HYDRAULIC PROPERTIES OF THE BAI-HASSAN AQUIFER IN TUZ-KHURMATU, SALAHADDIN, IRAQ

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ABSTRACT

The studied area is located within Salahadden Governorate between latitudes 34° 50' 00'' – 34° 55' 00'' and longitudes 44° 33' 00'' – 44° 40' 00'' south of Kirkuk city of about 70 Km with an approximate area of about 124 Km². The important geological formations in the area consist of Tertiary deposits Al-Fatha, Injana, Muqadadiya and Bai-Hassan formations as well as recent Quaternary deposits which cover the study area. Depending on the climatic data recorded in Tuz-Khurmatu station for the period 1991 – 2014, found that the summation of rainfall is 274.21 mm, average of temperature 22.8 °C, relative humidity 46.93%, wind speed 1.83 m/sec, sunshine 8.28 h/day and the total of evaporation is 2376.2 mm. The common climate in the area is humid to moist. The studied area is located within Al-Adhaim basin whose area is about 12000 Km². The productive hydrogeological unit in the studied area is Bai-Hassan Formation. The general direction of groundwater flow is from northeast towards the southwest. By using Theis recovery 1935 and Cooper-Jacob 1946 methods pumping test results which performed in seven wells that penetrate Bai-Hassan Formation partially without observation wells indicated a transmissivity values range between 95.47 – 335.72 and the median value of 176.11 m²/day and hydraulic conductivity values between 2.11 – 4.47 m/day and the median value of 3.06 m/day. These reflect that the hydraulic properties values of Bai-Hassan aquifer in the study area are heterogeneous and variant, as a result of heterogeneity of Bai-Hassan aquifer due to variations in lithology and porosity. Specific capacity for these wells is measured and found varying between 172.8 – 432 m³/d. It shows an inverse relationship between the specific capacity and drawdown in the wells.

Keywords: Hydraulic properties; Tuz-Khurmatu; Aquifers; Transmissivity; Hydraulic conductivity.
INTRODUCTION
The importance of the hydraulic properties of the aquifer lies in the identification of some of the properties of the reservoirs such as yield of groundwater and the movement of groundwater and the ability of reservoirs to compensation and nutrition during the pumping process.

The studied area Tuz-Khurmatu is located within Salahadden Governorate east of Tikrit city of about 90 Km, northeast of Baghdad city. The lowest elevation in the area reaches 200 m a.s.l., and highest elevation is of about 245 m a.s.l. near the anticline as shown in Figure (1). It lies south of Kirkuk city of about 70 Km, between latitudes 34°50'00" – 34°55'00" and longitudes 44°33'00" – 44°40'00" with an approximate area of about 124 Km².

![Fig. 1: Location map for the study area (Rasheed, 2012)](image)

GEOLOGY OF THE STUDY AREA
The important geological formations in the area consist of Tertiary deposits Al-Fatha, Injana, Muqadiya and Bai-Hassan formations as well as recent Quaternary deposits cover the study area. Al-Fatha Formation appears in Pulkhana anticline and affects the groundwater salinity in the area because of the evaporates rocks (gypsum rocks) (Mohamed et al., 2009), it contains the followings:

1. Al-Fatha Formation
   It is of M. Miocene and one of the most aerially widespread and economically important formations in Iraq (Buday, 1980). This formation appears in Pulkhana
anticline in the study area (Fig. 2). The sediments of this formation are cyclic and each geologic cycle is composed of anhydrite, gypsum, claystone, limestone, sandstone and marl.

2. Injana Formation
The age of this formation is Middle to Upper Miocene, it refers to two periods, late Miocene and Pliocene. The Injana Formation including the Middle Fars comprises fine-grained pre-molasse sediments deposited initially in coastal areas (lagoons) and later in a fluvial lacustrine system (Buday, 1980). The formation is characterized by consecutive beds of sandstone and claystone.

