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Investigation of Groundwater and The Impact of Over-Pumping in Al-Haydariyah Region, Iraq

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ABSTRACT

In this study; a three-dimensional model was created to simulate groundwater in Al-Haydariyah area of the governorate of Al-Najaf. A solid model was created to utilize the cross sections of 25 boreholes in the research region, and it was made out of two layers: sand and clay. The steady-state calibration was employed in six observation wells to calibrate the model and establish the hydraulic conductivity, which was 17.49 m/d for sand and 1.042 m/d for clay, with a recharge rate of 0.00007 m/day. The wells in the research region were reallocated with a distance of 1500 m between each well, resulting in 140 wells evenly distributed throughout the study area and with a discharge of 5 l/s, and the scenarios were run for 1000 days to explore the impact of over-pumping on groundwater levels. The wells were operated at three different operating hours: 4, 8, and 12 h/d. According to the results, the largest water table decrease for each scenario was 0.35, 8.25, and 8.68 m, respectively. It was discovered that the first scenario, with an operating duration of 4 h/day and a discharge of 72 l/s, was the best scenario in which dry cells did not happen.

Keywords: Groundwater, GMS, Al-Haydariyah, Iraq.

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دراسة المياه الجوفية وأثر الضخ الجائر في منطقة الحيدرية ، العراق

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الخلاصة

في هذه الدراسة تم إنشاء نموذج ثلاثي الأبعاد لمحاكاة المياه الجوفية في منطقة الحيدرية بمحافظة النجف الأشرف. حيث تم إنشاء النموذج الصلب باستخدام مقاطع عرضية لـ 25 بئر في منطقة البحث ، و النموذج يتكون من طبقتين : الرمل والطين. استخدمت معايرة الحالة المستقرة لستة آبار للمراقبة لمعايرة النموذج وتحديد الايصالية الهيدروليكية ، والتي كانت 17.49 م/ يوم للرمل و 1.042 م/ يوم للطين ، و معدل التغذية كان 0.00007 م/ يوم. تم إعادة توزيع الآبار في منطقة البحث بمسافة 1500 متر بين كل بئرين ، مما نتج عنه 140 بئراً موزعة بالتساوي في جميع أنحاء منطقة الدراسة وبتصريف 5 لتر/ ثانية ، تم تشغيل السيناريوهات لمدة 1000 يوم لدراسة تأثير الضخ الجائر على مستويات المياه الجوفية. في هذه الدراسة تم تشغيل الآبار في ثلاث سيناريوهات بساعات تشغيل مختلفة: 4 ، 8 ، و 12 ساعة/ يوم. وفقًا للنتائج ، كان أكبر انخفاض في منسوب المياه لكل سيناريو 0.35 و 8.25 و 8.68 مترًا على التوالي. اظهرت النتائج أن السيناريو الأول ، مع مدة تشغيل 4 ساعات في اليوم و تصريف 72 لتر / ثانية ، كان أفضل سيناريو حيث ان اكبر انخفاض في هذا السيناريو لم يؤدي الى جفاف في المنطقة.

