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QUANTITATIVE AND QUALITATIVE ASSESSMENT OF GROUNDWATER: THE CASE OF KHANAQIN ALLUVIAL (IRAQ)

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Abstract

The present study aims to simulate the groundwater flow in the alluvial area of Khanaqin numerically to identify the feasible locations of wells drilling with high productivity. Moreover, assessing the groundwater quality and evaluate their suitability for municipal and irrigation uses. Geographic information system GIS and groundwater modeling system GMS software were used to develop the conceptual model that simulates the groundwater flow in the soil layers of study areas. The collected data was used to create a solid model of study areas, which represent the investigated layers and geological formations. The storage coefficient and specific yield of these layers were then determined within the calibration of the model, Then, model results were verified by comparing these results with the field observations. It was found that the Muqdadiyah and Bay Hasan geological formations are of low permeability. The sediments formed over the Bay Hasan formation is considered the main layer of groundwater storage. The wells drilled in this region, in the opposite of Al-Muqdadiyah formation, have high productivity. It was also found through the model, and from the water budget, that the Al- Wand River works as drainage, and withdraw a volume of 28,841m^3 due to low water levels of the river compared with the groundwater table in the adjacent lands. Diyala River recharges the groundwater in some areas with about 11,339 m^3. While the groundwater recharges Diyala river, in other locations, with an estimated rate of 20,943 m^3. So, most of the groundwater is recharged from rain, irrigation water pumped from Al- Wand River, and sewage water inside the city. Field measurements were conducted over a period of six months for recording water tables and sampling wells groundwater. Multi-tests were implemented in the laboratory to test water samples. The comparison of test results with national and international standards shows that the parameters of water are within acceptable levels, where the groundwater can be used for domestic or agriculture purposes, and other uses.

Keywords: Groundwater simulation, Hydraulic conductivity, MODFLOW, Water quality.

1. Introduction

Groundwater constitutes a large proportion of the freshwater on the surface of the globe, as the water of rivers and lakes often comes from groundwater. It is surprising and not an exaggeration that almost all the water we use in agriculture, industry, and drinking water is considered groundwater, or at least it was at one-point groundwater in the water cycle in nature. Groundwater plays a major and effective role in the environmental and economic aspects. They may supply water to rivers, lakes, and wetlands, especially in dry months, when rain is minimal [1].

The importance of the present study is shown through that the groundwater should be placed as a good choice in water supply especially for the main periods in the dry areas with limited water resources for some reasons, the most important is the lack of surface water due to climatic changes and the construction of dams on the water sources in the adjacent countries of Iraq, that leads to the dependence of human on the use of groundwater as an alternative source, as it is in the case of Khanaqin area. And is necessary to mention that, no significant adequate previous studies, were conducted to investigate the groundwater productivity and their quality in the study area. Groundwater is often of high quality, as it has some limited desalination and filtration processes compared to river water, which makes it safe for human use, as the layers of soil and rocks act as a natural filter of water and sequester most of the pollutants. Most developing countries depend mainly on groundwater, as they do not need high costs for excavation work and raising water to the surface, and then desalination. As well as they do not need water tanks to be stored before use. Ground and surface water are strongly linked, both of them represents part of the overall hydrological cycle. When the displays the water cycle in nature, it will be seen that the rainwater not only flows and reaches the river through the surface but rather that a large part of the rainwater is absorbed by the soil, which in turn acts as a large sponge. The soil absorbs part of the water by the plant, and the water comes out again by a process called transpiration, and the remaining part of the leaked water enters the soil by a process called infiltration, and the water begins to descend till it reaches an impervious sublayer, there, groundwater would be formed and stored. At the level at which the rocks become saturated it is called "groundwater", which will be moves and bounded by Darcy Law.

Further researches on groundwater are required in the areas that used this water as an alternative source to study and establish suitable conditions for the use of groundwater. As well as, monitoring the quality of water and its validity for domestic use, irrigation, and industrial purposes must be assured [2]. Accordingly, a hydraulic model was created to the study area using the groundwater numerical modelling system using (GMS) and (GIS) software to specify the hydraulic behaviour of groundwater flow and to estimate the hydraulic conductivity of the aquifers in the study area in order to define the suitable use of groundwater. The required data for the twenty-four wells that were drilled in various locations of the study area were collected from the available records at authorities of the Ministry of Water Resources (Iraq). As well as field measurements were conducted over a period of six months starting from August 2019, for the purpose of gathering water levels at these wells, and sampling the produced water from, then implementing experimental tests for these samples.

The pioneer United States Company (AQUAVEO) developed many programs, ultimate models, for finite difference, working within the general framework to ensure the widest possible use of them. One of these programs is the GMS Program,), one of the most widespread 3D models in the world. This software give high accuracy for understanding the groundwater flow and they provide a useful tool to investigate the productivity of the groundwater and its behaviour in the different soil layers [3]. Ahmed [4] introduced a three-dimensional model for the Egyptian Sohag region. Three-dimensional 3D solid model was generated using the RockWorks software from the design data of the wells. The conceptual model was established with this model (MODFLOW 2000). The solid model is one of the better ways to reflect and describe the hydraulic properties of the soil layers. In this study, six layers of soil were identified: clay, clay mixed with sand, fine sand, coarse sand, sand mixed with gravel, and gravel. The hydraulic properties of the aquifers determined the characteristics of the soil layer components, and then the model was calibrated.

