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AN INTEGRATED HYDRO-ECONOMIC MODELING TO EVALUATE MARKETING REFORM POLICIES OF AGRICULTURAL PRODUCTS

HADI RAFIEI DARANI; MOHAMMAD REZA KOHANSAL*; MOHAMMAD GHORBANI; MAHMOUD SABOOHI
Ferdowsi University of Mashhad, Agricultural Economic Department, Mashhad 9177948974, Iran

Abstract

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Water scarcity is a global concern, particularly in arid and semi-arid. This fact should be considered in decision making and management of water resources and also policy makers should pay attention to the effects of these policies as a crucial criterion. This study was carried out to investigate the effect of different policies of agricultural products marketing network reform on water resources management, especially on the use of groundwater in the Neyshabur basin in Iran. Thus, taking into account the effects of marketing on the supply and demand water, we used hydro-economic (H-E) model. In the economic sector of the H-E model, Regional Positive Mathematical Programming (RPMP) was used to study the effects of various scenarios (marketing network reform policies) on crop patterns. In the hydrologic sector of the H-E model, WEAP was used to analyze and simulate of water resources according to the different crop patterns (results obtained from economic sector).

The results showed the network marketing reform leads to change in cropping pattern. The cultivated area of crops with high marketing margin was increased. Also, the cultivated area of alfalfa and cotton decreased in most scenarios. The results of the hydrological model simulations (WEAP model) showed that the change in cropping pattern (due to marketing network reform) made increase water use in Neyshabur basin and increase pressure on groundwater. It seems the marketing reform could not reduce overdraft of water resources. Complementary policies appear to be necessary to gain desirable achievements from marketing network reform and reduce groundwater overdraft.

Key words: water resources management; hydro-economic model; regional positive mathematical programming; WEAP

Introduction

Scarcity of water resources due to competitive demand for water makes it as an important economic input (Briscoe, 1996; Brouwer and Hofkes, 2008; Young and Loomis, 2014). FAO (FAO, 2015) reported that water use has been increasing more than twice the rate of population. By 2025, 1.8 billion people will experience absolute water scarcity and two-thirds of the world's population could experience water stressed conditions (FAO, 2015). Water usually is considered as an input factor in economic productions such as agriculture and industry or as consumption good. Therefore, water is critical limiting input in many economic sectors and a vital resource for economic and social development (Blanco-Gutierrez et al., 2011; Peter et al., 2008). In areas where agriculture is the main consumer of water and also is grappling with water scarcity, water resources management is very important. A comprehensive evaluation could assess how farmers may respond to different water policies or water management scenarios and what is the economic and the hydrologic effect of implementation of various policies? Interdisciplinary tools would able to simulate the economical and

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**Corresponding author*: kohansal@um.ac.ir

hydrological impacts of different policies or different conditions (such as environmental conditions or new economic conditions). Interdisciplinary models including of economy, hydrology, social and political aspects, marketing, etc., e.g. (Bateman et al., 2006; Hiwasaki and Arico, 2007; Krol et al., 2006; Loucks, 2006; Ludwig et al., 2011; Macleod et al., 2007; Turner et al., 2000; Voinov et al., 1999) have been developed in the last decades following different levels of intricacy. {Donati, 2013 #15}

Economic and engineering aspects have been applicably integrated for analyzing issues of water resources management in a variety of fields (Pulido-Velazquez et al., 2008). For assessing the complex interaction between water and the economy, the mathematical models are used with hydrological and biogeochemical procedures relevant to the economic laws of supply and demand in water scarcity situations (Brouwer and Hofkes, 2008). In the last decades, these models have been improved by interaction among a wide range of dominants which more attention paid to single or multiple objective decision-making and trade-offs (Andreu et al., 1996; Brouwer et al., 2009; Brouwer and Hofkes, 2008; Cai et al., 2003; McKinney, 1999). Because of the high consumption of water in agriculture, this model focused on agriculture. Hydro-economic models in compared with other methods of integrated water management (such as Bayesian networks, meta models, mental models, knowledge elicitation tools, risk-assessment approaches, among others) could provide the best optimization use of water resources (Blanco-Gutierrez et al., 2011; Brouwer and Hofkes, 2008). Hydro-economic models are applicable for evaluation both hydrologic and economic issues and integrated perceptions for water management.

