Journal of Hydrosciences and Environment
Available online at http://jhe.usb.ac.ir/

ISSN: 2345-5608

# The Economic Value of Irrigation Water, Cropping Pattern, and Farmer Gross Margin Under Drought Conditions: The case of the Qazvin plain

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ARTICLEINFO

**Article history:**

**Received:** *17 May 2019*
**Accepted:** *14 October 2019*

**Keywords:**
*Water price,*
*Available water,*
*Gross margin,*
*Policymaking,*

ABSTRACT

Water is a necessary but scarce input among the inputs used for crop production, so determining its economic value can be a good instrument to improve its management. In this respect, the present study aims to determine the economic value of irrigation water under drought conditions and to propose a cropping pattern and estimate farmer gross margin in the Qazvin plain in Iran using linear programming and positive mathematical programming (PMP) models. The statistical data were of the document type for the 2013-2014 growing season. The results showed that the economic value of irrigation water is 1,161 IRR/$m^3$ whereas farmers pay 417 IRR/$m^3$ as the water price. Also, the economic value of irrigation water is 1,152 IRR/$m^3$ in the base year, which increases by 12.2-94.1 percent to 1293-2236 IRR/$m^3$ under the scenarios of water limitation by 10-50 percent. In these conditions, farmers tend to reduce the acreage of sugar beet and sunflower and increase the acreage of irrigated wheat and barley. This will reduce farmers' gross margin. This reduction of gross return is maximized when the costs of coping with drought and production costs are maximal. So, timely informing of farmers before the occurrence of drought and holding training courses about methods to counteract the negative consequences of this climatic phenomenon by governmental agencies, such as Jihad-e Agriculture Organization and research and educational centers, can be helpful in supporting farmers and officials in their attempts to cope with the consequences of drought. Determining the economic value of irrigation water across the region and accepting a reasonable price as water price by farmers can lead to a considerable saving of this scarce input in the region. So, it is recommended to price irrigation water in accordance with its economic value and the consideration of its equivalence.

## 1. Introduction

Farmers' growing tendency to expand the planting area of crops and the excessive exploitation of water resources have dramatically deepened the gap in demand and supply of this vital source, leading to its scarcity. In addition, the low price of agricultural water as compared to its real economic value has created the perception that this input is for gratis and has resulted in its excessive use. This is threatening water resources and has had detrimental impacts on the environment, erosion, and soil destruction in Qazvin Province, Iran (Anonymous, 2014).

More than 96% of water use in this plain is related to agriculture. Due to the limitation of surface water resources and the seasonality of these resources, much of the irrigation water comes from underground sources. This brings about a surplus on the groundwater capacity of the plain up to about 200 million $m^3$ (Ministry of Energy, 2011; Barikani et al., 2012).

In addition, the cheap price of water paid by farmers of this province, especially in recent years, has aggravated excessive water use and low water efficiency in arable lands (Ehsani et al., 2011; Parhizkari & Sabohi, 2014). The surface waters of this province are in the form of seasonal rivers (the Abharroud, Khorroud, and Hajji Arab rivers and some small streams in southern foothills) formed by rainfall. These rivers dry up in hot seasons because of the lack of rainfall. Then, farmers resort to groundwater resources to satisfy their irrigation requirements. Consequently, the water tables have been faced with fallen surface and the water budget has become negative in most parts of the province, particularly in southern parts of the Qazvin plain (Parhizkari & Sabohi, 2014). In this regard, determining the economic value of irrigation water and accepting a reasonable price by farmers provides the basis for strengthening the economic role of water in development. It is essential that before making a decision in the agricultural sector, predictions are made about the possible effects of changes in the economic value of

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irrigation water and replacing this economic indicator on the pattern of crop cultivation and gross profits of farmers rather than the current price or cost of water input. This research analyzes and evaluates the economic impacts of droughts (restrictions on irrigation water supply) on crop cultivation and gross profits of farmers.

So, we use the positive mathematical programming (PMP) model and the constant elasticity of substitution (CES) production function to explore the response of farmers in the study site to the substitution of the economic value of irrigation water with the price or current cost of this input and to analyze the economic impacts of drought (limited supply of water) on cropping patterns and the gross profit of farmers. In the next paragraphs, we review the important research works at the national and regional levels:

- Doppler et al. (2002) used a crop production function to determine the economic value of irrigation water in the Jordan Valley. They found the economic value to be about 175 $ per 1000 m3. According to their results, irrigation water allocation based on its real value has a high potential to increase the financial return of the agricultural sector. Also, the results revealed that with the increase in the real price of water under risk conditions, crop production would decrease and this would negatively influence the supply status in the marketplace.
- Salman and Al-Karablieh (2004) used a linear programming model in a region in Jordan to explore a set of optimal activities maximizing the net income of farmers. They calculated the shadow price of water in crop production in the best cropping pattern in terms of the net income across the region. The calculation of the price elasticities of water led them to conclude that local farmers would respond to the changes in water prices.

In a case study in Gujarat, India to develop an instrument to improve water use efficiency, Singh (2007) claimed that there existed a deep gap between price and economic value of irrigation water and the increase in water price would require making a balance between water supply and demand, which would reduce the welfare of farmers. They, also, argued that technical complexities in assessing the real value of water had turned its pricing into an inappropriate method. In a study on increasing irrigation return through water demand management by different water pricing methods, Molle et al. (2008) concluded that different pricing methods would motivate farmers to select and produce crops that were compatible with water scarcity, but irrigation water pricing policy was not by itself a valid tool to modify irrigation return. Mesa-Jurdao et al. (2008) employed the residual method to valuate irrigation water in Southern Spain. In this method, the cost of inputs except water is subtracted from the gross return and the remaining return is attributed to water. The results revealed a considerable difference between the economic value of irrigation water and the water price paid by farmers in the studied region.

