A Two-Dimensional Numerical Model of Groundwater Flow in Safwan Al Zubair Area, South of Iraq

Ali H. Al Aboodi **Huda F. Munshid**

Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq

Abstract

A two-dimensional model was developed to simulate the unsteady state flow of groundwater in the upper part of Dibdibba sandy unconfined aquifer in Safwan-Zubair area, south of Iraq, in order to assess the hydraulic characteristics in this aquifer by the comparison of the observed head and calculated head, as well as the use of this model to predict the groundwater head in case of changing weather conditions**.** The suggested conceptual model, which is advocated to simulate the flow regime of aquifer, is fixed for one layer, i.e. the activity of the deeper aquifer is negligible. Seven cases were considered during sensitivity analysis**.** The results of sensitivity analysis showed that the increment of the initial values of hydraulic conductivity (K) and specific yield (Sy) more than 100% can lead to a noticeable increment in the level of groundwater. The unsteady state calibration results were evaluated by comparing the temporal variation in simulated heads with those of observed ones at thirteen observed wells. According to the calibration process, the hydraulic characteristics of the upper aquifer have been redistributed; the hydraulic conductivity in the study area was between (15-150) m/day, while the specific yield was between (0.125-0.45).

Keywords: Two-dimensional, Model, Groundwater, Flow, Modflow, Safwan Al Zubair

النموذج العددي ثنائي البعد لجريان المياه الجوفية في منطقة سفوان الزبير، جنوب العراق

الخلاصة

طور نموذج ثنائي البعد لمحاكاة الجريان الغير مستقر للمياه الجوفية للجزء الاعلى لحشرج الدبدبة الرملي الغير المحصور في منطقة سفوان الزبير ، جنوب العراق من اجل تقييم الخصائص الهيدروليكية لذلك الحشرج من خلال مقارنة المناسيب المقاسة مع المحسوبة، كذلك استخدام النموذج في التنبؤ بمنسوب المياه الجوفية في حالة تغير الظروف الجوية. النموذج المفاهيمي المقترح هو نمذجة الجريان للطبقة العليا فقط ، اي فعاليات الطبقات العميقة تم اهمالها. سبع حالات تم اخذها في تحليل حساسية النموذج حيث بينت النتائج بان زيادة قيم كل من الايصالية الهيدروليكية ومعامل العطاء النوعي ١٠٠% عن القيم الابتدائية تؤدي الى ارتفاع ملحوظ في المناسيب. قيمت نتائج المعايرة للحالة الغير مستقرة من خلال مقارنة التغير الزمني للمناسيب المحسوبة مع تلك المقاسة ولثلاثة عشر بئر مراقبة. من خلال عملية المعايرة اعيد توزيع الخصائص الهيدروليكية للحشرج الاعلى لمنطقة الدراسة حيث تبين ان الايصالية الهيدروليكية تتراوح بين (١٥-١٥٠) م/يوم ، بينما معامل العطاء النوعي يتراوح بين (٠,١٢٥-٠,٤٥).

Introduction

The use of groundwater has essential importance to meet the water demand of rapidly expanding urban, agricultural, and industrial, especially; at location zone where surface waters are scarce and seasonal such as the arid areas. Groundwater considers as about one-third of one percent of the total of water on earth, or nearly 20 times more than the surface waters on islands and continents. About 97% of the water resources in the world are confined in the sea without any practical value for people consumption, 75% of the remaining is the percent of the bound in ice sheets, glaciers etc. and just 25% is considered as percentage of available surface-water and groundwater. This percentage (25%) is distributed as 0.3% in rivers and lakes, and about 99.7% is available as groundwater [1].

The groundwater modeling is a management tool that can be used to obtain the necessary information about groundwater system. A model considers as valuable predictive tool that develop to represent a simplified version in case of properly constructed. The more complex and detailed model uses for obtaining an accurate represent of the real situation that is impossible to perfectly represent all natural processes practically [2]. Groundwater models can be classified into three broad categories: analog models (containing electrical models and viscous fluid models), sand tank models and mathematical models [3]. Mathematical modeling is an activated method can be applied in simulation techniques under different stress effects to forecast the natural head of the groundwater. The equations of mathematical models are simply exposed to specific assumptions in the aquifer, initial conditions and boundary to study the physical processes active. McDonald and Harbaugh (1984) introduced a three dimensional finite difference for the groundwater flow model by using FORTRAN 66 and adapted in some later versions titled MODFLOW computer code [4]. This code capacity to meet the requirements related to the simulation of appropriate boundary conditions therefore it can be utilized for several modelers and it was widely experienced and confirmed.

Three dimensional groundwater modeling of Firozabad plain (Iran) is presented by [5]. It is a mathematical representation of groundwater flow generated by (GMS) software using code MODFLOW (2000). The annual change in water table and forecast the fluctuations of the water table at an alluvial aquifer at Saudi Arabia is assessed by [6]. The methodology was performed by using numerical groundwater model (MODFLOW). The model had been predicted the elevations of water table after model calibration as a result of pumping in next 5 years. The results of this model were concluded that there was agreement compared with the earlier records.

A finite difference two dimensional model is presented in this study for simulating the groundwater flow for the upper aquifer in Safwan-Al Zubair area, in order to assess the hydraulic characteristics in this aquifer through the comparison between the observed head and calculated head, as well as the use of this model to predict the groundwater head in the event of changing weather conditions. Processing MODFLOW for windows is selected to simulate the groundwater flow in Safwan Al Zubair area, Basrah province, south of Iraq. This area is located in the south-west part of Basrah province. It lies between longitude line [47°30'– 47°55'] and latitude line [30°03'– 30°25'] and considered area is about 1400 km^2. The study area is considered as a part of the Dibdibba plain. Dibdibba formation consist of sand – gravel soil with rising the level of ground surface toward the west and southwestern, as shown in figure (1).