الكلمات الرئيسية: المياه الجوفية, GMS , الحيدرية , النجف

1. INTRODUCTION

Groundwater, along with surface water such as rivers and lakes, has traditionally been a major supply of water, particularly in locations where surface water supplies are few. Because of the shortage of surface water owing to climate change and the development of infrastructure such as dams that influenced the incoming amount of surface water, there has been a recent movement toward groundwater as an alternate supply. Choosing the best location for collecting this water from its reservoirs has become more important in order to increase the amount of this water while keeping its level and volume within the limitations. As a result, further study is needed in the future to accurately determine the depth and volume of this water, as well as to better understand and optimize the sophisticated processes of this source. Because it requires the digging of multiple wells and extensive testing of pumping flow rate and soil composition, the simulation approach for controlling and comprehending groundwater is considered a very difficult operation. Scientists developed both a physical and a mathematical model to evaluate the groundwater system. Researchers were able to better grasp how groundwater travels and is transported by using physical models built in the lab, **(Liang et al., 2010)**.The simulation approach for controlling and comprehending groundwater is regarded as a very difficult operation since it requires the digging of multiple wells and extensive testing of pumping flow rate and soil composition, which is both expensive and time-consuming. Scientists developed both a physical and mathematical model to evaluate the groundwater system. So, **(Al-mussawy and Al-din, 2014)** Using Processing MODFLOW Pro V.7, to create a three-dimensional mathematical model to simulate the flow system of AL-Dibdibba unconfined aquifer in Karbala Region. The static groundwater levels acquired in 24 wells situated within the research region were used to create the model. The results show that the water level in the area is dropping, with the greatest drop anticipated to be roughly 5 meters in 2033. **(Khadri, and Pande, 2016)** managed groundwater and offer a useful model for future research for the Mahesh River Basin in India by building a mathematical model in a steady state that was calibrated using historical data from the 2013 and 2014 years using GMS software. The constructed model was well-balanced between calculated and observed data, so the calculated and observed head values differed only a little. This difference was then rectified by transitivity to make the two numbers as close as feasible, allowing them to be utilized for forecasting various scenarios to model the consequences of human activities. This enabled decision-makers in the research region to utilize the model to manage groundwater**. (Aghlmand, and Abbasi, 2019)** built a hydraulic model for Birjand, Iran using the GMS program to manage groundwater in the study zone and assist the government in planning and managing the area Because there was a scarcity of data in the area, the calibration technique was utilized in steady state and semi-transient, and the observed head was used for seven years. The land was split into 25 zones using the PEST technique in the GMS program to examine the hydraulic conductivity and recharge rate. After running the model, it was observed that there was a good agreement between the real and measured heads. The model was completed and found to be acceptable for monitoring groundwater in the area, with mean errors ranging from -0.04 to 0.14 percent m, absolute mean errors ranging from 0.14 to 0.27 m, and root mean squared errors ranging from 0.18 to 0.33 m. **(Jalut et al, 2018)** used GMS program to generate a model using 244 randomly dispersed wells spread around Diyala City, notably in Al-Mansourieh zone. The model was calibrated using hydraulic characteristics such as hydraulic conductivity and storage coefficient, which were (9-15) m/day and 0.15, respectively. Three working times, 6, 12, and 18, were studied to show the best. Dry cells never happened; the dropping head never surpassed 8 meters after the first year and 15 meters after 20 years, and the best working duration was 6 hours per day. **(Hussein, and Abed, 2020)**, produced a three-dimensional numerical and a solid models were built for Qazaniyah City in Diyala, to simulate the optimal distribution of wells and to determine the best operating parameters for those wells. The hydraulic conductivity was determined to be 18 m/day, and constant storage coefficient was adopted 0.001. Various scenarios were imposed on the operational parameters for the wells in the research zone in order to determine the proper spacing between the wells. In those cases, operation times of six, twelve, and eighteen hours per day were considered. According to the modeling results, 1000 meters between the wells with a maximum operating rate of 12 hours per day is the optimal situation. **(Bayat et al., 2020),** used GMS to manage groundwater in Iran's Karvan aquifer since groundwater levels were dropping due to a variety of factors. The model was created and calibrated over 86 months. Certain scenarios were created in order to investigate the influence of six scenarios on groundwater. These scenarios comprised a 30% increase and a 10% decrease in surface recharge and precipitation, as well as a 30% increase and a 10% decrease in well water harvesting. As a result, precipitation was the most effective technique of regeneration. **(Mustafa et al, 2017)** created a MODFLOW to evaluate the influence of rising Tigris River water levels on groundwater in Al-Tuwaitha region, as well as the ability of the pumping well to collect groundwater and correct groundwater direction. The model was built in a steady state with a 0.09 inaccuracy. The calibration shows a good level of match between the model's estimated head and the observed head discovered in the field. According to the model's results, an increase in river head leads to an increase in groundwater head. The pumping well may lower groundwater levels while also directing groundwater flow toward the river.

The current study attempts to use GMS V 10.6.1 to perform hydraulic modeling of groundwater flow in the Najaf Governorate's Al-Haydariyah district. Redistribution the wells in the study areas to determine the best number of wells and assignment of these wells Specify the best-operating conditions for wells and the parameters necessary for good operation, as well as the effect of over pumping on the aquifer's water table level.

2. THE STUDY AREA

Al-Haydariyah area is located in the northeastern section of the governorate center of AL-Najaf, with longitudinal coordinates (44º 7'30" - 44º 21' 30") E and latitude coordinates (32º 12' 00" - 32º 21' 00") N. It has a total area of 309 km^2 and a perimeter of 72 km as shown in **Fig. 1**. The Euphrates River, which borders this region in the northeast of the area, is regarded as a significant supply of water for the governorate's population. Because the river is insufficient to satisfy those people's demands, the tendency toward groundwater has developed. Due to the overuse of groundwater and the drilling of random wells in the research area, it is critical to analyze the groundwater to assess the effect of excessive pumping of water from the wells. In this work, GMS (Groundwater Modeling Software) V 10.6.1 is utilized to model the aquifer in the study region.