Medellan-Azuara et al. (2010) used the PMP model to estimate the economic value of water in northern watersheds of Mexico. According to the results, water had similar economic value at the farm level and at the regional level, but diversity and distribution impacts were influenced by the applied scenarios. Using econometric methods, Sharzee and Amir Timouri (2011) first estimated a proper production function for pistachio in Ravar County of Kerman province, Iran. Then, they calculated the economic value of irrigation water consumed for the production of this crop. The economic value of groundwater was estimated at 1,987 IRR/m3 in the studied county. In addition, since water accounts for 49 percent of the total value of the pistachio crop and it is a scarce input in the region, it is necessary to increase its price to as high as its real value. In a study using the PMP model in the Alamut region of Qazvin province, Parhizkari and Sabahi (2014) determined the economic value of irrigation water and simulated the response of farmers to the policy of reducing water resource availability. The economic value of the irrigation was estimated to be 882, 716 and 845 IRR/m3 in the districts of Rudbar Alamut-e Gharbi, Rajaei Dasth, and Rudbar Alamut-e Sharghi, respectively. The results showed that as the availability of irrigation water was decreased, the economic value of water was increased and the cropping patterns were shifted towards crops that could generate stable income by less water use. Vakilpour and Varesee (2014) used the linear mathematical programming model to explore the impacts of reducing water use on cropping patterns and to estimate the economic value of irrigation water in the Dehgolan plain. The economic value was estimated by the model at 1,873 IRR/m3 in the studied plain. The results revealed that the economic value of water would be enhanced by applying different scenarios of reducing water availability so that the scenario of 50% less water availability would increase the economic value of water to 11,365 IRR. Nazari et al. (2014) employed the production function method to assess the economic value of agricultural water in Ahvaz County. The statistical population was composed of irrigated farms of the county in 2012-2013. The results showed that if water prices were modified in the agricultural sector, the demand for water could be expected to decline, allowing its saving and storage. In addition, amongst different functions, the Translog function was found to be the best form for the wheat crop. The economic value of water was measured to be 1,720 IRR by this function. Zamanian et al. (2015) used the maximum entropy-based PMP method to explore the effect of environmental stress and higher prices of agricultural inputs on planting patterns in Khomein Plain. They revealed that the estimated PMP model could well reproduce the values of base year and that the policy of increasing prices of water and fertilizer decreased the diversity of the planting patterns. Mousavi and Banaei (2015) examined the sustainability of water resources and planting patterns as affected by water management policies in Fars Province, Iran using the PMP model and data for 2015-2014 growing season. The study focused on two scenarios of increasing irrigation water prices and decreasing irrigation water use. They revealed that the increasing price had a mild impact on planting patterns and reduced farmers' profit, but it had a slight effect on water use.

In a study investigating the factors affecting the acceptance and development of pressure irrigation cultivation using the Logit model, Rahmani et al. (2016) showed that water manpower cost, literacy level, education, income, second job of farmer, cultivation level, satisfaction with administrative, expert and credit services, positive effect, and agricultural background, number of crops, amount of water consumed and initial cost of running irrigation system had negative impacts on adoption and development of new irrigation levels. Also, the average of the final effects of the studied factors on pressure irrigation development was 0.345. The review of the literature shows that the price farmers pay for water is negligible so that it accounts for just a small part of the costs of water resource exploitation. So, farmers are not so motivated to optimize water use. On the other hand, water pricing policies by themselves do not suffice to improve the economic return of water. Thus, a mix of pricing and non-pricing policies is required.

Mirzaei et al. (2018) explored the economic impacts of non-pricing policy of limiting water supply and the policies of water pricing, taxing, and subsidization as per each $m^3$ water use over or below the average gross requirement of the planting pattern on the components of the agricultural sector in Qazvin Province using the data and statistics for the 2013-2014 growing season and the expansion of positive mathematical programming model with the maximum entropy approach. The results showed that the non-pricing policy of 50% limitation of water supply would have the highest economic return per $m^3$ water use. It is estimated to be 0.23$. The highest reduction of chemical fertilizer use would be accomplished in the scenario of 50% limitation of water availability and the integrated scenario of 30% water availability limitation + 50% higher price for water.

## 2. Materials and Methods

In the agricultural sector, water is conceived as an input that can be considered a natural asset, and its value can be attributed to its capability in creating commodity and service flows over time. The point to note in water valuation and use is to distinguish extraction, use, and consumption. In this sense, it is necessary to consider the competing or complementary uses in the valuation of water resources because water as a production input can be utilized in different uses frequently and/or concurrently. The extraction values of water are usually divided into use values and non-use values (Young, 2005).

The empirical model of the present study is composed of the objective function of maximizing farmer gross profit with a set of resource constraints in the Qazvin plain. The relations and equations are described below.

