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# Hydrogeologic Conditions of Mulussa Aquifer Between Rutba and Dhabaa in Al-Anbar Governorate

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**Abstract**

Rutba area is located in Al-Anbar Governorate - West of Iraq. Hydrogeological investigation calculation of Mulussa aquifer between Rutba and Dhabaa is carried out. The groundwater moves in directions of (NE, E and SE) influenced by depletion process in the amount of hydraulic gradient ranged between (0.0000416 - 0.008036). The groundwater flux (V) and groundwater pore velocity (U) are reached (0.00451) m/day and (25.02) m/day, respectively. Mulussa aquifer is carbonate beds, where represents confined aquifer conditions. The values of transmissivity, permeability and storage coefficient are ranged between (0.507 – 250) $m^2$/day, (0.00547 - 3.05) m/day and ($9.65 \times 10^{-5}$ - $2.64 \times 10^{-4}$) respectively. While the estimated of transmissivities which are obtained from specific capacity ranged (208.041 – 862.166) $m^2$/day. This variation in the values revealing the great variations in the aquifer lithology, which was affected by intensity and the number of fractures and joints.

**Keywords:** Mulussa aquifer, Hydrogeological investigation, flow direction.

# الظروف الهيدروجيولوجية لخزان ملصي بين الرطبة والضبعة في محافظة الأنبار

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**الخلاصة**

تقع منطقة الرطبة في محافظة الأنبار – غرب العراق. تم إجراء دراسة هيدروجيولوجية لخزان ملصي في المنطقة بين الرطبة والضبعة. إن جريان المياه الجوفية هو باتجاه شمال الشرق، الشرق وإلى الجنوب الشرقي متأثرا بميل هيدروليكي يتراوح بين (0.0000416 – 0.008036)، وبجهد تدفق وبسرعة هي تصل إلى (0.00451) م/يوم و (25.02) م/يوم، على التوالي. تم تقييم الخصائص الهيدروليكية للخزان حيث إن قيم الناقلية، النفاذية ومعامل الخزن هي تتراوح بين (0.507 – 250) م$^2$/يوم، (0.00547 – 3.05) م/يوم و ($2.64 \times 10^{-4}$ – $9.65 \times 10^{-5}$) على التوالي. بينما قيم الناقلية التي خمنت من السعة النوعية هي بين (862.166 – 208.041) م$^2$/يوم. وان هذه التغيرات الكبيرة سببها التغاير في صخارية الخزان.

## Introduction

The study area is located between Rutba and Dhabaa site, crossed by the national highway and the old road in Western of Iraq. It bordered by longitudes of (40˚15′36″- 40˚32′24″) and latitudes of (33˚00′36″ –33˚04′12″). This located over an area of (174.87 $km^2$) with an elevation range between

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(585–645) m above sea level (a.s.l.). The average land surface slope is (2.2) m/km ranging between (0.04-13.4) m/km toward the NE (Figure-1). Tectonically, the study area is located within the Rutba subzone, which is located within Rutba-Jezira zone, which belongs to the stable shelf that is characterized by contain large basement high, no surface anticlines, dominated by the Huge Rutba Uplift [1]. The Rutba Uplift has exposed Permian rocks followed by Triassic and Jurassic rocks. The study area characterized by the geological formations that can be explained as follows (from older to younger) (Figure- 2):

**Ga'ara Formation** (Early–Late Permian): Consists of stacked sandstones interbedded with claystone, the depositional environment as fluvio – lacustrine (deltaic) [2]. It's appearing at a depth of 154 m in well (KH-5/2) in the study area.

**Mulussa Formation** (Late Triassic, Carnian–Norian): Composed of limestone, dolomitic limestone, and sometimes oolitic, lagoonal conditions and tropical to subtropical shallow water environments. It's about 120 m in Rutba region [2].

**Zor Hauran Formation** (Late Triassic, Rhaetic): It consists of yellow gypsiferous and marl, interbedded with yellowish green dolomitic limestone and dolomites [3]. The formation is deposited in lagoon and marine tidal environment [4].

**Ubaid Formation** (Early Jurassic, Lias): It consists of crystalline limestone, marly limestone, dolomitized limestone with abundant chert nodules, deposited in shallow littoral – lagoonal environment [5]. Ubaid Formation with a thickness between (47) m east of Rutba city and (65) m along southern rim of Ga`ara Depression [4].

**Mauddud–Nahr Umr Formations** (Early Cretaceous, Albian–Cenomanian): Mauddud Formation consists of grey limestone, with much fossiliferous limestone, and dolomitic limestone, and the environment of deposition is marine. It is exposed east of Rutba town with thicknesses are recorded about (5 – 8) m [6]; while the thickness of Nahr Umr changes between (29 – 44) m and increases toward the east. The environment of deposition is shallow coastal marine [4].

**Rutba Formation** (Late Cretaceous, Cenomanian): Consists of sandstones and ferruginous fine sands, silty sand in the form of successive alluvial sedimentary cycles. The lower part consists of basal conglomerate and coarse sand. The environment of deposition is continental, fluvial or littoral marine [5]. The thickness of the formation ranges between (20 - 30) m NW of Rutba town [4].

**Ms`ad Formation** (Late Cretaceous, Cenomanian – Turonian): is composed of mudstone, siltstone, sandstone, coralline limestone and marl in Rutba vicinity and eastwards [7]. It is reef, tropical and warm shallow marine environments; its thickness ranges between (11 - 65) m in the eastern part [4].

