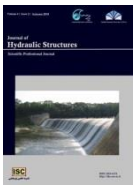
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Numerical investigation of groundwater balance and artificial recharge in the Kerman-Baghin Aquifer

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Abstract

In the present paper, the behavior of Kerman-Baghin aquifer has been investigated using the MODFLOW program and GMS 10.3 software. The piezometer data during October 2011 are applied for steady state condition of groundwater modeling. Then, the model is calibrated for 66 months for unsteady condition using observational information, and it is validated for 24 months. Finally, the results are compared with the available observed data and show acceptable accuracy in calibration and validation steps. After validating the model, the status of the aquifer is estimated for a period of 5 years. Management scenarios including 10, 20 and 30 percent reduction in groundwater abstraction as well as artificial recharge at eight selected aquifer sites have been investigated. The location of artificial recharge sites is selected based on seven parameters of land slope, distance from waterways, distance from faults, electrical conductivity, hydraulic conductivity, geology of the area and groundwater depth (thickness of unsaturated area). These parameters are combined with the index overlay method by Arc GIS 10.3 software. The results show that by continuing the current situation, the Kerman-Baghin aquifer could face an average annual deficit of more than 52 million cubic meters. It may cause various problems in the near future including abstraction water from groundwater sources and reducing water quality. The results of implementing different scenarios show that, the best scenario can be obtained by 10% reducing water withdrawal with artificial recharge in four zones 1, 2, 10 and 12.

Keywords: Numerical modeling, Groundwater, Artificial recharge, GMS, MODFLOW.

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1. Introduction

Iran is located among the arid and semi-arid regions, so water resources are of special importance. In most regions of the country, due to the lack of permanent surface water resources and also precipitation shortage, especially in desert and hot areas, groundwater resources are the only reliable and available resources. Most of the water consumption in Iran is supplied from groundwater resources, and the exploitation of groundwater has long been common in the country [1].

Proper management and optimal use of groundwater resources is necessary to maintain these resources. Understanding the behavior of aquifers requires geophysical experiments, drilling numerous exploratory wells, pumping operations, and spending a lot of time and money. Numerical simulation of groundwater flow is an indirect study method that can lead to an understanding of aquifer behavior at a lower cost rather than direct methods. The knowledge obtained from aquifers can result to solve the problems of aquifers. If a mathematical model is applied accurately, it can be used to predict the state of water resources in the future, and to explain the effect of conditions applied to a groundwater aquifer [2].

Due to the importance of modeling and managing water resources, various researches have been conducted on this subject. Simulation of groundwater resources in Sirjan plain using MODFLOW model was investigated by Najafabadi et al., 2007 in order to manage water resources in this plain. This study, referring to the change in the method of exploiting groundwater and the use of deep wells instead of using aqueducts, considered uncontrolled extraction and reduction of water level as the consequences of changes in the method of exploitation and use of deep wells. According to the hydrograph of the plain unit, the average annual drop of the water table in different parts of the plain is 70 cm per year and in the western areas of the plain due to the concentration of exploitation wells is about 2 meters per year. This has caused the influx of saline water aquifer to the Sirjan plain and the decrease of groundwater quality in these areas [3].

Yang et al., 2011 conducted a study of a 400-square-kilometer groundwater aquifer in the Chinese city of Tangli. A 3D modeling of the groundwater aquifer was done by MODFLOW software. It was concluded that the results of the model and the performed measurements are acceptable. This model can be used in the future to manage the aquifer and compare different scenarios of exploitation and management [4].

Al-Hassoun and Mohammad, 2011 studied an aquifer in Saudi Arabia. Numerical modeling of the aquifer based on extraction, rainfall, aquifer recharge, boundary conditions and hydrological conditions of the aquifer was performed by MODFLOW software. Results indicated that MODFLOW software performs simulations in dry areas with appropriate accuracy. It was also found that in the five-year period in which the simulation was performed, the decline in the water levels is not significant. This allows for more groundwater abstraction without serious impact on aquifer storage [5].

Sikdar and Chakraborty, 2017 investigated groundwater aquifers in northern India. Using the MODPATH software, the numerical model of the aquifer was created according to the amount of abstraction (based on the per capita consumption of the population of the region) and other boundary conditions and hydraulic conditions of the aquifer. The simulation was used to determine the effect of pumping on arsenic concentration in groundwater aquifers and water resources of North Bengal plain. Results showed that the path of arsenic in the groundwater aquifer is almost vertical [6].

Salameh et al., 2019 conducted a study on aquifers in Jordan. The purpose of this study was to evaluate the success or failure of aquifer artificial recharge projects and also to define a

management method for recharge and abstraction aquifers. In the study, according to the quality and amount of water abstracted from aquifers, topographic conditions and hydraulic conditions of aquifers, including the capacity and amount of recharge and water quality, a suitable structure for abstraction and recharge of each aquifer was proposed. As a result of this study, it was found that artificial recharge of groundwater aquifers can be useful in some aquifers and may not have good results in some others [7].

Norouzi et al., 2019 investigated the potential zones of groundwater artificial recharge in Shabestar region, northwest of Iran. They proposed a learning method based on ensemble decision trees, namely random forest model to determine the location of groundwater artificial recharge. Results showed the high accuracy of RF model in locating groundwater artificial recharge [8].

Sharafati et al., 2020 presented a new approach for prediction of the monthly groundwater level over the Rafsanjan aquifer located in Iran. They proposed an ensemble machine learning algorithm named Gradient Boosting Regression. The results showed that the proposed method is capable and reliable for water resources planning [9].

Alem et al., 2021 proposed a method based on GIS analysis to estimate the ground water recharge amount in the Mashhad plain, Iran. The study aimed to identify potential locations for developing karst formations using calculating infiltration percentage of formations [10].

The present paper deals with numerical investigation of groundwater balance in the Kerman-Baghin Aquifer. The area is among arid and semi-arid regions, and due to the lack of surface water resources, groundwater considered as the only available resource. According to recent droughts, the elevation of water table is decreased. A part of the Kerman-Baghin aquifer with an area of 357 Km^2 was modeled by Tahmasebi (2013) using the data of the year 2002. In the present study, the total area of the aquifer ,5420 Km^2 is considered. Furthermore, it is tried to numerically detect the aquifer balance and artificial recharge and some possible management solutions have been presented to return the aquifer to the acceptable level. Therefore, at first, all meteorological, hydrological, hydrogeological, geophysical, geological and geographical information of the plain has been analyzed. The main purpose of this research is the quantitative simulation of groundwater in the Kerman-Baghin plain by GMS software. This simulation is conducted by the MODFLOW program. With a quantitative simulation, the current trend of the plain can be examined. Predicting the future status of the aquifer under different management options can be considered as the final result of current numerical modeling.

2.1. Materials and Methods

2.2. The geographical location of the region

Kerman-Baghin study area with geographical coordinates of 56° and 30 minutes to 57° and 30 minutes of eastern length and 29° and 50 minutes to 30° and 30 minutes of northern latitude is located in Lut desert edge, southeast of Iran. Kerman-Baghin study area is shown in Figure 1. This area is about 5420 square kilometers, including 2719 square kilometers of heights and 2701 square kilometers of plains. The area of the aquifer located in this plain is 2025 square kilometers.