Hydro-economic models incorporate hydrology, water management, environmental condition and socio-economic measures of water resources management within a consistent framework (Harou et al., 2009; Kragt, 2013; Medellín-Azuara et al., 2009). Economics is the main component of water resources management in hydro-economic models, by evaluating the socio-economic factors generated by the different uses of water resources (Harou et al., 2009; Kragt, 2013; Pulido-Velazquez et al., 2008). In hydro-economic models, node networks are usually used to indicate water flows and stocks in a watershed or river basin and also to present stations linked to particular water demand and supply (Brouwer and Hofkes, 2008). Integrated hydro-economic models can be used in a wide range of researches for example, river management (Cai et al., 2003; Heinz et al., 2007; Pulido-Velazquez et al., 2008), water quality problems (Volk et al., 2008), climate change (Varela-Ortega, 2011; You and Ringler, 2010), food policy and water (de Fraiture, 2007; Rosegrant et al., 2000), conservation problems (Harou and Lund, 2008; Peña-Haro et al., 2009), impact of drought (Maneta et al., 2009), effect of land use changes (Ahrends et al., 2008), and strategies of water management (Jenkins et al., 2004; Qureshi et al., 2008).

The economic component{Volk, 2008 #4} of hydro-economic model was usually based on a mathematical programming model to estimate the water demands (special for agricultural sector) with respect to restrictions of resources. The hydrologic component usually was used to calculate water availability and water quality, for example, in a catchment or a river basin. The current study analyzed the effects of various scenarios of price changes for agricultural products for water management by using hydro-economic model. This model is based on the integration of an economic optimization model and a hydrologic water management simulation model constructed in WEAP. The model was run in the Neyshaboor basin, located in north-eastern of Iran. In this area there is high pressure on water resources due to growing water demands (particularly in the agricultural sector). The effects of changing prices for agricultural products on water allocation and on changes in cropping pattern are the major issues that policy makers should consider in Iran, especially in the Neyshabur basin. Economic component of the hydro-economics model employs positive mathematical programming (PMP) (a non-linear economic optimization model) (Howitt, 1995) that suggests a description of farmer's behavior and agricultural production processes. Hydrologic component of the hydro-economics model uses the WEAP model to assess future water demands and resources. Both models (hydrologic and economic models) are linked together and used to investigate the effects of changing in prices for agricultural products on the water allocation, farmer's decisions about using agricultural inputs, land allocation and groundwater storages.

Methodology

The first study in hydro-economic modeling was launched Bear and Levin (Bear and Levin, 1970). They used economic water demand functions for allocation of water in different regions (Harou et al., 2009; Medellín-Azuara et al., 2010). Hydro-economic models present a framework to explain economically-driven regional water resources (Medellín-Azuara et al., 2012; Medellín-Azuara et al., 2011). Usually, the object of the hydro-economic model is to maximize profit or to minimize costs in a system. Two crucial components of hydro-economic model are: (1) hydrology that is about the water balance in reservoirs, river reaches, and irrigation districts; (2) economics involving the maximization of farmer's benefit functions. Water supply is determined by the water balance in the basin, while water demand is determined based on water users in irrigated agriculture, industry, urban and rural consumption. The model is founded on optimizing the allocations of water to the various demand sites. It uses monthly volumes of rainfall, runoff, evapotranspiration, river flow and irrigation demand.

Economic model

The economic model is based on Positive Mathematical Programming (PMP) (Howitt, 1995), that is used in a wide range of studies (Cai et al., 2008; Cai and Wang, 2006; Chatterjee et al., 1998; Cortignani and Severini, 2009; Heckelei and Britz, 2000, 2005; Helming, 2005; Lence and Miller, 1998; Paris and Howitt, 1998; Preckel et al., 2002; Röhm and Dabbert, 2003).

Positive mathematical programming has three steps for demonstrating agricultural production. It is assumed that farmers' behavior is based on the maximization of profit for a group of crops, with respect to constraints (such as land and water) (Medellín-Azuara et al., 2012).