**Hartha Formation** (Late Campanian–Early, Maestrichtian): Consists in the lower part of dolomitic limestone and sandy limestone, and in the upper part of clayey dolostone interbedded with marly limestone. The environment of deposition is tropical and shallow marines, and its thickness ranges between (37) m in the eastern parts and (74) m exposed in the southern part of the study area [8].

**Quaternary Sediments**: Include valleys and depression fill sediments, consisting of mixture of clay, sand, silt, gravel, in addition to the calcareous soils, where its thickness ranges between (0 - 2) m and occupy various areas within depressions and slopes [4].

The main objective of this study is to determine the hydrogeologic characteristics of Mulussa aquifer (quantitative evaluation) through pumping and recovery tests in three sites included wells (W-A, W-B and W-C) and interpretation of a previous experimental data pump in the other sites (KH 5/2) and (W-17), and determine the direction of groundwater movement, groundwater flux and groundwater flow velocity through observation and measurement of groundwater levels in (20) wells.

**Hydrogeologic Situation**

The geological formations either water bearing formations or formations are not considered as yield aquifers either due to their locations above regional groundwater level, or due to lithological and structural properties [9]. The recharge sources of groundwater in the study area are mainly direct infiltration and/ or runoff the intermittent valleys (the transport from long distances) in the form of percolation into the aquifers. While the discharge is either in the form of underground inflow or from the production wells that forms an artificial discharge of groundwater.

In the study area the groundwater exists in Mulussa carbonate (limestone and dolomite) beds, where represents the saturation zone. While the zone of unsaturation comprises stratigraphic beds of Zor Hauran, Ubaid, Mauddud in addition to Quaternary sediments. The saturated and unsaturated zones are illustrated in the study area as a three-dimensional model Figure-3.

