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Hydrogeology of Al-Hamdaniya, Northern Iraq

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Abstract

The current study evaluated the hydrogeological conditions and hydraulic properties of the groundwater aquifers in Qaraqosh, Karamless and Bartella areas within Al-Hamdaniya district east Mosul. The depths and water tables of groundwater for 48 wells were measured in October 2019, ranging between 5 - 45 meters and 234 - 278.5 meters, respectively. The highest water table reaches in the center of the studied area north Qaraqosh and decreases gradually in all directions. A map of the flow net was drawn, and it was found that the general direction of water movement is from north to south, with local directions resulting by pumping from the aquifer, or due to the heterogeneity of the porous media. The results of the pumping test in Karamless area shows that the transmissivity was 107.671 m²/day and 100.682 m²/day according to Theis and Cooper-Jacob methods, respectively. The hydraulic conductivity of 157.65 m saturated thickness was found to be 0.683 m/day and 0.639 m/day using Theis and Cooper-Jacob methods, respectively. While the storage coefficient using Theis and Cooper-Jacob methods was 0.0023 and 0.0020, respectively. In Qaraqosh, the transmissivity was 87.1685 m²/day and 88.1004 m²/day according to the mentioned methods, respectively. While the hydraulic conductivity of saturated thickness of 71.07 m was found to be 1.24 m/day and 1.23 m/day using Theis and Cooper-Jacob methods, respectively. The values of storage coefficient using these methods was 0.00135 and 0.00115, respectively. The total dissolved solids (TDS) measured to conclude the hydrogeological system according to the quality of the groundwater aquifers, it was found that the concentrations of total dissolved solids are more than 3500 ppm in the mid of the study area and decreased towards all directions to the limits of 250 ppm. This wide variation in salinity may be because the wells in the central area penetrate the groundwater aquifers, represented by the layers of gypsum in Al-Fat'ha formation, which is hydraulically connected with the main aquifer of the Injana formation.

Keywords: Groundwater; Qaraqosh; Karamless; Bartella; pumping test; TDS

1. Introduction

The main problem in all over the world is the supply of drinking water for domestic uses, as a result of the population increase, and that the gap between the water supply and the need of drinking water can expand and reach dangerous levels (Awadh et al., 2020). and may be considered a threat to human life (Yajingli and Kunpeng, 2009). The reports indicating that the next crises will be caused by water, although, the water is necessary for life, may be caused hazards if it is polluted (WHO, 2017). Consequently, the scarcity of fresh water can cause a severe problem all over the world because only

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about 1% of the water in the world is fresh and potable water (Pangorkar, et al. 2010), especially in the area with an arid or semi-arid climate, when the study area is locating with (Lamei, et al, 2008). The increasing population growth in Iraq, which reached to 40 million people in 2020, this increasing also happen in the studied area constitutes more pressures exhausting on water resources that have become scarce than ever before. The management of natural resources has not been sufficient for years ago. According to available estimates, the per capita of water in Iraq reaches 2,400 cubic meters annually. All this will lead to an increase the demand for water and agricultural production (USEPA, 2012). The importance of the hydraulic properties of an aquifer lies in determining some of the reservoirs' characteristics such as groundwater movement and recharge during the pumping process (Al-Kubaisi et al, 2018). The study area represented by Qaraqosh district, Karamless district, and Bartella district, with an area of (130 km²) located to the east of Mosul district and to the west of Erbil Governorate. Within the UTM coordinates in (346800) to (363000) east and (4007800) to (4030000) north, Fig. 1.

Fig. 1. Location and geological map of the study area

Geomorphologically, the area bordered from the northeast by Ain Al-Safra anticline, Bashiqa and Al-Fadiliya anticline from the north, from the southeast the area bounded by Greater Zab River, and from the southwestern is bordered by the Tigris River. The area under study is important and promising in terms of the utilization of groundwater, which contributes to the expansion the agricultural area and also supply the needs of residential areas. Which required the study of the hydrogeological and hydraulic characteristics of the groundwater aquifers; consequently, it is used as a database to draw up a policy for investing this water for various purposes.

