Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.24099

151 (2019) 414–424
May

Prediction of groundwater level fluctuations in steady and unsteady state conditions using PMWIN in Rayen Aquifer, Iran

Fatemeh Amiri[a], Gholam-abbas Barani[b], Masoud Reza Hessami Kermani[b], Aida Tayebiyan[c,*], Rasoul Sabahi[a], Mohammad Malakootian[c,d]

[a]*Kerman Institute of Higher Education, Kerman, Iran, emails: en.fatemeh.amiri@gmail.com (F. Amiri), en.rasoul.sabahi@gmail.com (R. Sabahi)*
[b]*Department of Civil Engineering, Shahid Bahonar University of Kerman, Kerman, Iran, emails: gab@mail.uk.ac.ir (G.-a. Barani), hessami@uk.ac.ir (M.R.H. Kermani)*
[c]*Environmental Health Engineering Research Center, Kerman University of Medical Sciences, Kerman, Iran, email: ida_tayebiyan@yahoo.com (A. Tayebiyan)*
[d]*Department of Environmental Health, School of Public Health, Kerman University of Medical Sciences, Kerman, Iran, email: m.malakootian@yahoo.com (M. Malakootian)*

Received 7 September 2018; Accepted 9 March 2019

ABSTRACT

Groundwater is the major sources of water supply around the world. In arid regions like Rayen aquifer in Iran, groundwater is the main resource of irrigation, while the extraction volume is daily increasing due to population growth and drought. On the other hand, low average rainfall adds extra pressure on groundwater. Continuous extraction annually decreases the water table up to 1.1 m, so applying appropriate management is necessary for this aquifer. Accordingly, The Processing MODFLOW for windows (PMWIN) model was calibrated and validated using observed wells data (2001–2010) in steady and unsteady state conditions to simulate and predict the water level. Results showed that there is a strong correlation between observed and simulated data. Simulation output is firstly used to estimate hydraulic conductivity and specific yield. Then, the water levels in the next 4 years are predicted by current exploitation and in next 8 years will be predicted by 20% increase in water extraction. Results showed a sharp decline in the future water levels, which lead to destroy of the aquifer. Thereafter, three scenarios were studied based on discharge reduction up to 10%, 20%, and 30% to restore the aquifer to balance. Results showed that the aquifer could be saved by 30% reduction in groundwater discharge for future consumers.

Keywords: Groundwater management; Water level fluctuation; PMWIN

1. Introduction

Groundwater is considered as the largest supply of available fresh water on the earth. In areas with limited resources of surface water, groundwater can be replaced to provide water requirements [1]. Groundwater is the main source of irrigation, which is the major factor to increase crops yields. Unfortunately, the volume of extraction is increased daily due to population growth, food insecurity, poor water management, and low average rainfall that cause much pressure on groundwater. Continuous extraction is declining groundwater levels in many areas and the aquifers were no more capable of pumping under suction mode during the peak irrigation periods. It was observed that groundwater level fluctuated mostly in dry seasons due to no rainfall. Therefore, declining water table leads to dry up more shallow wells, require deeper tube wells, which causes an increase

* Corresponding author.

in pumping cost [2]. Hence, prediction of groundwater level fluctuations is necessary, since these resources are the only permanent water resources. Thus, proper knowledge about water balance helps the managers for integration of water resources for present and future [3].

Simulation of the regional groundwater systems and management of groundwater resources for water consumption in the future were done through many groundwater flow models [4]. Different models were developed to simulate groundwater flow such as Visual MODFLOW, which was developed by Waterloo Hydro geologic Inc. (Canada); the GMS or groundwater modeling system (which was developed by Department of Defense, US [5]; Groundwater Vistas, which was developed by Environmental Simulation Inc. (USA) [6]; the IGW or Interactive Groundwater, which was developed by University of Michigan State [7]; FEFLOW, which was developed by Department of Interior, US [8]; The PMWIN or Processing MODFLOW for windows, which was developed by [9]. From the above-mentioned models, the MODFLOW v.2000, PMWIN, and FEFLOW are often used for modeling groundwater. These models are applicable for different conditions of groundwater systems like simple or multiple aquifers [10], homogeneous or heterogeneous layers aquifer systems [11], and confined and unconfined aquifers [12].

In order to construct groundwater modeling system (GMS), several techniques should be applied such as finite element and finite difference, quasi-3 dimensional (3D), transient and steady-state solutions [13]. In addition, model conceptualization, grid and mesh generation, output post-processing and geostatistics should be performed to simulate Groundwater System. These steps can be used through integrating AutoCAD software and GIS (Geographic Information System) with a code of the MODFLOW in GMS for managing water resources [14]. For example, Researchers used an integrated GIS-PMWIN to model mine water exists in the Far West Rand in the Witwatersrand basin for simulating dewatering and re-watering conditions and scenarios [15]. Since, more than 70% of Punjab farmers in Pakistan depend on groundwater directly or indirectly, therefore, comprehensive studies were conducted at central Punjab-Pakistan about spatial-temporal variation in groundwater levels by Processing MODFLOW for windows; The PMWIN model was used for present and future prediction of groundwater level until 2030. The results showed that the groundwater level will decline in future and affect the crop production in Punjab, which has intensive dependence on groundwater [16].

Due to low rainfall, drought and water shortages in the recent decade, the table of groundwater is declining annually in the most aquifers in Iran. Rayen aquifer with 1,929 Km^2 area and the elevation of 2,600 m above sea level is located in 110 km far from southeast of Kerman City. The groundwater levels have shown a continuous decline about 1.1 m in Rayen aquifer annually. Therefore, the main goal of the present study is to simulate water level fluctuation of Rayen Aquifer in both steady and unsteady state conditions using PMWIN. Data from 11 observed wells 2002–2011 were collected to calibrate and validate the model. Hydraulic conductivity and specific yield coefficient estimated and corrected during these processes. Then, the groundwater levels were firstly predicted in the next 4 years by considering the current condition and secondly predicted in the next 8 years by applying 20% increase in water discharge. Thereafter, three scenarios were presented and compared to help the managers to save the aquifer and equilibrate the conditions. These scenarios were constructed based on the 10%, 20%, and 30% decrease in the water discharge in the next 4 and 8 years.

2. Materials and methods

Here, ArcGIS 10.0 (Environmental systems research institute [ESRI]) and PMWIN were used to construct the groundwater modeling system. At first, GIS was used to analyze geographic information. Then the required data for conceptual modeling were converted to the appropriate formats for numerical modeling [17].

The process of georeferencing, determination of case study boundaries, grid generation, and boundary conditions were conducted in GIS. Then, input data such as initial head, bedrock level, groundwater head, well discharge, hydraulic conductivity, and specific yield were collected from Kerman Regional Water Authority (KRWA) and Abfakerman and imported into PMWIN to construct the steady and unsteady state conditions in Rayen aquifer (located between 57°–13' and 57°–53' eastern longitude and 29°–23' and 29°–52' north latitude). Fig. 1 shows the flowchart of data processing and groundwater modeling.

2.1. Data collection

The data used in PMWIN are bedrock level, observation well, initial head, well recharge and discharge, hydraulic conductivity, and specific yield, which will be explained respectively.

