Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

# Water market simulation based on the principles of sustainable development (Case study: Hashtgerd plain, Alborz Province, Iran)

**Zohreh Shabani Rouchi[1], Saied Yazdani[2*], Reza Moghaddasi[1]**

*1. Department of Economics, Propagation and Agricultural Education, Science and Research Branch, Islamic Azad University, Tehran*
*2. Department of Agricultural Economics, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran*

** Corresponding author's E-mail syazdani@ut.ac.ir*

## ABSTRACT
The decrease in groundwater levels and the subsequent land subsidence of over 20 cm have now become one of the major environmental concerns in the plains of Alborz Province. On the other hand, over-extraction of groundwater resources in this province will cause a great catastrophe in the near future. To prevent this consequence, the installation of volumetric meters is one of the solutions in the province. Therefore, launching a water market is one of the best strategies that can be considered in this situation. This study was carried out in the Hashtgerd plain as the most important agricultural area of Alborz Province, which consumes 87% and 90% of surface water and groundwater resources in agriculture, to investigate the effects of water market simulation. So, a positive mathematical planning (PMP) model was estimated with the regional functions of Statewide Agricultural Production (SWAP) approach. A demand function was extracted using the information collected in the form of a questionnaire and through the relevant organizations. Accordingly, the equilibrium price of water is 3,394 Rials $m^{-3}$ in the Hashtgerd plain, which will save over 26% in water consumption. The implementation of this policy, is dis-advantageous for water buyers while advantageous (beneficial) for water sellers. Therefore, there will be less reduction in the resulting benefit by implementing this policy, such as increasing the efficiency of irrigation systems, at the same time as launching a water market.

**Keywords**: Water market, Equilibrium price, Sustainable development, PMP, SWAP, Hashtgerd plain.
**Article type:** Research Article.

## INTRODUCTION
The severe water crisis, which has now manifested in an increasing reduction in water security, is considered very serious and hazardous in Iran. At the same time, there is a serious conflict between the development plans in Iran with carrying capacity and natural water resources. The high ratio (> 90%) of water extraction to renewable resources (indicating the crisis ratio; ABFA Company, Alborz Province 2018) and the situation of Iran among the countries with high per capita annual water consumption (> 1000 $m^3$) clearly indicates this situation. Objective evidence, such as the drying of wetlands and lakes, lowering and perhaps downfall of groundwater levels in most residential and active areas of the country, reduced discharge or drying and salinization of well waters as the main source of water supply in Iran, declined soil moisture and potential for dust creation, widespread land subsidence and the creation of cracks and sinks, and evacuation of villages due to water shortages, are among the obvious signs of this growing crisis that have gradually captured the body of the country, the same as like osteoporosis (Forouzandeh 2016). To achieve the sustainability of these resources and to establish water security, policies were approved by the Supreme Water Council (SWC). To implement these policies, a reduction strategy of 20 billion $m^3$ (20%) was approved to extract the current sources of the renewable water resources based on the proposal of the Ministry of Energy (MOE) and the SWC, and it was decided to implement it as a stepwise strategy. At the first stage, a negative target of 11 billion $m^3$ was agreed in the Sixth Development Plan in Iran (Less-Water

Caspian Journal of Environmental Sciences, Vol. 20 No. 3 pp. 649-658 Received: Dec. 19, 2021 Revised: Feb. 26, 2022 Accepted: March 08, 2022
DOI: 10.22124/CJES.2022.5709

