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The Effects of Adaptation Strategies on Water Resources Management in Mashhad Plain: The Application of Hydro-economic-behavioural Modeling

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Abstract

Khorasan Razavi Province suffers from the most critical groundwater resources in Iran, i.e. the groundwater decline has reached 1 m; 34 out of 37 water plains are banned in Khorasan Razavi Province. Recently, Mashhad plain has been fighting with the crisis of drought and water scarcity. Illegal harvesting from groundwater resources and the warming trend caused by change in climate have exacerbated the crisis. Comprehensive water resources management, assuming the complicated nature of water-related issues, rapid growth of population, water requirement for a variety of purposes, and limited water resources, requires novel methods to stack up technical, economic, environmental, social, and logical perspectives in an integrated forum. One of the tools for comprehensive water resources management is utilizing hydro-economic models to simulate the present status of drainage basins and evaluate the impacts of different scenarios and policies. The current study used a hydro-economic model to simulate the hydrological status of Mashhad plain and evaluate the impacts of different scenarios. Then, the agent-based model (ABM) was used in order to reach an agreement with stakeholders on executing different conservation scenarios. The hydro-economic model results revealed that reducing the water demand of the agricultural sector and, as a result, surface and groundwater consumption is possible through following adaptation scenarios. Implementing various adaptation scenarios may alter the present cultivation pattern. Moreover, the ABM results showed a significant difference between the volume of available water, due to the execution of strategies, and water demand, bringing about the lack of farmers' cooperation regarding the implementation of conservation scenarios. However, through applying some incentive policies, a number of representative farmers may agree to pursue adaptation scenarios.

Keywords: Adaptation strategies, Water resources, Hydro-economic model, Mashhad Plain

Introduction

The evaluation of the water resources worldwide revealed that more than 50% of renewable and available water is consumed by human beings (Gleick and Palaniappan, 2010). In the last 60 years, the global population has more than doubled, from 2.6 billion in 1950 to 6.9 billion in 2010 (Ahmad and Dawadi, 2013), which has affected the water requirement, i.e. water demand has tripled from 1950 to 2003 and will double by 2035. Iran is an arid and semi-arid region in the globe with an average annual rainfall of 230 to 240 mm or annually 413 billion m^3 (Nazem al-Sadat *et al.*, 2006). Iran's population is rapidly rising which it is expected to reach 100 million

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by 2050 (Hosseini and Bagheri, 2012). Iran is located in the arid belt of the earth and is exposed to numerous droughts. Moreover, environmental degradation accelerated by population growth and its consequences on intensify use of resources to produce food while facing limited water resources have made the water crisis as a main challenge for Iran (*Poran et al.*, 2017). Factors that have created and intensified the crisis are water consumption patterns, ways of using the water resources, consumption situations, consumption technology, precipitation rate, and climatic changes (Shahnooshi *et al.*, 2016). Khorasan Razavi Province suffers from the most critical status of groundwater resources in Iran. The groundwater level declined by 1 m. Also, 34 out of 37 water plains are banned in Khorasan Razavi Province. Mashhad plain has been struggling for years with the crisis of drought and water scarcity (Yazdani *et al*., 2016). Mashhad Plain is one of the plains of the Kashfrud watershed. Accordingly, considering the problems in Kashafrud basin, the hydro-economic modeling method was used to simulate the current and future status of the plain and apply different adaptation scenarios. Hydro-economic models consider hydrological, economic, engineering, and environmental aspects in the form of a coherent framework in line with the requirements of integrated management of water resources. The main purpose is to include economic concepts in the water resources plans models (Harou *et al.*, 2009). Different studies have used this method to simulate drainage basins. Forni *et al.* (2016) and Esteve *et al.* (2015) integrated WEAP[1] and mathematical programming models in a hydro-economic model framework to assess the impacts of climate change and its adaptation methods in the Guadiana River Basin (Portugal and Spain) and the San Joaquin Basin (United States). Zekri *et al.* (2017) used a dynamic mathematical programming model and a hydrological groundwater simulation model in a hydro-economic model framework for feasibility of groundwater monitoring by adopting smart water meters at individual farms and a centralized online information management system. Sharafpour *et al*. (2019) used an integrated hydro-economic model to allocate agricultural water according to economic value in six irrigation networks at downstream of Zayanderud Dam.

Nevertheless, hydro-economic models running based on basin simulation do not consider issues like the acceptance and cooperation of stakeholder in prescriptive optimization models. In other words, hydro-economic models do not answer the question whether or not the optimization models obtained from the mathematical model are executable regarding the basin. Hence, to fill the leakage of the mathematical models the Agent-based model (ABM) is introduced by unique features and applied in studies concerned the water resources management (Barthel *et al.*, 2010)(Nikolic and Simonovic, 2015) As research argued the agent-based models (ABM) covers the analysis to confront socio-economic and environmental inter-relationships. The ABM or multi-agent systems involve a set of agents specified by unique features and interact with each other based on adequate rules defined in an environment (Nasirzadeh *et al.*, 2008).

Here, provide a paragraph on goal(s) of your study and how adjust the method(s) for following the goal(s). Then close the introduction.

Materials and Methods

Conceptual Framework

Figure 1 depicts the conceptual framework. First, the impact of the drought scenario and adaptation measures on optimal water allocation to different water consumption sectors including agriculture, industry, drink, and environment is evaluated using the hydro-economic model.

