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Groundwater Simulation and Wells Distribution at Qazaniyah City in Diyala Governorate

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ABSTRACT

In recent years, there is more interest in water sources availability, including groundwater due to an increase in demand for water because of the increasing population in the world, and the water recedes due to climate change also. Therefore, the study of groundwater has required more attention. The aim of the present study is to establish a MODFLOW model in the groundwater modeling system software to simulate the movement of groundwater in the Turssaq alluvial fan which is located in the Qazaniyah city, east of Diyala Governorate. The solid model was used to define the aquifer in the study area. Using the GIS software, mapping and preparing the data needed to create a conceptual model were carried out. The data of the wells were used to create and define the aquifer, then a three-dimensional model was created. Measuring the water table for some wells were simultaneously monitored to determine the hydraulic conductivity values of the aquifer through the (PEST) package provided by the software. The hydraulic conductivity value of the main layer was 18 m/d. Then several readings of observation wells were recorded for the period extended from 1/Nov/2018 to 22/May/2019 for the calibration process in the unsteady situation and to determine the coefficient of storage. The value of the storage coefficient was defined as 0.001. Several scenarios were conducted for the study area to find the best distance between the wells. Three distances were tested, 500, 1000 and 1500 m. The operating periods were 6, 12 and 18 (hours/day). Results obtained from the model show that the best distance between the wells is 1000 meters with a maximum operating rate of 12 hours/day. The maximum discharge with the lowest distance and the lowest drawdown of the groundwater table are considered.
Keywords: Alluvial fan, Groundwater, MODFLOW, Qazaniyah, water quality.

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محاكاة المياه الجوفية وتوزيع الابار في مدينة قزانية

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الخلاصة

شهدت السنوات الأخيرة اهتمام أكبر بمصادر المياه ووفرتها، بما في ذلك المياه الجوفية وذلك لزيادة الطلب على المياه والناتج عن تزايد عدد السكان في العالم، وانحسار كميات المياه بسبب التغير المناخي، مما تتطلب دراسة المياه الجوفية المزيد من الاهتمام. أن الهدف من هذه الدراسة هو انشاء نموذج رياضي في برنامج نظم المياه الجوفية لمحاكاة حركة المياه الجوفية في مروحة ترسق الغرينية في مدينة قزانيه شرق محافظة ديالى. تم استخدام النموذج الصلب لتعريف طبقات التربة في منطقة الدراسة وبالاستعانة ببرنامج نظم المعلومات الجغرافية تم رسم الخرائط واعداد البيانات الازمة لأنشاء نموذج مفاهيمي. حيث تم استخدام بيانات الابار لغرض انشاء وتعريف طبقات التربة وبعدها تم انشاء نموذج ثلاثي الابعاد. بعدها تم رصد مناسيب عدة ابار ضمن منطقة الدراسة في وقت واحد لغرض القيام بتحديد قيم الايصالية الهيدروليكية لطبقات التربة من خلال حزمة بيست التي يوفرها البرنامج وكانت قيمة الايصالية الهيدروليكية للطبقة الرئيسية هي 18 م\يوم وبعدها تم رصد عدة قراءات للفترة من 1-تشرين الثاني-2018 ولغاية 22-أيار-2019 لغرض اجراء عملية المعايرة في الحالة الغير مستقرة وتحديد قيمة معامل الخزين فكانت قيم معامل التخزين هي 0.001. بعد تحديد خواص التربة وبيان صحة الموديل تم اجراء عدة سيناريوهات لمنطقة الدراسة لغرض اختيار أفضل مسافة بين الابار، حيث اختير ثلاثة مسافات وهي 500 و1000 و1500 م وكانت فترات التشغيل في كل مرة هي 6 و12 و18 ساعة في اليوم وتبين ان أفضل مسافة بين الابار هي 1000 متر وبمعدل تشغيل 12 ساعة باليوم كحد أقصى والتي تعطي اعلى تصريف بأقل مسافة واقل انخفاض في مناسيب المياه الجوفية.

الكلمات الرئيسية: المياه الجوفية، تقييم نوعية المياه، مروحة غرينيه، قزانية.

1. INTRODUCTION

Groundwater is considered to be the second most important source of raw water, and it has been cared for since ancient times. It is available in most places, even in desert and dry places (**Karanth, K. R., 1987**). It was easy to extract and have low cost compared with other sources. It was often pure from impurities and plankton and did not need to be filtered because the aquifer act as a filter to clear the water, and it does not contain microscopic organisms or bacteria (**Abdulla H. H., 2001).** Climate change in the region, lack of rainfall, and increased demand for water in most parts of the world and Iraq (**Toure, A., Diekkrüger, B., and Mariko, A., 2016)**, as imports of rivers and valleys have declined due to human activates and climatic change. Therefore, the people resorted to use groundwater as an alternative source of surface water. Rainfall is the main source of groundwater recharge, and the amount of groundwater is not infinite, which must set the conditions and controls to be used optimally and maintain its sustainability (**Chitsazan, M., and Movahedian, A., 2015)**. The excessive use of groundwater leads to a decline in their levels and thus lead to the drying of wells and springs. Therefore, in this study, the modeling of groundwater in the Qazaniyah City was highlighted, where wells and springs are currently used. The Turssaq alluvial fan is identified as a study area due to its importance and the abundance of wells and springs therein.

The Qazaniyah City is located between latitude 30˚45’00” N and longitude 45˚30’00” E, at the east of Diyala Governorate, near the Iranian border, as shown in **Fig. 1.** The city suffered from a lack of surface water sources. The population and agriculture in this city have been influenced by surface water deficit, and people started using groundwater as an alternative source. Many wells have been drilled randomly in these areas, also the use of groundwater is not ideal, so it is necessary to study the characteristics of groundwater in this city and create a conceptual model by using (GMS) Groundwater Modeling System software.

