Integrated water resources management through scenarios based on using alternative water resources, Case study: Gavkhooni basin

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Abstract
Nowadays, integrated water resources management especially in arid and semi-arid areas, is concerned as an inevitable necessity for natural resources policy makers. Using alternative resources could be one of the solutions that recently are considered in arid countries. This study is defined to help supplying water needs in the Gavkhooni basin located in the arid district of Iran. In this study, a model of the Gavkhooni watershed was created using WEAP software. The model is mainly based on an integrated simulation of surface and groundwater resources, agricultural and drinking purposes and basin various climates altogether. The basin runoff was predicted by a model fusion approach combining Multi-Layer Perceptron (MLP), General Regression Neural Network (GRNN) and a linear regression (LR) models. The AR scenario (Aquifer Recharge) was defined based on natural replenishing of aquifers through rainfall, the CBB scenario (Conveyance between the Basins) and The IIE scenario (Increase Irrigation Efficiency) was defined to consider the renovation of irrigation systems and its cost. AR-IIE, IIE-CBB, CBB-AR and AR-IIE-CBB scenarios were also defined based on the combination of the single scenarios. Finally, considering both the water supply and construction costs, the AR-IIE is selected as the best scenario.

Keywords
Aquifer Recharge, Model fusion, WEAP, Water resources management

INTRODUCTION

Recently, water resources are exposed to excessive consumption, due to society development, more drinking, industrial and agricultural water needs. It makes authorities apply different strategies in each region, such as creating artificial precipitation, change in plant cultivation and water use patterns (Rostamafshar 2007). However, separate water resources management has already caused some damages on water resources and has wasted the national capital in different cases. Today, everyone is informed of the need for an integrated approach to water resource management considering various water supply sources, different types of consumption, different climatic conditions, minimum quality and quantity of water and basin local conditions. Integrated water resources management (IWRM) is a process that helps us plan the sustainable development of water, land and related resources in order to maximize the economic and social welfare without any conflict with sustainability of natural ecosystems (Loucks 2005). In this study, among vast concepts of integrated approach to water resources, a model of surface and groundwater resources needed for drinking and agricultural occupations, in drought and also wet conditions has been made and developed in WEAP software. This model compares different scenarios and presents the best one to facilitate the decision making process for the deciders.
General circulation models (GCMs) have shown that an increase in concentration of greenhouse gases can cause significant climatic changes in local and global scale, but unfortunately, due to low spatial accuracy and inability of these models to analyze small scale features such as clouds and topography, the output won’t be efficient enough in terms of water resource planning.

Recently, the artificial neural networks are widely used as a tool to estimate climate variables. In this study also we use a combination of different neural networks to reduce the scale of climate change scenarios.

STUDIED AREA

In the general hydrology classification of Iran, Gavkhoni basin is a part of the central plateau basin. The basin is limited to the Salt Lake basin on north, to the Daghsorkh basin and Kavirsiah Mountain on east, to the Abarghoosyrjan basin on south and to the Karoon basin on west and south-west. The basin is located between the geographical coordinates of 50°-02’ to 53°-22’ east longitude, and 31°-12’ to 33°-42’ north latitude. It has an area of 41,550 square kilometers, of which 40% is mountainous, 59% is lowland and 1% is the Gavkhoni swamp. The Gavkhoni basin position is illustrated in Figure 1. (Jamab 2005).