3. Al-Mukdadyia Formation
The age of this formation is L. Pliocene and is distributed mostly in the Foothill Zone where it is greater than 2000 m thick in the Kirkuk Embayment. Mukdadyia Formation was deposited in a fluvial environment in a rapidly subsiding foredeep basin (Jassim and Goff, 2006). The formation is characterized by sedimentary cycles increasing by size from sandstone and gravel; include mudstone and conglomerate masses (Barwary and Slewa, 1995).

4. Bai-Hassan Formation
The age of this formation is U. Pliocene and prevails in large areas of Al-Adhaim Basin. Bai-Hassan Formation is covered by Quaternary deposits in the study area. The formation is characterized by thick layers of conglomerates inter-bedded with sandstone, siltstone, and claystone. In general, the grain size of the clastics increases upward (Buday, 1980).

Quaternary Deposits
The Foothill Zone, especially in the Kirkuk city, is characterized by long anticlines with Miocene cores flanked by very broad and shallow synclines exposing Mio-Pliocene molasse along their flank. The inner parts of the synclines contain Quaternary deposits, referred to here as polygenetic synclinal fill. The thickness of this Quaternary veneer is variable but greater than 120 m in some water wells (Jassim and Goff, 2006). The Quaternary deposits cover all parts of the study area (Fig. 2), where its age varies from early Pleistocene to late Holocene (Barwary and Slewa, 1995) and include: Slope deposits, Sheet runoff deposits, Valley fill deposits and Flood plain deposits.
HYDROGEOLOGY OF THE STUDIED AREA

The studied area is not considered as an independent hydrogeological basin, but it lies within big basin represented by Al-Adhaim Basin. The area of the basin is about 12000 Km² located northeast of Baghdad (Al-Mamuri, 2005). The important water bearing formations (aquitards) in the basin consist of Tertiary deposits Muqdadiya and Bai-Hassan formations as well as recent Quaternary deposits (Al-Mamuri, 2005) and (Abdul-Razaq et al., 2007). Quaternary deposits cover all parts of the study area and consisting of fluvial deposits and deposits of gravel, sand and clay. Its thickness is small in the study area and increasing towards the west. All wells in Tuz-Khurmatu area are penetrating Bai-Hassan Formation partially by different depths. Therefore this formation represents the upper and main hydrogeological productive aquifer in the study area. It is considered an important aquifer because of its good porosity and permeability, and the confined location between the underlying Mukdadyia Formation and the overlying Quaternary deposit. Bai-Hassan Formation confined aquifer composed of sandstone and gravel consecutive with clay and conglomerate masses (Khudair et al., 2000) and (Al-Rubaii, 2008). The stratigraphic correlation for wells of the study area was drawn by depending on lithology of wells drilled by General Commission for Groundwater and the available information about the hydrogeology of
the study area and shows the main aquifer in the study area Bai-Hassan formation as shown in Figure (3).

**Fig. 3: Stratigraphic correlation between the wells in the studied area (Rasheed, 2012)**

**GROUNDWATER MOVEMENT**

Recharge areas of Bai-Hassan Formation, confined aquifer, are located in the northeast where its layers are exposed outside the study area and depend on rainwater (Khudair *et al.*, 2000), and it is affected by water infiltration from surface runoff (Tuz Chai river) and the water losses from irrigation canal (Kirkuk irrigation canal) in the study area. The general direction of groundwater movement in the area is from the recharge areas in northeast to the discharging areas at southwest (Ahmad and Al-Jibouri, 2005) and (Mohamed *et al.*, 2009). To clear up the flow direction of the groundwater, a flow net map was drawn (Fig. 4) depending on the groundwater level measurements in the wells of the study area. According to the flow net map the direction of groundwater movement in the study area is from northeast towards the southwest as shown in Figure (4). Groundwater moves from areas of high hydraulic effort towards areas of low hydraulic effort.
PUMPING TESTS ANALYSIS

Pumping test process is carried out by pumping water from the aquifer with a constant discharge for a specific period of time. The analytical methods represent the suitable methods for the pumping test data treatment. The following methods have been used:

1. **Cooper-Jacob method**

   Cooper and Jacob (1946) suggested that for small values of \( r \) and large values of \( t \), the following method may be applied for the analysis of pumping test of well. Accordingly, the value of transmissivity \( T \) can be obtained by noting \( (t/t_0) \) for one log-cycle, then \( \log t/\log t_0 = 1 \), Where:

   r: Distance from pumped well to observation well (m).

   t: Time of pumping (minute).

   t0: Intercept point of the fitted line on the time axis.