Publisher: University of Guilan, Iran

Development 2016). In this decision, however, the goal of reduction in water extraction is necessarily proposed as a strategy to cope with water scarcity, but there is no reference to permanent solutions for crisis management. By the emergence of serious water shortage problems in Iran, various studies have been conducted in this field in recent decades and government officials have paid increasing attention to this issue, which has resulted in a change in management approaches from the water supply management to demand these resources. This approach includes various methods, such as pricing based on economic value, installation of volumetric scale to control water extraction rate, and the formation of water markets, which are one of the relatively new tools to deal with the scarcity of water resources and have received serious attention. Briefly, a water market can be defined as the non-mandatory exchange of water rights between buyers and sellers and is therefore promising as its formation can help more efficient and sustainable consumption of water resources (water markets, a response to scarcity 2018). Water markets are divided into two main groups, formal and informal markets, and the former has long been active extensively in the American countries (such as the United States, Mexico, and Chile) and Australia. In contrast, informal (local) water markets have been experienced in our country since the past and are now widely observed in some other countries, such as India, Pakistan, and Spain. In recent years, the formation of formal water markets has highly been considered by policymakers in this sector and various studies conducted in this field have examined various effects of the market formation. Various studies have been conducted on the formation, conditions, and results of water markets in Iran and other countries. Zolfagharipour *et al.* (2020) studied the formation of an inter-sectoral water market in Borkhar City, Isfahan Province, Iran. They found that saving water consumption and cultivation of crops with higher incomes would increase farmers' incomes on the one hand and selling water extraction permits from groundwater to the industrial sector, on the other hand, would cause damage to them in the long run. A study by Abolhassani *et al.* (2019) revealed that the formation of water markets in the cities of Mashhad/Chenaran, and Torqabeh, south-eastern Iran would save between 20 and 40% in the consumption of water resources. Kiani (2016) examined water markets formed in Majan and Ardabil City, north-western Iran and introduced all factors that prevent the monopoly in the market as increasing the efficiency of water markets. In addition, the study introduced interference by the government or executive bodies in the market as reducing negative external consequences and enhancing market efficiency in some cases, in contrast to public belief. It was also found that the prices of water in the local markets of Majn and Ardabil are close to the economic value of water and water exchanges led to increased incomes of users. Zibaei *et al.* (2016) simulated the formation of a water market in Fars Province, Iran and suggested the implementation of quota policy in parallel with the formation of water market to reduce water extraction from groundwater resources, since market formation alone would not be compatible with the national goal of water use reduction. They reported that the implementation of this scenario led to 20-30% decrease in annual water use and 8-11% reduction in farmers' incomes. They concluded that there would be no considerable downfalls in incomes using a simultaneous policy of water markets and water quotas, in spite of the reduced water consumption. This water reduction is defined as protection purposes and supplying a part of the environmental water right, which can be implemented by installing volumetric scales and appropriate accounting methods at the farm and catchment levels. In general, the issue of sustainable development and sustainable protection of water resources have been discussed in some studies, most limited to water markets and simulation and calculation of water use reduction and have ignored the issue on non-extraction of water resources to strengthen groundwater. Unlike nationwide studies, a number of water markets in the world have been formed with the aim of sustainable development, called environmental restoration (water markets, a response to scarcity, 2016). In some cases, setting a water consumption limit (by setting a limit on the water volume for permanent permits or by subjecting permits to variable allocations each year) is the main mechanism for protecting these resources. In other cases, setting a consumption limit by strategies such as repurchasing existing permits by the Department of Environmental (DOE), is considered a solution, in which the repurchase issue is more favourable than the mandatory reduction of water rights without recompense. In other words, the DOE enters the water markets as a third base in the form of a buyer. In Australian water markets, one of the most advanced and active water markets in the world, limits have been set for the total volume of water permits and annual balances in water allocation for sustainable environmental protection. The final plan for groundwater extraction reduction, adopted and implemented in 2012 under the new water law in Australia, determined a 21% (2.8 billion $m^3$) extraction reduction. In this plan, which is implemented with the commitment of the government, a part of the permits owned by the users is repurchased annually by the government (Grafton *et al.* 2011). According to what was described above and considering the need to implement a policy to reduce the extraction of groundwater resources by the end of the Sixth Plan in Iran to achieve the goals of sustainable development, this study investigated the effects of a simulated sample water market in Hashtgerd plain, Alborz Province. In recent years, the rapid downfalls of groundwater levels and consequently land subsidence have become one of the environmental concerns in Alborz Province, Iran. According to the latest report of the Geological Survey and Mineral Explorations of Iran (GSI website, 2018), the groundwater level decreases by 81 cm annually in Alborz Province, leading to annual land subsidence of 21-22 cm in the plains of the province. On the other hand, the standard extraction from renewable water sources is less than 40% in the world, but this figure is close to 92% in Iran and 100% in Alborz (ABFA Company, Alborz 2018), and this extraction will bring about a disaster in the near future. To prevent this catastrophe, the regional water supply of the province has replaced conventional assessing with volumetric scale in recent years to control the extraction rate of water resources. In this situation, the market formation approach accounts for one of the best available solutions. In this study, therefore, Hashtgerd plain was studied as the most important agricultural area of the province, which consumes 87.23% and 90% of surface and groundwater resources, respectively, in the agricultural sector. On the other hand, the need for paying attention to the prevention of beneficial reduction and living standards of the audience in the implementation of a policy is the most important point that should be considered in the implementation of water market formation policy, which has received less attention in other studies. The rise of prices resulting from the formation of a water market (for buyers) on the one hand and its quotas, and on the other hand, lead to a decrease in the benefit of farmers. In this study, determining an equilibrium price and calculating the amount of savings in groundwater extraction, as well as the effects of an extraction market formation, the implementation of a simultaneous policy to increase the efficiency of irrigation systems have been studied and reviewed alongside the formation and simulation of a water market. Another noteworthy point of this study is the separation between the effects of market formation results for the groups of water buyers and sellers, which has not been considered in previous studies.

