Mesopot. J. Mar. Sci., 2019, 34(1): 85 - 97

Numerical simulation model of water-logging phenomenon at Al Jahza camp Al-Zubair town, Southern Iraq

L.S. Al-Qurnawy[1]* and A.M.A. Al-Abadi[2]
[1]Marine Science Centre, [2]College of Science University of Basrah, Basrah - Iraq
**e-mail: lms.salim@yahoo.com*

(Received: 6 December 2018 - Accepted: 25 June 2019)

Abstract - The current study is focused on the groundwater modeling with three scenarios as future plans to find a suitable solution for the problem at Al-Jahza Camp south east of Al-Zubair town, south of Iraq. The objective of the study is find out a numerical model for simulating the behavior of the groundwater flow using (MODFLOW) software. The model was calibrated in the steady and transient states for four randomly distributed monitored wells in the study area with 21 stress periods. Suitable match was obtained from the comparison between the levels of the observed and calculated heads. The model was simulated to control the water-logging. The water level of the simulated head remains extremely constant in condition of constructing the underground barrier. By Supposing of digging wells and increasing the water pumping with an average of 432 and 216 m/day, the head level at exceeding extraction with constructed subsurface barrier decreased more than the head level in case of increasing the water pumping with no subsurface barrier to reach 35-40 cm and 45-50 cm respectively, and to enhance the benefit to control and decrease the water from waterlogged area in the future.

Keywords: subsurface barrier, MODFLOW software, simulation, hydraulic parameters.

Introduction

Throughout the last years, water-logging problem has been a potential crises at Al-Jahza Camp which calls for urgent intervention measures to help in facing an environmental, health and social dilemma. The groundwater seeping from the high neighboring south west lands in addition to the accumulation of local waste water due to the deterioration of the drainage infrastructure (old sewer pipes and insufficient sewage disposal maintenance) being the main reasons. A few local residents who can afford to move away already left their sewage-water-logging houses empty. The less privileged who stayed behind still have two endure daily suffering in living conditions on many levels such as disease, bad odours, damp and loss of house ware. As a temporary rather basic rescue solution was a dumping process aiming at raising floor levels of their houses which is limited by the height of the ceiling. Each house has an average of three electric water pumps connected to narrow rubber tubes abstract water from house sinkhole which then collected at the main manhole called "collector" and waiting scheduled pumping by responsible governmental agencies. This is further exacerbated in rainy days in winter season with increasing levels of water and chronic dysfunction of the national electricity network making water-logging in the area a critical situation. The subsurface barrier is designed to be established beneath the surface of the earth to cut off flow of ground water (Ishida *et al.*, 2011).

So, the numerical simulation model of constructing subsurface barrier could be responsible for controlling the water-logging and rescuing the people from an environmental catastrophe.

The term of Water-logging includes the percolation of water that presents in a place near depression, Seepage from irrigation channels, and the presence of impermeable layer beneath soil that leads to raise the groundwater level. From those reasons the water-logging phenomenon leads to high groundwater level that mixes with sewage water, absence of drainage system that reduces water logging, and the assemblage of frequent rainfall in the region (Marghani, 2002).

The Study Area:

Al-Jahza is a small Camp situated within the study area in the south eastern part of Al-Zubair town, southern Iraq (Fig. 1). The area is approximately 462 Km² by measurements of GIS. All the study area covers 1,212 Km² at a latitudes of 30°05' - 30°25' and a longitudes of 47°30'-47°55' and represents the eastern part of the western desert of Iraq. The elevation of the study area is between 0-149 m above the sea level (Fig. 2).