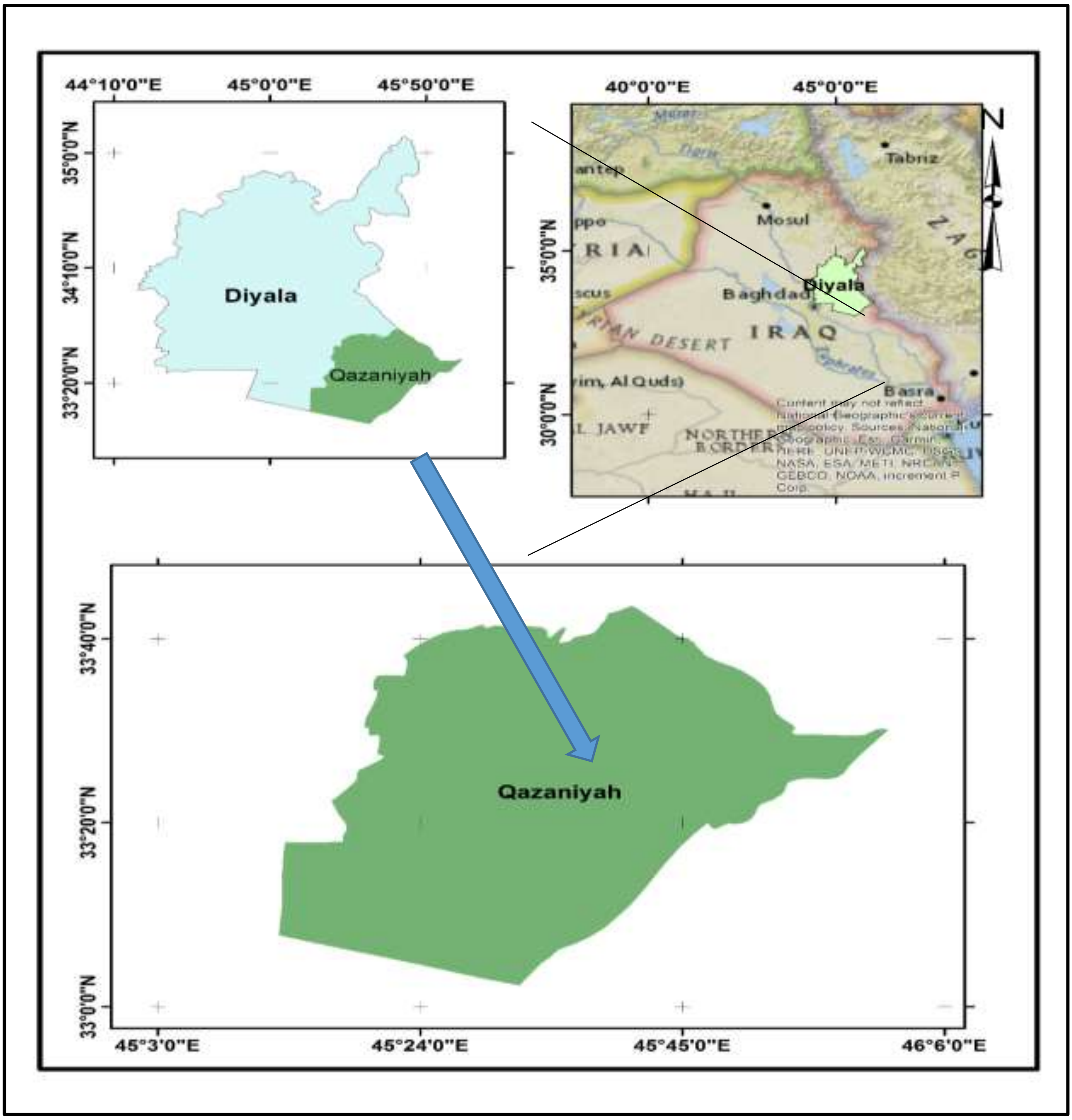

Figure1. Location of the study area (GIS Map Online).

1. RESEARCH OBJECTIVES

The present research aims at developing a MODFLOW model to simulate the groundwater movement in the Turssaq alluvial fan and specifying the hydraulic characteristics of the aquifer for the study area by using Geographic Information Systems (GIS) and Groundwater Modeling

System (GMS) software, as well as determining the best distribution of wells with best operation conditions.

2. EQUATIONS GOVERNING GROUNDWATER FLOW

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 and in accordance with the law of conservation of mass.

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

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,
S_y = Specific yield for the porous medium, *dimensionless*.

Two methods can be used to create a developed MODFLOW simulation in the groundwater modeling system—first, the grid method, or the conceptual model method. The grid method includes working immediately with the 3D grid and applying sinks/sources and other model parameters on a cell-by-cell basis, (**GMS User Manual 10.4, 2018)**. However, the conceptual model method includes using the GIS tools in the Map module **(Dawood, A. S., 2018)** to improve a conceptual modeled study area. The location of sinks/sources, layer parameters (like hydraulic conductivity), and all other data required for the simulation can be defined at the conceptual model level. Once this model is complete, the grid is generated, the conceptual model is converted to the grid model, and all of the cell-by-cell assignments are performed automatically (**Wang, S., et al., 2008**). The conceptual model is the best way to create complex models for easy handling with lots of data.
The steps of creating a three-dimensional conceptual model in the GMS software include three main steps; firstly, is the establishment of the solid data model, which represents the aquifer and type of material. Secondly, creating boundary condition layers, that includes the recharge layer, sink and source water layer, border layer, and observation wells layer. Finally, the 3D grid and the MODFLOW layer is created.

2.1 Methodology

Fig. 2 illustrates the methodology of developing the three-dimensional conceptual model for the study area with the necessary data step-by-step, as well as the calibration process of the model.