This section evaluates different scenarios' effect on the amount of available water for each sector in Mashhad plain. The optimal crop pattern of the representative farmers and

1- Water Evaluation and Planning System

different scenarios' impact on the crop pattern and each farmer's expected yield are assessed using the hydro-economic model (alterations in available water) and a multi-objective economic optimization model (at the farm level). Then, the representative farmers' cooperation in running various adaptation measures is assessed using the ABM and the economic optimization model. The statistics of Agriculture Jihad, Khorasan Razavi Regional Water Authority, and different sources such as the website of the Department of Basic Studies of Water Resources, planning and optimization reports of Mashhad plain water resources, and questionnaires were compiled in the statistics section and data related to hydro-economic modeling and ABMs.

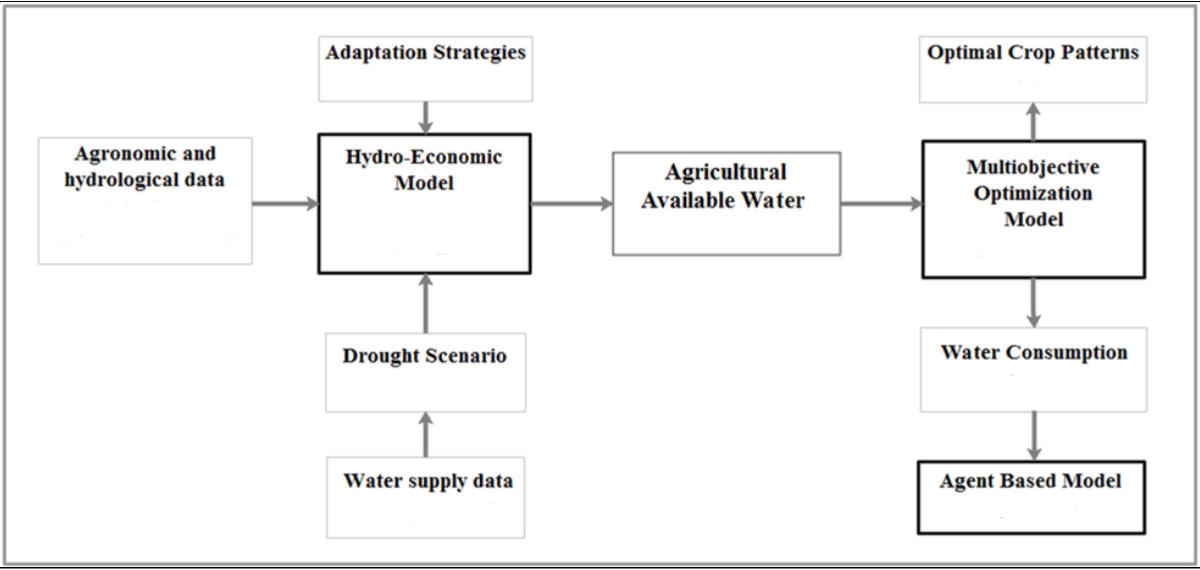

Figure 1- Conceptual framework of the model for assessing the impact of drought on the agricultural and hydrologic status of Mashhad plain

Hydro-economic Model

Allocating water to different sectors in the Kashfrud Basin is based on the principle of maximum economic advantage, emphasizing efficiency in the allocation of water. So, an objective function of water allocation model refers to the maximization of the net economic benefit of decreasing water consumption in different sectors, expressed as Relations (1) and (2) (Ward and Pulido-velazquez, 2008):

$$NPV_1 = \sum_u \sum_t \frac{NB_{ut}}{(1+r_u)^t} \quad (1)$$

$$NPV_2 = \sum_e \sum_t \frac{NB_{et}}{(1+r_e)^t} \quad (2)$$

NPV_1 is the discount net present value with r discount rate, obtained from the sum of economic benefits of water consumption (NB_{ut}) for agriculture, urban, and industry sectors (u). NPV_2 is the sum of environmental advantages (NB_{et}) for the environment sector through a specific time period (t).

Model Constraints

In optimization models, the values of all decision variables are computed for the maximization or minimization of the objective function under a set of constraints. Hence, a variety of constraints have been taken into account in different water distribution studies. The constraints below are applied to each model node.

Simple Nodes Constraints

This constraint states that the water exit from these nodes (a subset of the model nodes) is equal to the sum of the water entering the same nodes (Relation 3).

$$\sum_n R(n,t) = \sum_n Q(n,t) \tag{3}$$

$R(n,t)$ is the water exit from the simple node in the t^{th} time period, and $Q(n,t)$ is the water entering the simple node in the t^{th} time period. In addition to the so-called constraint, canal capacity constraint was applied to the simple nodes. Based on this constraint, the maximum water input and output from simple nodes must be lower than each canal's capacity. The canal capacity constraint can be expressed as Relation (4):

$$Q(n,t) = R(n,t) \leq R_{Max} \tag{4}$$

R_{Max} is the maximum water conveyance capacity through the dam's irrigation canals.