Hussein [5] studied the groundwater quality and implemented an assessment of this water in the northeast of Wasit Governorate. Ninety-eight total samples of water were collected from the specified wells in the area of the study. After conducting physical analysis, the water was found to be colourless and odourless. Different elements in the water were analysed in order to assess groundwater and indicate the possibility of using this water for municipal and irrigation purposes after comparing the result with Iraqi and international standards. It was found that there was a significant difference between the results due to regional geology. It was found that the closeness of groundwater from the surface of the earth increases evaporation rates, which leads to an increase in salt concentrations in shallow groundwater. Groundwater in the study area is considered unsuitable for drinking. As well as, it is suitable only for culturing some types of plants. Mustafa et al. [6] simulated the movement of groundwater using MODFLOW to indicate the effect of water level change in Tigris River on the groundwater of the study area (nuclear research centre at Tuwaitha area). The proposed capacity of the pumping was assessed to maintain the groundwater with slight change with time. Their results showed a good interaction between calculated groundwater levels and measured values, with an error not exceed 0.09 m. The study also referred that the increase in the water level of the Tigris River has caused an increase of groundwater levels, while the use of pumping caused to reduce the levels. The direction of groundwater flow coincided with the direction of the Tigris River, and the dominant flow occurs in the distinctive third layer (medium sand of 0.005 m/day hydraulic permeability).

Jalut et al. [7], concerned the establishment in the Diyala Governorate of a MODFLOW model for Al-Mansuriya region, in this region, 244 wells were identified, and a grid of (500×500) m per cell was established. The principal purpose of this study is to detect safe water pumping from these wells. Steady-state process calibration and model hydraulic properties stabilization, many pumping scenarios have been checked and operational under three conditions. It turns out that the optimal operating time is 6 hours because the water in the aquifers is balanced. They also evaluated the chemical and physical characteristics of groundwater quality and its safe use in irrigation and humans, by Iraqi and international requirements. Most water wells were found to be suitable for irrigation purposes, and several wells fit for domestic purposes. Zaib-Un-Nisa et al. [8], study was conducted on groundwater pumping to overcome the scarcity situation in the behaviour of groundwater using the water table measurement and the rate of water table fluctuation and water discharge in Pishin district of Baluchistan, Pakistan. For this purpose data from WASA was incorporated to find out the fluctuation rate of the water table. The measurements were conducted over the period from 2005 to 2016 using the GIS-based Inverse Distance Weight (IDW) technique to implement the maps of water level. They were concluded that a decline in all four Tehsils of Pishin district and the condition was worst at Huramzai tehsil whereas groundwater was depleting there rapidly. Also, they defined that the main reason for this decline in the groundwater table was tube well pumping from groundwater resources which got exceeded the natural recharge. Moreover, the rapid increase in urbanization decreased the infiltration rate in recent years.

The objectives of the current research are to study the properties of the aquifers for the Khanaqin area; Numerical simulation of the hydraulic behaviour of groundwater flow, by building a conceptual model for the study area, using the GIS & GMS program; Determining the feasible locations of wells drilling with high productivity; Moreover, study the physical properties of groundwater to specify the quality of the groundwater and their feasibility for drinking and agriculture uses.

2. Methodology

Using the data available for the drilled wells and the field measurements conducted and the topographical and geological maps of the study area, a three-dimensional model was created after processing the data with the specialized programs and creating MODFLOW software. That was conducted simultaneously with studying and defining the properties of the aquifers and of the groundwater reservoirs, the hydraulic parameters were determined, the flowchart presented in Fig. 1 shows the steps followed to conduct the simulation of groundwater flow.

2.1. Study area

Khanaqin district is located in the eastern part of the Diyala governorate, 130 km east of Baghdad, and it is adjacent to the Iraqi-Iranian border. Al-wand River is flowing through the district, which originates from Iranian territory, is considered one of the most important sources of surface water for the region. It is a seasonal river and flows into the Diyala River southwest of the city of Khanaqin. The discharges of the river are often low, with the exception of the rain season, where the discharges are high, so the residents of this region resorted to using groundwater. Figure 2 shows the study area selected in Khanaqin area.

2.1.1. The geological information of the study area

When studying groundwater, it is necessary to study the geology of the area. This is because the soil formations are considered the main reservoir for groundwater, and through the reviewing of the geological sources and maps, it is found that the soil layers in the study area consists of Al-Muqdadiyah geological formation (Lower Bakhtiari) that consists of limestone and claystone [9], that characterized with very low permeability. Above this layer, there is a formation called Bay Hassan (Upper Bakhtiari) which relatively has low permeability and consists of sandstone and calcareous. On top of these formations, there are fresh deposits that formed as a result of overflowing rivers and heavy rains.

2.1.2. The study area climatological information

The main source of groundwater is rainwater, rivers, and water bodies. So, when creating any numerical model, it must take into account the climate records of the study area, mainly including precipitations, namely rain, temperature, and the amount of evaporation. The following data represent the annual averages of climate information for thirty-eight years for the study area, as shown in Table 1, extended for the period 1980 - 2018 [10].