## MATERIALS AND METHODS

In most studies, hypothetical and simulated markets are analysed to investigate the effects of water market simulation, because the real water market has not been stablished in Iran and the existing markets are in the form of local ones. In this study, the demand function was estimated using a positive mathematical programming (PMP) model (aiming at estimating the equilibrium price) as it is more compatible with real conditions. The main idea behind this model, first introduced by Howitt (1995) and employed by Parhizkari (2017) and Abolhassani (2019), is the use of information in dual variable calibration that limits the answer to the linear programming problem to the level of existing activities. In fact, dual values are used to specify a nonlinear objective function that reconstructs the observed levels of activity through the optimal solution of a new programming problem that lacks the calibration limitation (Howitt 1995 2005). The PMP and production functions of Statewide Agricultural Production (SWAP) are among the techniques used to simulate a water market and study the effects of its formation, the role of a water market in economic value alterations, etc. The SWAP method employed in this study is used as the infrastructure of water network models to establish a connection between economic variables and water models, optimization of water consumption in the agricultural sector, and the formation of local and regional water markets. This model is a suitable solution for the determination of spatial aggregation level and definition of the working scope of PMP models. It determines the spatial aggregation level and, instead of analysing policies in a broad dimension, combines local or regional characteristics with a smaller dataset and examines policies of interest at the level of designated regions (Medellin-Azura *et al.* 2010; Howitt *et al.* 2012; Parhizkari *et al*. 2013; Abolhassani *et al.* 2019).

### Step 1: Zonation of the study area and collection of required data

The required basic information is collected at this stage. According to a pilot study, irrigated wheat, barley, tomatoes, grain maize, pinto beans, potatoes, and alfalfa are the most important irrigated crops grown in Hashtgerd plain, Alborz Province, including Savejbolagh, Taleghan, and Nazarabad counties.

### Step 2: Solving the linear programming model and determining dual values or shadow prices of constraints

This step involves solving a linear programming problem with respect to resource and calibration constraints. Afterward, shadow prices (dual values) are obtained for resource and calibration constraints (Howitt *et al.* 2009, 2012).

**Step 3: Estimation of the secondary constant elasticity of substitution (CES) production function**
The secondary CES production function, also called the nested CES function, is used to replace capital and water inputs in the SWAP model. By using this function, investment irrigation can partially replace water consumption (Madeleine-Azura *et al*. 2012):

**Step 4: Estimation of the original CES production function**
At this step, constant output parameters are estimated relative to the original CES production function scale for each region and product. The original CES production function allows establishing a constant substitution rate between production inputs and Leontief coefficients with a constant ratio and Cobb-Douglas function coefficients with a single substitution (Madeleine-Azura *et al.* 2010; Parhizkari & Saboohi 2014).

**Step 5: Estimation of the exponential cost function**
In this part, the nonlinear cost function is estimated and its parameters are calculated using the total land cost function (Howitt *et al.* 2012).

**Step 6: Estimating demand functions of agricultural products based on endogenous prices**
Estimation of demand functions of agricultural products based on their prices (as an endogenous variable) is a suitable method to calculate the consumer surplus. In fact, the estimated demand function for individual crops shows the consumer's willingness to pay at a certain level of price and production of that crop (Howitt *et al.* 2012).

**Step 7: Building the final planning model and explaining the calibrated PMP model**
In this step, the total regional producer and consumer surplus function is estimated using the calibrated exponential cost function, and a nonlinear programming model is constructed according to resource constraints (Eq. 1):

$$MAX \quad PS+CS = \sum_i \left(\Psi\alpha_i^1\left(\sum_g y_{gi}\right) + \frac{1}{2}\alpha_i^2\left(\sum_g y_{gi}\right)^2\right) + \sum_g\sum_i\left(rm_{gi}(y_{gi})\right) - \sum_g\sum_i\left(\delta_{gi}exp\left(\gamma_{gi}x_{gi,land}\right)\right) - \sum_g\sum_i\left(w_{gi,supply}x_{gi,supply} + w_{gi,labor}x_{gi,labor}\right) - \sum_g\sum_w\left(w_{gw}wat_{gw}\right) \qquad (11)$$

Subject to:

$$\sum_{i=1}^{n} x_{igj} \leq A_{igj} \qquad for \qquad \forall g, j \neq water \qquad (1)$$

$wat_{gw}$ _ $wat_{consgw}$

Equation 1 is a non-linear objective function of the PMP model in which the first equation in the objective function represents the sum of net income and consumer surplus for all crops in all regions. The second equation shows the special net income of each region based on the deviation of regional prices from the original ones. In fact, this difference shows marketing costs in each region. The third relationship shows the cost function of land, and the fourth and fifth relationships indicate the costs of other inputs, including labour, capital, and finally water. Equation 2 is the input constraints (except for water) where $A_{igj}$ indicate the available resources of each region. The results of the PMP model are also used to estimate water demand functions. The nature of water inflow is such that the amount of water demand can not be extracted properly by changing the cost of water supply input. In this method, therefore, the shadow price of water is estimated through the cropping pattern obtained from confirmed PMP models by changing the amount of available water. Then, water demand functions are estimated in different functional forms and the best fit is selected having shadow values at each available water level. In this study, farmers were studied in Hashtgerd plain, including Savejbolagh, Nazarabad, and Taleghan counties. Statistical information of production costs related to the crop year 2016-2017 was obtained by collection using questionnaires and user information collected by the Ministry of Agriculture-Jihad, Tehran, Iran. The questionnaires were prepared separately for the two groups of people willing to participate as buyers and sellers in the water market, and the calculations of the two groups were also done separately. The separation of these two groups is important in terms of a careful study of market effects and the extent of changes in benefit.