   Therefore, if \( \Delta s \) is the drawdown difference per log-cycle of \( t \), then the equation below can be set to determine \( T \) value as follows:

\[
T = \frac{2.3 \ Q}{4\pi \Delta s}
\]
Where:

\[ T: \text{Transmissivity m}^2/\text{day} \]
\[ \Delta s: \text{Difference in the drawdown m. per log-cycle of } t. \]
\[ Q: \text{Discharge m}^3/\text{day}. \]

2. **Theis recovery equation**

In this method (Theis, 1935) the residual drawdown \((s')\) is plotted versus \((t/t')\) on semi-logarithmic paper and a straight line is fitted through the plotted points, Where:

\( t: \text{Total time of pumping plus the recovery time (minute).} \)
\( t': \text{Time since the cessation of pumping (Recovery time) (min).} \)

The equation below is applied to determine the transmissivity (Kruseman and De-Ridder, 2000) as follows:

\[ T = \frac{2.3 \, Q}{4 \, \pi \Delta s'} \]

Where:

\( \Delta s': \text{Difference in the residual drawdown, in (m) per log-cycle of } (t / t'). \)

Terms of application in this equation is the same as in "Cooper-Jacob equation", with the exception of using residual drawdown instead of the drawdown. This method is more meticulous in knowing the hydraulic properties because the water level recovery will be normal to avoid the groundwater problem fluctuation during the pumping because of the fluctuations in pumping rate which happens as result of pump work.

**Analysis results of pumping test**

A single well pumping test was carried out for two wells in the studied area with a constant discharge rate and single well pumping test data are available for five wells drilled in the study area. Observation wells are not available in the studied area, therefore these tests have been conducted without observation wells, and thus the storage coefficient is not determined. The experimental data and graphs for the seven pumping tests well in the study area (Fig. 5). Cooper-Jacob and Thies recovery methods were used in the treatment of these data. From the graphs in the Figures (6, 7, 8, 9, 10, 11 and 12) it can be observed that some forms of data analysis of pumping tests by Jacob and Thies methods reflect the existence of two layers; and this was evident in the stratigraphic correlation map of the study area (Fig. 3), which it showed and confirmed the existence of gravel layers successive with the layers of clay within Bai-Hassan Formation. Therefore, the transmissivity and hydraulic conductivity values are
calculated for each layer and then is calculated the average. Table (1 and 2) show the hydrogeological data of wells (Transmissivity, hydraulic conductivity and specific capacity) values obtained from pumping test data analysis by Jacob and Theis recovery methods. The average of transmissivity values ranges between 95.47 – 335.72 m²/day and the average of hydraulic conductivity range 2.11 – 4.47 m/day. This reflects that the hydraulic properties values of Bai-Hassan aquifer in the study area are heterogeneous and variant, as a result of heterogeneity of Bai-Hassan aquifer due to variations in lithology and porosity of aquifer.

**Fig. 5: Locations of the pumping wells in the studied area**

**Table 1: Results of hydraulic properties by two methods used in a single well pumping test analysis for wells of the study area**

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Jacob (Drawdown) Method</th>
<th>T1 m²/d</th>
<th>T2 m²/d</th>
<th>K1 m/d</th>
<th>K2 m/d</th>
<th>T m²/d Average</th>
<th>K m/d Average</th>
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<tr>
<td>1</td>
<td>76.32</td>
<td>167.69</td>
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<td>3.1</td>
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<td>122</td>
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<td>2</td>
<td>168.2</td>
<td>277.38</td>
<td>2.61</td>
<td>4.31</td>
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<td>3</td>
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<td>2.7</td>
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<td>---</td>
</tr>
<tr>
<td>4</td>
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<td>3.64</td>
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<td>1.78</td>
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<td>---</td>
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<td>195.2</td>
<td>385.63</td>
<td>2.6</td>
<td>5.14</td>
<td></td>
<td>290.41</td>
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<td>7</td>
<td>99.86</td>
<td>---</td>
<td>2.21</td>
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<td>---</td>
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</table>
Table 2: Results of hydraulic properties by two methods used in single well pumping test analysis for wells of the study area