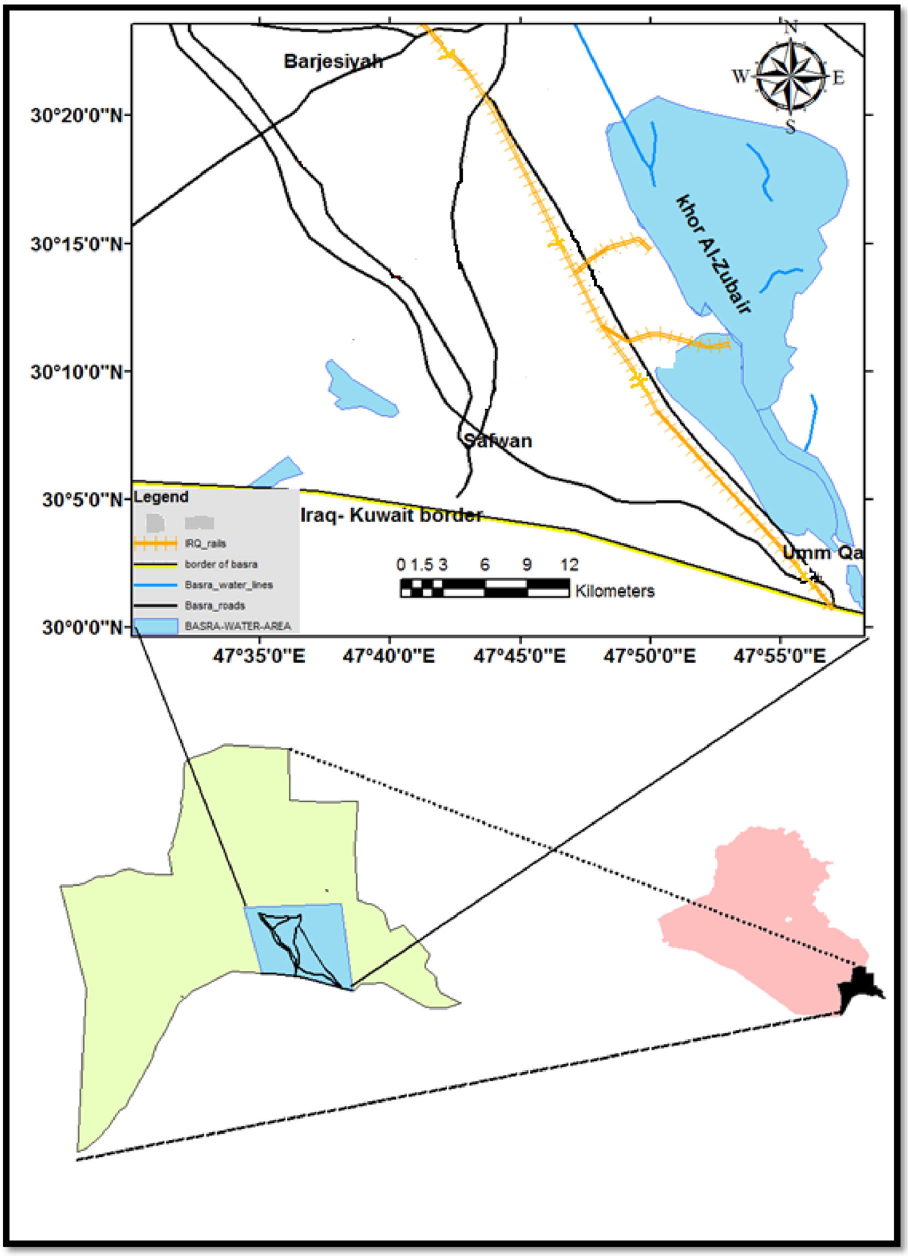

Figure (1) Location of study area in reference to map of Iraq.

Model structure

The partial differential equation of two dimensional groundwater flow used in MODFLOW for unsteady state is [4]

$$\frac{\partial}{\partial x}\left[kxx\,\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[kyy\,\frac{\partial h}{\partial y}\right]-w=Ss\,\frac{\partial h}{\partial t} \qquad (1)$$

Where:

kxx, kyy :- values of hydraulic conductivity along x and y coordinate axes (L/T)

h: potentiometric head (L)

w: volumetric flux per unit volume representing sources and/ or sinks of water, with w<0.0 for flow out of the groundwater system, and w>0.0 for flow in (T^{-1}).

Ss: specific storage of the porous material (L^{-1}).

t: Time (T).

Analytical solutions of equation (1) are possible for very simple systems, so various numerical methods must be employed to obtain approximate solutions for complex systems. One of such approach is the finite-difference method in which the groundwater flow system is divided into a grid of cells. For each cell, there is a single point called a node, at which head is simulated. The process leads to systems of simultaneous linear algebraic difference equations; their solution yields of head at specific points.

Geological properties of the study area

Dibdibba Formation (Upper Miocene-Pliocene age) extends over a large area in the south of Iraq, and also it is found in some parts in the middle of Iraq. Dibdibba Formation has a simple slope in the south of Iraq toward the north-eastern side of Dibdibba plain. The sediments of Dibdibba Formation gradually changes from marine sediments into river sediments which are generally increased in the quantity and sizes of granules from oldest into recent. It consists mainly from sand and gravel with some cementing materials like silt and clay, especially in the west of Al-Zubair area [7].

Model grid and boundary conditions

The present model consists of 80 columns and 80rows. Where, the area of one cell is equal to ($2500m^2$). Figure (2) shows the model grid of the study area with the applied boundary conditions. In the present model, the northern, southern west and southern edges of the area almost parallel with the flow lines, therefore; these boundaries are represented as no flow boundaries [8]. The eastern edge of the model area is considered as a constant head boundary because the canal of Shatt Al-Basrah River lies along this edge. The western boundary is modeled as head-dependent boundary to allow inflow to the modeled region at a rate proportional to the dead difference between the aquifer outside the simulated area and the model boundary. The top of the model was represented as unconfined aquifer. The water table elevation changes as part of the model solution. The bottom of the model was represented as a no-flow condition. The vertical location of this boundary was selected to correspond with the base of the aquifer (the hard clay layer) (see figure 3)