The highest point in this area is Jopar, which is 4000 meters above sea level and is located in the south of the plain. This high point plays a major role in the recharge of the region. Precipitation on Jopar Mountain affects the inlet parts of the plain, including Jopar lands, and finally is transferred to the main river of the region by the waterways created in this area and the existing canals. This river flows from the branches of Jopar Mountain and the slopes of the southern heights of Kerman as well as the heights of Fallah Mountain in 40 km northwest of

Baft city to Baghin-Kabutarkhan. Then finally leads to the lands of Kabutarkhan. The maximum altitude in the study area of Kerman is 4200 meters on the heights of the plain margin, and the minimum height to the central part of the Kerman-Baghin plain is 1700 meters above sea level. The slope of the plain is from south and southwest to north and northeast. The flow of water with a gentle slope follows the slope of the plain [11].

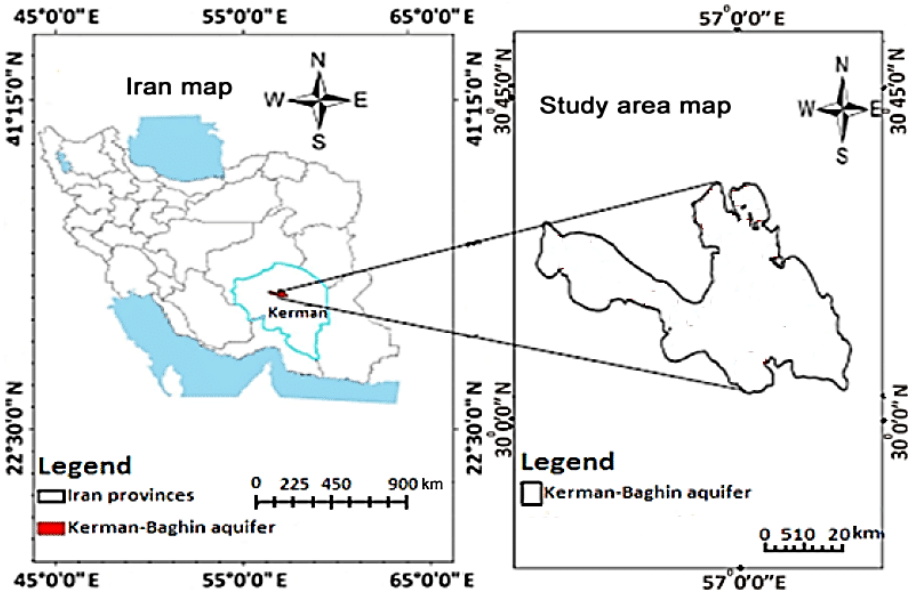


Figure 1. Location of Kerman-Baghin study area in Kerman province

2.3. Preparation of conceptual model

The conceptual model expresses the interactions in nature simply and graphically. Creating a conceptual model requires knowing all the effective parameters in groundwater flow. These factors include determining the aquifer's geometry, type and materials, how the aquifer relates to the geological formations around the plain, the status of the model boundaries, sink sources, and the groundwater flow system.

The first step in preparing a conceptual model is introducing the desired aquifer's geometry to the software. It was done by entering the aquifer map into the software.

Identifying boundaries requires field information. Boundaries with special hydraulic head are mostly used for areas where the river is part of the aquifer boundary. In Kerman-Baghin aquifer, impermeable boundaries with general head was used. The general head boundary means the water is not fixed, and it level may change. In order to determine the water level and assign it to nodes at both ends of the border with general head, the information of observation wells and drawing of contour lines of water level were used. For unsteady modeling, the water level at these boundaries must be calculated several times and assigned to these boundaries due to changes in the aquifer water level.

The most important supply sources for the Kerman-Baghin aquifer are groundwater flow, rainfall, return of water from wells, and due to seasonal rivers and canals. A recharge set was used to apply the inflow in different areas to the model. Aquifer recharge is considered as a calibration parameter, and its initial value was considered based on the infiltration of rainfall and return of agricultural, drinking and industrial water to the aquifer. The basis of this recharge is only the upper layer of the aquifer and the inlet flows to the aquifer enter the aquifer through the

borders with a general hydraulic head. River recharge can also be applied to the model by the rivers. Since the Kerman-Baghin plain rivers are seasonal rivers, their effects on aquifer recharge to the entire aquifer surface have been applied by the recharge set.

When the water level rises above a certain level and is close to the ground (up to a depth of four meters), it can evaporate under the influence of sunlight. The GMS software simulates evaporation from the water table using a set of evapotranspiration. According to the information of observation wells in Kerman-Baghin plain, the groundwater level has always been at a depth of more than five meters from the ground surface. Therefore, evaporation from the water table does not occur in this aquifer and evapotranspiration has not been considered in this modeling.

Pumping wells, aqueducts and springs are discharge points indicated by the node in the model. In modeling, the pumping rate is specified for each node. In both 2D and 3D modeling, it is assumed that the well penetrates the entire thickness of the aquifer and as a result water is extracted from the total thickness of the aquifer.

Observatory wells or piezometers are the criteria for calculating the model and measuring its acceptability. For this reason, accuracy in counting observation wells and simulating them is of particular importance.

There are 107 observed wells in the Kerman-Baghin plain, many of which have lack of data for several years. Therefore, 35 observed wells with suitable scattering in the aquifer were identified that the water level information was complete during the modeling period and used for aquifer modeling.

Physically, the upper boundary of the groundwater aquifer is the surface topography. The ground surface DEM file was used to apply the ground surface topography to the model. 10,000 ground points were randomly selected by the GIS software and introduced as ground points in the area. By interpolating between these points, the land surface in the area was obtained by the Kriging method.

The lower boundary of the aquifer is often considered the most impermeable layer, called the bedrock. The main reference for applying bedrock topography to the model is exploratory studies conducted in the plain. In order to apply the topography of the bedrock in addition to the information of the exploratory wells in the Kerman regional water report [9], the statistics of old exploration wells in the archives of the Regional Water Organization, including 330 exploration points located in the Kerman-Baghin plain, were also used. In order to create the topography of the bedrock, the Kriging method interpolation between exploratory wells was used.

According to the pumping experiments performed in Kerman-Baghin plain, at the beginning of modeling, the hydraulic conductivity in different areas of the aquifer was considered between 0.4 to 85 meters per day. Due to the small amount of pumping tests in the plains, it is necessary to modify this value during modeling to achieve maximum compatibility between computational data and field data. The calibration process is performed for this parameter. Anisotropy of hydraulic conductivity was initially considered for all parts of the aquifer. This parameter can also be changed in the model calibration process and improve the model performance.

The aquifer's basic conceptual model was prepared after entering information such as the aquifer's hydraulic boundaries, aquifer recharge, the aquifer utilization, observation wells, surface topography, bedrock topography and hydraulic gradient of the aquifer. Rectangle cells with dimensions of 450 meters were used for meshing the Kerman-Baghin watershed numerical domain. In this way, the conceptual model information was identified to each cell, and the governing equations were numerically solved.