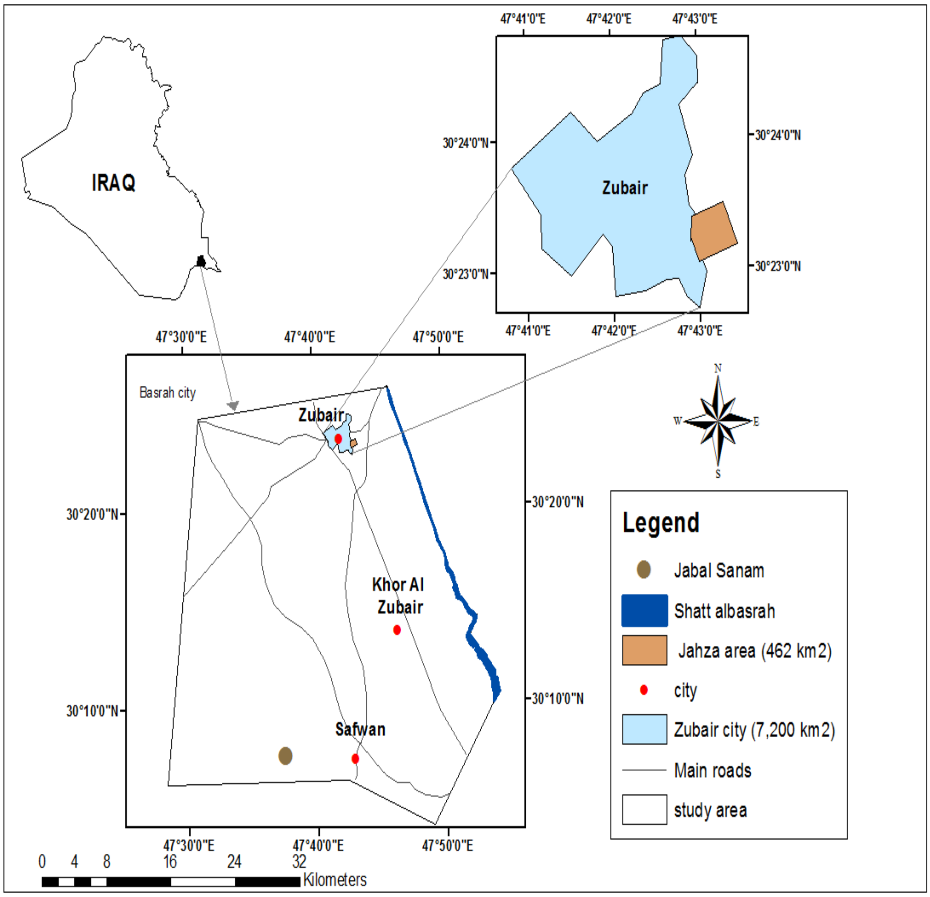

Figure 1. Location map of the study area.

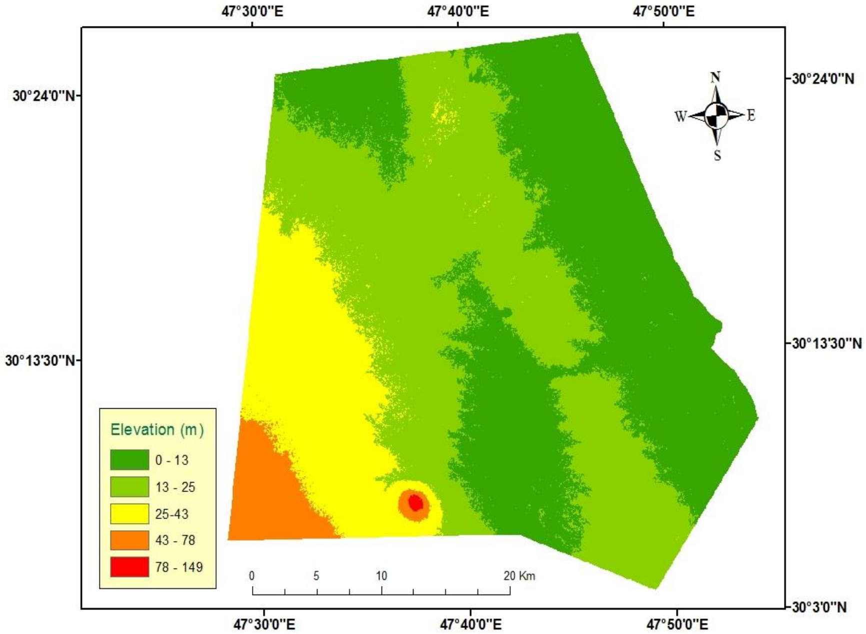

Figure 2. Elevations of the study area.

For the geologic situation, the sediments consist mainly of sand and gravels in addition to the clayey beds (Al-Kubaisi, 1996 and Shalib, 2000). A small part of Al-Batin alluvial fan covers approximately three quarters of the study area, in spite of the fact that tidal flat deposits (which are close to Shatt Al-Basrah) and the estuarine Sabkha spread in the eastern and north eastern parts, respectively. The flood plain deposits and the inland Sabkha cover the north part of the study area (Sissakian *et al.,* 2014). As for the geomorphologic setting, the area concerned extends over a flat plain that increases in its height to the west and south west. The southern and western parts of the region include land forms of sand dunes which reflect the desert environment (Al-Kubaisi, 1996). Some shallow valleys distributed unevenly through the study area. Jabal Sanam is another feature, a type of salt plug, with semi-oval shape that has its long axis trends in a N.W.-S.E direction (Al-Muttory, 2002). The Stratigraphic succession involves a great geological formations comprising the area concerned begins with the oldest namely: Fatha (Lower Fars), Dibdibba, and Quaternary. The Fatha Formation consists of anhydrite, gypsum, salts, inter bedded with limestone and marl, and shallow water limestone (Jassim and Goeff, 2006) and the formation deposited in the Middle Miocene (Al-Naqib, 1967). The Dibdibba Formation comprises mainly of gravelly and sandy granules of igneous origin such as quartz and granite in addition to a clayey beds deposit in a Deltaic environment. The rate of the formation thickness reaches to more than 350 meter and it is almost free of fossils. The age of the Dibdibba formation ranges from the Pliocene at the top and the Upper Miocene at the bottom basing on its location between terrace gravels above and Lower Fars below (Buday, 1980). The sediments of Quaternary are mainly exposed in the study area.

The thickness of these sediments reaches to more than 250 m in the Mesopotamian plain (Jassim and Goeff, 2006). They are comprised of sands and gravels that are transported from the Dibdibba Formation and partially covers the Dibdibba Formation by unconformity surface.

The hydrogeologic conditions at Al-Zubair-Safwan area represent mainly a shallow part of the Dibdibba aquifer which consists of two aquifers, the upper unconfined, and the lower semi-confined which exists in the deeper layer (Al-Jawad *et al.,* 1989).