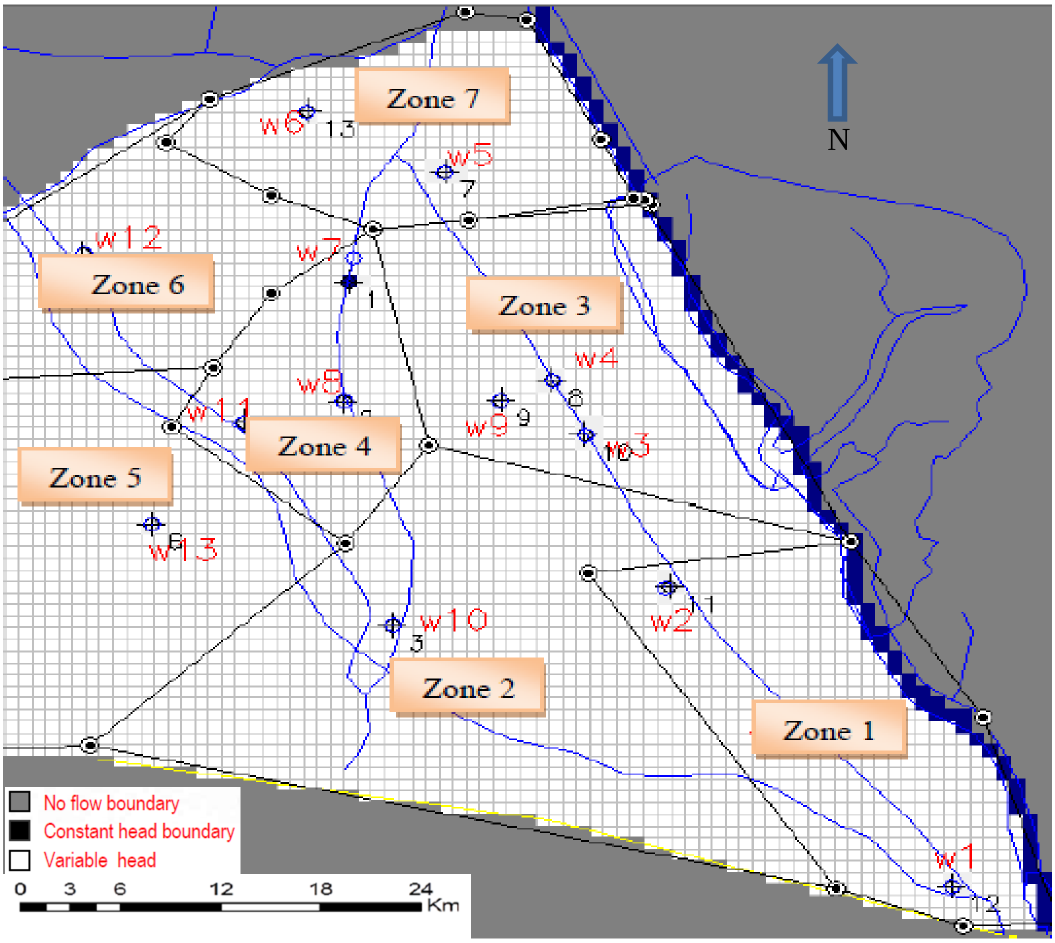

Figure (2) Configuration of model network and boundary conditions.

Input Data

Input data may be introduced into the following classes:

1. Hydraulic conductivity and specific yield

Two parameters must be supplied in the modeling of groundwater for unconfined aquifer, hydraulic conductivity (k) and specific yield (S_y).

Dibdibba Formation has maximum thickness in most northern wells of Zubair oil fields up to 350m and decreases gradually toward the south and west of Iraq [8]. The upper part of Dibdibba formation was divided into two hydrogeological units. The first one is unconfined aquifer (Quatemary in age) which contains brackish water, and its saturated thickness extended from (15 m) to (20 m) [9]. The second aquifer is semi-confined (Tertiary) which contains saline water and it is separating from the first one by hard clay bed called locally (Jojeb) [9]. Hard clayey lenses are often disposed throughout the body of aquifer in both saturated and unsaturated parts, as shown in figure (3). The spatial distribution of hydraulic characteristics over the model area is concluded depending on the numerical solution technique results which applied by Atiaa [10]. (see Table 1 and figure 2).

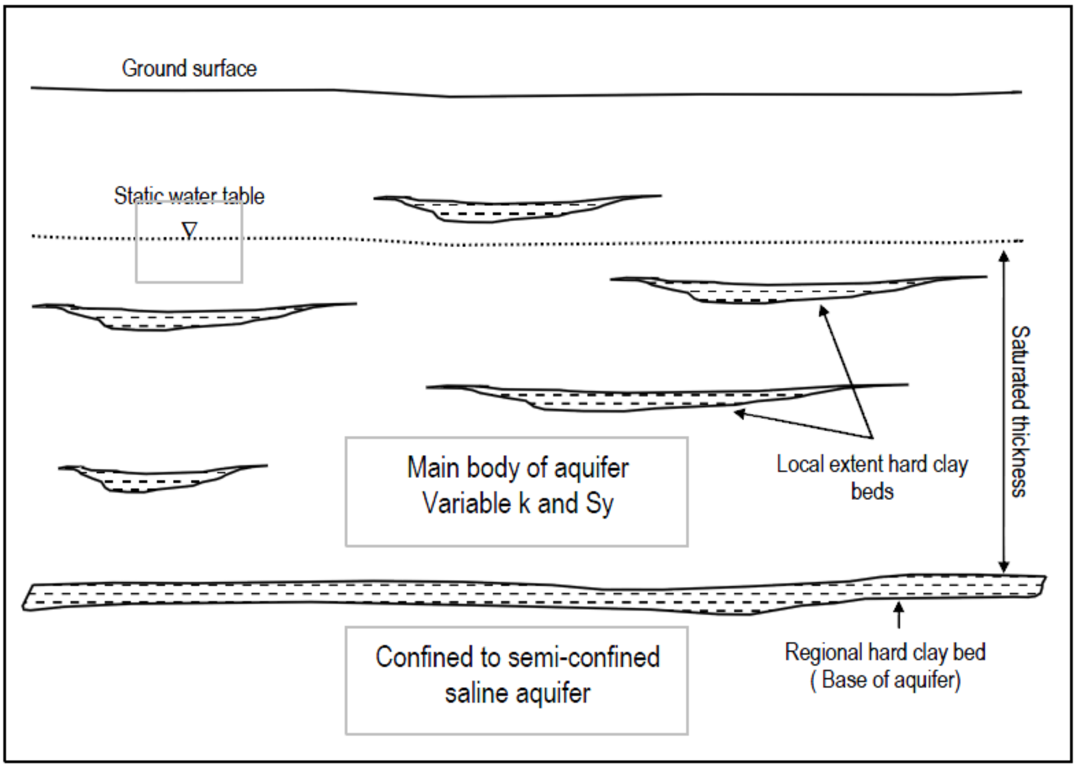

Figure (3) A prototype of upper unconfined Dibdibba aquifer in Safwan-Zubair area [11]

Table (1) Initial hydraulic conductivity and specific yield values according to the zones distribution [10]

Zone No.	1	2	3	4	5	6	7
K (m/day)	15	20	145	22	150	24	45
Sy	0.45	0.35	0.40	0.33	0.30	0.38	0.12

2. Distribution of wells and pumping rate

Most irrigation wells of Safwan-Zubair area penetrate the quadral sediments and then Dibdibba Formation. Large diameter hand dug wells are commonly used for abstract groundwater compared with tube wells due to (1) shallow depths of water table (2) high well capacity (3) and the seepage area they are provided. Hand dug wells are conducted randomly with non-uniform shapes. Operating wells are located at various spaces from each other, ranging from (500 to less 100 m).

