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Assessment Scenarios of Water Resources Management in Arid Areas (Case Study: Birjand Plain, Iran)

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ABSTRACT

Groundwater has often been considered one of the major sources of drinking and agricultural water, particularly in arid and semiarid regions. In this respect, the present study dealt with a combination of numerical models of groundwater and water resource management model. The first conceptual model was prepared to simulate the groundwater table of Birjand plain in South Khorasan province, Iran. Then, the groundwater level was predicted and verified using numerical models. The output of these models was used to investigate the influence of parameters such as climate change and population growth rate on the groundwater level within the WEAP management model. The scenarios discussed in this research included the assessment of the demand rate and saving underground water resources by increasing the rate of population growth, reducing the planting area, and using drip irrigation method instead of traditional irrigation practices until the year 2020. The results showed that by reducing the planting area to 20% by the year 2020 and using drip irrigation with an efficiency of 90% instead of traditional irrigation would reduce water demand by 14% and as a result, an average rate of 8.2 million m^3 of water would be saved from 2016 to 2020.

1. Introduction

The management of water resources, with system and comprehensive attitude, allocation and utilization of small water of reservoirs, as well as the prioritization of development projects, has attracted considerable attention of researchers, experts and policymakers in the water sector. Water resource planning has been considered in the world since 1980. Water allocation management using scenario analysis and evolutionary programming is one of the best ways to increase water supply capacity and optimum use of available water. In other words, with proper management on existing dams and underground tanks, optimum policies for their exploitation, as well as the prediction of future demand, can be without implementation of new projects increasing the capacity of existing water supplies at a reasonable cost and prevent water damage resulting from improper allocation (Jahani 2001). In general, planning for the allocation of water to different uses of surface and groundwater resources is dependent on factors such as cost and resource availability, especially in connection with surface sources, the quality of resources, priority in satisfying all needs and supplying environmental constraints. In recent years, willingness to integrated study and attitudes to water resources development projects increased against individual and independent study of sources and water consumption and needs, quality issues, economic issues, and other issues related to water resources are considered together (Alizadeh 2006).

To solve the problem of low water level of rivers in Aprasink catchment area in the US, Larson (2000) used the ModFlow model to model groundwater and finally, evaluated the effects of water re-allocation on other uses with the WEAP model. To improve the allocation of water within the Dengue catchment in Vietnam, Ringlr et al. (2001) studied water allocation process in terms of economic efficiency and comprehensive view by the WEAP model. Kholghi et al. (2001) applied a water resource analysis to the Garmsar plain by the WEAP model for inside and outside lands of irrigation and drainage networks. Saeed Nia et al. (2008) conducted a comprehensive modeling of water resources of Koohrang Beheshtabad using the WEAP model and showed that required volume for water storage and regulation should be considered up to 600 million m^3 that this figure is below than one- third of figure that plan consultant were considered in studies. In order to assess and manage water resources at the basin level using communication between WEAP and ModFlow, studies were conducted by the German Federal Institute for Natural Resources and Arid Zones Research Center, Saudi Arabia. Dorobi et al. (2008) in Brechid area in the south of Casablanca, Morocco conducted a project on the management and protection of groundwater and soil. The total area of catchment was 1500 km^2 whose slope was 0.2% in the southern edge and not greater than 0.8% in the rest of the catchment. Reference scenario defined for 1980 and

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2004. The results showed a reduction in the reserve tank and only in the years 1997-1996 and 2007 which were wet years, a significant increase in the storage tank was predicted. Noir et al. (2012) investigated groundwater tables in the aquifer of Haoz Kotain with the help of communicating between the two models of WEAP and ModFlow and found that using desalination plants can be grabbed from seawater and until 2030 supply the water needs of the basin districts. This will reduce the exploitation of the aquifer.

Given that the regional climate and water demand exceeds the capacity of the aquifer, the present study investigates and predicts the groundwater level changes and demand allocation management. Since groundwater models have no role in water resources management and just predict the groundwater level on the one hand, and on the other hand, the WEAP model is a managerial model and cannot manage groundwater resources and assess their effects on the level of ground water, so we used a combination of these two models which have the ability to manage groundwater resources and assess the impact of various defined scenarios on the groundwater level. To the best knowledge of the authors, this is the first study of this kind in Iran conducted on the plains of Birjand in South Khorasan province.

2. Materials and Methods

2.1. Study area

Birjand is located in the northern part of the Bagheran highlands (Lat. 32°34'-33°08' N., Long. 58°41'-59°44' E.). The catchment of the Birjand plain covers a total area of about 3,425 km^3, of which about 1,383 km^3 are plains and the rest are highlands. The maximum elevation of the area is 2,720 meters above sea level in the Bagheran highlands (Sahkoh) and the minimum is 1,180 meters at the plain outlet (Fedeshk area). The Birjand unconfined aquifer with an area of 269 km^2 is composed of various alluvium, involving alluvial fan coarse grain deposits and clay and sandy silt sediments in the west. Generally, toward west size of the aquifer materials decrease hence hydrodynamic coefficients. Mean annual drawdown 40 cm which has been started 26 years ago, cuts down on aquifer domain constantly (Figure 1).