2.1.1. Bedrock level

The lower aquifer boundaries are considered as the most superficial impervious layer, which is called bedrock. The Surfer software is used to simulate absolute altitude map of the bedrock through lowering the depth of bedrock at the electrical sounding places of earth surface topography.

2.1.2. Observation well

In the whole area, the data of 11 observation wells were available and used in this research from 2001 to 2011 in a monthly scaled. Based on the available data, water level fluctuations varied from 0.7 to 11.2 m. Due to the rainfall reduction, the groundwater levels have consequently declined. Results of this phenomenon are drying shallow wells, digging deeper wells, and increasing pumping cost.

2.1.3. Initial heads

PMWIN requires an initial guess for transient simulation and head distribution in steady state condition. Initial head data are collected from Kerman Regional Water Authority and presented in Table 1 [18].

2.1.4. Well recharge and discharge

The water table of Rayen plain was located at the depth of more than 12 m from earth surface [19]. Therefore, it was

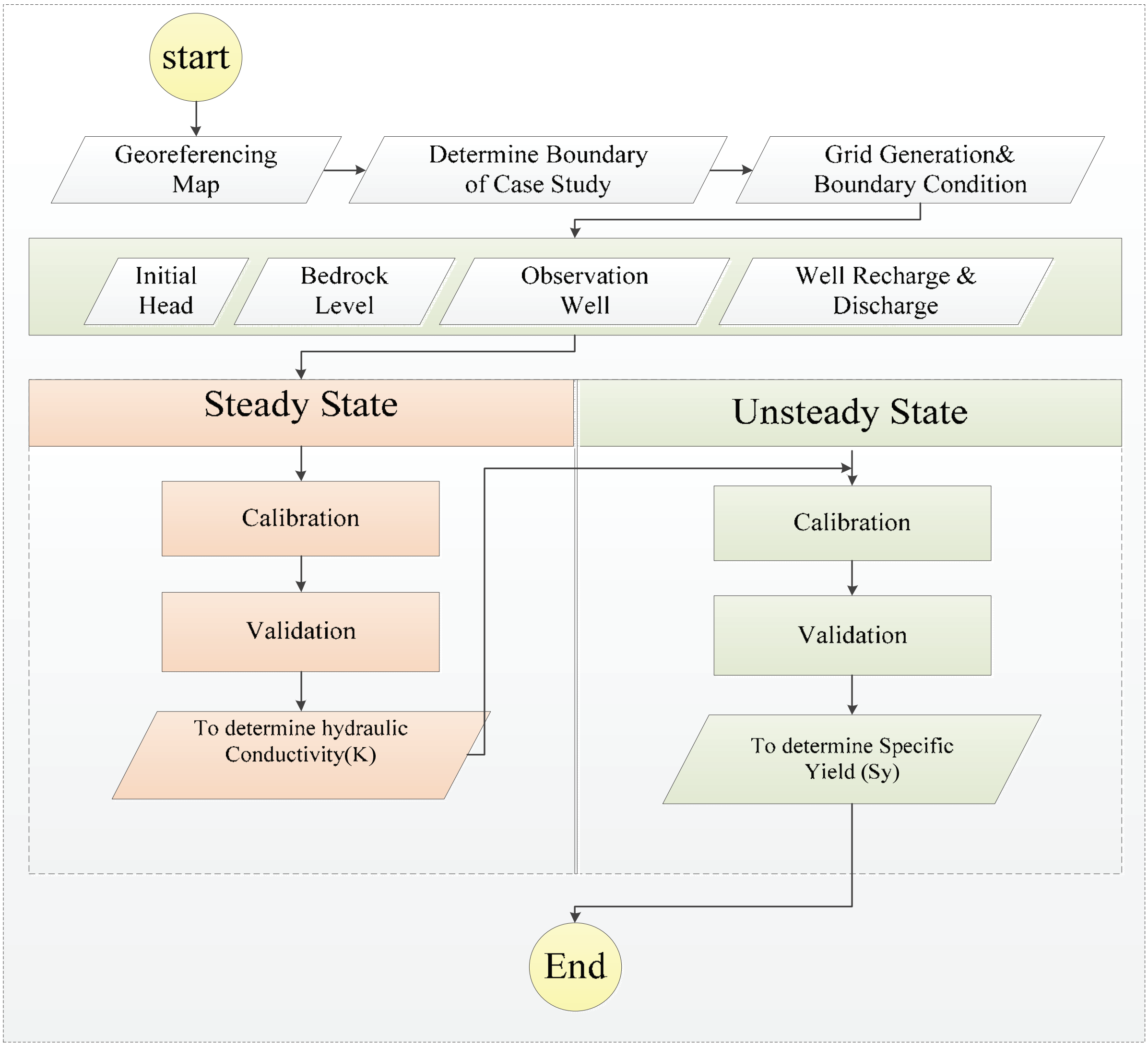

Fig. 1. The procedure of groundwater modeling and data processing by PMWIN.

Table 1
Location of observed wells and specification of an initial head in the starting point of PMWIN

Observation wells	UTM_x	UTM_y	Initial head
p1	560840	3271060	2,004.06
p2	546475	3273448	2,066.53
p3	546859	3278672	2,055.64
p4	556415	3272531	2,046.34
p5	548837	3275230	2,052.69
p6	551067	3272181	2,044.24
p7	536132	3283235	2,096.97
p8	559390	3266778	1,993.03
p9	552495	3266778	2,015.02
p10	540934	3281514	2,085.74
P11	541852	3277598	2,060.65

assumed that the groundwater evaporation was zero. There are three sources of water recharge in this area including water infiltration during rainfall, agricultural return flows, and using deep absorbent wells to transfer sewage of Rayen City. According to the Water organization of Kerman region report, an average amount of infiltration due to precipitation in this area is about 12% of total precipitation, which was considered to the model in zoning form [20]. There are 124 exploitation wells in the region with different consumptions like farming and industry. The infiltration percentage due to the agricultural return flows in different areas were measured (15% of output discharge of well minus evaporation rate), which was applied to the model. The last source of water recharge is sewage return flows. Since there is not any sewage transfer system in Rayen City, relatively deep absorbent wells is using instead. Therefore, the urban sewage system is very effective in supplying the aquifer. According to the amount of sold water, which was recorded by the Kerman Water and Sewage Company and the size and types of particles in this aquifer, the percentage of infiltration due to sewage was estimated

30% [20]. The groundwater cross section is determined using a water table map. According to the hydraulic gradient, transmission coefficient and width of each section, the discharge and recharge flow rates were calculated using Eq. (1).

$$Q = T \cdot i \cdot w \tag{1}$$

In Eq. (1), Q is the water discharge ($L^3 T^{-1}$), T is the transmission coefficient (L^2T^{-1}), i is the hydraulic gradient, and w is the section width (L). Groundwater discharge and recharge rates were considered in the form of wells in boundary, which the discharge was taken as negative rates and the recharge was taken as positive rates.

2.1.5. Hydraulic conductivity

Hydraulic conductivity is one of the most important and sensitive parameter in providing a model. It should be tried to design a model using real values of k obtained in a desert and preferably by pumping tests. Since few pumping tests were conducted in Rayen plain, hydraulic conductivity coefficient was estimated in calibration process of the model in stable conditions.