Figure 2 represents the procedure of preparation and implementation of the conceptual and numerical model for the Kerman-Baghin aquifer.

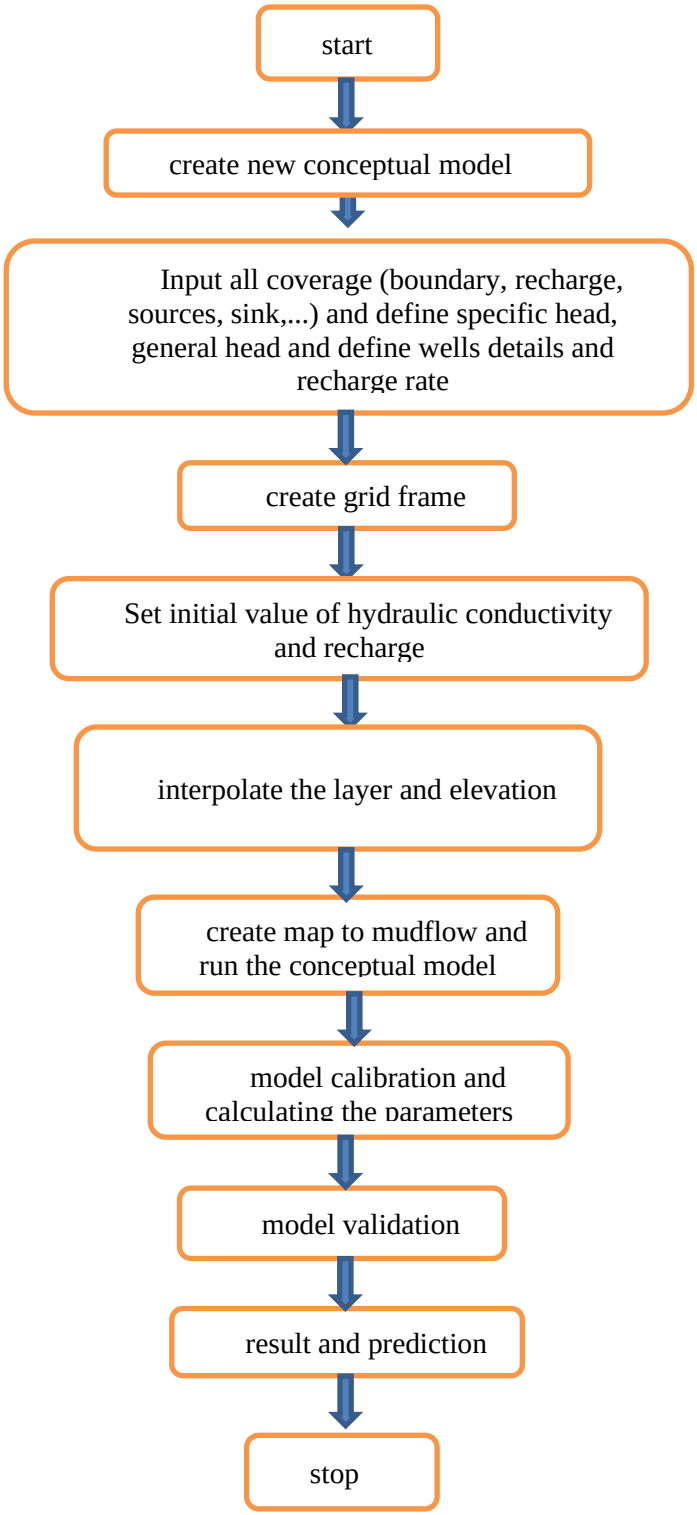


Figure 2. the flowchart of methodology for the Kerman-Baghin aquifer model

2.4. Governing equations

The governing equations include the Darcy law for water flow through a porous media, general equation for groundwater flow and unsteady flow in an unconfined aquifer [13].
For a three-dimensional flow of groundwater in a porous medium with a constant specific gravity, the following partial differential relation can be expressed:

$$\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_{zz}\frac{\partial h}{\partial z}\right)\pm w=s_s\frac{\partial h}{\partial t} \quad (1)$$

Where, k_{xx} ، k_{yy} and k_{zz} are the hydraulic conductivity along the x, y and z axe; h piezometric head; w current flow per unit volume, which indicates the source or sink, s_s specific storage coefficient and t is time.

Equation (1) describes groundwater flow in conditions of imbalance in a heterogeneous environment and unsteady conditions along axes. In steady-state currents, equation (1) will be equal to zero [14].
The general equation of flow in an unconfined aquifer is presented as equation (2):

$$\frac{\partial}{\partial x}\left(k_x h\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y h\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z h\frac{\partial h}{\partial z}\right)=s_y\frac{\partial h}{\partial t} \quad (2)$$

If the medium is homogeneous and isotopic, it is expressed as equation (3):

$$\frac{\partial}{\partial x}\left(h\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(h\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(h\frac{\partial h}{\partial z}\right)=\frac{s_y}{k}\frac{\partial h}{\partial t} \quad (3)$$

If the changes in the water table are small relative to the thickness of the aquifer, the head changes along the Z- axis is not considered and equation (3) is changed to equation (4) [15].

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}=\frac{s_y}{kh}\frac{\partial h}{\partial t}=\frac{s_y}{T}\frac{\partial h}{\partial t} \quad (4)$$

Where, s_y is the specific yield that represents the storage coefficient in an unconfined aquifer.

2.5. Implementation of mathematical model

After the model parameters were correctly assigned to each cell, a computational method must be selected for solving the governing partial differential equation. In this research, the MODFLOW 2000 computational model and the forward method were used. In this study, the Preconditioned Conjugate Gradient (PCG) [16] computational method was selected to run the model. The initial implementation of the model in steady state based on the information of observation wells, exploitation wells, aqueducts and springs was carried out in October 2011.

Impermeable boundaries and general head boundaries were applied for the Kerman-Baghin aquifer model. The reason for using the general type of hydraulic head boundary is that the water level in this type of boundary is not fixed and the water level may change. Moreover, the inlet or outlet flow rate changes according to the hydraulic gradient at the boundary and permeability of the boundary cells. To determine the water level and assign it to the nodes at both ends of the borders with general hydraulic head, the information of observation wells and drawing contour

lines of water level were used.

In order to calibrate the model in the steady state, data from 35 observation wells in October 2011 were used. At this stage, the hydraulic conductivity, recharge rate and general hydraulic head at some permeable boundaries were changed by trial and error based on the model response to the applied changes. Then, using the Pest algorithm, the calibration was performed automatically. In automatic calibration, hydraulic conductivity, horizontal anisotropy, aquifer recharge and hydraulic head at permeable boundaries were introduced as calibration parameters. Transferability after several calibration steps was considered as a constant value for each boundary.