The upper unconfined aquifer comprises of sandstones and gravels and it's saturated thickness reaches 10-20 m (Hassan *et al.,* 1987; Al-Jawad *et al.,* 1989; Al-Kubaisi, 1996 and Shalib, 2000). Some clay lenses are spread throughout the saturated and unsaturated parts. A hard clay bed of aquitard layer at the southern and western parts of the study area with a thickness of 2 to 4 m which represents a semi hydraulic connection between the aquifers and reduces in thickness towards the eastern and northeastern parts which explained the high mixing ratio between the brackish and saline waters in the two aquifers (Al-Kubaisi, 1999 and Atia, 2000).

Typically, the hydraulic properties were detected by pumping test analysis at the Dibdibba. It scored high values of transmisivity and hydraulic conductivity in the western and south-western parts which represents Safwan and Jabal Sanam owing to the proximity to recharge area, while the north and north-eastern parts of the study area had decreasing values because of the discharge of the ground water (Al-Manssory, 2000).

Materials and Methods

The "MODFLOW "numerical model is one of the superior computer programs applied to the groundwater modeling. It was developed by the USGS for simulating the groundwater flow in aquifers through porous media. Numerical modeling is important not only for management of ground water and understanding the behavior of aquifer but also for influential hydrological stresses produced by natural conditions and human activities.

Modeling provides arrangement of data as a framework, and prediction of hydrological stresses (Senthilkumar and Elango, 2011). The operative files can serve simulation process relying on data type.

This process assumes three principal steps namely input operation, calculating program, and output operation. Aquifers of groundwaters that have some of heterogeneity and anisotropic properties use a three dimensional modeling as indicative concept of simulated a steady state models, while developing yield, usages of pumping types in addition, the discharge and recharge areas all together were considered prediction results of percolation effect on the water level growth in aquifers at transient conditions (Qadir *et al.,* 2016).

A Graphical user interface (GUI) is necessary to prepare the data files for running the code and letting analyzing results and prediction of model (Kumar, 2015).

Processing MODFLOW for windows (PMWIN) version 5.1 is a selected numerical code (Chiang and Kinzelbach, 2006), which numerically approximates the governing equations (Fetter, 2001):

$$Q = - KIA \qquad (1)$$

Where; Q is the flow rate through the aquifer, K is the hydraulic conductivity (L/T), A is the surface area(L^2), I is the hydraulic gradient, The Flow net is from the recharge to the discharge area that represents from west and south west to the east and north east, respectively, depending on the hydraulic gradients which equals to 0.000015 (Atiaa and Al-Aboodi, 2006).

A general groundwater flow equation can be written in Cartesian form as:

$$\nabla^2 h = \frac{S}{T} * \frac{\partial h}{\partial t} \qquad (2)$$

Where delta is the alteration of the hydraulic head along x, y, and z coordinates, h is the potentiometric head (L), S is the specific storage of the porous material (L^1), T is the transmissivity (L^2/T), and t is the time (T).

The data were taken from the previous studies (Atia, 2000; Atiaa and Al-aboodi, 2006) and the Digital Elevation model (DEM) for modeling included some available important data of four observation wells (Fig. 3), hydraulic head, hydraulic conductivity, specific yield, recharge and discharge rates wells that had been calibrated for 9 months and one water year before construction of underground barrier.

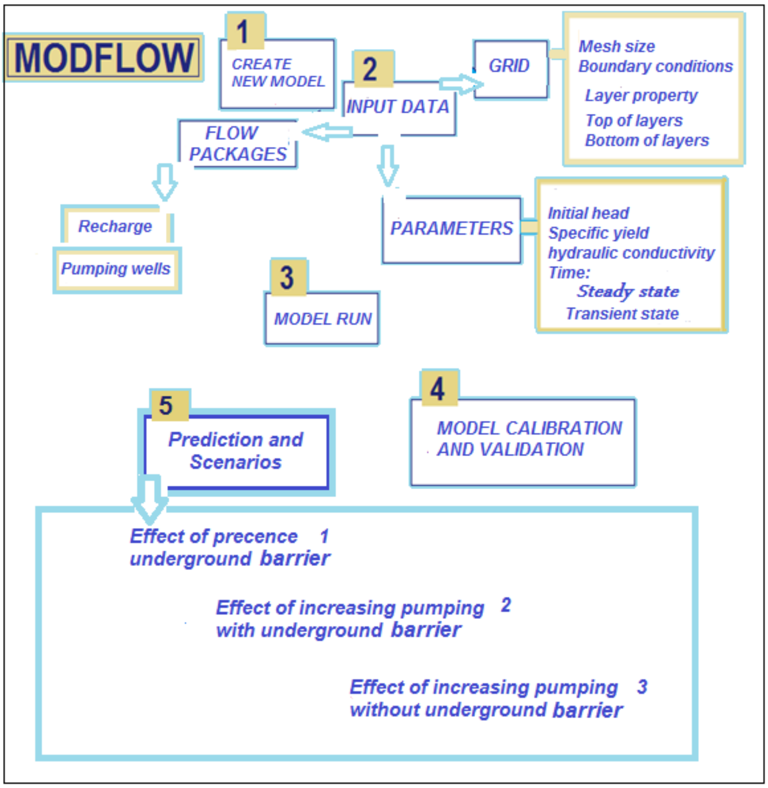

Figure 3. Flow chart of the study area modeling.