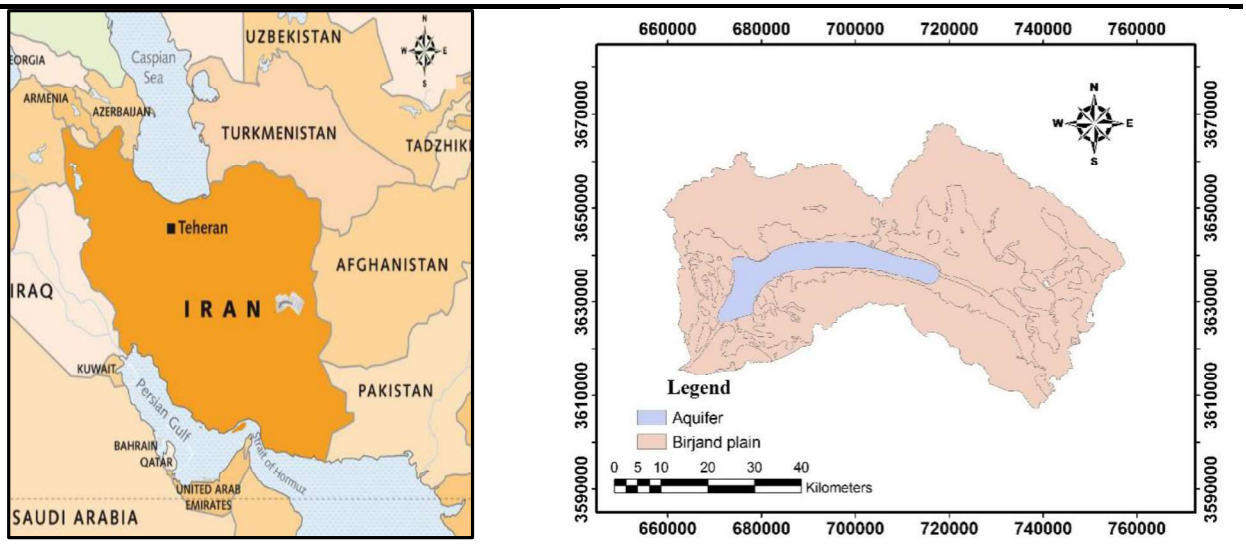


Fig. 1. Geographical location of the Birjand Plain (Mohtashami et al. 2017a)

2.2. Groundwater Model

This model is one of the models used to simulate groundwater tables. In this model, the simulation method using numerical methods is based on finite difference equations. This model can perform simulations in steady and unsteady conditions (Nasirian et al. 2018; Nasirian et al. 2019). Groundwater equation that is used in this model is the *Boussinesq* equation as below:

$$\frac{\partial}{\partial x}h\frac{\partial h}{\partial x}+\frac{\partial}{\partial y}h\frac{\partial h}{\partial y}+\frac{\partial}{\partial z}h\frac{\partial h}{\partial z}=S_y\frac{\partial h}{\partial t}\pm\frac{R}{2K_{xy}} \quad (1)$$

in which K_{xy} = hydraulic conductivity coefficient, S_y = specific yield of the aquifer, and R = extraction (negative sign) or injection rate to aquifer (positive sign) (Mohtashami et al. 2017b, Hamraz et al. 2015, Sadghi-Tabas et al. 2016, Sadeghi-Tabas et al. 2017; Mohtashami et al. 2019; Doulabi et al. 2019). Information stored in the database using emulation software of the groundwater becomes to conceptual model and then produced conceptual model become to array of numerical model and model is executed. Preparation of conceptual model includes determining geometry, type and ingredients of aquifer, mode of communication of groundwater aquifer with geological formations surrounding plains and surface water series, identification of hydrological boundaries, resource depletion, and groundwater flow system and injecting (Ghoochanian et al., 2013). (In the first step, 13 timely step were entered into the model as monthly which includes one step one day, and 6 step 31-day, 5 steps 30 days and a step 29 days). After the preparation of the conceptual model and

its transformation into a numerical model (ModFlow 2000), the model was implemented and calibrated in unsteady condition.

2.3. WEAP model

The WEAP model is a linear programming model to provide maximum needs and according to the minimum volume of water required. In its equations, the model considers the issues of need (water consumption patterns, equipment efficiencies, re-use, cost and allocation) to sync with resource issues (surface flows, groundwater, reservoirs and water transfer). In the WEAP model, the demand consumption place is calculated as the sum of requirements for all subordinate branches of applicant consumption place. The total annual demand of each location can obtained from Eq. (2).

$$A_{DS} = (\sum T_{BR} * W_{BR}) \quad (2)$$

in which A_{DS} = the annual demand for demand consumption place and T_{BR}= active level for demand consumption place. This parameter is for agricultural lands under cultivation, places of urban and rural consumption, population in the consumption places and for industrial consumption place and the amount of production per year. Also, W_{BR} in Eq. (2) denotes annual water consumption per unit of total active level for demand consumption place. To calculate the need for supply source on demand consumption place must consider the amount of losses in demand consumption place, the amount of redistributable flow in demand consumption place, or if there is, the use of managerial patterns in each demand consumption place.

