistical attributes (Kite, 1989). There are many factors that affect the hydrogeology of any area, where the climate is considered one of the important factors affecting the hydrogeology of the Rabia sub-basin.

Depending on the stations (Talafar, Rabia, and Sinjar) within the study area, there is an interruption in the recording of climate data from After the year 2014 to 2021 due to the wars that the study area experienced.

The conclusion from the foregoing climate dataset is that the rain and the relative humidity have a direct relationship, while both of them have an inverse relationship with the rest of the climatic elements (Figure 4). In other words, the more rain, the higher the relative humidity, and the lower the temperature, Sunshine duration, and evaporation time.

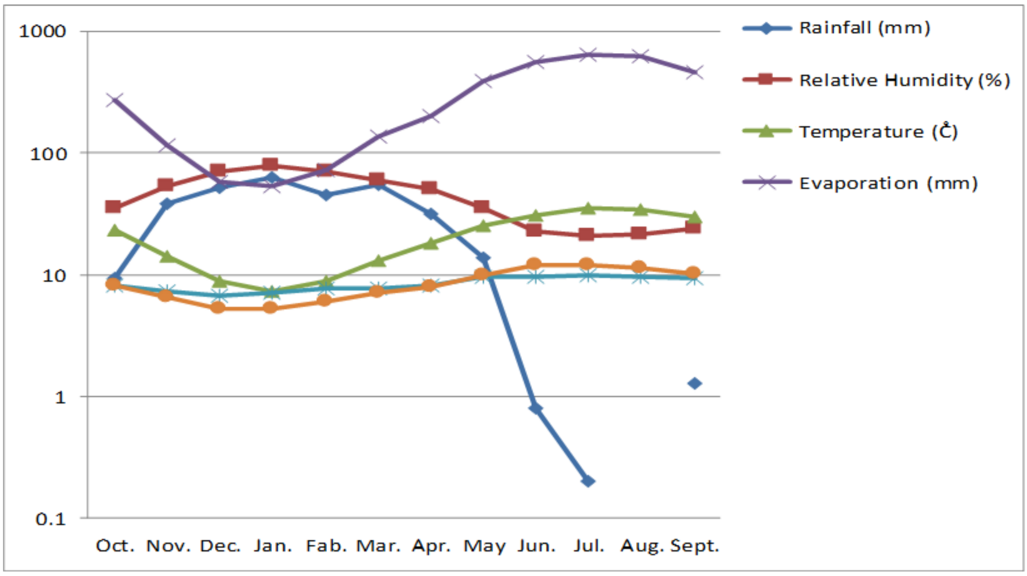


Figure 4: Shows the various relations between the mentioned elements in the study area for the period (1984 – 2014).

– **Climate classification:** Climate classification is caused by many reasons based on various objectives. These classifications are based on a variety of variables or elements in order to determine the type of climate in the study field, as well as the complexity of combining them into a single classification (Al-Hassani and Al-Sahaf, 1990).

– **Mather classification** (1974)**:** The classification proposed by Mather (1974), is based on the Aridity Index (AI) and describes the ratio of rainfall (P) to correct evapotranspiration (PEc) (Tables 1 and 2).

The Aridity index is given as:

$$AI = \{(P/PEc) - 1\} * 100 \text{ ------------------------------ } (1)$$

where AI: Aridity Index, P: Total Rainfall (mm), PEc: Total Correct evapotranspiration (mm).

According to Table (2), the values of the aridity index (AI) become as follows:

$$AI = \{(310.7/1186.928) - 1\} * 100 = \mathbf{-73.8} \text{ mm}$$

Table 1: Climate classification according to Mather (1974).

Climate type	Range of AI	AI in the studied area
Dry-sub humid	0.0 to -33.3	
Semi-Arid	- 33.3 to - 66.6	
Arid	- 66.6 to -100	- 73.8

According to the classification recommended by Mather (1974), the AI is (-73.8), indicating that the study area is arid.

Table 2: The mean monthly evapotranspiration values using the Thornthwaite method for the period (1984 – 2014).

month	Temperature (°C)	P	j	PE (mm)	K	PEc (mm)	Evaporation (mm)
Oct.	23.5	9.4	10.41	85.8	0.97	83.3	272.3
Nov.	14.1	38.3	4.80	26.1	0.86	22.5	115.9
Dec.	8.8	51.7	2.35	8.7	0.87	7.6	58.3
Jan.	7.4	63.2	1.81	5.8	0.88	5.1	54.3
Fab.	8.8	45.9	2.35	8.7	0.86	7.5	73.5
Mar.	13	54.5	4.25	21.6	1.04	22.4	136.6
Apr.	18.3	31.5	7.13	47.9	1.09	52.1	201.0
May.	25.5	13.9	11.78	103.7	1.17	121.1	396.6
June	31.2	0.8	15.99	165.9	1.19	196.6	566.4
July	35.3	0.2	19.28	221.1	1.22	268.9	644.9
Aug.	34.6	0	18.73	211.0	1.14	241	618.1
Sept.	30.3	1.3	15.30	154.9	1.02	158.7	462.3
Total		310.7	J=114.2	1061.2		1186.9	3600.2

- **Water Balance**

To find the water balance, one must identify the factors affecting water loss and the factors affecting the increase in water. One of the most important factors affecting water loss is evapotranspiration, which is an important part of evaporation in general. The amount of evaporated water is inversely proportional to the increase in water. Table (2) shows the result of determining potential evapotranspiration (PE) values.

The highest value of potential evapotranspiration (PE) is **221.16** mm in July, while the lowest value is **5.83** mm in January, for a total of **1061.2** mm. The total sum of corrected evapotranspiration (PEc) is **1186.93** mm, with the highest value of **268.9** mm in August and the lowest value of **5.15** mm in January.

Rainfall is the major input parameter in the water balance of the study area, while major output factors are discharge from wells and evapotranspiration. According to Todd (2007), the water balance equation is.

$$\text{Input-Output} = \Delta S \text{ ----------------------------- (2)}$$

where: ΔS: change in storage.

According to Food and Agriculture Organization (FAO) (Nachtergaele *et al.*, 2012), the soil moisture (SM) in the study area is 150 mm.

$$WS = P \text{ ----------------------------- (3)}$$

PEc = APE, when P > Pec

WS = (P – PEc) – SM ------------------------------ (4)

Where WS = 188.5 – 150, WS = **38.5** mm, WS: water surplus (mm), P: rainfall (mm), PEc: corrected evapotranspiration (mm), APE: actual evapotranspiration (mm), and SM: soil moisture Table (3).

WS % = WS / P × 100 ------------------------------ (5)

where WS: water surplus (mm), WD: water deficit (mm), APE: actual Evapotranspiration (mm), and WS% = (38.5 /310.7) *100 = **12.4 %**

WD = PEc – P ------------------------------ (6)

P = PE, when P < PEc ------ WD: water Deficit (mm)

The water deficit (WD) ratio can be represented as:

WD% = 100 – WS % ------------------------------ (7)

WD% = 100 - 12.4 = **87.6 %**

The value of WS may be used to determine groundwater recharge volume. Surface runoff in the Rabia Sub-basin was approximated using the following equation based on experimental work by Sogreah (1983):

SR (mm) = 0.167× [P (mm) – 180] ------------------------------ (8)

Where SR = surface runoff (mm), P = total annual rainfall (mm), and SR = 0.167 × [310.7-180] = **21.8** mm

Fetter (1980) considered that the water surplus (WS) includes surface Runoff (SR) and groundwater recharge (GR) as in the equation below:

WS = SR + GR ------------------------------ (9)

GR = WS – SR = 38.5 – 21.8 mm = **16.7** mm is the amount of groundwater recharge in the study area Groundwater % = 16.7 / 310.7 × 100 = **5.37** % of the total rainfall

where a percentage (5.37) of annual rainfall almost penetrates groundwater.

Table 3: The monthly main of water surplus and water deficit for the studied area period (1984 – 2014).

Month	P	PEc	APE	WS	WD
Oct.	9.4	83.26	9.4	0	73.86
Nov.	38.3	22.54	22.54	15.76	0
Dec.	51.7	7.56	7.56	44.14	0
Jan.	63.2	5.15	5.15	58.05	0
Fab.	45.9	7.48	7.48	38.42	0
Mar.	54.5	22.39	22.39	32.11	0
Apr.	31.5	52.09	31.5	0	20.59
May.	13.9	121.15	13.9	0	107.25
Jun.	0.8	196.62	0.8	0	195.82
Jul.	0.2	268.9	0.2	0	268.7
Aug.	0	241.02	0	0	241.02
Sept.	1.3	158.74	1.3	0	157.44
Total	310.7	1186.928		188.5	1064.68

- **Groundwater Depth**

Through the fieldwork, 54 villages located within the boundaries of the Rabia sub-basin were visited, 38 wells were employed for the purposes of the study and 16 wells were neglected because they were closed and could not be investigated. The depth of groundwater was measured by a sounder during the end of the summer season and spring season as shown in Table (4).