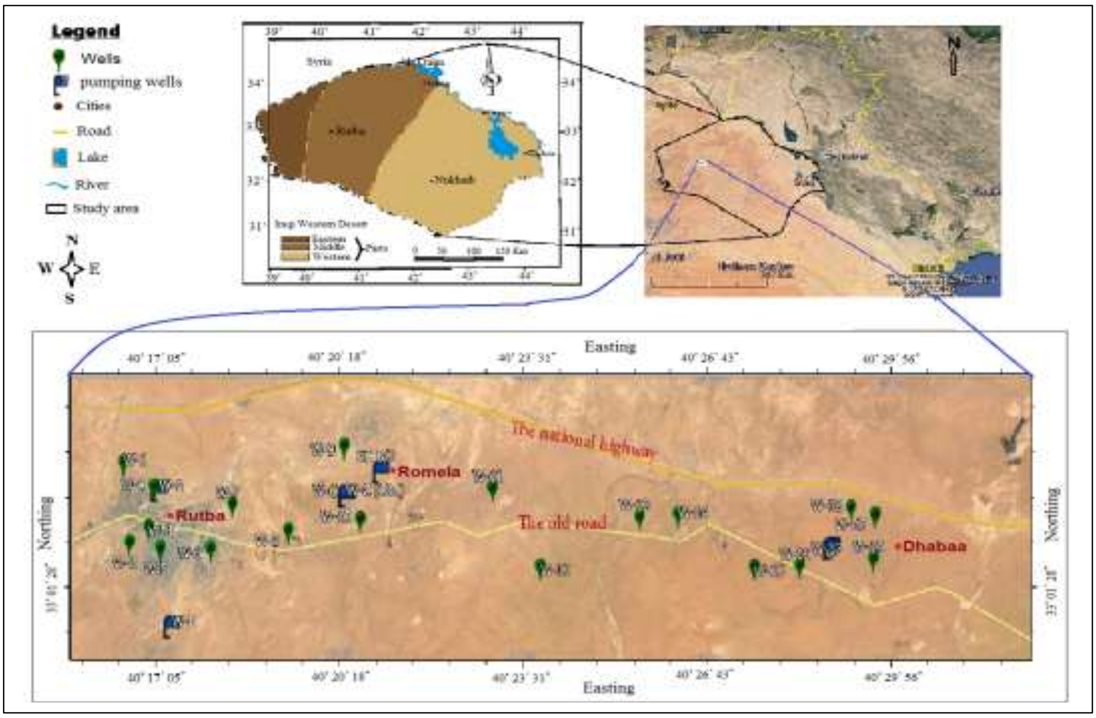


**Figure 1-** Location map of the study area shows the observation wells and the pumping wells.

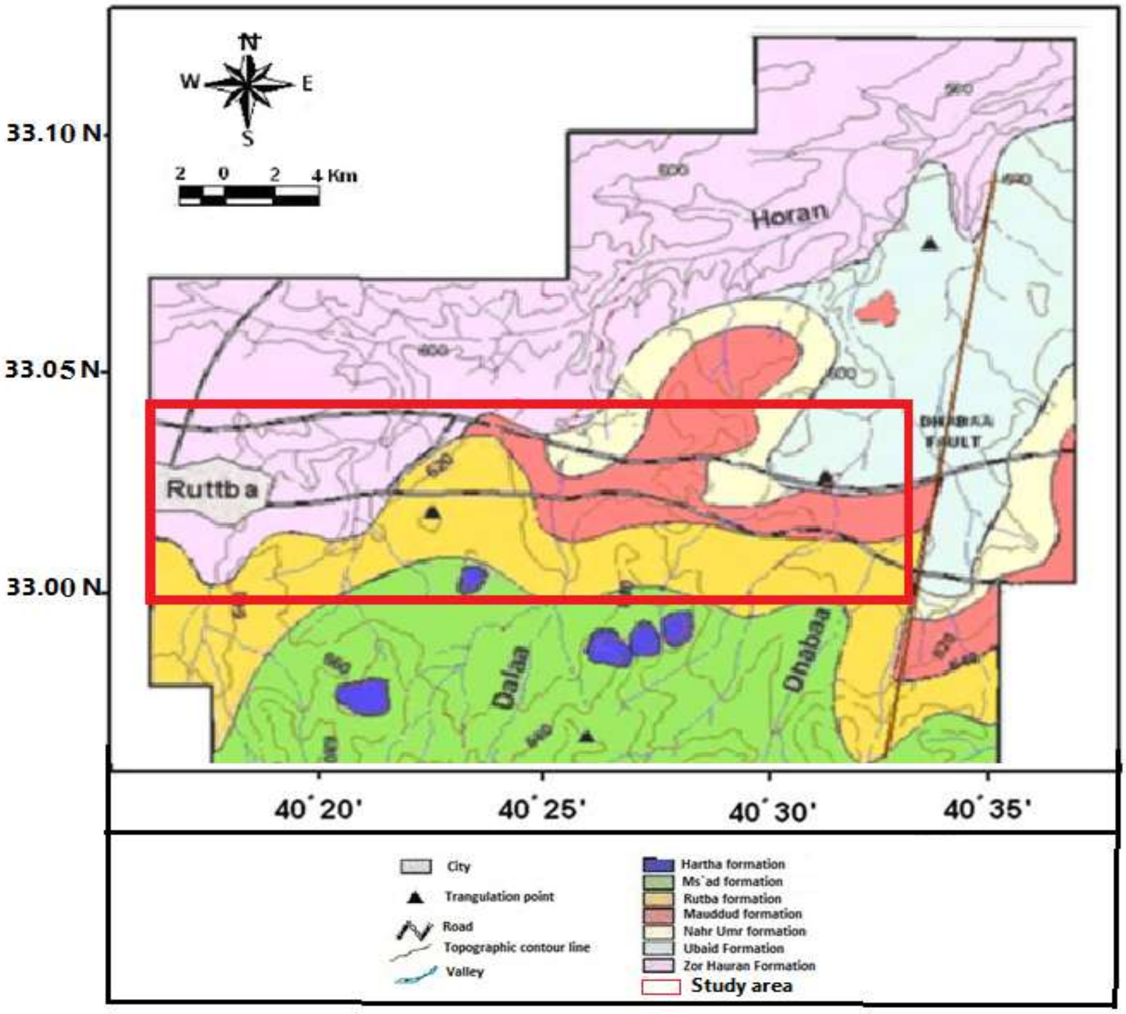


**Figure 2-** Geologic map of the study area, Modified from [10].

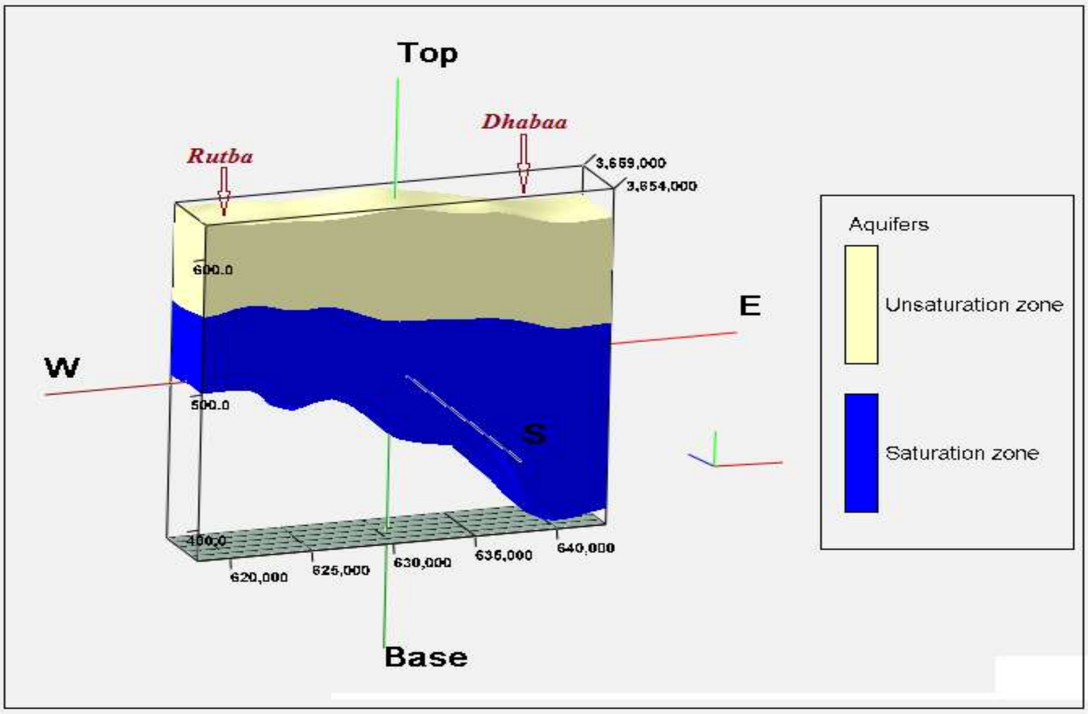


**Figure 3-**3D model of the Mulussa Aquifer in the study area created by (RockWorks16) software.

Mulussa aquifer is recharged from the scope of Rutba Uplift along Hauran Valley and its tributaries. In addition, the exposed Rutba Uplift zone, particularly in the southern part of Ga'ara depression is consider another source of recharge [11]. Its characterized by wide extensions up to outside the study area, where the thickness of the aquifer reaches (137) m in well (KH-5/9) in the Amij area to the east of the study area and (100) m to the south in Wadi Abu Menttar and (50) m towards the southwest in Nihaydin and (120) m to the west in Traybil border city, while it's extension ends at the edge of Ga'ara depression toward the north of the study area. In the well (KH-5/2) the thickness of Mulussa aquifer is about (131) m [12]. A computer program (RockWorks16) was used to complete the three-dimensional model of the study area and adjacent areas using geological data of (7) keyholes, where shows the thickness and extension of Mulussa aquifer [12], (Figure-4).

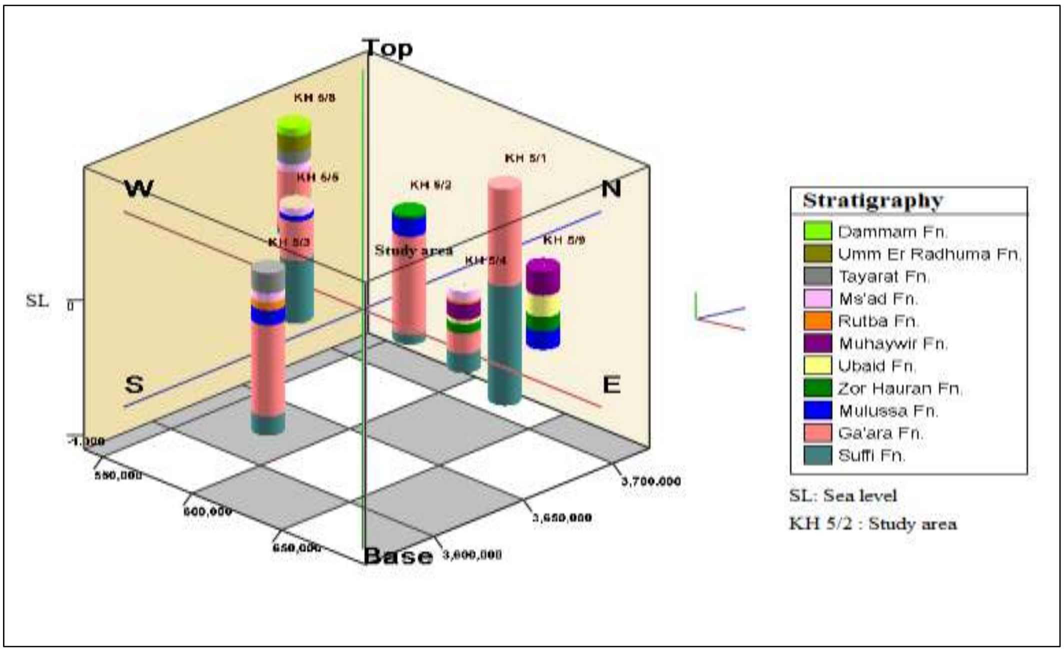