### 2.1 Objective function of linear programming problem

Equation (1) shows the objective function of maximizing farmer gross profit aggregately for the studied regions of Qazvin province.

$$Max\ Z = \sum_{i=1}^{7}(P_i * Y_i - \sum_{j \neq wat}^{5} TCI_{ij} * MI_{ij})X_i - \sum_{j=Swat}^{5}(TCS * SW + TCG * GW) \quad (1)$$

This objective function is composed of four main components: income, the cost of surface water resources, the cost of underground water resources, and the cost of other production inputs except for surface and underground water resources (i.e. land, labor, capital, and machinery) in the study site. The subscript *i* represents the selected crops (irrigated wheat, irrigated barley, grain corn, tomato, sugar beet, sunflower, and canola) and the subscript *j* represents inputs or production factors (water, land, labor, capital, and machinery). $P_i$ and $Y_i$ denote the market price and yield of the crop *i* in the study site, and $TCI_{ij}$ and $MI_{ij}$ represent the cost and rate of the production input *j* (except water) consumed to produce the crop *j* in the study site, respectively. The cost of water is thought in two states of surface water (the cost of water transfer) and underground water (the cost of water extraction). *TCS* is the cost of transfer or the unit price of surface water, and *SW* is the amount of allocated or consumed surface water resources in the study site. Similarly, *TCG* shows the cost of extraction or the unit price of underground water, and *GW* shows the amount of allocated and consumed underground water in the study site.

### 2.2. Constraints on water availability

Equation (2) shows the constraints of water in the study site in terms of total allocated surface and underground water resources and crop water requirement.

$$\sum_{i=1}^{7} WR_i * X_i \leq SW + GW \quad (2)$$

in which $WR_i$ denotes the water requirement of the crop *i* and *SW* + *GW* denotes total available water resources (surface and underground resources in terms of million $m^3$) in the study site. This constraint shows that the water requirement of the crops in a given region is equal to or smaller than the total allocated or available surface and underground water resources.

### 2.3. Constraints on crop acreage

Equation (3) concerns the constraint on the input 'land' or arable lands in the study site.

$$\sum_{i=1}^{7} X_i \leq TA \quad (3)$$

in which $X_i$ represents the acreage of the crop *i* and *TA* represents the total arable lands of the study site. This constraint means that lands allocated to activities or the acreages of the selected crops cannot exceed total arable lands of the region.

### 2.4. Constraints on farming labor

Equation (4) shows the constraint on labor in the agricultural sector in the study site.

$$\sum_{i=1}^{7} La_i . x_i - TLa \leq 0 \qquad (4)$$

in which $La_i$ shows the labor required to produce the crop $i$ and $TLa$ is the total available labor in the study site. This constraint implies that total available labor and labor requirement of the agricultural sector is always equal to or smaller than zero and that the labor requirement of a region cannot exceed total available labor in the region.

### 2.5. Constraints on practical capital

Equation (5) is related to the constraint on capital available to farmers to supply seed, fertilizer, and herbicide requirements of the selected crops in the region.

$$\sum_{i=1}^{7} K_i . X_i - TK \leq 0 \qquad (5)$$

in which $K_i$ represents the technical coefficient of cost per unit area of the crop $i$ and $TK$ denotes total capital available in the study site. The left-hand side shows the capital requirement of the production activities, which corresponds to the variable costs of crop production per ha. The right-hand side shows total capital that can be allocated to agronomic activities in the study site.

### 2.6. Constraints on agricultural implements and machinery

Equation (6) shows the constraint on working hours of machinery and mechanized implements, such as tractors, combines, and harvesters, in the studied area.

$$\sum_{i=1}^{7} Ma_i . X_i - TMa \leq 0 \qquad (6)$$

$$x_i \geq 0 \quad \forall i = 1, 2, \dots, 7 \qquad (7)$$

in which $Ma_i$ is the machinery working hour requirement to produce the crop $i$ and $TMa$ represents total working hours of machinery in the studied region.

After the optimal cropping pattern is determined in the Qazvin plain based on the objective function of maximizing farmer gross margin and the set of systemic constraints (resource constraints) in the region and the economic value of irrigation water is estimated for the farms, focus should be oriented to studying the impacts of drought arising from water resource limitation and the reduction of available water on cropping patterns and farmer gross margin. To this end, the present study employed an aggregate modeling system that included the objective function of gross margin maximization, crop yield or production estimation function, and a nonlinear cost function. This economic modeling system is described below in detail:

Unlike simple linear programming models that determine optimal levels of inputs and crops for a certain region, the above model is used to accomplish the goals described earlier aggregately across the Qazvin plain. Another capability of the proposed model is that it allows including more systemic constraints. If crop rotations are used in a region, this constraint can be included in the model too. We included compatible market inputs (seed, fertilizer, and herbicide requirements of the selected crops- practical capital) as constraints in the model. Since our model is positive, it simulates farmers' real behavior after calibration. This programming model is highly flexible for decision-makers or users to include systemic constraints pertaining to regional conditions.

After the estimation of the economic value of irrigation water, it can be compared with the water price paid by farmers under the status quo and shows farmers' behavior patterns in the Qazvin plain to pay a part of the economic value of irrigation water as water price. According to the objective function in the linear programming model, as the economic value of irrigation water is calculated, the optimal cropping pattern can be determined for the study site considering the constraints on the input 'water'. Then, the comparison of optimal cropping pattern with the current cropping pattern of the region allows studying the changes in the acreages of the selected crops and farmers' gross margin under equal conditions.

In Normative Mathematical Programming (NMP) models, it is difficult to reproduce or replicate the levels observed in the base year of decision variables due to the lack of a calibration mechanism and it is likely for some crops not to be included in the planting pattern (this phenomenon is due to the hidden marginal costs) whereas this would not be observed in real world even if other crops are highly profitable. Positive Mathematical Programming (PMP) model has been introduced by Howitt (1995) to overcome this normative feature. PMP model is composed of three following steps in a broad sense.