Table 4: The hydrologic information of Rabia sub-basin.

Well No.	Longitude	Latitude	Location	Elevations (m.a.s.l)	Depth of water (m)	Water table (m.a.s.l)	Well depth (m)
W1	42°10'52"	36°52'10"	Mahmoudia	433	27.8	405.2	190.00
W2	42°12'26"	36°32'14"	Al-akhween	436	27	409	288.00
W3	42°13'01"	36°51'30"	The second Asefiya prj	431	35	396	200.40
W4	42°08'24"	36°49'35"	Jilbahrat	406	23	383	168.00
W5	42°11'30"	36°48'40"	Bir Aglah	400	20.5	379.5	199.00
W6	42°10'25"	36°47'44"	Tal Hayal	390	13	377	222.00
W7	42°07'01"	36°47'51"	Alsada - Rabia	388	9	379	200.00
W8	42°05'36"	36°47'00"	Al-ekhwa	383	5	378	250.00
W9	42°08'12"	36°45'29"	Al- Jlobe	382	5.5	376.5	258.00
W10	42°07'16"	36°44'17"	Abu Khashab	380	4.5	376.5	252.00
W11	42°10'44"	36°42'53"	Ajil	369	4.5	364.5	300.00
W12	42°04'31"	36°42'54"	Rjm Hassan	397	16	381	250.00
W13	42°05'35"	36°32'31"	Abakh El Shour	427	22	405	160.00
W14	42°08'02"	36°40'32"	Algana	383	5.75	377.25	260.00
W15	42°04'17"	36°33'14"	Tal al-Bayader	420	20	400	256.00
W16	42°05'25"	36°37'51"	Al Azaem	391	10.5	380.5	250.00
W17	42°14'18"	36°40'22"	Almajihim	369	14	355	252.00
W18	42°17'21"	36°42'26"	Beader Thtany	355	5	350	256.00
W19	42°12'45"	36°45'52"	Abu Hujairah	390	23	367	198.00
W20	42°15'45"	36°48'44"	Mushrif Village	407	32.5	374.5	240.00
W21	42°18'04"	36°45'11"	Tal Al Hawa	384	18	366	198.00
W22	42°16'05"	36°46'38"	Tal Al Hawa Group	369	10	359	208.2
W23	42°21'22"	36°43'29"	Tall Wardan	355	8	347	200.00
W24	42°20'29"	36°46'03"	Gran (2)	378	20	358	198.00
W25	42°25'34"	36°41'16"	Aweinat	352	9	343	180.20
W26	42°14'58"	36°45'28"	Injana control well	381	19.9	361.1	140.00
W27	42°30'59"	36°40'46"	Southern Caraccafer	333	8.5	324.5	230.00
W28	42°37'24"	36°41'31"	Abu Wajnah	355	34	321	198.00
W29	42°27'06"	36°37'19"	Abu Walee	357	24	333	256.00
W30	42°22'33"	36°37'22"	Khurmar	363	19	344	186.00
W31	42°18'18"	36°37'06"	Almuthalathah1	381	29.3	351.7	250.00
W32	42°17'08"	36°37'56"	Almuthalathah2	379	27	352	226.00
W33	42°14'27"	36°38'32"	Cuapr	381	25	356	248.00
W34	42°13'35"	36°36'47"	Khuttaf Village	397	23.5	373.5	180.00
W35	42°09'53"	36°35'39"	Al Katour Village	399	16	383	130.00
W36	42°21'46"	36°35'35"	Burghliya	370	21.5	348.5	35.00
W37	42°17'38"	36°35'07"	Umm Hajrah	402	32	370	131.00
W38	42°20'18"	36°32'43"	Bir alhullw	412	39	373	146.00

The depths of groundwater have been determined within Quaternary sediments and the Injana Formation of the Rabia sub-basin. The depths of the groundwater ranged from 4.5 to 39 m where the maximum depth of the Rabia sub-basin groundwater appeared in the southeastern part of the study area (W38) and the lowest depth in the western part of the study area (W10 and W11) (Table 4 and Figure 5).

- **Groundwater Flow and Water Table**

The data in Table (4) indicates the groundwater levels in 38 wells in the Rabia sub-basin. It is necessary to know the groundwater levels of the Rabia sub-basin to know the water table in each of the villages within the Rabia sub-basin and the highest and lowest water tables, as well as the direction and distribution of groundwater, for investment purposes.

In these wells, the lithology of ten wells in the Rabia sub-basin is described by using (Strater 5) software (W4, W14, W16, W13, W21, W17, W37, W23, W25, and W28) as shown in Figure (6).

The variation between levels of groundwater in the aquifer and the degree of slope of the aquifer determine the flow of groundwater (Domemico and Schwartz, 1998).

The water table of the study area results from the difference between the depth of groundwater and elevation for each well, water table levels in the study area ranged from 321 m to 409 m above sea level.

Evident from the water table values that the main direction movement of the groundwater in the area is from the northwest and southwest (Jilbahrat village and Mahmoudia village) represented by (W4 and W1) (Net Recharge) towards the east (Abu-Wajnah village) represented by (W28) which represents the discharge area from Rabia sub-basin.

By using ArcGIS (V. 10.4) tools, we show the color of gradients the direction, and values of the water table within the Rabia sub-basin area (Figure 7).

- **Pumping Test**

The basic idea behind a pumping test is that if pumping water from a certain well and measuring the discharge of another well within a determined distance as well as the drawdown in the well at known distances from the well, the researcher can plug these data into an accurate well-flow equation and calculate the aquifer hydraulic characteristics (Kruseman and de Ridder, 1994).

Through reconnaissance tours at the beginning of the fieldwork, measuring static water levels and fixing well sites, a group of wells covering the study area was selected to conduct the test pumping in those areas and to identify the hydraulic characteristics and determine the type of aquifer, the wells selected for monitoring in the test pumping process were (W4, W13, W14, W17, W21, W25, W28, and W37) considering that these wells are distributed on all sides of the study area.

The positions of the pumping and observation wells within the Rabia sub-basin were determined using GPS, and the altitudes were modified in the area using the Digital Elevation Model (DEM) to prevent GPS errors as shown in (Figure 8).

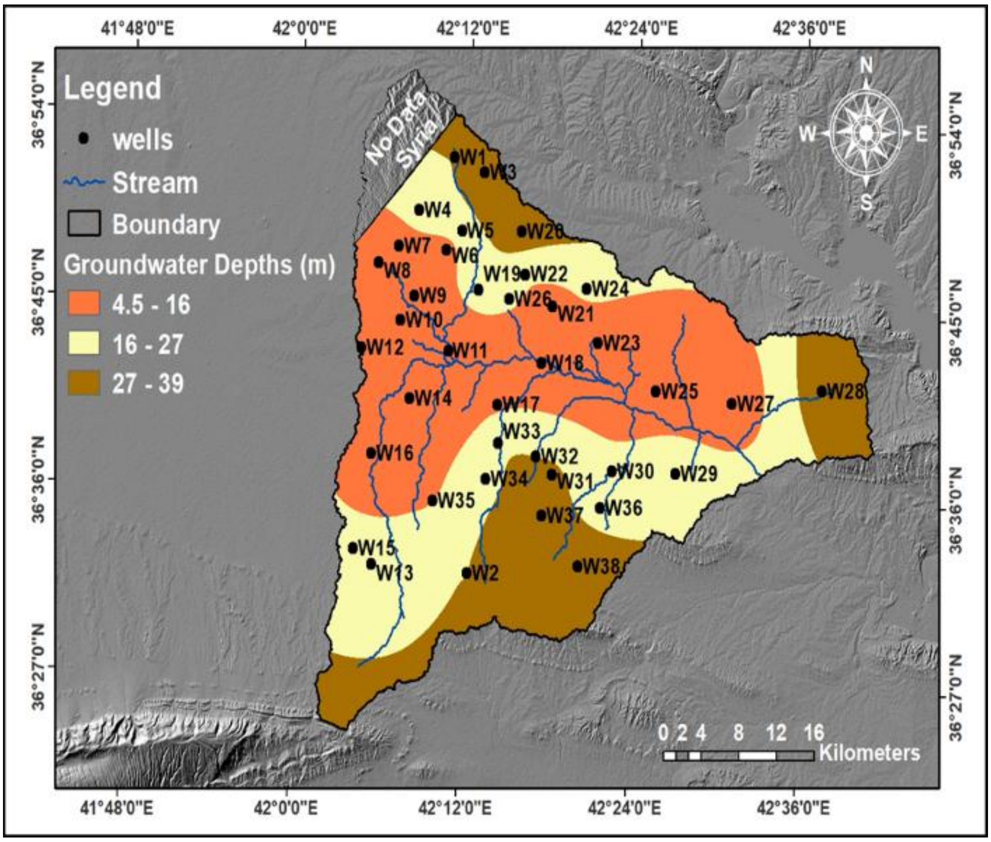


Figure 5: Depth of the groundwater map of the Rabia sub-basin.