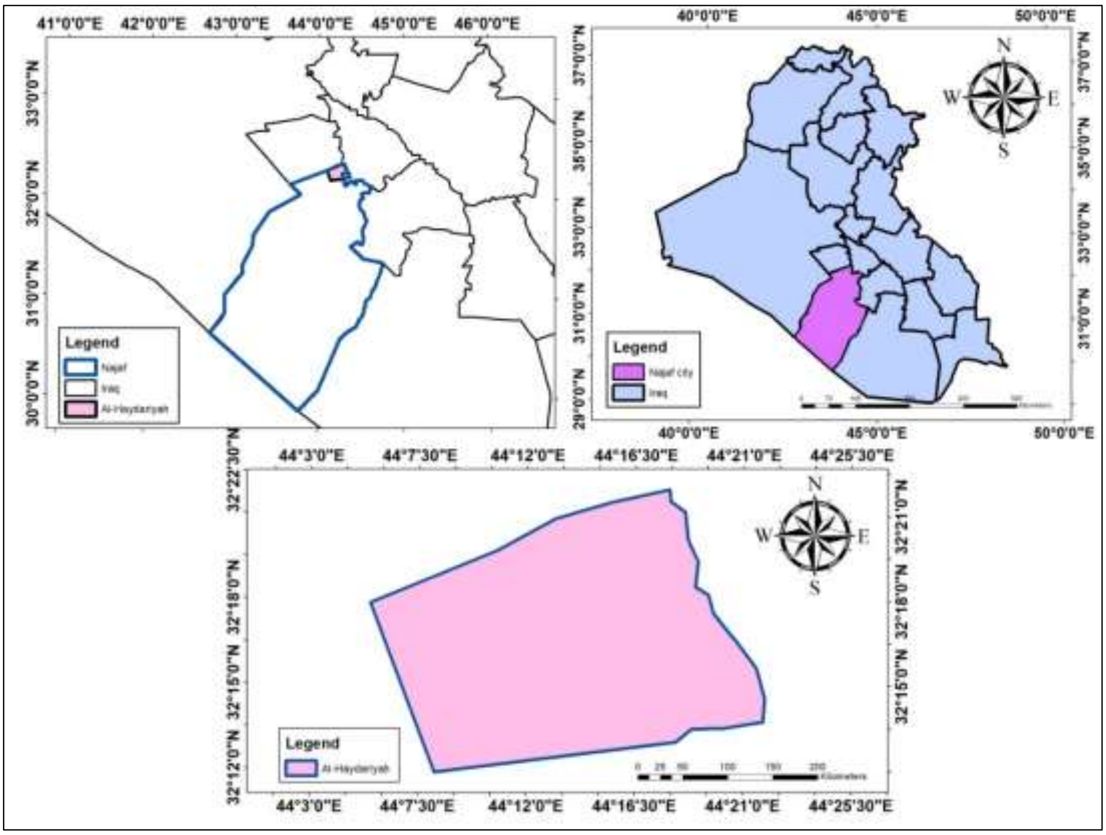

Figure 1. The location of the study area

3. THE DETAILS OF THE STUDY AREA

Important information required to understand the research region were collected. These information were used as input data to generate the hydraulic model.

- The geological details

AL-Dibdibba aquifer, an unconfined aquifer formed of clay, coarse, and fine sandstone with a thickness ranges between 20 to 85 m, is the principal geological formation in Al-Haydariyah region. This structure is visible from Tar-AL-Najaf and the road that links AL-Najaf to Karbala. AL- Dibdibba formation is above Injana formation**, (Kareem, 2018)**. The formation contains a moderate amount of water, large pumping has a significant impact on its level.

- The study area's topography

GIS software generates a digital elevation model (DEM) that is used to represent the Earth's surface using TIN (Triangulated-Irregular-Network). The DEM is used to calculate ground elevations, river and drain levels. The region's surface elevation varies from 85 m in the west to 15 m in the east, near the Euphrates River.

- The weather information

Climate unquestionably has an impact on groundwater since climatic parameters such as rain, evaporation, humidity, temperature, and solar radiation all have a direct impact on how much groundwater recharges. Rain is the most crucial factor to consider. The annual precipitation was given by Seismology and the Iraqi Meteorological Organization from 1980 to 2021, as illustrated in **Table 1**. According to the table below, the most rain was recorded in November, and the yearly rainfall was projected to be 91.3 mm. The dryness in the examined region rises as a result of rising temperatures, which causes an increase in the evapotranspiration process. The temperature in Al-Najaf city can occasionally reach 50 degrees. The region's yearly relative humidity value is calculated to be about 41.55 percent, indicating that the region will see dry weather. The quantity of water vapor is specified as the relative humidity.

Table 1. The annual precipitation of AL-Najaf city from 1980 to 2021

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	July	Aug.	Sep.	Oct	Nov	Dec	annual
Rain (mm)	15	12.2	12	13.3	3.4	0	0	0	0	4	17.6	13.8	91.3

4. THE SIMULATION OF THE AQUIFER

The GMS must build a solid model, a conceptual model, and a grid model to simulate groundwater. The models will be performed in two modes, stable and unstable, to determine the hydraulic properties of the aquifer.

4.1 Methodology of the Study

A hydraulic model will be developed in this work to simulate groundwater flow behavior in the selected study area. These issues necessitate the following:

1. Gathering accessible groundwater records and data, such as geological formation maps, locations, coordinates, and distribution of drilled wells, levels and soil characteristics from the General Authority of Groundwater.
2. Obtaining the weather information from the Meteorological and Seismic Monitoring Authority.
3. Monitoring the groundwater level in the observation wells using a level water sounder.
4. Using GMS software, create a virtual model of the specified location to simulate the hydraulic behavior of groundwater flow in the area under various situations.
5. Impose many scenarios with varied operating circumstances to define the variations in groundwater level.
6. Predict and recommend the best operational conditions to maintain groundwater levels and ensure water sustainability.