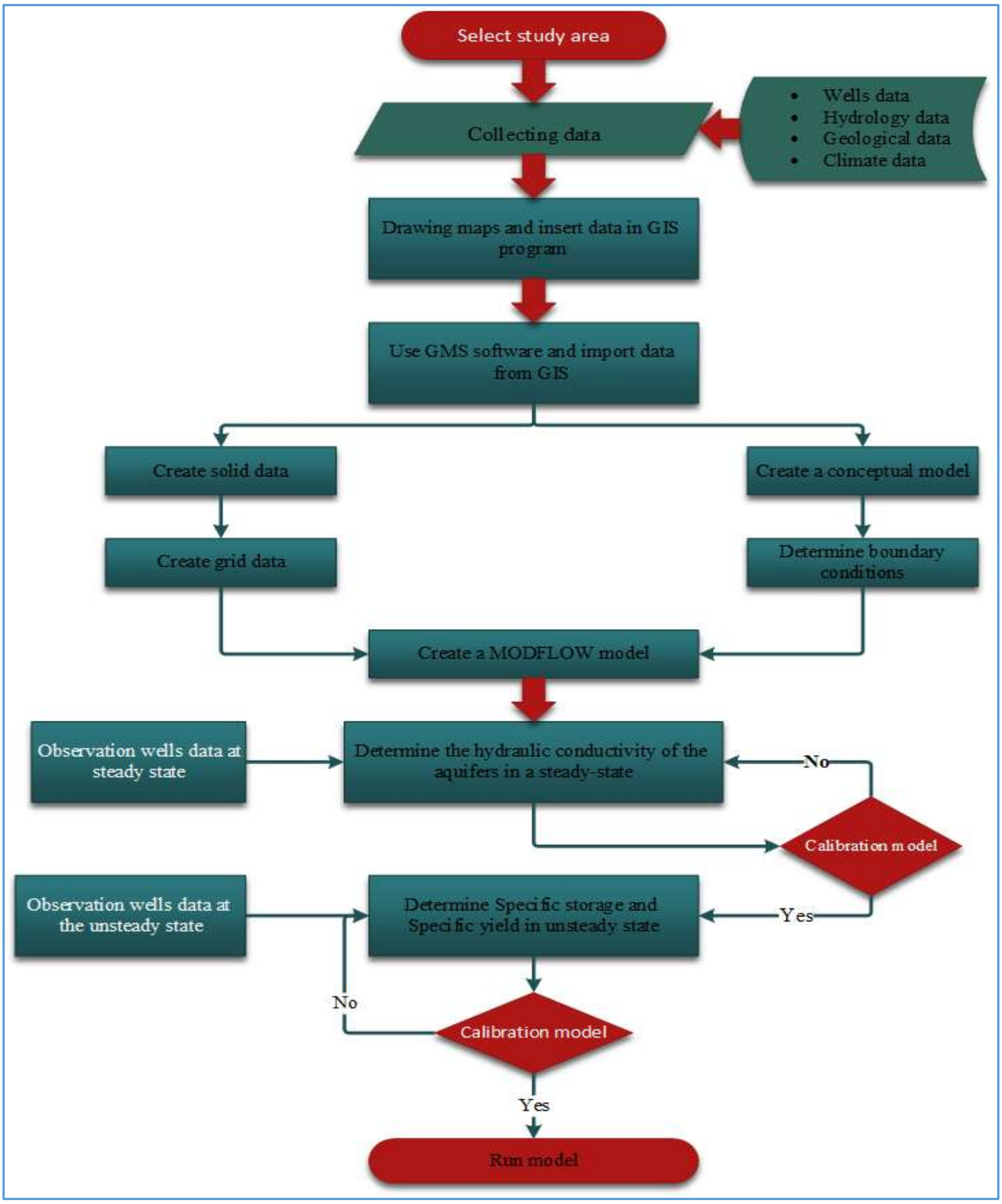

Figure2. The methodology of developing the conceptual model groundwater simulation.

2.2 Specifications of the study area

From the previous figure, the first stage of the model development is achieved by collecting the wells' data, hydrological, geological, and climate data for the study area.

1. Geological data; The geological formations found in the study area are Lower Bakhtiari (Al-Muqdadiyha). It consists of sandstone, silt, and Claystone. This type of formation is for the confined aquifer that extends into the lower layers of the study area (**Jiburi, Hatem K., and Naseer H. Al-Basrawi 2015**). Above this layer, the alluvial fan was formed and is considered one of the modern formations resulting from the flow of water in the flood seasons of Wadi Turssaq. The fan was composed of several layers formed from coarse materials such as gravel and sand deposits in high discharges of the flood in the lower layers, and then the fine sediments above that layer to form a higher layer with low permeability during the low discharge, **Fig.3**.

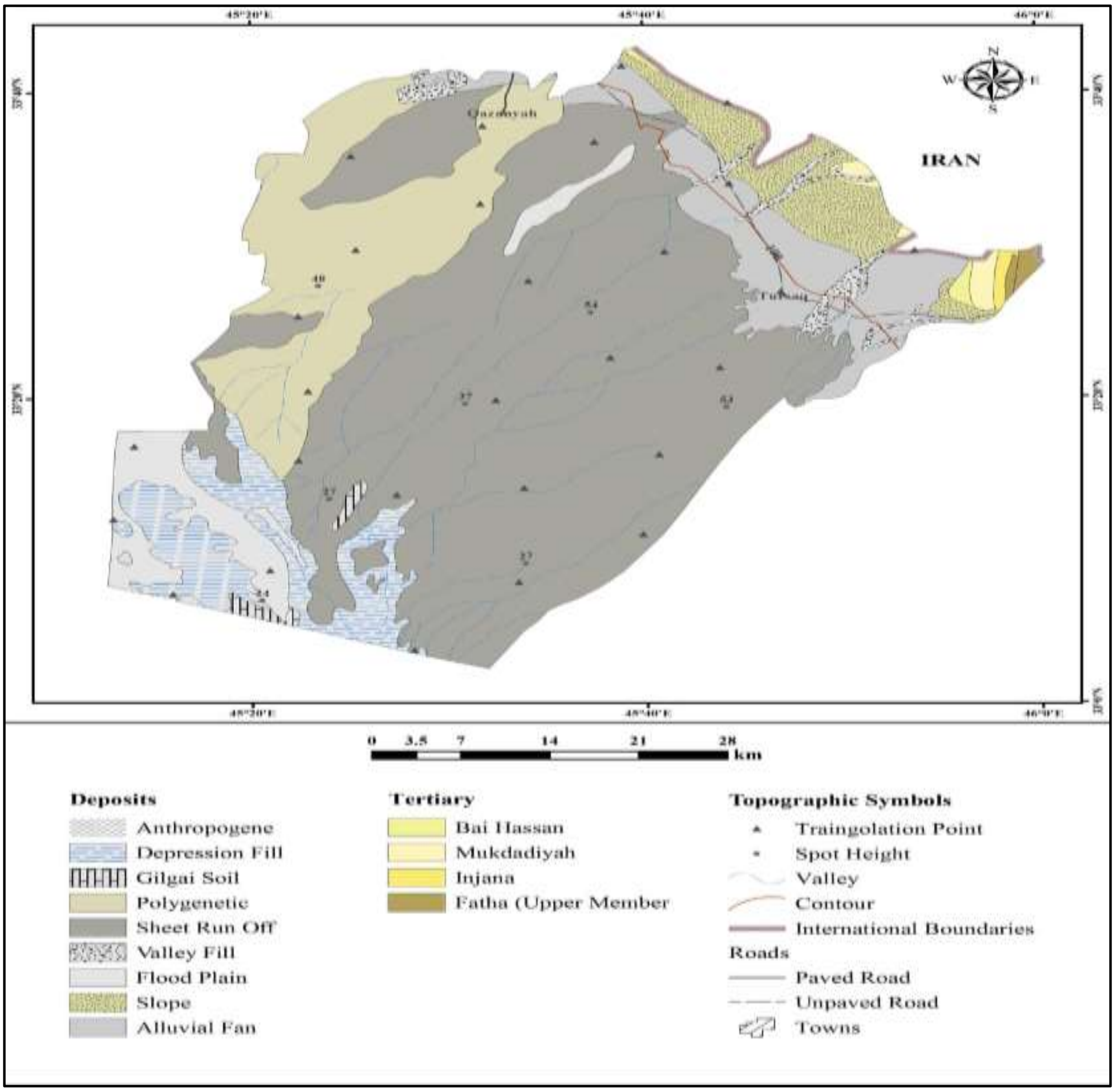

Figure3. Geological map of Qazaniyah (**MoWR**, **2018)**.

Table 1 illustrates the geometric data of the wells, which contains the coordinates, elevation, depth, water levels, diameter, and the productivity of wells **(Ministry of Water Resources, General Authority for Groundwater 2019)**.

Table1. Geometry Data of Wells of Turssaq Alluvial Fan.