The study aims to define the hydrogeological system and the type of groundwater aquifers in the area, then, estimate the hydraulic characteristics of the aquifer using pumping test analyses, and identify the water bearing layers and formations, through the lithological description of the wells. The study also objects to monitor the depths to groundwater and derive the flow net using the data obtained from monitoring wells, determine the recharge and discharge areas.

2. Materials and Methods

The fieldwork included a first exploratory trip of the study location at the beginning of October 2019, to identify the outcrops of geological formations, geomorphological and structural phenomena that related to the hydrogeological system, observation of major valleys, and determination of various field measurements. A second field tour was conducted in mid-October 2019, and lasted for more than a month, during which a field survey was conducted to view the geological and geomorphological features and determine the coordinates of the existing wells, using a Global Positioning System (GPS) (Table 1).

Table 1. The coordinates of the wells that have been studied

Well No.	X	Y	Well No.	X	Y	Well No.	X	Y
	Karamless		B20	355272	4025685	Q40	357944	4009675
K1	357526	4017293	B21	354451	4025048	Q41	355710	4012571
K2	357872	4017865	B22	353032	4025741	Q42	355579	4012406
K3	357110	4017784	B23	352954	4025586	Q43	356014	4012325
K4	357887	4018252	B24	353064	4026386	Q44	355953	4012353
K5	357525	4017292	B25	353867	4025716	Q45	356489	4011149
K6	357485	4017990	B26	353365	4026721	Q46	356719	4011285
K7	356257	4019337		Qaraqosh		Q47	354800	4013763
K8	357619	4018999	Q27	356599	4016218	Q48	356370	4012232
K9	358007	4018992	Q28	354808	4013922	Q49	349649	4011322
K10	357549	4018945	Q29	354474	4017538	Q50	352085	4013310
K11	357826	4018990	Q30	353911	4017276	Q51	350642	4013855
K12	358136	4019122	Q31	354038	4017784	Q52	352545	4013937
K13	357595	4018827	Q32	356532	4011868	Q53	355186	4014205
	Bartella		Q33	356411	4011871	Q54	354490	4015218
B14	354361	4024240	Q34	356560	4011627	Q55	355127	4014941
B15	354030	4024101	Q35	358504	4009373	-	-	-
B16	354796	4024128	Q36	357938	4010066	-	-	-
B17	354341	4024324	Q37	357574	4009972	-	-	-
B18	354717	4025439	Q38	357939	4010421	-	-	-
B19	353619	4022826	Q39	357616	4009530	-	-	-

Groundwater depths were measured (for the period 10/10/2019 to 11/15/2019), using a groundwater depth detector, which measured from a fixed point on the ground surface, while, the heights of ground surface were determined using digital elevation model (DEM), by Global Mapper software. The samples were collected from 55 wells by poly ethaline bottles of 0.5 liter for testing the TDS to be used for hydrogeological description. The bottle was washed by the sample water for three times, and filling the bottles after 25 minutes pumping, in order to sampling from aquifer water. The bottles filled

slowly to avoid the turbidity or bubbles, and then it was labeled by the name of the well owner, the number of the well, and the date of sampling, and then the samples kept in cold container, to avoid the qualitative changes, and then transfer the samples to the laboratory.

The specialized software package (Aquifer Win 32) was used in analyzing the pumping data, according to the methods and the examples contained in the documents accompanying the software, (Theis, 1935, Reed, 1980, Kruseman and Deridder, 1990). The total dissolved solids were measured in the laboratory using TDS measuring device. The measurement was made by shaking a quantity of the water sample in a glass beaker, and then placing the probe of the device in the sample.

3. Results and Discussion

3.1. Water-Bearing Aquifers

An aquifer can be defined as a layer or layers of rocks or sediments that have permeability and porosity that contain water in quantities that allow it to move through it under natural conditions (Todd, 2005). Unconfined aquifers generally accept recharge from the earth's surface over their entire stretch, while recharge to confined and semi-confined aquifers is restricted to areas where hydraulically permeable materials connect the aquifers to the land surface or upper aquifers (Richard, et al. 2019).