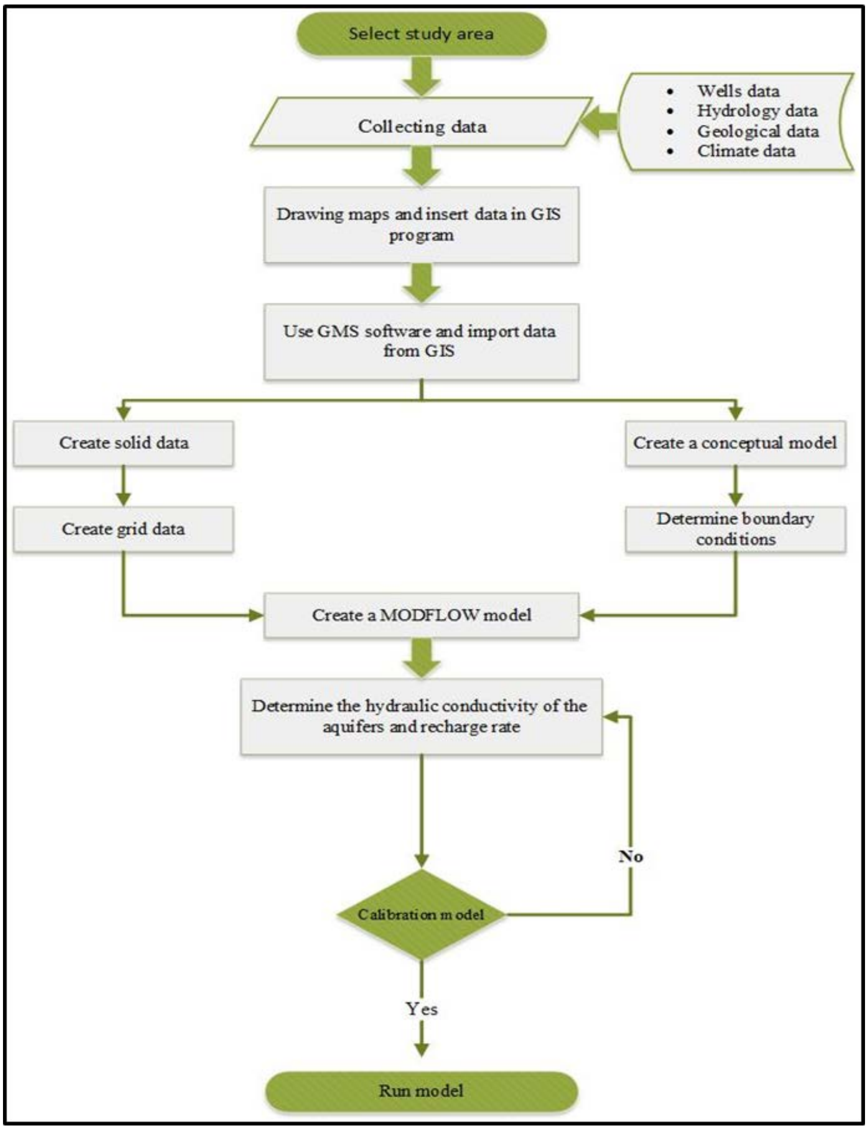

Fig. 1. Flow chart of the simulation process.

Fig. 2. Study area with respect to the map of Iraq.

2.1.3. Topography of the study area

The region of Khanaqin is relatively high, as its average height above sea level is 300 meters, and its boundary on the southern side is a mountainous area, and the region generally slopes down to the western direction adjacent to the Diyala River as shown in Fig. 3. AL wand River and Palgo River passes through the study area. The effect of Palgo River was neglected because the river is lined and has very little effect on the groundwater.

Table 1. Climate data, annual average recording values for the period 1980-2018.

Month	Mean Temp. °C			Sunshine hr	Relative Humidity %	Wind Speed m/sec	Rainfall mm	Evaporation mm
	Min	Max	Average					
Jan.	4	15.5	9.7	5.7	76.9	2.2	40	50.7
Feb.	5.3	18.2	11.7	6.5	67.7	2.8	30	75.4
Mar.	9.1	22.8	15.9	7.2	58.3	3	25	146
Apr.	14.3	29.3	21.8	8.2	52.6	3	23.8	189.8
May	19	35.7	27.3	9.5	41	2.7	5	266.5
Jun.	22.5	40.8	31.6	11.4	34	3.1	0	362.3
Jul.	24.8	43.2	34	11.3	34	3.4	0	384.4
Aug.	24.1	43	33.5	11.2	35.1	2.7	0	334.1
Sep.	19.9	39	29.4	10.1	40.2	2.1	0	263
Oct.	15.9	33	24.4	8.1	50	1.8	11.2	171.3
Nov.	8.8	23.5	16.1	7	65.5	1.7	24.7	87.9
Dec.	5	17.4	11.2	5.6	74.6	1.9	31.3	51.9
Annual	14.4	30.1	22.2	8.5	52.50%	2.5	191	2383.3

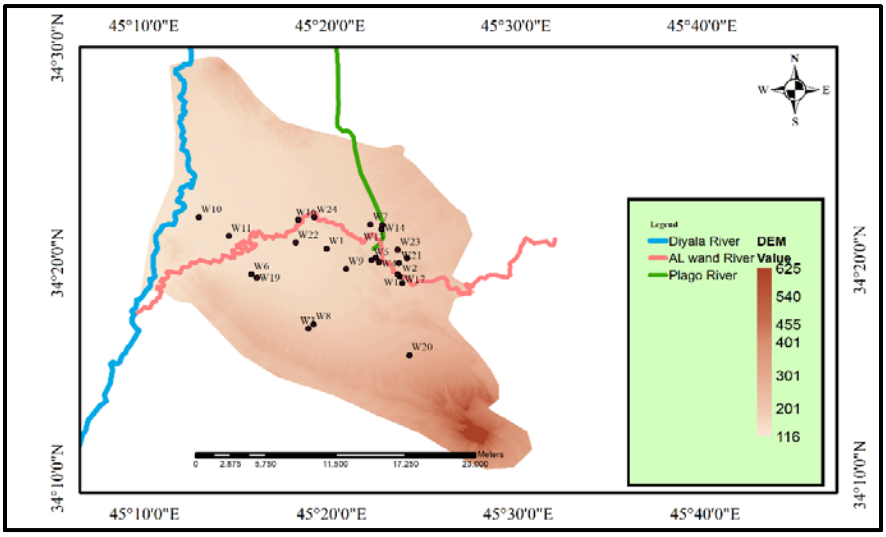

Fig. 3. Topographic map of Khanaqin city, and the locations of involved wells.