Name	**X-axis**	**Y-axis**	**Elevation *m a.m.s.l.***	**Depth. *M***	**water level. *m***	**Q. *l/sec***	**dia. *mm***
W1	45.80055	33.448	93	48	71	5	200
W2	45.7383333	33.456388	93	66	81	8	200
W3	45.8013888	33.445555	96	66	73	7	200
W4	45.8191666	33.413888	86	72	54	6	200
W5	45.7736111	33.473056	85	66	69	7.5	250
W6	45.7841666	33.456667	84	60	58	6	200
W7	45.8094444	33.4325	84	62	66	7	200
W8	45.7875	33.499167	96	61	74	7	200
W9	45.7588888	33.460556	69.5	60	44.5	6	200
W10	45.8208333	33.413611	80	72	64	8	200
W11	45.7508333	33.510555	81	72	68	7	250
W12	45.7727777	33.482777	85	72	58	7	250
W13	45.8194444	33.431944	90.6	60	68.6	6	250
W14	45.8519722	33.408111	83	72	75.2	7	250
W15	45.8632478	33.425342	94	72	80.7	7	250
W16	45.8555833	33.414833	88	66	73.5	7	250
W17	45.8219722	33.428694	88	60	79.7	7	250
W18	45.8121388	33.441305	93	72	80.5	7	250
W19	45.7833611	33.443916	82	66	74.4	7	250
W20	45.7819444	33.458	88	60	81.7	7	250
W21	45.7793888	33.473027	90	72	80.5	7	250
W22	45.7981944	33.508611	106	66	90	7	250
W23	45.7541944	33.523972	89	60	89	7	250
W24	45.7851111	33.463805	93	66	79	7	250

Note: The X and Y-axis represented the well coordinate in decimal degree unit.

2. Hydrological data; the study area is located on the foot of the mountains in eastern Diyala province near the Iraqi-Iranian border. It contains many valleys having a seasonal flow during the rainy period (**Ali M., 2007**). The Wadi Turssaq is one of its most important valleys. **Fig. 4** shows the hydrology map of the study area. The map was drawn by using Hydrological tools in GIS Software. The stream order in the legend of the map represented type of valley.

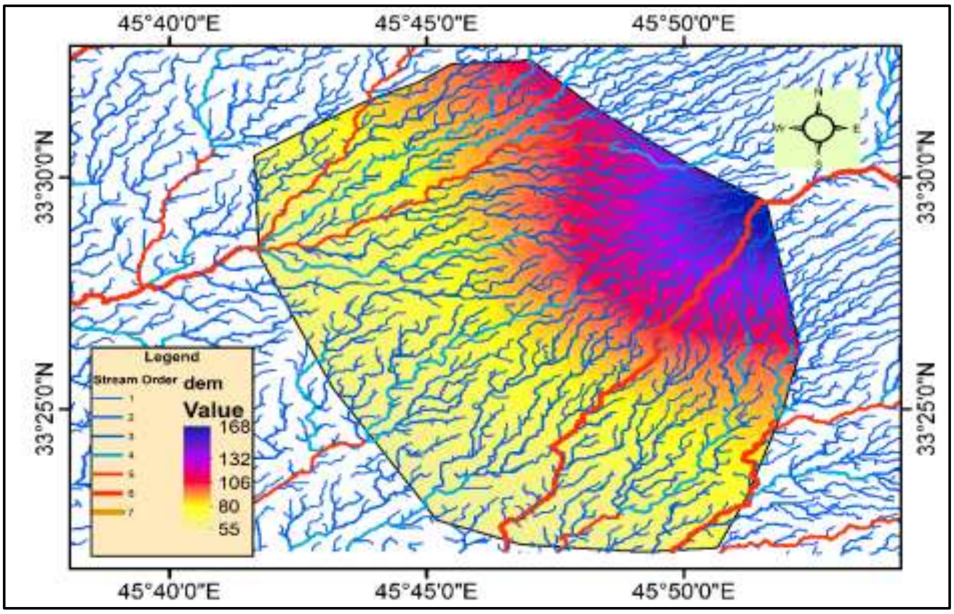

Figure4. Hydrological map of the Qazaniyah.

3. Climate data should be taken into consideration at the calculation of the quantity and quality of groundwater. Rain is the primary source of groundwater as a direct recharge, where there is an indirect recharge of groundwater from other sources. Direct feeding is estimated at about 5% from rainfall (**Ali, S. M., and Oleiwi, A. S., 2015**), and indirect feeding results from the deep percolation of water flow in the valleys and from surface irrigation of agricultural crops. **Table 2** shows the amount of rainfall in the Mandali region for the period 2010 to 2019. Rainfall data depended on the Mandali station data because it is the closest station to the study area.

Table 2. Rainfall data of Mandali City for the period from 2010 to 2019, *MoWR.*

Year	Rainfall, mm												
	Month												**Total**
	Jan	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	
2010	41	36	26	36	42	0	0	0	0	0	6	26	213
2011	82	0	0	0	13	0	0	0	0	34	1	1	131
2012	3	35	36	4	0	0	0	0	0	0	146	43	267
2013	30	24	0	0	30	0	0	0	0	0	69	28	181
2014	20	31	4	4	0	0	0	0	0	10	14	6	89
2015	3	24	0	0	0	0	0	0	0	141	68	25	261
2016	18	34	95	95	0	0	0	0	0	0	0	23	265
2017	24	14	19	19	0	0	0	0	0	14	10	0	100
2018	2	157	0	21	10	0	0	0	0	35	181	112	518
2019	42	31	92	32	0	0	0	0	0				197

The boundary of the Turssaq alluvial fan, the boundary of study areas, can be drawn from satellite images, geological maps, and wells sites. This border will be included in the simulation model. **Fig.5** shows the boundary of the Turssaq alluvial fan in Qazaniyah city. Since there are no natural boundaries, so the boundary will be defined as a constant head in the conceptual model (**Maheswaran, et al. 2016)**