A new model on MODFLOW was created of mesh size 2800 cell equal cell as area of cell in 70 rows and 40 columns with grid size of 750m x 750m with fixed coordinate systems of observation wells in the model, (Fig. 4 and Table.1). For steady and transient state conditions, time had been calculated with per day unit. The temporal of domain was submitted to partition into 21 stress periods with one day as time step. Some parameters can be changed when connected to stress periods such as rates of pumping wells and recharge rates.

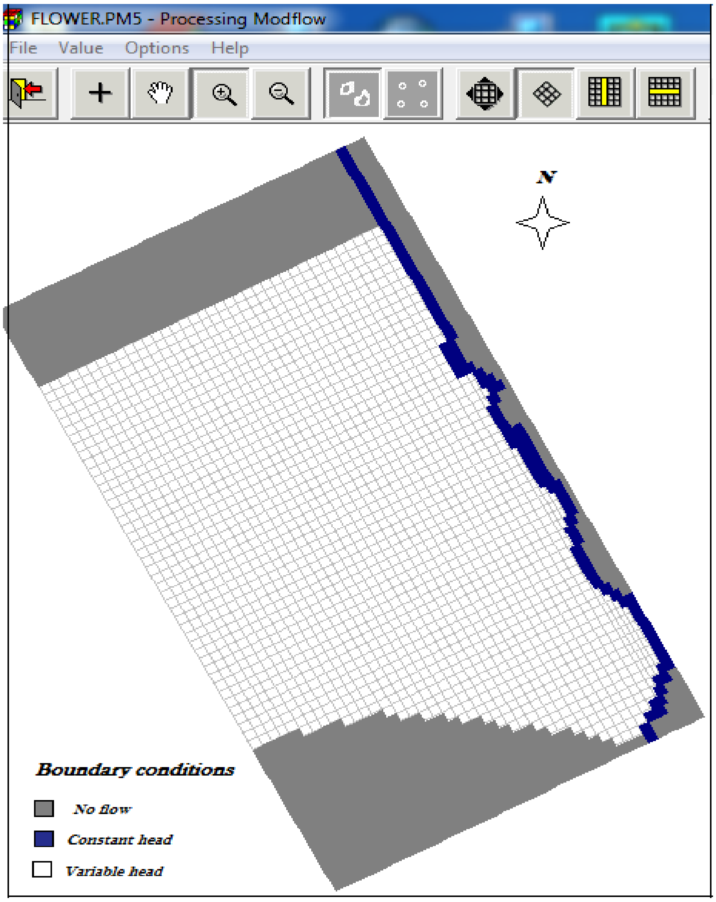

Figure 4. The model grid of the study area.

Table 1. coordinate system of observation wells locations.

Well No.	Location on earth surface		Location on Model grid of MODFLOW			
	UTM Meters		Meters		Cell	
	X Coordinate East	Y Coordinate North	X Coordinate East	Y Coordinate North	(J) Column	(I) Row
OBS1	761192.628	3353704.564	18375	31125	25	29
OBS2	760134.292	3362065.414	19125	39000	28	15
OBS3	767225.140	3349788.723	22125	25875	30	36
OBS4	771670.149	3332326.188	19875	10125	27	57

The MODFLOW required the initial data of hydraulic head (Fig. 5) which was obtained from the measured water levels of observation wells. The hydraulic parameters illustrated the hydraulic conductivity (K) through rows of model. As for the specific yield (Sy), MODFLOW modeling need to insert the storage terms specified in an unconfined layer for simulation.

Many of natural sources are responsible for the ground water recharge such as precipitation, percolation flow from irrigation, recharge from rivers, and inflow from storing valleys and ponds (Senthilkumar and Elango, 2011). As for the study area, some of the factors affect the amount of recharge such as percentage of infiltration from the rainfall and irrigation are assumed to 20 % and more than 80 %, respectively (Atiaa and Al-Aboodi, 2006).

The saturated soil with water is neglected because no water has kept in sandy gravelly soils, in addition to a little amount of surface runoff that comes from small and shallow valleys (Atiaa *et al*., 2007). Pumping periods are different from season to another along the year. It may have reached a high level of about 24 h/day in the months from August to October. While in November to May it is considered half of the period approximately 12 h/day (Al-Abadi, 2001). About 5000 pumping wells had been dug on an irregular basis within the area concerned (Atiaa, 2000). Those wells took out large amounts of ground waters and by reason of its large diameter, it had been appointed for extracting water in comparison with tube wells owing to high capacity and seepage area supplied (Atiaa and Al-Aboodi, 2006). The average of abstraction rates is approximately equal to 5 L/S, this value can be increased or decreased according to the stress period for one water year.