Irrigation Node Constraint

Based on this constraint, the water demand of agricultural nodes is gained by multiplying the area under cultivation by the water requirement of plants cultivated in these nodes. Relation (5) shows this constraint for agricultural nodes merely integrating surface and groundwater resources (nrr):

$$Demand(nrr,t) = \sum_j X1_j * Da(j,nrr) \tag{5}$$

In Relation (5), $Demand(nrr,t)$ is the water demand of agriculture node, and $Da(j,nrr)$ is the water demand of different plant types. Relation (6) shows this constraint for agricultural nodes merely using surface water (nrw):

$$Demand(nrw,t) = \sum_{jj} X2_j * Da(j,nrw) \tag{6}$$

Another constraint was applied to the model based on the water supplied (released) to the agricultural demand nodes equal to the demand of this node. Relation (5) shows this constraint for both groups of agricultural nodes as Relations (7) and (8):

$$Divert(nrr,t) = Demand(nrr,t) \tag{7}$$

$$Divert(nrw,t) = Demand(nrw,t) \tag{8}$$

The constraint of area under cultivation was applied to the model based on the maximum area under cultivation of agricultural nodes as Relations (9) and (10):

$$X1(nrr,t) = X1_{Max} \tag{9}$$

$$X2(nrw,t) = X2_{Max} \tag{10}$$

$X1_{Max}$ is the maximum cultivation area of agricultural nodes integrating surface and groundwater, and $X2_{Max}$ is the maximum cultivation area of agricultural nodes using merely surface water.

Environmental Node Constraint

Another constraint is the environmental constraint, based on which the water allocated for the environment must be equal to or more than the minimum environment requirement:

$$R(nl,t) \geq MDT(nn,t) \tag{11}$$

$MDT(nn,t)$ is the minimum environment water need of the basin downstream in the t^{th} period of time.

Groundwater Node Constraint

Groundwater nodes ($n\lg$) are the source of supplying agricultural water with wells and using the groundwater resources through pumping. This relation is similar to the continuity equation and states that there must be a mass balance between the input and output values to the groundwater sources in all optimization stages. This constraint for all groundwater nodes is presented in Relation (12):

$$S(n\lg,t) = S(n\lg,t-1) + \sum_{n\in in} Q(n\lg,t) - \sum_{n\in out} R(n\lg,t) \tag{12}$$

$S(n\lg,t)$ is the volume of groundwater in the t^{th} period, and $R(n\lg,t)$ is the amount of harvest from the groundwater resources, and $Q(n\lg,t)$ is the amount of water entering the groundwater resources in t^{th} period of time. In addition to the above constraint, a constraint was also applied to the model named the maximum harvest from groundwater nodes. Based on this constraint, the maximum harvestable water from groundwater nodes must be lower than the maximum harvestable water from active irrigation wells in farms (Reltion (13)):

$$R(n\lg,t) \leq R_{Max}(n\lg) \tag{13}$$

$R_{Max}(n\lg)$ is the maximum harvestable water from the wells in farms, determined based on the well discharge.

Farm-level Optimization Model

The farm-level optimization model is a dual-objective linear optimization model to maximize farmer's planned yield and minimize water use to save for environment use (Kal Tangal Shur). In this model, the optimal combination of land allocation ($X_{c,r}$) to agricultural crops and different irrigation techniques (r) are gained by maximizing the farmer's planned yield and minimizing water use based on technical, structural, and political constraints. The objective functions are defined as Relations (14) and (15):

$$Max\ Z_1 = \sum_c \sum_r p_c . y_{c,r} . x_{c,r} - \sum_c \sum_r tc_{c,r} . X_{c,r} - \sum_c \sum_r wp.(nw_c / ef_r) X_{c,r} \quad (14)$$

$$Min\ Z_2 = \sum_c \sum_r (wf_c). X_{c,r} \quad (15)$$

p_c is the price of each crop unit (c); $y_{c,r}$ is the crop yield with irrigation technology (r) per unit area. $tc_{c,r}$ is the production cost of agricultural crops per unit area; wp is the price of each unit of water use, nw_c and wf_c are, respectively, the net water requirement and water footprint of agricultural crops per unit area. ef_r is the efficiency of irrigation techniques. The model variables are $X_{c,r}$ which is the decision variable of the area under cultivation with irrigation technology (r), Z_1 which is the farmer's planned yield, and Z_2 which is the water footprint.

The model constraints include Relations (16) to (18):

$$\sum_c \sum_r X_{cr} \le land \quad (16)$$

$$\sum_c \sum_r ie_r . X_{cr} \le Energy \quad (17)$$

$$\sum_e (wreq_c / h_i) . x_{c,i} \le Available\text{Water}.\text{Eff}_i \quad (18)$$

$land$ and $Energy$ indicate the available land and the energy of agricultural crops per unit area. $wreq_c$ is the net water need of agricultural products. h_i is the i irrigation technique efficiency. AvailableWater is the available water for each farm, and Eff_i is the efficiency of the water conveyance system.