**Figure 4-**3D diagram shows the extension of Mulussa aquifer in the study area and adjacent areas.

**Materials and Methods**

Depth to groundwater was measured by the Sounder instruments (Typ 010, France) for the 20 wells selected to determine the direction of groundwater movement, groundwater flux and groundwater flow velocity, as shown in Table-1.

The hydraulic parameters of the aquifer are found by the analysis of pumping test results carried out on the wells in three sites included wells (W-A, W-B and W-C) and interpretation of a previous experimental pumping test data in the other sites (KH 5/2) and (W-17) Figure-1. A computer program (Schlumberger Aquifer Test 2011.1) is used to analyze the result of pumping and recovery tests to extract these parameters for Mulussa aquifer. where Cooper-Jacob I [13] and Theis Recovery method [14] is used for this purpose, Cooper-Jacob I method using the following equation:

$$T = 2.3\,Q / 4\,\pi\,\Delta s \qquad (1)$$

Where: (T) Transmissivity ($m^2$/day). ($\Delta s$) Difference in the drawdown, in (m) per log-cycle of t. (Q) Discharge ($m^3$/day).

Theis Recovery method using the following equation:

$$T = \frac{2.3\,Q}{4\,\pi\,\Delta s'} \log\left(\frac{t}{t'}\right) \qquad (2)$$

Where: (T) Transmissivity ($m^2$/day). (Q) Discharge ($m^3$/day). ($\Delta s'$) Difference in the residual drawdown, in (m) per logarithmic cycle of (t / t'), where: (t) Total time of pumping plus the recovery time (minute). (t') Time since the cessation of pumping (Recovery time) (minute).