In order to change the model to the unsteady state, the parameters calibrated in the steady state used as the basis for the formation of the model in the unsteady state. Also, the desired time steps for unsteady modeling and information of piezometers, exploitation wells and boundaries with general hydraulic head in these time steps were introduced to the model. The model was run in unsteady mode from October 2011 to March 2017 in 66 months. Data of 35 observation wells were used to calibrate the model in the unsteady state. Like steady-state calibration, the first calibration was performed in several stages with trial and error. During these stages, the hydraulic conductivity and recharge rate have changed. Then it was automatically calibrated using the Pest algorithm. In automatic calibration by regional method, hydraulic conductivity, specific yield and aquifer recharge were introduced as calibration parameters.

The purpose of validation is to prove that the calibrated model has the ability to simulate events. Also, the combination of parameters used in the model is correct. In the validation stage, if the model can simulate events with appropriate accuracy, the combination of parameters used in the model is correct. As a result, model predictions can be acceptable.

This model was validated without changing the amount of calibrated parameters for 24 months from April 2017 to March 2020. To understand the behavior of observation wells over time, Figure 3 shows the trend of observed and simulated water level changes for two monitoring wells.

To ensure the accuracy of the model, the model was validated for 24 months. The accuracy of this modeling is shown in Table 3. Each of the parameters presented in Table 1 is based on equations 5 to 9.

$$\mathrm{ME} = \max\{|c_i - o_i|\}_{i=1}^{n} \tag{5}$$

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n}|c_i - o_i|}{n} \tag{6}$$

$$\mathrm{RMSE} = \left[\sum_{i=1}^{n}\frac{(c_i - o_i)^2}{n}\right]^{0.5} \tag{7}$$

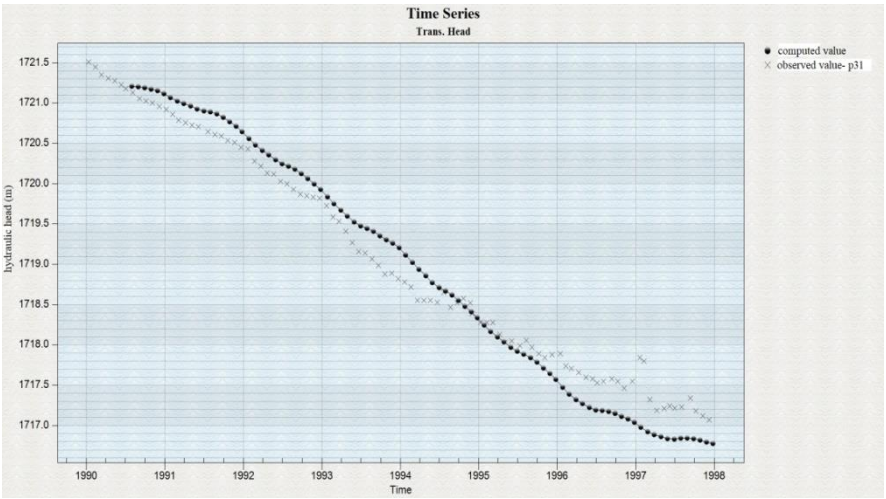
$$\mathrm{NRMSE} = \frac{\mathrm{RMSE}}{O_{max} - O_{min}} \tag{8}$$

$$R^2 = \left(\frac{n(\sum_{i=1}^{n} c_i o_i) - (\sum_{i=1}^{n} c_i)(\sum_{i=1}^{n} o_i)}{\sqrt{\left[n\sum_{i=1}^{n} c_i{}^2 - (\sum_{i=1}^{n} c_i)^2\right]\left[n\sum_{i=1}^{n} o_i{}^2 - (\sum_{i=1}^{n} o_i)^2\right]}}\right)^2 \tag{9}$$

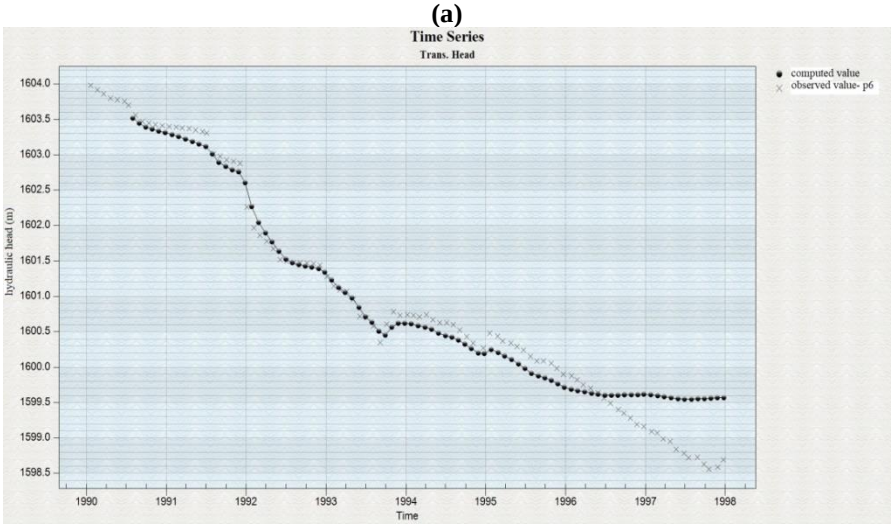
In the above equations o is the observed value, c is the calculated value by the model and n is the data number.

Table 1. Modeling accuracy

Validation period (24 time steps)		Calibration period (66 time steps)	
ME (m)	0.35	ME (m)	0.37
MAE (m)	1	MAE (m)	0.83
RMSE (m)	1.35	RMSE (m)	1.42
NRMSE	0.44 %	NRMSE	0.46 %
R^2	0.99	R^2	0.99



(a)



(b)

Figure 3. Computed and observed values in the calibration and validation stage (a) for piezometer 31 (b) for piezometer 6

3.1. Prediction of various management scenarios

Using the modeling, the condition and level of the aquifer can be predicted under various scenarios, including an increase or decrease in abstraction or a change in aquifer recharge. It is possible to compare the efficiency of groundwater management programs with each other and

(b)(a)

choose the best solution to balance and prevent excessive water level drop in the Kerman-Baghin aquifer. This is one of the best and least expensive ways to manage an aquifer.

Table 2 examines the future status of the aquifer under various stresses and management scenarios in a five-year period after the validation period, ie from April 2019 to March 2024. In this study, in order to predict the status of groundwater aquifers, the MODFLOW 2005 calculation code was used with the forward method and PCG calculation method.