2.4. Data extraction from ground water model and transferred to WEAP model

Modeling in WEAP software using graphical data and functions available in the model needs reading data such as nutrition values of groundwater, observation wells data, and hydraulic conductivity values which are stored in the groundwater files. Number and type of information depend on the selected file of groundwater. For this purpose, intermediary software is used to read data from groundwater model and prepare them for the transfer into the WEAP environment. The ModFlow to WEAP model is a model taking data with specified extensions from the ModFlow model output. This is comprised of two parts. In the first part, there is a list containing general information about groundwater model structure, such as the number of rows and number of columns in the grid, the number of aquifer layers. The second part is a possibility to select the output files from the ModFlow model. In this stage, information that is necessary to enter into the WEAP environment is selected. The second part of the model consists of two parts of different functions that by choosing any of the functions and implementation of model the output file becomes to a spreadsheet (Excel file) or GIS file, which is used to communicate between the two models (Figure 2). The inputs of the WEAP software include monthly evaporation and transpiration values, the coefficient of plant products, monthly rainfall, land use, and water needs in various sectors of drinking, industry and agriculture, whose information were gathered from the relevant agencies and were entered into the model as an Excel spreadsheet, and the output of the groundwater model (underground water balance and water table changes) as input data was entered into the WEAP model. The values of each sub-basin area and injection values were extracted from the ModFlow model as an Excel spreadsheet by the ModFlow to WEAP and would be assigned to each subwatershed through a readable function in WEAP. Also, monthly requirement for various uses in each sub-domain could be entered manually through the monthly function. After entering the required information to the WEAP model and by selecting the file from the output of the WEAP model, communication windows between two models would appear. In this window, all the information about time steps considered in the unsteady-state model of groundwater, groundwater well data, land cover and water needs in different uses are shown (Figure 3). If there was a harmony in the data format between the two models, the link would be established and simulation would be done in the base year (2010). Finally, to simulate the rate of groundwater and the rate of storage in the aquifer, the demand for various uses in the form of four scenarios was introduced to the model.

2.5. Scenarios considered for managing the study area

The present research on water resource management for efficient use of water resources is an attempt to answer some questions as follows. What is the impact of system to rich balance on the amount required of supply system? What is the impact of applying demand managerial methods on consumption? What is the impact of using drip irrigation method on demand site, the drop of water tables and the changes in groundwater storage? What is the impact of changes in agricultural land level and population changes on amount demanded? Then, different scenarios are defined to present appropriate methods to optimize water usage. In the groundwater simulation model, the crop year 2010 began in September and in WEAP model first that year data were entered to model and after establishing the link between the two models to evaluate aquifer and storage groundwater. Scenarios discussed in this paper are divided into four categories:

1- The impact of reduced acreage of cultivated land and orchard on groundwater shortage, supply and demand resources, and changes in water table level until 2020.

2- The impact of population growth on the depletion of groundwater reservoirs, supply and demand resources, and changes in water table until 2020.

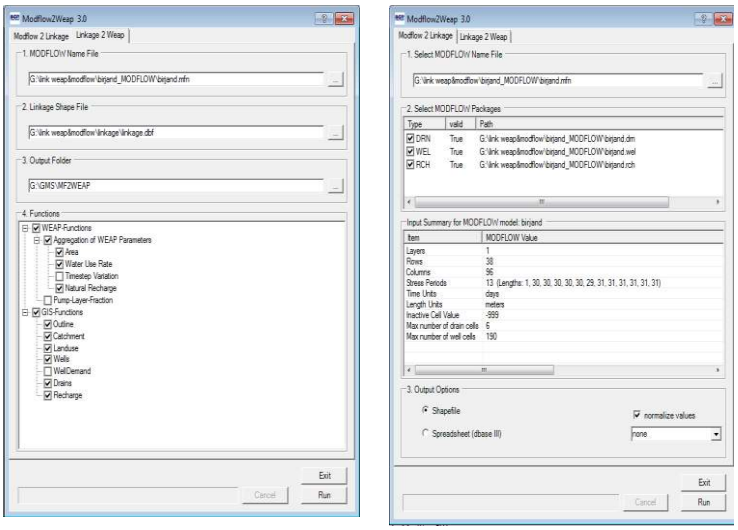


Fig. 2. Data mining ModFlow by the ModFlow2Weap model

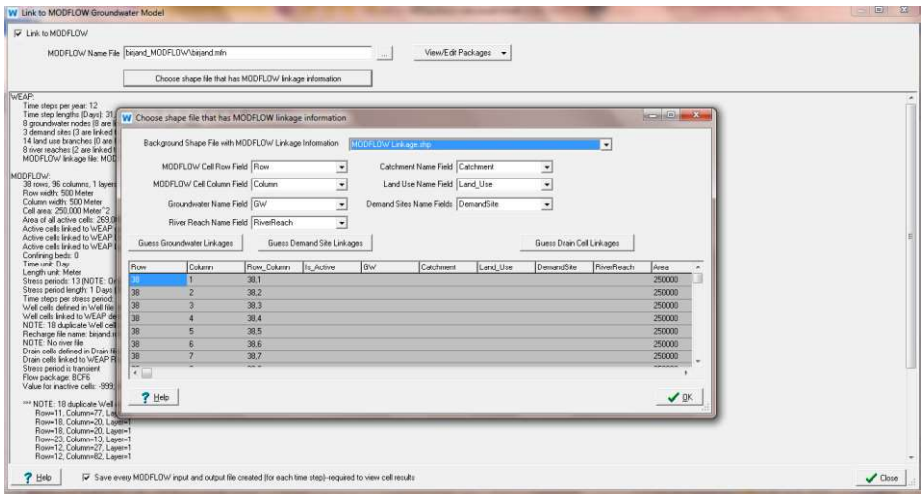


Fig. 3. Data communication between the two models

3- The impact of increasing water use efficiency in farms (from 50 percent to 90 percent) on the supply and demand situation, depletion of groundwater reservoirs, and changes in water table until 2020.

4- The impact reduced acreage by 20 percent and population growth with the rate of 1.7 percent and increasing water use efficiency in farms until 2020.