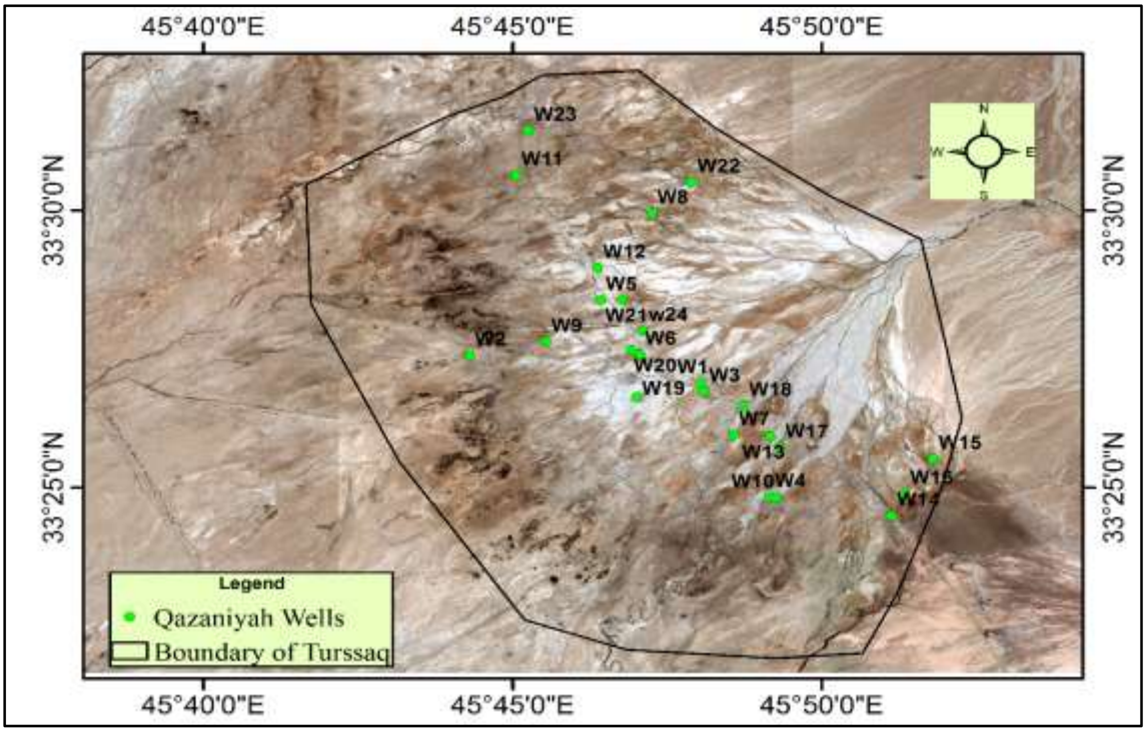

Figure 5. The boundary of the Turssaq alluvial fan in Qazaniyah City.

4. Modeling of Groundwater Flow

To create an integrated MODFLOW model it is necessary to create several basic models, where each model carries specific characteristics, and then consolidate the obtained data in the main model (**Al-Taiee, T. M., and Hasan, A. A., 2006**) and (**Mustafa, A. et al., 2017**) That facilitates the representation of complex data in this process of the creation of the models as follows;

3.1 Solid model

This model represents the geological formation. It was created from the cross-sections of the wells and the geological map of the study area. **Fig. 6** illustrates the geological formation of the alluvial fan, which consists of four layers. From the geological properties of the layers can be estimated the hydraulic specifications of each layer. **Table 3** represents the estimated values that will be adopted and validated at the steps of the calibration of the model.

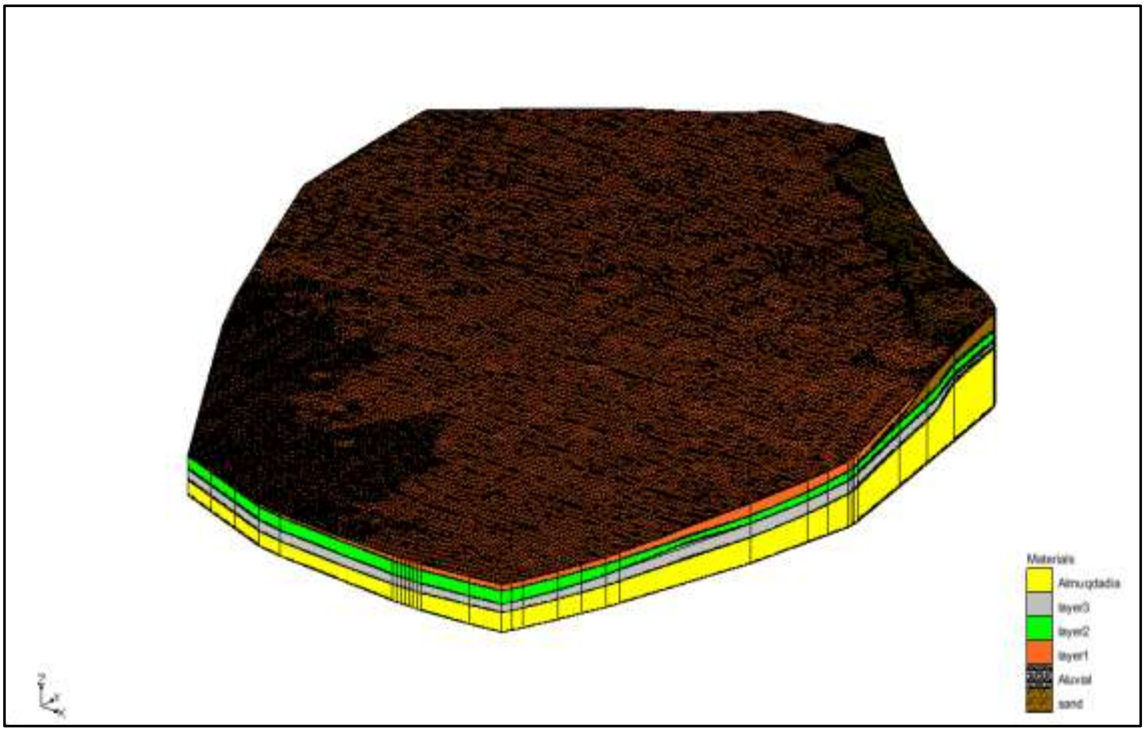

Figure6. Representation of geological formation in the Solid Model.

Table 3. The initial estimated value of hydraulic conductivity and recharge rate of Turssaq Alluvial Fan.

Name	ID	Initial value	Min.	Max.
Layer1	HK_40	9	5	15
Layer2	HK_10	3	0.5	5
Layer3	HK_30	12	12	25
Muqdadiyha	HK_20	0.5	0.005	1
Recharge	RCH-100	0.001	0.000001	0.01

3.2 Conceptual Model

This model represents four secondary layers. First, the boundary layer includes the type of boundary in the model and the starting head, as shown in **Fig. 7**. Second, the sink source layer, which includes wells data. Third, the recharge layer, this layer represents the amount of water that feeds the groundwater from the rain. The estimated percentage was 5% (**Ali M., 2007)** of the annual rainfall rate as an initial guess rate, which will be verified during the calibration of the model. Finally, it represents the wells' observation layer. **Table 3** presents the recorded data at Turssaq alluvial fan.