Table 2 Management Scenarios

Scenario	Description	Duration	Feedback The average level in the Kerman-Baghin aquifer in March 2024 (meters)
Reference scenario	none of the model parameters have changed and in these five years, the amount of pumping and recharge was applied to the model as in previous years.	5 years	1683.2
Scenario 1	Since April 2019, only groundwater abstraction has been reduced by 10% and other parameters have been applied to the model without change compared to previous years.	5 years	1686.7
Scenario 2	Since April 2019, only groundwater abstraction has been reduced by 20% and other parameters have been applied to the model without change compared to previous years.	5 years	1689.1
Scenario 3	Groundwater abstraction was applied to this model in 2019 and 2020 unchanged and as in previous years, and then the groundwater abstraction rate was 10% in 2022, 20% in 2023 and 30% in 2024. Other parameters have been applied to the model without change compared to previous years.	3 years	1688.02
Scenario 4	From April 2018, artificial recharge was applied at sites number one, two, three, five, seven, nine, ten and twelve. The amount of recharge in these areas has changed. Other parameters have been applied to the model without change compared to previous years.	5 years	1689.7
Scenario 5	Since April 2018, groundwater abstraction has been reduced by 10% and artificial recharge has been applied at sites number one, two, ten and twelve, and the amount of recharge in these areas has changed. Other parameters have been applied to the model without change compared to previous years.	5 years	1690.8

In artificial recharge scenarios, after determining the susceptible location of artificial recharge, according to Darcy's law, the amount of infiltration from artificial recharge to the aquifer was calculated and applied to the model. The ratio of vertical hydraulic conductivity to horizontal hydraulic conductivity for sedimentary materials is between 0.1 and 0.5. If there are layers of clay in them, it reaches 0.01 [17]. Due to the fact that after the implementation of artificial recharge projects, some fine particles deposit in the area and reduce permeability. In this study, 0.01 of horizontal hydraulic conductivity was used to calculate the vertical hydraulic conductivity. Due to the fact that in Kerman-Baghin plain, the average monthly rainfall in January, February, March and April is higher than other months, the time of applying artificial recharge to the aquifer from January to the end of April 2019 to 2023 Taken. To identify suitable places for recharge, it is necessary to identify the effective parameters and use them as a criterion for selecting a suitable place for artificial recharge. In this study, seven parameters of land slope, distance from waterways, distance from faults, electrical conductivity (EC), hydraulic conductivity (HK), geology of the area and groundwater depth (thickness of unsaturated area) as effective parameters in locating artificial recharge used. The information layers of the parameters mentioned in Arc GIS software have been prepared. Weighing and layering were performed by index overlay method.

The index overlay model was used to integrate information layers. In this model, in addition to weighing the units of the information layer, each layer (map) is weighed based on its value. In this research, multi-class maps model has been used in which the value of each pixel in the output map is determined according to equation (10). The weight range in this model depends on the researcher [18].

$$S = \frac{\sum_i^n S_{ij} W_i}{\sum_i^n W_i} \tag{10}$$

In the above formula S is the value of each pixel in the final map; S_{ij} is unit weight from jth map and W_i is ith map weight. The unit weight of each layer and the weight of each layer of information are presented in Table 3.

Table 3 Classification and weighting of effective factors in locating artificial recharge in Kerman-Baghin plain

The weight of each layer	The Weight of each unit (substrate)	value	parameters	The weight of each layer	The Weight of each unit (substrate)	value	parameters
0.07	10	0-1000	Electrical conductivity (Micro mohs per centimeter)	0.2	10	0-2	Slope (percentage)
	9	1000-1500			9	2-4	
	8	1500-2000			8	4-5	
	7	2000-3000			6	5-7	
	6	3000-4000			5	7-9	
	5	4000-5000			4	9-14	
	3	5000-7000			3	14-20	
	2	7000-9000			2	20-29	
	1	9000-11000			1	29-40	
	0	11000-13000			0	40-50	
0.08	0	0-0.2	Hydraulic conductivity (meters per day)	0.15	0	0-100	Distance from waterways (meters)
	1	0.2-0.5			10	100-500	
	2	0.5-1			9	500-750	
	3	1-2.5			8	750-1000	
	5	2.5-5			7	1000-1500	
	6	5-10			6	1500-2000	
	7	10-20			4	2000-2500	
	8	20-30			3	2500-3000	
	9	30-50			2	3000-3300	
	10	50-78			1	3300-3800	
0.15	10	QS	Geology	0.15	0	0-200	Distance from faults (meters)
	9	Qt2, Qt1			10	200-500	
	3	other			9	500-1000	

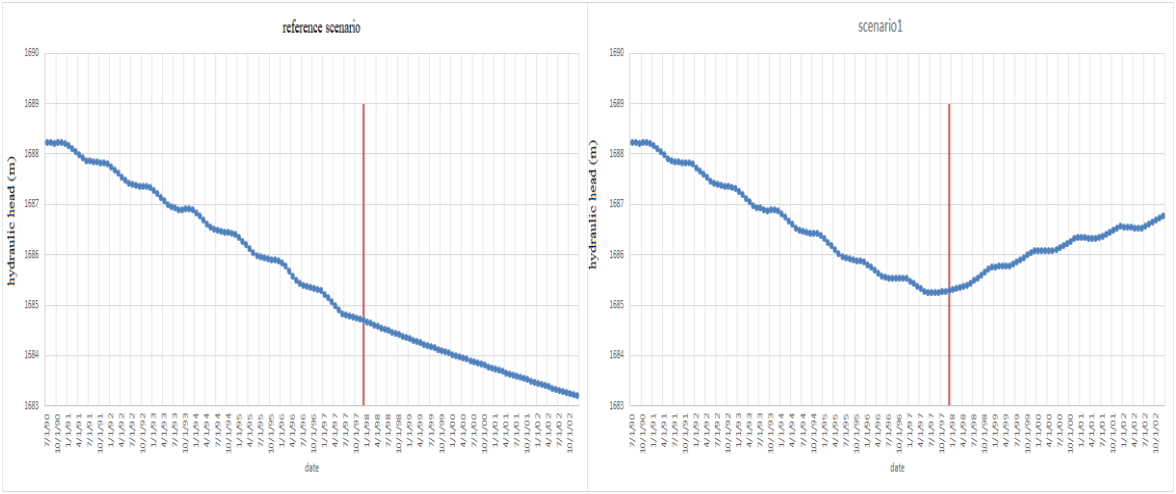
The weight of each layer	The Weight of each unit (substrate)	value	parameters	The weight of each layer	The Weight of each unit (substrate)	value	parameters
0.2	0	0-15	Unsaturated Area thickness (meters)	0.15	8	1000-2000	Distance from faults (meters)
	10	15-30			7	2000-3000	
	9	30-40			6	3000-5000	
	8	40-50			4	5000-10000	
	7	50-60			3	10000-15000	
	6	60-70			2	15000-20000	
	5	70-80			1	20000-27000	
	4	80-90					
	2	90-100					
	1	100-130					

4.1. Results and discussion:

According to the past sections, after entering complete information in GMS software, the conceptual model of Kerman-Baghin aquifer was prepared. A conceptual model was developed to determine the boundary conditions and simplify the model. Then, by gridding the model and dividing the aquifer into squares with a size of 450 meters, the conceptual model became a numerical model. This grid size has been selected according to grid sensitivity analysis. There are three different grid sizes including 350, 450 and 1000 meters considered for the modeling. The model results for grid size 1000m produced larger error rates than grid size 450m, and the model results for grid size 350m did not cause any improvement. Moreover, the run-time was increased compared with the grid size of 450 meters. Therefore, the square grid size of 450 meters is selected.