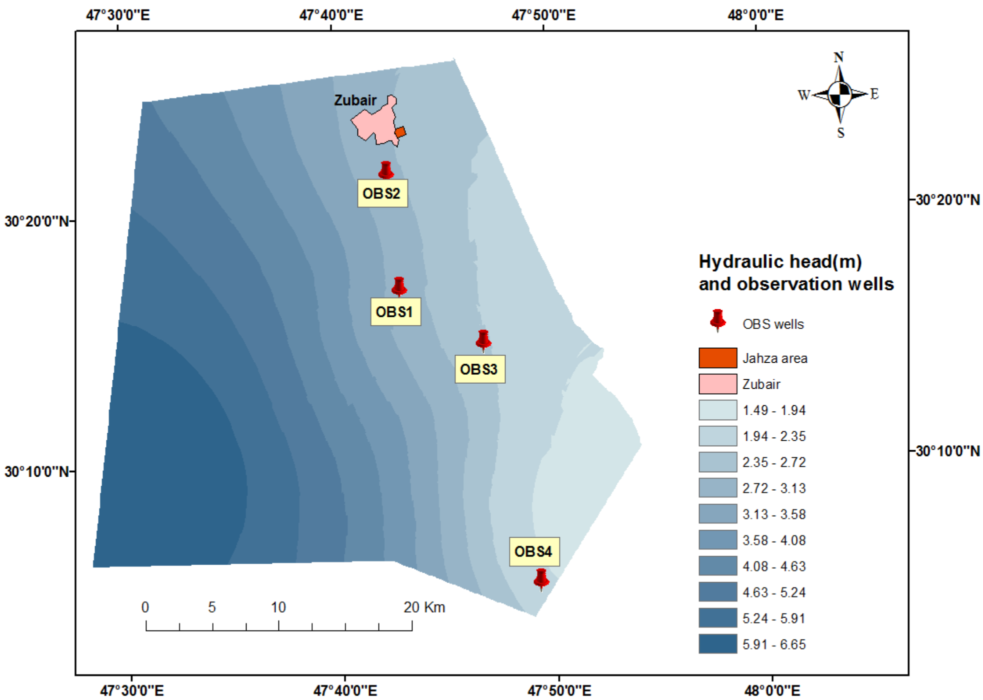

Figure 5. Initial hydraulic head and observation wells.

Results and Discussion

The calibrated period had been separated into 21 stress period equals to 630 day. Acceptable calibrated results were gained from matching between observed and predicted head many times by trial and error methods (Fig. 6).

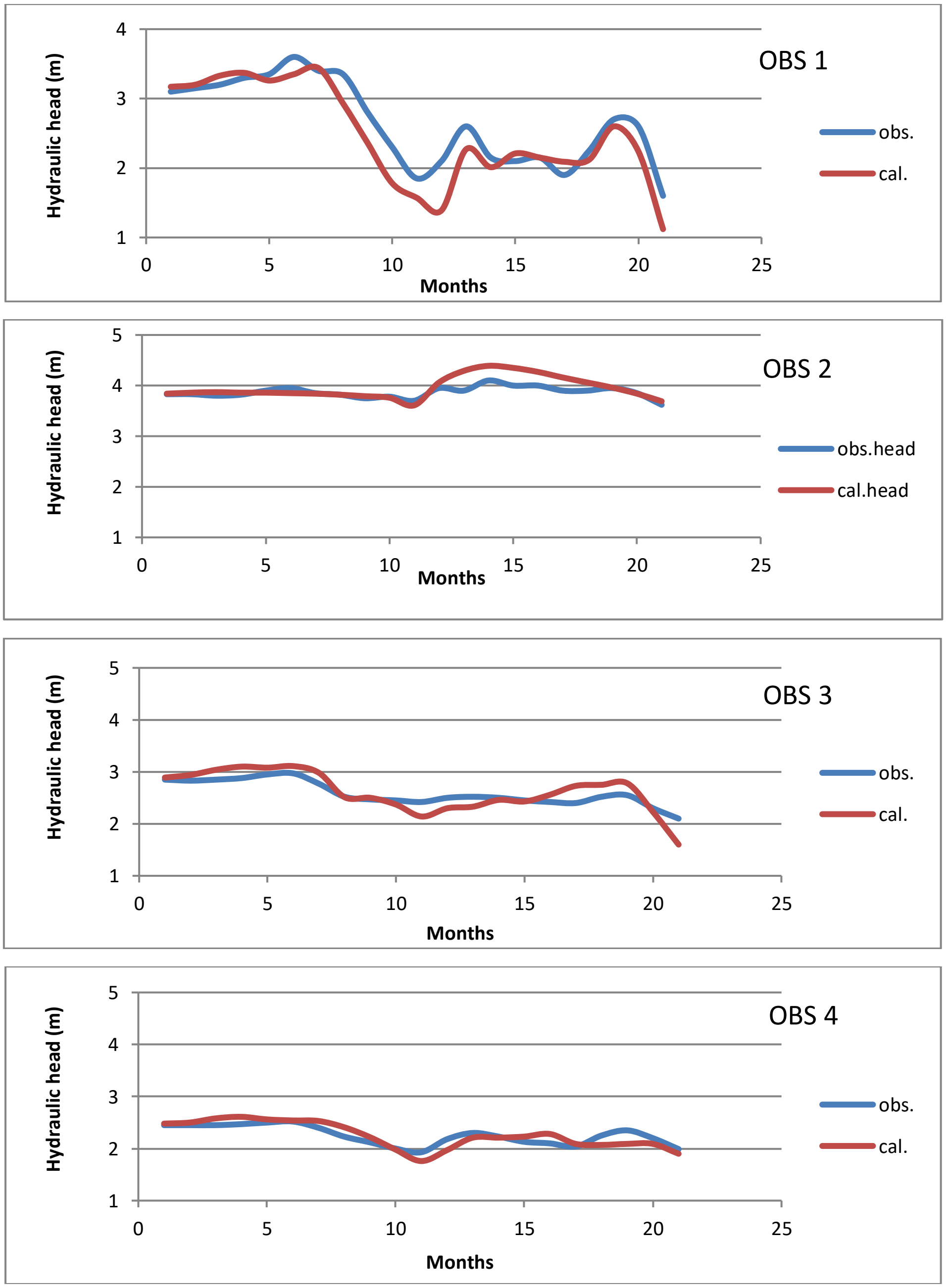

Figure 6. A comparison between the observed and calculated heads.

