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Groundwater Modeling of Ahmed Taher and Bakhtiari areas southwest of Khanaqin Basin in Diyala Governorate – Iraq

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Abstract. A foretelling of the groundwater level declining is substantial for the administration of subsurface water resources system, particularly in dry and semi-dry zones (area under this study), in which ground-water is the main exporter for agrarian and Household requirements. The purpose of this study is to investigate the influence of the increasing withdrawal rates from the aquifer on the condition of the groundwater. In addition to the effect of the decreasing recharge rate on the groundwater for the area under study. The study area (the southwest part of Khanaqin city) extended over 129 km² was simulated using the mathematical model (GMS10-MODFLOW2000). Under a steady-state calibration process, good matching between model and observed groundwater head values has been found. To observe and evaluate the competence of the groundwater water system, five different scenarios have been used for the unsteady state. The first case used as a reference case for comparison, in which the existing withdrawal rates were modeled, after that the discharging rates will be increased up to (50 %, 100 %, and 200%) on the current rates through the next ten years. For the fifth case, the recharge rate was decreased by up to 25% by keeping the same condition applied in the previous cases. Maximum drawdown values resulted from these scenarios are equal to (11.58, 19.14, 27.58, 46.82 and 48.35 m) respectively. According to the drawdown map, the maximum value recorded on the left side of the modeled region in the study area, and the minimum was recorded in the area near Al-Wand River.

Key Words: Groundwater Modeling; Aquifer Mining; Water table fluctuations

1. Introduction
Groundwater is one of the most important natural resources of water for a variety of uses. These sources of the water provide water approximately for all water neediness for different purposes such as industrial, agriculture and domestic except hydropower generation and electric plant cooling. It represents 40 percent of water use [1]. The lack of quality and quantity of the data for mass assessment of the groundwater quality represents a function of the heterogeneity for all of the hydraulic properties, geological formation and drilling difficulties for a good data [2]. The scarcity and luck of the quality of the surface water pushed the efforts toward focusing on the groundwater to use it for different purposes. A high degree of good management is needed in order to keep the ability of the aquifer to recover its water as well as control the water quality and protect it from contamination [3]. By using the MODFLOW model a numerical groundwater flow model was established by Ali and Oleiwi [4], for the study to simulate the groundwater resources systems in the Khanaqin basin, Northeast Iraq. [5].
identify the hydraulic aquifer parameters of the Khanaqin basin by analyzing pumping test data using Cooper-Jacob and Theis Recovery test methods. Analyzing results shown that the average transmissivity values for confined and unconfined units were ranged between (14.47-244.35 m²/day) and (273-4590 m²/day) respectively, while the storage coefficient values ranged between (3.5*10⁻⁵) to (1.14*10⁻³). As well as results indicated an increase in transmissivity values and production rates of the Khanaqin basin toward the northwest direction. Ramadhan, et al [6], studied the aquifer hydraulic system of the whole Khanaqin basin. In this study, it was found that the unconfined aquifer extended through southern areas of the Khanaqin basin, while the north part near the Iraq-Iran border and the western part of basin represent the confined aquifer part. These two areas are promising areas that can be exploited significantly in the future. This study aimed to investigate the influence of the increased pumping rates from the aquifer on the condition of the groundwater as well as the effects of decreasing recharge rate on the groundwater for the southwest part (lower part) Khanaqin city.

2. Study Area Description
The study area lies between Latitudes 34°22'37"N and 34°15'58"N and between Longitudes 45°24'24"E and 45°10'10"E (Figure 1). It is one of the local government areas in Khanaqin District, Diyala governorate, east of Iraq. It has an altitude approximately ranged between (120-250) m above mean sea level with an area extent of approximately 129 km². It is bounded to the northwest and southwest by the Al-Wand river.

![Map of Iraq showing Diyala Governorate](image1)

Figure 1. Khanaqin district location map [7]

3. Study Area Climate Conditions
Climatic elements have a significant impact on the status of groundwater in a particular area. Climate data for the study area were obtained from the Khanaqin rain gauge station for the period extended from 1980 to 2017 as demonstrated in Table 1. The mean annual values of both rainfall and temperature are equal to 290.5mm and 16-31°C successively while the total evapotranspiration value equal to 1528
mm/month. The average annual values of both relative humidity and total solar radiation are equal to 48% and 8hr/day respectively. According to the (Raghunath classification system), the climate of the study area is classified as an arid climate region [8].