2.1.4. Wells data

The information and data and of the drilled wells in the study area can be divided into two parts; firstly, the geometric data, including the coordinates, depth, water levels, diameters, and cross-sections of the wells as shown in Table 2. Secondly, groundwater quality data of these wells as shown in Table 3. The first part of data used to study and estimate the hydraulic properties of the aquifers and to establish the conceptual model using the GIS and GMS software to redistribute wells in the study area. While the second part, used for assessing the water quality. The samples were taken on the period 1/8/2019 to 12/2/2020.

Table 2. Information of wells geometry.

Name	X-Coordinate	Y-Coordinate	Elevation	Depth m	Water level m	*Q* L/sec	Dia. mm
W1	45.43625	34.53519444	312	120	297	4	200
W2	45.36569444	34.38288889	185	72	168	7	200
W3	45.32947222	34.344	151	72	139	7	200
W4	45.56122222	33.73444444	114	84	89	8	200
W5	45.38833333	34.36888889	206.5	84	167.5	6	200
W6	45.39472222	34.32277778	199	60	174	7	200
W7	45.31305556	34.28222222	188.33	107	145.33	3.5	200
W8	45.37638889	34.33361111	177	60	162	8	250
W9	45.36972222	34.33527778	183	60	170	7	250
W10	45.34777778	34.30527778	172	60	147	6	200
W11	45.26222222	34.32444444	115	63	101	7	200
W12	45.36888889	34.36277778	176	68	161	8	200
W13	45.3175	34.28555556	189	111	157	6.5	200
W14	45.34694444	34.32833333	165	56	144	6.5	200
W15	45.21527778	34.36888889	149.5	84	122.5	7	200
W16	45.24222222	34.35416667	147.7	61	131.7	7	200
W17	45.39305556	34.32388889	182	63	167	8	200
W18	45.37888889	34.35888889	181	60	171	8	200
W19	45.37944444	34.36222222	183	60	173	8	200
W20	45.37361111	34.33694444	186	60	173	7	200
W21	45.30416667	34.36666667	156	50	147	9	200
W22	45.39722222	34.31722222	186	66	171	7	200
W23	45.40166667	34.33638889	85	72	60	5	200
W24	45.26722222	34.32166667	151	72	136	7	200

Table 3. Mean physical results of tests data of the groundwater of drilled wells.

No. of well	EC	TDS	PH	Ca	Mg	Na	K	Cl	Hco3	So4	No. 3
W1	477	399	7.12	38	24	46	0.9	92	10	95	-
W2	1226	-	-	-	-	-	-	-	-	-	-
W3	1337	906	7.25	88	67	90	5	185	50	380	0
W4	1792	1260	7.25	43	43	192	2	320	96	270	3
W5	7400	5300	7.2	71	32	428	16	360	260	511	2
W6	1150	971	7.46	109	68	87	5	183	51	379	6
W7	551	410	7.41	30	10	50	0.7	93	14	75	2
W8	983	634	7.2	53	41	68	1.2	180	84	113	4
W9	930	850	7.9	79	50	129	3.1	257	62	251	2
W10	383	295	7.2	16	8.6	30	4	62	50	12	1.1
W11	956	750	7.3	53	27	147	1	188	68	232	1.2
W12	451	390	7.35	36	21	41	0.8	85	92	82	1.1
W13	501	460	7.12	40	25	43	4	90	67	116	1.2
W14	1154	870	7.31	79	50	129	3	257	309	796	4
W15	529	396	7.15	29	13	48	2	88	17	73	3
W16	1292	1010	7.5	101	51	132	5	167	99	421	6
W17	1285	965	7.31	57	31	152	1.2	205	71	241	2.1
W18	690	470	7.22	33	8	52	0.7	91	17	70	2
W19	945	787	7.23	54	28	156	1.5	188	70	230	3
W20	981	820	7.16	56	28	151	2	1.1	68	233	1.1
W21	1380	1265	7.16	117	80	164	9	311	84	559	9
W22	1050	760	7.51	42	25	51	0.9	93	125	87	4
W23	3940	2900	7.5	260	160	250	7	426	260	1010	4
W24	418	350	7.45	26	13	32	0.6	55	68	45	1

2.2. Governing Equation of Groundwater Flow Modelling

The governing equation used to estimate the three-dimensional groundwater flow in the GMS software and the determination of water levels is the Darcy equation in accordance with the law of conservation of mass, show Eq. (1).

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

where x, y, z = Cartesian coordinates (m), K_x, K_y, K_z = The hydraulic conductivity (m/day), h = Head of groundwater pressure, (m), W = Flux per unit volume, (m^3/day), t = Time (day), and Sy = Specific yield for the porous medium (dimensionless).

From the Darcy equation, the flow of the aquifers can be calculated by using the finite difference method adopted in GMS software. From the geological data of the drilled wells in the study area, the solid model layers were constructed (solid data), shown in Fig. 4.