For the estimation of parameters in Table (2), the calibration statistics equations: root means square error (RMSE), the mean absolute error (MAE), and the determination coefficient (R^2) as shown in Figure (7), are used for checking up the ability of the model for prediction (Venkatesan and Rajesh Prasanna, 2015).

$$RMSE = \sqrt{\frac{1}{n}\sum^{n}(H_{observed} - H_{predicted})^2} \qquad (3)$$

$$MAE = \frac{1}{n}\sum^{n}\left|H_{observed} - H_{predicted}\right| \qquad (4)$$

$$R^2 = \frac{\sum^{n}(H_{observed} - H_{mean..observed})^2 - \sum^{n}(H_{observed} - H_{predicted})^2}{\sum^{n}(H_{observed} - H_{mean.observed})^2} \qquad (5)$$

Where n is the number of observing wells, H is the hydraulic head. The accurate predicted model has a small value of RMSE and MAE.

Table 2. Calibration statistics of Groundwater head through wells.

Observation wells	Normalized data (RMSE)	Normalized data (MAE)	R^2
OBS1	0.485	0.448	0.88
OBS2	0.451	0.435	0.69
OBS3	0.322	0.423	0.81
OBS4	0.209	0.292	0.74

As for the simulated results of the underground barrier and increasing water pumping effect representing the three scenarios (Fig. 8) by running of two years as a stress period. The first one showed that the ground water levels became more controlled by constructing dam through operating period without any undesirable effect of increasing or decreasing levels. While low differences of levels had been noticed in the second scenario through the beginning of running which decreased by 2-9 cm, in the year and a half period, the water table continued to decrease by 20-30 cm to reach the level of extremely 35-40 cm with the end of the running period.

The third scenario results was a large depression of the ground water level may occurred more than the head depression in the second case reaching extremely to 45-50 cm. The model predicted which increased abstraction with the presence of subsurface barrier has low levels of ground water more than the increasing pumping with no subsurface barrier.