2.1.6. Effective porosity

According to the findings, effective porosity is equal to the specific yield parameter, virtually at the time of compressibility is ignored. Based on the KRWA reports, the value of specific yield estimated to be 5%.

2.2. Model design

2.2.1. Conceptual model

2.2.1.1. Geo-referencing map and determining boundary Using geographic information systems (GIS) for spatial hydrologic data analysis have many benefits for water resources design. The GIS is the initial tool, which used to develop modeling procedure performance, model grid, and model analysis. The topology grid was placed in the geographic coordinates, facilitating geo-referencing, and orientation of the grid to base maps. Boundaries Condition of the case study were determined using this geo-referencing map. Afterwards, this map and pertinent information were used to generate input files for PMWIN simulation.

2.2.1.2. Boundary condition By checking topographic, geologic and water resource maps, it was cleared that physical boundaries of Rayen plain aquifer have mountain and plain types. In this region, the Joopar Mountains was the northeast physical boundary [21]. Moreover, the flow lines corresponding to the margin of the plain were considered as a boundaries without hydraulic flow or the impervious boundaries in this aquifer.

2.2.1.3. Grid generation A flow model of groundwater in Rayen was made using PMWIN. The area of Rayen is 1,267.89 km^2 and in form of quasi-rectangular. The grid cells were determined as "inactive" outside and "active" inside the domain of the model. The model was divided into 3,055 cells including 10,013 active cells and 2,054 inactive cells, which included 65 columns and 47 rows. Based on Rayen aquifer grids and considering spatial distribution of input data, the size of each cell is selected 500 × 500 m. The model includes one layer representing hydrogeological condition and porous aquifers data of the study area.

2.2.2. PMWIN model

The groundwater flows under no equilibrium conditions in a heterogeneous and isotropic medium is shown in Eq. (2). Regarding the equation, the main axes of hydraulic conductivity are shown with the x–y Cartesian coordinate's axes. The equation flow of groundwater and flow specification and/or initial head at boundary conditions presents a mathematical depiction of the aquifer system. The numerical methods are used to solve the flow equation of groundwater generally, the mudflow software which is developed by McDonald and Harbaugh (United States geological survey [USGS]) [5] was used in the present study.

$$\frac{\partial}{\partial \mathrm{x}}\left[K_{\mathrm{x}}\frac{\partial h}{\partial \mathrm{x}}\right]+\frac{\partial}{\partial \mathrm{y}}\left[K_{\mathrm{y}}\frac{\partial h}{\partial \mathrm{y}}\right]+\frac{\partial}{\partial \mathrm{z}}\left[K_{\mathrm{z}}\frac{\partial h}{\partial \mathrm{z}}\right]=S\frac{\partial h}{\partial t}+I \tag{2}$$

In Eq. (2), $k_{z,}$ K_x, and K_y are the hydraulic conductivity in the three-dimensional directions of Cartesian coordinates [LT^{-1}], S is the specific yield coefficient, and I is the volumetric flux/unit volume ("−" outflow and "+" inflow) [T–1].

2.2.2.1. Model calibration Calibration of the model includes changing the input parameters values of the model to match field conditions with an acceptable criterion. An automated parameter estimation code or trial/error adjustments of parameters were used for calibration. Here, calibration of the model was done using observed wells data. Then, before more comprehensive and qualitative calibration, this was used as a qualitative step [22]. Calibration targets were the groundwater levels of 11 observed wells from 2001 to 2007. Observed wells, which are distributed throughout the study areas are representative of the regional aquifer conditions.

Trial and error were used to calibrate the model by the following procedure [23]. Firstly, in order to minimize the difference between the observed and calculated groundwater level contour maps and heads, the recharge rate was adjusted. Then, in order to minimize the variance of the differences, the hydraulic conductivity and specific yield were adjusted [13]. In order to reach a reasonable range, the procedure was repeated.

2.2.2.2. Model validation After designing the model, applying data, implementation of the model and calibration, the validation of the model was done to measure its accuracy and determine the power of model prediction. In validation, a model has to simulate natural conditions up to an acceptable limit under different stresses, without any variation in hydrodynamic coefficients of the aquifer and obtained zoning for hydraulic conductivity and special discharge. Otherwise, the model is not acceptable and a combination of applied parameters was not correct. The output results from the model were compared with the piezometer contour of observed wells by using statistical tests such as the coefficient of determination (R^2) and root mean square error (RMSE) tests.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(y_{ip} - y_{io}\right)^2}{n}} \tag{3}$$

$$R^2 = \frac{\left(\sum_{i=1}^{n}\left(y_{io} - \overline{y_o}\right)\left(y_{ip} - \overline{y_p}\right)\right)^2}{\sum_{i=1}^{n}\left(y_{io} - \overline{y_o}\right)^2 \sum_{i=1}^{n}\left(y_{ip} - \overline{y_p}\right)^2} \tag{4}$$

In Eqs. (3) and (4), y_{io} is the observed data for test sample i, y_{ip} is the predicted variable for test sample i, n is the number of test data samples, $\overline{y_o}$ is the mean observed value for test samples, $\overline{y_p}$ is the mean predicted value for test samples, R^2 is the coefficient of determination, and RMSE is the root mean square error.

2.3. Case study

The Rayen basin with an area of 1,929 km^2 is a part of Lout Desert basin [15]. This basin is placed at the 2,600 m height from sea level and is located in the southwest of Lout Desert and eastern hillside of Hezar Mountain, and 110 km far from southeast of Kerman City. The geographical coordination is 570–13' to 570–53' eastern longitude and 290–23' to 290–52' northern latitude. The basin is along the southeast-northwest line and an alluvial plain is along this direction [2]. The location of Rayen aquifer and observation wells and boundary condition is shown in Figs. 2(a) and (b), respectively.

2.3.1. Geology and geomorphology

Geologically, the Rayen region located at the end of east and southeast part of central Iran zone beside the Lout block. The geological formations exist in Rayen region belongs to Mesozoic and Cenozoic periods. A major part of these formations composed of igneous rock and tuffs. The Rayen alluvial plain is surrounded by mountains composed of igneous, limestone, sandstone and other sedimentary rocks and its surface covered by alluvia as results of these mountains destruction [19].

2.3.2. Hydrology

The average evaporation and precipitation of Rayen region are 2,883 and 117 mm per year, respectively. Since evaporation is much more than precipitation, a huge amount of surface water will be lost in this region.

There is no any permanent river in the Rayen basin and all rivers are in category of seasonal rivers. Therefore, a major part of the required water for drinking and farming in this region is supplied by groundwater [18]. Totally, 4 exploratory and 11 piezometer wells were dug in 1990 and 1998, respectively, under the supervision of Groundwater Department of Power Ministry to determine the type and thickness of watery layers, detection of the bedrock, a situation of watery layers, and hydrodynamic properties of Rayen aquifer [24]. These wells were equipped with data logger during 2005–2006. Total of digging depth in these 4 wells were 700 m and no piezometer well was dug in the vicinity.