To solve the dual-objective optimization model, the Augmented Epsilon Constraint Method was used, where the constraints are converted from inequation to equation, for which slack and surplus variables are used:

$$\begin{aligned}
&\max(Z_h(x_1,x_2,...,x_n) + eps(s_1 + s_2 + ... + s_{h-1} + s_{h+1} + ... + s_k))\\
&Z_1(x_1,x_2,...,x_n) - s_1 = e_1\\
&Z_2(x_1,x_2,...,x_n) - s_2 = e_2\\
&\vdots\\
&Z_{h-1}(x_1,x_2,...,x_n) - s_{h-1} = e_{h-1}\\
&Z_{h+1}(x_1,x_2,...,x_n) - s_{h+1} = e_{h+1}\\
&\vdots\\
&Z_k(x_1,x_2,...,x_n) - s_k = e_k
\end{aligned} \quad (19)$$

eps is a negligible value, usually 10^{-3} to 10^{-6}. $s_i.r_i$ is used instead of s_i variables in the objective function to avoid the measurement scale problem, where r_i is a range of the i^{th} objective function (the distance of the worst and the optimum value of the expected objective). Thus, the objective function is changed to Relation (20):

$$\max(Z_h(x_1,x_2,...,x_n) + eps(\frac{s_1}{r_1} + \frac{s_2}{r_2} + ... + \frac{s_{h-1}}{r_{h-1}} + \frac{s_{h+1}}{r_{h+1}} + ... + \frac{s_k}{r_k})) \quad (20)$$

The best response was chosen from among the Pareto efficiency responses obtained from the above technique based on different opinions of decision-makers and stakeholders using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method.

ABM

The ABM was used to evaluate the cooperation or non-cooperation of water harvesters with the optimal model gained from the previous two models for Mashhad plain (base scenario). If farmers' cooperation is based on the model, it will positively affect the environment; otherwise, it will have a negative impact. Moreover, the government can positively protect the environment via creating incentives and imposing fines and new laws with respect to cooperation or non-cooperation of harvesters. Furthermore, the adaptation management policies of water resources were evaluatred using the ABM, like utilizing new technologies related to water resources and new water tariffs, altering the cultivation pattern, and indicating environmental water requirements for rivers. Formulating the ABM and assessing farmers' cooperation in each scenario are given in the following relations (Akhbari and Grigg, 2015):

$$TAW_{y,m} = f\,(Q_{in,y,m}, Q_{min,y,m}) \quad (21)$$

$$AW_{i,y,m} = f\,(TAW_{y,m}, LA_i, CWD_i) \quad (22)$$

$$\begin{aligned} &if\ \ AW_{i,y,m} < D_{Max,i,y,m} \Rightarrow i \rightarrow NC \\ &if\ \ AW_{i,y,m} \geq D_{Max,i,y,m} \Rightarrow i \rightarrow C \end{aligned} \quad (23)$$

$TAW_{y,m,d}$ is the total available or allocated water obtained from the simulation model. $AW_{i,y,m,d}$ is the available or allocated water to each water harvester. LA_i is the land area of each water harvester. CWD_i is the water demand of the crop cultivated by the harvester agent. $D_{Max,i,y,m}$ is the maximum water demand for each harvester. m and y are, respectively, the month and year. Thus, if the allocated water to each agent is lower than the maximum demand of that agent, the agent's behavior is non-cooperative (NC), otherwise cooperative (C). After indicating the agents' cooperation or non-cooperation, the utility of different agents to continue or alter their behavior is estimated using Relations (24-27) (Edwards *et al*., 2005):

$$U_i(C \rightarrow C) = a \times V_i(C) + F_m \quad (24)$$

$$U_i(C \rightarrow NC) = b \times V_i(NC) \quad (25)$$

$$U_i(NC \rightarrow C) = c \times V_i(C) + F_m \quad (26)$$

$$U_i(NC \rightarrow NC) = d \times V_i(NC) \quad (27)$$

$U_i(C \rightarrow C)$ is the utility of agent i with cooperative behavior who still wishes to remain cooperative. $U_i(C \rightarrow NC)$ is the utility of agent i with cooperative behavior who wants to alter his behavior to be non-cooperative. $V_i(C)$ and $V_i(NC)$ are, respectively, a fraction of neighbors of agent i having cooperative and non-cooperative behavior. In other words, others' behavior affect agents' cooperation or non-cooperation. The values of *a*, *b*, *c*, and *d* model parameters were considered $a = b = 0.7$ and $c = d = 0.7$ in the study of Edwards *et al*. (2005). F_m is the adjustment factor and a function of allocated water, representing different water management scenarios (government activities and education). If the available water to farmers is sufficient, $F_m = F_m^*$ (Relation (28)):

$$F_m^* = \begin{cases} 1 - [0.7 \times V_i(C)] \\ 1 - [0.3 \times V_i(C)] \end{cases} \quad (28)$$

By substituting F_m^* (Relation (14)) in Relations (24) and (26), $U_i = 1$ is obtained (utility 100 %). Thus, if the available water meets agent i demand, this agent will cooperate in the scenario and achieve 100% utility. If he does not cooperate, the government may fine him or he may encounter stricter laws or may be sued by the environmental agent. F_m can vary from 0 to F_m^*; 0 means the lack of management scenarios, and F_m^* means strict practices and forcing farmers to bear cooperation in the optimal model. Management scenarios may involve motivating farmers to cooperate, imposing fines, and education by the government. So, it is possible to find out which scenario or what incentive or fining can close the water consumption status to the optimal status or the theory. The following relation indicates the agent's new demand: based on the relation, if an agent's maximum demand is more than the allocated water ($D_{\max,i,y,m} > AW_{i,y,m}$), that agent will not cooperate. Thus, that agent's excess demand is obtained from $(D_{\max,i,y,m} - AW_{i,y,m}) \times (1 - U_i)$. U_i is the utility of the non-cooperative agent and wishes to alter to cooperative status. If the maximum demand of an agent is lower than the allocated water, i.e. $D_{\max,i,y,m} \leq AW_{i,y,m}$, that agent will cooperate. Thus, its excess demand ($D_{i,y,m}^m$) is 0.