4.2 Creating the Models

DEM can be used to represent subsurface geological layers **(Al-Kilabi, 2018).** This area is composed of two layers: the first is sand, and the second is an impermeable layer of clay towards the reservoir's bottom. **Fig. 2** shows a 3D solid model produced by the GMS software from drill cross sections collected from the General Authority of Groundwater / Al-Najaf branch. In addition to the digital elevation model (DEM) created in GIS V 10.6.1

(Geographical Information System), 25 drill cross-sections were utilized to estimate the solid strata of the aquifer as shown in **Fig. 3**.

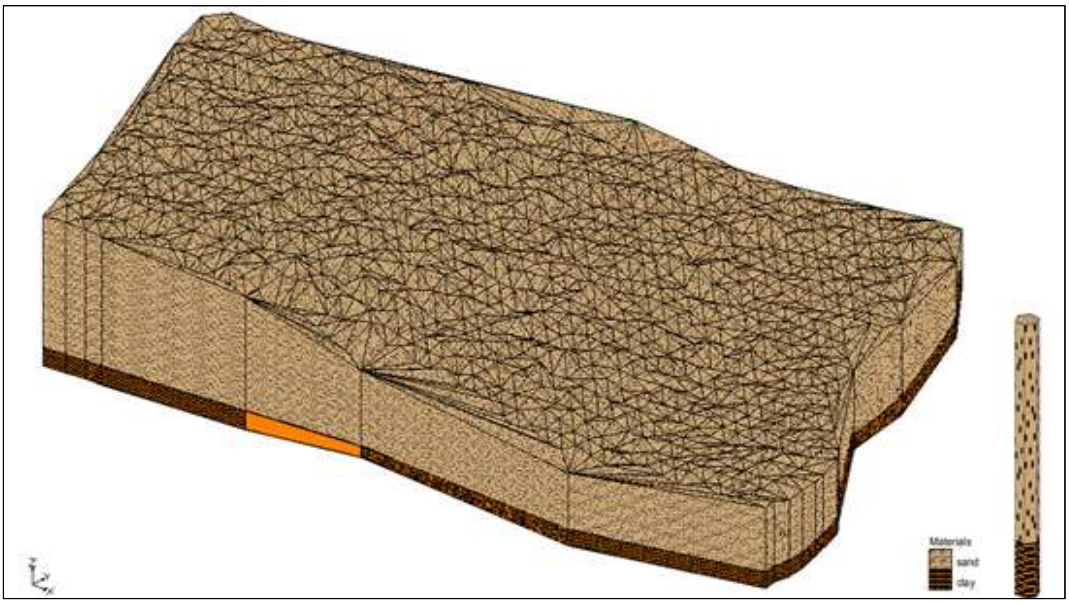

Figure 2. The solid model and boreholes cross-section of the Al-Haydariyah region