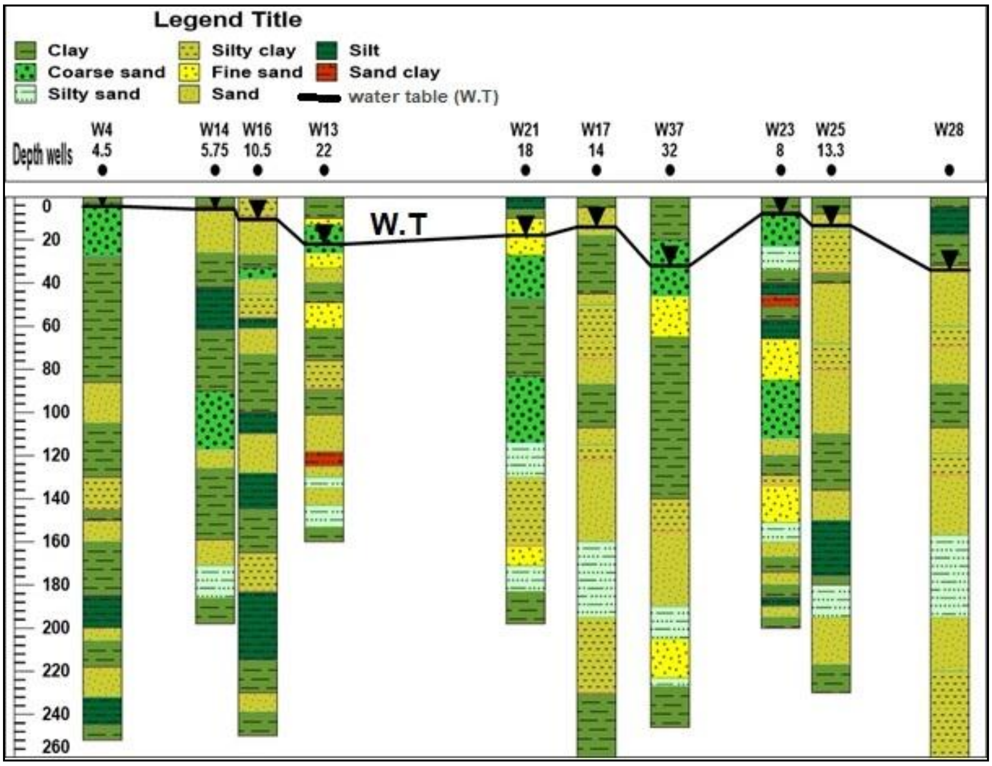


Figure 6: Hydrogeology and lithological profile for some wells of the Rabia sub-basin modified after (the General Commission of Groundwater/ Nineveh).

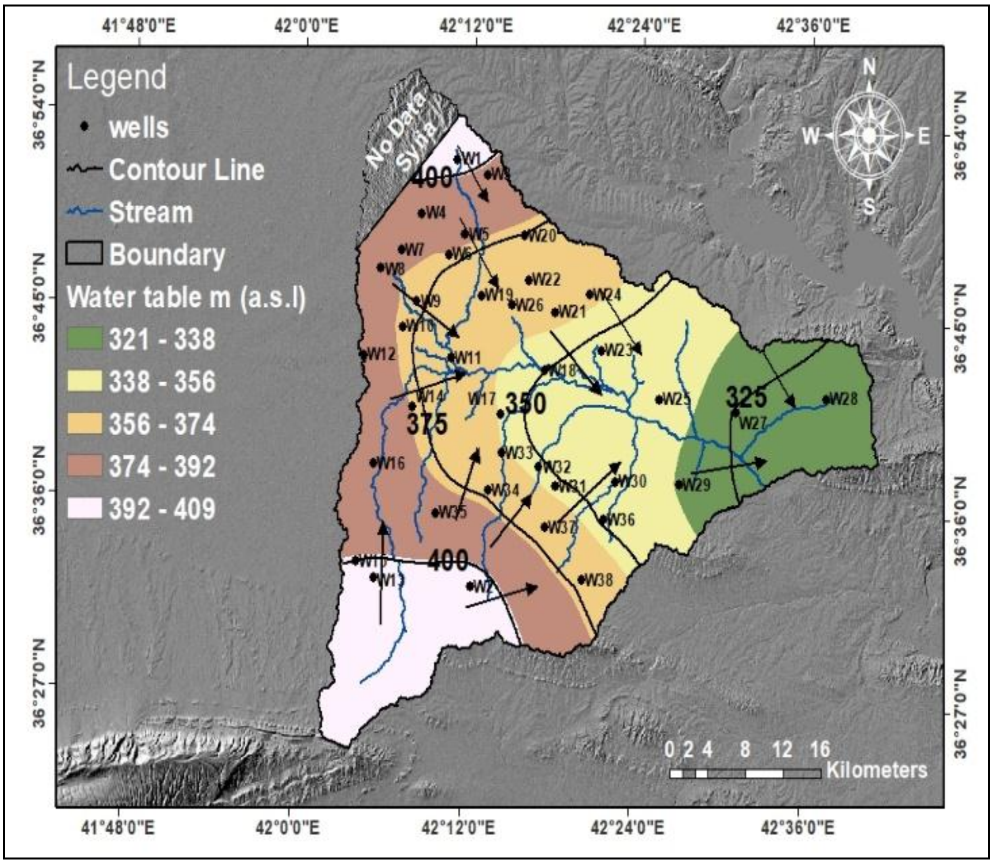


Figure 7: Water table map of the Rabia sub-basin.

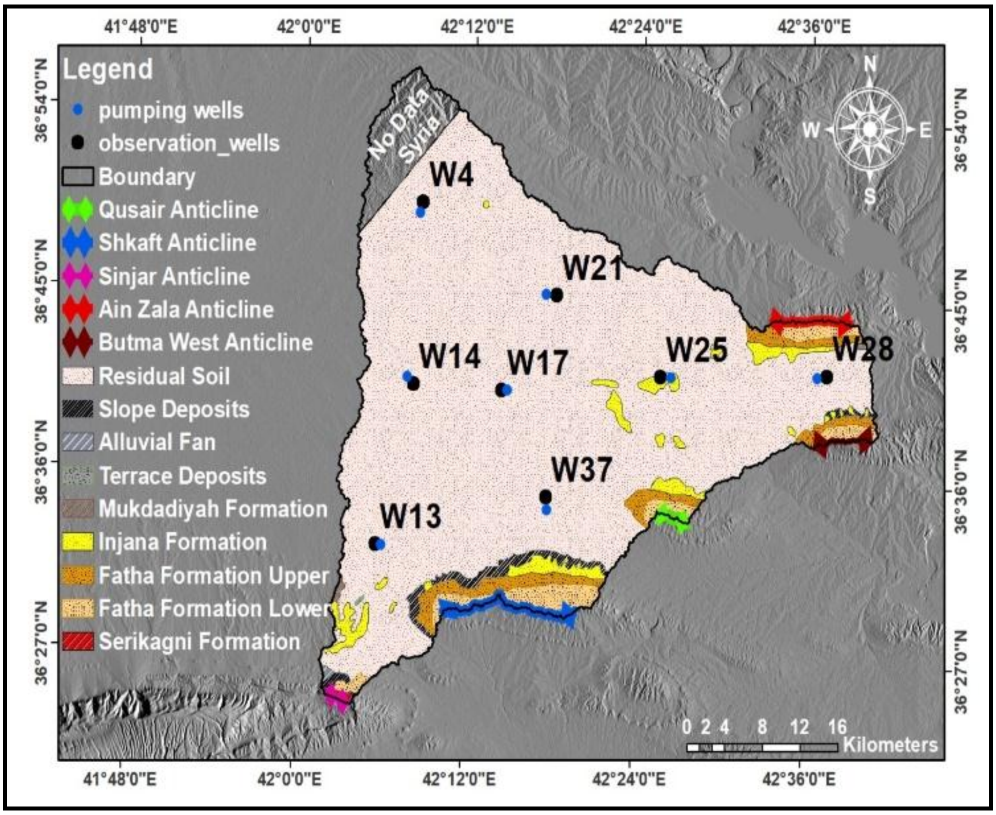


Figure 8: Selected wells for pumping test analysis of the Rabia sub-basin.