First step: Using linear programming model and calculating of shadow prices

In the first step, PMP calculates shadow values of resources (such as water and land) through the use of a linear programming model and described by equations (1) to (3). Calibration constraints are used to observe the value of land use.

$$\max z = \sum_g \sum_i (PP_{gi} Y_{gi} XL_{gi} - \sum [a_{gij} XL_{gi',land} \omega_{gij}]) \tag{1}$$

Subject to:

$$\sum a_{gij} XL_{gi} \leq b_{gi} \ \forall g,j \quad [\lambda_1] \tag{2}$$

$$XL_{gi} \leq \tilde{X}_{gi} + \varepsilon \quad \forall g,i,j \quad [\lambda_2] \tag{3}$$

$$XL_{gi} \geq 0 \quad \forall g,i,j \tag{4}$$

The first equation represents the objective function of model that is maximization of farm profit. Equation (2) shows the constraints of resources in each region and equation (3) shows the model calibration limits. The variables are displayed in the model (equations (1) to (3)) as follows: is the area planted for crop *i* and region g, is the marginal revenue per ton of crop *i* in region *g*, *is* average yields, is the average variable costs and is the Leontieff coefficients that are given by the ratio of total factor usage to land. The equations of (2) and (3) show the constraints of limiting resources (such as land and water) and calibration. The perturbation term *ε* is used to decouple the resource constraints and calibration constraints (Howitt, 1995; Howitt et al., 2012; Medellín-Azuara et al., 2010; Medellín-Azuara et al., 2012).

Second step: PMP cost function parameter estimation

In this step, parameters of PMP cost function are estimated for a quadratic cost function using the shadow value of the calibration constraint. The quadratic cost function demonstrates that a greater proportion of a farm's area for a given crop reduces the profit per hectare (Howitt et al., 2012). Quadratic cost function is as follows:

$$TC = a_{gij} XN_{gij} + y_{gij} XN^2_{gij} \tag{5}$$

Third step: Estimation of regional CES production function parameters

In this step, regional CES production function parameters are estimated (Howitt et al., 2012). Equation (6) represents the regional CES production function. is variable in terms of the elasticity of substitution inputs (calculated by equation (7)) and is the scale parameter (Medellín-Azuara et al., 2012).

$$Y_{gij} = \tau_{gij} [\sum_j \beta_{gij} k_{gij}^{\rho i}]^{1/\rho i} \tag{6}$$

$$\rho \mathrm{i} = \sigma - 1 \tag{7}$$

$$\tau_{gij} = \frac{\left(\frac{y_i}{x_i}\right) . \tilde{X}_i}{[\sum_j \beta_j k_j^{\rho}]^{1/\rho i}} \ \forall g,i,j \tag{8}$$

$$\beta_{gi,land} = \frac{1}{1 + \left(\left(\frac{\tilde{X}^{-1/\sigma_\mathrm{i}}_{\mathrm{gi,land}}}{\mathrm{CS}_{\mathrm{gi,land}}} \right) \sum_{\mathrm{j} \neq \mathrm{land}} \left(\frac{\tilde{X}^{-1/\sigma_\mathrm{i}}_{\mathrm{gij}}}{\mathrm{CS}_{\mathrm{gij}}} \right) \right)} \tag{9}$$

$$\beta_{\mathrm{ij} \neq \mathrm{land}} = \mathrm{CS}_{\mathrm{gij}} \left(\frac{\beta_{\mathrm{ij,land}}}{\mathrm{CS}_{\mathrm{gi,land}}} \right) * \left(\frac{\tilde{X}_{\mathrm{gi,land}}}{\tilde{X}_{\mathrm{gij}}} \right) \tag{10}$$

CS_{gij} is the opportunity cost of input *j* so that $CS_{gij} = \omega_{gij} + \lambda_{1gij} + \lambda_{2gij}$. In this equation, λ_1 and λ_2 are calibration Lagrange and resource constraints of region *g* and product *i* and input *j* (Medellín-Azuara et al., 2012). In addition, production function and regional cost function have been calculated through steps 2 and 3.

Fourth step: Determining regional calibrated PMP model

In this step, final model is presented as follow by using the information obtained from before steps:

$$\max \pi = \sum_g \sum_i PP_{gi}[\tau_{gij}(\sum_j \beta_{gij} XNN_{gij})^{\rho i}]^{1/\rho i} - \sum_g \sum_i \sum_j (\alpha_{gij} XNN_{gij} + \alpha_{gij} XNN^2_{gij}) \qquad (11)$$

Subject to:

$$\sum_i XNN_{gi} \leq b_{gij} \; \forall g,j \in \textit{(constraints resources and inputs)} \qquad (12)$$

Equation 10 represents nonlinear objective function of PMP, according to different regional (regional production function and regional cost function). Resource constraints are represented in equation 11.