Equation (3), [15] utilized in estimating aquifer transmissivity from specific capacity data as follows:

$$T = \frac{Q}{Sw}\,\frac{2.3}{4\pi}\log\frac{2.25Tt}{r^2\,S} \qquad (3)$$

Where: (T): Transmissivity ($m^2$/day). (Q/Sw): is the specific capacity of the well ($m^2$/day/m). (t): is the period of pumping (day). (r): is the radius of the pumping well (m). (T): is the aquifer transmissivity ($m^2$/day). (S): is aquifer storativity (dimensionless).

To classification of hydraulic parameters used Laboutka classification [16] Table-2.

**Table 1-**Water table elevation above sea level for the wells

| Well no. | Latitude | Longitude | Depth well(m) | Elev. (m.a.s.l.) | Depth water (m) | P. L. (m.a.s.l.) |
|---|---|---|---|---|---|---|
| W-1 | 33°02'55.03" | 40°16'28.15" | 125 | 623 | 75 | 548 |
| W-2 | 33°01'53.05" | 40°16'34.66" | 130 | 630 | 74.25 | 555.75 |
| W-3 | 33°02'5.28" | 40°16'54.66" | 110 | 627 | 82.70 | 544.3 |
| W-4 | 33°02'36.43" | 40°17'0.60" | 120 | 614 | 52.50 | 561.5 |
| W-5 | 33°01'48.50" | 40°17'7.25" | 117 | 619 | 48.62 | 570.38 |
| W-6 | 33°01'48.26" | 40°18'0.72" | 120 | 623 | 51 | 572 |
| W-7 | 33°02'22.95" | 40°18'23.72" | 130 | 625 | 74.25 | 550.75 |
| W-8 | 33°02'2.78" | 40°19'22.83" | 175 | 623 | 76.95 | 546.05 |
| W-9 | 33°03'8.16" | 40°20'21.47" | 110 | 617 | 62.40 | 554.6 |
| W-10 | 33°02'11.34" | 40°20'38.41" | 110 | 618 | 50.20 | 567.8 |
| W-11 | 33°02'35.03" | 40°22'58.46" | 140 | 627 | 91.75 | 536.25 |
| W-12 | 33°01'34.86" | 40°23'48.71" | 180 | 626 | 86 | 540 |
| W-13 | 33°02'13.04" | 40°25'33.12" | 180 | 617 | 73.90 | 543.1 |
| W-14 | 33°02'14.99" | 40°26'14.54" | 157 | 616 | 75.90 | 540.1 |
| W-15 | 33°01'34.68" | 40°27'34.33" | 140 | 621 | 80.80 | 540.2 |
| W-16 | 33°01'35.26" | 40°28'22.00" | 210 | 610 | 72.30 | 537.7 |
| W-17 | 33°01'51.00" | 40°28'56.00" | 210 | 604 | 81.32 | 522.68 |
| W-18 | 33°02'20.29" | 40°29'16.58" | 231 | 602 | 79.81 | 522.19 |
| W-19 | 33°01'40.56" | 40°29'39.78" | 231 | 600 | 78.3 | 521.7 |
| W-20 | 33°02'14.73" | 40°29'41.88" | 231 | 598 | 77.1 | 520.9 |

P.L.: The piezometric level

**Table 2-** aboutka classification of hydraulic parameters [16]

| Class | Discharge $m^3/day$ | Specific capacity $m^3/day/m$ | Transmissivity $m^2/day$ | Permeability m/day |
|---|---|---|---|---|
| Very high | >2160 | >864 | >950 | >864 |
| high | 432 - 2160 | 86.4 - 864 | 95 - 950 | 86.4 - 864 |
| middle | 43.2 - 432 | 8.64 - 86.4 | 9.5 - 95 | 8.64 - 86.4 |
| low | <43.2 | <8.64 | <9.5 | <8.64 |

**Results and Discussion:**

**Ground water levels and flow direction**

The piezometric level in the present study (18-19 September 2017) ranges between (520.9 m a.s.l.) in the eastern of the study area and (572 m a.s.l.) in the western of the study area, as shown in Figure-5. And according to [10] the piezometric level in the study area during (2013 year) was ranges between (485 m a.s.l.) in the eastern of the study area and (595 m. asl) in the western of the study area. In the western part decrease in the groundwater level is due to dewatering process from the groundwater of Rutba site caused by intense groundwater extraction for Rutba water supply. While in the eastern part increase in the groundwater level is due to pumping stopped from the Dhabaa wells between 2013 to 2017 year and then resumed pumping. To illustrate this by the Figure-5 show the flow direction map of study area.