2.3.3. Hydrogeology and exploitation of Rayen aquifer

The alluvial aquifer of Rayen is an open aquifer [19]. By studying the contour lines of discharge, the discharge of this aquifer in southeast areas is better than others. The amount of discharge in Hamidiyeh and Feyzabad lands was atleast 4.5 L/s and maximum 67 L/s respectively. Totally, 2 exploratory and 10 exploitation wells in the aquifer of Rayen plain were used for pumping test to determine hydrodynamic coefficients [25]. Census of groundwater resources of Rayen plain was done in 1992 for the first time and then repeated every few years due to necessity. In 1992, the exploitation rate

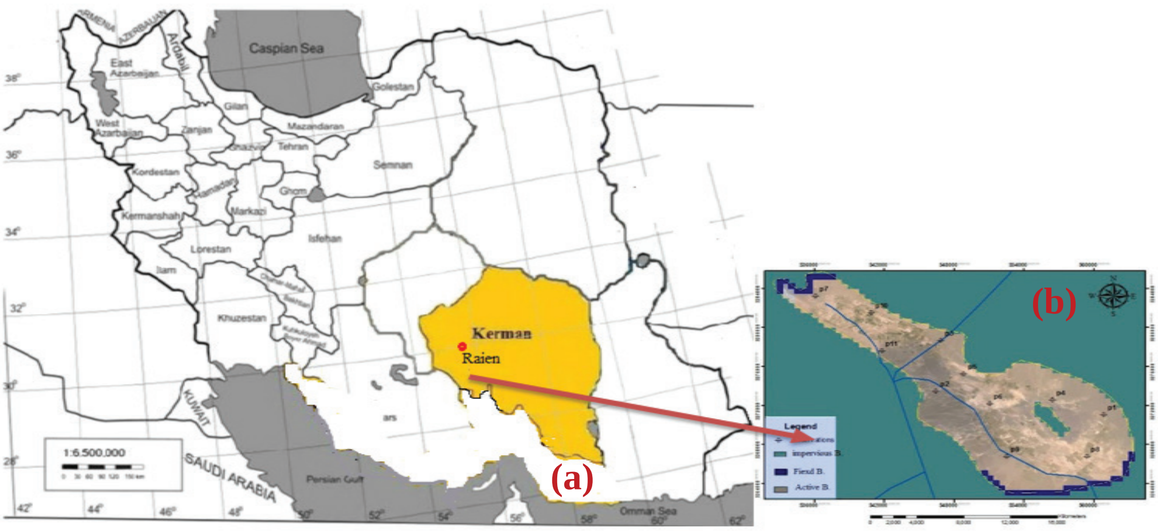

Fig. 2. (a) Location of Rayen aquifer in Kerman, Iran. (b) Location of observation wells and boundary condition.

of water from 95 deep and semi-deep wells was about 35.684 MCM. In the last census (2007), the exploitation rate from 124 wells in the alluvial aquifer of Rayen was about 62.08 MCM. Moreover, in 1992, the exploitation rate from 8 Qanats was about 4.288 MCM. In 1999 and 2006, it was about 4.273 and 3.05 MCM from 12 Qanats which shows discharge reduction of the Qanats area [18].

2.3.4. The assumptions/conditions of the model

Some assumptions and conditions are necessary to simulate the aquifer in PMWIN. These assumptions are specified and summarized in Table 2.

Table 2
Assumptions and conditions for PMWIN modeling

Specific yield	0.05
Active cells	1,001
Cells size	500 × 500
Number of Rows	47
Number of columns	65
Hydraulic conductivity	Kx=ky
Time step (daily)	1
Stress periods (month)	96

3. Results

PMWIN output results including model calibration, validation and prediction, and construction of scenarios to manage the system in the future are shown in Fig. 3.

Based on the monthly observed well data from 2001 to 2006 (70% of the data), the model is calibrated. The scatter plot is shown in Fig. 4, which compared the observed and

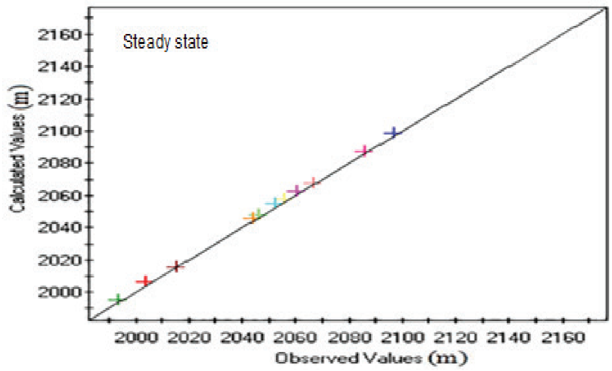

Fig. 4. Scatter plot of observed vs. computed water level in steady state conditions.

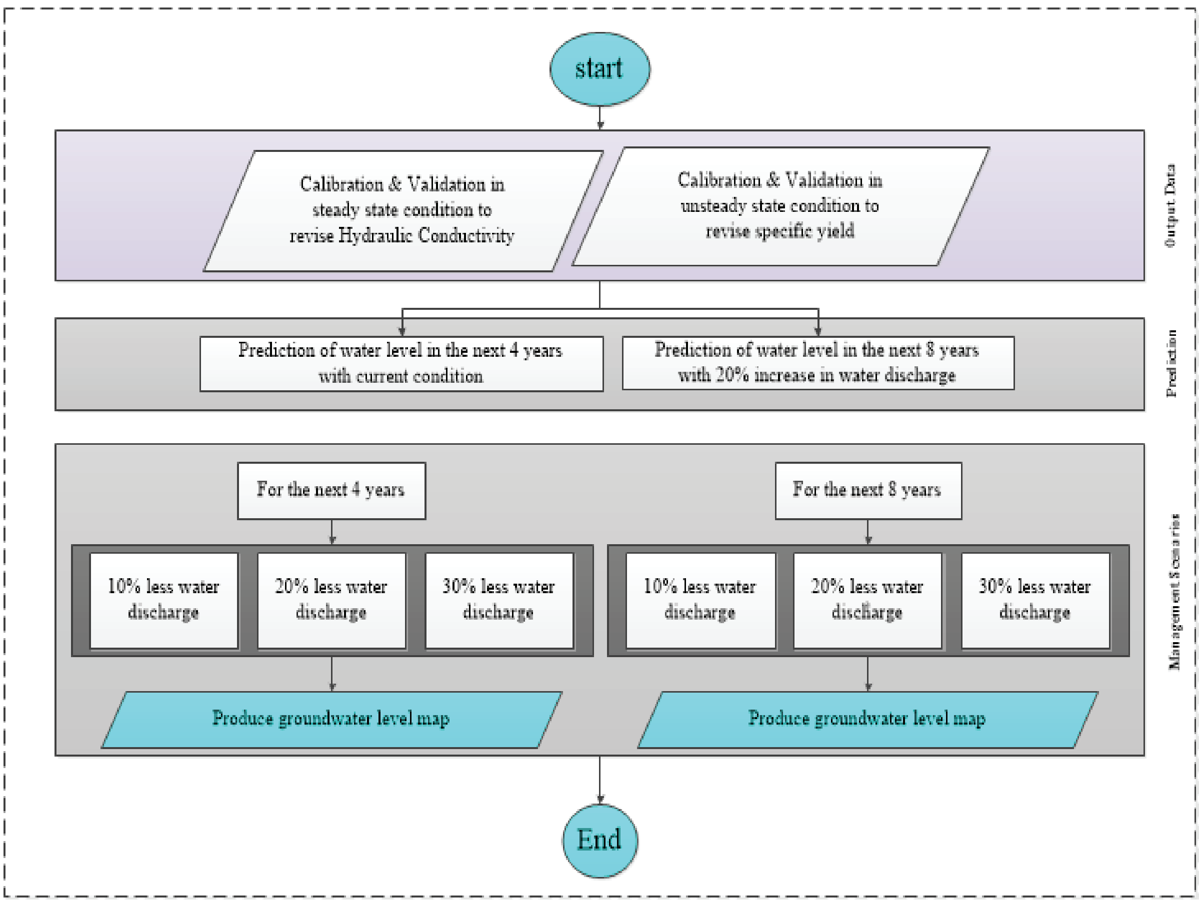

Fig. 3. Flowchart of the output model, prediction, and result.