Table 1. Khanaqin meteorological monthly and annual average for the period (1980-2017) [9]

| Month | R mm | TM °C | Tm °C | T °C | Humidity % | WS m/s | SRt hr/day | Et˳ _tot mm/month |
|-------|------|-------|-------|------|------------|--------|------------|------------------|
| Jan   | 55.2 | 15.70 | 5.20  | 9.90 | 77.00      | 1.50   | 5.60       | 38.00            |
| Feb   | 43.8 | 18.00 | 6.20  | 11.70| 69.00      | 1.80   | 6.00       | 51.00            |
| Mar   | 46.2 | 22.50 | 9.70  | 15.80| 60.00      | 1.90   | 6.80       | 87.00            |
| Apr   | 27.5 | 29.30 | 15.10 | 21.80| 50.00      | 2.10   | 7.60       | 130.00           |
| May   | 6.0  | 36.40 | 21.10 | 28.80| 37.00      | 1.90   | 8.80       | 180.00           |
| Jun   | 0.0  | 42.20 | 24.90 | 33.80| 27.00      | 1.90   | 10.90      | 214.00           |
| Jul   | 0.0  | 45.00 | 27.30 | 36.30| 25.00      | 1.70   | 10.90      | 227.00           |
| Aug   | 0.0  | 44.80 | 26.60 | 35.40| 26.00      | 1.60   | 10.40      | 209.00           |
| Sep   | 0.1  | 40.50 | 22.40 | 31.10| 29.00      | 1.40   | 9.50       | 162.00           |
| Oct   | 13.7 | 33.70 | 17.80 | 25.20| 39.00      | 1.70   | 7.70       | 125.00           |
| Nov   | 52.3 | 24.30 | 10.80 | 17.00| 60.00      | 1.40   | 6.70       | 65.00            |
| Dec   | 45.7 | 41.00 | 6.50  | 11.90| 73.00      | 1.20   | 5.30       | 40.00            |
| Avg.  | 29.0 | 30.90 | 16.10 | 23.20| 48.00      | 1.70   | 8.00       | 1528.00          |

4. Geology of the Study Area

The studied Area is situated on the left side of Al-Wand River (south-west) Khanaqin town. Generally the topography of the Khanaqin basin is flat that gradually rises from south-west to north-east. The geological formation locates in this basin consist of two types are Quaternary and Tertiary deposits [17]. The Quaternary deposit (Pleistocene – Holocene) is the main formation in Khanaqin basin and consists of loam, clay, sand and gravel, and this formation has a large thickness near the river. The Tertiary deposits divided into two types, Upper Bakhtiyar (Bai Hassan) which consists of an alternation of sandstone, siltstone and claystone and Lower Bakhtiyar formations (Muqdadiya) which consists of conglomerate alternations interbedded with sandstone, claystone, and scattered siltstone [10,11]. For the selected area the Quaternary deposit whole cover of it and has governed by two types of deposits a valley fill and flood plain shown Figure 2 and Figure 3.
Figure 2. Sequence of the geological formations in the Khanaqin basin [12]
5. Hydrogeology of the geological formation Within the Study Area

Upper Bakhtiari (Bai Hassan), Lower Bakhtiari (Muqdadiya) formations and Quaternary deposits represented the main hydrogeological rock units in the Khanaqin region. Lower Bakhtiari (Muqdadiya) formation and Quaternary deposits are the main aquifer system in the Khanaqin zone [12]. Material included sand, agglomerate, clay, silt and gravel are represented the Quaternary deposits which have a thickness ranging between 5 and 40 m, while claystone, sandstone and gravel represent the materials of Muqdadiya formation. The hydraulic properties of the aquifers such as transmissivity and production rates are high especially in wells that have a low brininess. Hydraulic parameters values \((T,K \text{ and } S_y)\) for the study area, according to the previous study range between \((47-1322) \text{ m}^2/\text{day}, (0.6-30) \text{ m/day and } (0.01-0.3)\) respectively [3].