During ~30 days, from mid-March to mid-April 2021, a performance pumping test for eight wells was conducted in the Rabia sub-basin to obtain (transmissivity and storage coefficient), which is important in determining vulnerability.

The information on time and drawdown of the groundwater level has been listed in each well of the observation wells using aquifer win 32 software to obtain the hydraulic properties accurately.

- **Hydraulic Characteristics**

– **Hydraulic conductivity (K):** It is the amount of water that moves in the porous medium per unit of time under the unit hydraulic gradient in an area and at an angle perpendicular to the direction of flow (Kruseman and de Ridder, 1994).

Hydraulic conductivity is a significant parameter for determining the number of pollutants flowing downwards by influencing of transition of groundwater into the saturation zone (Amit *et al*., 2021).

$$K = T / b \text{ ------------------------------ } (10)$$

K: Hydraulic conductivity (m/d), T: Transmissivity (m^2/d), and b: Saturation Thickness (m).

– **Transmissivity (T):** The quantity of water that may be transported horizontally through an aquifer unit by the full saturated thickness of the aquifer for a unit hydraulic gradient is defined as transmissivity (T) (Sharp, 2007).

Transmissivity values are changing based on the lithology in the fieldwork location, as in equation (2). The capacity of an aquifer to pass groundwater is measured by its conductivity (Walton, 1970).

$$T=K * b \text{ ------------------------------ } (11)$$

T: Transmissivity (m^2/d), K: Hydraulic conductivity (m/d), and b: Saturation Thickness (m).

– **Storage coefficient (Sc):** The aquifer's capacity to store or release water is measured by the value of its storage coefficient, or storativity (S), which is determined by the aquifer's elasticity and the fluid's compressibility, as well as the aquifer type. In a confined aquifer, S is the specific storage (Ss) multiplied by the thickness of the aquifer. S is approximately equivalent to the specific yield in an unconfined aquifer, (S) is basically identical to the specific yield (Sy) or effective porosity of an unconfined aquifer, which delivers water by physical dewatering or gravity drainage of the material through, which the water table declines (Sharp, 2007).

- The methods used to calculate hydraulic characteristics
  1. **Cooper and Jacob's method (1946):** In this method a semi-log plot of the field drawdown data (Sw) versus time (t), the equation below can be set to determine transmissivity (T) values as follows (Todd, 2007):

$$T: 2.3\, Q/4\pi\Delta S \text{ ------------------------------ } (12)$$

$$Sc: 2.25Tt^{\circ}/r^2 \text{ ------------------------------ } (13)$$

T: Transmissivity (m^2/d), Q: Pumping rate (m^3/d), ΔS: Drawdown through one cycle logarithmic, t°: Cross straight Line with a time axis, r^2: Distant between pumping well and observation well, and Sc: Storage coefficient.

2. **Theis method (1935):** It was the first to include the time component and storativity into a formula for unsteady-state flow. When a well penetrating a wide confined aquifer is pumped at a steady rate, the discharge's impact extends outward with time, observed. The discharge is equal to the rate of decrease of the head multiplied by the storativity and aggregated over the region of effect. (Kruseman and Ridder, 1979).

$$T=Q/4\pi s*W(u) \text{ ------------------------------ } (14)$$

$$Sc=4uTt/r^2 \text{ ------------------------------ } (15)$$

T: Transmissivity (m^2/d), Q: Pumping rate (m^3/d), s: Draw down (m), W (u): Theis well function, and Sc: Storage coefficient

PUMPING TEST ANALYSIS

A pumping test is a process of pumping from a well and monitoring from another well within a limited distance and measuring the discharge in the observation well with time and representing these values in an equation, which results in the hydraulic properties.

The start of pumping work is on the 13th of March after laying the foundations required for the pumping process. Fortunately, it was noted that it is possible to pump from eight wells in the sub-basin Rabia (W4, W13, W14, W17, W21, W25, W37, and W28). Pumping wells were distributed over the study area in an attempt to cover the area completely, as shown below.

- **W4**

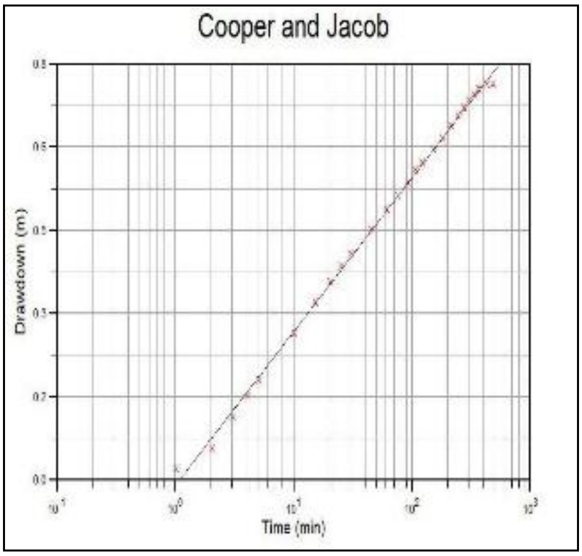
Well (W4) is located in Jilbahrat village and penetrates Quaternary sediments and Injana Formation, coordinates of pumping and observation wells are (42º 08' 12" – 36º 40' 23") and (42º 08' 24" – 36º 49' 35"), respectively. The groundwater level (static water level) in the pumping and observation wells are (23.2 m) and (23 m), respectively, and the distance between them is (57 m).

The depth of the observation and pumping wells is (252 m). At an elevation of (406 m) for two wells. The pumping rate was (4.51 L/sec). The transmissivity value was (241.234 m^2/d) and the Storage coefficient was (0.0001248) by the Cooper-Jacob method Figure (9A), while for the Theis method, the transmissivity value was (240.155 m^2/d) and the Storage coefficient (0.0001097) as shown in Figure (9B).

- **W13**

Well (W13) is located in Abakh El Shour village and penetrates Quaternary sediments and Injana Formation, coordinates of the pumping and observation wells are (42° 05' 59" – 36° 32' 30") and (42° 05' 35" – 36° 32' 31"), respectively. The groundwater level (static water level) in the pumping and observation wells are (22.35 m) and (22 m), respectively, and the distance between them is (53 m).

The depth of the observation and pumping wells is (160 m). At an elevation of (427 m) for two wells. The pumping rate was (4.61 L/sec). The transmissivity value was (237.932 m^2/d) and the Storage coefficient was (0.0001275) by the Cooper-Jacob method Figure (10A), while for the Theis method, the transmissivity value was (232.759 m^2/d) and Storage coefficient (0.0001129) as shown in Figure (10B).



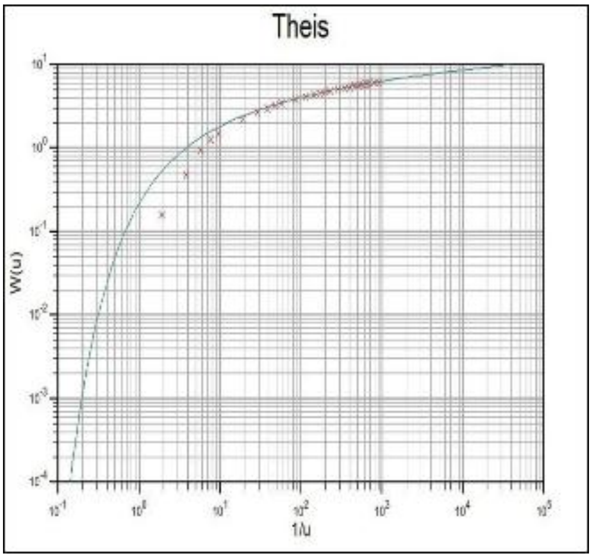
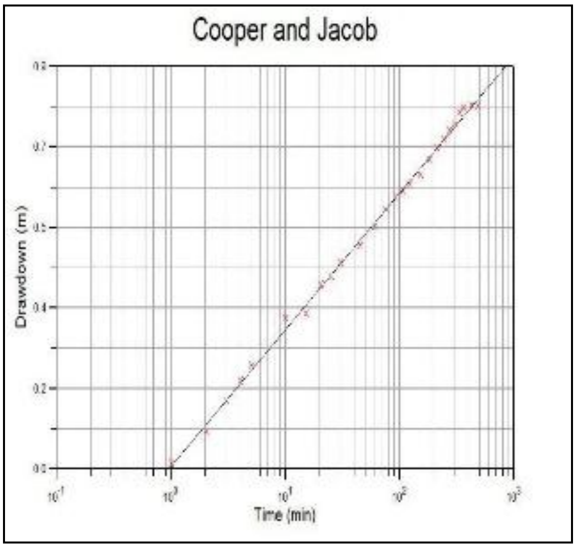


Figure 9A: Pumping test data analysis (W4) Cooper.