Step 1: Calculating shadow price of crops using a linear programming model

The first stage of a PMP model can be presented as below using a simple linear programming model designed to maximize gross returns:

$$Max \quad Z = GM'X \qquad (8)$$

subject to:

$$AX \leq b \qquad [\pi] \qquad (9)$$

$$X \leq (X^0 + e) \qquad [\lambda] \qquad (10)$$

$$X \geq 0 \qquad (11)$$

where $Z$ is the value of the objective function (should be maximized), $X$ is the vector of activities, and $GM$ is the vector of crop gross return (the product of price in crop yield minus production variable costs) that is derived by

$$GM = (YP) - C \qquad (12)$$

where $p$ denotes the crop price, $Y$ represents the crop yield, and $C$ shows the total costs of the variable. $A$ is the matrix of technical factors, $b$ and π represent the vector of existing resources and their dual variables (or shadow prices), respectively, $e$ and λ denote a vector of small positive numbers and the dual variable of calibration constraint, and $x^0$ shows the level of activity observed in base year (Howitt, 2005). Equation (9) is called resources constraint and Equation (10) is called calibration constraint. When calibration constraints are added, the optimum answer to mathematical programming gives the planting levels of the activities observed in the base year exactly (Howitt, 1995; Howitt et al., 2012).

Step 2: Estimating the parameters of nonlinear cost function of crops

The second step uses the values of λ, derived in the first step, to estimate the nonlinear variable cost functions of the crops. For simplicity and the lack of strong reasons to select other functions, the following quadratic variable cost function is usually applied (Heckelei, 2002):

$$C^v = d'x + \frac{1}{2}x'Qx \tag{13}$$

where $C^v$ is the variable cost, $d$ is a vector (n × 1) of parameters pertaining to the linear component of the cost function, and $Q$ is a certain, positive, symmetric matrix (n × n) of parameters pertaining to the quadratic component of the cost function. This function is derived provided that the final variable cost of the activities is equal to total accounting cost of the activities (c) and the dual variable of calibration constraint (λ). Therefore, the parameters of the cost function should be calculated under the following condition:

$$MC^v = \frac{\partial C^v(x^0)}{\partial x} = d + Qx^0 = c + \lambda \tag{14}$$

The nonlinear cost function is estimated by maximum entropy introduced by Paris and Howitt (1998) to estimate all parameters of the vector $d$ and the matrix $Q$. These models allow the fitting of production or cost functions by econometrics and mathematical programming methods. The maximum entropy to estimate the parameters of the model is formulated as below (Heckelei & Britz, 2001):

$$\text{Max } H(p) = -\sum_{k=1}^{K}\sum_{i=1}^{n} pd_{k,i}\ln pd_{k,i} - \sum_{k=1}^{K}\sum_{i=1}^{n}\sum_{i=1}^{n} pq_{k,i,j}\ln pq_{k,i,j} \tag{15}$$

subject to:

$$d_i + \sum_{j=1}^{n} q_{i,j}x_j^* = c_i + p_i \forall_{i,j} \qquad i = 1,\ldots,n \qquad j = 1,\ldots,n \tag{16}$$

$$d_i + \sum_{k=1}^{K} pd_{k,i}zd_{k,i} \forall_j \qquad i = 1,\ldots,n \qquad k = 1,\ldots,k \tag{17}$$

$$q_{i,j} + \sum_{k=1}^{K} pq_{k,i,j}zq_{k,i,j} \forall_{i,j} \qquad i,j = 1,\ldots,n \qquad k = 1,\ldots,k \tag{18}$$

$$\sum_{k=1}^{K} pd_{k,i} = 1 \qquad \forall_{\mathrm{j}} \qquad i = 1,\ldots,n \qquad k = 1,\ldots,k \tag{19}$$

$$\sum_{k=1}^{K} pq_{k,i,j} = 1 \qquad \forall_{\mathrm{i,j}} \qquad i,j = 1,\ldots,n \qquad k = 1,\ldots,k \tag{20}$$

$$q_{i,j} = q_{j,j} \forall_{\mathrm{i,j}} \qquad i = 1,\ldots,n \qquad j = 1,\ldots,n \tag{21}$$

Equation 16 expresses the first constraint to estimate the coefficients of the variable cost function as described above. The second and third constraints (Equations 17 and 18) introduce the parameters of the vector $d$ and the matrix $Q$ that are the fixed component and the slope of the nonlinear variable cost function, respectively. The fourth and fifth constraints (Equations 19 and 20) express the probability sets for $d$ and $Q$, respectively. Finally, the sixth constraint (Equation 21) assures the asymmetry condition of the elements of the matrix $Q$.

Step 3: Calibration of mathematical programming model

This step uses the nonlinear cost functions calibrated for various crops as well as the resource constraints to build a nonlinear programming model as below given the calibration constraints:

$$MaxZ = GM'x - d'x - x'Qx/2 \tag{22}$$

subject to:

$$Ax \le b \tag{23}$$

$$x \ge 0 \tag{24}$$

In this model, the non-linear cost functions of the alternative crops become their mean costs in linear programming model and the model is re-run under the constraints of production resources and in the absence of calibration constraints. The output of this calibrated model under base year conditions would be exactly the levels of base year activities. In this state, the policies can be analyzed in the model by altering the conditions and the definition of different scenarios. The data of the present study are documents registered in governmental agencies. They were collected directly from the relevant agencies (Jahad-e Agriculture Organization and Regional Water Organization) in Qazvin Province. The mathematical programming model of the study was coded and run in GAMS.24 Software Package.

