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Using Pumping Tests and Two Techniques of the Water Balance to Assess the Aquifer Hydraulic Characteristics and the Groundwater Recharge of Shewasoor Sub-Basin Kirkuk, NE Iraq

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Abstract

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Shewasoor sub-Basin represents one of the hydrogeological sub-basins of the Lower Zab River and covers an area of 160 km². It is located between longitude (44° 31' 23.9" – 44° 37' 75") and latitudes (35° 45' 28.9"–35° 48' 59"). The basin is bounded from the north and northeast by *the* Taqtaq anticline and Chamchamal anticline represents the western and southwest boundaries, while the southeast boundary is a surface water divide with the Al-Khassah River sub-basin. The groundwater distribution levels and movement maps show that the water depths range between 414-862 m a.s.l, and it moves in line with the movement of water surface drainage, as it moves from the east, southeast, south, and southwest (recharge areas) towards the northwest regions, while the water depths vary from the ground level between relatively deep in the southwestern part to medium and shallow in the rest of the parts. An evaluation of the hydraulic characteristic and groundwater recharge by two techniques of the water balance for aquifers of the study area has been carried out. The results showed that the hydraulic properties, transmissivity value ranges between 5.6 - 169 m²/day, the hydraulic conductivity values range between 0.67 - 5.1 m/day, and the storage coefficient values, ranging from the lowest value (0.0013) to the highest value (0.27). The results reflected that the types of the aquifers are unconfined and semi-confined as well as heterogeneous and anisotropic. after analyzing and calculating the climatological parameters of Koya meteorological station as the nearest station to *the* Shewassor area, showed the water surplus is equal to 333.94 mm which represent 53.8% of the annual rainfall value (628.3mm) and the surface water is equal to 138.5mm as a runoff. 199.44mm (31.74%) out of the annual rainfall is percolated to recharge the aquifers of Shewasoor, while water table fluctuation method WTF showed there are two zones of specific yield in the study area and the groundwater recharge is 232.06mm, so can be said that the 215.8mm is the average of the groundwater recharge in Shewasoor sub-basin. Finally, and by using the groundwater flow net analyzing technique that the amount of groundwater discharged from the study area is about 12 million m³ (MCM) and the renewal groundwater storage is 19.42 million m³ (MCM), which means there is 7.39 million m³ is groundwater can be invested as a safe investment.

Keywords: Shewasoor sub-basin; Pumping test; Hydraulic properties; Water balance; Groundwater recharge

1. Introduction

Water is very important for human activities, many regions around the world depending on groundwater which considered as one of the most important sources of fresh-water (AL-Hayali et al., 2021). The shortage of water resources, especially in the surface water, led to Iraq's tendency to exploit groundwater to meet its domestic, agricultural and industrial requirements. The irrigation return, rainfall infiltration, and the riverbed floods flow led to groundwater recharge in the region (Tizro et al., 2014). Efforts to control and monitor water sources and groundwater use have become indispensable for maintaining sustainable groundwater availability (Waspodo et al., 2020). Hydrogeological methods are among the important foundations for the development and management of groundwater resources and their exploitation. Therefore, groundwater must be invested based on an assessment of the hydrogeological conditions and hydraulic properties of the aquifer layers of water and their drainage and their relationship between them (Moharir et al., 2020). Groundwater in its natural state moves steadily and depends in its movement on several fixed hydraulic properties such as (hydraulic conduction, transmissivity and storage coefficient (Todd and Mays, 2004). hydrogeological properties are very beneficial in describing subsurface hydrology. (Mendosa et al. 2003) (Al-Naqash et al., 2003).

Shewasoor subbasin is located to the north eastern part of Iraq, far 40 Km northeast of Kirkuk city, between longitudes ($44^{\circ} 31' 23.9''$ E - $44^{\circ} 37' 07.5''$ E), and the latitudes ($35^{\circ} 45' 28.9''$ N - $35^{\circ} 48' 59.1''$ N), the elevation ranged between 438 - 879 m. a.s.l, and covers about 160 km², the Shewasoor Subbasin is bounded from north and northeast sides by Taqtaq Anticline, from west and southwest sides by Northern ChamChamal Anticline, and by topographic Surface water wear between Al-Khassa Sub-basin and the study area from south and southeast side's (Fig.1).

pumping test in two methods, namely the climatic water-balance method and the groundwater level fluctuation change. Assessment the hydraulic characteristics (hydraulic conductivity, transmissivity, storage coefficient) of the aquifer and identify the type of aquifer in the Shewasoor Sub-basin, evaluating the renewal groundwater storage, determination the special distribution and the movement direction of the groundwater in the study area.