Figure 9B: Pumping test data analysis (W4) Theis.



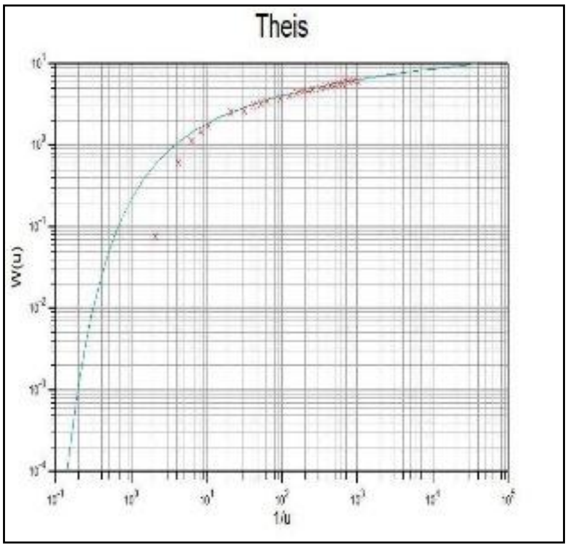
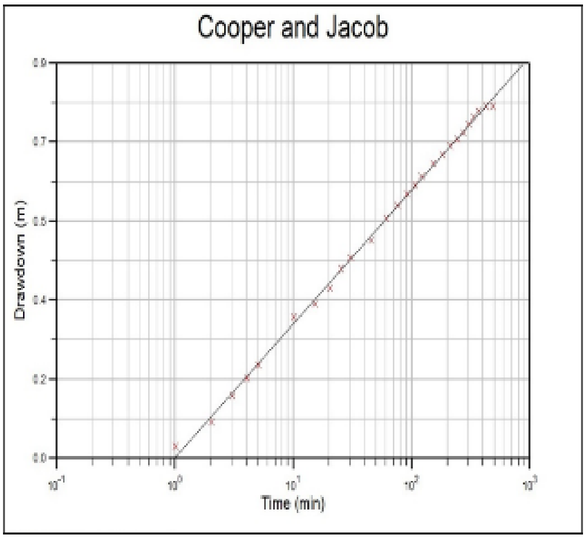


Figure 10A: Pumping test data analysis (W13) Cooper.

Figure 10B: Pumping test data analysis (W13) Theis.

- **W 14**

Well (W14) is located in Algana village and penetrates Quaternary sediments and Injana Formation, coordinates of the pumping and observation wells are (42° 07' 34'' – 36° 40' 54'') and (42° 08' 02'' – 36° 40' 32''), respectively. The groundwater level (static water level) in the pumping and observation well is (5.9 m) and (5.75 m), respectively, and the distance between them is (51 m). The depth of the observation and pumping wells is (198 m). At an elevation of (383 m) for two wells. The pumping rate was (4.7 L/sec). The transmissivity value was (246.345 m^2/d) and the Storage coefficient was (0.0001462) by the Cooper-Jacob method Figure (11A), while for the Theis method, the transmissivity value was (246.054 m^2/d) and the Storage coefficient (0.0001542). as shown in Figure (11B).



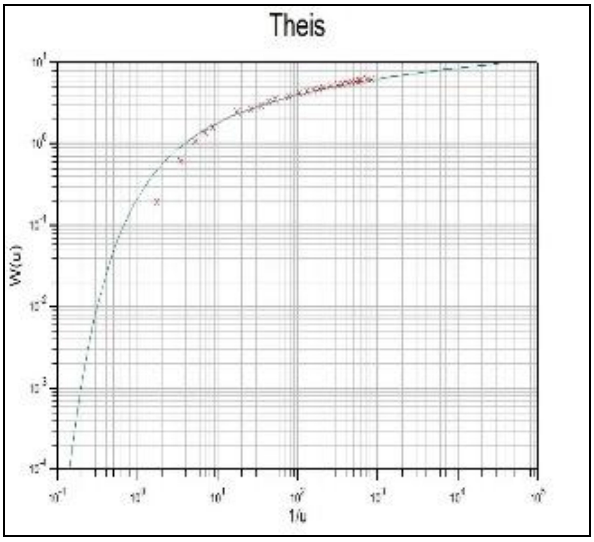


Figure 11A: Pumping test data analysis (W14) Cooper.

Figure 11B: Pumping test data analysis (W14) Theis.

- **W17**

Well (W17) is located in Almajaihim village and penetrates Quaternary sediments and Injana Formation, coordinates of pumping and observation wells are (42° 14' 41'' – 36° 40' 23'') and (42° 14' 18'' – 36° 40' 22''), respectively. The groundwater level (static water level) in the pumping and observation wells are (14.15 m) and (14 m), respectively, and the distance between them is (93 m). The depth of the observation and pumping wells is (260 m).

At an elevation of (369 m) for two wells. The pumping rate was (6 L/sec). The transmissivity value was (318.584 m²/d) and the Storage coefficient was (0.0001066) by the Cooper-Jacob method Figure (12A), while for the Theis method, the transmissivity value was (294.968 m²/d) and Storage coefficient (0.0001262) as shown in Figure (12B).

- **W 21**

Well (W21) is located in Tal Alhawa village and penetrates Quaternary sediments and Injana Formation, coordinates of the pumping and observation wells are (42° 08' 12'' – 36° 40' 23'') and (42° 08' 24'' – 36° 49' 35''), respectively. The groundwater level (static water level) in the pumping and observation well is (17.8 m) and (18 m), respectively, and the distance between them is (51 m).

The depth of the observation and pumping wells is (198 m). At an elevation of (384 m) for two wells. The pumping rate was (5.43 L/sec). The transmissivity value was (287.54 m²/d) and the storage coefficient was (0.0001886) by the Cooper-Jacob method Figure (13A), while for the Theis method, the transmissivity value was (282.785 m²/d) and Storage coefficient (0.0001918) as shown in Figure (13B).

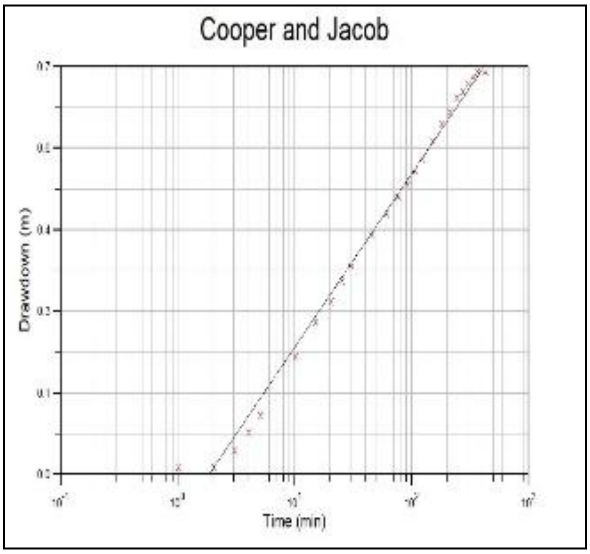


Figure 12A: Pumping test data analysis (W17) Cooper.

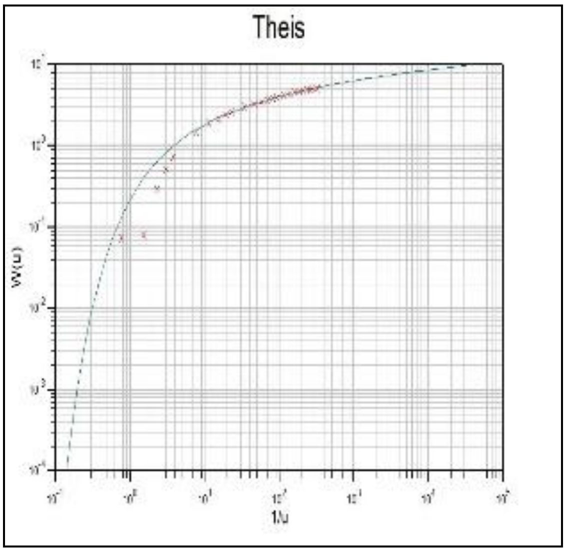


Figure 12B: Pumping test data analysis (W17) Theis.