Hydrologic model

We used WEAP (Water Evaluation and Planning) model to simulate the hydrological behavior. WEAP is comprehensive, straightforward and easy-to-use software that provides an integrated approach to water resources management. It Operates on the basic principle of water balance and determines the optimal allocation of water for demands (as agriculture, industry and municipal users), supply preferences (as groundwater, river), mass balance, and other physical and controlling constraints. WEAP evaluates a full range of water development and management. It also simulates water demand, water supply and other hydrologic and engineer components (such as rainfall runoff, base flow, storage, water pollution generation, water conservation, hydropower generation, etc). It is also run for comparing and forecasting scenarios of hydrological changes (Bhave et al., 2014; Harma et al., 2012; Höllermann et al., 2010).

Model dataset and scenarios

The case study of this paper is Neyshabur basin, located the north east of Iran. More than 96 percent of the total water supply for agriculture in Nayshabour basin is groundwater and annually overdrafts estimated about 130 MCM (Million cubic meters) (KHRW, 2015). Dataset of hydrological modeling was obtained from Khorasan Razavi Regional Water Authority (KHRW, 2015) and Meteorological Organization (MO, 2015). Data used in the economic model was provided from interviews and questionnaires of 366 Neyshabur farmers.

Results

Neyshabur basin is located in the center of Khorasan Razavi province. It has 11 seasonal rivers, KalShoor is the most important river. A schematic representation of the Neyshabur basin WEAP application is depicted in Figure 1. The WEAP system designed for Neyshabur basin included groundwater, 6 major rivers, catchments, municipal and industrial water demands. Neyshabur basin has been characterized by 6 sub-catchments that each of them includes areas of similar land use classes (non-irrigated agricultural land, irrigated agricultural land, semi-natural areas, and pasture). The main source of water supply in Neyshabur basin is groundwater (about 96% of total supply) and then seasonal rivers. So groundwater is most reliable source for different uses, particularly in the agricultural sector. The crop pattern of irrigated land consists of different crops such as: wheat, barley, maize, tomato, melon, cotton, sugar beet and alfalfa.

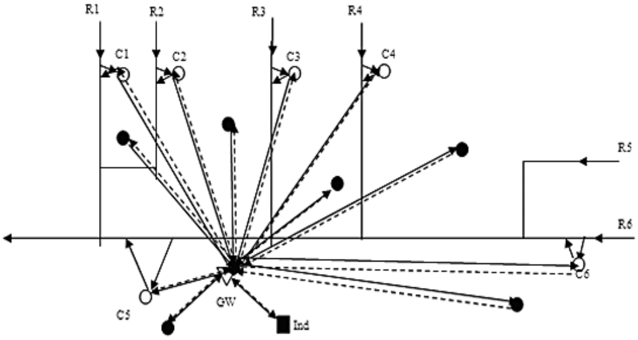

Fig. 1. Schematic representation of the Neyshabur basin WEAP application

In the economic sector of hydro-economic model, Neyshabur basin divided into 4 groups: the first group (FG1) included farmers of hydrologic catchments C1 and C2, the second group (FG2) included farmers of hydrologic catchments C3, the third group (FG3) also consisted farmers of hydrologic catchments C4 and C5 and the fourth group (FG4) consisted farmers of C6 hydrologic catchments (Table 1).

Table 1

Catchments of hydrologic model related to farmer groups

	Farmer group/ Catchment					
Farmer group	FG1		FG2	FG3		FG4
Catchment	C1	C2	C3	C4	C5	C6

In this study, we used 3 price-change scenarios for agricultural products. These scenarios are designed based on the results from analyzing marketing network reforms of agricultural products. In defining the scenarios we added part of the marketing margin to prices of agricultural products. In the first scenario, 20% of marketing margin added to the product price, in the second scenario that was 35% and about the third scenario 50% of marketing margin was added to the product's price. Agricultural crops patterns would be affected by changing of the price and this in turn lead to change of the hydrological system and subsequent change of water resources.

Tables 2, 3, 4, 5 represent the changes of crop patterns based on different scenarios. The results obtained from the economic sector of the hydro-economic model by using the regional positive mathematical programming (RPMP). The results of various scenarios showed the price change of agricultural products lead to change in cropping patterns. So that in FG1 in all scenarios, the alfalfa cultivated area became zero and removed from cropping pattern. Cultivated area of sugar beet and watermelon increased considerably in all scenarios. While in comparison with the current situation the watermelon cultivated area in the first scenario increased 8.67% and in third one increased 18.96%. About the sugar beet, cultivated area in the first scenario increased 12.7% and in the third one was increased 19.46%. However, in FG1, the most cultivated are devoted to wheat and barley. Although the cultivated area of sugar beet and water melon increased, their shares were small in cropping pattern.