3. Results and Discussion

After initial data were entered into the groundwater model, the ModFlow model was to be executed. After running the model calibration is presented. In the first phase, the calibration hydraulic conductivity polygons were divided into smaller parts and according to available reports and expert opinion, a certain amount of hydraulic conductivity was assigned to each region. Then, in order to increase the accuracy of the calibration model, the stochastic simulation method was selected so that an average and minimum and maximum values were considered for hydraulic conductivity in each polygon and simulation began randomly. In this study, 30 iterations were considered for random simulation to obtain the best values for hydraulic conductivity (Figure 4). The results of calibration model indicated that the groundwater model was consistent with the actual situation of aquifer. The results of groundwater model implementation and their comparison with the actual values of groundwater table represents the efficiency of the model (Figures 2 and 3). Calibration error in groundwater model was equal to 0.398 (Figures 5 and 6). According to experts report, the regional water company of the Birjand plain was faced with a shortage of 11 million m^3, which is consistent with the results of the groundwater model and illustrates the accuracy of the model (Table 1). After running the groundwater model using information from its output, the area studied in the WEAP model was divided into 8 sub-basins and 6 classes of land use (Table 2). For the calibration of the studied area was cited to statistics of piezometric wells. Finally, the decline in groundwater levels resulting from communication between two models

of ModFlow and WEAP was consistent with the decline in groundwater levels estimated by piezometric wells and groundwater model. The fraction of the reservoirs in the base year was equal to 3.11 million m^3 (Tables 1 and 3).

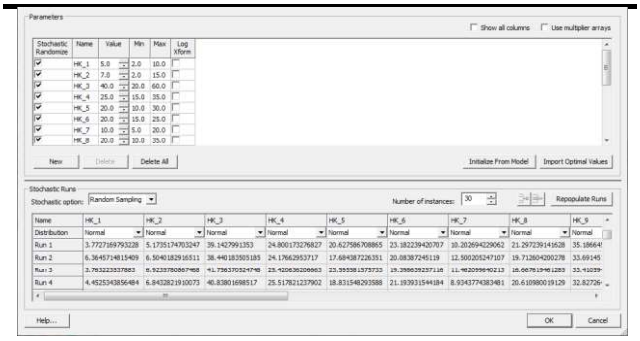


Fig .4. Correct amount of hydraulic conductivity random

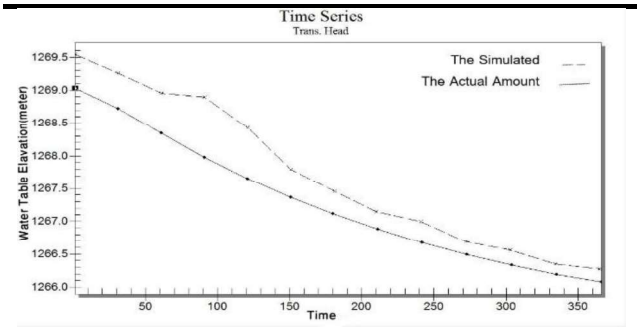


Fig. 5. Comparison of model results with actual values in piezometer 7

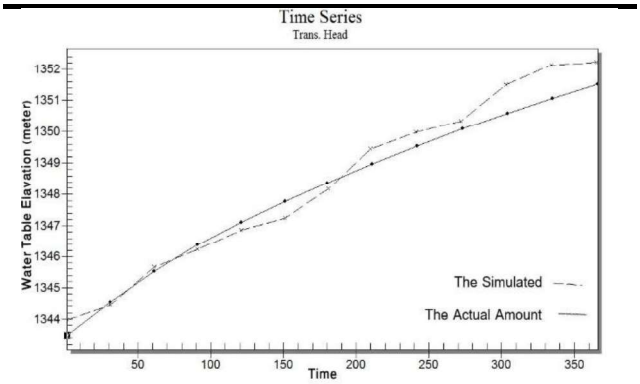


Fig. 6. Comparison of model results with actual values in piezometer 3

Table 1. Groundwater balance calculated by the model

Water Balance	Inflow(MCM)	Outflow(MCM)
Storage	42.65	53.96
Wells	-	73.87
Recharge	88.26	-
Total	130.91	127.83
Water Shortage	-11.3	

Table 2. Landuse and the area of each class (ha)

	shrub	Rainfed farming	Irrigated farming	Forestary	Residential	Grass land
1	1288	-	1087	-	-	-
2	763	-	3537	-	-	-
3	-	6113	405	557	-	-
4	-	1005	720	-	-	-
5	-	1575	-	-	-	-
6	-	825	-	-	-	-
7	-	2675	-	-	2100	-
8	-	-	-	-	-	3250

Table 3. Groundwater storage variations in different months of the year, based on the WEAP (MCM)

Month	Storage up	Storage down
April	-	19.2
May	-	18.28
June	-	6.25
July	-	0.6
August	-	0.64
September	-	6.85
October	7.11	-
November	6.54	-
December	6.66	-
January	6.68	-
February	6.74	-
March	6.83	-
Sum	40.56	51.82

3.1. The results of the scenarios

1. The impact of reduced acreage on the reduction of ground water storage, water table changes and changes in demand

Cropping pattern for the studied area in the base year consists of the cultivation of wheat, barley and saffron and orchard products such as jujube, apricot, grape, etc. so that the total planting area of horticultural and agricultural crops in the study area in the base year was 6000 ha. Generally, by decreasing the acreage of horticultural crops and increasing rain-fed farming, the reservoir fraction was reduced so that by decreasing the planting area by 20%, 36.5million m^3 of water use was saved (Table 4). In reference scenario (population growth rate of 1.7% and the planting area is as traditional irrigation and have horticultural products) a sharp drop will happen in groundwater level by 2020 (reservoir will face a shortage of 58 million m^3). But, defining the scenario and reducing 20% of garden lands and turning them into rain-fed farms will

prevent the further decline of groundwater table, and groundwater shortage in 2020 will be 38 million m^3. As shown in Fig 7, with the definition and application of this scenario in 2020, 20 million m^3 of groundwater resources will be saved. Due to the reduced planting area of horticultural crops ant true it into dry land, agricultural water back into the aquifer be decreases and is projected to 2020 water table suffered from sharp drop (Fig. 8 and 9).