calculated heads in steady state condition. It is obvious that, there is a good match between the observed and calculated head values. As it can be seen the difference of the lowest and the highest water level is about 100 m, which shows that the discrepancy of the water table is considerable in this area. Then, based on the observation data from 2007 to 2010, the model was validated. Based on the results, the root means squared error (RMSE) was found 0.06 and the coefficient of determination (R^2) was found 0.98 in steady state. In order to revise the estimated hydraulic conductivity (its map is shown in Fig. 5), the output of PMWIN model in a steady state condition was used.

After model calibration and validation in steady state condition, the model is calibrated again in the unsteady state condition. Observed hydraulic and calculated heads in unsteady state condition is shown in Fig. 6. Based on the output results, there is a good match between the observed and calculated head values. Then, the model was validated. The root mean squared error (RMSE) and the coefficient of determination (R^2) were found 0.09 and 0.99 respectively in an unsteady state condition. In order to revise the estimated specific yield (its map is shown in Fig. 7). The output of PMWIN model in unsteady state condition was used.

After calibration and validation steps, the system was predicted for the next 4 and 8 future years. Prediction of groundwater modeling system for the next future 4 years after the modeling period was done with basic conditions, while for the next future 8 years was done by considering 20% more water discharge from the aquifer. This prediction is chosen due to the situation of the area, which thousands hectares of the studied region is cultivated with crops and fruits, which needs irrigation. On the other hand, due to the weak supervision in this area, seven unauthorized wells were identified in this area. The amount of the water discharge from these wells are measured 0.71 Mm^3 annually. The discharge from these unauthorized wells also decrease more groundwater table and add more pressure on the groundwater system [20].

The output results of the water table in the first 4 and 8 years of prediction is shown in Fig. 8. As it is observed in Fig. 8, the decline rate of water table in this region during 4 years prediction is 1.1 m annually. According to 20% extra extraction of exploitation wells, the variation rate of the water table during future 8 years in Fig. 9 shows 12 m reduction of groundwater contour, which means a sharp decline of the water table in Rayen plain region. Note that, if extraction is done at this rate, the hydraulic conductivity of the aquifer will be reduced due to subsidence and porosity reduction.

4. Discussion

The main goal of modeling groundwater flow is to recognize the behavior of the aquifer system and finally applying proper management to optimally use groundwater resources. Studying the annual average of the water table of observation wells in Rayen aquifer showed that the water table was always decreasing (Fig. 10). The line graph of annual average of piezo metric levels of observation wells showed that during the study time (2001–2010), 3 observation wells (P7, P10, and P11) were dried up due to excessive extraction.

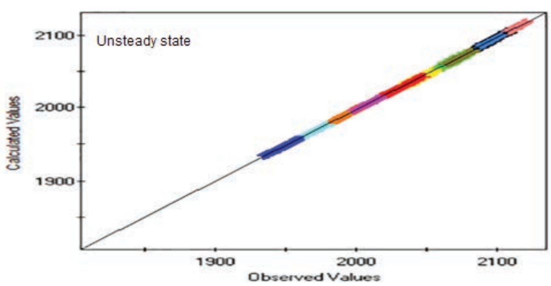

Fig. 6. Scatter plot of observed vs. computed water level in unsteady state conditions.

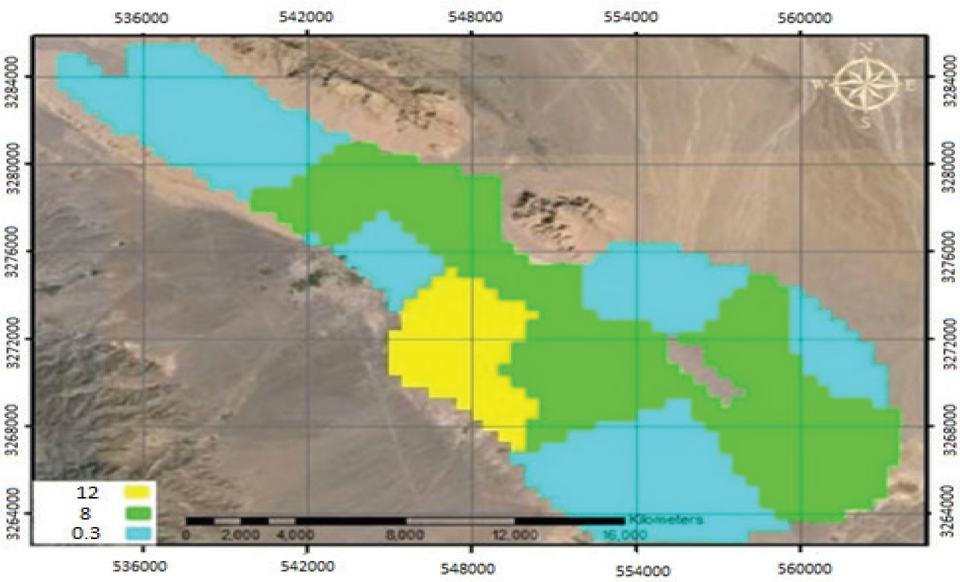

Fig. 5. Estimated hydraulic conductivity map.

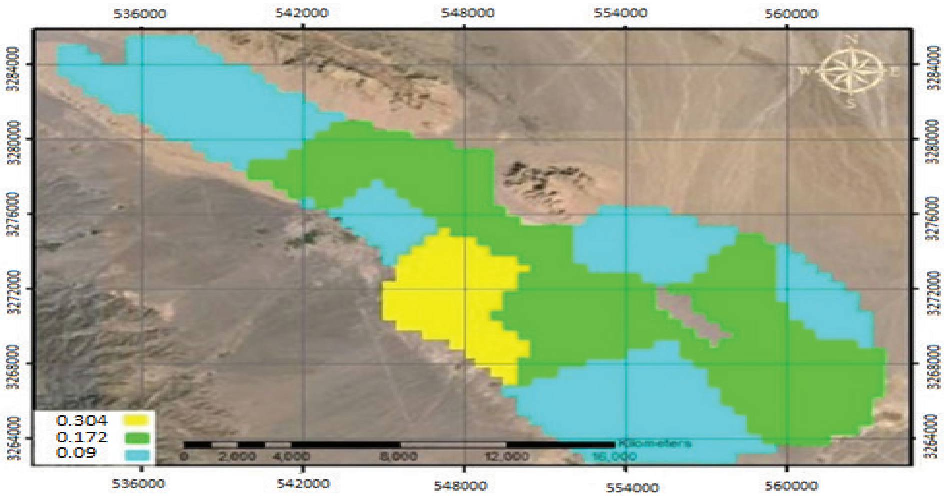

Fig. 7. Estimated specific yield map.