6. Results

GMS10.0- MODFLOW 2000 used in the present study supports several models such as (MODFLOW 2000, 2005, and NT, MODPATH, MT3DMS/RT3D, SEAM3D, ART3D, UTCHEM, FEMWATER and SEEP2D). In this study conceptual model is selected. The govern equation in Cartesian coordinates \((x \text{ and } y \text{ coordinates })\), transient flow for homogenous and isotopic aquifer with (source/sink terms) can be written as:

\[
\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{S}{T} \frac{\partial h}{\partial t} - \frac{R(x,y,t)}{T}
\]  

(1)
In which \( h \) is ground water head, \( S \) is storage coefficient, \( T \) is transmissivity and \( R \) is the source or sink term. This equation can be solved based on the finite elements and finite-difference numerical methods with specifying boundary and initial conditions [15]. \( R(x,y,t) \) the source-sink term represents the summation of discharge rate (Pumping, evaporation and evapotranspiration) and recharge rate (precipitation) as:

\[
R(x, y, t) = P_{\text{net}} - Q_{\text{pumping}}
\]

(2)

Where \( P_{\text{net}} = \) (net infiltration, precipitation, evaporation, evapotranspiration ) and \( Q_{\text{pumping}} = \) Pumping from the wells

6.1 Model design and boundary conditions
The steps needed for groundwater modeling such as site conditions, model development, calibration process (automatically and manually) have been provided in it. The groundwater modeling steps demonstrated in Figure 4. The Conceptual model approach was used to build a model system for the study area. In this approach, the GIS tools in the map module are used to constructs a study site modeled area. All the area characteristics that needed to site simulation such as a boundary condition, well data, hydraulic parameters identifying on the conceptual model level. After the modeling is complete, generate the grid system and converted the conceptual model to it [13]. For the study site, a uniform grid is selected with a cell spacing of 200 by 200 m in x, y directions, the total number of the active cells, columns and rows are 3223, 107 and 62 respectively, Figure 5. Two types of boundary condition assigned to the modeled area are Dirichlet (specified head) and Neumann (No-flow) boundaries. Al-Wand River, which extended from northwest to southwest (upper to left sides) of the study area assigned as a specified head boundary, while the right and lower sides were assigned as no-flow boundary conditions. The well information has been demonstrated in Table 2. The hydraulic conductivity and specific yield values for the study site are taken from previous studies.

Figure 4. GMS-conceptual model Flow-chart
Figure 5. Study area grid design system

Table 2. Field data information for investigated wells (General Commission of Groundwater [13])

| Well No. | UTM coordinates X(m) | UTM coordinates Y(m) | Well Elevation (m) | Well Depth (m) | Static water level (m) | Discharge L/sec | Well radius (in) | Casing radius (in) |
|----------|----------------------|----------------------|-------------------|---------------|-----------------------|---------------|-----------------|------------------|
| W-1      | 529896               | 3793077              | 199               | 192           | 45.18                 | 7             | 15              | 8.625            |
| W-2      | 529891               | 3793076              | 199               | 192           | 46.3                  | 7             | 9.875           | 5                |
| W-3      | 530251               | 3800348              | 163               | 72            | 12                    | 7             | 13.75           | 8.625            |
| W-4      | 531972               | 3796953              | 168               | 60            | 20                    | 8             | 15              | 10.75            |
| W-5      | 530439               | 3796794              | 164               | 60            | 20                    | 8             | 13.75           | 8.625            |
| W-6      | 528855               | 3796758              | 159               | 60            | 15                    | 9             | 15              | 10.75            |
| W-7      | 528821               | 3793493              | 188               | 107.2         | 43                    | 3.5           | 13.75           | 8.625            |
| W-8      | 524571               | 3797867              | 156               | 72            | 15                    | 7             | 13.75           | 8.625            |
| W-9      | 529214               | 3793848              | 187               | 110.5         | 41                    | 6.5           | 13.75           | 8.625            |
| W-10     | 531990               | 3796069              | 171               | 60            | 25                    | 6             | 13.75           | 5                |
| W-11     | 531464               | 3800620              | 171               | 60            | 15                    | 7             | 13.75           | 8.625            |
| W-12     | 529701               | 3797330              | 160               | 60            | 20                    | 8             | 10              | 5.625            |
| W-13     | 531972               | 3796953              | 169               | 60            | 20                    | 8             | 15              | 10.75            |
| W-14     | 531744               | 3796428              | 169               | 66            | 24                    | 9             | 15              | 8.625            |
| W-15     | 531359               | 3796766              | 167               | 66            | 23.5                  | 9             | 15              | 8.625            |
| W-16     | 531311               | 3795965              | 172               | 66            | 24                    | 9             | 15              | 8.625            |
| W-17     | 531488               | 3796582              | 168               | 66            | 23                    | 9             | 15              | 8.625            |
| W-18     | 531308               | 3796858              | 169               | 66            | 23                    | 8             | 15              | 8.625            |
| W-19     | 532025               | 3796399              | 170               | 66            | 22.5                  | 8             | 15              | 8.625            |
| W-20     | 531769               | 3796582              | 168               | 66            | 19.5                  | 8             | 15              | 8.625            |
| W-21     | 532181               | 3797077              | 169               | 172           | 18                    | 9             | 15              | 8.625            |
6.2 Model calibration