Table 4. The effect of reduced planting area scenarios on demand

	Current planting area	20 percent reduction in planting area
Demand (million m^3)	82.98	46.44
The amount of demand reduction (million m_3)	36.54	

Table 5. The impact of population growth on demand and changes in groundwater storage variations from 2007 to 2020

	Demand in 1400 year (million m^3)	Ground water storage decreased in 2021 year(million m^3)
Reference (growth rate 1.7%)	0.73	78.39
Mild changes in population growth (growth rate 2.3%)	0.76	81.45

2. The impact of changes in population growth rate on the reduction of ground water storage, water table variations and changes in demand

In this scenario to be addressed to comparison of the annual population growth rate changes with rate of 1.7percent in reference scenario and modest changes in annual population growth with rate 2.3% on supply and demand, Groundwater storage changes and water table level until 2020. According to smaller share of demand for drinking water than demand by agricultural sector, the impact of population growth rate variations on demand and groundwater storage is subtle (Table 5 and Figure 10). Due to the droughts in this plain and water scarcity, migration is happening from surrounding villages to Birjand and this will increase the population of the city. Therefore, to investigate the effect of population on water resources, two growth rates of 1.7% and 2.3% were defined in a scenario. Growth rates of 1.7% and 2.3% have each been defined as distinct for this scenario over the past 10 years. According to Figure 10, we can see that with growth rate of 2.3% no significant variation happens in the demand rate because the two curves overlap. On the other hand, with current situation the anticipation of the water table in 2020 will produced Figure 11, which is roughly consistent with the curve which can be obtained from 2.3% change in population growth rate (Figure 12). This reveals that its impact is not significant. In both scenarios, the water table has fallen sharply and almost 70 percent of the aquifer is dry.

3. The impact of increasing water use efficiency on farms (from 50 percent to 90 percent) on the supply and demand, the groundwater reservoir deficits and changes in ground water level decline until 2020.

In this scenario examined the impact of all agricultural land equipped with drip irrigation system by application efficiency of 90 percent, by increasing area under cultivation by 1% annually, and by reducing area under cultivation by 1% annually until 2020, on the required water of resources and groundwater tank fraction. It is noteworthy that in reference scenario, water use efficiency on farm has been considered to be 50%. Generally, by replacing the new irrigation system for the traditional irrigation, agricultural water demand rate will be reduced by 28 million m^3 annually. The results of 1 percent annual increase in planting area and annual reduction in planting fields equipped with drip irrigation system is shown in Table 6 and Figure 13. With regard to the water loss is reduced with the use of drip irrigation systems, return of agricultural water to aquifer have also plummeted, as a result, deficit of reservoir in scenario of use of modern irrigation systems is more than traditional irrigation. This increasing in fraction of reservoir be more if be associated with increasing in area under cultivation in modern irrigation systems. By using drip irrigation method until 2013, there will be is no change in the water table drops. From 2007 to 2020 has seen drastic changes in decline of water table in both reference scenarios and use of drip irrigation method scenario. The use of drip irrigation method will render it possible to increase water use efficiency, more water will be used, and less water will return to the aquifer. Since in Birjand plain, the evaporation rate is high and the level of water table is low, by using drip irrigation method decline intensify observed in water table level and cells be dried and he result of will be salinization soil in agricultural areas (fig 14 and 15). The purpose of defining scenarios 1 to 3 was to examine the effects of parameters of planting area, population, irrigation system on demand and saving groundwater separately. The results showed that the maximum and minimum impacts on the demand and saving of groundwater were related to agricultural sector and population, respectively. Finally would be addressed to the definition of combining scenario of parameters of cultivated area, population growth rates and the use of drip irrigation systems.

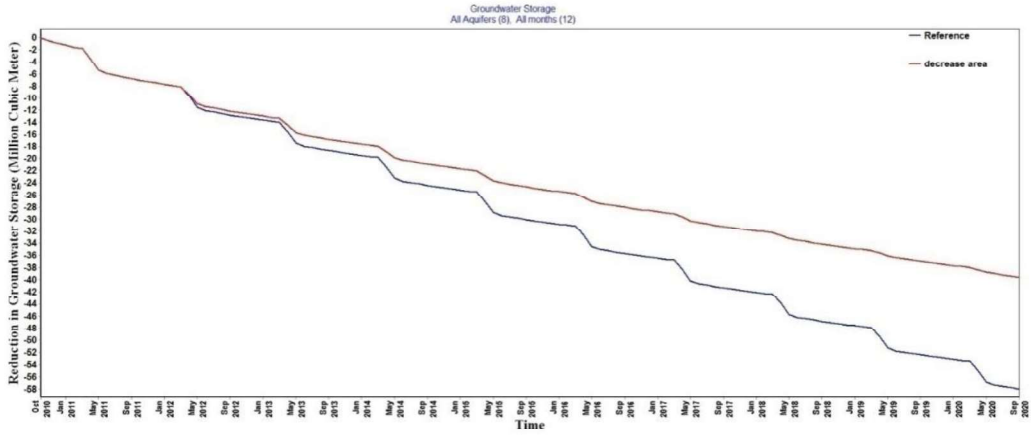


Fig. 7. The comparison of variations in groundwater storage reduction in the reference scenario and the scenario of reduction in planting area, first scenario.