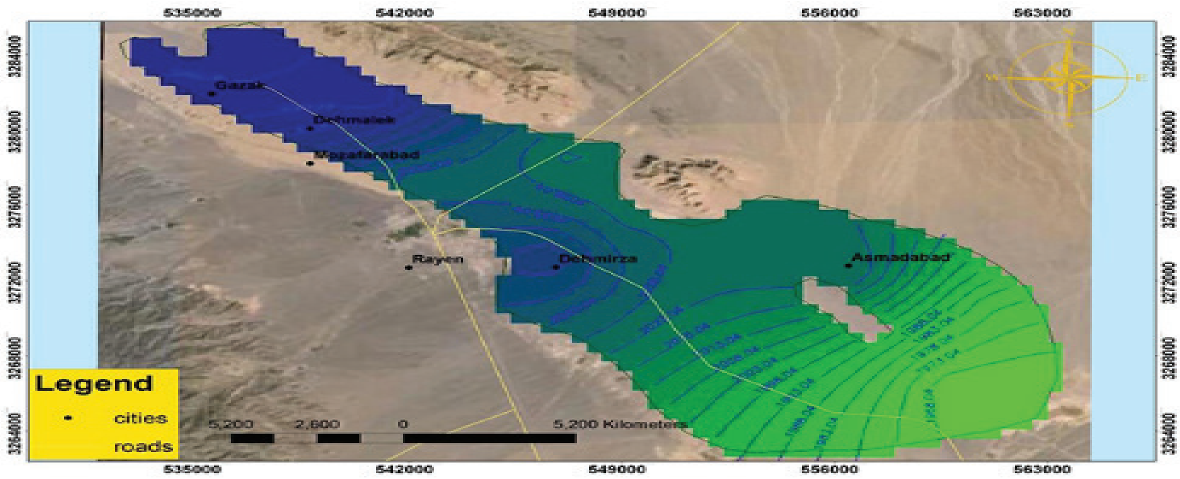

Fig. 8. Prediction of water level map in the next 4 years in current conditions.

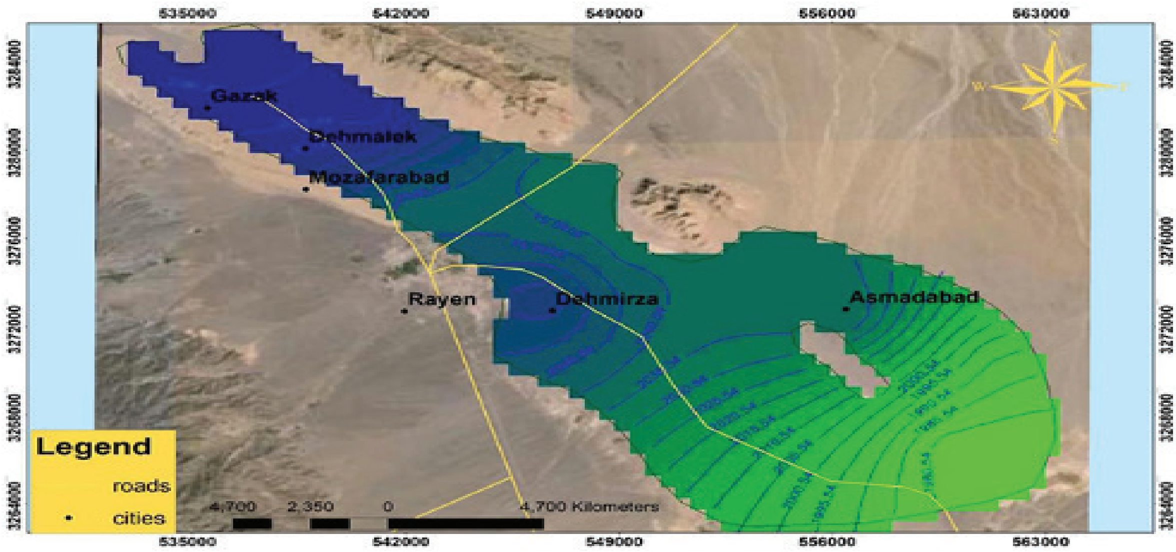

Fig. 9. Prediction of water level map with 20% more water discharge in the next 8 years.

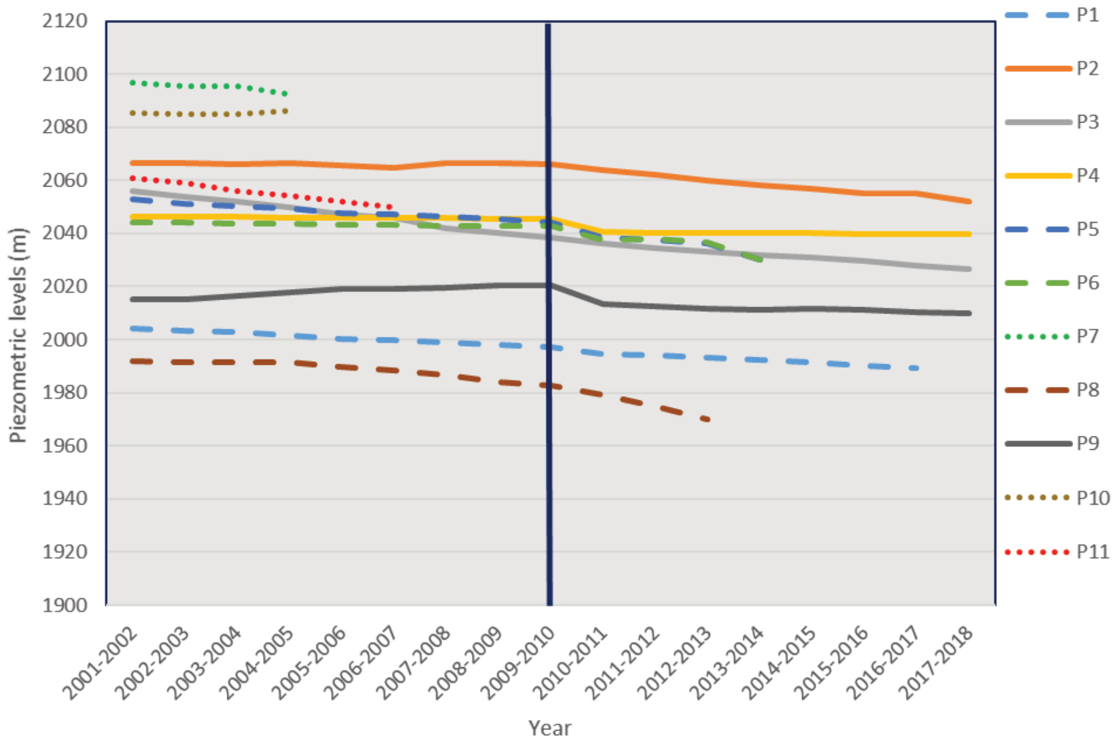

Fig. 10. An annual average of piezo metric levels of observation wells from 2001 to 2018.