After the above modeling system was designed, the impacts of drought was studied on cropping pattern and farmer gross margin by focusing on water supply constraint in the studied region because the major consequences of drought in the Qazvin plain (and other plains of Iran) are the rise of temperature, the decline of rainfall, the decrease in surface water resources, and finally, the loss of water resource availability to farmers, or in other words, the limitation of irrigation water supply. After the impacts of drought on cropping patterns and farmer gross margins were analyzed by taking data to the base year data in the PMP model, total available water resources to farmers, which is shown in the right-hand side of water constraints in Eq. (8), was reduced by 10, 20, 30, 40 and 50 percent(based on the percentage of the loss of water available to farmers in droughts over the past 30 years) within different scenarios and thereby, the impacts of the decline of water availability or water supply limitation caused by drought at different intensities were analyzed on cropping pattern and farm gross margin. The research data are related to the 2013-2014 growing season and they were available in documents of the relevant public agencies. The data included farmer gross margin per ha per crop, market price of crops, average annual yield of crops, input consumption rate (water, fertilizers, herbicides, seeds, machinery, etc.) per ha per crop acreage, cost of additional inputs, water resource availability in the study site, water requirement of the selected crops, and total amount of resources and inputs used for crop production.

### 3. Results and Discussion

Table 1 presents the results of solving the linear programming model of optimal cropping pattern and those of comparing the acreage of the selected crops in this pattern with the present pattern (base year) in the Qazvin plain. After the model was optimized for the set of systemic constraints (resource limitations), we observed acreage decline for irrigated wheat and irrigated barley versus the present cropping pattern so that the acreage of irrigated wheat was decreased from 56,825 ha in base year to 51,730 ha in the optimal cropping pattern, exhibiting an 8.96 percent decrease in acreage. Similarly, after the systemic constraints were included in the model, the acreage of irrigated barley was decreased by 12.59 percent from 32,400 ha in the base year to 28,318 ha in the optimal pattern. This decline of the acreage in the optimal pattern can be attributed to the relatively low yields of irrigated wheat and barley that makes them less economical than other selected crops of the pattern (i.e. grain corn, tomato, sunflower, and canola).

Table 2 displays the variations of the gross rate of return for the agricultural activities in the Qazvin plain under the present cropping pattern and the pattern derived from the linear programming model.According to Table 2, the highest possible farmer gross profit in the study site can be obtained from growing irrigated wheat and barley, as well as canola and sunflower oilseeds, on a large scale. Although grain corn is highly economical among the studied crops in the plain, water limitation has constrained the development of its acreage, especially in recent years. The results of the cropping pattern optimization show that the decrease in the acreage of irrigated wheat and barley reduces the gross profit derived from these crops so that the total gross profit is decreased from 8,245.64 to 7,506.33 million IRR for irrigated wheat and from 4,169.23 to 3,643.96 million IRR for irrigated barley, showing the reduction of the return for these crops by 11.85 and 15.37 percent, respectively. The water saved by the reduced acreage of the grains is allocated to more economical crops, so the increase in the acreages of grain corn, tomato, canola, and sunflower (as more profitable crops) entails higher farmer gross profits per unit area for these crops. Indeed, the gross rate of return for grain corn, tomato, sunflower, and canola in the optimized pattern is 49.94, 18.51, 88.53, and 45.91 percent higher than those in the present cropping pattern, respectively.

Table 3 presents the results of estimating economic value per m$^3$ water in the above programming models (linear and PMP).The slight difference in the economic value of water estimated by these models (1,161 IRR in the linear programming model vs. 1,152 IRR in the PMP model) is associated with the inclusion of a calibration constraint in the first stage of the PMP model, which is imperative to make data coincide with the data of the base year. The results in Table 3 reveal a deep gap between the estimated economic value per m$^3$ irrigation water and the water price paid by farmers in the study site. The results of the linear programming model and the PMP model in Table 3 show that the estimated value per m$^3$ irrigation water in the Qazvin plain in the base year 2013 was 1,161 and 1,152 IRR, respectively showing a very slight difference, whereas farmers in this plain pay 417 IRR as water price. This means that farmers pay 35.94-36.20 percent of the economic value of the irrigation water in the context of extraction and transfer costs, so farmers perceive water to be a free input that is excessively used in farms. Figure 1 schematically displays the significant difference in the economic value of irrigation water and the price paid by farmers in the Qazvin plain based on the results of the linear programming model and PMP model in the base year.

**Table 1.** Comparison of crop acreages between current cropping pattern and the pattern derived from the linear programming model

| Selected crops | Base year pattern | | Linear programming pattern | | Variation % vs. base year |
|---|---|---|---|---|---|
| | Acreage | Crop share (%) in pattern | Acreage | Crop share (%) in pattern | |
| Irrigated wheat | 56825 | 49.5 | 51730 | 45.06 | -8.96 |
| Irrigated barley | 32400 | 28.2 | 28318 | 24.7 | -12.59 |
| Grain corn | 9380 | 8.16 | 14527 | 12.5 | 56.87 |
| Tomato | 8760 | 7.62 | 10722 | 22.4 | 22.39 |
| Sugar beet | 1327 | 1.15 | 0 | 0.00 | -100 |

| | | | | | |
|---|---|---|---|---|---|
| Sunflower | 2920 | 2.54 | 4641 | 4.04 | 58.93 |
| Canola | 3203 | 2.78 | 4827 | 4.20 | 50.70 |
| Total | 114815 | 100 | 114815 | 100 | - |