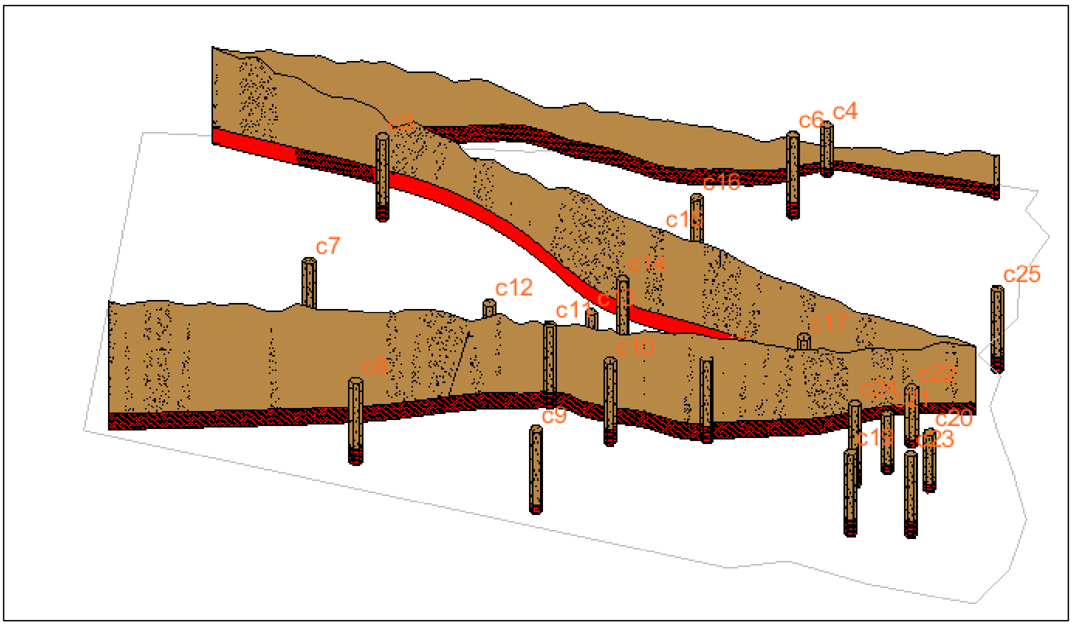

Figure 3. The cross sections of the boreholes for the studied area

For the Al-Haydariyah region, there are five coverages to develop a conceptual model. It provides boundary coverage; the area's borders were defined using the satellite map image and the geographical map, based on the region's topography and the distribution of wells. Sinks and sources coverage that includes all well data, including locations, discharges, and other parameters. Because of the existence of the Euphrates River in the east, all of the borders had a specific head type except for the one in the east, which had a general head type. 33 wells were employed in the Al-Haydariyah research zone, as indicated in **Fig. 4** and **Table 2.** This had information about the wells, including their coordinates, discharge, ground surface elevation, groundwater elevation, and depth. Hydraulic conductivity coverage depends on soil layer type. Its initial values were set by the soil type and Todd's classification. The three-dimension grid model of the Al-Haydariyah research area was as follows: the origin was 413166.67 N, 356177.38 E, and 60 m below sea level, and the grid model length was 28289.3, 20286.4, and 145 m in X, Y, and Z directions. There were 114898 cells in all. The active cell count was 62802, and the inactive cell count was 52096.

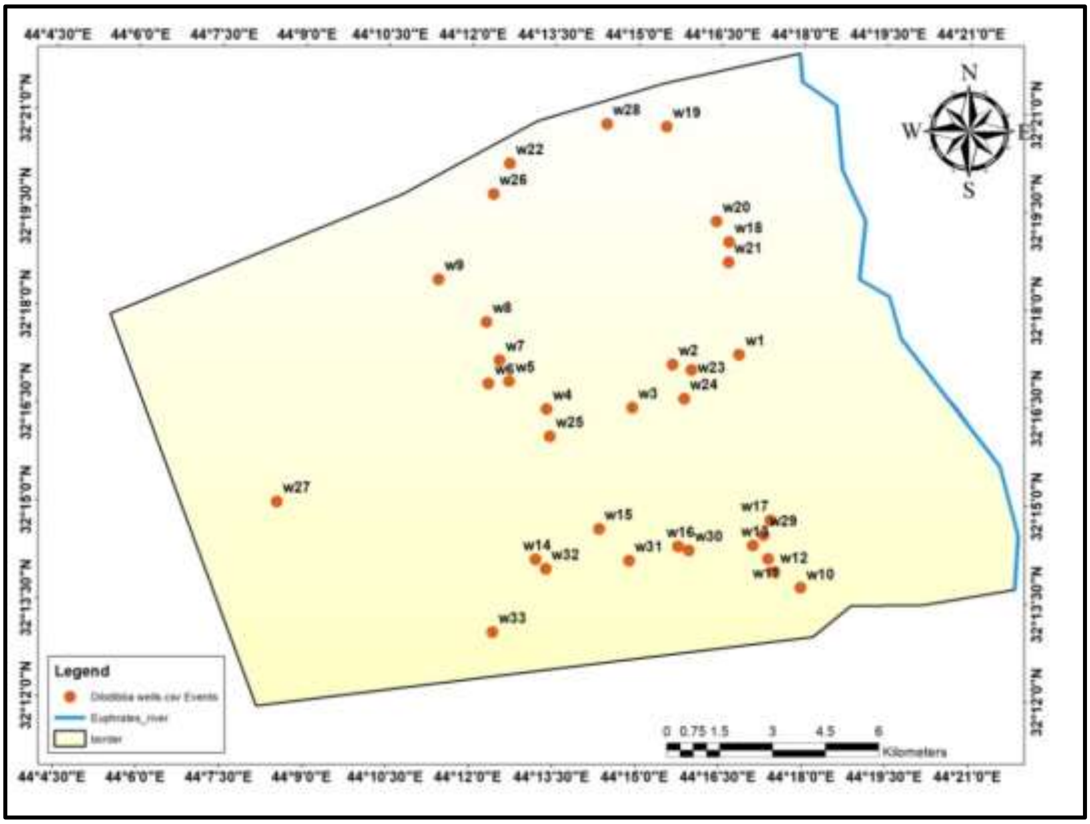

Figure 4. Distribution of the wells in the studied area

4.3 Groundwater Flow Modeling

The saturated zone of a 3D model created by the US employs a block-centered finite difference approach. The differential equation for a three-dimensional saturated flow in a saturated porous medium **(Todd, 1980)** can be expressed for an unconfined aquifer (Al-Haydariyah study area) as:

$$\frac{\partial}{\partial x}\left(K_x h \frac{\partial h}{\partial X}\right) + \frac{\partial}{\partial y}\left(K_y h \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z h \frac{\partial h}{\partial z}\right) - w = Sy \frac{\partial h}{\partial t} \quad (1)$$

where:
K_x, K_y, and K_z are the hydraulic conductivity in the cartesian coordinates, m/day
h is the groundwater head for unconfined aquifers, m.
t is the time of the day.
w is source/sink terms are represented as volumetric flow per unit of volume, or m/day.
Sy refers to the dimensionless specific yield for an unconfined aquifer.