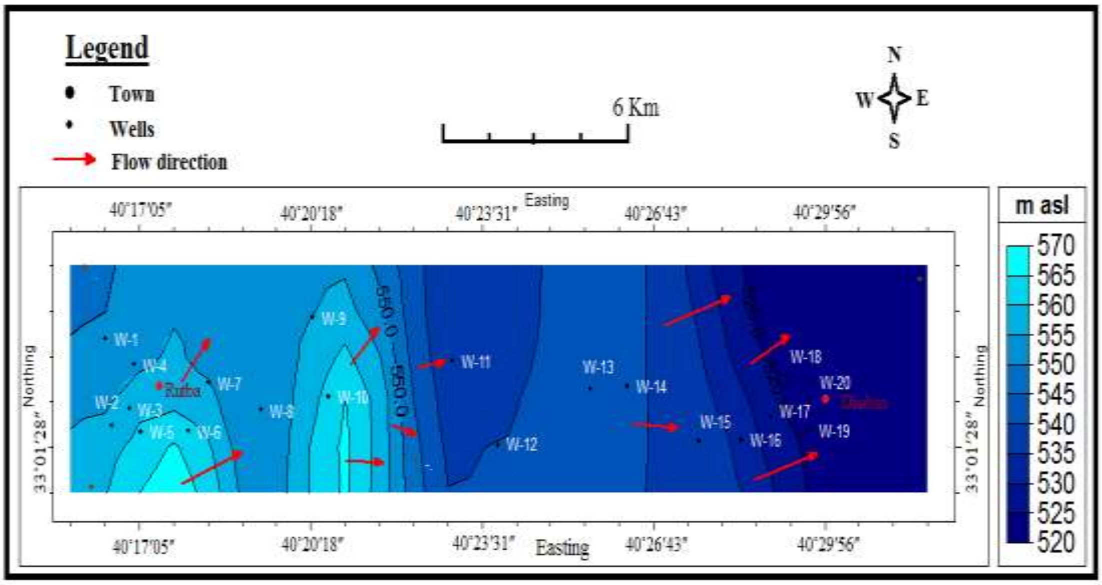


**Figure 5**-Groundwater flow map for studied area.

From the Figure-5 can be seen, the ground water moves in trends of (NE, E and SE) in the sector limited by equipotential lines of (572 - 520.9 m asl.) between recharge area in Horan valley and discharge area in the Dhabaa site. The amount of the hydraulic gradient is calculated according to the following equation [17]:

$$I = dh/dl \qquad (4)$$

Where: (I) hydraulic gradient (dimensionless unit). (dh) Head loss between two water points (m). (dl) Horizontal distance between the same two water points (m).

The groundwater moves under the effectiveness of hydraulic gradient, the groundwater flux and groundwater pore velocity, where the amount of hydraulic gradient ranged between (0.0000416 - 0.008036) with an average of (0.0040388). Also can be calculate the groundwater flux (V) and groundwater pore velocity (U) according to the following equation [18]:

$$\text{Groundwater flux } (V) = K\, I \qquad (5)$$

Where: (K) permeability (m/day). (I) hydraulic gradient (dimensionless unit). Groundwater pore velocity (U) = V / S (6)

Where: (V) groundwater flux (m/day). (S) storage coefficient (dimensionless unit).

According to the equation (5 and 6) the amount of the groundwater flux (V) and groundwater pore velocity (U) are reached (0.00451 m/day) and (25.02 m/day), respectively.

**Hydraulic properties and pumping test**

The hydraulic properties of Mulussa aquifer including Hydraulic conductivity (K), Transmissivity (T), Storage coefficient (S) and Specific Capacity (Sc) are determined from aquifer pumping test data Table-3. Analysis curves for resulting data of the selected wells are shown in (Fig.6). The values of transmissivity (T) of Mulussa aquifer ranged between (0.507 – 250) $m^2$/day، with an average of (108.857 $m^2$/ day), and it is classified as an aquifer of high transmissivity depending on the classification of [16] Table-2. While the values of the storage coefficient (S) of Mulussa aquifer ranged between (9.65 x $10^{-5}$ and 2.64 x $10^{-4}$), this value indicates that the aquifer is confined aquifers.

The values of the hydraulic conductivity (K) of Mulussa aquifer ranged between (0.00547 - 3.05) m/day, with an average of (1.117 m/day), where the aquifer was classified as of low permeability depending on the classification of [16].

The variation in the values of hydraulic parameters within Mulussa fractured aquifer is due to the spatial variation in the intensity of fractures and joints [19]. In addition, the dissolution process affects the hydraulic parameters, where the openings in the limestone may range from microscopic original pores to large solution caverns and it's playing a main role in determining the nature and characteristics of an aquifer.

**Table 3-**Results of the hydraulic properties from pumping test analysis

| Well No. | W-A | W-B | Ob. W-C | KH 5/2 | W-17 | Average |
|---|---|---|---|---|---|---|
| Well depth (m) | 105 | 94 | 120 | 950 | 210 | |
| Piez. L. (m) | 61.20 | 41.65 | 72.10 | 39.06 | 84 | |
| b (m) | 92.8 | 112.35 | 81.9 | 114.94 | 130 | |
| Q ($m^3$/day) | 42.985 | 198.62 | 129.60 | 127.70 | 777 | |
| T ($m^2$/day) | 0.507 | 8.72 | 250 | 249 | 36.057 | 108.857 |
| K (m/day) | 0.00547 | 0.0776 | 3.05 | 2.166 | 0.286 | 1.117 |
| S | ----- | ----- | 9.65x$10^{-5}$ | ----- | 2.64 x $10^{-4}$ | 1.8x$10^{-4}$ |
| Sc ($m^2$/day) | 1.4424 | 7.584 | 664.6 | 8.657 | 168.9 | 170.236 |