$$\begin{cases} D_{i,y,m}^m = (D_{\max,i,y,m} - AW_{i,y,m}) \times (1 - U_i);\ \forall y, m,\ D_{\max,i,y,m} > AW_{i,y,m} \\ D_{i,y,m}^m = 0;\ \forall y, m,\ D_{\max,i,y,m} \leq AW_{i,y,m} \end{cases} \quad (29)$$

Thus, the maximum new demand of each agent is given (Relation (30)):

$$ND_{\max,i,y,m} = AW_{i,y,m} + D^{m}_{i,y,m} \quad (30)$$

In this study, the necessary information has been prepared from the Regional Jihad Agricultural and Water Organization of Razavi Khorasan Province. The data used in this research include: price, yield, production cost, cultivated area, inflow of rivers, discharge of hydrometric stations, information of dams (storage capacity, volume-height diagram), monthly water demand of different sectors (drinking, industry, agriculture and environment), geographical location, water requirement of crops and irrigation efficiency.

Results and Discussion

Simulation results of the economic water allocation to agriculture, drink, industry, and environment sectors in Mashhad plain are shown in Table 1. Agriculture sector has harvested the most groundwater and surface water (Table 1). The agriculture sector of Mashhad has the greatest share (396 million m^3). Harvesting water for drink and sanitation ranks the second. Among different cities, groundwater harvesing in Mashhad ranks the first (115 million m^3), which is justifiable considering the extent and higher population of Mashhad in comparison with other cities. This is also true about the industry sector. The comparison of harvesting water from groundwater and surface water reveals that 79% of harvested water is supplied by groundwater, out of 1116 million m^3 of harvested water in Mashhad plain, confirming the prominence of groundwater in Mashhad plain. However, evaluation of the consumption indicates that 45 million m^3 of environmental requirements are provided through surface water in the base scenario. The optimal allocation of water in drought shows that harvesting groundwater and surface water will decline because of reduction in water supply in the drought scenario. The reduction of the total water supply in the drought from 1116 to 829 million m^3 (26 %) decreases water harvesting, which is normal value. However, among different water consumtions, the maximum decrease in water harvesting is related to agriculture. In general, the available water in the industry sector has decreased from 107 to 57 million m^3, manifesting the highest variation (Table 1). However, the available drink water has had a lower decrease, i.e. water harvesting in this sector has declined from 292 to 271 million m^3. This is justifiable assuming the significance of drink water in terms of safety and being vital. The available water for agriculture has decreased from 671 to 475 million m^3. The allocated water to the environment has decreased by 45% from 45 to 24.75 million m^3. As previously stated, farmers can adopt numerous adaptation measures to overcome drought to save agricultural water and receive water requirement of other sectors.

Table 1- Results of economic water allocation model in Mashhad plain under different scenarios

The whole basin	Environment	Industry			Drink			Agricultural areas			Water resource	Scenario
		Chenaran	Binaloud	Mashhad	Chenaran	Binaloud	Mashhad	Chenaran	Binaloud	Mashhad		
878.2	-	11.56	13.48	78.76	30.98	25.02	115.81	184.94	61.67	355.98	Groundwater	Base
238.09	45	0.42	0.46	2.88	21.71	17.53	81.16	21.15	7.05	40.7	Surface water	
1116.29	45	11.98	13.97	81.64	52.69	42.55	196.97	206.09	68.72	396.68	Total	
643.54	-	11.56	11.46	49.41	30.98	25.02	115.81	134.63	41.62	214.03	Groundwater	Drought
188.50	31.78	0.30	0.37	1.84	21.71	17.53	75.85	13.36	4.83	20.89	Surface water	
823.04	31.78	11.86	11.83	51.25	52.69	42.55	191	148	46.46	234.92	Total	
643.54	-	11.56	11.46	49.41	30.98	25.02	115.81	134.63	41.62	214.03	Groundwater	Deficit irrigation
188.50	31.78	0.30	0.37	1.84	21.71	17.53	75.85	13.36	4.83	20.89	Surface water	
823.04	31.78	11.86	11.83	51.25	52.69	42.55	191	148	46.46	234.92	Total	
624.18	-	11.56	10.07	51.72	30.98	25.02	115.81	124.27	43.01	211.71	Groundwater	Saffron cultivation
187.97	34.17	0.30	0.37	1.84	21.71	16.90	81.16	9.69	4.92	16.88	Surface water	
812.16	34.17	11.86	10.45	53.57	52.69	41.92	196.97	133.97	47.94	228.60	Total	

Source: Research findings

An adaptation agricultural measure to overcome drought in the Mashhad plain is benefiting from the deficit irrigation technique. Accordingly, the effect of employing the deficit irrigation was studied on water allocation status to different sectors. The results show that the deficit irrigation scenario largely decreases water consumption in the agricultural sector. The groundwater and surface water harvest in the agricultural sector has decreased from 475 to 429 million m^3. This stored water (36 million m^3) has been conveyed to other sectors. The total available water in the drink sector in drought conditions has reached 287 million m^3 from 272 million m^3. The remaining stored water is consumed by the industry and environment, i.e. the available water of the industry sector also increases by 17 million m^3.