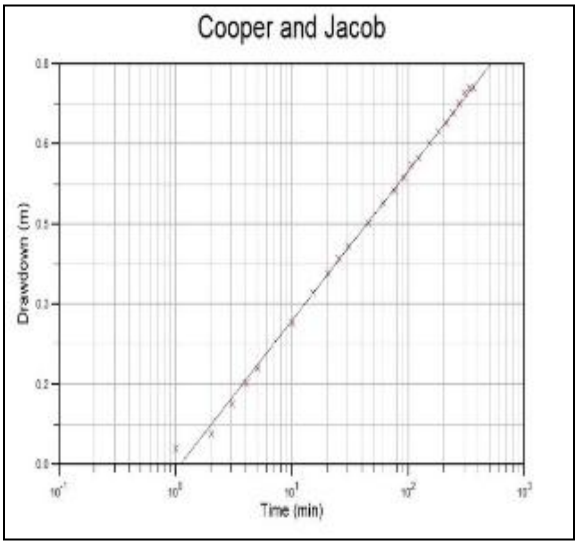


Figure 13A: Pumping test data analysis (W21) Cooper.

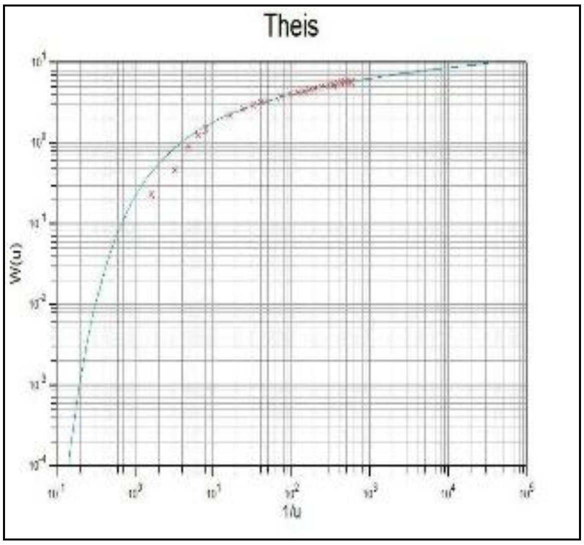


Figure 13B: Pumping test data analysis (W21) Theis.

- **W 25**

Well (W25) is located in Aweinat village and penetrates Injana Formation, coordinates of the pumping and observation wells are (42° 26' 20" – 36° 41' 15") and (42° 25' 34" – 36° 41' 16") respectively. The groundwater level (static water level) in the pumping and observation well is (9 m) and (8.75 m) respectively, and the distance between them is (42 m).

The depth of the observation and pumping wells is (230 m). At an elevation of (352 m) for two wells. The pumping rate was (6.25 L/sec). The transmissivity value was (569.12 m²/d) and the Storage coefficient was (0.0002212) by the Cooper-Jacob method Figure (14A), while for the Theis method, the transmissivity value was (558.44 m²/d) and Storage coefficient (0.0002037) as shown in Figure (14B).

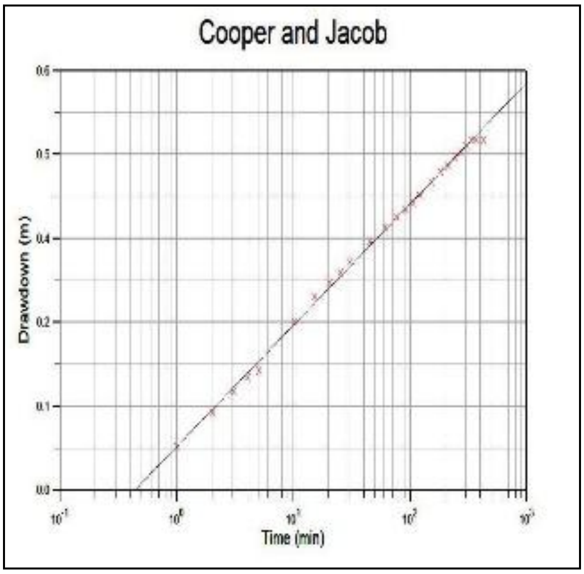


Figure 14A: Pumping test data analysis (W25) Cooper.

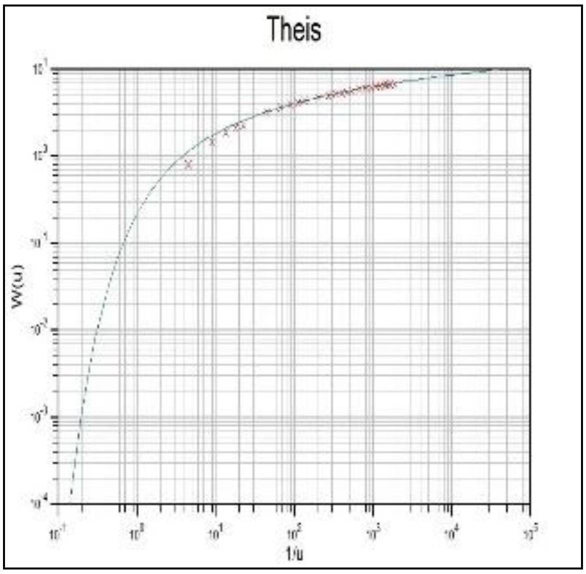


Figure 14B: Pumping test data analysis (W25) Theis.

- **W 37**

Well (W37) is located in Umm Hajrah village and penetrates Quaternary sediments and Injana Formation, coordinates of the pumping and observation wells are (42° 17' 43" – 36° 34' 29") and (42° 17' 38" – 36° 35' 07"), respectively. The groundwater level (static water level) in the pumping and observation well is (32.1 m) and (32 m), respectively, and the distance between them is (41 m).

The depth of the observation and pumping wells is (246 m). At an elevation of (402 m) for two wells. The pumping rate was (6.5 L/sec). The transmissivity value was (496.754 m²/d) and the Storage coefficient was (0.0004056) by the Cooper-Jacob method (Figure 15A), while for the Theis method, the transmissivity value was (494.318 m²/d) and Storage coefficient (0.0003641) as shown in Table (5) and Figure (15B).

- **W 28**

Well (W28) is located in Abu Wajnah village and penetrates Quaternary sediments and the Injana Formation, coordinates of the pumping and observation wells are (42° 17' 43" – 36° 34' 29") and (42° 17' 38" – 36° 35' 07"), respectively. The groundwater level (static water level) in the pumping and observation well is (33.8 m) and (34 m), respectively, and the distance between them is (49 m).

The depth of the observation and pumping wells is (260 m). At an elevation of (355 m) for two wells. The pumping rate was (8 L/sec). The transmissivity value was (710.596 m²/d) and the Storage coefficient was (0.0003833) by the Cooper-Jacob method Figure (16A), while for the Theis method, the transmissivity value was (697.902 m²/d) and Storage coefficient (0.0004131) as shown in Table (5) and Figure (16B).

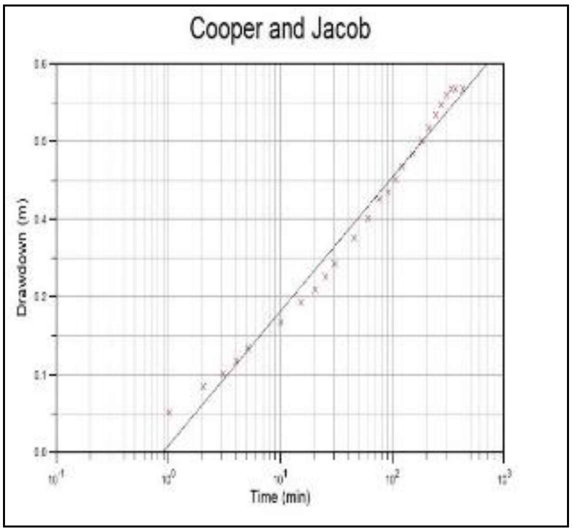


Figure 15A: Pumping test data analysis (W37) Cooper.

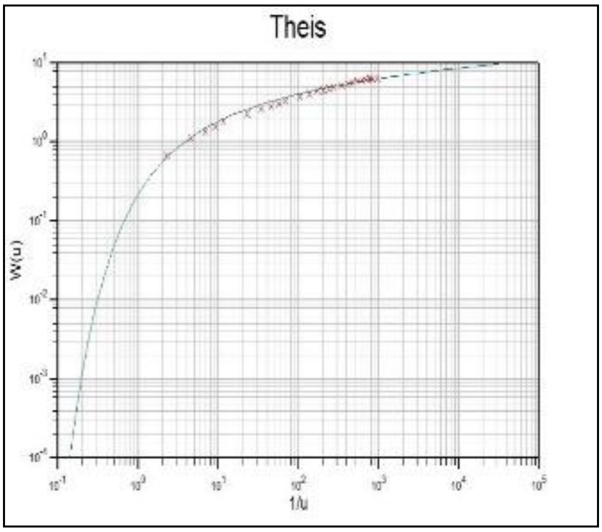


Figure 15B: Pumping test data analysis (W37) Theis.