## RESULTS AND DISCUSSION

Descriptive results of information, including the number of farmers and their areas under cultivation, for farmers in the region are presented in the following tables. Among plain farmers, 97% are engaged in irrigated agriculture, which also accounts for 97% of the total area of farmlands. In Alborz Province, the important and strategic crops include irrigated wheat, barley, tomatoes, grain corn, pinto beans, potatoes, and alfalfa, which are of interest to farmers due to high production and productivity in cities located in Hashtgerd plain. In the present study, therefore, information about these crops was used in calculations. Since water supply is not available at different price levels in a hypothetical water market and, on the other hand, water supply is considered as the share of available water in all water market simulation studies (Garrido 2000; Arriaza *et al.* 2002; Calatrava & Garrido 2005; Zekri & Easter 2005; Pujol *et al.* 2006; Gomez-Limon & Martinez 2006), the share of available water in this study was considered from different water sources as water supply. Accordingly, the agricultural water balance of Alborz province is reported in Table 1. The results of studies conducted by the Alborz Regional Water Supply Company show that on average approx. 63% of agricultural water is consumed in the agricultural sector, which is about 67% in the Hashtgerd plain. Based on the results of studies, the results of water supply in Hashtgerd plain are also reported in Table 1.

**Table 1.** Agricultural water balance in Alborz Province (million m$^3$).

| Straps and Pumping | Traditional Streams | Qanat (Subterranean canal) | Springs | Wells with exploitation license | Wells without exploitation license |
|---|---|---|---|---|---|
| **15.97** | **308.57** | **1.56** | **45.65** | **244.4** | **277.16** |

| Description | Surface water resources | Groundwater resources |
|---|---|---|
| **Alborz Province (million m$^3$)** | 324.5 | 568.7 |
| | Total of Agriculture: 893.3 | |
| | Total of cultivating: 560.1 | |
| **Hashtgerd plain (million m$^3$)** | 58.1 | 292.5 |
| | Total: 350.6 | |
| | Total of cultivating: 234.5 | |

Source: Regional Water Company in Alborz Province, Iran (2016).

The estimation results of the PMP model are reported in Table 2. The insignificant difference of the estimated values with the current model indicates a good fit of the model. The total area under cultivation is 21,210 hectares and the benefit resulting from the implementation of this cropping pattern is 2272.1 million Rials in the final model estimated in Hashtgerd plain. The highest share of area under cultivation belonged to irrigated barley with 47.2% of the total area, followed by irrigated wheat and alfalfa with 32.9% and 13.2% of the total cultivated area, respectively (Table 2).

**Table 2.** PMP cropping pattern estimation and calculating the benefit of Hashtgerd plain farmers (million m$^3$).

| Product | Current pattern | Cropping pattern of PMP model | Share of the total |
|---|---|---|---|
| Irrigated wheat | 6981 | 6985.01 | 32.9 |
| Irrigated barley | 9983 | 10016.98 | 47.2 |
| Irrigated tomato | 889.29 | 890.24 | 4.2 |
| Irrigated maize | 224 | 222.99 | 1.1 |
| Irrigated pinto beans | 179.5 | 179.67 | 0.8 |
| Irrigated potato | 113.7 | 123.00 | 0.6 |
| Irrigated alfalfa | 2853 | 2792.06 | 13.2 |
| Total cropping area | 21233.49 | 21209.95 | 100 |
| Achieved benefit (million rials) | | 2272.1 | |

Source: The study findings.

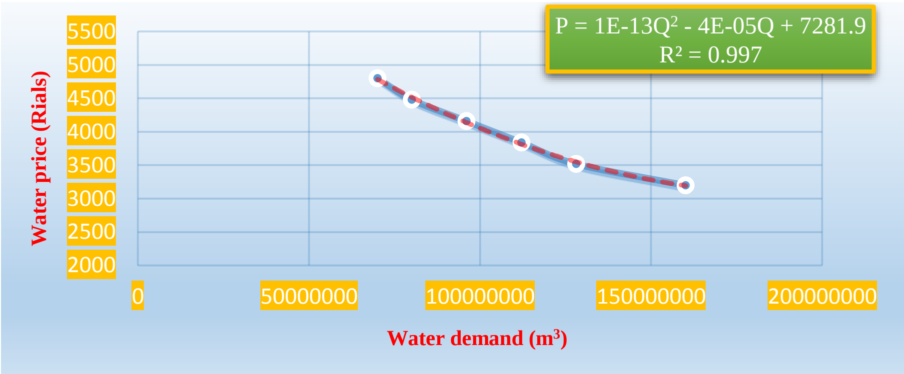
The calculation results of the economic value of water resources based on the water final production value in the proposed optimal cropping pattern of the PMP model are presented in Table 3, showing a value of 3199 Rials m$^{-3}$ water (shadow price of water input) in the Hashtgerd plain. This figure indicates that farmers' benefit increases by 3,199 Rials for each unit consumed more than water input. It is noteworthy that the amount of water consumed per hectare to produce different crops, the amount of crop produced per hectare, and the price of the produced crop are factors affecting the economic value (Table 3). The results show that the cost of supplying water to farmers is 440 Rials m$^{-3}$ in Hashtgerd plain in the current situation (in the study year) while the economic value of each m$^3$ of water is estimated at 3199 Rials based on the results of calculations, about 7 times the cost that being paid currently. This indicates that there is the necessary potential to form a water market in Hashtgerd plain. Given this assumption, therefore, a water market was simulated and its effects were studied here.