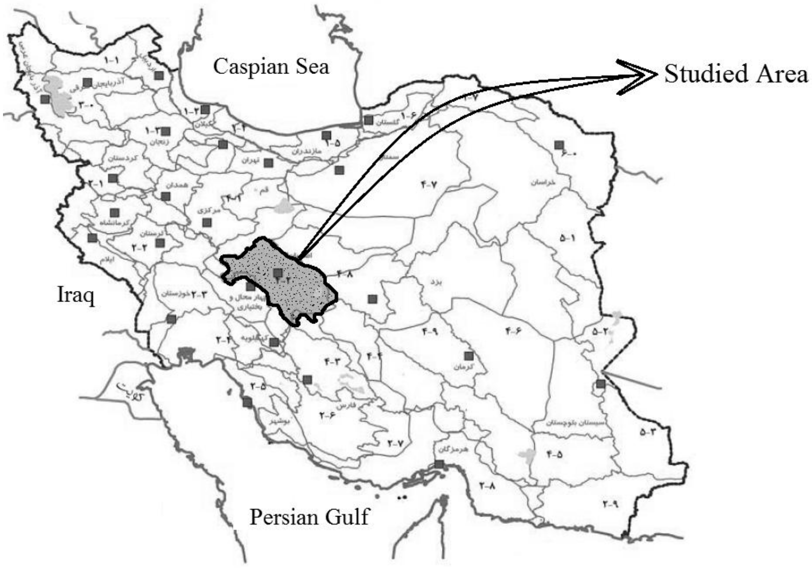

Figure 1. Studied area

WEAP SOFTWARE

WEAP as a database provides a system to maintain information on resources and consumptions. As a forecasting tool, it has the ability to simulate water needs, resources, flow, reserve size, production and refining, and as a policy analysis, it evaluates a complete range of options for water development and management. This software has been developed by SEI (Stockholm Environment Institute) and has been supported by some institutions such as the World Bank and USAID (U.S. Agency for International Development) (Sieber 2008).

Different hydrological process simulation models in water resources can be classified as follows:

1. Theoretical or empirical: a theoretical model is based on physical principles while empirical models (statistics) are based on observed data.
2. Deterministic or probabilistic: If one or more variable or process within a mathematical model is random, then the model is defined as a probability; otherwise the model is deterministic.
3. Single or continuous event: a single event model, takes in to account a runoff event resulting from a single precipitation that may last from several hours to several days, whereas a continuous model simulates basin behavior in a given period and don’t take into account what is happening inside it.
4. Distribution, mass and half-distributed: mass models are not sensible to the location of profile change, whereas distributed models do consider the location of changes in basin

(Loucks 2005).

In summary characteristics of hydrological model in this software are: theoretical - deterministic - Continuous event – half distributed (UN Report 2005). In hydrological modeling, WEAP software performs all the necessary processes for quantitative surface water balance and interaction of underground water with river flow. Figure 2 is an example of WEAP modeling ability (WEAP21.org).

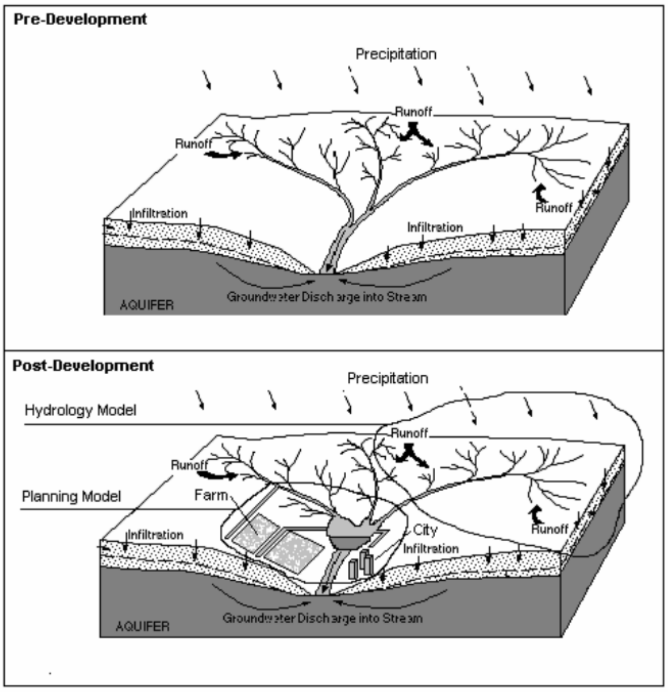

Figure 2. WEAP's ability in integrated modeling (Sieber 2008)

DATA

In this study, the Gavkhoni basin is divided into 19 sub-basins, namely, Alaviche, Boin, Bonsaman, Chadegan, Chehelkhane, Damane, Lenjanat, Meyme, Shahabad, Borkhar, Dasht, Esfandaran, Izadkhast, Kuhpaye, Mahyar, Murchekhort, Najafabad, Qomshe and Batlagh. Baseline year is 1380 (equivalent to 2001 in Christian calendar) and according to the country long-term plan, the modeling end year is chosen as 1404 (2025 in Christian calendar). Units are used in SI system. An overall scheme of the model is represented in Figure 3.