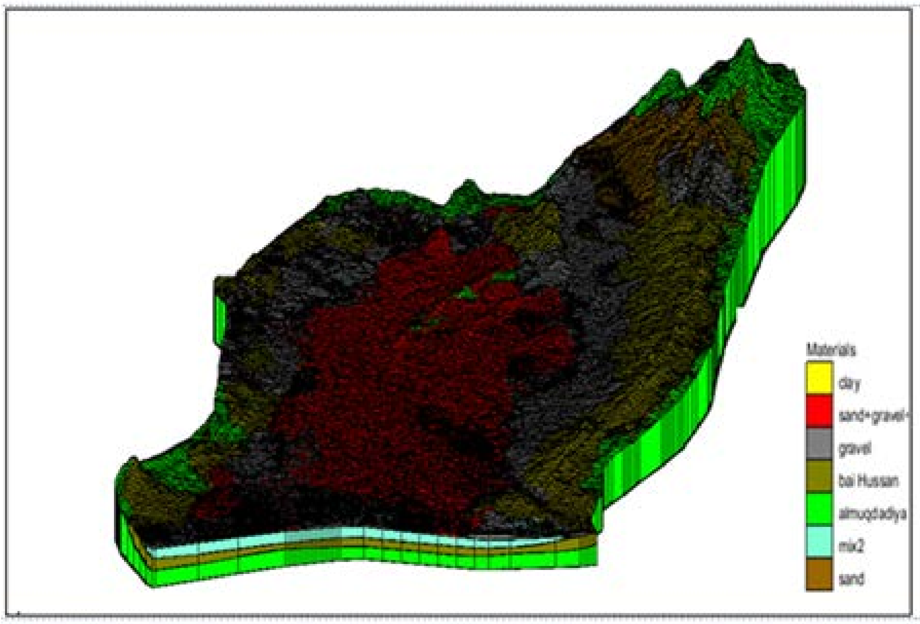

Fig. 4. Solid model for the study area.

Soil layers were named based on the geological maps of the study area with the properties of these layers determined from the available data, as Al- Muqdadiyah formation shown in green has little permeability and is present at the bottom of the model layers with its appearance in some places near the surface of the earth. Bay Hassan formation is newer than the Muqdadiyah formation with higher permeability, the rest of the layers are modern deposits and are classified according to the layer components.

When the solid model was created, MODFLOW model must be constructed, and this model requires the creation of a three-dimensional network that covers the entire solid model, where a three-dimensional network of 250 meters was created on the horizontal axes with seven layers on the vertical axis. Then the conceptual model would be created, that can be defined from it the boundary condition for the

MODFLOW model, and the rate of recharge from surface water to the groundwater, and all data related to the wells, such as pumping data, water level, and all others data required.

2.3. Defining Layers of the Conceptual Model

The preliminary information available for the model is that most of the boundaries of the study area are impermeable, except for the western region bordering the Diyala River, which is considered a constant head area. Also, the Wand River, which passes through the study area, was defined as a natural river, and the annual discharge rate was adopted, shown in Fig. 5.

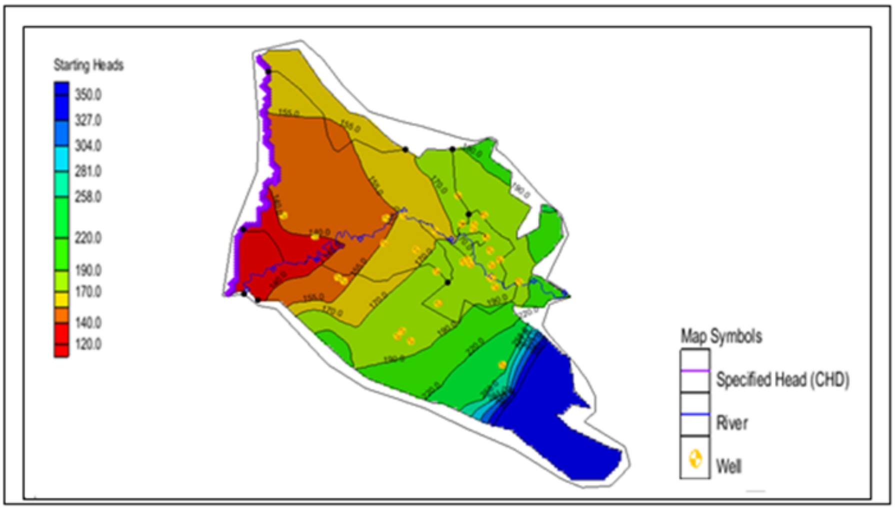

Fig. 5. Boundary conditions and the considered starting heads.

The recharge amount of groundwater in the study area is variable and depends on the nature and topography of the area. Therefore, the study area was divided into three regions. Firstly, are the highland areas that are mostly fed by rainwater only, and which is symbolized by the number -120 as showing in Fig. 6. Secondly, the agricultural areas where the recharge rate is more than the recharge rate in other areas due to surface irrigation in this area, and it is symbolized by the symbol -100. Finally, residential areas where the groundwater recharge depends on rainwater and wastewater and is symbolized by the symbol.

These symbols were used in order to refer to the estimation of initial values for the recharge rate due to the difficulty of determining the actual feeding quantities of groundwater. Therefore, the supported estimation feature was used in the groundwater modeling program to obtain high-accuracy results. These numbers and the negative sign do not represent the default values, but rather are just symbols for the program to deal with during the estimation process [11].

Observation wells layer: Eleven of wells in the study area were selected, Fig. 7, that different from the twenty-four wells involved in the present study, as observation wells and the groundwater tables were recorded in it in order to determine the hydraulic properties of the aquifer, the flow path of the groundwater, and the calibration of the model in the GMS software. A layer was created within the conceptual model that includes all the data of the wells, such as the pumping data, the water table, and the productivity of these wells. That layer named the sink and source layer.

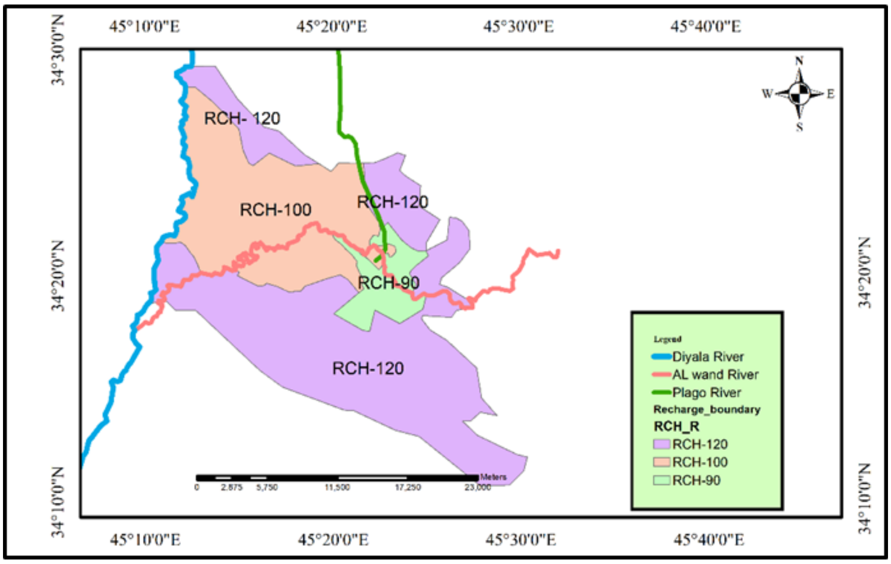

Fig. 6. Recharge rate zones.