Through the study of the lithological sections of the drilled wells in the region, from the data bank of the General Authority for Groundwater in Nineveh, the lithological description for some wells were processed into Rockwork software to draw the lithological sections, (Fig. 2). The groundwater-bearing formations in the study area have been identified, represented by the formation of Injana, which represents the main aquifer is in the study area, and there is a secondary aquifer within the sediments of the Quaternary period it was found that most of the sediments are composed of sequences of mudstone, sandstone, and siltstones, and fine, coarse and sandy gravel rocks that interbedded with layers of sandy, clayey and Silty rocks. This aquifer can be considered (Aquisystem) consisting of (multi layers aquifer), due to the presence of permeable and impermeable rock units. Because of the difficulty of isolating these aquifers from each other during pumping test operations, what the results of pumping test operations give a final result of the characteristics of the aquifers that the wells penetrate. As the presence of mud layers extending for wide distances in the aquifer suggests the presence of confined aquifers, and it has also been observed that the water table is located within the boundaries of the clay layers confirms this result and therefore the combined aquifers may behave as semi-confined aquifers, this was confirmed by the results of the pumping test that was carried out on two wells in the study area.

Fig. 2. lithology of five wells within the study area (L.D.2, L.D.3, L.D.4) Bartella, (L.D.1) Karamless, (L.D.5) Qaraqosh, the upper part of the aquafer represents by quaternary deposits, while, Injana Formation begins when the absence the last gravel layers

3.2. Depth to Groundwater

The depths are affected by the topography of the area and the human activities represented by the extraction of groundwater. The depth considered as one of the influencing factors controlling the drilling methods, the type of pumps and the dimensions of wells. The depths to groundwater in the area were measured using the ground water depth detector in 48 of the 55 wells, and it is ranged from 5 meters in the center of the study area, and increased in all directions to reached 45 meters approximately, (Fig. 3). The seasons of heavy rains and floods caused by the rains storms, raise the water table to near the ground surface due to the absence of sewage drainage systems. It is noticed from the map of groundwater depths that it is consistent with the map of groundwater table, (Fig. 3) as the area that has high groundwater table corresponds to a certain extent with the area with lower depths on the map of groundwater depths.

Fig. 3. Maps representing A. the depths of the groundwater; B. the groundwater levels and flow net in the study area

3.3. Groundwater Table and Flow Direction

Groundwater table is very importance in the groundwater studies, as they are one of the controlling factors in groundwater extraction, and determining the directions of its movement and natural drainage. The elevation of ground surface from sea level was measured using Digital Elevation Model (DEM), and the groundwater table in the wells ranged from 234-278.5 meters above sea level.

The coordinates of the wells locations were determined using GPS the data of the water table and coordinates of the wells were inputted into ARC GIS software (V10.3) to draw the contour map of groundwater table in the area, (Fig. 3). Flow net map gives information about the gradient of water table and the direction of groundwater flow and it is known that groundwater moves from high-pressure towards low-pressure levels. The groundwater movement is controlled by the hydraulic gradient, and

hydraulic conductivity within the groundwater aquifer as well as affected by other factors, such as porosity, the nature of aquifer (confined or unconfined), the recharge and discharge areas.

The groundwater table equipotential map was plotted for the study area, to determine the direction of groundwater movement and natural drainage. Thus, the direction of groundwater flow lines dawn perpendicular to the equipotential lines (Sanders, 1998), as in Fig. 3. It was found that the direction of groundwater movement is in the center and south of the area towards the Balawat area southeast of Qaraqosh. While the flow in northern part is towards Khazna Tabba area north of Bartella.

The trend of groundwater flow corresponds the direction of the surface drainage system (valleys) and the topographical slope, and compatible with the geomorphological concepts that the high lands in general represent the recharge areas and low lands as discharge areas. It has been observed that there are local changes in the directions of flow, due to several reasons, including the variation in groundwater pumping from one area to another (Al-Taweel, 1983), the heterogeneity of the porous media, the variation of hydraulic properties in terms of permeability and porosity, or due to the presence of abnormal recharge.

3.4. Hydraulic Gradient

Hydraulic conductivity is defined as the ability of aquifer materials to transfer water (Al-Gburi, and Al-Tamimi, 2020). The hydraulic gradient was calculated at selected sites in the study area, it was about 0.022, 0.003 and 0.008 in north, middle and south of the area, respectively.