Therefore, interfering among adjacent wells is possible under the existing pumping activities. The locations of these wells were obtained from Wateriness Resources Directorate/ Groundwater Branch in Zubair city for the year 2014. Pumping rates of wells are variable and may range from (5 to 8 l/s). The average of pumping rate is taken as (7 l/s).

Under consideration of the agricultural season there are three main pumping periods in the study area as follows:-

1. Normal pumping periods have been almost in November up to May, they attain about twelve hours per day.
2. Extensive pumping periods are during the months of August, September and October, they attain about twenty hours per day.
3. Relaxation periods are an approximately the two months June and July, where irrigation activities are stopped.

The soil of study area does not possess water except for a very short time, percentage of irrigation water that returns to the groundwater system is estimated to be (84%) [8]. Propagation of the trickle irrigation system usage decreases this quantity because this system leads water to be evapotranspired instead of percolated into the groundwater system. The uses of this irrigation method increased considerably with time because it is easily constructed and economical in irrigation water amounts. In the present study, the percentage used to represent the percolated quantities of water that return back to groundwater from irrigation water is assumed equal to 70% and only 30% of water is consumed.

3. Direct recharge

Several field studies on the amount of the irrigation water that might possibly percolate downward to the groundwater. The percentage of this amount was found to be more than (80%) [11]. There are no significant valleys that collect water in the study area with the exception of Al-Battin valley. These valleys are small and short, that is why one can accept that the surface runoff may be of little amount. Owing to the nature of the soil under study, it is believed that such soil does not remain wet for a long period, as water either percolates to the groundwater or evaporates to the atmosphere. For this reason, the saturation factor is neglected when calculating the components of water budget. From what has been mentioned above, it is assumed that the percentage of the direct recharge from rainfall is equal to (20%) [8].

4. Initial condition and Historical water table elevations

Thirteen monitoring wells were selected for measuring the groundwater levels on monthly basis for one year (November/2013 to October/2014) [12]. The locations of these wells are shown in figure (4). The static groundwater level of the wells is interpolated within the model to obtain the initial hydraulic heads for the entire model. MODFLOW requires initial hydraulic heads at the beginning of a flow simulation. Initial hydraulic heads at fixed-head cells will be kept constant during the flow simulation. For transient flow simulations, the initial heads must be the actual values. For steady-state flow simulations, the initial heads are starting guessed values for the iterative equation solvers. The heads at the fixed-head cells must be the actual values while all other initial heads can be set arbitrarily. Thirteen observation wells represent historical groundwater elevations distributed in the study area. These data were introduced for the period (November/2013-October /2014).

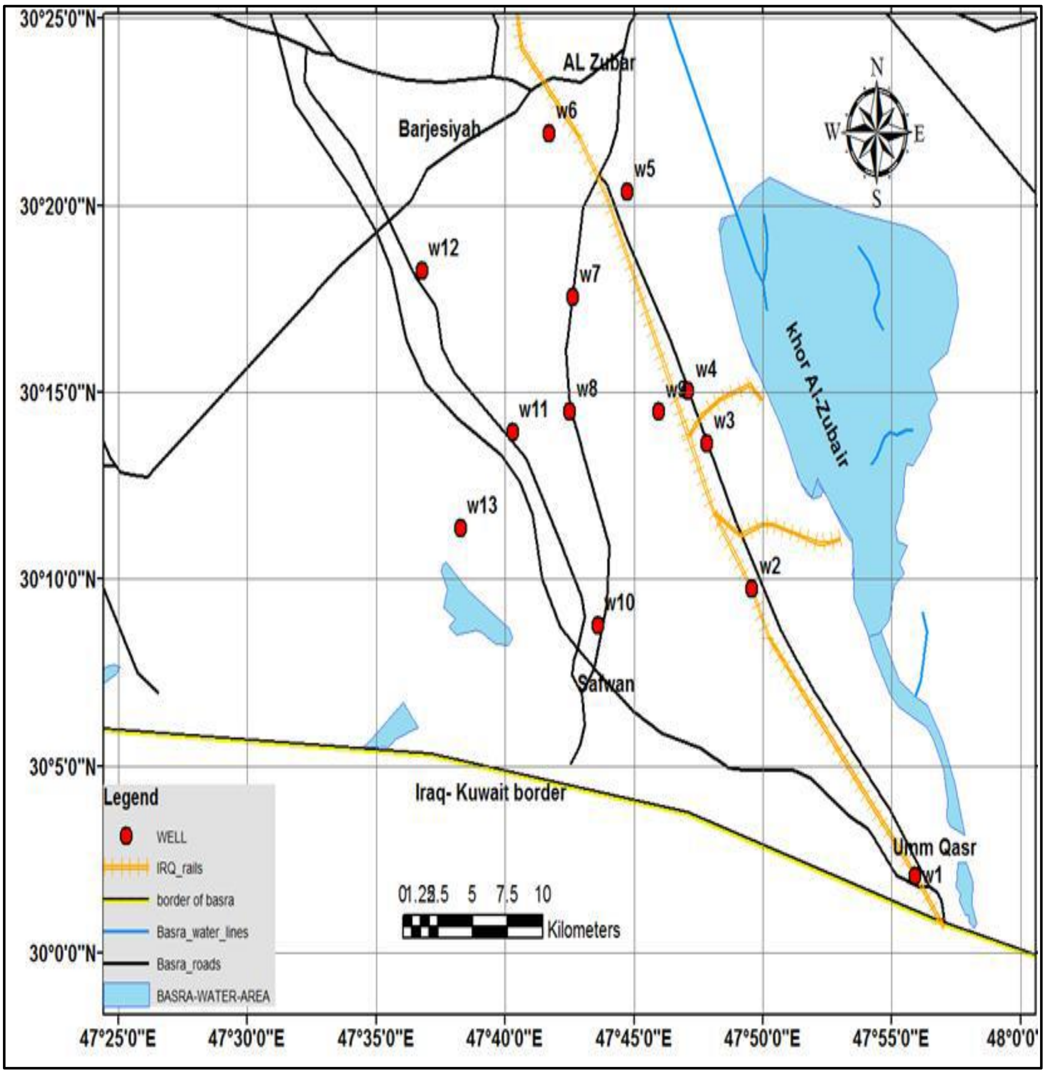

Figure (4) Location of monitoring wells in study area

Calibration

Calibration was conducted through trial and error by varying aquifer hydraulic parameters and comparing calculated heads with those measured heads in wells. A trial and error method can be used to iteratively adjust model parameters until the model computed values match the field observed values to an acceptable level of agreement. In the present model, a trial and error procedure was used to calibrate the model. Input parameters, such as hydraulic conductivity and specific yield, were suitable to adjust after each simulation run until a good match was obtained between simulated and observed heads. In the present model, root mean squared error (RMSE) and mean absolute error (MAE) were used as evaluation criteria.