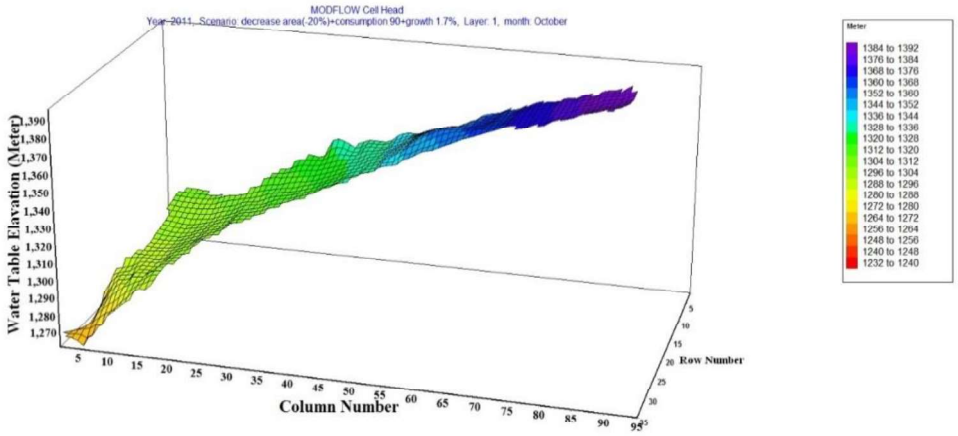


Fig. 8. The water table in 2010

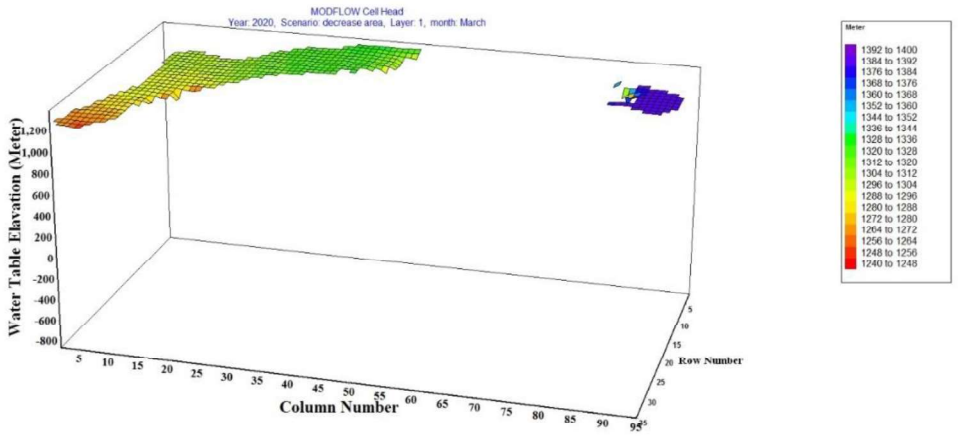


Fig. 9. The water table in 2020

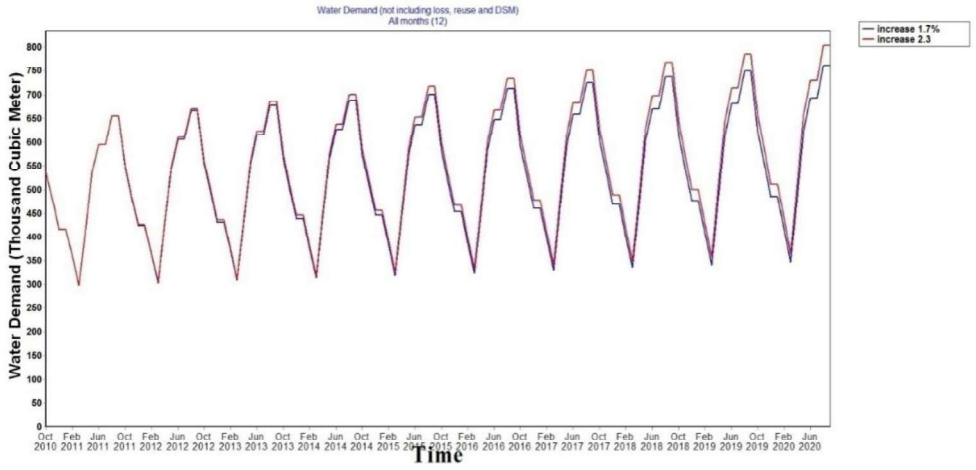


Fig. 10. Diagram of potable water demand in scenario of the population growth rate changes