Assuming the formation of a competitive market, it is necessary to have a demand for water to estimate the equilibrium price of water in the simulated market, in addition to this supply described in the aforementioned section. Fig. 1 shows the estimation results of the water demand function using the information obtained from the PMP model in Hashtgerd plain.

Table 3. Comparing the economic value of water with the cost of water supplying in the current situation ($m^3$-rials).

| Town | Economic value (VMP) | Current cost of water supplying (Pw) | Results of comparing |
|---|---|---|---|
| Hashtgerd plain | 3199 | 440 | VMP>Pw |

Source: The study findings.




Source: The study findings.

**Fig. 1**. Demand function of water inflow, Hashtgerd plain.

By solving the above relationship, the minimum price per cubic meter of water and the water consumption resulting from this pricing will be 3282 Rials and 200 million $m^3$, respectively. This is the highest amount of water consumption at the minimum price, thereafter the increased water consumption can not be justified despite an increase in the price. In the case of pricing, therefore, care must be taken from the beginning to determine the price per cubic meter of water more than this amount, which is clearly close to the economic value of water (3,199 Rials $m^{-3}$). According to the market rule, on the other hand, the best equilibrium price in the market is the one at which there are equal supply and demand of inputs. By calculating the 234.5 million $m^3$ of water supply in the plain, the equilibrium price of each cubic meter of water will be 3,394 Rials in the market. The results of water saving in different pricing modes (minimum and equilibrium prices) are listed in Table 4.

**Table 4.** The amount of water saving in market simulation situation with equilibrium price in Hashtgerd plain (Rials $m^{-3}$).

| Description | | Minimum price (optimized price) 3282 (Rials $m^{-3}$) | Market price 3394 (Rials $m^{-3}$) |
|---|---|---|---|
| **Demand (cubic meter)** | | 200 000 000 | 167 320 000 |
| Water saving | Compared with optimize mode (minimum price) | - | 32 680 000 |
| Percentage of water saving | | - | 16.3 |
| Water saving | Compared with current mode (supplying 234.5 million $m^3$) | 34 500 000 | 67 180 000 |
| Percentage of water saving | | 14.7 | 28.6 |

Source: The study findings.

If the price of water is determined to be equal to the minimum price (3,282 Rials $m^{-3}$), 34.5 million $m^3$ will be consumed less than the current conditions of water supply (234.5 million $m^3$). In other words, it saves 14.7% of water inputs. Similarly, if the price of this water is determined to be 3,394 Rials $m^{-3}$ (equilibrium price) based on the results of calculations for water market simulation, the reduction in consumption will be 67.18 million $m^3$ (equal to 28.6% saving) compared to the current conditions of water supply (234.5 million $m^3$). In recent years, a 20% reduction in groundwater resource extraction to protect these valuable resources has been one of the policies seriously considered and pursued by the DOE (following the approvals of the Sixth Development Plan in Iran). By establishing a water market in Hashtgerd plain, the amount of saving will be greater than that of the aforementioned plan as described above. In any event, the values obtained for the price of water in Hashtgerd plain are an average estimate of the current situation. The following characteristics are generally necessary for the prices proposed in the water market of crops of this plain.

$$3282 \leq P_{water} \leq 7282$$

According to the results of the water demand function, a rise in the price of water to 7282 Rials $m^{-3}$ in the agricultural sector of this city will shut down agriculture according to the current situation of farmers. Otherwise, an improvement in the market of this crop in the plain can increase the producer's share of the market. After the water market simulation and estimation of the equilibrium price, its effects should be investigated on the cropping pattern of the region and the welfare of farmers. Obviously, changes in the price of water will increase the total production costs. However, the cost of water purchase will increase the costs of farmers who want to buy surplus water beside their water right quotas. Farmers who want to sell their quota surplus will have an increase in their income equivalent to selling the quota. To better evaluate the results, therefore, the effects of water market establishment were investigated separately for these two groups. As shown in Table 5, the benefit of water sellers will increase by 13.7% after the market formation compared to the conditions with the absence of a water market, and the benefit of water buyers will decrease by 12.1% compared to the conditions before its establishment. The calculation results reveal that the total area of cultivation will decrease for both groups, however, this decrease is much higher for sellers than buyers. So that, sellers tend to reduce approximately 10% of total area under cultivation compared to the conditions before the water market establishment and to sell their water quota. In contrast, the area under cultivation of the crops will have a very insignificant reduction (0.04%) for water buyers who tend to maintain their previous cultivation areas.