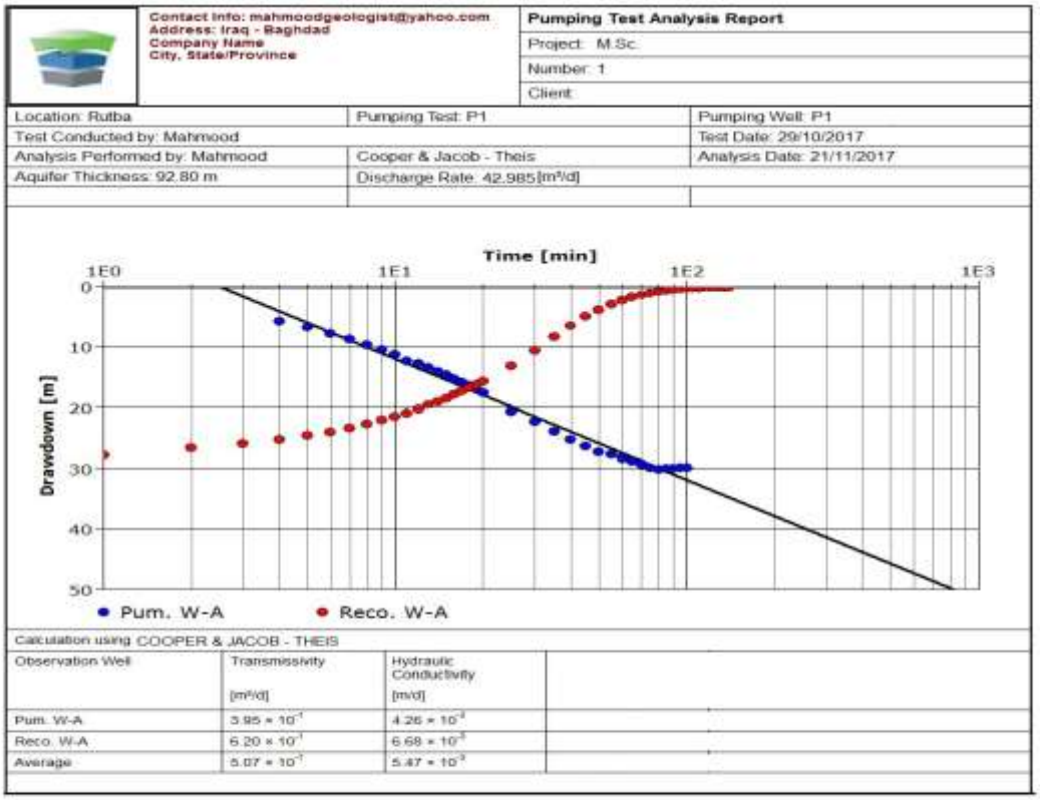


**Figure 6a-**Graphs of drawdown and water level recovery with time for well (W.A) by using Cooper-Jacob (Drawdown) and Theis (Recovery) methods.