The environment available water has increased from 24 to 31 million m^3. The low amount of released water for the environment is because the water requirement of the environment is supplied by surface water (Kashfrud), and the volume of surface water released from the agricultural sector cannot supply the environment requirement. Another scenario to reduce the influences of drought regarding the hydro-economic status of Mashhad plain is increasing the area under cultivation of saffron by 20% of the area under cultivation of the base year (Table 1). The results demonstrated that employing this scenario may decrease the volume of water consumed in the agricultural sector (surface and groundwater) from 475 to 410 million m^3. Assessment of the safforn cultivation scenario with deficit irrigation scenario shows that the volume of stored water is higher in safforn cultivation scenario.

The impact of different scenarios on the optimal cultivation pattern of representative farmers in Mashhad

This section presents the optimal cultivation pattern of representative farmers and drought adaptation scenarios' imoacts on the optimal pattern of cultivation. The results about farmer M1 shows that the largest area under cultivation is for tomato. The area under cultivation of tomato in the base status is 11.54 ha (54.9%). Wheat and barley are ranked the next, 21.6 and 17.86% (4.55 and 3.75 ha), respectively. The total area under cultivation of fruit crops (cherries and apples) is 5.5% (1.17 ha). However, by employing the drought scenario and reducing the available water, the area under cultivation of tomato, a water-demanding intensive crop, is reduced and is allocated to wheat and barley which are less water-intensive. Fruit crops are also eliminated from the cultivation pattern, and their area under cultivation is allocated to these agricultural crops. Applying the adaptation strategy of deficit irrigation could in part compensate the volume of available water and reduce the area under tomato cultivation. However, increasing the area under cultivation of saffron by 20% of the base cultivation area has also decreased wheat, barley, and tomato crops. The barley has had the greatest decrease, which is justifiable due to the low planned yield of barley. Moreover, the volume of water saved by the deficit irrigation technique returns cherry to the cultivation pattern.

The evaluation of farmer M2 results shows that in the base status, wheat has the largest area under cultivation (31.5%, 3.93 ha). Sugar beet is ranked the next (27%, 3.38 ha). The area under cultivation of apple, walnut, and pear is around 24% (3 ha). Barley has the least area under cultivation (17.29%). The area under cultivation of wheat and sugar beet decreases by application of the drought scenario due to their high water requirement, and the area under cultivation of barley increases. Furthermore, the area under cultivation of two fruit crops of apple increases and walnut is eliminated from the pattern as its water requirement is high. Nevertheless, barley is replaced by wheat and sugar beet via the deficit irrigation scenario. The area under cultivation of wheat and barley decreases and is replaced by saffron and sugar beet through 20% saffron cultivation scenario. The results of the representative farmer in Torghabeh show that, in the base status, the greatest area under cultivation is related to wheat, i.e. its area under cultivation is 3.64 ha (52%). Onion and barley are ranked the next with 19.94 and 13.77% (1.39 and 0.96 ha), respectively. The total area under cultivation of cherry and apple is 14.29% (1 ha). However, apple and onion have been eliminated from the cultivation pattern through the drought scenario and reducing the available water. The area under cultivation of onion is allocated to wheat and barley and the area under cultivation of apple is allocated to cherry. The reason for elimination of onion from the cultivation pattern is its higher water requirement. Applying the adaptation strategy of deficit irrigation, however, has compensated for the volume of available water and has returned onion to the cultivation pattern. Increasing the area under cultivation of saffron by 20% with regard to the base area under cultivation has reduced the area under cultivation of wheat and onion; the utmost decrease has been observed in the wheat. Its area under cultivation has decreased from 56% to 20%. The fruit crops and cherry did not change (14.29%) with employing deficit irrigation and increasing the area under saffron cultivation.

Tomato has the largest area under cultivation (31.23%) in the optimal cultivation pattern of Shandiz in the base status. Wheat and barley are ranked the next, 23.38 and 16.92%, respectively. The only fruit crop in Shandiz is cherry with 14.08% area under cultivation. Cherry is eliminated from the cultivation pattern through applying the drought scenario, and the area under cultivation of tomato is decreased by about 4% and the freed area under cultivation is allocated to wheat and barley. However, by applying the deficit irrigation scenario, the area under cultivation of tomato is increased by 4%, and cherry is returned to the cultivation pattern. But, by the scenario of 20% increase in the area under cultivation of saffron, the area under cultivation of wheat, barley, and tomato decreases and the area under cultivation of onion increases as compared to the drought scenario. Wheat crop faced the highest decrease from 33 to 18%.

Figure 2 shows that wheat and tomato have the largest area under cultivation of the optimal cultivation pattern of Ch1 representative farmer (27%, about 4 ha). Saffron is ranked the next (22.56%, 1 ha). Among fruit crops, pistachio and pear have 6.58 and 4.39% of the area under cultivation. By applying the drought scenario, the area under cultivation of tomato and wheat decreased by 14 and 7%, respectively, as compared to the base status, and instead, the area under cultivation of saffron and barley increased by 11% (1.32 ha) and 13% (1.87 ha), respectively.

This is justifiable considering the water requirement and adequate planned yield of these crops as compared to the other two crops. However, the evaluation of fruit crops indicates that by applying the drought scenario, pear has been eliminated from the cultivation pattern and has been replaced by pistachio. However, the area under cultivation of barley partially decreases using the deficit irrigation scenario and is replaced by tomato. Pear also does not exist in the cultivation pattern of fruit crops. However, the scenario of increasing saffron cultivation has decreased by 20% the area under cultivation of wheat and has increased the area under cultivation of tomato by almost 2% as compared to the drought scenario. The evaluation of the cultivation pattern of horticultural crops also shows that the pistachio cultivation area has not changed.