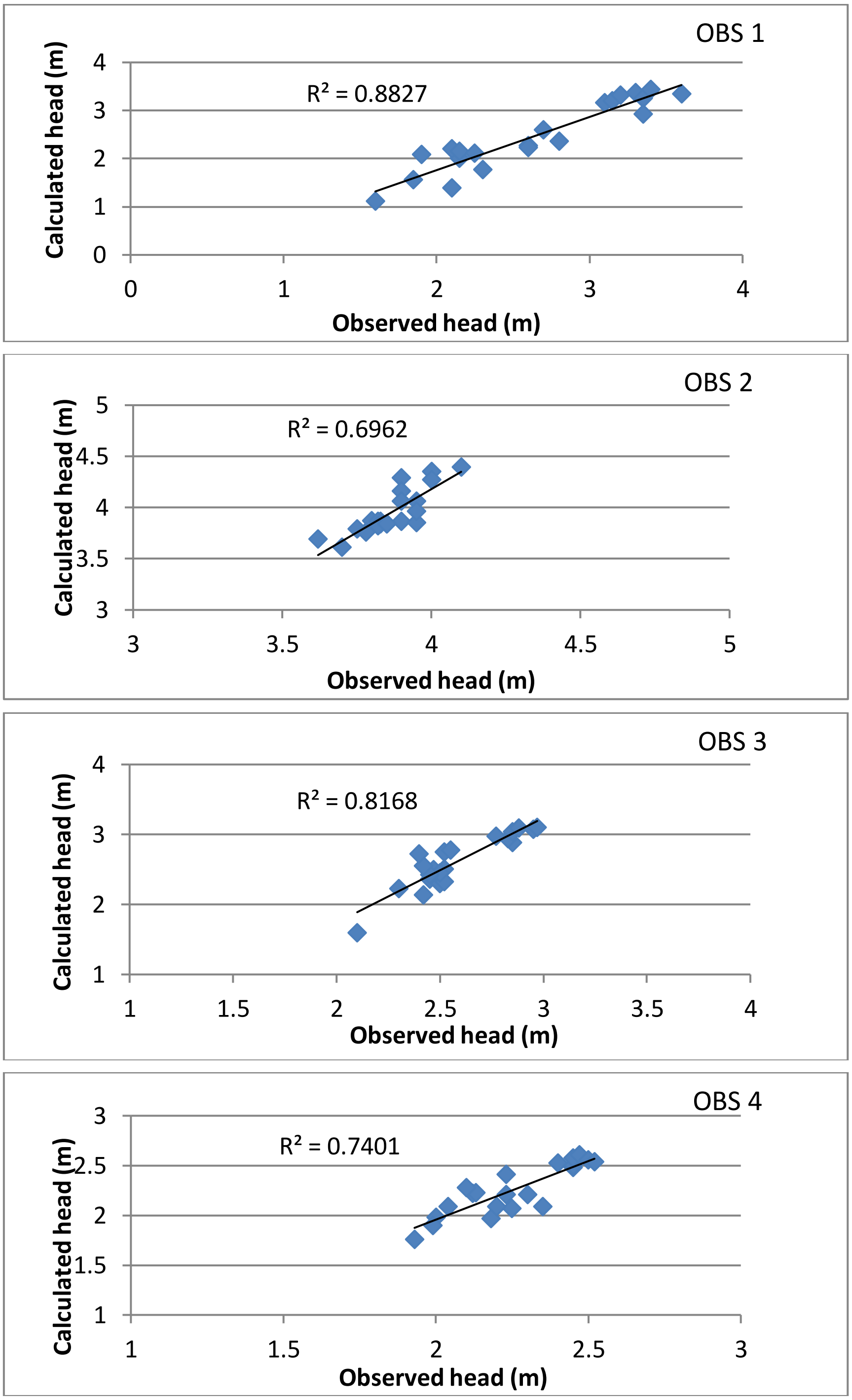

Figure 7. The determination coefficient (R^2) between the observed and calculated heads.

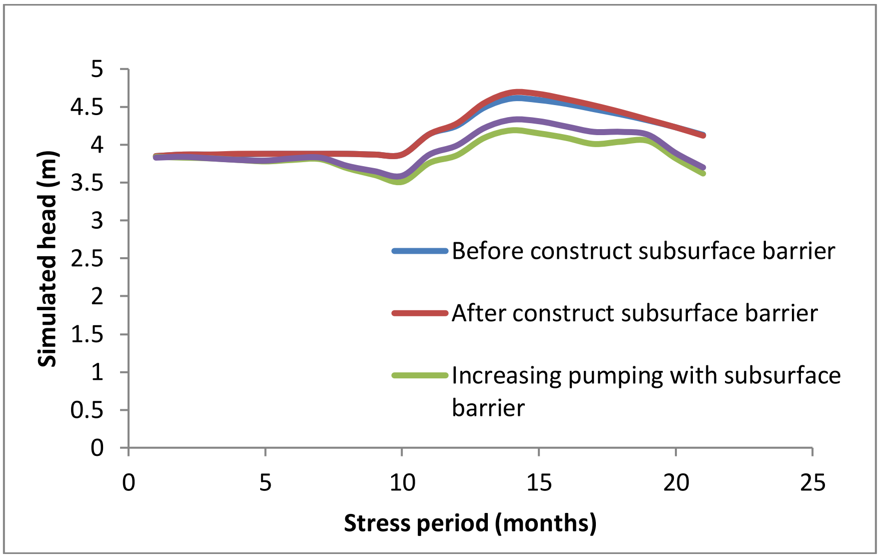

Figure 8. Simulation of levels with and without effect of pumping rate.

Conclusions

The modeling approach was good for simulated and predicted the decreasing water level. Application of constructing the underground barrier contributed to create the stability condition in water levels, on the other side the head level at exceeding extraction with the presence of subsurface barrier will decrease more than the head level in case of increasing pumping rate with the absence of subsurface barrier. The constructing of the barrier and digging additional systematic pumping wells is necessary to control and draft the water from waterlogged area. This issue could get high management when the modeling techniques are used within the institutes of the Water Resources.

References

Al-Abadi, M.A. 2001. Optimum Management of Model of Groundwater Resources in Safwan-Zubair Area, South of Iraq. Unpub. M.Sc. Thesis, College of Science, Univer. of Basrah, 110p.

Al-Jawad, S.B., Ayob, M.S., Khalil, S. and Al-Rida, N.H. 1989. Hydraulic properties of dibdibba sandstone using pumping tests data in large diameter wells. Proc. 5th Sci. Conf. / SRC., Iraq, 1(3): 135-146.

Al-Kubaisi, Q.Y. 1996. Hydrogeology of Dibdibba aquifer in Safwan-Zubair area, south of Iraq. Ph.D. thesis, College of Science, University of Baghdad, 86p (In Arabic).

Al-Kubaisi, Q.Y. 1999. Quaternary-Tertiary hydrogeologic boundary condition at Safwan-Zubair area, South of Iraq. Iraqi Jour. Scie., 40(3): 21-28.

Al-Manssory, H.B.G 2000. Hydrogeochemistry and the pumping influences of Groundwater quality of the Dibdibba aquifer in Safwan-Zubair Area, Southern Iraq. M.Sc. thesis, College of Science, University of Basrah, 150p. (In Arabic)

Al-Muttory, W.G. 2002. Structure and Tectonism of Jabal Sanam Southern Iraq. M.Sc. Thesis, College of Science, University of Basrah, 87p (In Arabic).

Al-Naqib, K. 1967. Geology of the Arabian Peninsula-Southwestern Iraq. U.S. Geological Survey Professional Paper, 560–G, 1–54. Retrieved from http://pubs.usgs.gov/pp/0560d/report.pdf

Atiaa, A.M. 2000. Hydrogeology of Safwan-Zubair area, South of Iraq. M.Sc. Thesis, College of Science, University of Basrah, 90p (In Arabic).

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, 47(1): 119-137.