In this research, three need points are defined which include agricultural water requirements, drinking water in urban and rural areas. In Table 1 Shahabad demand's data is presented as an example. Future demands are considered as the national plan presented in Table 2. Moreover, Monthly variation of demands is shown in Table 3. To simulate the surface water resources, branches' flow and reservoirs' profile are given to the model as input. In Table 4, flows of Shahabad sub-basin branches are presented. Table 5 identifies the basin reservoir properties. In order to simulate underground water resources, information about nutrition, aquifers unloading and storing has been defined in the model. Table 6 contains the data for Shahabad sub-basin.

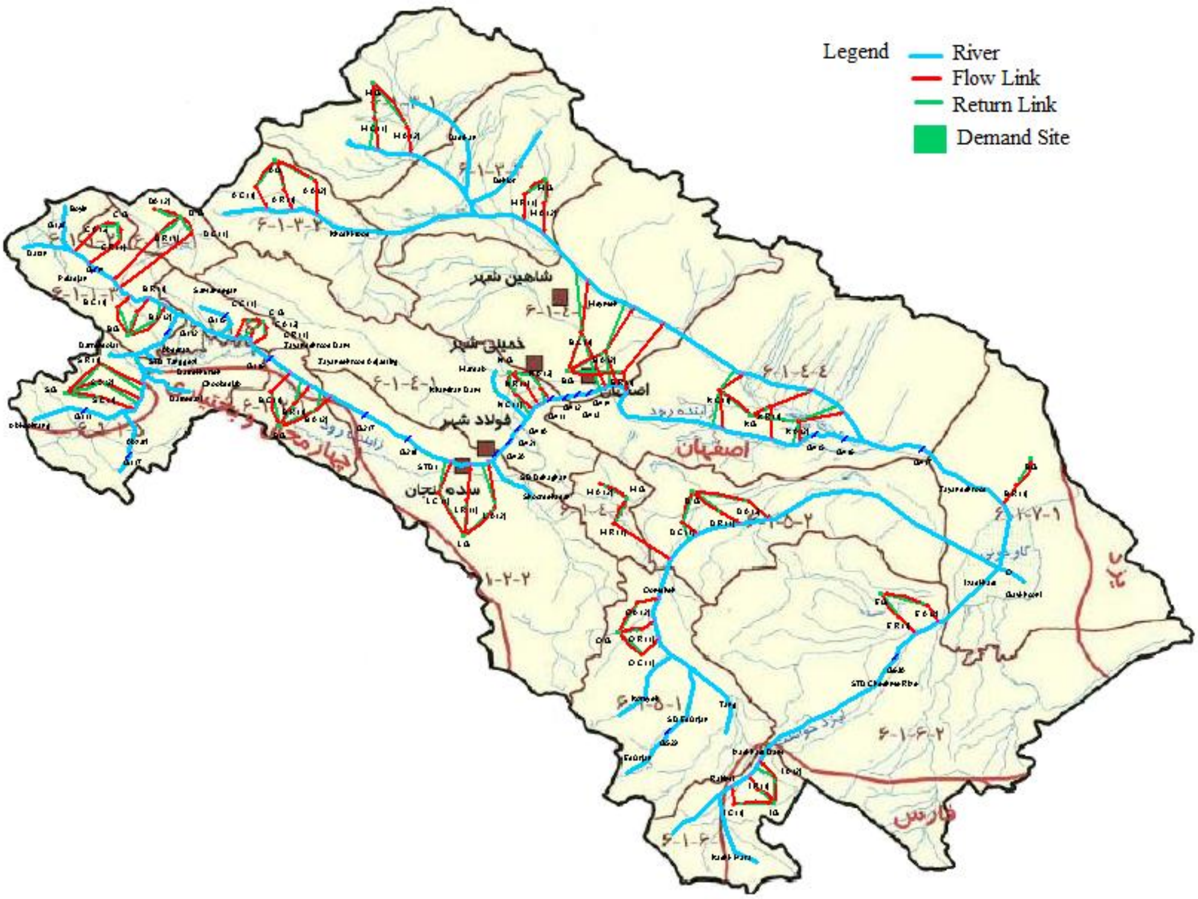

Figure 3. Model Schematic

Table 1. Demand Characteristics in Shahabad

	Type of demands		
	Agr.	Rural	City
Annual Activation Level (Cap or ha)	9930	38000	8500
Annual Usage Rate (m^3/Cap or m^3/ha)	11531	49	68
Water Consumption* (%)	63	26	16
Priority	2	1	1