**Table 2**. Value (million IRR) and variation percentage of planned return derived from the cropping pattern under the status quo in the study region and after cropping pattern optimization

| Selected crops | Base year pattern | | Linear programming pattern | | Return variation % vs. base year |
|---|---|---|---|---|---|
| | Planned return | Crop share (%) in pattern | Planned return | Crop share (%) in pattern | |
| Irrigated wheat | 8245.64 | 47.14 | 7506.33 | 41.55 | -11.85 |
| Irrigated barley | 4169.23 | 23.83 | 3643.96 | 20.17 | -15.37 |
| Grain corn | 1836.30 | 10.49 | 2843.92 | 15.74 | 49.94 |
| Tomato | 1714.69 | 9.80 | 2098.74 | 11.61 | 18.51 |
| Sugar beet | 251.25 | 1.43 | 0.00 | 0.00 | -100 |
| Sunflower | 6263.03 | 3.63 | 1011.32 | 5.59 | 53.88 |
| Canola | 6376.24 | 3.64 | 960.91 | 5.32 | 45.91 |
| Total | 174937.3 | 100 | 180652.4 | 100 | 3.27 |

**Table 3.** The comparison of economic value of irrigation water with the price tariff paid by farmers in the Qazvin plain in the 2012-2013 base year (IRR/m3)

| Study site | Used method | Water price paid by farmers | Economic value of water (Water shadow price) | Percent from economic value of water paid by farmers |
|---|---|---|---|---|
| The Qazvin plain | Simple linear programming | 417 | 1161 | 35.91% |
| | Positive mathematical programming | 417 | 1152 | 36.20% |

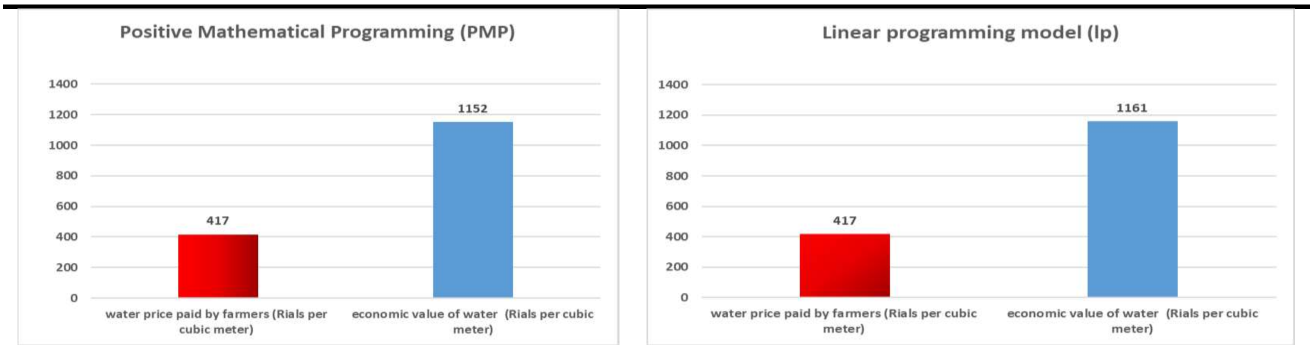


**Fig. 1.** The comparison of economic value of water and the water price paid by farmers in the Qazvin plain in the base year

Table 4 shows the share of each input after estimating the CES production function for individual crops in the study site. Accordingly, we can see that the total share of the inputs is equal to one for each crop. This is associated with the constant elasticity of the CES production function to scale.In Table 4, the share of the production inputs in the production of main selected crops in Qazvin province has been estimated with respect to 100 percent based on the reference year and the statistical reports of the Deputy of Planning and Economic Affair, Jihad-e Agriculture Organization of Qazvin. It is evident that the input 'land' has higher contribution than other inputs (water, capital, labor, and machinery) in producing all selected crops in the plain, so it is of higher importance. After land, irrigation water is the second most important input in producing the selected crops in the plain, and other inputs (labor, capital, and machinery) had lower contributions in this process. Furthermore, the results in Table 4 reveal higher estimated value of beta parameters (the share of production inputs) for the input 'water' in estimating the production function of crops with higher water requirement (sugar beet, sunflower, canola, and tomato) whereas the estimated value of this parameter for irrigation water was the lowest (0.002 and 0.005, respectively) for the irrigated wheat and barley that are crops with lower water requirement.

**Table 4.** The share of inputs in the production of the selected crops in the Qazvin plain in the base year

| Selected crops | Input use for crop production | | | | |
|---|---|---|---|---|---|
| | Land | Water | Capital | Labor | Machinery |
| Irrigated wheat | 0.997 | 0.002 | 0.003 | 0.009 | 0.002 |
| Irrigated barley | 0.994 | 0.005 | 0.006 | 0.002 | 0.006 |
| Grain corn | 0.959 | 0.038 | 0.003 | 0.001 | 0.005 |
| Tomato | 0.944 | 0.050 | 0.004 | 0.001 | 0.003 |
| Sugar beet | 0.492 | 0.646 | 0.037 | 0.006 | 0.002 |
| Sunflower | 0.785 | 0.194 | 0.016 | 0.003 | 0.001 |
| Canola | 0.820 | 0.163 | 0.011 | 0.005 | 0.001 |