**Table 5.** Changes of cropping area and farmers welfare after water market simulation, Hashtgerd plain.

| Product | Water sellers (%) | Water buyers (%) |
|---|---|---|
| Irrigated wheat | 0.77 | 0.27 |
| Irrigated barley | -3.15 | -0.34 |
| Irrigated tomato | -0.33 | -0.38 |
| Irrigated maize | -9.27 | -1.10 |
| Irrigated pinto beans | -2.04 | 0.45 |
| Irrigated potato | -4.87 | 0.74 |
| Irrigated alfalfa | -57.62 | 0.43 |
| Total cropping area | -9.14 | -0.04 |
| welfare | 13.70 | -12.14 |

Source: The study findings

Based on the results in Table 5, alterations in the cropping pattern are also different for these two groups. Except for the wheat, the area under cultivation of other crops will be reduced for sellers such that alfalfa with 57.6% accounts for the highest reduction in the area under cultivation. Alfalfa is a perennial plant with high water requirements. In the case of a water market establishment, therefore, farmers who tend to participate in the market prefer to exclude this crop from their activities and, in return, sell their water quota. Although the reduction in the area under cultivation has been very inappreciable for water buyers, the greatest decrease belongs to grain corn. In addition to high water requirements, the corn crop is very sensitive to water shortage shock and a sharp drop in the quality of the produced crop will occur due to a slight disturbance in irrigation levels. Thus, farmers who face water shortages and have to pay an extra cost for purchasing water inputs will prefer to cultivate a crop with lower production risk. The results of experts' opinions show that the average irrigation efficiency is currently 40% in the Hashtgerd plain. However, this amount is higher in other parts of the country and the average irrigation efficiency is reported to be 70% in the agricultural sector worldwide. Therefore, one of the most important goals pursued by the Ministry of Agriculture-Jihad, MOE, and DOE in Iran is to achieve an irrigation efficiency of 70% in agriculture, which is able to be verified by the government's supportive policies. In the water development act of Alborz Province, achieving an efficiency of 60% is considered a long-term goal. The creation of a water market in the agricultural sector will lead to an increase in the price of this input, and this will happen while the actual cost (value) of water input, the same as other inputs, has not so far been received from vulnerable farmers due to the lack of proper infrastructure and mechanisms and the government support. Therefore, it should be borne in mind that a multifold increase in the water price in the probable market will seriously damage the benefit of farmers and will abolish many people who work for self-consumption and daily livelihoods. Therefore, this requires parallel supportive policies by the government, one of which is to support the increase in the use efficiency of inputs, in particular water input. This study investigated whether or not an increase in the efficiency of irrigation systems from currently 40% to 70% globally (long-term goals of development plans) in parallel with a water market formation would affect cropping patterns and farmers' benefit. As depicted in Table 6, a 10% increase in the efficiency (an increase from currently 40% to 50%) after the market establishment will not significantly change the total area under cultivation in the Hashtgerd plain. The area under cultivation will decrease for barley, beans, and potatoes, however, it will rise for wheat, tomato, grain corn, and alfalfa. Contrary to the previous scenario, wheat cultivation levels will reduce at 60% efficiency level. In addition, the area under cultivation will decrease for barley, beans, and potatoe crops. Tomatoes, grain corn, and alfalfa will have increased cultivation as in the previous scenario, which is expectable due to the water requirements of these crops. Although the elevated irrigation efficiency of all farms up to 70% is slightly far from the expected rate, it deserves investigations considering that it is among the plans of the MOE. However, notably the efficiency has upraised by 70% in farms using pressurized irrigation systems, according to the Regional Water Supply Company of Alborz Province. In this scenario, wheat, barley, beans, and potatoes are crops that maintain the decreasing trend of their area under cultivation, however, it will elevate in tomatoes, grain corn, and alfalfa. Comparing the implementation of different scenarios reveals that a rise in the productivity of irrigation systems will also elevate the tendency of water buyers to increase the area under cultivation of crops with high water requirements (providing them with more income).

**Table 6.** Alterations of cropping pattern, water consumption and benefit in the upraised agricultural water efficiency scenarios (percentage)- buyers in Hashtgerd plain.

| **Description** | **Increasing of agricultural water efficiency (upper 40%)** | | | |
|---|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| Product/Scenario | 40% | 50% | 60% | 70% |
| Irrigated wheat | Current situation | 0.02 | -0.07 | -0.13 |
| Irrigated barley | | -0.04 | -0.04 | -0.03 |
| Irrigated tomato | | 0.11 | 0.11 | 0.10 |
| Irrigated maize | | 0.71 | 0.90 | 1.03 |
| Irrigated pinto beans | | -0.10 | -0.19 | -0.27 |
| Irrigated potato | | -1.43 | -1.86 | -2.17 |
| Irrigated alfalfa | | 0.34 | 0.57 | 0.73 |
| Total cropping area | | 0.04 | 0.04 | 0.04 |
| Water consumption | | 0.1 | 0.04 | 0.03 |
| Benfit | | 2.56 | 4.66 | 6.17 |

Source: The study findings.