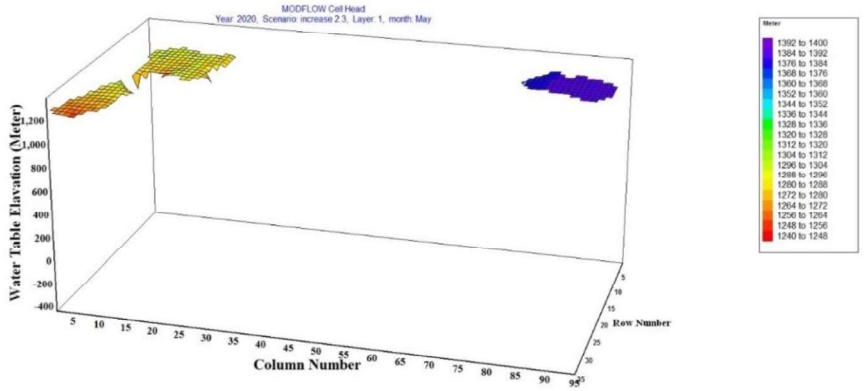


Fig. 11. The effect of change in 1.7 % population growth rate on Water table

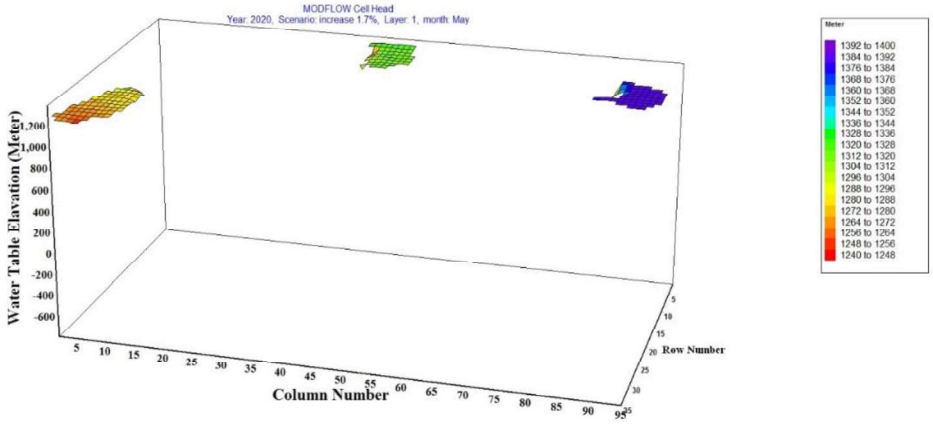


Fig. 12. The effect of change in 2.3 % population growth rate on water table

Table 6. Average annual volume of water requireemnt of resources by using efficient drip irrigation system until 2020 (millions of m^3)

Scenario	No change in planting area	1% annual increase in planting area	1% annual reduction in planting area
Using drip irrigation	18.8	13.91	21.85

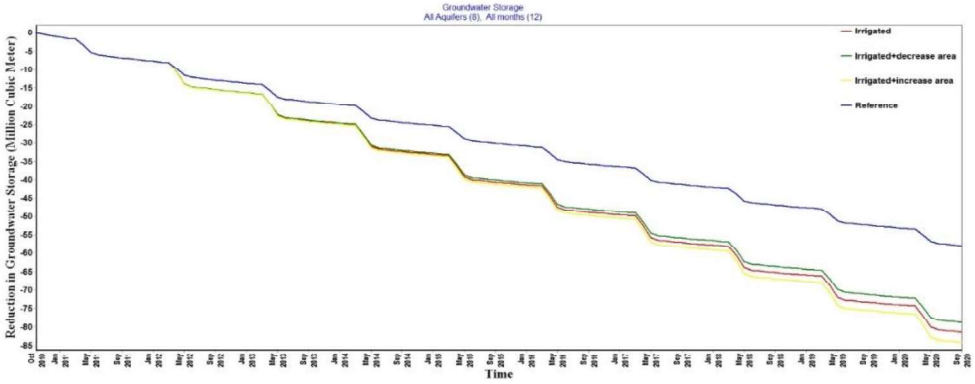


Fig. 13. Changes in groundwater storage reduction using drip irrigation system by 2020

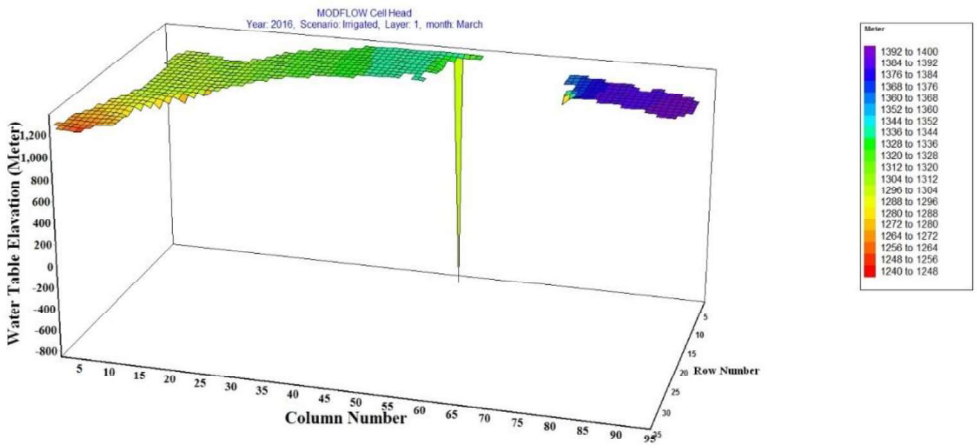


Fig. 14. Water table using drip irrigation system in 2007

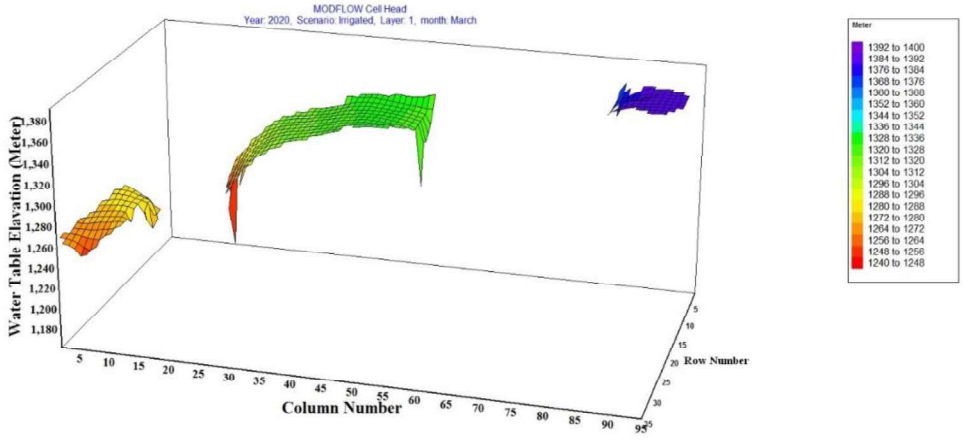


Fig. 15. Water table using drip irrigation system in 2020

4. The impact of reducing planting area by 20 percent and increasing population growth rate by 1.7 percent and increasing water use efficiency on farms until 2020.