$$RMSE = \left(\frac{\sum_{j=1}^{n}(Y_j - \hat{Y}_j)^2}{n}\right)^{\frac{1}{2}} \quad (2)$$

$$MAE = \frac{\sum_{j=1}^{n}|Y_j - \hat{Y}_j|}{n} \quad (3)$$

Where:

Y and $\hat{Y}$: the observed and estimated values respectively,

n : the number of observations,

$\bar{Y}$and $\bar{\hat{Y}}$: mean of observed and estimated values respectively.

Sensitivity Analysis

The main objective of the sensitivity analysis is to understand the influence of various model parameters and hydrogeological stresses on the aquifer system and to identify the most sensitive parameter(s) which will need a spatial attention in the feature studies. Sensitivity analysis was performed by systematically changing the calibrated value conditions [2]. The most sensitive parameters will be the most important parameters for matching the model result with the observed values. Seven cases were considered during sensitivity analysis as shown in Table (2). For example during case No.4, k values equal to the initial values, while, S_y values equal 125% of initial values. The results of sensitivity analysis are showed for each case and for the thirteen considered wells in Figure (5). This figure demonstrate that increment the initial values of k and S_y more than 100% can lead to noticeable increment in the level of groundwater.

Table (2) Cases of sensitivity analysis

Case No.	K	Sy
1	Initial values	Initial values
2	1.25×Initial values	Initial values
3	1.50×Initial values	Initial values
4	Initial values	1.25×Initialvalues
5	Initial values	1.50×Initialvalues
6	2.0×Initial values	2×Initial values
7	3.0×Initial values	3.0×Initial values

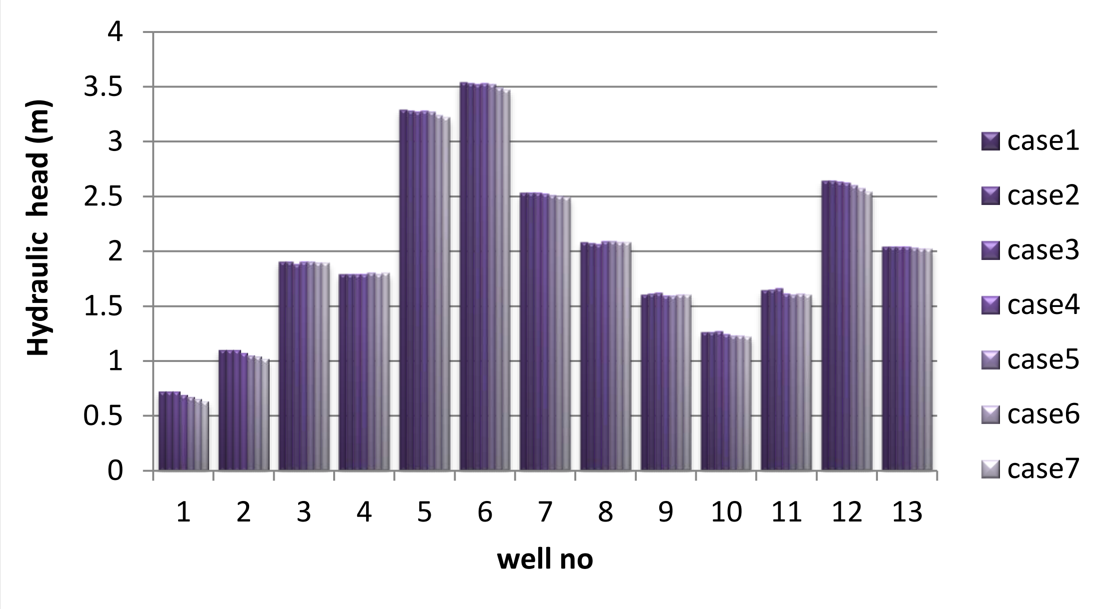

Figure (5) Sensitivity analysis of unsteady state flow

Results and Discussion

The unsteady state calibration results were evaluated by comparing the temporal variation in simulated heads with those of observed ones at thirteen observed wells. In the process of unsteady state calibration, hydraulic conductivity and specific yield values were modified on a trial and errors basis, until a good match between the observed heads and the calculated heads. Figures (6) and (7) show the final distribution of calibrated hydraulic conductivity and specific yield respectively. It can be shown that the calibrated values of hydraulic conductivity vary over the range (15-150) m/day, while, the calibrated values of specific yield vary over the range (0.125-0.45). Figures (8) to (20) show comparisons of calculated and observed hydraulic heads for thirteen wells in the study area. From these figures, it was found that the reasonable match between the simulated and measured data for every month of the same well. Two statistical parameters are used as evaluation criteria. Table (3) shows the values of root mean squared error (RMSE) and mean absolute error (MAE). It can be shown that the maximum and minimum values of root mean squared error (RMSE) are 0.349 and 0.003 for well No.3 and well No.12, respectively and the maximum and minimum values of mean absolute error (MAE) are 0.313 and 0.035 for well No.3 and well No.5, respectively.