In FG2 region, the alfalfa cultivation area decreased in all scenarios, in the first scenario alfalfa cultivation area decreased about 23.43% and in the third scenario, that decreased 57.26%. The cultivation area of other crops compared to the current situation increased, especially for sugar beet and cotton. In the first scenario cultivation area for sugar beet increased about 11.36% and in the third one increased 23.39%, compared to the current situation. The cultivation area of cotton crop increased about8.86% in the first scenario and 18.8% in the third scenario. In FG2, the main product is wheat and barley and then alfalfa. Sugar beet and cotton had smaller shares in the cropping pattern.

The results indicated that in FG3, cultivation area of cotton and alfalfa decreased in different scenarios. So that the cotton dropped from the crop pattern and about alfalfa, cultivation area decreased about51.18% in the first scenario and dropped in the third scenario compared to the current

Table 2
Changes of crop patterns based on different scenarios (Hectare) (F.G.1)

Crop	Cultivation area of crops(current situation)	Cultivation area of crops			Percentage change of cultivation area (Percent)		
		Scenario1	Scenario2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Wheat	2.99	3.04	3.05	3.05	3.48	3.58	3.71
Barley	3.94	3.97	3.92	3.87	2.50	1.27	0.05
Watermelon	0.69	0.74	0.78	0.81	8.67	13.91	18.96
Sugar beet	0.25	0.28	0.29	0.29	12.70	16.22	19.46
Corn	0.25	0.26	0.26	0.26	4.22	4.22	4.61
Alfalfa	0.16	0.00	0.00	0.00	-100.00	-100.00	-100.00
Total	8.29	8.29	8.29	8.29	-	-	-

Table 3
Changes of crop patterns based on different scenarios (Hectare) (F.G.2)

Crop	Cultivation area of crops(current situation)	Cultivation area of crops			Percentage change of cultivation area (Percent)		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Wheat	4.16	4.23	4.29	4.35	2.63	4.18	5.59
Barley	6.01	6.06	6.11	6.15	2.00	2.76	3.36
Watermelon	1.99	2.07	2.14	2.21	5.34	8.88	12.26
Sugar beet	1.65	1.82	1.93	2.02	11.36	17.89	23.39
Corn	0.82	0.84	0.85	0.86	3.09	4.46	5.54
Tomato	0.50	0.53	0.56	0.58	8.12	13.38	18.41
Cotton	1.99	2.15	2.25	2.34	8.86	14.12	18.80
Alfalfa	2.40	1.82	1.39	1.01	-23.43	-41.44	-57.26
Total	19.52	19.52	19.52	19.52	-	-	-

Table 4
Changes of crop patterns based on different scenarios (Hectare) (F.G.3)

Crop	Cultivation area of crops(current situation)	Cultivation area of crops			Percentage change of cultivation area (Percent)		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Wheat	2.62	2.66	2.69	2.69	3.08	4.33	4.30
Barley	1.10	1.12	1.13	1.12	2.58	3.41	2.74
Watermelon	0.41	0.42	0.44	0.45	5.80	9.31	12.57
Sugar beet	0.17	0.18	0.19	0.20	10.58	16.39	20.58
Corn	0.53	0.54	0.54	0.54	3.31	4.50	4.63
Tomato	0.24	0.26	0.27	0.28	9.96	15.85	20.90
Cotton	0.00	0.00	0.00	0.00	-100.00	-100.00	-100.00
Alfalfa	0.23	0.11	0.02	0.00	-51.18	-89.38	-99.97
Total	5.28	5.28	5.28	5.28	-	-	-

Table 5
Changes of crop patterns based on different scenarios (Hectare) (F.G.4)