2. Materials and Methods

Groundwater monitoring and recording of water level changes in wells are carried out in the study area and the pumping test process was used to obtain the hydraulic properties (transmissivity, storage coefficient, hydraulic conduction) of groundwater aquifer, which give an indication about the velocity of water within the porous medium and its effect on the groundwater level (Hem, 1985). Twenty groundwater wells were monitored to measure the groundwater levels and the water tables which shown in Table 1 while pumping was tested on four wells distributed in study area in order to assess the hydraulic properties, as mentioned above the pumping test data were analyzed in the Aquifer Win - 32 software program, by using the Copper-Jacob and Hantush methods (Ali, 2020). The reason for choosing these wells 4 is that there are available wells and the difficulty of accessing other wells due to the ruggedness of the area and the lack of consent of the people of the area to conduct the experimental pumping process in their wells because most of the wells in the area are dug by the people of the area and not governmental.

Table 1. Basic data of the water well in the study area

wells	Longitude	Latitude	Elevation (m. a. s. l)	Depth to water (m)	SWL (m a.s.l)
W1	44° 35' 55"	35° 45' 50"	618	31.1	586.9
W2	44° 33' 04"	35° 45' 58"	609	18.55	590.45
W3	44° 33' 36"	35° 46' 53"	488	11.2	476.8
W4	44° 33' 47"	35° 45' 51"	580	32.05	547.95
W5	44° 31' 54"	35° 46' 45"	586	36.6	549.4
W6	44° 31' 23"	35° 46' 42"	580	29.5	550.5
W7	44° 31' 41"	35° 47' 08"	560	24.7	535.3
W8	44° 33' 05"	35° 47' 51"	438	2.55	435.45
W9	44° 34' 31"	35° 47' 43"	566	4.55	561.45
W10	44° 35' 57"	35° 47' 56"	618	28.15	589.85
W11	44° 36' 27"	35° 47' 12"	673	16	657
W12	44° 37' 05"	35° 47' 13"	713	25.65	687.35
W13	44° 36' 27"	35° 45' 45"	665	61	604
W14	44° 39' 40"	35° 45' 54"	879	7.25	871.75
W15	44° 35' 41"	35° 45' 39"	617	54.3	562.7
W16	44° 36' 08"	35° 45' 39"	649	24.65	624.35
W17	44° 37' 07"	35° 45' 52"	706	64	642
W18	44° 33' 48"	35° 48' 56"	510	23.3	486.7
W19	44° 33' 31"	35° 48' 55"	494	20.4	473.6
W20	44° 32' 56"	35° 48' 59''	477	28.25	448.75

After that, the groundwater recharge for the aquifer of the study area has been calculated through using two common and important methods (Climatological water balance and water table fluctuation WTF) which are inserted within the water balance of the hydrological basin.

3. Results and Discussion

Depending on the basic data of water wells in the study area (Table 1) and drawing the groundwater flow net of shewasoor sub-basin (Fig.2), (the groundwater distribution levels and directions of the movements) showed that the water tables range between 414-862 m a.s.l, and the movements are from the east, southeast, south and southwest (recharge areas) towards the northwest regions. (Discharge areas) which is follow in this condition the surface water patterns of the study area while, the water depths vary from the ground level between relatively deep in the southwestern part (61) m to medium and shallow in the rest areas (2.5) m. After analyzing the pumping test data, (Table 2), (Figs. 3 and 4) , the result of the hydraulic characteristics showed there were some variations in the study area. The value of transitivity range between 5.6 - 169 m²/d, the hydraulic conductivity values are varying from one place to another and range between (0.67 – 5.1) m/d and values of storage coefficient, differ in the study area, where they range from the lowest value (0.0013) and the highest value (0.27) that shown in Table 3. The variation of hydraulic characteristics values is reflected variation in lithology and the saturated thickness of the aquifers, which mean the heterogenic and an isotropic formation. The results of the pumping test of the selected wells within the study area indicate that the aquifer types are (Unconfined and Semi-Confined) also it is anisotropic and heterogenic. The values of the hydraulic parameters and saturation thickness which were listed in Table 3 and illustrated in Figs. 5, 6, 7 and 8.

Fig.2. Equipotential lines and flow directions of the groundwater in the study area

Table 2. Pumping tests data of the four wells in the study area

Time(min)	Drawdown(cm) (Observationwell)		Drawdown(m) (Single well)	
	W8	W5	W12	W15
1	1	1	2.5	1.35
2	2.2	2.5	4.5	2.1
3	3.3	3.5	6	2.92
4	4	5	8	3.7
5	5	6.5	9	4.32
10	7	9	11	6.64
15	8.2	10.5	13.1	7.9
20	9.1	12	14	9.2
25	9.75	13	15	10
30	10.6	13.5	16.25	11
45	12	15.5	17.5	13
60	13.4	16.5	18	14.8
75	14.25	17.25	19.1	15.6
90	15	18	20	16.66
105	15.9	18.5	20.5	17
120	17	20	21	17.33
150	17.5	21	21	17.5
180	17.5	22		17.5
210	17.5	22		

Table 3. Wells number and their coordinate and the results of the methods T, K and S in the study area.