Table 2. The wells data of the Al-Haydariyah study area

Well No.	Longitude (m)	Latitude (m)	Discharge (l/s)	Ground Surface elevation (m.a.s.l)	Groundwater elevation (m.a.s.l)	Well depth (m)
W1	432273.0	3572629.3	5	26.1	11.6	35
W2	430390.4	3572343.3	5	29.9	7.9	50
W3	429244.0	3571128.9	6	35.9	18.14	50
W4	426821.1	3571090.7	5	40	32.4	52
W5	425756.9	3571874.5	5	47.6	42.4	50
W6	425173.1	3571814.0	4	43.9	33.9	50
W7	425481.4	3572470.8	5	49.5	27.4	50
W8	425115.4	3573560.5	5	45.1	30.1	50
W9	423759.2	3574756.3	5	48.7	30.7	50
W10	434014.0	3566034.2	4	35.9	24.4	52
W11	433090.2	3566847.0	4	31.6	18	50
W12	433265.7	3566482.5	4	31.7	19.7	45
W13	432663.5	3567234.8	5	35.3	24.3	50
W14	426502.5	3566840.4	4	53.4	38.4	50
W15	428304.0	3567695.8	4	47.8	35.8	50
W16	430543.4	3567202.9	5	43.2	33.2	50
W17	433152.3	3567936.7	5	36.6	24.6	50
W18	431983.3	3575812.2	4	25.5	14.5	50
W19	430227.8	3579085.2	4	25.7	13.7	50
W20	431636.8	3576405.8	5	23.4	12.4	50
W21	431974.2	3575248.7	4	24.5	16.5	50
W22	425778.7	3578033.0	6	26.6	9.2	48
W23	430925.5	3572191.9	5	32	12.0	50
W24	430716.0	3571383.5	5	52	18	55
W25	426909.7	3570311.0	4	62	12.5	70
W26	425314.8	3577174.2	5	21	18.9	36
W27	419176.7	3568476.0	5	32	14	48
W28	428529.1	3579158.8	5	50	18	55
W29	432963.8	3567522.2	6	53	15.0	70
W30	430851.5	3567086.9	6	28	12.5	48
W31	429156.2	3566803.0	4	32	17.66	50
W32	426788.4	3566564.2	5	42	16	55
W33	425288.6	3564773.7	4	50	18	85

5. THE OPERATION OF THE MODEL

Due to their sensitivity, the hydraulic conductivity, specific storage, and specific yield of the aquifers are some of the most crucial factors that influence the groundwater system. Because the value of these parameters is unknown in this study. Todd's 1980's geological and hydraulic characteristics are utilized to calculate the initial value for these characteristics. There are two modes of operation for the model. The following are steady and transmit states:

5.1 The steady state

The steady-state calibration approach and the PEST (parameter Estimation technique) are used to compute the two soil layers' hydraulic conductivity and recharge rate. Todd's geological and hydraulic properties are input for the initial value. Furthermore, the aquifer recharge may be computed, with 5% of the annual rainfall as the initial recharge point. Annually, AL-Najaf receives 91.3 mm of rain. By evaluating the sensitivity of variables such as hydraulic conductivity and recharge rate during the calibration process using PEST in the steady state, it is feasible to discover who has the most effect on the model. As seen in **Fig. 5,** hydraulic conductivity is the most influential characteristic compared to the other components. The area model's steady-state calibration technique is based on six observation wells. The calibration procedure is repeated until the software's estimated value is as close to the observed value in the field as possible, with an observed head interval of 0.5 m, as shown in **Table 3**.

Table 3. The observed and computed steady head of the Al-Haydariyah hydraulic model.

Well No.	Observed Head	Observed head interval	Observed Head conf. %	Computed head	Residual head
W3	18.14	0.5	95	17.721	0.418
W23	12.0	0.5	95	12.5	-0.5
W25	12.5	0.5	95	12.5	0.0
W26	18.9	0.5	95	19.882	-0.983
W29	15.0	0.5	95	15.828	-0.828
W31	17.66	0.5	95	17.441	0.218

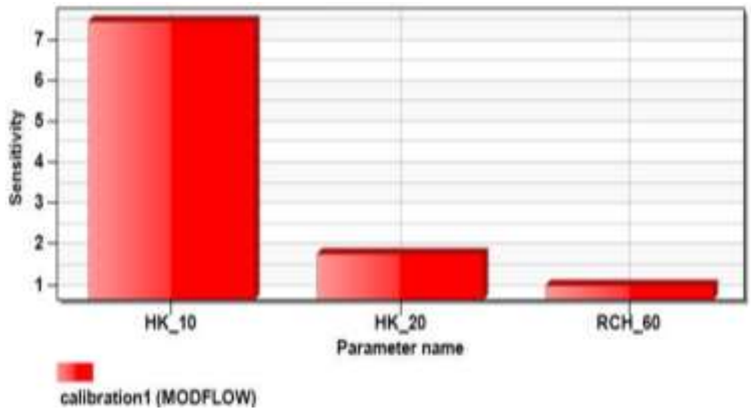

Figure 5. The steady-state sensitivity analysis of the hydraulic parameters for the research area

The computed head is the estimated head calculated by the GMS software, whereas the observed head is the head observed in the field. The conf. % stands for confidence. The difference between the observed and computed heads is the residual head.