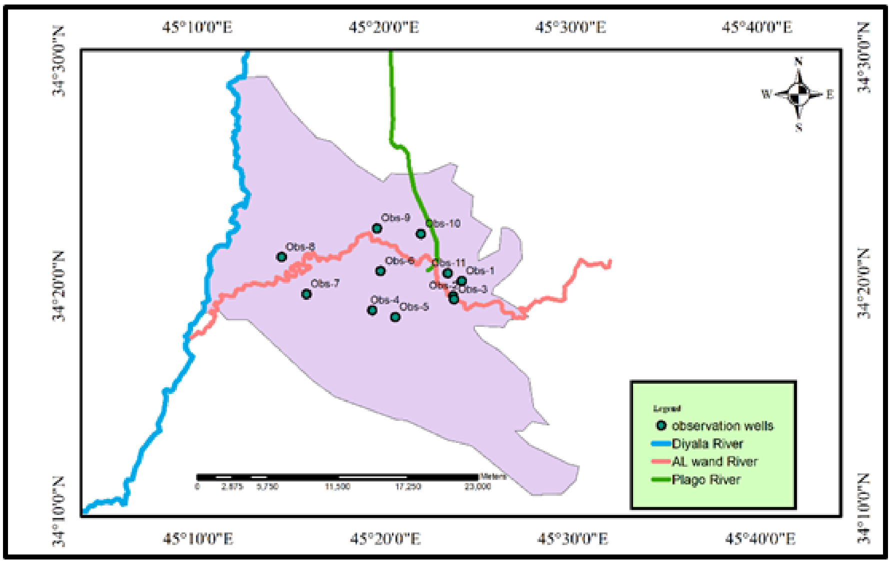

Fig. 7. The locations of the observation wells.

3. Results and Discussion

3.1. Estimating of properties of the layers and MODFLOW runs

As the required models have been created, the groundwater flow was simulated in the aquifer of the study area. The boundary conditions and the initial values of the hydraulic conductivity of the soil layers must be specified within the limitation of the minimum and maximum values of each layer. These values were imposed based on the properties of the soil for each layer After Todd [12], with determining initial values of the recharge rate for the study area too. Then, the estimation feature in the GMS software was activated in order to determine the actual values of the hydraulic conductivity for each aquifer.

When starting to run MODFLOW numerical model, the accuracy and the range of the permissible error rate must be specified. In the present study, the accuracy rate was defined to be 95%, and this percentage was determined by a comparison between the calculated results and the recorded data of the observation wells.

The obtained results are shown in Tables 4 and 5, these values were adopted and generalized for each layer, while the values of the recharge rates of groundwater were taken as was shown in Fig. 8.

Table 4. Predicted values of hydraulic conductivity of soil layers (*k*).

Type	Name	ID	Calculated value	Unit
Horizontal conductivity	Clay	HK_30	1	m/day
	Mix.1	HK_40	5	m/day
	Gravel	HK_50	30	m/day
	Bai Hassan	HK_60	3	m/day
	Al-Muqdadiyah	HK_70	0.001515929	m/day
	Mix.2	HK_80	9.2360134	m/day
	Sand	HK_80	9.2360134	m/day
Recharge rate	Zone1	RCH_120	1.47E-06	m/day
	Zone2	RCH_100	0.000194809	m/day
	Zone3	RCH_90	0.000123782	m/day

Table 5. Comparison between observed and computed heads in the observation wells.

Name	Obs. Head m	Obs. Head interval	Obs. Head conf. (%)	Obs. Head std. dev.	Computed head	Difference in head
Obs-1	176.4	0.25	95	0.51021	176.3597	0.0403
Obs-2	176.5	0.25	95	0.51021	176.5489	-0.0489
Obs-3	176.5	0.25	95	0.51021	176.5048	-0.0048
Obs-4	155.5	0.25	95	0.51021	155.3643	0.1357
Obs-5	157.6	0.25	95	0.51021	157.4241	0.1759
Obs-6	156.8	0.25	95	0.51021	156.6899	0.1101
Obs-7	142.3	0.25	95	0.51021	142.3474	-0.0474
Obs-8	139.9	0.25	95	0.51021	139.8412	0.0588
Obs-9	160.3	0.25	95	0.51021	160.3335	-0.0335
Obs-10	172	0.25	95	0.51021	171.9584	0.0416
Obs-11	175.65	0.25	95	0.51021	175.6734	-0.0234