Wells	Long.	Lat.	T	B	Sc (Sy)	K	Well Type
W8	459465	3961580	169	33	0.002	5.1	Observation Well
W12	465484	3960390	6.1	9	0.132	0.67	Single Well
W15	463363	3957500	5.6	8	0.278	0.7	Single Well
W5	457673	3959560	141	30	0.0013	4.7	Observation Well
Recharge of the area					215.5 mm/Year		
Study area cover					158.545 Km

Well 8

Well 5

Fig .3. Pumping test data analysis of W8 and W5 by Hantuosh method

Well 12

Well 15

Fig .4. Pumping test data analysis of W12 and W15 by Copper- Jacob method **Fig .5.** Saturated thickness map of the study area.

Fig. 6. Transmissivity map of the study area

Fig. 7. Hydraulic conductivity map of the study area

3.1 Climatic Water Balance

An important part of the hydrological cycle is climatological water balance and it has a relationship between the rainfall on the area and the amount of water lost with different patterns, (Domenico and Schwartz, 1998). The water balance equation based on the principle that inputs equal outputs (Todd and Mays, 1980). The input elements in the water balance are rainfall and snow (Table 4). The two outputs are matching by evaporation and transpiration. Evaporation defines as the process of losing water from water surfaces or from the soil. Transpiration is the process of losing water from plants. The two mentions processes called evapotranspiration that consists of (Potential evapotranspiration). Potential evapotranspiration is the water lost with enough quantity at the time while the quantity is determined when calculating the Actual evapotranspiration. Actual evapotranspiration is the highest rate or equal to the calculated evapotranspiration and it is the reference of the amount of water that wanted for germination purposes in the area, which has reflected the total annual proportion of rainfall to the annual total of evapotranspiration to identify the type of area according to this type. The inputs are equal to the outputs based on the flowing equation (Todd and Mays, 1980) (Table 5).

Table 4. The climatic water balance elements of the study area

Months	rainfall (mm)	Pec (mm)	AE (mm)	SM (mm)	WS (mm)	WD (mm)
Oct.	43.9	87.64	43.9	0	0	43.74
Nov.	74.6	26.61	26.61	47.99	0	0
Dec.	99.5	10.16	10.16	100	37.33	0
Jan.	120	5.66	5.66	100	114.34	0
Feb.	92.9	8.48	8.48	100	84.42	0
Mar.	104.2	21.77	21.77	100	82.43	0
Apr.	70.6	51.18	51.18	100	19.42	0
May.	14.7	120.38	14.7	0	0	105.68
June.	0.7	206.73	0.7	0	0	206.03
July.	0	281.54	0	0	0	281.54
Aug.	0	254.61	0	0	0	254.61
Sep.	7.2	164.13	7.2	0	0	156.93
Total	628.3	1238.89			337.94	1048.53

When calculating the water balance of the Shewasoor sub- basin for the period 2002 – 2019 depending on 100 mm. The amount of the soil reaches the saturation point (Al Forat Research Center and Design irrigation projects, 2000). The months Dec, Jan, Feb, Mar and Apr are the period of the water surplus which is the wet period is equal to 337.94 mm of the annual rainfall which equal to 629.3 mm and that equal 53.786 % percentage.

$$WS \% = (WS/P) * 100 \quad (1)$$

$$WS \% = (337.94/628.3) * 100 = 53.786 \% \quad (2)$$

The surface runoff is included in the calculations of the water balance equation used in calculating the amount of groundwater recharge. The surface runoff of the study area is 138.5 depending on surveying final report of the Italian company which is constructed Shewasoor dam. The value of the surface runoff depending on the slope and nature of the ground surface (Ali, 2020). Groundwater Recharge (Gr) the amount of water, which percolates into the groundwater levels, was calculated and the results of groundwater recharge were as follows: $WS = Gr + Sr$, $337.94 = Gr + 138.5 = (4.911/628.3) * 100 = 31.742 \%$ from the rainfall percolated to recharge the groundwater in the study area.

3.2. Water Table Fluctuation Method (WTF)

Water table fluctuation method is an estimated of groundwater recharge accomplishment by analyzing water-level fluctuations in the wells that have been monitored. This method based on the assumption that the measured groundwater level rise in these wells as a response from the addition of recharge to the groundwater table (Freeze and Cherry, 1979) (Table 5) and (Fig. 8). Recharges calculating by using the following equation (Healy and Cook, 2002): $GR = Sy \times \Delta h$ showed that the groundwater recharge is equal to 232.07 mm (Table 5) and (Fig. 9).