* Water consumption refers to the water that exit from the system

Table 2. Future Annual Activation Level in Shahabad (Cap or ha)

	Type of demands		
Year	Agr.	Rural	City
2000	9930	38000	8500
2005	-	34900	11700
2010	-	33000	13100
2015	-	30600	14700
2020	-	27600	16300
2025	-	25100	17800

Table 3. Demands' Monthly Variation in Shahabad (%)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Agr.	4	1	0	0	0	5	7	15	23	22	16	7
Rural	8	7	6	5	5	6	8	9	11	12	13	10
City	8	8	6	5	6	7	8	9	10	11	12	10

Table 4. Headstreams Flow (CMS)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Abzari	0.87	1.36	1.12	0.75	0.67	0.89	4.57	11.5	11.2	8.69	3.94	1.63
Abkuhrang	5.19	5.01	4.33	3.49	3.68	6.32	15.4	19.5	18.8	16.7	12.2	7.41

Table 5. Basin's Dams

Dam's Name	Operation Year	Capacity (MCM)	River
Zayandehrood Dam	1969	1450	Zayandehrood
Khamiran Dam	1991	6.5	Marqab
Izadkhast Dam	1999	10.5	Rahimi
Zayandehrood Controlling Dam	1969	1.5	Zayandehrood
Esfarjan Dam (Suggested)	2012	11.5	Esfarjan

Table 6. Shahabad's Groundwater Monthly Transactions (MCM)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Allowable Discharge	1.6	1.3	0.9	0.9	0.9	1.1	1.3	1.4	2	2.3	2.3	2
Natural Inflow	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25

Future climatic conditions are estimated by using the Water Year method. In this method, five modes are explored for future climatic conditions. In each case a coefficient is applied for surface and groundwater feeding. These coefficients are presented in Table 7.

Table 7. Coefficients for surface and underground flows

Climate Condition	Very wet	Wet	Normal	Dry	Very dry
Coefficients	1.4	1.2	1	0.7	0.4

Using the SRES climate change scenarios, the basin runoff was predicted by a model fusion approach combining MLP[1], GRNN[2] and a LR[3] models. This approach puts together the result of each method taking into account the distributed weight of different results. The A2 and B2 scenarios were downscaled using 1975 to 2000 historical data. The results of B2 scenario had better agreement to the observed data in the 2000 to 2010 period. Therefore the B2 scenario was selected. In this regard, we used the time series of run-off gauging stations records. Finally, the fifth station was selected and coefficients of Water Year method were chosen according to the basin run-off flows, (Figure 4).

[1] Multi-Layer Perceptron
[2] General Regression Neural Network
[3] linear regression

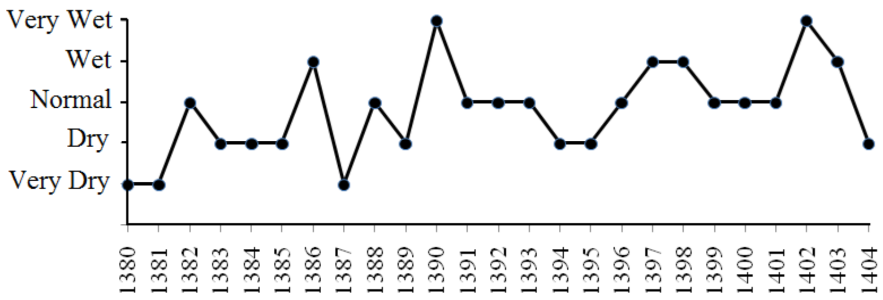

Figure 4. Predicted Coefficients for water year method

RESULTS AND DISCUTION

In this section, the results of WEAP data analysis are discussed. In Figure 5, total water demand and supply and in Figure 6, supply water coefficients are illustrated. Since priority of providing drinking water for sub-basins is considered as one, drinking water supply coefficient in all parts would be equal to 100% and only agriculture water supply can be investigated.