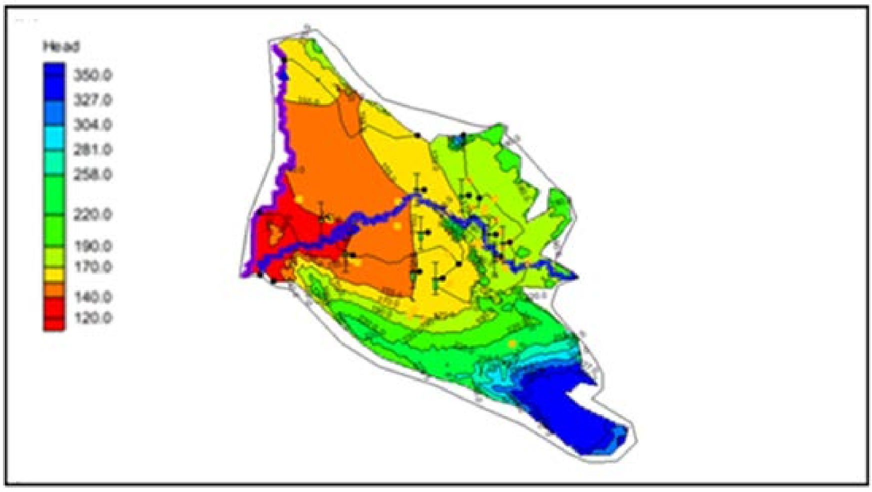

Fig. 8. The computed heads in study area for the steady state.

3.2. Sensitivity analysis of the parameters in the study area

Using the feature of estimating hydraulic properties by PEST (parameter estimation package) in the GMS program where the hydraulic conductivity and recharge rates can be determined simultaneously with the model calibration. For the purpose of estimating the optimal values of the hydraulic parameters, PEST was used to distinguish the sensitivity of the parameters involved in the model. The sensitivity of parameters is a useful tool for identifying the influence of each parameter and defines the significant, little, and insignificant effect of those parameters on the prediction results of the developed model. Fig. 9 shows the sensitivity of the hydraulic conductivity of the aquifers, the obtained results clearly referred that the hydraulic conductivity effect of the third layer is most effective, and this layer is considered the main storage layer for groundwater. While Fig. 10 shows the sensitivity of the recharge of groundwater, it can be seen that residential and agricultural areas are more affected compared with highland areas.

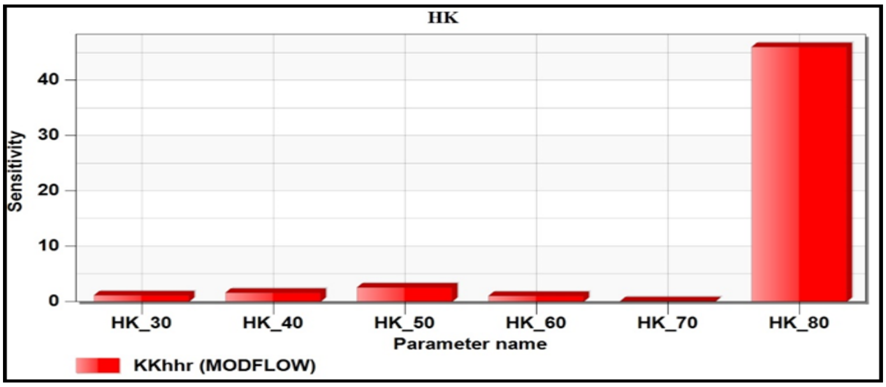

Fig. 9. Sensitivity results of hydraulic conductivity.

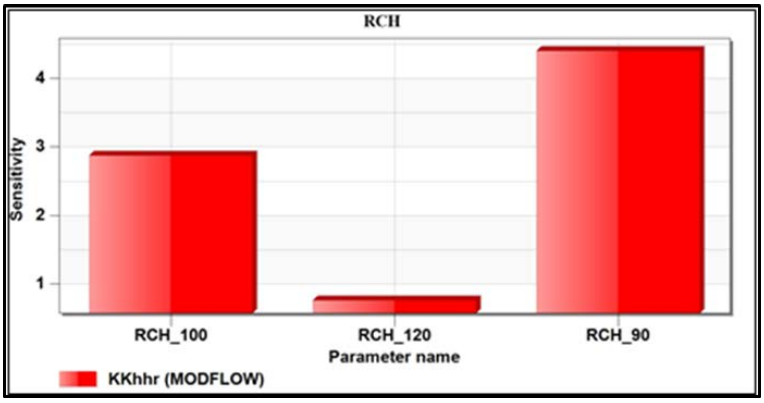

Fig. 10. Sensitivity results of the recharge rate in three zones of the study area.

3.3. Water budget and the best location for drilling wells

The water budget of the area was investigated and the results show that the Al-Wand River works as drainage, which was due to the low water levels of the river compared with the groundwater table in the lands adjacent to the river. The results also show that the volume of drained groundwater to the river is about 28,841 m^3.

On the other side, Diyala River recharges the groundwater along a limited reach of the river by about 11,339 m^3, while the groundwater feeds Diyala River in most of the adjacent downstream areas, and the estimated rate of feedback is about 20,943 m^3. Therefore, most recharges of groundwater are from all types of precipitation, rain mainly, and percolated of excess irrigation water, which is often pumped from the Wand River to the cultured areas, and wastewater inside the city.

For identifying the best locations for drilling wells with high productivity, the results obtained from the layer formation study, as well, the analysis of the results of hydraulic behaviour of the numerical model was considered, these results showed that best locations for drilling wells must have projected within the layer coloured by heavenly colour extends from the middle of the study area to the Diyala River to the west shown in Fig. 11.

Moreover, the screen of the wells must penetrate the third layer which is considered the main store of groundwater and the richest layer. Also, the results show that wells drilled in the formation of Al-Muqdadiyah, where what locates above the groundwater table, is not feasible for water production and has low quality, such as wells No.5, and No.23. That can be interpreted as due to the low permeability of that formation and due to groundwater affected by the compositions that the Muqdadiyah formation consists of. So, the areas having that formation must be avoided for drilling new wells. The areas with that formation are located at the surrounding of the study area, as well as this type appears in the middle of the study area, specifically at the natural highland at the center of Khanaqin City.