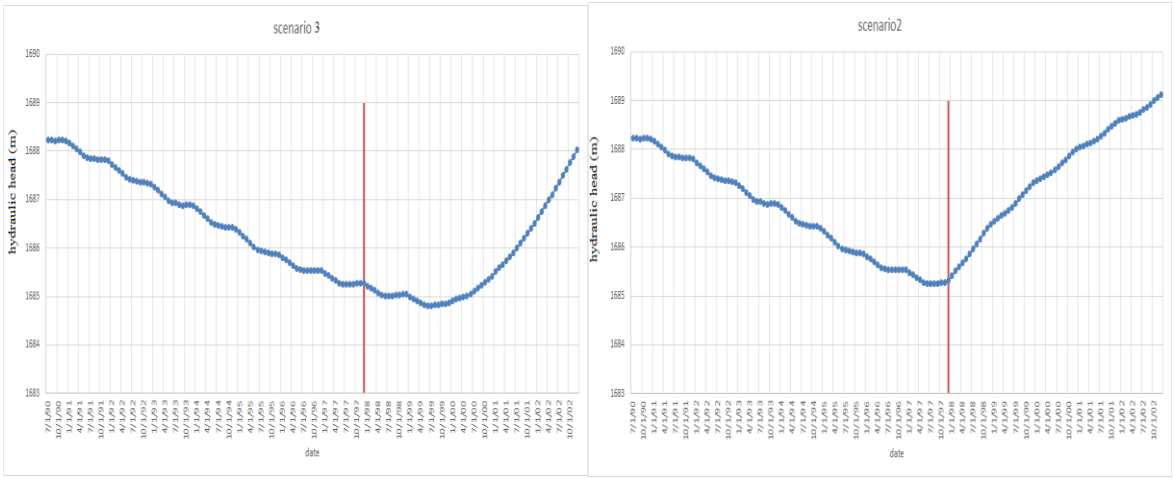
The calculated values of error estimation indices including ME, MAE, RMSE and R^2 for both calibration and validation stages showed the accuracy and capability of the numerical model.

According to the modeling results and its acceptable error, the behavior of Kerman-Baghin aquifer was predicted for 5 years and management scenarios including reducing groundwater abstraction were applied to the model, the results of which are shown in Figures 4 and 5.



(a) **(b)**

Figure 4. Changes in average water level in Kerman-Baghin aquifer a) under reference scenario b) under first scenario



(a) **(b)**

Figure 5. Changes in the average water level in the Kerman-Baghin aquifer a) under second scenario b) under third scenario

In order to prepare the classification maps for applying the artificial recharge scenario, seven parameters including land slope, distance from waterways, distance from faults, electrical conductivity (EC), hydraulic conductivity (HK), geology of the area and groundwater depth (Unsaturated area thickness) have been determined according to Table 2. Figures 6 to 13 show the classification maps based on these parameters.