3.5. Pumping Test Analysis Methods

In order to identify the best methods for processing pumping data and evaluating hydraulic properties, it is necessary to recognize the geological and hydrogeological conditions of an aquifer, in other word, the availability of information such as the type of the aquifer, flow circumstances, presence or absence of monitoring wells, hydrogeological boundaries and well pumping rates. The purpose of pumping test experiments is to obtain hydraulic properties that are useful in solving complex problems of wells in terms of well productivity, well efficiency, groundwater table, and groundwater flow. This is done by pumping the water from the aquifer for a certain period of time and with a constant pumping rate, and the drawdown of groundwater table is measured in the nearby observation wells, the measuring continues until the steady state of groundwater table (the constant level) (El-Rawy, and De Smedt, 2020). Two methods were used to analyze pumping test, they are Theis method and Cooper-Jacob method (Kruseman and Deridder, 1979).

3.6. Pumping Wells and the Pumping Test Analysis:

The pumping test was carried out in the study area at two sets of wells only because the absence of more suitable sets for this experiment, monitoring and observation wells selected for each sets. The results of hydraulic properties estimated by pumping test may represent multilayer groundwater aquifer, due to the difficulties of separating the aquifers from each other, during the pumping test and the lack of ideal conditions for this method, and these wells are:

1. A well (Saint Barbara Monastery / Karamless village, east of the study area).
2. A well (afra Rafu Shito / Qaraqosh village, south of the study area).

The pumping test data were processed in the Aquifer Win 32 software as in the following:

3. 6. 1. The well of the Monastery of Saint Barbara

This well is located in the east of the study area (Karmless district), with the monitoring well 14 meters apart. The depth groundwater in the monitoring well is (22.35) meters, and the total depth of this

well is (180) meters. The pumping process was carried out on 21/10/2020, with pumping rate of (8) bThen the pumping was stopped when the level had steadied in the monitoring well Since the groundwater level reach the depth to groundwater was (17.96) m. From the processing of pumping data, it was found that the Transmissivity was $107.671 \text{ m}^2/\text{day}$ by Theis, and $100.682 \text{ m}^2/\text{day}$ by Cooper-Jacob methods, (Fig. 4). Moreover, the hydraulic conductivity of saturated thickness (157.65) m was reached 0.683 m/day by Theis method, and 0.639 m/day by Cooper-Jacob methods, which were conducted in the same conditions for the study area, as for the storage coefficient, it reached 0.0023 by Theis and 0.0020 by the Cooper-Jacob methods (Table 2). Which is very close to that was mentioned by Todd (2005) regarding to the storage coefficient of confined groundwater aquifers that consist of fine grain clastic sediments between silt and fine sand which is ranged between confined and unconfined groundwater aquifers. From the curve of the relationship between time and drawdown in Fig. 4 it was found that this curve is similar to the curves of semi-confined aquifer by Hantoush (Todd, 2005). It was observed that the points represent the field data fall on the standard curves except for those that represent the beginning of pumping due to the effect of well storage. The great similarity in the values of hydraulic parameters by different methods confirms the accuracy of the results.

Table 2. The results of the pumping test of the monastery of Saint Barbara well by Theis and Cooper-Jacob method

Parameter	Theis Method	Cooper-Jacob Method
Transmissivity (T)	$107.671 \text{ m}^2/\text{d}$	$100.682 \text{ m}^2/\text{d}$
Hydraulic Conductivity (K)	0.683 m/day	0.639 m/day
Storage Coefficient (S_c)	0.0023	0.0020
Radial Distance	14 m	14 m
Pumping Rate	8 l/sec	8 l/sec

Fig. 4. The results of the pumping test by Theis method on the (A) and Cooper-Jacob on the (B) the well of the monastery of Saint Barbara