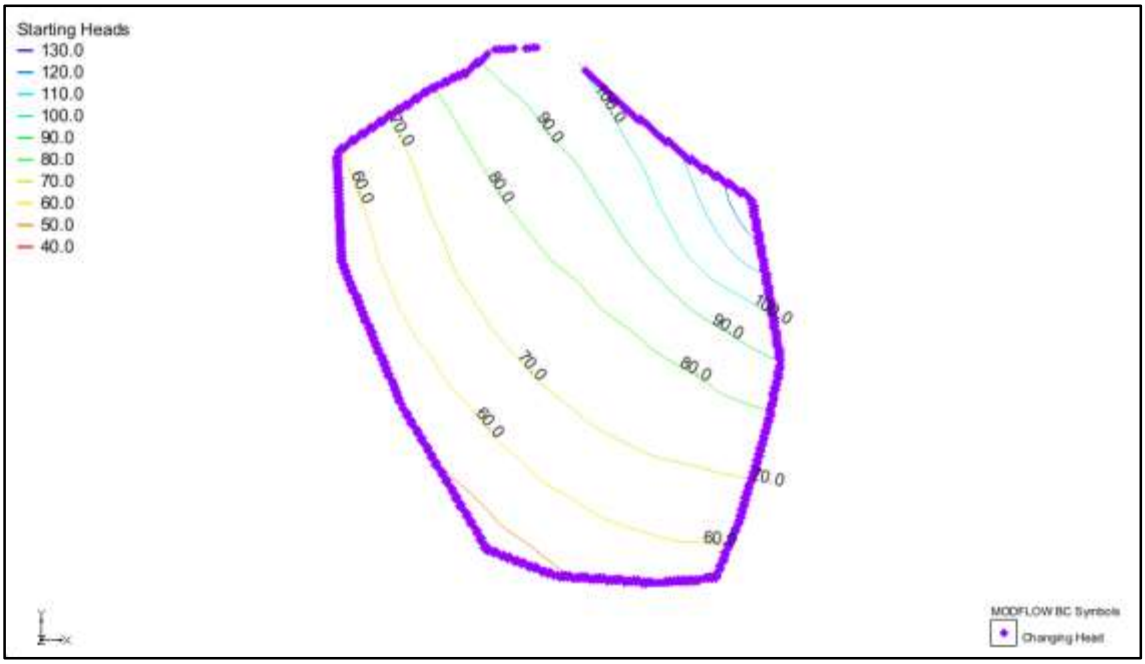

Figure7. Boundary condition and starting head of Turssaq alluvial fan.

Table3. Records of observation wells at Turssaq Alluvial Fan.

Name	Obs. Head	Obs. Head interval	Obs. Head conf., %
W1	78.5	0.5	95
W3	78.28	0.5	95
W14	73.1	0.5	95
W15	80.75	0.5	95
W18	79.05	0.5	95
W19	75	0.5	95
W20	77.5	0.5	95
W21	80.5	0.5	95
W23	86.5	0.5	95
W24	79	0.5	95

3.3 Grid and MODFLOW models

The three-dimensional grid model of the Turssaq area was created. The origin of the grid model is 3703000N, 558500E (UTM), and 20 meters under sea level. The lengths in the direction of X, Y and Z were 22450, 16950and 220 meters, respectively, cell lengths in the direction X and Y are 100 meters, and the number of layers in Z direction was five layers, the high of the cell depends on the top and bottom elevation of the aquifer. The total number of cells was 191250, the number of active cells was 119740, and inactive cells were 71510. The dimension of one cell is 100x100 m, and the area of the cell will be equal to 0.01 km^2, as shown in **Fig. 8.**

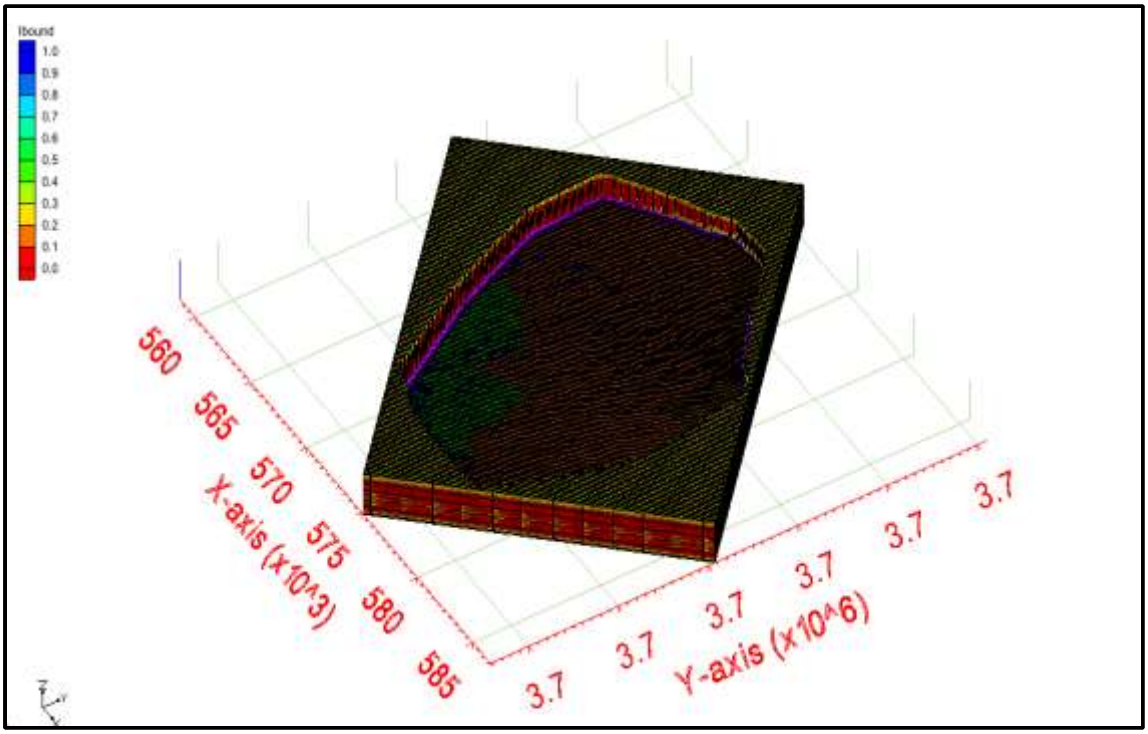

Figure 8. The grid design of Turssaq Alluvial Fan

5. Determination of Hydraulic Properties of the Aquifer

In this step, the software is run in a steady-state, and after several cycles, the software will correct the initial values of hydraulic conductivity and groundwater recharge rate (**Ahmed, A. A., 2009**). **Table 4** represents the final results for these values. At the same time, the calibration of the model was accomplished by matching the simulated water tables at the observation wells with the field measuring water tables of the observation wells, **Fig. 9**.

Table 4. Hydraulic conductivity (K) of the aquifer, recharge rate, and porosity in Turssaq.