**Table 5.** Estimation of $\alpha_i$ and $\gamma_i$ parameters of the quadratic cost function for the input 'land' for the selected crops in the Qazvin plain in the base year

| Selected crops | Estimated parameters of the quadratic cost function | |
|---|---|---|
| | $\alpha_i$ | $\gamma_i$ |
| Irrigated wheat | -32.838 | 1.719 |
| Irrigated barley | -15.814 | 1.969 |
| Grain corn | -72.387 | 19.71 |
| Tomato | -65.126 | 20.64 |
| Sugar beet | -6.654 | 47.95 |
| Sunflower | -70.647 | 63.46 |
| Canola | -59.188 | 49.62 |

Table 6 shows the amount and percentage of the variations of acreage and economic value of irrigation water after applying the impacts of drought arising from the constraint on irrigation water supply in the Qazvin plain over the base year. It can be observed that as water availability is decreased and water supply is restricted due to drought with various intensities (different scenarios), the acreages of crops with higher water requirement, i.e. grain corn, tomato, sugar beet, sunflower, and canola, are decreased versus the base year, but the acreages of irrigated wheat and barley, which require less water, are increased. So, the scenarios of 10-50 percent reduction of water availability resulted in 0.28-2.08, 0.42-3.06, 10.8-69.5, 1.69-11.7, and 1.54-10.8 percent lower acreage of grain corn, tomato, sugar beet, sunflower, and canola and 0.32-2.19 and 0.38-2.56 percent higher acreage of irrigated wheat and barley versus the base year, respectively. In total, Table 6 reveals that the reduction of the acreages for crops with higher water requirement and farmers' more tendency to produce grains with lower water requirements are among the main consequences of drought in the Qazvin plain. In other words, farmers in this plain tend to reduce the planting area of crops with high water demand and increase the planting area of crops with lower water requirement (irrigated wheat and barley). In addition, the results of the PMP model indicate that when drought happens in the study area and the available water resources to farmers are decreased, the economic (real) value of water per m$^3$ is increased versus the base year (the status quo). The results in Table 6 show that the economic value of irrigation water is 1,152 IRR/m$^3$ in the base year, which increases by 12.2-94.1 percent to 1293-2236 IRR/m$^3$ under the scenarios of water limitation by 10-50 percent. Overall, the increase in the economic value of irrigation water is another consequence of drought in the study area. So, it is of crucial importance to consider the conservation and sustainability of the existing water resources in the region and to cope with the possible impacts of drought.

Figure 2 depicts the irrigation water demand function for farmers in the Qazvin plain based on the variations of the economic value of water due to drought and the loss of water availability under different scenarios in 2013-2014. According to the estimated demand function for farmers in the Qazvin plain (Figure 2), the economic value of irrigation water is increased (decreased) versus the base year with the decrease (increase) in the availability of water resources. This economic concept (irrigation water demand function) reflects the establishment of demand rule in the water resources sector and shows the reverse relationship between the amount of water availability and its economic value (real price). In addition, lower slope of the estimated curve of demand in the right-hand and lower part of Figure 2 and its higher slope in the left-hand and upper part of the figure implies that when irrigation water is priced at lower levels (lower estimated value), farmers demand more irrigation water, whereas when it is priced at higher levels (higher estimated value), farmers' demand for irrigation water declines as they reduce the acreage of the selected crops or they do not change their demand for water by preserving crops with lower water requirements, such as irrigated wheat and barley (and sometimes increasing their acreages) and reducing the acreage of crops with higher water requirements, such as sugar beet, tomato, and grain corn.

**Table 6.** Impact of drought arising from water supply shortage on the acreage of the selected crops and the economic value of water in the Qazvin plain

| Selected crops | Base year cropping pattern* | Variations | Limited supply of water due to lower water availability | | | | |
|---|---|---|---|---|---|---|---|
| | | | 10% | 20% | 30% | 40% | 50% |
| Irrigated wheat | 56825 | Amount | 57008 | 57215 | 57453 | 57733 | 58070 |
| | | Percent | 0.32 | 0.68 | 1.10 | 1.59 | 2.19 |
| Irrigated barley | 32400 | Amount | 32524 | 32663 | 32822 | 33008 | 3323 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Percent | 0.38 | 0.81 | 1.30 | 1.87 | 2.56 |
| Grain corn | 9380 | Amount | 9353 | 9322 | 9286 | 9241 | 9185 |
| | | Percent | -0.28 | -0.61 | -1.01 | -1.48 | -2.07 |
| Tomato | 8760 | Amount | 8723 | 8680 | 8629 | 8568 | 8492 |
| | | Percent | -0.42 | -0.91 | -1.49 | -2.18 | -3.06 |
| Sugar beet | 1327 | Amount | 1184 | 1024 | 845 | 641 | 405 |
| | | Percent | -10.8 | -22.8 | -36.3 | -51.6 | -69.5 |
| Sunflower | 2920 | Amount | 2871 | 2814 | 2749 | 2672 | 2578 |
| | | Percent | -1.69 | -3.62 | -5.86 | -8.50 | -11.7 |
| Canola | 3203 | Amount | 3153 | 3097 | 3031 | 2952 | 2857 |
| | | Percent | -1.54 | -3.32 | -5.38 | -7.82 | -10.8 |
| Water value** | 1152 | Amount | 1293 | 1472 | 1699 | 2003 | 2236 |
| | | Percent | 12.2 | 27.8 | 47.0 | 73.8 | 94.1 |