3. 6. 2. The well of Afram Raffo Shitto farm

This well is located to south of the study area (Qaraqosh district), with the monitoring well 18 meters apart. The depth groundwater in the monitoring well is 11.93 meters, and the total depth of this well is 83 meters. The pumping process was carried out on 21/10/2020, with pumping rate of 7 l/sec., the pumping continued for 90 minutes, the time and corresponding drawdown were monitored. Then the pumping was stopped when the level had steadied in the monitoring well Since the groundwater level reach the depth to groundwater was 17.96 m. From the processing of pumping data, it was found

that the Transmissivity was 87.1685 m²/day by Theis, and 88.1004 m²/day by Cooper-Jacob methods, (Fig. 5). Moreover, the hydraulic conductivity of saturated thickness (71.07) m was reached 1.23 m/day by Theis method, and 1.24 m/day by Cooper-Jacob methods which were conducted in the same conditions for the study area, as for the storage coefficient, it reached 0.00135 by Theis and 0.00115 by the Cooper-Jacob methods. (Table 3). Which is very close to that was mentioned by Todd (2005) regarding to the storage coefficient of confined groundwater aquifers that consist of fine grain clastic sediments between silt and fine sand which is ranged between confined and unconfined groundwater aquifers. From the curve of the relationship between Time and Drawdown (Fig. 5), it was found that this curve is similar to the curves of semi-confined aquifer by Hantoush (Todd, 2005). It was observed that the points represent the field data fall on the standard curves except for those that represent the beginning of pumping due to the effect of well storage. The great similarity in the values of hydraulic parameters by different methods confirms the accuracy of the results.

Table 3. the results of the test pumping of the well of Afram Raffo Shitto farm by Theis and Cooper-Jacob method

Parameter	Theis Method	Cooper-Jacob Method
Transmissivity (T)	87.1685 m ² /d	88.1004 m ² /d
Hydraulic Conductivity (K)	1.23 m/day	1.24 m/day
Storage Coefficient (Sc)	0.00135	0.00115
Radial Distance	18.25 m	18.25 m
Pumping Rate	7 l/sec	7 l/sec

Fig. 5. The results of the test pumping by Theis method on the (left) and Cooper-Jacob on the (right) of the well of the farm of Afram Raffo Shitto

3.7 Total Dissolved Solid (TDS)

Total dissolved solids generally reflect the amount of dissolved minerals content in the water, especially salts, the origin of these salts may be deduced from the lithological description of the aquifers of groundwater (Awadh and Ahmed, 2013), this feature indicate the hydrogeological system and the types of the groundwater aquifers. It was noticed from that the concentrations of total dissolved solids raised to more than 3500 ppm in the mid of the study area and decreased towards all directions to reach 250 ppm. This wide variation in salinity may be because that the wells in the central region penetrates saline groundwater aquifers, and it is most likely the layers of Al-Fat'ha Formation, which is in hydraulic contact with the main aquifer of the Injana Formation. A high concentration of TDS may cause adverse effects on plant growth and soil quality. Its concentrations are varied according to the geological

background, the difference of rock materials solubility, and the period that the water in contact with the rocks.

4. Conclusions

The geology of the region controls the hydrogeological system of the basin, the sediments of the Quaternary (alluvial fans and river terraces) represented a secondary aquifer. While the Injana formation which contains a succession sand, silt and clay represent the main confined – semiconfined aquifer due to the presence of impermeable clay layers. The results of storage coefficient indicate the conditions of the confined to semi-confined aquifers. Structural phenomena controlled the basin's characteristics and its hydrogeological boundaries, as in the case of Ayn al-Safra and Bashiqa anticlines, which are NW-SE strike, and represent the eastern and northeastern boundaries of the study area, which is recharge the studied area, while the western hydrogeological boundary represented by Tigris River. The depths of the groundwater in the study area varied from 5 m in the center to 45m in the north and south. The measurements of groundwater table indicate that it reaches to about 278.5 m (a.s.l) in the center and decreased gradually to 234 m (a.s.l) in the north and south. The general direction of groundwater movement in the aquifer is from the recharge area adjacent to Bashiqa, towards the south, which is correspond to the direction of the surface topographical slope in the area, with the presence of local movement directions resulted by pumping from the aquifer or due to the heterogeneity of the porous medium. The wide variation in salinity may be because that wells in the central area penetrate groundwater aquifers of a saline lithology as in Al-Fat'ha formation, which is in hydraulic contact with the main aquifer represented by Injana formation.

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