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Theis (Recovery) Method</th>
<th>Average</th>
<th>Specific Capacity</th>
</tr>
</thead>
<tbody>
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<td>T1 m³/d</td>
<td>T2 m³/d</td>
<td>K1 m/d</td>
</tr>
<tr>
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<td>108.5</td>
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<td>4</td>
<td>163.56</td>
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<td>494.1</td>
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<tr>
<td>7</td>
<td>71.86</td>
<td>110.31</td>
<td>1.59</td>
</tr>
</tbody>
</table>

Fig. 6: Graphs of drawdown and water level recovery with time for well W1 by using Jacob (Drawdown) and Theis (Recovery)
Fig. 7: Graphs of drawdown and water level recovery with time for well W2 by using Jacob (Drawdown) and Theis (Recovery) methods.
Fig. 8: Graphs of drawdown and water level recovery with time for well W 3 by using Jacob (Drawdown) and Theis (Recovery) methods
Fig. 9: Graphs of drawdown and water level recovery with time for well W 4 by using Jacob (Drawdown) and Theis (Recovery) methods.
Fig. 10: Graphs of drawdown and water level recovery with time for well W 5 by using Jacob (Drawdown) and Theis (Recovery) methods.
Fig. 11: Graphs of drawdown and water level recovery with time for well W 6 by using Jacob (Drawdown) and Theis (Recovery) methods.
Fig. 12: Graphs of drawdown and water level recovery with time for well W 7 by using Jacob (Drawdown) and Theis (Recovery) methods
SPECIFIC CAPACITY (SC)

Specific capacity is the ratio of the obtained rate of the discharge to the drawdown, which is required to produce the obtained discharge and expressed in cubic meter per day for each meter of drawdown (Fetter, 1994), according to the following equation:

\[ SC = \frac{Q}{s} \]

Where:
- \( SC \): Specific Capacity \( \text{m}^2 / \text{day} \).
- \( Q \): Discharge \( \text{m}^3 / \text{day} \).
- \( s \): Drawdown m.

The specific capacities for the pumping wells are calculated by Fetter’s (1994) equation and shown in the Table (2). The difference in specific capacity values of wells penetrating the same aquifer in the study area is attributed to differences in the discharging quantity and the total depth in addition to the saturated thickness. So when the specific capacity is high, it reflects that the productivity of the well is good and this depends on the lithology of the aquifer, and also on depth, saturated thickness, design and development of wells.

CONCLUSIONS

The studied area is not considered as an independent hydrogeological basin, but it lies within big basin represented by Al-Adhaim basin. The productive hydrogeological unit in the studied area is Bai-Hassan Formation confined aquifer and composed of sandstone and gravel consecutive with clay and conglomerate masses. The general direction of groundwater flow in the study area is from northeast towards the southwest. Al-Fat'ha Formation appears in Pulkhana anticline and affects groundwater salinity in the area because of its content of evaporates rocks (gypsum rocks). Results of single pumping test performed on seven wells distributed in the study area are analyzed to measure transmissivity \( T \) and hydraulic conductivity \( K \) values for wells. Jacob and Theis recovery methods are used in the treatment of these results. \( T \) values range between 95.47 – 335.72 \( \text{m}^2 / \text{day} \) and \( K \) values between 2.11 – 4.47 \( \text{m} / \text{day} \). This reflects that the hydraulic properties values of Bai-Hassan aquifer in the study area are heterogeneous and variant as a result of heterogeneity of Bai-Hassan aquifer due to variations in lithology and porosity. Specific capacity for these wells is measured and found varying between 172.8 – 432 \( \text{m}^2 / \text{d} \). It shows an inverse relationship between the specific capacity and drawdown in the wells.
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