5.2 Unsteady state

The model run in an unstable state to determine the specific storage and yield and, based on the data gained from the steady state. The model requires one year of data to run in an unstable state. A massive amount of data, including pumping wells, monitoring wells, recharge data, and river level, is required. Due to a data limitation, data from 2013 can be used to show the model's calibration and its use of rainfall data from that year as a recharge rate, as shown in **Fig. 6**. All data must be given in the form of a time series. The pumping data ranges between (2–5) l/s. There were two observation wells in the Al-Haydariyah region. The specific storage for unconfined aquifers is between 0.01 and 0.3. When the strata are saturated, the yield for unconfined aquifers equals the specific storage (**Todd, 1980)**.

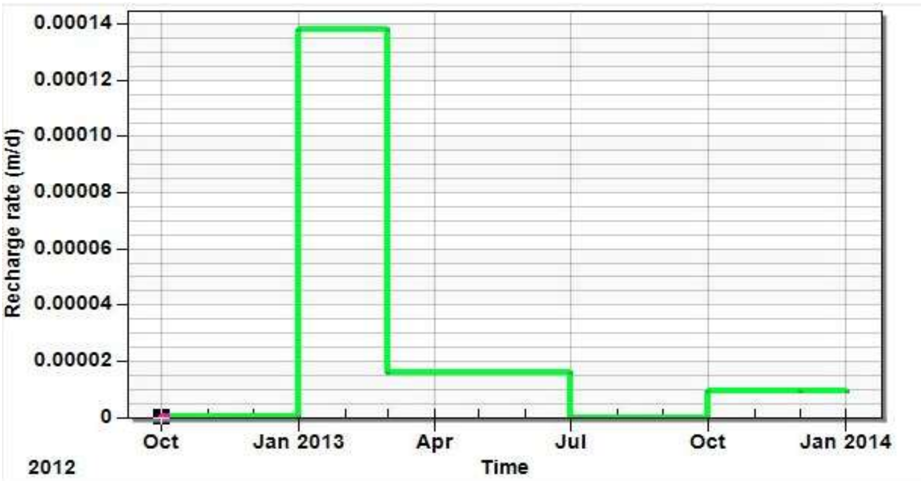

Figure 6. The transient recharge rate

Table 4. The hydraulic characteristics of the studied region after calibration in two states

Layers	Hydraulic conductivity m/day	Specific yield	Specific storage 1/m
sand	17.490	0.3	-
clay	1.042	-	5.25182* 10-7
The recharge rate		0.00007 m/day	

6. OUTCOME OF PROPOSED SCENARIOS

A spacing between the wells was set at 1500 m, resulting in 140 wells, depending on the distance. Three scenarios are used to evaluate the over-pumping of groundwater and determine the optimal operation for these wells that do not cause the area to dry out with a discharge of 5 l/s. The operation time was 4, 8, and 12 h/d with a discharge of 72, 144, 216 m^3/day for 1000 days. When it was run for 4 hours per day, the greatest decline in groundwater was 0.35 m, making it a safe scenario that may be used because it did not dry up the land **Fig. 7**.

However, when the model is run under the same previous conditions but with an operation time of 8 hours per day, the maximum drawdown increases to 8.25 m. This drawdown in the water level leads to drying out in a very small area. It also causes the groundwater quality to deteriorate and the salinity to rise, as shown in **Fig. 8**.

The third scenario was performed when the operation period increased to 12 h/day with a discharge of 216 m^3/s. The drawdown increased to 8.86 m as the maximum drop and caused the region in the middle to dry, as illustrated in **Fig. 9**.

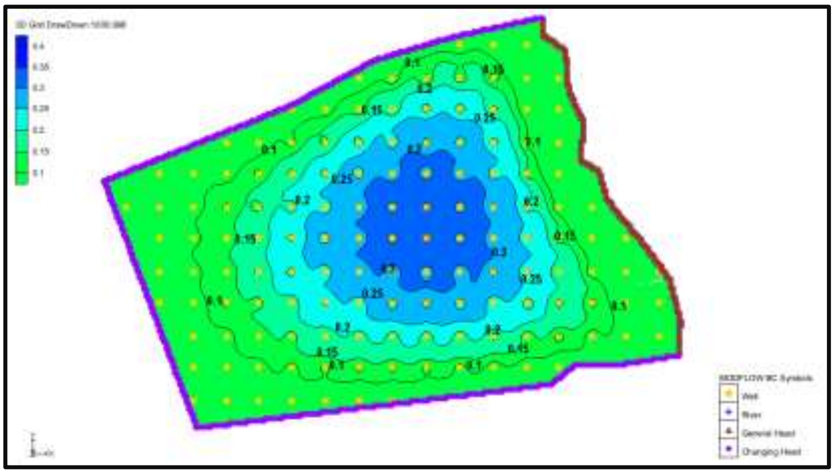

Figure 7. The decline of the water table at a run time of 4 hours per day and a distance of 1500 m meters in the Al-Haydariyah area