3.4. Quality assessment of groundwater

This section includes an assessment of the groundwater quality by comparing the results of the analysis with international and Iraqi standards. Moreover, the possibility of using groundwater for domestic, irrigation uses will be specified. As it was mentioned before, twenty-four wells were included in the present study, these wells were chosen from different locations to represents all of the study areas, and water samples were taken from these wells to be tested experimentally to determine the concentration of the dissolved elements in these samples. Tests were conducted in the laboratory of the Water Resources Engineering Department, University of Baghdad, using the standard methods of analysis cited in ASTM [13].

The validity of groundwater in the study area will be evaluated based on the analysis of results of tests of water samples taken from wells and compare these results with national IQS [14] and international WHO standards [15]. Table 6 illustrates the limitations of the standards of the acceptable quality of water for drinking uses. The assessment of test results of groundwater, the chemical analysis of water samples, and the concentration of dissolved elements in the water for all wells in the study area which were listed in Table 2, shows that most of these wells can be classified as freshwater, that can be used for domestic uses, except W5 and W23, which are exceed the allowable limits and considered unfit for drinking use, that is due to the proximity of the location of the two wells to the Al-Muqdadiyah formation which affects the water quality of these wells. Moreover, all these wells were qualified for the use of Irrigation due to an acceptable concentration of TDS in this water, as well as it was feasible for industrial uses.

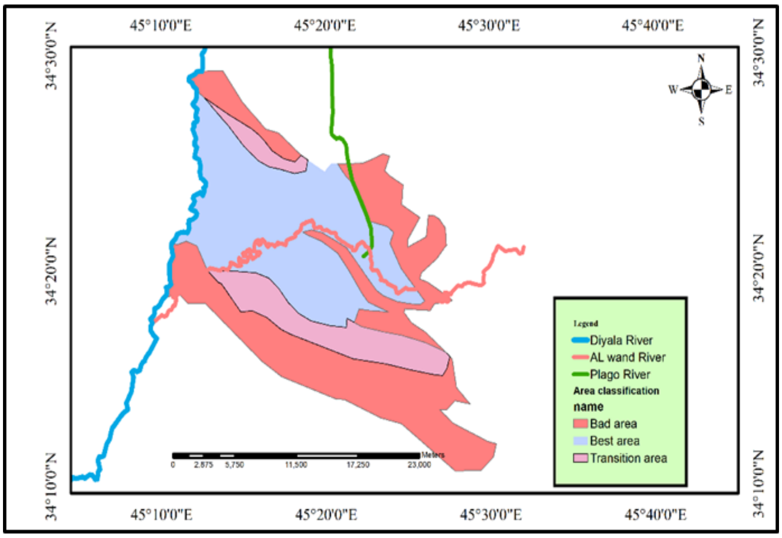

Fig. 11. The best locations of drilling wells.

Table 6. Iraqi and International Standards for drinking water.

Parameter	IQS (2009)	WHO (2008)
PH	6.5-8.6	6.5-8.5
TDS	1000 mg/l	1000 mg/l
Ca^{+2}	150 mg/l	100 mg/l
Mg^{+2}	100 mg/l	125 mg/l
Na^{+1}	200 mg/l	200 mg/l
K^{+}	12 mg/l	-----
Cl^{-1}	350 mg/l	250mg/l
SO_4^{-2}	400 mg/l	250 mg/l
NO_3^{-1}	50 mg/l	50 mg/l

4. Conclusions

This study included groundwater modelling for Khanaqin areas, located in the east of Diyala Governorate using the GIS and GMS software, a hydraulic model was created to simulate the groundwater flow in the study area, a solid model was constructed, and the boundary condition was determined. Twenty-four wells were included in the present study, field measurements and experimental tests were conducted to determine water levels and to assess the water quality.

The geological study shows that the study area consists of a number of soil layers, that the depths of the wells did not overtake it, it is seven layers. Among these layers are ancient geological formations such as Al-Muqdadiyah formation and the Bai Hassan formation, and it turns out that these layers have low permeability. The other layers are of modern formation formed from the deposits during the flood seasons. It was found that the main layer of groundwater storage is the third layer, which has a hydraulic conductivity of 9 m^3/ day. Therefore, it is recommended that the drilling of wells must be within the boundaries of this layer, and avoiding drilling wells in areas whereas the formation of Al-Muqdadiyah is higher than the levels of groundwater because of the low permeability of this layer.

The results of the hydraulic model showed that the recharge of the groundwater in most of the study area is mainly from the rain, while the access water of irrigation is contributing to the recharge of groundwater in the cultured areas, and the wastewater was considered as the secondary recharge source of groundwater in the residential area especially within Khanaqin City. Also, these results showed that Al-wand River acts as a drain and it receives an estimated volume of water about 28,841 m^3. Diyala River is characterized by a different condition, it feeds groundwater along a part of its length, while it received groundwater in another part of its length along the study area, and that net results in a volume of water received to the river were estimated by 9,603 m^3.

The assessment of the groundwater quality of all wells resulting from the comparison with the local and international standards indicates the validity of using water for drinking purposes, it was found that most of these waters can be considered as freshwater and can be used for domestic purposes except the wells No. W5, and W23, Moreover, this water is adequate for Agriculture and industrial uses.

Nomenclatures

Dia.	Diameter of wells, mm
h	Groundwater pressure, L
Kx, Ky, Kz	Hydraulic conductivities in three directions, L^3/T
Q	Productivity of wells, L/s
S_Y	Specific yield of the porous media
t	Time, s
w	Volumetric flow rates per unit volume, L^3/T
X, Y	Coordinates in decimal degree

Abbreviations

ASTM	American Society for Testing and Materials
GIS	Geographic Information System

GMS	Groundwater Modelling System
HK	Hydraulic Conductivity
IQS	Iraqi Standard Specifications
RCH	Recharge Rate
WHO	World Health Organization

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