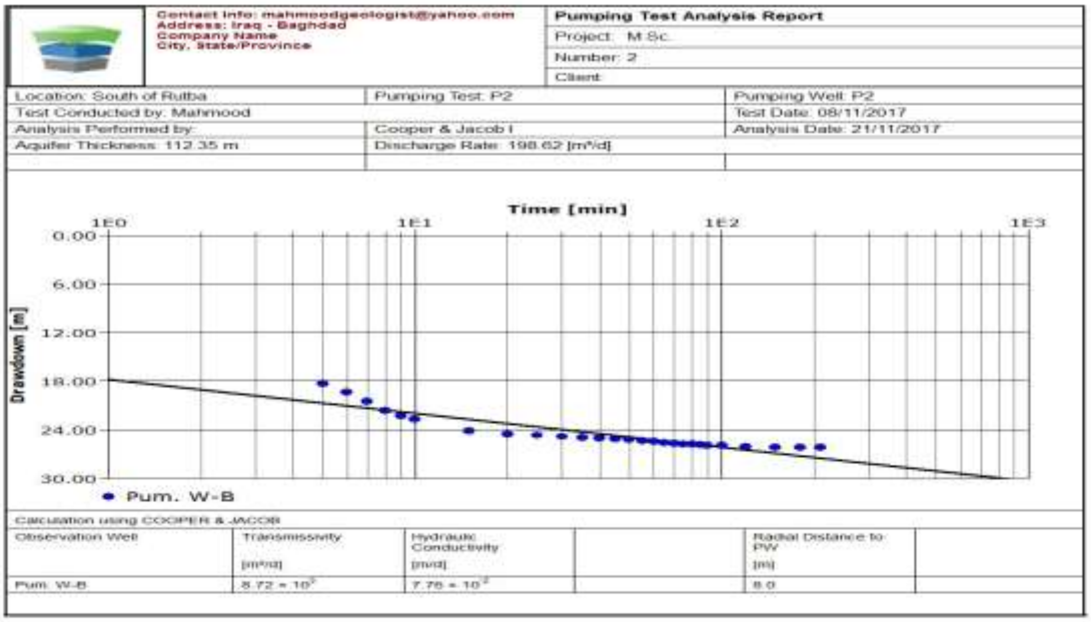


**Figure 6b-**Graphs of drawdown with time for well (W.B) by using Cooper-Jacob (Drawdown) method.

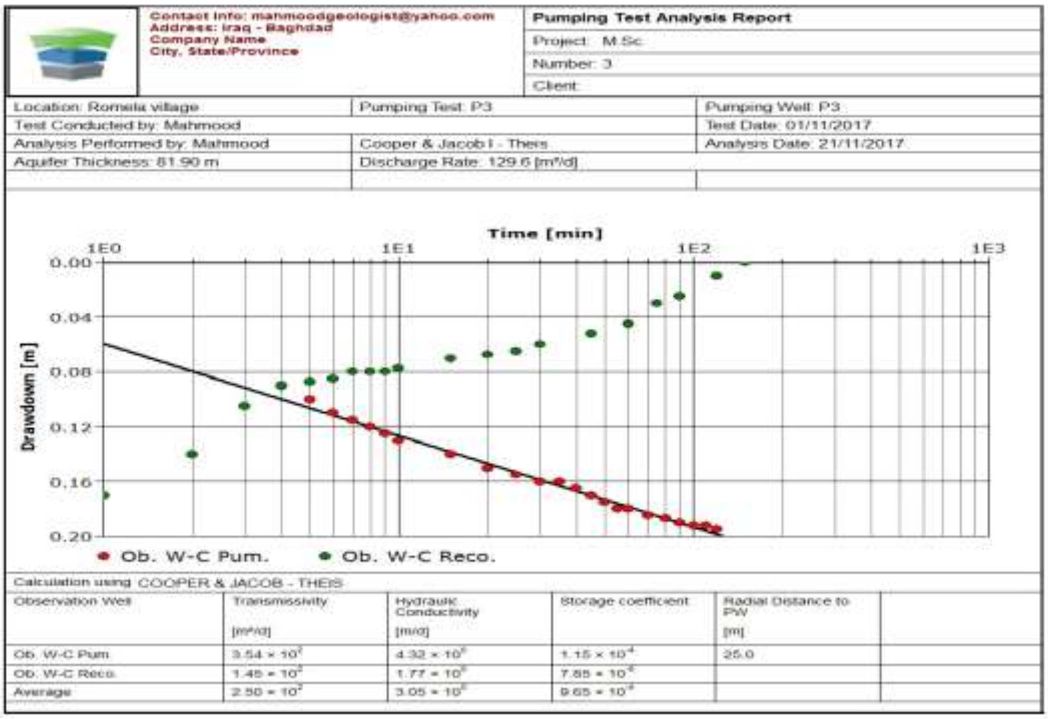


**Figure 6c**-Graphs of drawdown and water level recovery with time for well (W.C) by using Cooper-Jacob (Drawdown) and Theis (Recovery) methods.

**Estimates of Aquifer Transmissivity from Specific capacity data**

Transmissivity can be deduced from the pumping test. Also, it can be estimates from many empirical relationships exist between aquifer transmissivity and specific capacity suggested by [15] proposed a way of estimating the aquifer transmissivity from the specific capacity of a well for confined aquifer. The [20], who had developed an empirical relationship between transmissivity (T) and specific capacity (Sc) in Sandstone aquifers, while [21] developed a similar approach to estimate the transmissivity from specific capacity (Sc) data and transmissivity (T) data for karstic aquifers.

In this study, the simulation by [15] is probably more accurate for Mulussa aquifer. The estimated aquifer transmissivities which are obtained from specific capacity range from (208.041) $m^2$/day to

(862.166) $m^2$/day, with an average of (535.1035) $m^2$/ day for two wells only (Ob. W-C and W-17) due to provide a storage coefficient of these two wells only (Table - 4), and it is classified as an aquifer of high transmissivity depending on the classification of [16] Table-2. According to this value of transmissivity (T) which are obtained from the specific capacity (Sc) are relatively different from the values obtained from pumping test, because of aquifer test program which take into account the time of pumping, the drawdown values, piezometric level and pumping rate.

**Table 4-**Transmissivity values for pumping test wells in the study area by using two methods

| Well No. | Sc ($m^2$/day) | $T = Sc\ \frac{2.3}{4\pi}\log\frac{2.25Tt}{r^2\ S}$ | T ($m^2$/day) |
|---|---|---|---|
| **W-A** | 1.4424 | | 0.507 |
| **W-B** | 7.584 | | 8.72 |
| **Ob. W-C** | 664.6 | 862.166 | 250 |
| **KH 5/2** | 8.657 | | 249 |
| **W-17** | 168.9 | 208.041 | 36.057 |
| **Average** | 170.236 | 535.1035 | 108.857 |

Generally, Specific capacity tests provide unbiased estimates of transmissivity. However, they often are highly variable and may require many tests to provide a good estimate of transmissivity, while the pumping tests are essential to evaluate aquifer hydraulics in the vicinity of the well. Therefore, the transmissivity calculated by pumping test, is more reliable than Specific capacity method.

**Conclusions**

**1.** The ground water moves in trends of (NE, E and SE) in the sector limited by equipotential lines of (572 - 520.9 m a.s.l.). The amount of hydraulic gradient ranged between (0.0000416 - 0.008036) with an average of (0.0040388). The groundwater flux (V) and groundwater pore velocity (U) are reached (0.00451 m/day) and (25.02 m /day), respectively.

**2.** Mulussa aquifer is classified as an aquifer of high transmissivity and low permeability under confined conditions, where the values of transmissivity, permeability and storage coefficient are ranged between (0.507 – 250) $m^2$/day، (0.00547 - 3.05) m/day and (9.65 x $10^{-5}$ - 2.64 x $10^{-4}$) respectively.

**3.** Value of transmissivity (T) which are obtained from the specific capacity (Sc) are relatively different from the values obtained from pumping test. Generally, Specific capacity tests provide unbiased estimates of transmissivity.

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