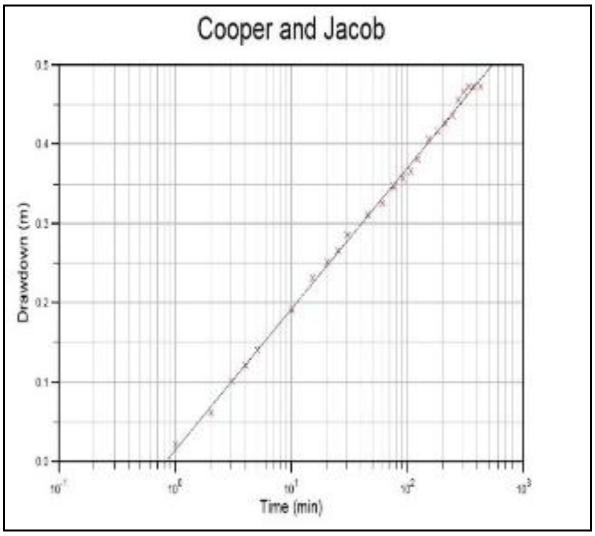


Figure 16A: Pumping test data analysis (W28) Cooper.

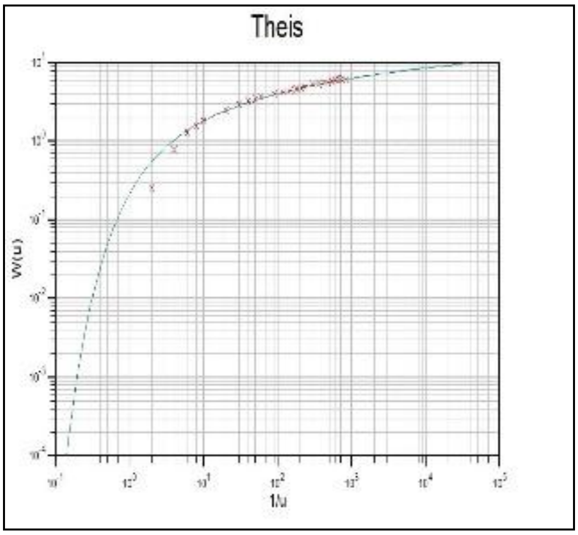


Figure 16B: Pumping test data analysis (W28) Theis.

THE RESULT OF THE PUMPING TEST

The following results were obtained from fieldwork and pumping tests for eight wells:

- According to the classification of Laboutka (1974), the values of Rabia sub-basin Transmissivity (T) ranged from (235.34 to 704.24) m²/day, and as a result of these values, it is categorized as an aquifer with high Transmissivity, Table (5).
- While the values of the storage coefficient (S) of the Rabia sub-basin ranged between 1.16 x 10^{-4} average values of the two methods and 3.98 x 10^{-4} average values of the two methods, this value indicates that the aquifer is confined aquifers.
- The values of the hydraulic conductivity (K) of the Rabia sub-basin aquifer ranged between (2.91 and 5.55) m/day, where the aquifer was classified as of low permeability

depending on the classification (Laboutka, 1974). Using the ArcGIS 10.4 program, created the maps for the hydraulic parameters for pumping tests in the study area.

Table 5: Classification of hydraulic parameters (Laboutka, 1974).

Class	Discharge L/ sec	Specific capacity m^3/day/m	Transmissivity m^2/day	Permeability m/day
Very high	>25	>864	>950	>864
high	5 – 25	86.4 – 864	95 – 950	86.4 – 864
Middle	5 – 0.5	8.64 – 86.4	9.5 – 95	8.64 – 86.4
Low	<0.5	<8.64	<9.5	<8.64

Table 6: The hydraulic parameters obtained from the pumping test analysis.

Well No.	The average between the two methods		b (m)	Hydraulic conductivity K (m/day)	Discharge Q (L\Sec)
	Transmissivity T (m^2/day)	Storage coefficient (S)			
W17	306.776	0.000116	102	3.01	6
W21	285.163	0.000190	97	2.94	5.43
W13	235.346	0.000120	75	3.14	4.61
W37	495.532	0.000385	105	4.72	6.5
W25	563.780	0.000212	111.7	5.05	6.25
W4	240.695	0.000117	73	3.30	4.5
W14	246.195	0.000150	84.5	2.91	4.7
W28	704.249	0.000398	129	5.55	8

Figure (17) shows an increase in the transmissivity from west to east, and this is due to the increase in saturated thickness in the direction of discharge of the Rabia sub-basin and the nature of the sediments in the area. Compared to the western regions to the eastern observed values of storage coefficient noticed an increase in values of storage coefficient from the west toward the east Figure (18).

The Rabia sub-basin is separated into four zones based on saturated thickness, which varies between (73 and 127) meters shown as in Figure (18).

The first range of low thickness is positioned at 73 – 86.5 in the western part of the research region (W4-W14-W16, and W13), which extends to the north and south, while saturated thickness rises eastward until it reaches a range (127 – 113.5) m with discharge zones, (Figure 19).

The Rabia sub-basin is separated into four zones based on hydraulic conductivity, which extends between (2.9 and 5.55) m (Figure 20).

The first range of low hydraulic conductivity is (2.9 – 3.54) m/day, which is located, in the western part of the study area near wells (W4, W14, W13, W17, and W21), which extends to the north and south, while hydraulic conductivity rises eastern ward to reaches range (5.55 – 4.82) m/day, which represents discharge zones (Figure 20).

After creating and analyzing four maps (T, S, b, and K), the obtained result showed that all of the hydraulic properties increased towards the east of the sub-basin, indicating a lithology and physical property difference between the east and west of the study area, which indicate Rabia sub-basin is heterogeneous and anisotropic.

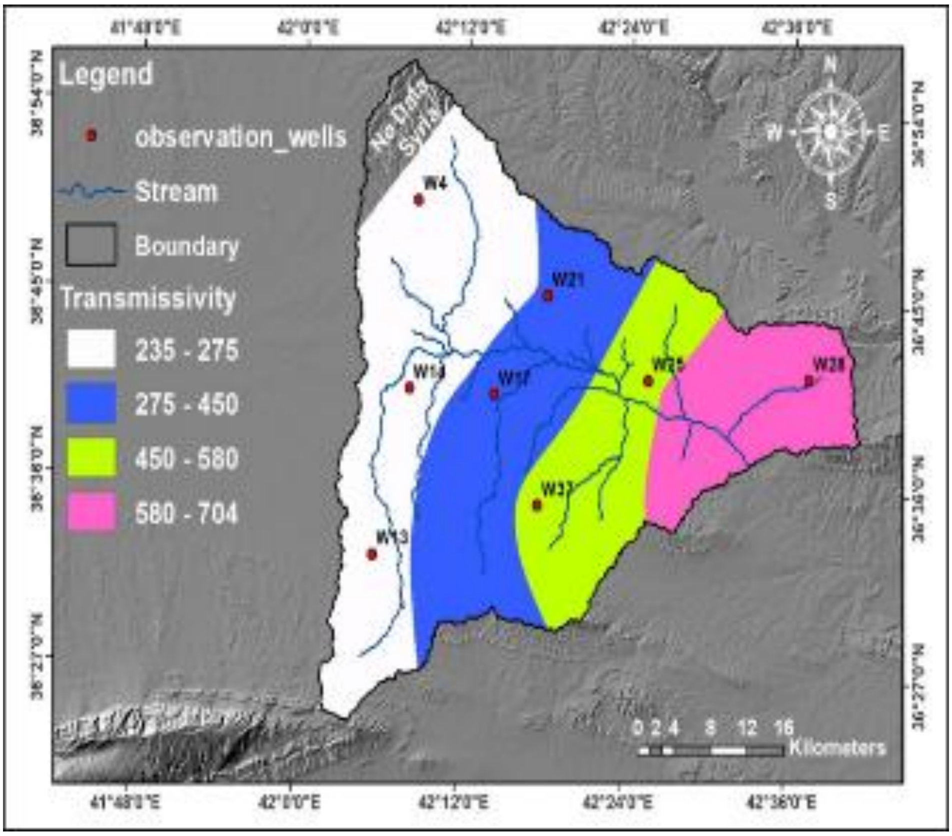


Figure 17: Spatial distribution of the transmissivity of the study area.