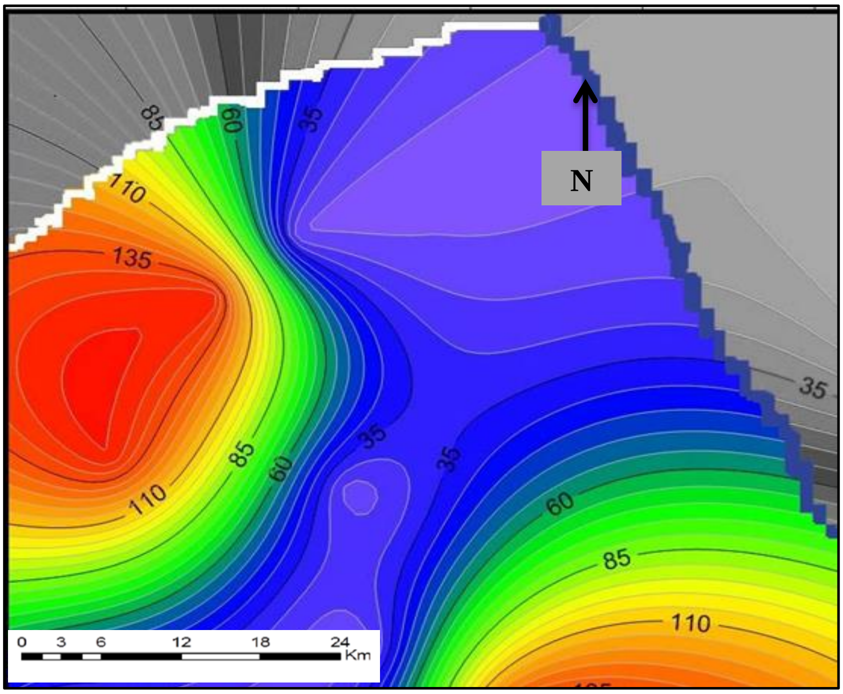

Figure (6) Distribution of calibrated values of hydraulic conductivity (m/day)