This scenario would address the comparison of reference scenario in which planting area was constant and population growth rate was 1.7 percent and water use efficiency was 50% with the scenario in which planting area declined by 20 percent, population growth rate was 1.7%, and the efficiency of water use in agricultural sector declined by 90 percent. The results showed that by 20 percent reduction in planting area and increasing the efficiency of water use in the fields, water demand would be annually 14 percent lower than that in the reference scenario. By using the scenario of drip irrigation and reducing planting area and population growth rate of 1.7 percent, the fraction of reservoir would be reduced by nearly 12 million m^3

compared to the reference scenario (Figure 16). Water table level dropped sharply in both scenarios and more cells would dry by 2020 (Figures 17 and 18).

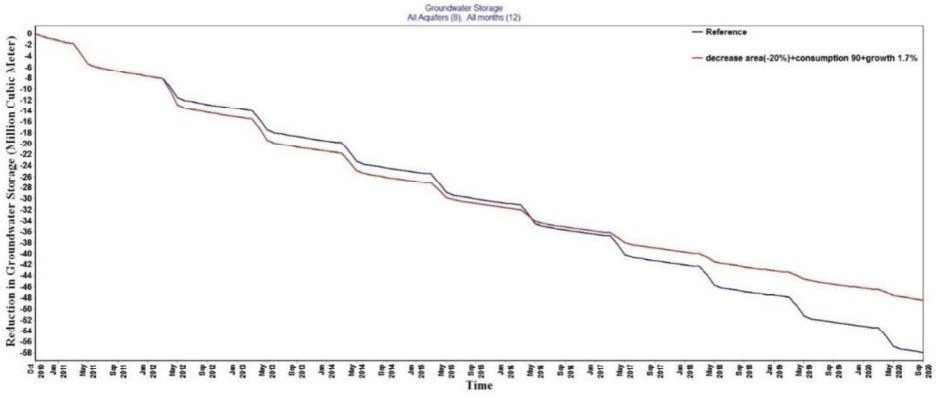


Fig. 16. Changes in groundwater storage reduces the efficiency of water use 90% and 20% decrease in area under cultivation and population growth rate 1.7% in 2020 year

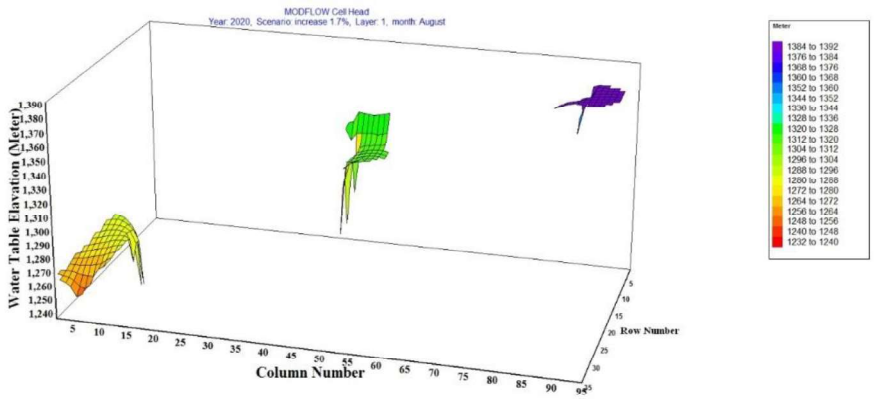


Fig. 17. The status of water tables assuming the population growth rate of 1.7% by 2020

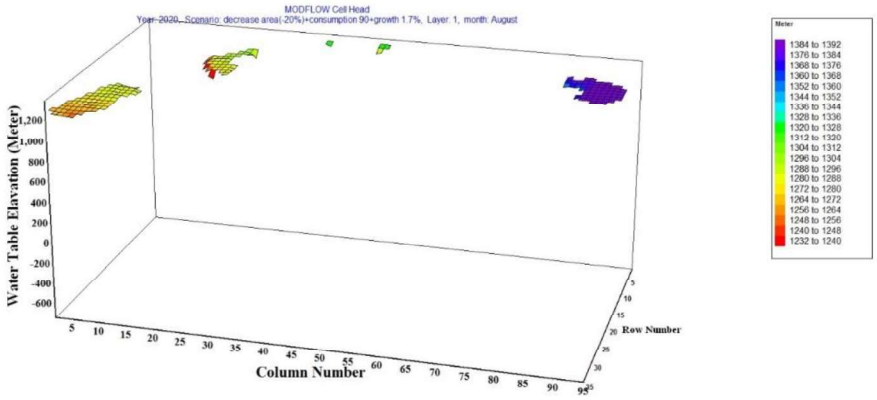


Fig. 18. The status of water tables assuming a growth rate 1.7 and cultivation area reduction of 20% and use of drip irrigation system with an efficiency of 90%

4. Conclusion

In this study, a combination of numerical models and simulation of groundwater and water management were performed. The purpose of defining scenarios of reducing planting area by 20 percent, impact of changes in population growth rate and farms equipping with modern irrigation system scenarios was to determine the sensitivity of demand and storage of water resources by changing parameters available in each scenario. The results showed the greatest changes in demand and storage of water resources was, respectively, in the agricultural sector includes the extent of

area under cultivation and irrigation methods and finally, the rate of population growth. In scenario 4, it was predicted that by 2020 if the population growth rate is 1.7%, and the planting area is reduced by 20%, and drip irrigation with an efficiency of 90% replace traditional irrigation, the demand rate will be reduced by 14% versus the reference scenario, and from 2007 to 2020 an average of 8.2 million m^3 of water will be saved annually.

5. Reference

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