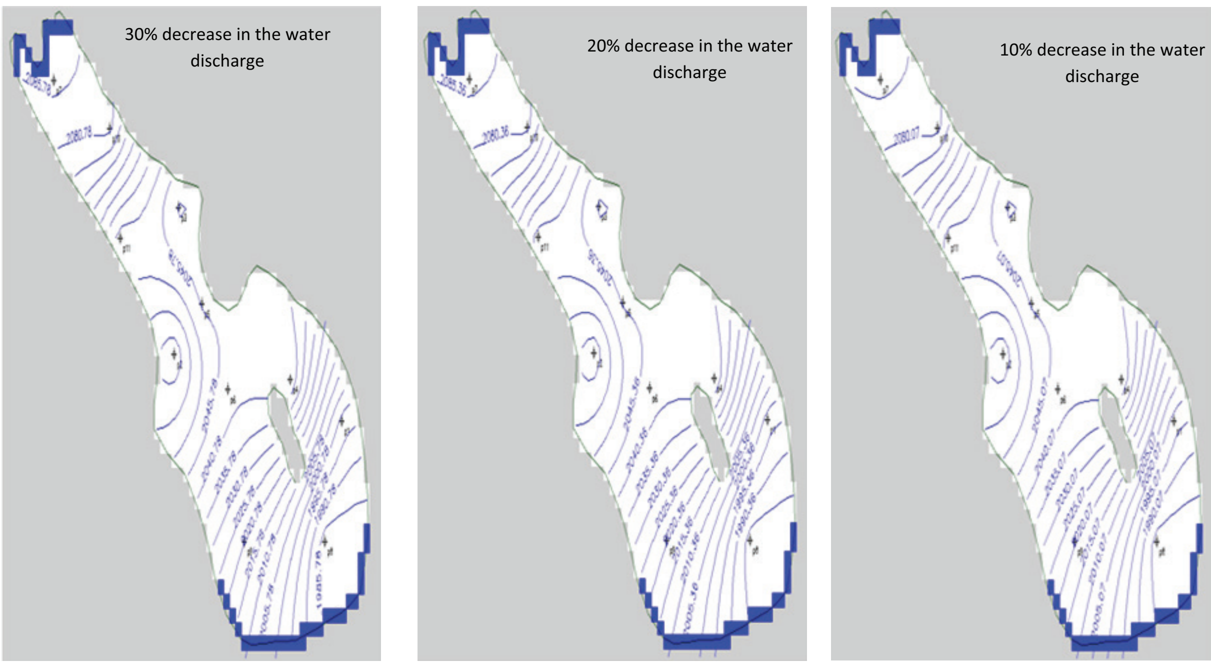

Fig. 11. Water level fluctuation map by considering 10%, 20%, and 30% decrease in the water discharge in the next 4 years (2010–2014).

So, more precise analysis was necessary to keep the aquifer for the future use. Meanwhile, the water table of observation wells from 2010 to 2018 were investigated. The results showed that by using this rate of water extraction from the aquifer, more wells were dried up (P5, P6, and P8). It means from 2010 to 2018, 6 observation wells out of 11 wells dried up. The obtained results show that if the extraction is continued from the aquifer in this way without proper management, other wells will be dried up soon.

In order to keep the aquifer, three scenarios 10%, 20%, and 30% reduction of extraction from the region wells in the next 4 years (2014) and 8 years (2018) were studied to manage the aquifer properly, prevent wells from drying up and return the aquifer to the balance situation. These scenarios

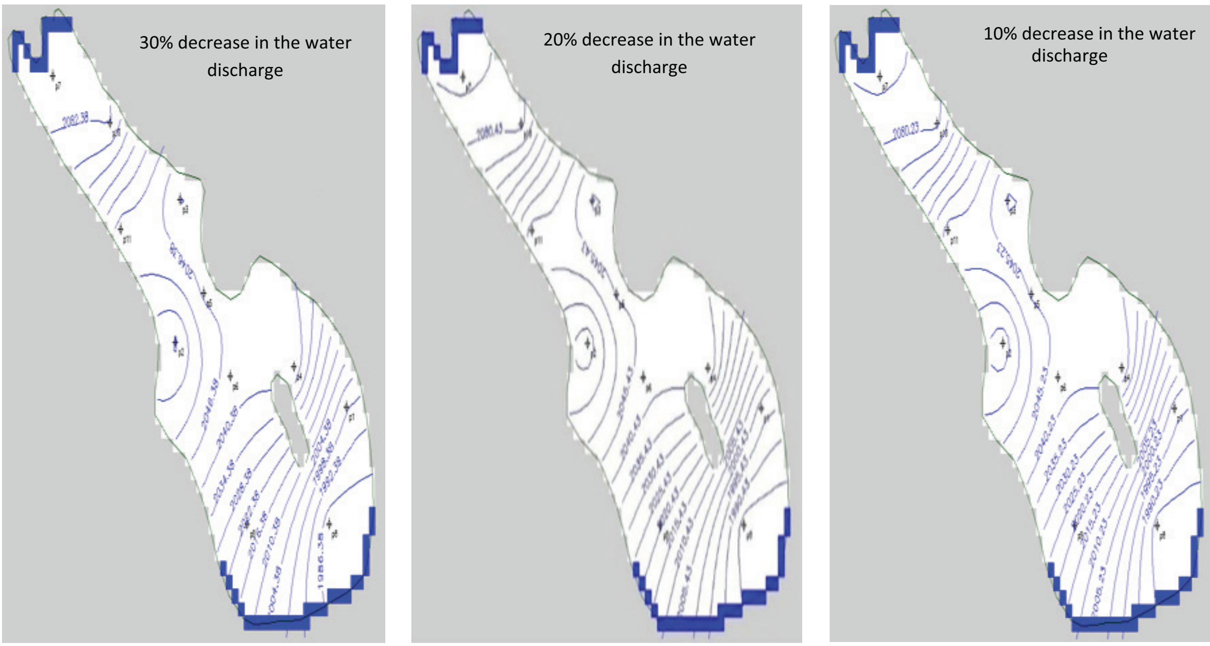

Fig. 12. Water level fluctuation map by considering 10%, 20%, and 30% decrease in the water discharge in the next 8 years (2010–2018).

were defined with the purpose of returning aquifer to the balance mode. Since the supply rate is almost uncontrollable, the supply rate considered as a past process in all scenarios but the extraction rate from groundwater in different scenarios were reduced for 10%, 20%, and 30% based on the data analysis and supply rate in different parts of aquifer. The results showed that by reducing 30% of the extraction from exploitation wells, whole aquifer could be saved for the future use. While 20% reduction in water extraction could keep parts of the aquifer and numbers of wells will be dried up. Moreover, by 10% reduction in water extraction rate, almost half of observation wells will be dried up. Results of predicting groundwater contour of the aquifer in future 4 and 8 years are shown in Figs. 11 and 12 respectively. El Idrysy et al. [26] evaluated the sustainability of the groundwater resources of the Trifa plain to manage the aquifer in a better way. The results indicated in order to achieve sustainable conditions, reduction in groundwater abstraction by at least 25% is necessary. Gibrilla et al. [27] investigated the groundwater levels reduction (2005–2014) by Mann-Kendall test, ARIMA models in the Upper East Region of Ghana and Sen's slope estimator since the groundwater is the main source of irrigation in this area. Based on the predicted results an average rate of reduction of 1.008 m/year observed where the groundwater level is expected to reduce to about 12 m by 2020.