Due to limitations on taking water from aquifers, their reserves stay generally constant, but aquifers like ones on hillside and foothills, will have a decreasing trend. Zayandehrood River Dam would also be almost empty, most of the time.

With regard to water supply shortages in Gavkhoni basin, water resource infrastructure development in this basin seems imperative. Consequently, different scenarios will be investigated in this regard.

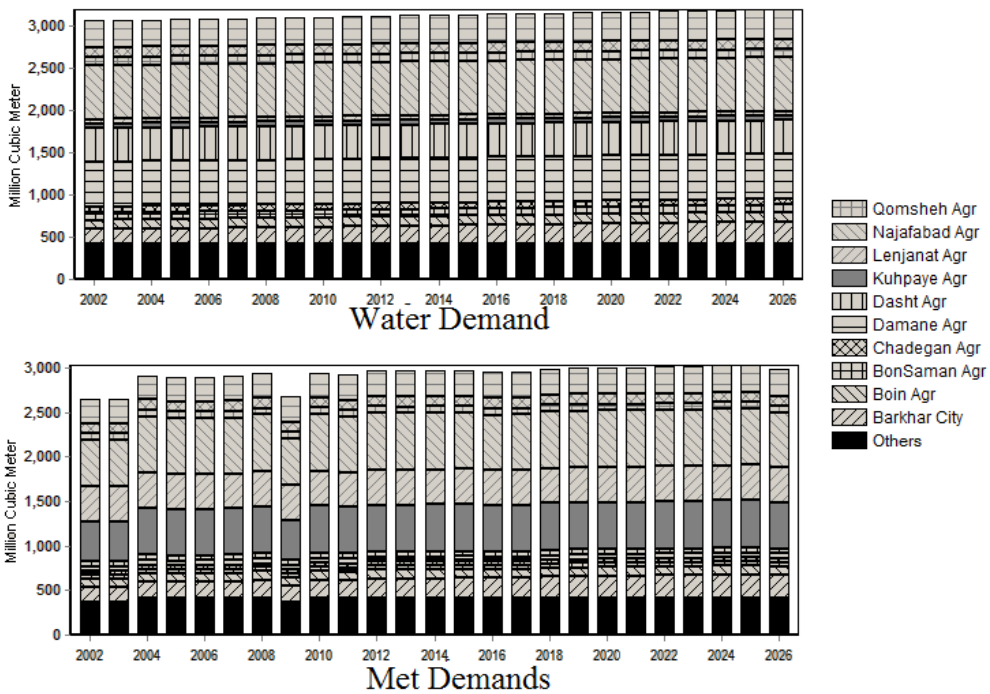

Figure 5. Total and met demands

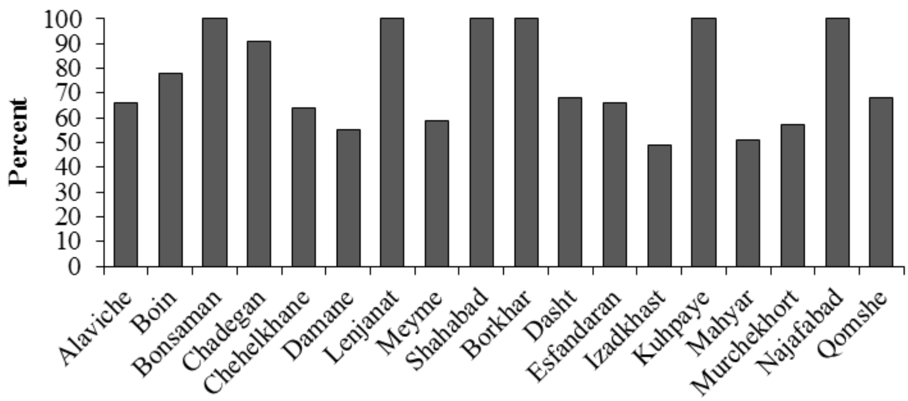

Figure 6. Agricultural demands coverage

Increase irrigation efficiency scenario (IIE)