Since the area under cultivation has increased for crops with high water requirements, water use has also generally increased, though insignificantly, by elevating the efficiency. This shows that farmers prefer to buy more water at a higher price despite the increased price of water after the market formation due to changes in cropping patterns towards crops with high water requirements. However, it should be borne in mind that farmers will gain more income by cultivating crops, such as tomatoes and grain corn than those such as wheat and barley. This is also confirmed by the increase approx. 3, 5, and 6% in farmers' benefit by implementing the policy of increasing the irrigation system efficiencies. If farmers (with or without government support) can successfully increase the efficiency of irrigation systems in farms from 40% to 70% (which is expectable and observable in Alborz Province), they can both change their cropping patterns toward higher-income crops and are potentially able to buy surplus water from other farmers, despite the increased price of water in the market. However, their benefit is increased despite the rise in costs (Table 7). The results for the effects of increasing the efficiency of irrigation systems on water sellers show that the increased area under cultivation will be higher for sellers than for buyers in the Hashtgerd plain. This group of farmers had little difficulty in the supply of their resources in conditions of before the market formation (for any reason, they owned surplus water and tended to sell it). Therefore, they possessed more surplus water after the market establishment and by elevating the productivity of irrigation systems. This will lead to an increase in the area under cultivation of the crops so that the area under cultivation of all crops will increase by upraising the efficiency up to 50% level, with corn having the highest increase. The implementation of the second scenario, i.e. increasing the efficiency up to 60%, will repeat the same behaviour as the first scenario, however, the greatest increase in the area under cultivation will belong to potatoes in these conditions. Assuming an increase in efficiency up to 70%, the cultivation area will decrease for wheat but continue to increase for the other crops. Given the existing problems concerning the guaranteed purchase of wheat, it seems that there will be more tendencies to cultivate the other crops provided that water is available.

**Table 7.** Changes of cropping pattern, water consumption and welfare in increasing of agricultural water efficiency scenarios (percentage)- sellers in Hashtgerd plain.

| Description | Increasing of agricultural water efficiency (upper 40%) | | | |
|---|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| Product/Scenario | 40% | 50% | 60% | 70% |
| Irrigated wheat | Current situation | 0.02 | 0.10 | -1.20 |
| Irrigated barley | | 1.09 | 3.83 | 3.66 |
| Irrigated tomato | | 0.15 | 0.68 | 0.67 |
| Irrigated maize | | 3.06 | 8.34 | 11.17 |
| Irrigated pinto beans | | 0.40 | 0.03 | 0.66 |
| Irrigated potato | | 1.85 | 7.48 | 5.54 |
| Irrigated alfalfa | | 0.40 | 0.03 | 0.66 |
| Total cropping area | | 1.33 | 6.01 | 10.06 |
| Water consumption | | 2.24 | 8.66 | 9.46 |
| Benefit | | 0.38 | 1.49 | 1.86 |

Source: The study findings.

Using water will also increase for this group, so that the upraised using percentage of this water will be higher than the buyer group. One of the reasons for this result is that water sellers owned surplus water and tended to sell it before implementing the policy of rise in the irrigation system efficiency. The benefit of this group will also elevate by implementing the policy of the upraised efficiency. However, the results of calculations exhibit that the elevation in this group is less than that of the group of water buyers. This is because the increased benefit of buyers is mainly due to changes in cropping patterns towards high-value crops (the income of this group will increase more than the costs), while alterations in the cropping patterns are associated with the increased cultivation area and more consuming water in the seller group. In other words, the costs of this group have also increased along with revenues from increased production and water sales, leading to a lower increase in benefit than the buyer group.

## CONCLUSION AND RECOMMENDATIONS

It can be concluded that the required water resources were 234.5 million $m^3$ before the establishment of the suggested water market in the Hashtgerd plain, Alborz Province. After the market formation and the application of market prices (3,394 Rials $m^{-3}$), the use of water will reduce to 167.32 million $m^3$, i.e., a 28.6% saving in water resources. In the simulated market, the minimum and maximum water prices are 3282 and 7282 Rials $m^{-3}$, respectively. After the water market establishment, the cropping pattern will undergo changes in the region, which are different for the group of water buyers and sellers. Sellers tend to reduce the area under cultivation of all crops, except for wheat, due to the low water requirement of this crop than the others. This means that the income from the sale of water to applicants is higher than that of cultivating the crops in these conditions. Buyers will also reduce crops with high water requirements and elevating the cultivation of the other crops. Increasing the efficiency of irrigation systems is one of the policies that, if accomplished in parallel with the water market establishment, will lead to an upraised benefit of buyers to compensate for their lost benefit after the water market establishment. According to the results of the calculations, the following recommendations are presented regarding water resource management using the establishment of a water market. To prevent the reduction of farmers' benefit, policymakers are recommended to simultaneously implement supportive policies, such as supporting the increased irrigation system efficiency (and other inputs). Given that rising the price to the equilibrium limit will cause a sudden shock to the sector, it is suggested to first determine the minimum obtained price (3,282 Rials $m^{-3}$) as the market price. This price is closer to the economic value and, with a saving of approx. 15%, also covers step-wise policies of water use reduction (approved by the Sixth Development Plan in Iran). Since it is possible to save water resources after a water market establishment, the DOE, as the responsible organization, is recommended to adopt a measure to prevent water extraction from the land by sellers and, in return, provide them with the benefits of selling water. In other words, a water market will be formed between farmers and the DOE by redeeming a portion of the shares of water rights owned by farmers. Another recommendation of this study is efforts to change the cropping pattern in the region with the approach of cultivating crops that have higher yields and higher income with less water. Further studies on medicinal plants are recommended in this regard.