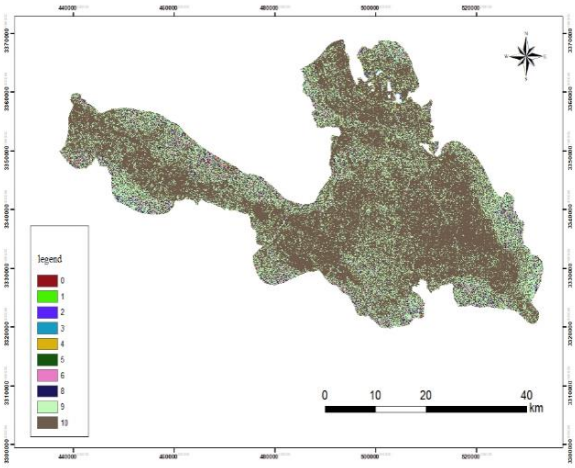


Figure 6. Land slope classification

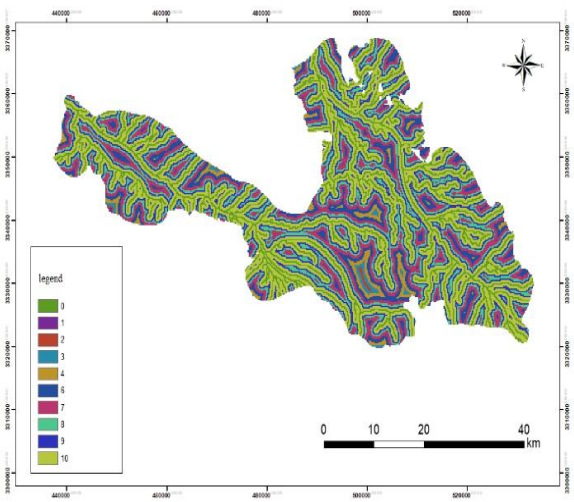


Figure 7. Classification of distances from waterways

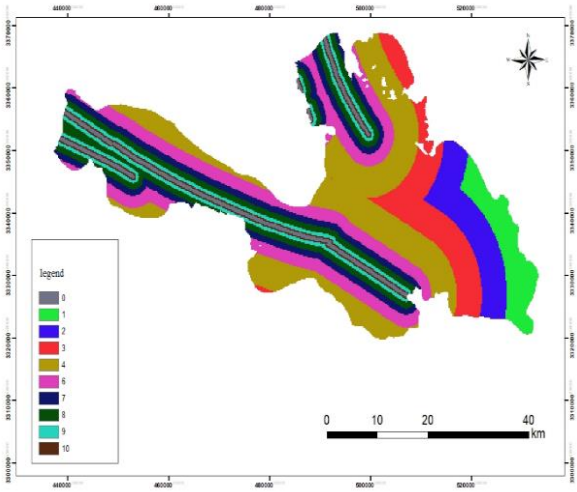


Figure 8. Distance classification of faults

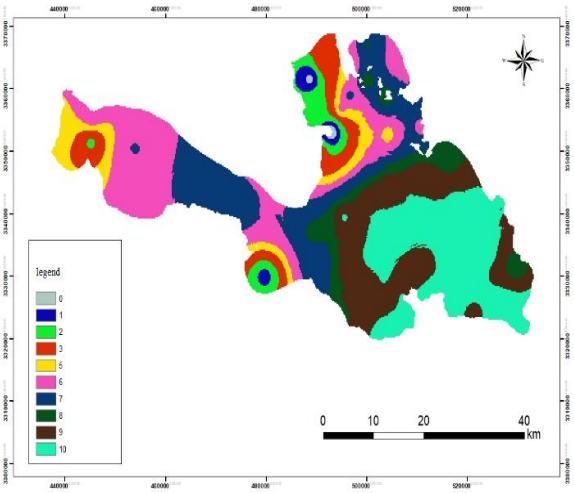


Figure 9. Classification of electrical conductivity

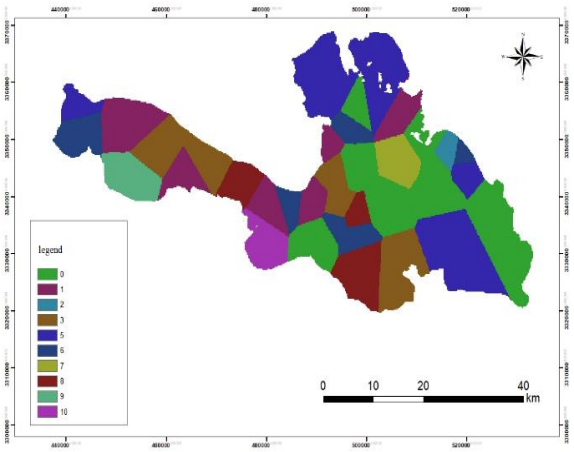


Figure 10. Classification of hydraulic conductivity

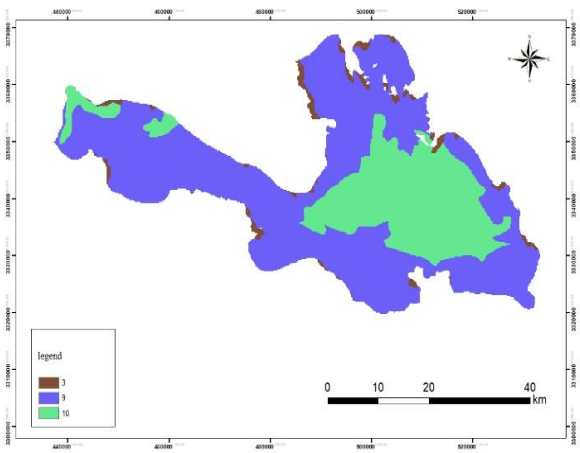


Figure 11. Geological classification of the area

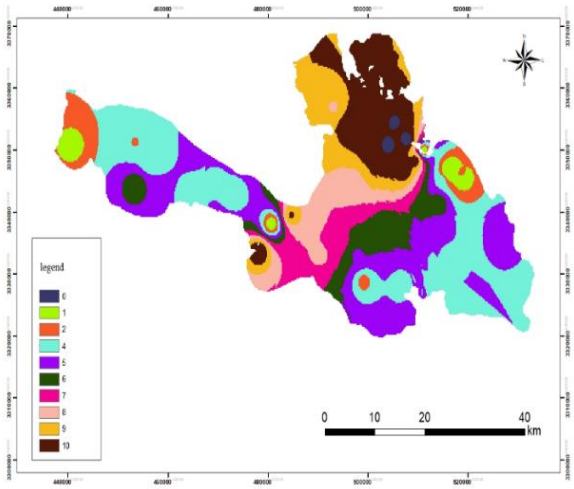


Figure 12. Groundwater depth classification

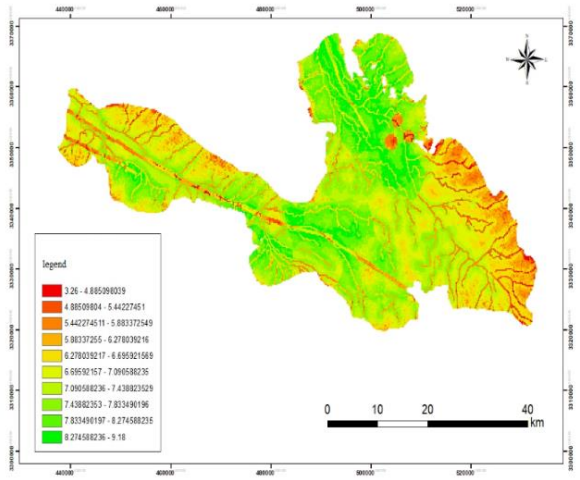


Figure 13. Zoning of Kerman-Baghin aquifer for locating areas prone to artificial recharge

As shown in Figure 13, different Kerman-Baghin aquifer regions scored between 3.26 and 9.18 points. In order to select suitable areas for artificial recharge, the parts that scored more than 8 points were identified. These areas are shown in Figure 14. After identifying suitable places for artificial recharge, 14 areas were identified separately and with clear boundaries for the implementation of the artificial recharge project. The locations of these sites are shown by numbers from 1 to 14 in Figure 15.

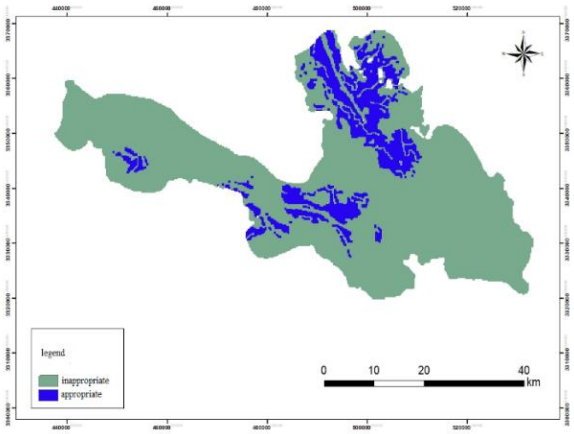


Figure 14. Sites intended for artificial recharge

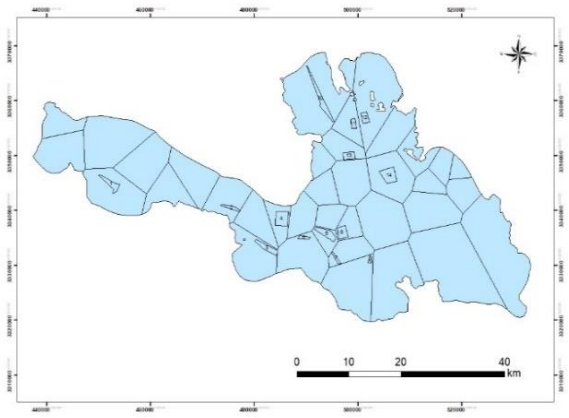


Figure 15. Zoning of areas suitable for artificial recharge

By determining the exact location of the artificial recharge sites, it was possible to apply artificial recharge to the model. Because there are many artificial recharge places along each waterway and no places to build a lot of artificial recharge places along the waterway, only eight sites number one, two, three, five, seven, nine, ten and twelve were used to apply the artificial recharge scenarios. The result of the changes in the average aquifer level of the artificial recharge scenario is shown in Figure 17. The result of the combined application scenario of simultaneous reduction of 10% extraction and artificial recharge at four sites number one, two, ten and twelve is also shown in Figure 16.