This scenario which has been named IIE, investigates the influence of irrigation efficiency augmentation on water supply needs for Gavkhoni basin. It’s carried out through a renovation and reparation of irrigation system. As a result of these operations, irrigation efficiency is raised by 10% meaning that water waste coefficient in agricultural sector decreases by 10%. The operation currently costs over half a million USD per hectare of agricultural land. To calculate the cost of operations in each sub-basin, first the cost per hectare in the first year has been calculated, and then the area under cultivation of each sub-basin has been multiplied to this cost per hectare. Cost per hectare in the first year (baseline year - 10 years ago) by considering an interest rate of 15%, is equal to (Oskoonezhad 2006):

$$P = F\ (P/F,\ i\%,\ n) = 1500000\ (P/F,\ 15\%,\ 8) = 1500000 \times 0.3269 \approx 500{,}000 \text{ USD/ha}$$

Aquifer recharge scenario (AR)

The AR scenario (Aquifer Recharge) was defined based on natural replenishing of aquifers through rainfall. Moreover, in this scenario aquifers can also be recharged by utilizing Aqueonics' efficient system that injects the surface water to the aquifer by means of wells or percolation beds. This operation needs about 3700000 USD in current year. For the baseline year it’s calculated as below:

$$P = F\ (P/F,\ i\%,\ n) = 2500000\ (P/F,\ 15\%,\ 8) = 3700000 \times 0.3269 \approx 625{,}000 \text{ USD/ha}$$

Conveyance between Basins (CBB)

In this scenario which is called CBB, we proceed to analyze the effect of the third Koohrang tunnel construction in Gavkhoni basin water supply and its economic aspects. As a result of this project the possibility of transferring 255 MCM water per year to Gavkhoni Basin is achieved (Kohrang3.com). This fact is modeled by a flow increase of 8 CMS in Zayandehrud main branch. Considering the current development situation, this project cost over 650 million dollars. This cost in the baseline year (10 years ago) considering an interest rate of 15%, is equal:

$$P = F\ (P/F,\ i\%,\ n) = 650000000\ (P/F,\ 15\%,\ 8) = 650E{+}9 \times 0.3269 \approx 200{,}000{,}000 \text{ USD}$$

The combinations of individual scenarios are also considered as new scenarios. Therefore AR-IIE, IIE-CBB, CBB-AR and AR-IIE-CBB scenarios are available.

Scenario analysis

As a comparison between scenarios, the effects of each on water supply and costs have been analyzed. Figure 7 shows the increase of the water supply coefficient in the agricultural sectors for various scenarios in comparison with the reference scenario.

Since the priority of one has been assigned for drinking water in all parts of the basin, different scenarios have no impact on the supply factor. It means the effect of such scenarios, IIE, and CBB in water supply of the basin is the same. Comparison of initial investment costs for different scenarios is represented in the Figure 8.

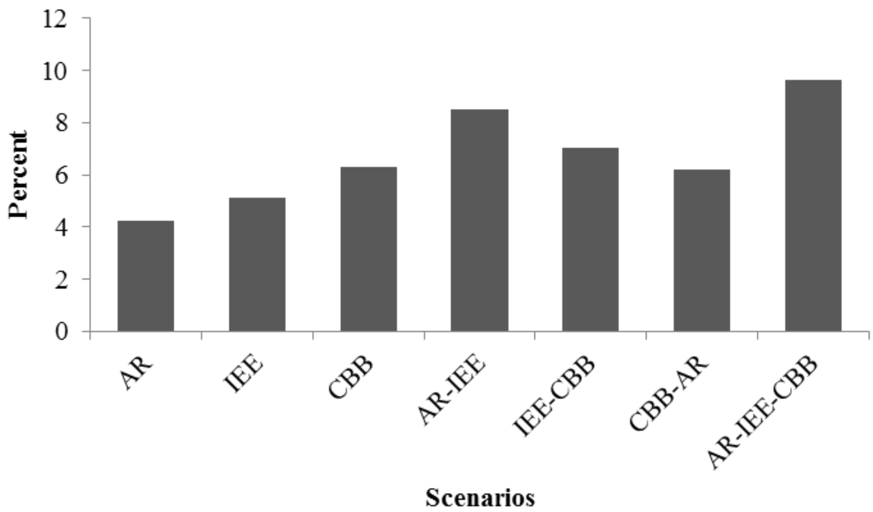

Figure 7. Increase in Agricultural demand coverage for various scenarios related to reference scenario