5. Conclusion

Groundwater is the main source of irrigation and important parameter to increase crops production. Nowadays, due to population growth, food insecurity, poor water management, and low rainfall, the amount of groundwater extraction has been increased. Regarding these conditions, the groundwater levels in many areas are declining and STWs are not capable of pumping the groundwater during the peak irrigation period. The water table of Rayen plain in 2002–2010 was simulated by PMWIN software in the present study. Then, the model was calibrated and validated in both steady and unsteady conditions. The output results showed that the total groundwater level reduction during the studied period (2002–2010) was 9 m (averagely 1.1 m reduction annually), which shows a sharp decline of groundwater levels in this region. Therefore, for studying and predicting groundwater levels in future, the variation rate of the groundwater levels in next 8 years were studied by considering 20% extra extraction from exploitation wells. The given results showed the groundwater level reduction to 12 m. This shows a severe reduction of the water table in Rayen aquifer. Hence, after passing this period, even if the supply of aquifer is possible, the aquifer will not be supplied due to severe reduction of hydraulic conductivity that is resulted in losing groundwater reservoir. Thus, three scenarios were studied in order to return aquifer to its balance situation. These scenarios were constructed based on reducing groundwater extraction by 10%, 20%, and 30%. The results showed that proper planning with 30% reduction in extraction from exploitation wells could help to maintain the aquifer in the future.

References

[1] Z. Alipour, A.M.A. Ali, F. Radmanesh, M. Joorabyan, Comparison of three methods of ANN, ANFIS and time series models to predict ground water level: (Case study: North Mahyar plain), Bull. Environ. Pharmacol. Life Sci., 3 (2014) 128–134.

[2] G.A. Rahman, M.J. Faruque, M.H. Sohel, A. Sayed, Ground water level fluctuation and its impact on irrigation cost at Jessore Sadar of Bangladesh, Agric. For. Fish., 5 (2016) 37–42.

[3] A. Toure, B. Diekkrüger, A. Mariko, M. Boukari, A. Cisse, Groundwater Flow Modeling with Processing Modflow for Windows (PMWIN) for Water Balance Assessment Under Climate Variability in the Klela Basin, Southern Mali, in: AGU Fall Meeting Abstracts, 2015.

[4] A. Sedki, D. Ouazar, Swarm intelligence for groundwater management optimization, J. Hydroinform., 13 (2011) 520–532.
[5] M. McDonald, A. Harbaugh, A Modular Three-Dimensional Finite-Difference Groundwater Flow Model, U.S. Geological Survey Techniques of Water-Resources Investigations, 1988.
[6] J. Rumbaugh, D. Rumbaugh, Guide to Using Groundwater Vistas, Environmental Simulation, Reinholds, PA, USA, 2004.
[7] S.-G. Li, Q. Liu, Interactive ground water (IGW), Environ. Model. Softw., 21 (2006) 417–418.
[8] A. Harbaugh, E. Banta, M. Hill, M. McDonald, The US Geological Survey Modular Ground-water model-user Guide to Modularization Concepts and the Ground-water Flow Process, open-file rep 00-92. Technical report, US Geological Survey, Denver, CO, 2000.
[9] W.-H. Chiang, W. Kinzelbach, 3D-groundwater modeling with PMWIN, Springer, Berlin, 2001.
[10] P.-L. Lin, K.-C. Hsu, C.-W. Lin, H.-H. Hwung, Modeling compaction of multi-layer-aquifer system due to groundwater withdrawal, Eng. Geol., 187 (2015) 143–155.
[11] N.W. Kim, I.M. Chung, Y.S. Won, J.G. Arnold, Development and application of the integrated SWAT–MODFLOW model, J. Hydrol., 356 (2008) 1–16.
[12] A. Kallioras, F. Pliakas, I. Diamantis, Simulation of groundwater flow in a sedimentary aquifer system subjected to overexploitation, Water Air Soil Pollut., 211 (2010) 177–201.
[13] S. Qiu, X. Liang, C. Xiao, H. Huang, Z. Fang, F. Lv, Numerical simulation of groundwater flow in a river valley basin in Jilin Urban area, China, Water, 7 (2015) 5768–5787.
[14] W. Shiqin, S. Jingli, S. Xianfang, Z. Yongbo, H. Zhibin, Z. Xiaoyuan, Application of MODFLOW and geographic information system to groundwater flow simulation in North China Plain, China, Environ. Geol., 55 (2008) 1449–1462.
[15] H. Lin, L. Lin, The development of GIS-PMWIN and its application for mine-water modelling in the Far West Rand, South Africa, Water SA, 40 (2014) 313–322.
[16] A. Shakoor, M. Arshad, Vulnerability assessment of groundwater quality deterioration using PMWIN model, Int. J. Environ. Ecol. Eng., 2 (2015) 1–10.
[17] F. Lachaal, A. Mlayah, M. Bédir, J. Tarhouni, C. Leduc, Implementation of a 3-D groundwater flow model in a semi-arid region using MODFLOW and GIS tools: the Zéramdine–Béni Hassen Miocene aquifer system (east-central Tunisia), Comput. Geosci., 48 (2012) 187–198.
[18] K.R.W. Authority, Hydrologic Studies, Quantitative and qualitative studies of the Rhine Plain, Vol. 2, 2003.
[19] K.R.W. Authority, Geology and Hydrogeology, Quantitative and qualitative studies of water resources in the Rayen Plain, Vol. 3, 2003.
[20] K.R.W. Authority, Report on Rayen area Studies, Department of water-based studies, 2006.
[21] O.O.W.R.S. Planning, Geophysical Studies of the Raine Plain of Kerman, geo-electric sections, groundwater department, Geophysics group, (1990) 48–57.
[22] Y. Yao, C. Zheng, J. Liu, G. Cao, H. Xiao, H. Li, W. Li, Conceptual and numerical models for groundwater flow in an arid inland river basin, Hydrol. Process., 29 (2015) 1480–1492.
[23] I. Chenini, A.B. Mammou, Groundwater recharge study in arid region: an approach using GIS techniques and numerical modeling, Comput. Geosci., 36 (2010) 801–817.
[24] L.C. Engineer, Statictics and Information Primary Review of Technical Exploration and Pizeometric Wells, Integr. Rep. Water Resour. Loot Desert Basin, 1 (2010) 1–57.
[25] L.C. Engineer, Analysis of Water Balance Statistics and Information, Integr. Rep. water resour. Loot Desert Basin, 3 (2010) 153–210.
[26] H. El Idrysy, F. De Smedt, Modelling groundwater flow of the Trifa aquifer, Morocco, Hydrogeol. J., 14 (2006) 1265–1276.
[27] A. Gibrilla, G. Anornu, D. Adomako, Trend analysis and ARIMA modelling of recent groundwater levels in the White Volta River basin of Ghana, Groundwater Sustainable Dev., 6 (2018) 150–163.