Fig.8. Groundwater level fluctuations in wells 16, 12, 6, 18, 15 and 2 in the study area

Table 5. Result of fluctuation of the groundwater balance in the study area

Well No.	Sy	$\Delta h(m)$	GR (mm)
W2	0.00137	8.4	11.508
W6	0.00137	8.2	11.234
W12	0.1325	9	1192.5
W18	0.002	8.65	17.3
W16	0.0278	4.35	120.93
W15	0.0278	1.4	38.92
Average			232.065

Fig.9. Average of specific Yield value used in WTF method

3.3. Estimation of (Recharge and Discharge) Ground and Surface water in Shewasoor subbasin

Groundwater resources management takes in consideration estimation of the major components of the groundwater budget, such as recharge and discharge. Depending on Theis (1940); Bredehoeft (2007) the size of groundwater resources is determined by the amount of captured discharge and the induced recharge, rather than by the rate of natural recharge. Groundwater always moves towards the lower head, this discharge area is always at a lower elevation than the water table where groundwater enters the system as recharge (Fitts, 2002). Groundwater flow of the study area was determined by using the Flow Net Analysis Method (Fig. 2). Groundwater flow calculated by the following equation (Ahmed et al., 2005; Raghunath, 2006):

$$Q = T iL \text{ and } i = dh/l \quad (3)$$

Where:

i : Hydraulic gradient. dh : total head difference (m)

L : Length of the flow path (m)

T : Average of Transmissivity (m^2/day)

Q : Discharge (m^3/day)

l : Front length (m)

The major aquifers in the study area are (quaternary and Bi-Hassan), which extend to large areas as shown in the geological map. Depending on the results of the water budget obtained by the Italian report and WTF methods (31.742 and 36.953 mm), respectively, (34.338 mm as an average) to estimate renewal groundwater recharge. Annual or renewal groundwater recharges quantity in the unconfined semi unconfined aquifer calculated based on equation (Raghunath, 2006):

$$\text{Renewal storage} = A \times G.R \quad (4)$$

Where:

Renewal storage: Annual groundwater recharges quantity ($m^3/year$)

A : Area of recharge region (m^2)

G.R: Groundwater Recharge (m). $G.W=90.3 \times 0.215 \times 10^6 \rightarrow G.W=19.42 \times 10^6$

G.W = 19.42 MCM Annual groundwater recharges in the study area

$\Delta s \pm = G.W_{in} - G.W_{out} \rightarrow \Delta s \pm = 19.42 - 12.03$

$\Delta s \pm = 7.39$ MCM

This value can be investing in the region and not exceeded to ensure that there is no depletion of groundwater storage in the region in line with the effects of climate change and the succession of dry seasons. After conducting the water balancing using the two methods mentioned above, as the first method was dependent on the elements of the climate and the second depended on the fluctuation of levels groundwater during the months of the water year, when comparing the two methods, the results were very close, despite the difference between the two methods, as the first method relied on inputs (rains) and outputs (evaporation and evapotranspiration) of water, while the second method relied on monitoring levels directly for a month and after making calculations and graphs between months. And the level shows that the wet period brings the largest amount of water into the basin, and after entering these values to calculate the recharge, it turns out that the recharge value in this method is 232.06 to calculate the water balance in this way, while the value of recharging in the first classical method was 199.44 and since the results of the two methods are very close, the average use of the two methods and its use in the general water budget 215.7.

4. Conclusions

pumping test experiments, shows there are two zones: The recharge areas and the discharge areas in which the values range from 140–170 m² / day the hydraulic conductivity values are between 0.7 to 5.0 m/day between the two mentioned zones, while the type of aquifer is unconfined to semi-confined. The groundwater moves from the east, southeast, south and southwest (recharge areas) towards the northwest regions (discharge areas). The water surplus is equal to 333.94 mm which represents 53.8% of the annual rainfall value (628.3mm) and the surface water is equal to 138.5mm as a runoff. 199.44mm (31.74%) out of the annual rainfall is percolated to recharge the aquifers of Shewasoor, while water table fluctuation method WTF showed the groundwater recharge is 232.06mm, so can be said that the 215.8mm is the average of the groundwater recharge in Shewasoor sub-basin. Finally, the amount of groundwater discharged from the study area is about 12 million m³ (MCM) and the renewal groundwater storage is 19.42 million m³ (MCM), which means there is 7.39 million m³ is groundwater can be invested as a safe investment. The area is under the influence of a climate ranging from semi-dry to semi-humid.

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