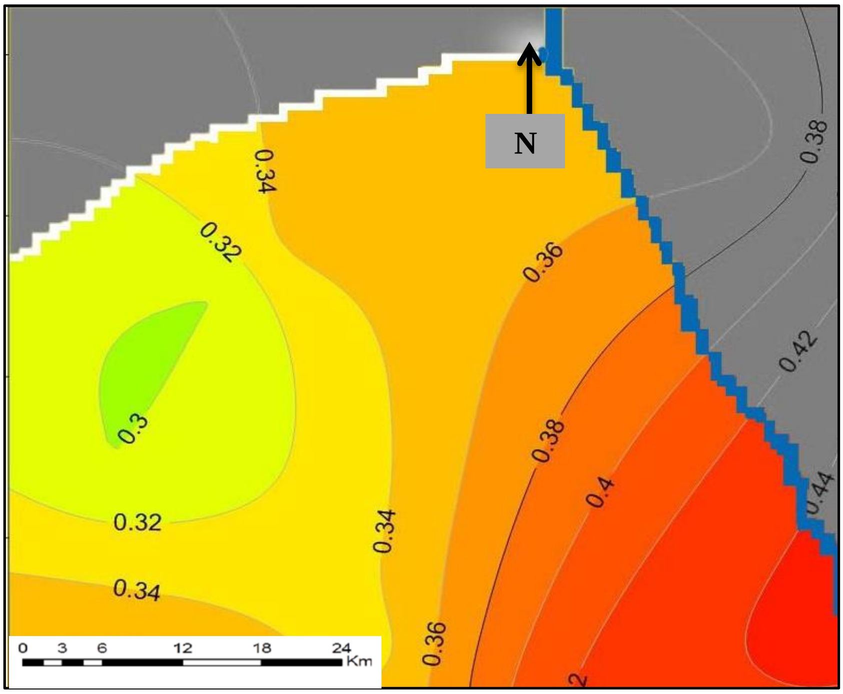

Figure (7) Distribution of calibrated specific yield values

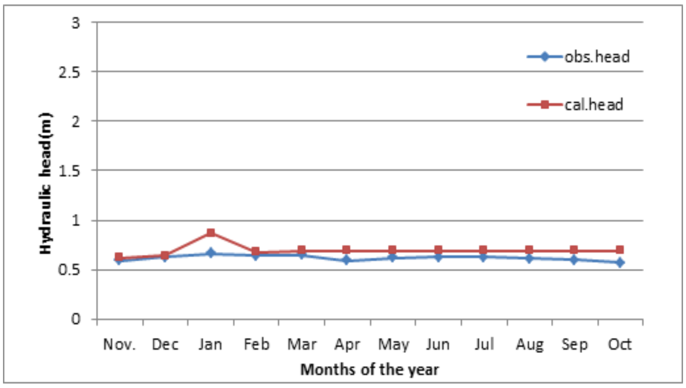

Figure (8) Comparison of observed and simulated heads for well No.1

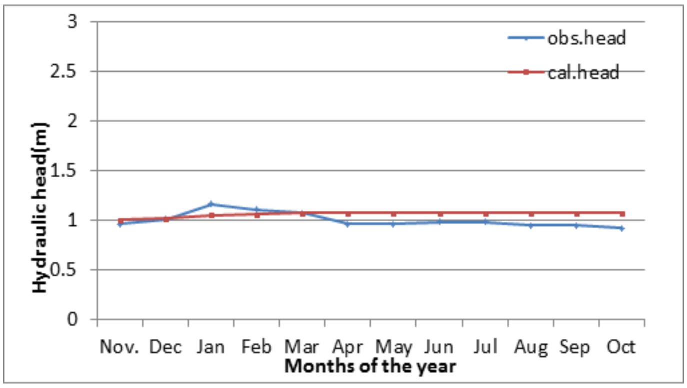

Figure (9) Comparison of observed and simulated heads for well No.2

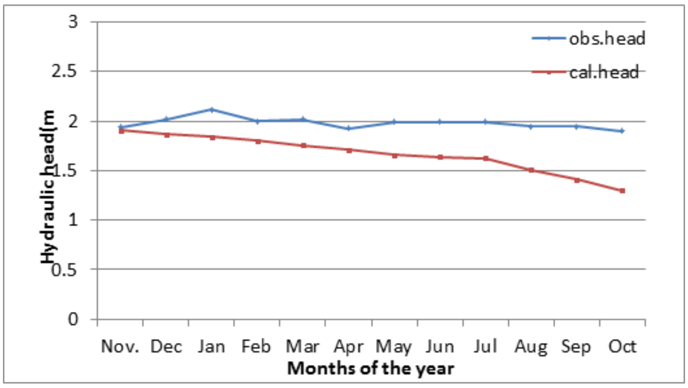

Figure (10) Comparison of observed and simulated heads for well No.3

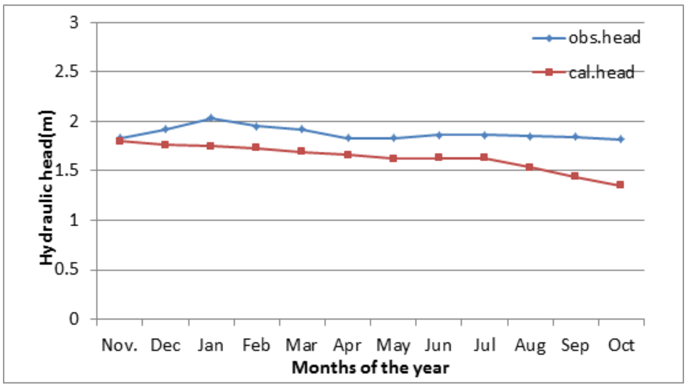

Figure (11) Comparison of observed and simulated heads for well No.4

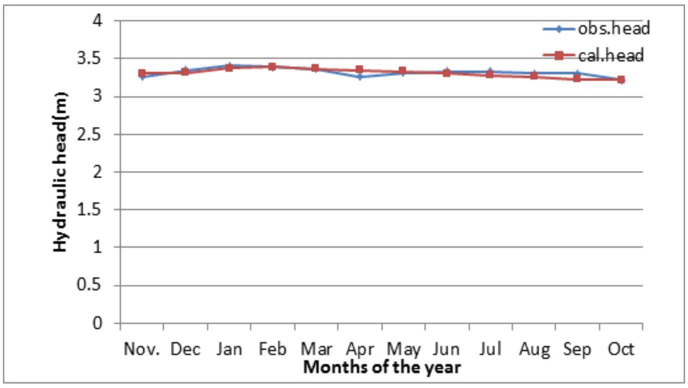

Figure (12) Comparison of observed and simulated heads for well No.5

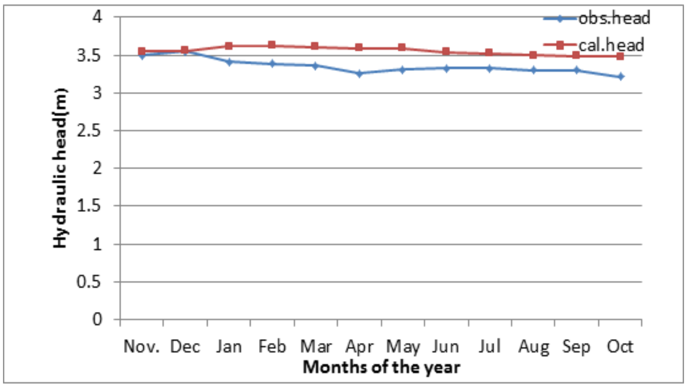

Figure (13) Comparison of observed and simulated heads for well No.6

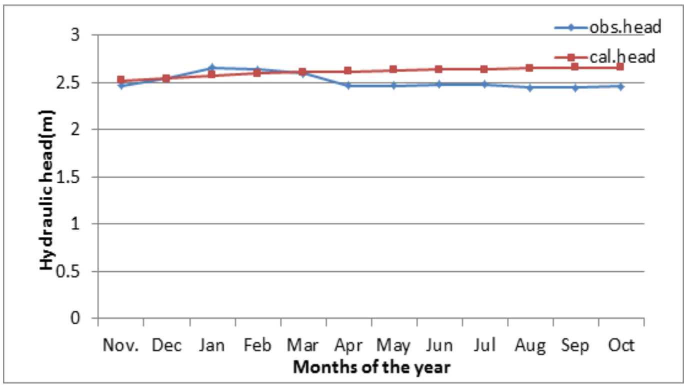

Figure (14) Comparison of observed and simulated heads for well No.7

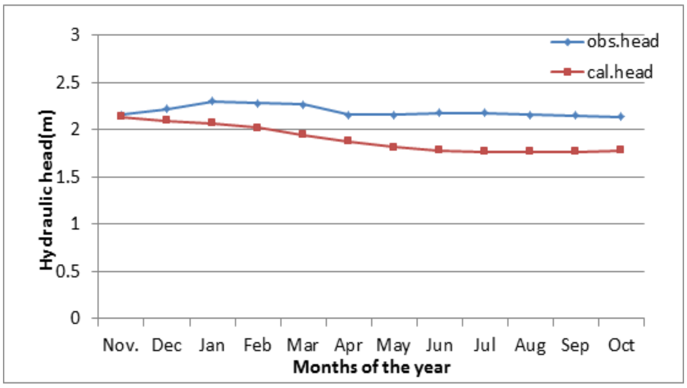

Figure (15) Comparison of observed and simulated heads for well No.8

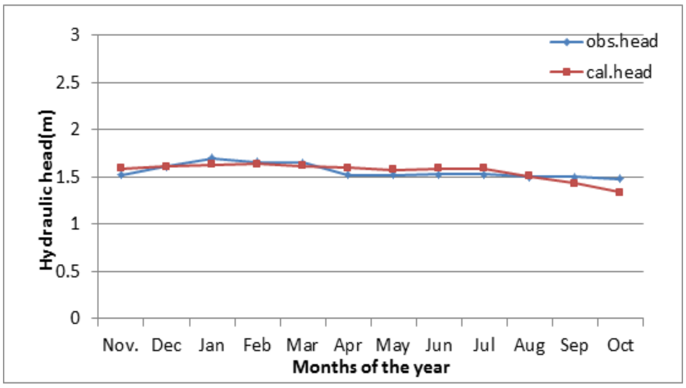

Figure (16) Comparison of observed and simulated heads for well No.9

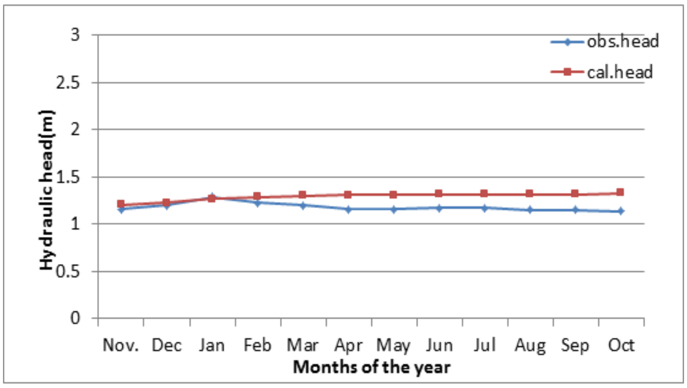

Figure (17) Comparison of observed and simulated heads for well No.10

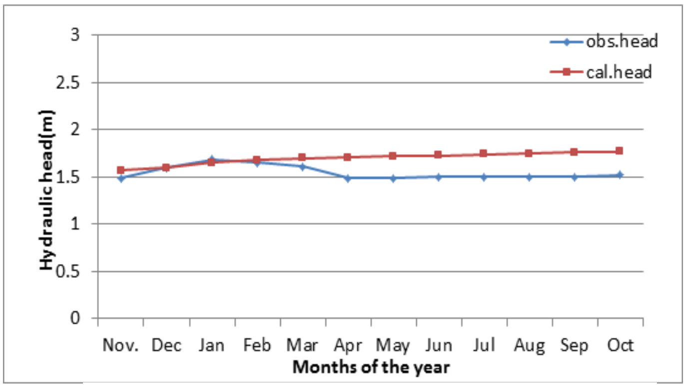

Figure (18) Comparison of observed and simulated heads for well No.11

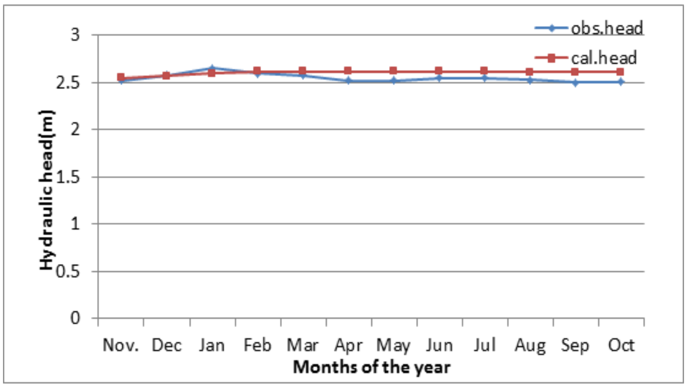

Figure (19) Comparison of observed and simulated heads for well No.12

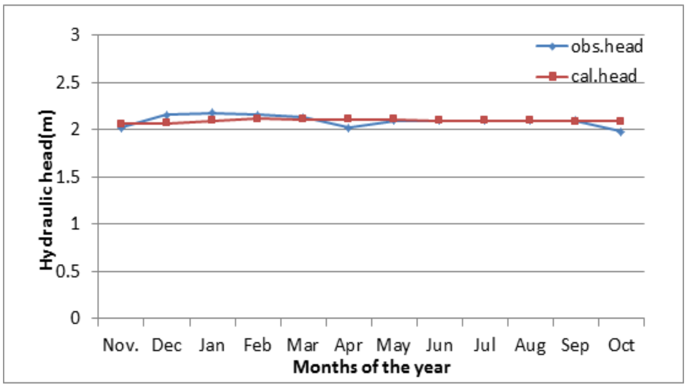

Figure (20) Comparison of observed and simulated heads for well No.13

Table (3) Values of root mean squared error (RMSE), mean absolute error (MAE)

well No.	RMSE	MAE
1	0.091	0.076
2	0.095	0.083
3	0.349	0.313
4	0.269	0.246
5	0.044	0.035
6	0.219	0.202
7	0.140	0.118
8	0.314	0.293
9	0.066	0.056
10	0.130	0.116
11	0.187	0.16
12	0.003	0.065
13	0.057	0.041

Conclusions

A two-dimensional mathematical model is developed for simulating groundwater flow for upper unconfined aquifer in Safwan-Zubair area, south of Iraq, the suggested conceptual model, which is advocated to simulate the flow regime of aquifer, is fixed for one layer, i.e. the activity of the deeper aquifer is negligible. The percentage used to represent the percolated quantities of water that return back to groundwater from irrigation water is assumed equal to 70% and only 30% of water is consumed. Also, the percentage of the direct recharge from rainfall is equal to (20%). The results of