Two hydraulic parameters (recharge rate and hydraulic conductivity) in steady-state were adjusted for the study area groundwater model calibration by using trial and error and PEST techniques. In PEST technique the error quantity resulted from the differences between observed and calculated head appear on the map and the color of target show the error values Figure 6. Calibration target have three degree of color each of them (green, yellow and red) gives indicates about the calibration result accuracy (Christensen and Cooley, 2003). Good matching has been reach between observed and calculated values with difference ranged from (0.14) m to (1.54) m shown Table 3 and Figure 7, 8.

![Calibration target](image)

**Figure 6. Calibration target [15]**

| Cell | Observed | Computed | Residual Head |
|------|----------|----------|---------------|
| W-22 | 532179   | 3797292  | 169           |
| W-23 | 533120   | 3797634  | 170           |
| W-24 | 533121   | 3797357  | 171           |
| W-25 | 532188   | 3796584  | 169           |
| W-26 | 531972   | 3797045  | 168           |

**Table 3. Observed and simulated head values at selected pivot points (wells)**
6.3 Simulation scenarios

To observe and evaluate the competence of the subsurface water system, five different scenarios will be studied as shown in Table 4. The first scenario was done by keeping the existing withdrawal rates and increasing discharging rates up to (50%, 100%, and 200%) through the next ten years. For the fifth case, decreasing the recharge rate with keeping the same condition applied in the previous case.
Table 4. Simulated Cases of pumping using GMS-MODFLOW

| Cases  | Recharge mm/day | Boundary Condition | Applied Pumping Rate m³/day | Applied Pumping Rate m³/day |
|--------|----------------|--------------------|----------------------------|----------------------------|
| Case 1 | Not Change      | Not Change         | Current                    | 16761.6                    |
| Case 2 | Not Change      | Not Change         | Increased up to 50%        | 25142.4                    |
| Case 3 | Not Change      | Not Change         | Increased up to 100%       | 33523.2                    |
| Case 4 | Not Change      | Not Change         | Increased up to 200%       | 50284.8                    |
| Case 5 | Reduced by 25%  | Not Change         | Increased up to 200%       | 50284.8                    |

6.3.1. First Scenario
In this scenario, examined the influence of the current production rates (16762 m³/day) from about 26 water well, drilled in the Quaternary deposits. Model run under stress period equal to 10 steps (next 10 years) and head values were computed for each step. The maximum drawdown value computed for this case is equal to 11.58m shown Figure 9.

Figure 9. Computed drawdown values at 3650 days

6.3.2. Second Scenario
In this state, it will increase the discharge rate up to 50% over present rates. Figure 10 shows the computed drawdown values of the study site at each time step. For this case the maximum drawdown value equal to 19.14m.
6.3.3. Third Scenario
In this scenario, it will increase the discharge rate up to 100% over present rates. Maximum drawdown value computed from this applied case is equal to 27.58m.

6.3.4. Fourth Scenario
Under this case, the withdrawal rate increasing up to 200% over the discharging rate applied in first case. The drawdown map shown in Figure 11. From drawdown map, a great impact resulted from increasing the discharging rates can be seen in the (left side) with maximum value equal to 46.82m.

6.4.5. Fifth Scenario
In this state, decreasing the recharge rate up to 25% over origin value with keeping the same condition applied in the previous case. Maximum recorded drawdown value for this case is equal to 48.35 m.
7. Conclusions

From the site modeling and results analyzing the following points can be concluded:

1- Maximum drawdown values resulted from discharge values increase and recharge decreasing area equal to (11.58, 19.14, 27.58, 46.82 and 48.35 m) respectively.