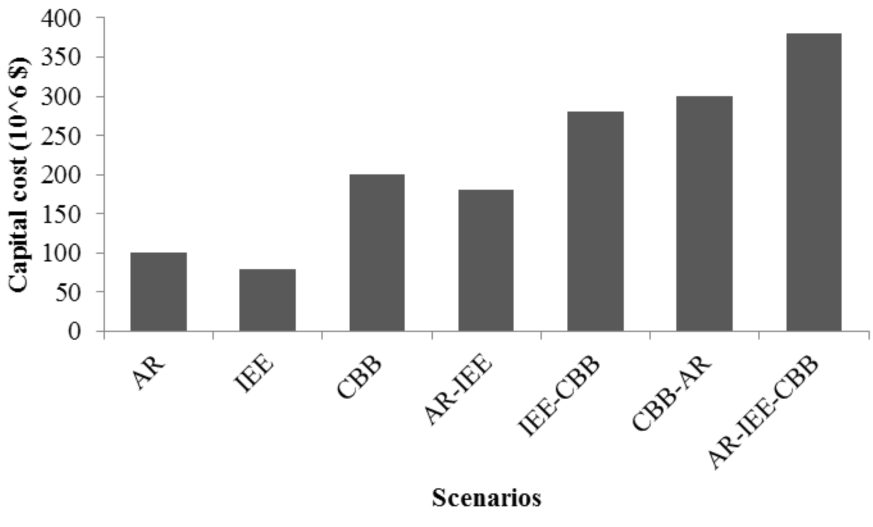

Figure 8. Capital cost for various scenarios

To select the best scenario the objective function values are standardized and the added together. The results of combining have been shown in Table 8. According to Table 8 AR-IEE is the best scenario.

Table 8. Standardized Objectives

	Cost	Water Supply Increase	Sum
AR	-0.07	0.00	-0.07
IEE	0.00	0.16	0.16
CBB	-0.40	0.38	-0.02
AR-IEE	-0.33	0.79	0.46
IEE-CBB	-0.67	0.52	-0.15
CBB-AR	-0.73	0.37	-0.37
AR-IEE-CBB	-1.00	1.00	0.00

* Best scenario is highlighted by grey background

Model validation

For validation, Population and resources in 1963 (oldest course in statistics of basin gauging stations) are given to the model as the initial conditions, then the model is launched and analyzed till 1380 (2001), and finally the results are compared with reality. To get the growth function of the under cultivation area, linear functions and also exponential functions for population growth, are fitted to the existing data at any given sub-basin. Examples of these calculations are depicted in the Figure 9.

To control the validation results, supplied needs and storage of aquifers in 1380 (2001) were used (Figure 10 and 11). Supplied need, is dependent to the simulated water resources, tanks, consumption points and geographical conditions, and that's the reason why in this chapter it's been precisely analyzed. Water storage in tanks also includes water exchanges between different sources and it can verify the similarity of the model to reality.