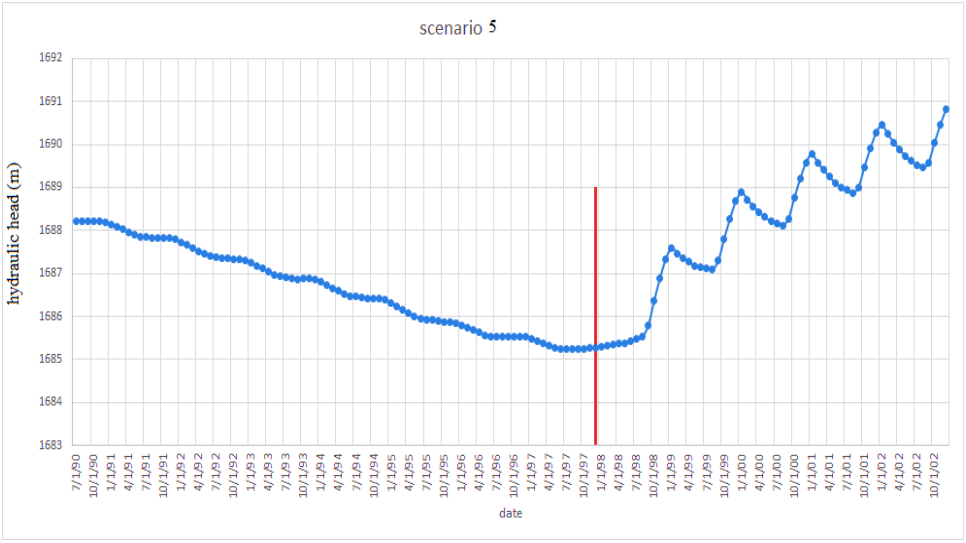


Figure 16. Changes in the mean water level in the Kerman-Baghin aquifer under fifth scenario

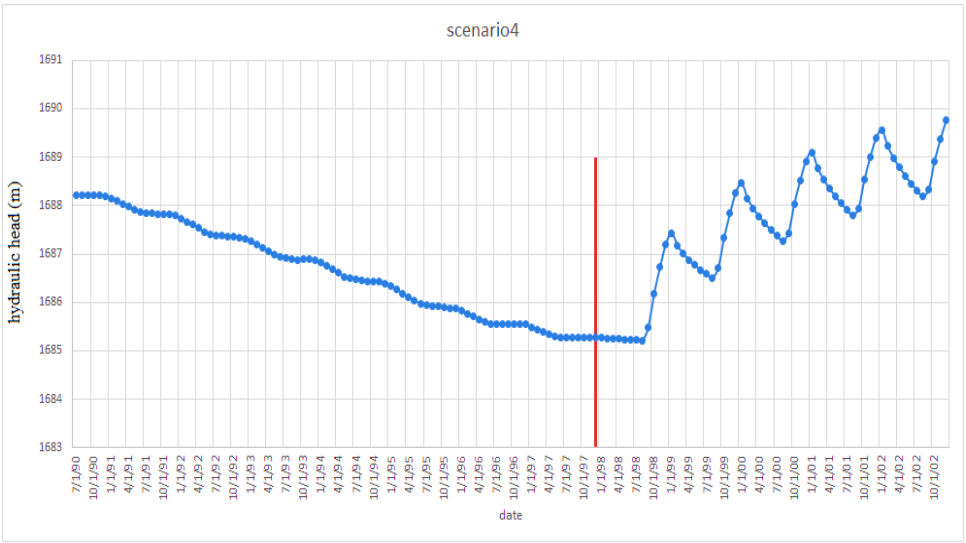


Figure 17. Changes in the mean water level in the Kerman-Baghin aquifer under fourth scenario

Table 4 represents the amount of average water infiltration during artificial recharge periods through each the recharge sites.

Table 4 Estimation of aquifer infiltration rate in artificial recharge projects

Region	Average water infiltration (m^3/day)	Average water infiltration (m^3/four months)	Area (m^2)
NO-1	946556.18	113.5867	3786224.75
NO-2	332273.02	39.8727	1582252.49
NO-3	1037171.67	124.4606	4148686.67
NO-5	1914.8	0.2297	1063778.41
NO-7	49377.13	5.9252	987542.62
NO-9	165651.99	19.8782	720226.08
NO-10	198070.23	23.7684	6602341
NO-12	46960.86	5.6353	2348043.26

As shown in Figure 4b, the water level will increase from 1688.2 to 1684.7 meters after five and a half years. This means that the average annual drop of this aquifer is about 40 cm. According to the following formula, the average annual reservoir deficit can be obtained.

$$\Delta V = \Delta H \times s_y \times A \quad (11)$$

In this formula, ΔV represents the change in reservoir volume, ΔH represents the average change in water level, s_y represents the average specific discharge of the aquifer, and A represents the aquifer area. Therefore, considering the average annual drop of 40 cm and 0.0655 as the average discharge of the average aquifer and 2025 square kilometers as the aquifer area, the average annual deficit of the Kerman-Baghin freshwater aquifer is 52.65 million cubic meters.

According to scenarios number one and two, with a 10 and 20 percent reduction in groundwater abstraction, and as shown in Figures 4a and 5a, the water level at the end of 2024 will reach 1686.7 and 1689.1, respectively. As a result of these scenarios, the average water level will increase by about 1.5 and 3.8 meters over five years, respectively. This means a significant effect of groundwater abstraction on the aquifer surface.

Scenario number three is a scenario to reduce the withdrawal of groundwater resources, but with the difference that in this scenario the first two years, i.e. until the end of 2019, the same aquifer trend is implemented on the model. These scenarios have only been applied to aquifers for three years. As shown in Figure 5b, as a result of scenario number three, the average water level will increase by about three meters over three years.

According to scenario number four, if artificial recharge is done in all eight identified areas, the average water level in the Kerman-Baghin aquifer will reach 1689.7 by the end of 2024. As shown in Figure 17, as a result of scenario 4, the average groundwater level will increase by about 4.4 meters over five years. According to Table 4, the amount of water that penetrates the aquifer during each four-month period of artificial recharge through these eight sites is about 333 million cubic meters.

As a result of the implementation of the combined scenario five, which is a combination of scenarios one and artificial recharge at sites number one, two, ten and twelve, the average water level will increase about 5.5 meters during 5 years.

5.1. Conclusion

In this study, the Kerman-Baghin aquifer has been numerically simulated using MODFLOW program. At first, the aquifer information was imported to the GMS software, and the conceptual model was obtained. The conceptual model was developed to determine the boundary conditions and simplify the model. Based on the conceptual model, the numerical model was obtained with rectangle cells of 450 meters dimensions. The numerical model was calibrated over a period of 66 months. In this process, the values of uncertain parameters were estimated. The model was calibrated in two ways: trial and error and also the Pest algorithm automatically. The model was validated for 24 months to ensure the accuracy of the results.

Finally, the situation of the aquifer was examined in the next five years. It was found that the Kerman-Baghin aquifer continues its downward trend. The aquifer faces an average annual deficit of more than 52 million cubic meters. This indicates a significant overdraft in the study area.

In the present paper, according to the results obtained from modeling and applying different management scenarios in the Kerman-Baghin plain, it can be concluded that if the current trend continues, the water level in the Kerman-Baghin aquifer will decrease rapidly. In the near future, this groundwater aquifer will face various problems in extracting water from groundwater sources and reducing water quality. Since the need to manage groundwater resources in this aquifer is obvious, five management scenarios were applied to the model. As a result, it was found that controlling the abstraction of groundwater resources in the Kerman aquifer can have a significant impact on preventing the reduction of water levels and the return of water levels to previous years. On the other hand, if water demand increases and the possibility of groundwater abstraction decreases, artificial recharge of Kerman groundwater aquifer can have a significant effect on increasing groundwater levels in the Kerman-Baghin plain and compensate for the reduction of previous years. The results of examining different scenarios show that a 10% reduction of the aquifer with artificial recharge in four zones one, two, ten and twelve is the best scenario to return the aquifer to the level of previous years.

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