Saffron (37.5%, about 4.5 ha) has the largest area under cultivation of the optimal cultivation pattern of Ch2 representative farmer. Wheat is ranked the next (24%). Pistachio, cherry, and apple have a total of 16.67% of the area under cultivation. However, the application of the drought scenario reduced the area under cultivation of saffron and wheat by about 4%. Instead, barley increased by 7% (0.9 ha), which is justifiable assuming the low water requirement of barley as compared to the other two crops. The comparison of the optimal area under cultivation of fruit crops in the base status and drought scenario reveals that apple and cherry have been eliminated from the cultivation pattern and replaced by pistachio through employing this scenario. However, the deficit irrigation scenario has reduced the area under cultivation of barley by 13%, and wheat and saffron are replaced. But apple and cherry are still eliminated from the cultivation pattern of fruit crops. However, the scenario of increasing saffron cultivation by 20% (compared to the base year) has decreased the area under cultivation of barley and wheat by 13 and 10%, respectively. The cultivation pattern of fruit crops also shows that cherry has returned to the cultivation pattern.

Evaluation of farmers' behavior in the face of adaptation scenarios

Employing adaptation strategies with regard to climate change is done by farmers at the farm level. A number of non-cooperative farmers in adopting different adaptation strategies hinder the studied strategies to be executed at the basin. Accordingly, farmers' behaviour in encountering adaptation scenarios must be assessed to indicate the feasibility of each scenario at the farm and the whole basin. Thus, the scenarios' impact on the planned yield of representative farmers in different areas was first evaluated. According to Table 2, the drought scenario may reduce the planned yield per hectare of representative farmers of all areas. The maximum decrease in the planned yield is observed in representative farmers of Mashhad (M1 and M2) and the minimum in Chenaran (Ch1 and Ch2). However, the deficit irrigation scenario has greatly decreased the drought impact on the planned yield of farmers. For instance, the deficit irrigation scenario has reduced the planned yield of Ch1 representative farmer from 95.5 to 79.6, exceeding the base status (62.6). The improvement rate was high in the representative farmers of Mashhad (M1 and M2), and their total planned yield increased from 4.91 and 4.17 to 6.27 and 5.21 million tomans per ha, respectively. The deficit irrigation scenario has mostly affected the farmer of Shandiz and has decreased the planned yield of this farmer from 26 to 3.79%. The saffron cultivation scenario has greatly affected the farmers of Mashhad. For example, the planned yield of the representative farmer M1 has increased from 4.91 to 6.36 million tomans per hectare. In general and assessing all representative farmers, these scenarios may have a considerable impact on the economic status of all farmers in Mashhad.

Despite the positive impact of these scenarios on the farmers' planned yield, the farmers must be convinced about these strategies so that the adaptation scenarios can be implemented in Mashhad plain. Accordingly, incentive policies, fining, and legislation can be influental. Incentive strategies to persuade farmers to follow adaptation strategies at the farm level are as below:

Encouraging farmers to adopt the adaptation strategy of saffron cultivation through guaranteeing the reasonable purchase price of saffron.

Encouraging farmers to use the deficit irrigation method by subsidy payment for fertilizers and pesticides to those implementing the deficit irrigation technique.

Table 3 compares the volume of available and demand water with and with no incentives. In most areas, the volume of available water by adaptation strategies and water demand with no incentive greatly differ; however, this difference is different depending on different areas and strategies. The results revealed that incentives can bring the water demand of representative farmers closer to the volume of available water. A closer look at Table 3 shows that the demand of farmers in Chenaran in the two scenarios and their available water differ greatly. For Ch1 representative farmer, this difference is, respectively, 775 and 811 m^3/ha for the deficit irrigation and saffron cultivation.

Figure 2- The effects of different scenarios on the cultivation pattern of representative farmers of Mashhad plain

Table 2- The effect of adaptation strategies on the planned yield of representative farmers of different areas (million Tomans/ha)

Variation (%)	Drought + Saffron cultivation	Variation (%)	Drought + Deficit irrigation	Variation (%)	Drought	Base	Strategies
-9.62	6.36	-10.91	6.27	-30.15	4.91	7.04	M1
-10.91	5.23	-11.29	5.21	-28.93	4.17	5.87	M2
-1.8	5.6	-3.92	5.19	-11.95	4.75	5.40	T
-6.32	6.31	-3.79	6.48	-26.48	4.95	6.74	Sh
-0.46	6.59	2.44	6.79	-10.20	5.95	6.62	Ch1
-4.03	5.82	-12.25	5.32	-16.88	5.04	6.06	Ch2

Source: Research findings

This difference for Ch2 representative farmer is, respectively, 764 and 561 m^3/ha. In fact, the farmers of Chenaran are less inclined to cooperate in adaptation scenarios, while this is different for the farmers of Mashhad. For example, the difference between the water demand (with no incentive) and the available water of farmer M1 for deficit irrigation and saffron cultivation scenarios is 157 and 126 m^3/ha, respectively, which is much lower compared to the difference between the water demand and the available water of Chenaran representative farmers. The table also shows that the difference in the water demand with no incentive and the available water of the representative farmers of Binaloud is in the middle of two other cities. The evaluation of the available water and the water demand with incentive for the deficit irrigation scenario demonstrates that applying the so-called solutions, such as subsidy payment for fertilizers and pesticides, can decrease the water demand of M1, M2, and Sh representative farmers and persuade them to accept this scenario.