2- According to the drawdown map, the maximum value recorded on the left side of the study area, and the minimum recorded in the area near Al-Wand River.

3- Due to the not existing negative budget of the aquifer, it can be drilling new discharging wells in the area, especially near the Al-Wand River.

4- The results of these scenarios confirm that must build an effective management plan to manage the processes of the drilling wells.

References

[1] Ralph C.H.: (2009): Groundwater Hydrology. edited by (De Smedt . F.). U.S. Geological Survey. Water-supply Paper 2220, 1987, 84 pp.

[2] Delleur, J.W. (editor) (2000): The Handbook of Groundwater Engineering, School ofCivil Engineering Purdue University West Lafayette, Indiana. Corporate Blvd., N.W. Boca Raton,FL 33431, U.S.A.

[3] Al-Sudani, H. I. Z.; (2017) : Hydrogeological study of Khan Al-Baghdadi area in Anbar Governorate - West of Iraq. Diyala Journal for Pure Sciences. Vol. 13, No,2. 192-207 pp.

[4] Ali, Sawsan M., and Alyaa S. Oleiwi (2015). "Modelling of groundwater flow of Khanaqin Area,Northeast Iraq." Iraqi Bulletin of Geology and Mining 11.3: 83-94.

[5] Al-Sudani, Hussein Ilaibi Zamil (2017). "Hydraulic Parameters Of GroundwaterAquifers In Khanaqin Basin." Journal of Basrah Researches (Sciences) 43.1B.

[6] Ramadhan, Ahmad A., Hussein IZ Al-Sudani, and Batool M. Ali M. Saeed.(2018) "Groundwater System of Khanaqin Basin in Diyala Governorate–East of Iraq." Tikrit Journal of PureScience 23.6 (2018): 111-121.

[7] Khwedim, K. H., H. A. Salah, and J. A. Al-Adely(2011)."Heavy Metals in some soils of Baquba city: determination Distribution and Controlling Factor." Diyala Journal for pure sciences 7.2.

[8] Mohammad Amaar Hassan and Dr. Qassem H. Jalut(2018) Mathematical Modeling of Rainwater Harvesting System for Ungauged Catchment Area, International Journal of Civil Engineering and Technology, 9(11), pp. 823–837.

[9] Iraqi General Organization for Meteorological Information. (2017 a.) Atlas of Climate of Iraq for the years (1980–2017). Internal Report. Ministry of Transportation. Baghdad. Iraq.

[10] Buday T. The Regional Geology of Iraq, Vol. I. Stratigraphy and Paleogeography. I.I.M. Kassab and S.Z.Jassim (eds). SOM, Baghdad, Dar El Kutib Publ. House, Univ. of Mosul., 1980; 445.

[11] Araim HI, Said H. (1980)Groundwater regional study in the adhaim river basin with emphasis on the pain area. Manuscript report, Geosurv, Baghdad.

[12] Barwary, A.M.; and Said, F.S.: (1992): The Geology of Khanaqin quadrangle sheet NI-38-37 (GM 15) Scale1:250000. Technical report no. 0002. Directorate of Geological Survey. State establishment of Geological Survey and Mining. (GEGSURV) .Baghdad. Iraq. 29 P.

[13] Ghodoosipour, Behnaz (2013) . "Three dimensional groundwater modeling in Laxemar-Simepevarp guaternary deposits."

[14] Christensen, S. and R.L. Cooley, 2003. Experiences gained in testing a theory for modeling groundwater flow in heterogeneous media: In Calibration and Reliability in Groundwater Modeling. IAHS pub. No. 277, p: 22-27.

[15] EMS-I, 2005. Groundwater Modeling System, Environmental Modeling Systems, Inc., http://www.emsi.com/GMS/GMS_Overview .

[16] General Commission of Groundwater (2013): Geological and Hydrogeological information of Groundwater wells in Diyala Governorate. Hydrogeological Data Bank. Internal reports. Ministry of Water Resources . Baghdad. Iraq.
[17] Sufyan M. Jasim, Qassem H. Jalut (2020). Modelling of Groundwater Flow of Baquba District Area, Diyala Governorate, North-East, Iraq. Diyala Journal of Engineering Sciences, 13(3), 9-22. https://doi.org/10.24237/djes.2020.13302