Name	ID	Computed value *m/day*	porosity
Layer1	HK_40	5.0	0.25
Layer2	HK_10	2	0.2
Layer3	HK_30	18.546839	0.3
Muqdadiyha	HK_20	0.57995316	0.2
Recharge layer	RCH_100	0.000108*m/day*	

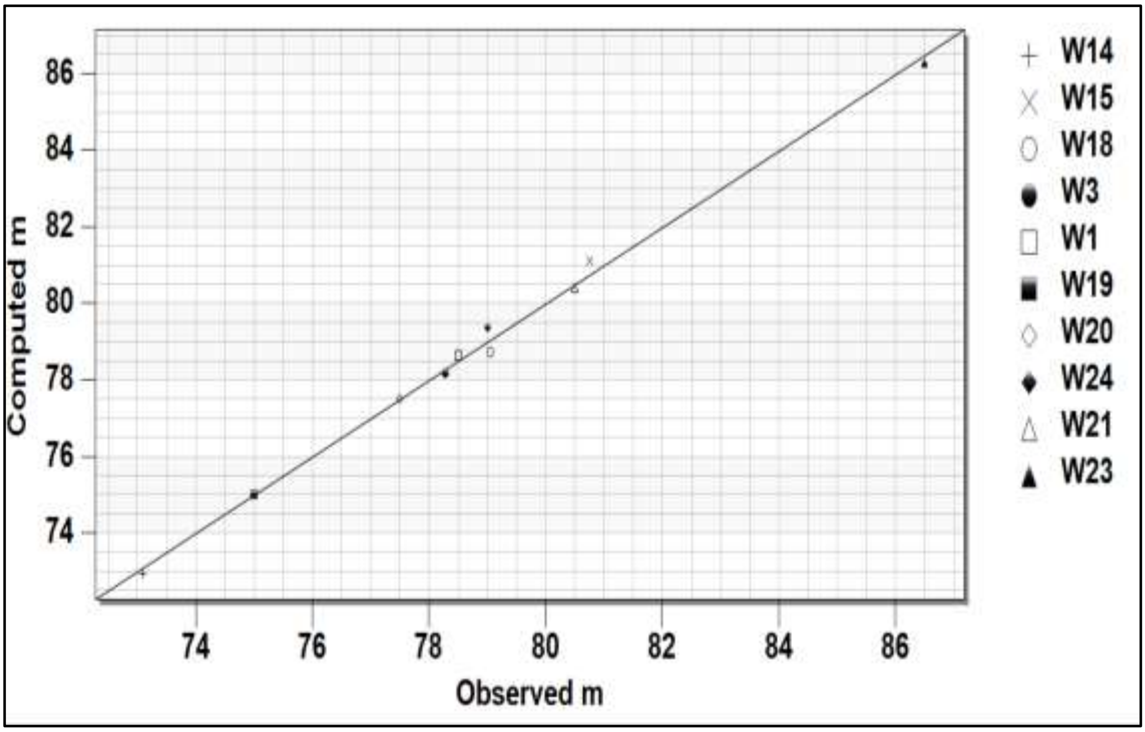

Figure 9. Comparison between observation and computed heads at the steady-state condition.

The specific yield and storage coefficient can be calculated in the same way as the hydraulic conductivity was calculated. The first step in an unsteady state is to convert the MODFLOW model from a steady to unsteady form, then import the transient data like transient water table data of observation wells in the study area. **Table 5** presents the observed heads of two wells for the period (11/1/2018 till 5/1/2019), and Tables **6** and 7 illustrate rainfall data and pumping data, respectively.

5- Field observations

Several field observations were conducted to be used in the calibration and verification of the numerical model. The wells W24 and W18 were selected as observation wells in the study area, and then water tables were recorded during the research period. The selection of these wells was because they are located in the center of the study area. The readings were taken at stable times, and there was no pumping from these wells as shown **Fig. 10**.

MODFLOW model is constructed where all of the hydraulic soil properties are specified, as shown in **Table 8**. The simulated head is compared with the recorded head in two observation wells W18 and W24, as shown in **Fig. 11** and **Fig. 12**.

Figure10. Measure the groundwater table in the well.

Table 5. Field Measurements of the head for wells in Turssaq Alluvial Fan.

Date	Observed Head at W18,*m*	Observed Head at W24,*m*
11/1/2018	72.45	73.00
12/1/2018	74.90	75.40
1/1/2019	74.80	75.25
2/1/2019	74.5	74.70
3/1/2019	74.55	74.75
4/1/2019	75.40	76.00
5/1/2019	75.10	75.4

Table 6. The transient recharge data, MoWR.

Date	Rain, *mm/month*	Date	Rain, *mm/month*
9/1/2018	0	2/1/2019	44
10/1/2018	0	2/1/2019	48
10/1/2018	51	3/1/2019	48
11/1/2018	51	3/1/2019	123
11/1/2018	201	4/1/2019	123
12/1/2018	201	4/1/2019	39
12/1/2018	103	5/1/2019	39
1/1/2019	103	5/1/2019	0
1/1/2019	44	6/1/2019	0

Table7. Pumping data for all wells.

Date	Discharge, m^3/day	Date	Discharge, m^3/day
9/1/2018	-300	2/1/2019	0
10/1/2018	-300	2/1/2019	0
10/1/2018	-100	3/1/2019	0
11/1/2018	-100	3/1/2019	0
11/1/2018	0	4/1/2019	0
12/1/2018	0	4/1/2019	-150
12/1/2018	0	5/1/2019	-150
1/1/2019	0	5/1/2019	-300
1/1/2019	0	6/1/2019	-300

Table 8. Properties of Aquifer in Turssaq Alluvial Fan.

Name	Horizontal k *m/day*	Vertical. anisotropy *kh/kv*	storage coefficient	specific yield
Layer1	5.0	3	0.0001	0.15
Layer2	2	3	0.00001	0.025
Layer3	18.55	3	0.0001	0.25
Muqdadiyha	0.58	3	1.00E-06	0.005

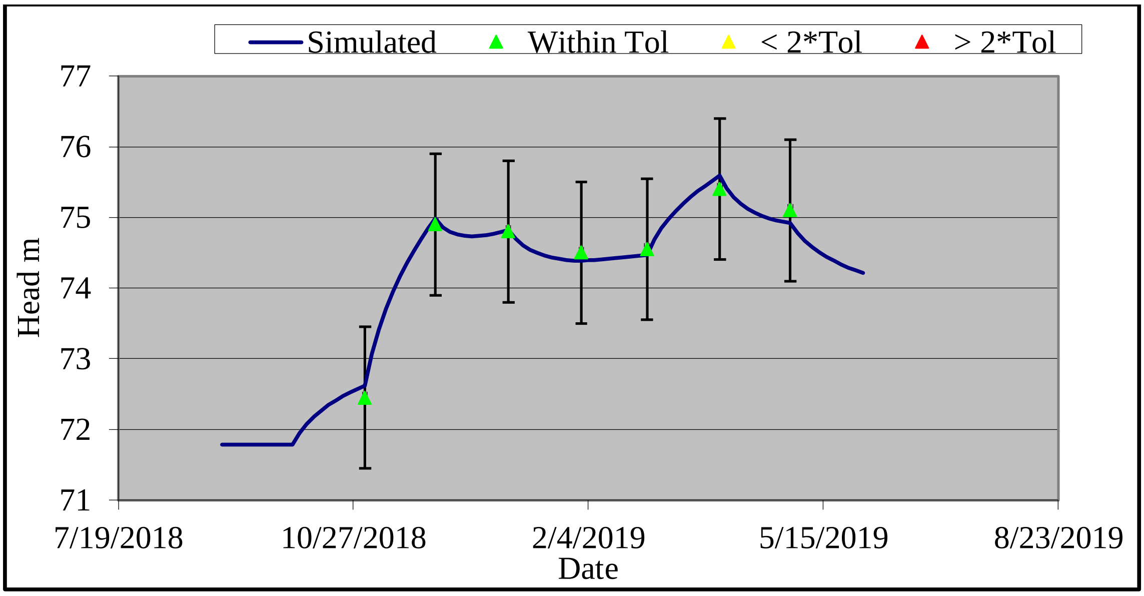

Figure11. Measured and simulated heads in Turssaq Alluvial, Fan W18.