Table 3- Water demand of representative farmers with and with no incentive solution (m^3/ha)

Water demand considering social pressures and incentive solution		Water demand considering social pressures and no incentive solution		Available water		Agricultural areas
Drought + Saffron cultivation	Drought + Deficit irrigation	Drought + Saffron cultivation	Drought + Deficit irrigation	Drought + Saffron cultivation	Drought + Deficit irrigation	
5245.18	5067.96	5431.46	5299.76	5305.05	5142.47	M1
5650.50	5590.95	5765.57	5763.66	5669.39	5605.61	M2
4453.31	4463.62	4551.46	4552.02	4276.64	4304.52	T
5464.10	5631.86	5625.68	5728.09	5302.52	5643.89	Sh
4689.09	4361.79	4835.88	4812.44	4204.71	4037.33	Ch1
4056.97	3642.59	4103.73	4024.85	3542.63	3260.93	Ch2

Source: research findings

Conclusion and Suggestions

Considering the complicated nature of water-related issues, rapid increase of population, water demand for various consumptions, and limited water resources, comprehensive water resources management require novel methods to assemble technical, economic, environmental, social, and logical perspectives into a coherent framework. One of these tools is utilizing hydro-economic methods to simulate the current status of drainage basins and evaluate the role of different scenarios and policies. Accordingly, considering the recent frequent droughts in the Kashfrud Basin, the present study used the hydro-economic modeling to simulate the current and future status of the plain and apply different adaptation scenarios. This model consists of an optimal water allocation model between different sectors and a multi-objective optimization model at the farm level, used to simulate the current status of the water resources of the Kashfrud Basin as the base scenario. The role of adaptation scenarios, i.e. the deficit irrigation and the cultivation of saffron, in the cultivation pattern and sustaining management of water resources was studied. The optimal water allocation model manifested that the drought scenario may reduce the available water in different areas. Moreover, this scenario differently affects the hydro-economic status of various cities. However, the assessment of conservation scenarios including the deficit irrigation and saffron cultivation indicated that they may in part reduce the consequences of drought. Afterwards, the ABM was applied to establish an agreement with stakeholders to execute different conservation scenarios. Furthermore, the model findings disclosed a great difference between the volume of available water, due to implementing the strategies, and the water demand, which may impede the farmers' cooperation regarding the conservation scenarios. However, incentive policies may partially satisfy farmers with running the adaptation scenarios.

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اثرات راهبردهای تطبیقی بر مدیریت منابع آب در دشت مشهد: کاربرد مدل‌های اقتصادی- هیدرولوژیکی و رفتاری

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چکیده

استان خراسان رضوی هم‌اکنون بحرانی‌ترین منابع آبی زیرزمینی در سطح کشور را داراست به طوری که افت سطح آب‌های زیرزمینی در این استان به یک متر رسیده است. دشت مشهد در طی سال‌های اخیر با بحران خشکسالی و کم‌آبی دست و پنجه نرم می‌کند. منشا بحران خشکسالی برداشت‌های بی‌رویه و گرمایش جهانی است. مدیریت جامع منابع آب با توجه به ماهیت پیچیده مسائل آب، رشد سریع جمعیت، نیاز به آب برای مصارف مختلف و منابع آبی محدود، نیازمند روش‌هایی است که دیدگاه‌های فنی، اقتصادی، زیست‌محیطی، اجتماعی و منطقی را در یک قالب یکپارچه گردآوری نماید. یکی از ابزارهای مدیریت جامع منابع آب، استفاده از روش‌های هیدرولوژیکی اقتصادی به منظور شبیه‌سازی وضعیت کنونی حوضه‌های آبریز و بررسی اثرات سناریوها و سیاست‌های مختلف می‌باشد. در مطالعه‌ی حاضر به منظور شبیه‌سازی وضعیت هیدرولوژیکی دشت مشهد و بررسی اثرات سناریوهای مختلف از یک مدل اقتصادی- هیدرولوژیکی استفاده شد. در گام بعد به منظور رسیدن به توافق با ذینفعان بر سر اجرای سناریوهای مختلف حفاظتی از مدل عامل محور استفاده گردید. نتایج مدل هیدرولوژیکی- اقتصادی نشان دادند که با اتخاذ سناریوهای تطبیقی امکان کاهش تقاضای آب بخش کشاورزی و در نتیجه مصرف آب سطحی و زیرزمینی در این بخش وجود دارد. همچنین اجرای سناریوهای مختلف تطبیقی موجب تغییر الگوی کشت کنونی خواهد شد. از سوی دیگر نتایج مدل‌سازی عامل محور نشان داد که میان میزان آب در دسترس ناشی از راهبردها و تقاضای آب تفاوت زیادی وجود دارد که این موضوع موجب خواهد شد که کشاورزان با اجرای سناریوهای حفاظتی همکاری نکنند. اما با به کارگیری سیاست‌های تشویقی می‌توان برخی از کشاورزان نماینده را به اجرای سناریوهای تطبیقی راضی نمود.

واژه‌های کلیدی: دشت مشهد، راهبردهای تطبیقی، منابع آب، مدل اقتصادی-هیدرولوژیکی

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