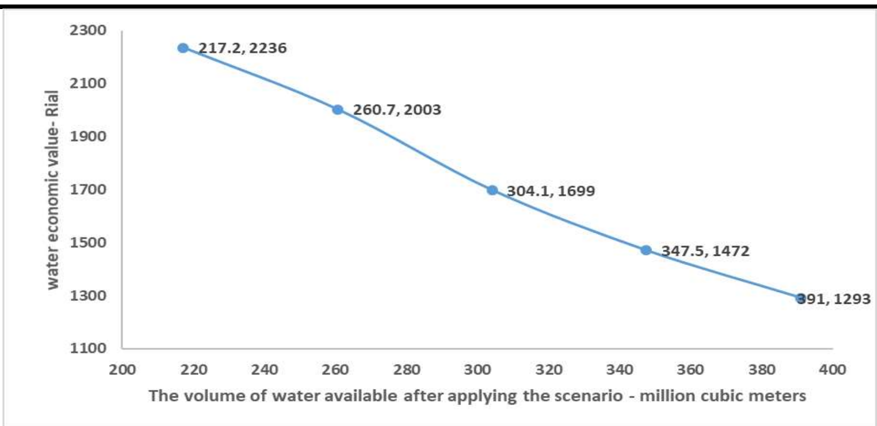


**Fig. 2.** An estimation of the water economic value function under drought conditions in the Qazvin plain

Table 7 shows the impacts of drought arising from limited water supply on farmer gross margin per unit area of the selected crops in the Qazvin plain over the base year 2013. It is evident that when drought happens due to the limited supply of irrigation water and the decline of water availability to farmers by 10-50 percent, not only does the acreage of the selected crops change, but farmer gross margin also falls down. The variations of gross margin are greater for crops with higher water demand and higher production costs (including sugar beet, tomato, and grain corn), but they are negligible for crops with lower water demand and lower production costs (irrigated wheat and barley).

## 3. 4. Conclusion

Given the importance of water for the agricultural sector of the studied region, the following recommendations can be drawn from the results:

1. Determining the economic value of irrigation water across the region and accepting a reasonable price as water price by farmers can lead to a considerable saving of this scarce input in the region. So, it is recommended to price irrigation water in accordance with its economic value and the consideration of its equivalence.

**Table 7.** Impact of drought arising from water supply shortage on farmer gross margin per unit area of selected crops in the Qazvin plain in the base year

| Selected crops | Base year gross margin* | Variations | Limited supply of water due to lower water availability | | | | |
|---|---|---|---|---|---|---|---|
| | | | 10% | 20% | 30% | 40% | 50% |
| Irrigated wheat | 14.510 | Amount | 14.512 | 14.513 | 14.514 | 14.515 | 14.517 |
| | | Percent | 0.008 | 0.016 | 0.025 | 0.034 | 0.044 |
| Irrigated barley | 12.868 | Amount | 12.870 | 12.872 | 12.874 | 12.876 | 12.879 |
| | | Percent | 0.016 | 0.032 | 0.050 | 0.068 | 0.088 |
| Grain corn | 19.576 | Amount | 19.588 | 19.601 | 19.614 | 19.628 | 19.643 |
| | | Percent | 0.061 | 0.125 | 0.193 | 0.264 | 0.340 |
| Tomato | 19.574 | Amount | 19.589 | 19.605 | 19.623 | 19.641 | 19.660 |
| | | Percent | 0.079 | 0.162 | 0.249 | 0.341 | 0.441 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sugar beet | 18.933 | Amount | 19.106 | 19.287 | 19.478 | 19.682 | 19.901 |
| | | Percent | 0.912 | 1.871 | 2.879 | 3.952 | 5.109 |
| Sunflower | 21.791 | Amount | 21.848 | 21.907 | 21.971 | 22.038 | 22.113 |
| | | Percent | 0.260 | 0.535 | 0.825 | 1.134 | 1.470 |
| Canola | 19.907 | Amount | 19.951 | 19.998 | 20.047 | 20.100 | 20.157 |
| | | Percent | 0.223 | 0.458 | 0.706 | 0.971 | 1.258 |
| Water value** | 174937.3 | Amount | 174383.6 | 173784.3 | 173097.4 | 172296.5 | 171340.1 |
| | | Percent | -0.317 | -0.659 | -1.052 | -1.510 | -2.056 |

2. Since drought causes the loss of gross margin for farmers in the Qazvin plain, it is recommended to the government and officials of the agricultural sector to compensate for the loss of farmers in drought period by providing them with financial helps and facilities such as crop insurance and the implementation of guaranteed purchase policy for the selected crops (except for grains).
3. If farmers are well informed of the programs for saving water use prior to the occurrence of drought, they can adjust their contingency plans for the reduction of water use. Undoubtedly, reducing water use can reduce farmers' gross return in the plain. This reduction of gross return is maximized when the costs of coping with the drought and production costs are maximal. So, timely informing of farmers before drought and holding training courses about methods to counteract the negative consequences of this climatic phenomenon by governmental agencies, such as Jihad-e Agriculture Organization and research and educational centers, can be helpful in supporting farmers and officials in their attempts to cope with the consequences of drought.
4. Temporarily increasing irrigation water price paid by farmers under drought conditions is another managerial approach to reduce water use at the farm level and alleviate the wastage of the limited water resources. Experience in the region shows that this type of temporary water price increase (i.e. temporarily increasing water price until the end of drought period) is more acceptable and understandable by farmers because this policy is implemented only in emergency and farmers are not concerned about the increased tariff of water by water suppliers to compensate their lost income of the drought period.

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