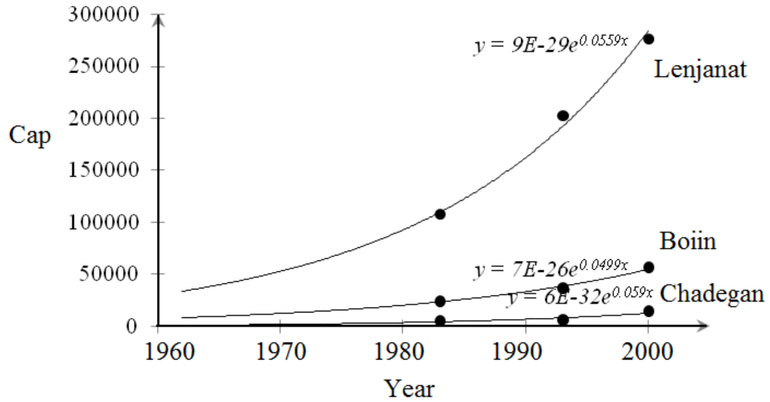

Figure 9. Estimation the fitness function for population

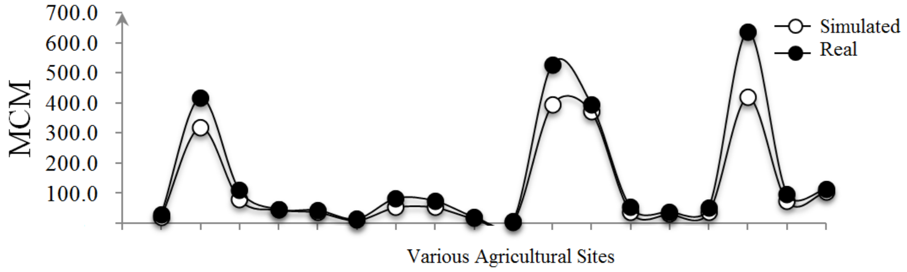

Figure 10. Comparison of real and simulated data in met demands

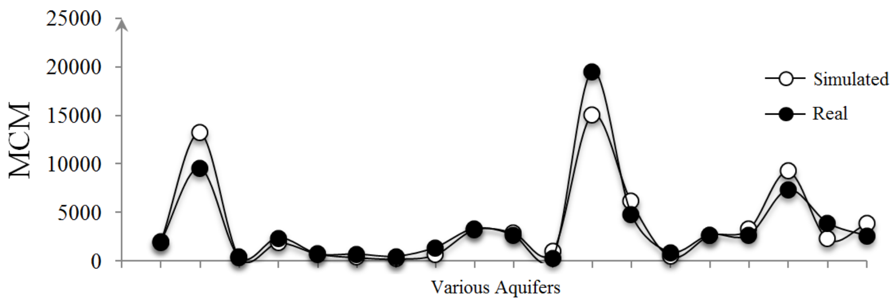

Figure 11. Comparison of real and simulated data in aquifer storage

These investigations prove an acceptable compliance between actual (real) and calculated values. The match points that have less compliance than others are: sub-basins of Borkhar, foothills and Najafabad. In these points flow statistics do not exist in many branches, consequently they are not considered in the model.

Sensitivity analysis

In this research, the loss of all water supply systems is considered as equal to 5%. Here, we evaluated the sensitivity of the model to increase or decrease of one percent drop in water supply systems. For this purpose, values of 3%, 4%, 5%, 6% and 7% are chosen and their effect on the water supply coefficient of different regions has been examined. Figure 12 represents the results of these changes compared to the reference scenario (5% loss) for the most effective places.

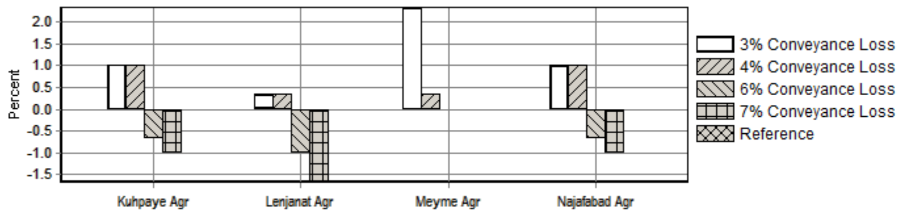

Figure 12. The most affected sites by changing in conveyance loss

The highest impact occurred in agricultural sector in Meimeh with a drop of 3%, where we can observe an increase of 2.2% in the supply coefficient. However, averagely a drop of one percent in transmission systems can cause a half a percent change in the total result, which is in the acceptable range.

CONCLUSION

In the present study, after analyzing the reference scenario (continuation of current situation) it turns out that in the Gavkhoni basin, considering future population growth and climate conditions, water supply particularly in the agricultural sector requires some developing strategies. Accordingly seven scenarios were defined: The AR scenario (Aquifer Recharge) was defined based on natural replenishing of aquifers through rainfall. The CBB scenario (Conveyance Between the Basins). The IIE scenario (Increase Irrigation Efficiency) was defined to consider the renovation of irrigation systems and its cost. AR-IIE, IIE-CBB, CBB-AR and AR-IIE-CBB scenarios were also defined based on the combination of the single scenarios. Finally, considering both the water supply and construction costs, the AR-IIE is selected as the best option for administrators and decision makers.
To ensure the validity of model results presented here, resources and consumptions in the past were given to the model to be able to compare the calculated conditions with the current and real ones. The results indicated a reasonable match between the conditions.

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