**REFERENCES**

Abolhasani, L, Shahnoushi, N, Rahnama, A, Azam Rahmati, E & Heyran, F 2019, The effect of water market simulation on agricultural water resources consumption case study: Mashhad plain, *Agricultural Economics and Development Journal*, 27: 1-29, [In Persian].

Arriaza, M, Gomez-Limon, JA & Upton, M 2002, Local water markets for irrigation in southern Spain: A Multicriteria approach. *The Australian Journal of Agricultural Resource Economics*, 461: 21-43.

Calatrava, J & Garrido, A 2005, Modelling water markets under uncertain water supply. *European Review of Agricultural Economics*, 322: 119-142.

Forouzandeh, R 2016, Fear of dehydration: The third case of the water crisis. *Tejarat Farda Tomorrow Business*, Weekly Magazine, 20 August, [In Persian].

Garrido, A 2000, A mathematical programming model applied to the study of water markets within the Spanish agricultural sector. *Annals of Operations Research*, 94: 105- 123.

Grafton, RQ, Landry, C, Libecap, GD, McGlennon, S & O, Brien, R 2011 An integrated assessment of water markets: A cross-country comparison. *Review of Environmental Economics and Policy,* 52: 219- 239.

Grafton, RQ, Landry, C, Libecap, GD, McGlennon, S & O, Brien, R 2011, An integrated assessment of water markets: A cross-country comparison. *Review of Environmental Economics and Policy*, 52: 219- 239.

Gomez-Limon, JA & Martinez, Y 2006, Multi-criteria modelling of irrigation water market at basin level: A Spanish case study. *European Journal of Operational Research*, 173: 313-336.

Howitt, RE 1995a. Positive mathematical programming. *American Journal of Agricultural Economics*, 772: 329-342

Howitt, RE 1995b, A Calibration method for agricultural economic production models. *Journal of agricultural Economics*, 462: 147-159.

Howitt, RE 2005, Agricultural and environmental policy models: calibration, estimation and optimization. Unpublished, Available at: www. Agecon.ucdavis.edu/ people/ faculty/ facultydocs/ Howitt/ master. Pdf.

Howitt, RE, Medellin-Azuara, J, MacEwan, D & Lund, R 2012, Calibrating disaggregate economic models of agriculture production and water management. *Science of Environmental Modeling and Software,* 35: 244-258.

Kiani, GH 2016, The role of market in optimal water resources allocation and efficacious factors influencing the efficiency of water markets. *Journal of Water and Sustainable Development*, 3: 93-102 (In Persian).

Parhizgar, A, & Badi Barzin, H 2017 Determining the economic value of water and simulating the behaviour of farmers on agricultural water resources reduction in Takestan region, Journal of Water Research in Agriculture, 31 (1).

Parhizgari, A, Sabouhi, M & Ziaie, S 2013, Simulation of water market and analysis of the effect of irrigation water sharing policy on cropping pattern under water stress. *Journal of Agricultural Economics and Development,* 273: 242-252.

Pujol, J, Raggi M & Viaggi, D 2006 The potential impact of markets for irrigation water in Italy and Spain: a comparison of two study areas. *The Australian Journal of Agricultural and Resource Economics*, 50: 361-380.

Water and Waste water Company. Alborz Province. 2018. https://www.abfa-alborz.ir/

Water markets as a response to scarcity. 2018. Iran water policy research institute iwpri

Water markets as a response to scarcity. Peter Debaere et al. Water Policy 16 2014 625–649.

Zekri, S & Eeaster, E 2005, Estimating the potential gains from water markets: A case study from Tunisia. Agricultural Water management, 72: 161-175.

Zibaei, M & Malekvar Nosfadarani, M 2017, Potential effects of water market simulation on productivity promotion and water conflicts reduction in Fars Province. Water and Sewerage Organization, Tehran, Iran, No. 1, [In Persian].

Zolfagharipoor, MA, Ahmadi A, & Nikouei, AR 2020 Development of inter-sectional water market framework for improving economic efficiency of groundwater consumption. *Iranian Journal of Water Resources Research.* 16: 332-3346, [In Persian].

***Bibliographic information of this paper for citing:***

Shabani Rouchi, Z, Yazdani, S, Moghaddasi, R 2022, Water market simulation based on the principles of sustainable development (Case study: Hashtgerd plain, Alborz Province, Iran). Caspian Journal of Environmental Sciences, 20: 649-658.