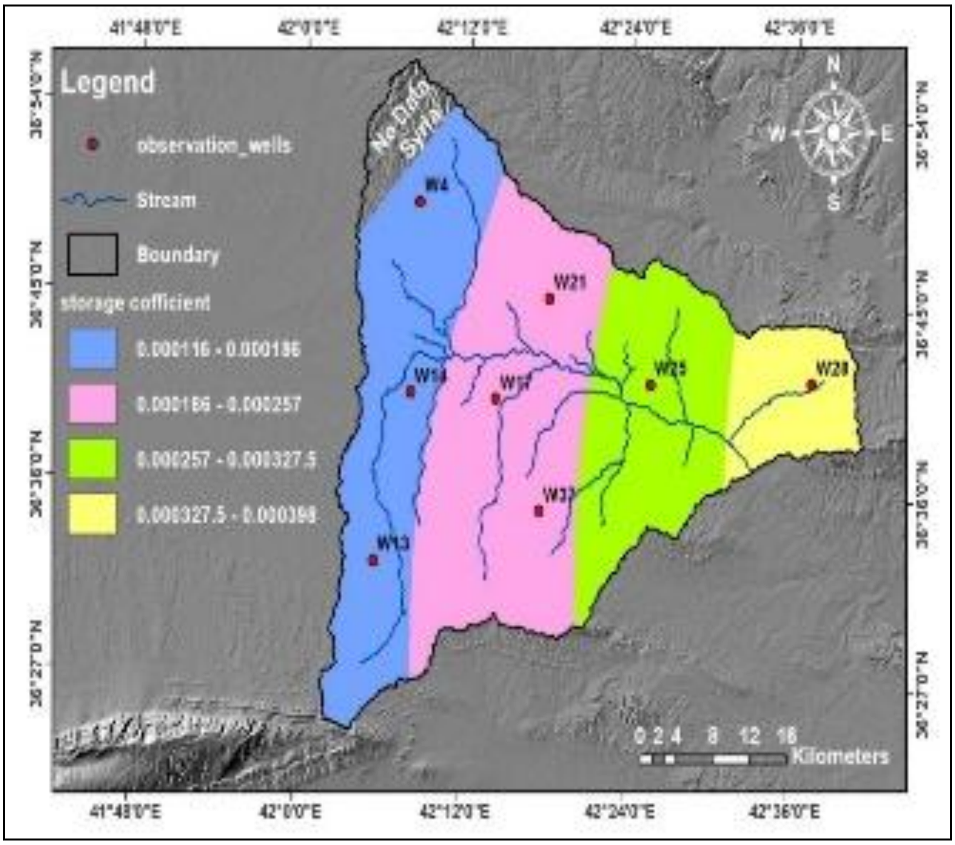


Figure 18: Spatial distribution of storage coefficient of the study area.

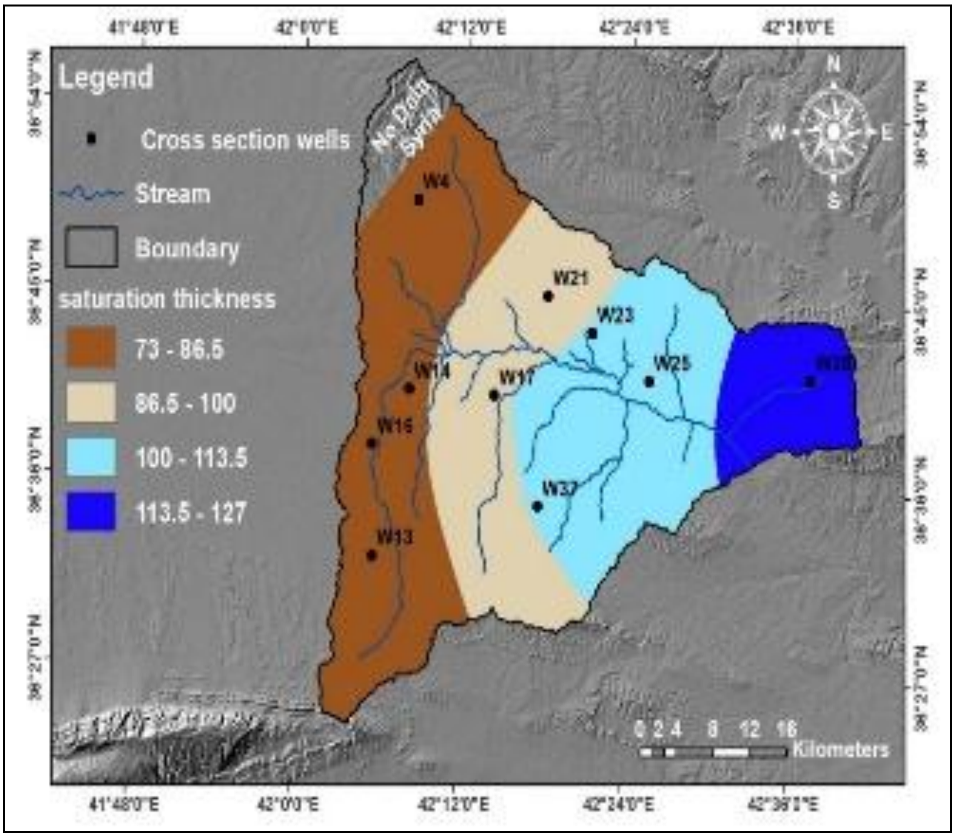


Figure 19: Spatial distribution of saturation thickness of the study area.

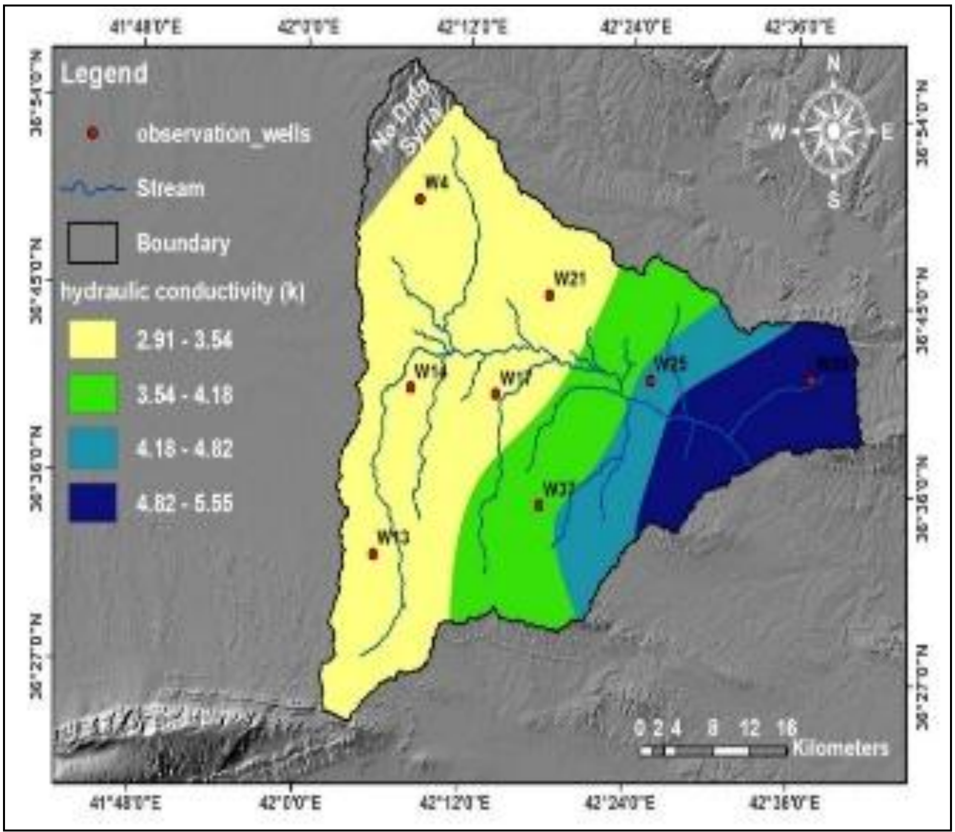


Figure 20: Spatial distribution of hydraulic conductivity of the study area.

CONCLUSION

- The research area's water table levels ranged from 321 to 409 meters above sea level, and the Rabia sub-saturated basin's thickness (b) values were between (73 and 129) m, with the predominant flow direction being east to west.
- Hydraulic conductivity (K) values in the Rabia sub-basin of the main aquifer ranged from 2.91 to 5.55 m/day.
- The aquifer values of storage coefficient (S) for the Rabia sub-basin ranged between 1.16 x 104 and 3.98 x 104, and this number shows that the aquifer is confined, and the values in the main aquifer Rabia sub-basin of the transmissivity ranged from (235.3 to 704.3) m²/day.

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