Atiaa, A.M., Bana, D.S., Mutasher, W.R. and Flayh, Q.M. 2007. Simulation of influence of artificial recharge on ground water elevations of Sandy Dibdibba Formation in Safwan region, southern Iraq. Basrah Journal of Science, 25(1): 18-27.

Buday, T. 1980. The Regional Geology of Iraq, Vol 1: Stratigraphy and Paleogeography. Publications of Geological Survey of Iraq, Baghdad, 445p.

Chiang, W.H. and Kinzelbach, W. 1998. Processing MODFLOW, A simulation system for modeling groundwater flow and pollution. Software Manual, 325p.

Fetter, C.W. 2001. Applied Hydrogeology. University of Wisconsin-Oshkosh, Library of Congrress Cataloging-in Puplication Data. Fourth Edition, 598p. www. prenhall.com.

Hassan, H.A., Ismail, S.K. and Al-Dabbas, M. 1987. The general Hydrogeological conditions of the Dibdibba basin, south Iraq. Agricultural and Water Resources Research Center, Baghdad, Tech. Rep., 31p.

Ishida, S., Tsuchihara, T., Yoshimoto, S. and Imaizumi, M. 2011. Sustainable use of groundwater with underground dams. Japan Agricultural Research Quarterly, 45(1): 51-61. https://doi.org/10.6090/jarq.45.51

Jassim, S.Z. and Goef, J.C. 2006. Geology of Iraq. Printing, Mosul, Iraq. https://doi.org/10.1007/s13398-014-0173-7.2

Kumar, C.P. 2015. Modeling of Groundwater Flow and Data Requirements, 2(2): 18-27.

Marghani, A.M. 2002. High level of Groundwater is natural hazard in some villages and cities in Egypt from the perspective of geomorphologic. Journal of Faculty of Arts, Benha University, 40p (In Arabic).

Qadir, A., Ahmad, Z., Khan, T., Zafar, M., Qadir, A. and Murata, M. 2016. A spatio-temporal three-dimensional conceptualization and simulation of Dera Ismail Khan alluvial aquifer in visual MODFLOW: A case study from Pakistan. Arabian Journal of Geosciences, 9(2): 1-9. https://doi.org/10.1007/s12517-015-2069-z

Senthilkumar, M. and Elango, L. 2011. Modelling the impact of a subsurface barrier on groundwater flow in the lower Palar River basin, southern India. Hydrogeology Journal, 19(4): 917-928. https://doi.org/10.1007/s10040-011-0735-0

Sissakian, V.K., Shihab, A.T., Al-Ansari, N. and Knutsson, S. 2014. Al-Batin Alluvial Fan, Southern Iraq. Engineering, 6: 699-711.

Venkatesan, V. and Rajesh Prasanna, P. 2015. Simulating ground water flow using numerical model and artificial neural net work-A case study. International J. of Civil and Structural Engineering Research, 3: 190-214.

مقارنة نموذج محاكاة عددي لظاهرة تغدق المياه في منطقة الدور الجاهزة في قضاء الزبير جنوب العراق

لميس سالم القورناوي[1] و علاء محسن عطية[2]
[1]مركز علوم البحار, [2]كلية العلوم, جامعة البصرة, البصرة - العراق

المستخلص - الدراسة الحالية سلطت الضوء على نمذجة جريان المياه الجوفية للسيطرة على مشكلة تغدق المياه في منطقة الدور الجاهزة الواقعة في الجزء الجنوبي الشرقي من قضاء الزبير جنوب العراق. تم استخدام نموذج عددي لمحاكاة نظام الجريان للمياه الجوفية باستخدام برنامج حاسوبي (المد فلو). تمت معايرة النموذج لأربعة آبار مراقبة موزعة بصورة عشوائية في منطقة الدراسة ولفترة تشغيل مقدارها 21 شهرا ومن ثم اجراء عملية المقارنة والحصول على تطابق مقبول بين مناسيب المياه المأخوذة من ابار المراقبة في الحقل مع تلك المناسيب المحسوبة من قبل البرنامج. تمت محاكاة النموذج وفق ثلاث خطط مستقبلية للسيطرة على مناسيب المياه الجوفية ولفترة سنتين من تشغيل النموذج. الخطة الاولى تضمنت انشاء حاجز تحت سطحي في منطقة الزبير اما الخطة الثانية والثالثة فكانت حفر ابار افتراضية مع زيادة معدل الضخ في حالة وجود الحاجز وحالة عدم وجوده على التوالي. بينت النتائج ثبات مناسيب المياه الجوفية ووصول حالة الاستقرار لمستوى عمود الماء المحسوب قبل انشاء الحاجز وبعد انشاءه. وحصول انخفاض كبير في مناسيب المياه الجوفية عند زيادة الابار وزيادة معدل الضخ (بحدود 216-432 م^3/يوم) في حالة وجود الحاجز بمستوى انخفاض يصل الى (45-50) سم اكثر مما هو عليه في حالة زيادة الضخ مع عدم وجود الحاجز بمستوى انخفاض يصل الى (35-40) سم عن مستوى المنسوب الاصلي للمياه مما يعزز الفائدة المرجوة من انشاء حاجز تحت سطحي وزيادة ضخ ابار المياه للسيطرة على التغدق في المنطقة.