Crop	Cultivation area of crops(current situation)	Cultivation area of crops			Percentage change of cultivation area (Percent)		
		Scenario1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Wheat	9.96	10.32	10.57	10.74	4.45	6.93	8.72
Barley	4.64	4.78	4.87	4.93	3.90	5.91	7.15
Watermelon	1.20	1.29	1.37	1.44	8.78	15.10	21.10
Sugar beet	0.05	0.06	0.06	0.06	18.27	30.27	39.03
Corn	0.69	0.71	0.73	0.75	4.69	7.84	10.39
Tomato	0.51	0.57	0.63	0.68	14.10	24.50	34.25
Cotton	0.00	0.00	0.00	0.00	-100.00	-100.00	-100.00
Alfalfa	2.28	1.59	1.10	0.72	-29.86	-51.50	-68.17
Total	19.33	19.33	19.33	19.33	-	-	-

situation. In FG3, cultivation area of sugar beet and tomato increased considerably. Cultivation area of sugar beet increased about 10.58% in the first scenario and 20.58% in the third scenario. Also the cultivation area of tomato increased about 9.96% in the first scenario and 20.9% in third one. FG3 region had the smallest farm size than other regions (average of 5.28 hectares per farm). The cotton and alfalfa that were dropped from the crop pattern had relatively low shares in the cropping pattern.

In the FG4 region the cotton crop dropped from the crop pattern in all scenarios and cultivation area of alfalfa decreased. However the cultivation area of sugar beet, tomato and watermelon considerably increased. The cultivation area of sugar beet and tomato increased about 18.27% and 14.1% in the first scenario and 39.03% and 34.25% in the third scenario respectively. However, tomato and sugar beet had smaller shares in crop pattern than other crops (such as wheat, barley and Alfalfa).

In line with our results, in all scenarios defined by reform the marketing network, alfalfa crop cultivation area in all regions and cotton cultivation area in FG3 and FG4 decreased or dropped.

Table 6 shows the effects of change in cropping patterns (economic modeling) on water resources. These results obtained from the hydrological sector of hydro-economic model. In this model changes in water consumption that is due to changes in cropping patterns were simulated by WEAP. We found that although the price change scenarios (reform

Table 6
Changes of overdraft in different scenarios - cubic meters (CM)

Status	Total overdraft	Annual average overdraft	The difference with the current situation
Current situation	2 678 832 790	133 941 639	–
Scenario 1	2 683 060 052	134 153 003	4 227 263
Scenario 2	2 685 803 494	134 290 175	6 970 704
Scenario 3	2 690 046 206	134 502 310	11 213 416

the marketing network of agricultural products) was to increase the farmer's income, but increasing pressure on water resources caused, particularly on groundwater which is the main water suppliers. Therefore the overdraft of groundwater would increase in all scenarios.

Our finding showed that all scenarios lead to increasing overdrafts in comparison with the existing situation. Current overdraft of groundwater is about 133 941 639 CM (per year). Difference amongst current overdraft with the first scenario was about 4 227 263 CM with the second scenario was 6 970 704 CM and with the third one was 11 213 416.

Accordingly designed reform of agricultural marketing network leads to increase the cultivation area for crops such as sugar beet and tomato and subsequent increasing water consumption. Due to the low shares of the crop area of sugar beet and tomato in the crop patterns, changes in water consumption wasn't considerable. Overall, the reform of marketing network could not reduce the overdraft of groundwater; however it increased farmers' income.

Conclusion

In this study, we studied the effects of different marketing network reform policies on water management in Neyshabur basin. Hydro-Economic model was used to assess the impact of different scenarios of marketing network reform on water resources. In economic and hydrologic sectors in the H-E model, we respectively used Regional Positive Mathematical Programming (RPMP) and WEAP. The results demonstrated that policies of marketing network reform of agricultural products were associated with the changes of crop pattern. It seemed that about crops with higher marketing margin, the area under cultivation were growing higher, however, share of cultivation area of the crops were low.

In line with our results, changes in cropping patterns due to different scenarios had an effect on water use. In other words, the reform of agricultural marketing network affected on crop patterns and this in turn increases water consumption in several areas. Although, this increase in water consumption was not significant, it can be concluded that the network marketing reform of agricultural products would not reduce overdraft of water resources, and so it would be considered as a conflict in policy. So it seems implementation of network marketing reform policies should be accompanied by supplementary policies to reduce water consumption, particularly about groundwater in Neyshabur basin. Such policies could be as follows: new technologies in agricultural production such as technologies related to irrigation techniques, new varieties of crops and low water consumption and also economic policies of reward and punishment in water use (such as price policies, etc) (Arjoon et al., 2014). To explain the effects of additional policies on water resources, we recommend using comprehensive models such as H-E models that examine the various effects of policies on water management.

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