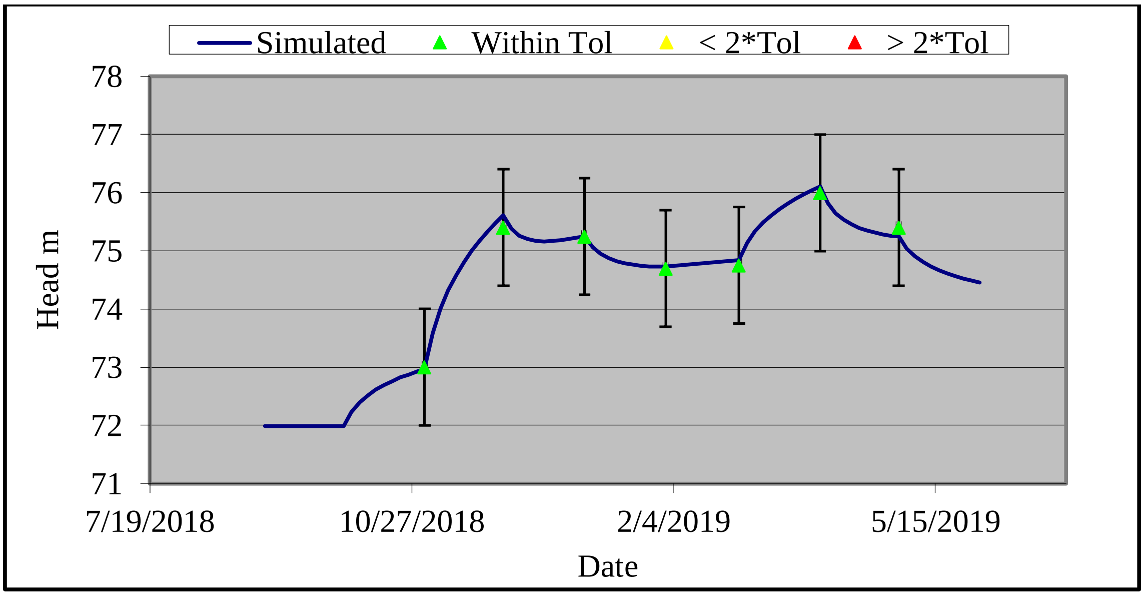

Figure 12. Measured and simulated heads in Turssaq Alluvial Fan, W24.

6. Results of Suggested Scenarios

Several scenarios were implemented to simulate and assessment of groundwater of the Turssaq alluvial fan to simulate the groundwater flow and testing all operation conditions of drilled wells, then defining the best distribution of drilled wells and the appropriate number of wells in the specific study area. To determine the best distribution of wells with the best operational conditions it is necessary to redistribute the wells and change the operating times then compares the results and determine the best scenario (**Jalut, Q. H., Abbas, N. L., and Mohammad, A. T., 2018)**. The scenarios that will be applied in the study area are the redistribution of the wells so that the separation distances between the wells are 500, 1000, and 1500*m*. The pumping times are 6, 12, and 18 *hr/day,* and the adopted productivity of the well is about 7 *l/s* for all cases. The recharge rate will be 0.000108 *m/day,* as calculated in the model. The results for the assumed scenarios and the comparison of the results are presented in **Table 9**.

Table 9. The Result of the Scenario Applied in Turssaq Alluvial Fan.

Scenario No.	1			2			3		
Separation distance, m	500			1000			1500		
No. of wells	911			233			107		
Time of operation *hours/day*	6	12	18	6	12	18	6	12	18
production of the well, m^3/day	150	300	450	150	300	450	150	300	450
Maximum drawdown *m*	50	pass	pass	13	24	40	7.5	12.2	17
The total volume of wells discharge, m^3/d	-	-	-	34250	69900	-	16050	32100	48150

From the results illustrated in **Table 9**, it can be noted that the drawdown of groundwater in the first scenario is very high, causing dryness of the cells in the model. So, the distance of 500*m* between the wells is unacceptable at any time conditions. When the distances between the wells are 1000 *m*, the average value of the drawdown water table is acceptable during the low and medium operating periods. In contrast, the drawdown of the water table increases during the operation period of 18 *hours*. When the separation distances between the wells are 1500*m* were used, the drawdown in the water table is acceptable with all operating conditions. So with the third scenario, the drawdown was low compared with other cases. Still, the total discharge at the maximum operation condition was less than the amount of wells discharge in the second scenario. The daily operating rate of the pumps will be variable as the running hours in winter are less than in the summer. Besides, operating hours in the urban area are less than in agricultural areas. The nature of the study area is agricultural land, and it is famous for the cultivation of wheat and barley, which are winter crops. Therefore, the average operating hours per year does not exceed 12 hours/day. However, a distance of 1000 *m* between the wells will be the best distance that can be adopted.

7.CONCLUSIONS

The main concluded of establishing a conceptual model for the Turssaq alluvial fan are to simulate groundwater movement and calculated the hydraulic properties of the aquifer with the best distribution method for wells and the best operating time as follows:

1- It was found that the study areas consist of four layers. First, the upper layer of the surface of the earth, which was a mixture of sediments of the modern era. The second layer was an impermeable layer that is formed of clay mixed with sand and gravel with a thickness of 15 m. The third layer consists of a mixture of sand and gravel, which is the main storage layer and is a confined aquifer. It has a thickness of 20 m, and the hydraulic conductivity is 18 m/d, and the transmissivity is 360 m^2/d. The last layer is impermeable, which is the formation of Al-Muqdadiyha.

2- The developed conceptual model for the study areas was well simulating the groundwater flow and gave accurate results compared with the field observations, at the same time, the calibration of the model was accomplished by matching the simulated water tables at the observation wells with the field measuring water tables of the observation wells

3- Several scenarios were tested to predict the best distribution of wells in the study area, as well as to define the best timing of the operation. It was found that the best distance between wells is 1500 m has an acceptable drawdown. But for providing adequate water to cover the high percentage of demand, the operation time of 12 hours a day with a separation distance of 1000 m was adopted. That was due to the unharmed water table caused and expectable drawdown results.

4- The distance between wells 500 m or less and the extensive operation of these wells, that actually use, is unacceptable under any operational time condition. And the operation of these wells simultaneously together will lead to a significant reduction in the groundwater table and inability to recover of the water table with an existent recharge.

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