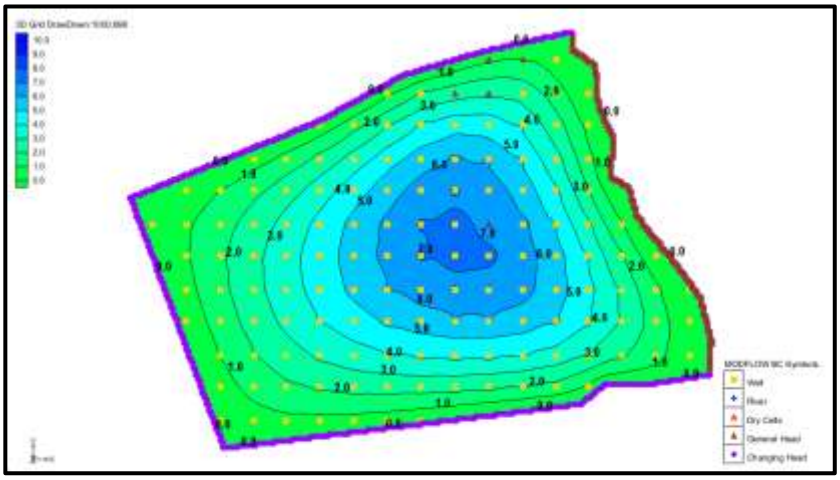

Figure 8. The decline of the water table at a run time of 8 hours per day and a distance of 1500 m meters in the Al-Haydariyah area

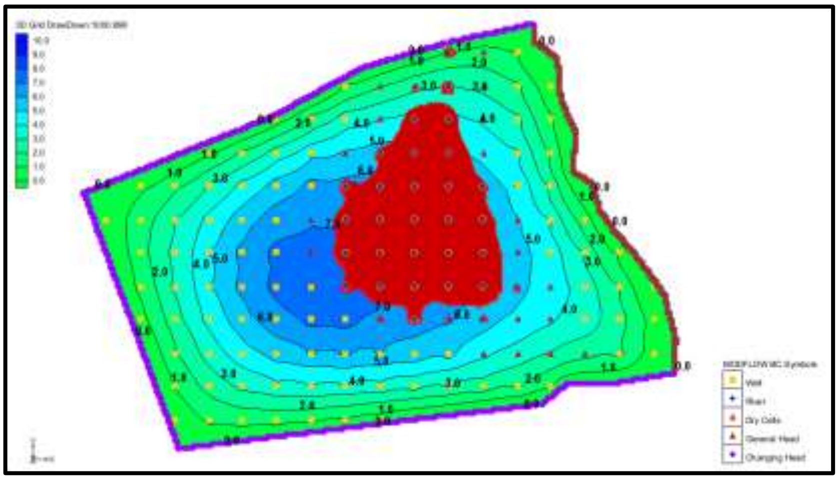

Figure 9. The decline of the water table at a run time of 12 hours per day and a distance of 1500 m meters in the Al-Haydariyah area

6. CONCLUSIONS

The following conclusions can be extracted per the previous discussion for the obtained results:

1. The GMS software demonstrated strong agreement between the observed head and the computed head in both steady and unsteady states. Even though it requires much data, it is one of the best tools for managing groundwater. The simulation of groundwater software, GMS, was used to manage the groundwater in the regions. The GMS software was successfully used to determine the hydraulic flow behavior and hydraulic characteristics of the groundwater system in the study area.
2. The hydraulic conductivity for the first layer, the soil layer, which is the main layer that stores water and is a component of the AL-Dibdibba unconfined aquifer, equals 17.4 m/d. The hydraulic conductivity for the second layer, the clay layer, which is an impermeable layer with a small thickness located at the bottom of the aquifer, equals 1.04 m/d.
3. The wells were spread equally throughout the research area to determine the influence of well overpumping on the water table of the unconfined aquifer. The spacing between wells was set at 1500 meters, resulting in the utilization of 140 wells in the region.
4. Three scenarios were tested, each with a daily operation time of 4, 8, and 12 hours. The maximum drawdowns were 0.35, 8.25, and 8.68 m. The dry cells occurred in the second and third situations due to water deprivation.
5. The results suggested that the optimal scenario for the Al-Haydariyah region was to adopt 140 wells with a well spacing of 1500 m, an operating period of 4 h/d, and a maximum drawdown of 0.35 m without resulting in dry cells.
6. Over-pumping creates several issues. One of these issues is groundwater exhaustion, which leads to a decrease in the level of this source, impacts the water quality, and increases the concentration of water salinity.

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