sensitivity analysis are showed that increment for initial values of k and Sy more than 100% can lead to noticeable increment in the level of groundwater. The model is calibrated using trial and error procedure for unsteady state flow. According to the calibration process, the hydraulic characteristics of the upper aquifer has been identified, the hydraulic conductivity in the study area ranged (15-150) m/day, while the specific yield ranges between (0.125-0.45).

References

1. Gleick, P.H., 2000. The world's water 2000-2001, the biennial report on freshwater resources. Washington, DC, Island press.
2. Anderson M.P. and Woessner, W.W., 1992. Applied groundwater modeling: simulation of Flow and advective transport. Academic Press. San Diego, 381pp.
3. Wang, H.F, and Anderson, M.P., 1982, Introduction to groundwater modeling, finite difference and finite element methods, New York, 237p.
4. McDonald, M.G.,and Harbaugh, A.W., 1988, MODFLOW,A modular three-dimensional finite difference groundwater flow model , U.S.Geological Survey, Open-file report 83-875, chapter A1
5. S. Askari Marnani, M. Chitsazan, Y. Mirzaei and B. Jahandideh, 2010, Groundwater Resources Management in Various Scenarios Using Numerical Model, American Journal of Geoscience 1 (1): 21-26.
6. Saleh A. Al-Hassoun and Thamer Ahmed Mohammad, 2011, Prediction of Water Table in an Alluvial Aquifer Using Modflow, Pertanika J. Sci. & Technol. 19 (1): 45 – 55.
7. MacFadyen, W. A., 1983, Water Supplies in Iraq. Ministry of Economics and Communications, Iraq Geological Department, Government of Iraq, Baghdad Printing Press, 428p.
8. Al-Aboodi, A. H., 2003. "A Study on Groundwater Characteristics in Safwan-Zubair Area", M.Sc. thesis, College of Engineering, University of Basrah, 104 pp.
9. Al-Kubaisi, Q. Y., 1999. "Quaternary-Tertiary Hydrogeologic Boundary Condition at Safwan-Zubair Area, South of Iraq" , Iraq Jour. Scie., Vol.40, No.3, pp. 21-28.
10. Atia, A.M., 2000, "Hydrogeology of Safwan-Zubair area, South of Iraq", Unpub. M.Sc., Thesis, College of Science, Univ. of Basrah, 90pp,.
11. Atiaa, A. M., and Al-Aboodi, A. H., 2006," Simulation of Flow Regime of Dibdibba Dandy Aquifer in Safwan-Zubair Area, South of Iraq", Iraqi Journal of Science, Vol.47, No.1, PP. 119-137,
12. Ali S. Al-Aidani, 2015. Prediction of groundwater level in safwan-zubair area using artificial neural networks, M.Sc. thesis, College of Engineering, University of Basrah, 110 pp.