Official Journal of the World Water Council
Water Policy

Water Policy Vol 24 No 7, 1095 doi: 10.2166/wp.2022.248

Irrigation water demand management with emphasis on pricing policy

Simin Mohseni[a], Mohammad Reza Zare Mehrjerdi [a,*], Mohammad Abdolahi Ezzatabadi[b] and Hossein Mehrabi Boshrabadi[a]

[a] Department of Agricultural Economics, Shahid Bahonar University of Kerman, Kerman, Iran
[b] Pistachio Research Center, Horticultural Sciences Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Rafsanjan, Iran
*Corresponding author. E-mail: zare@uk.ac.ir

MRZ, 0000-0003-4292-9988

ABSTRACT

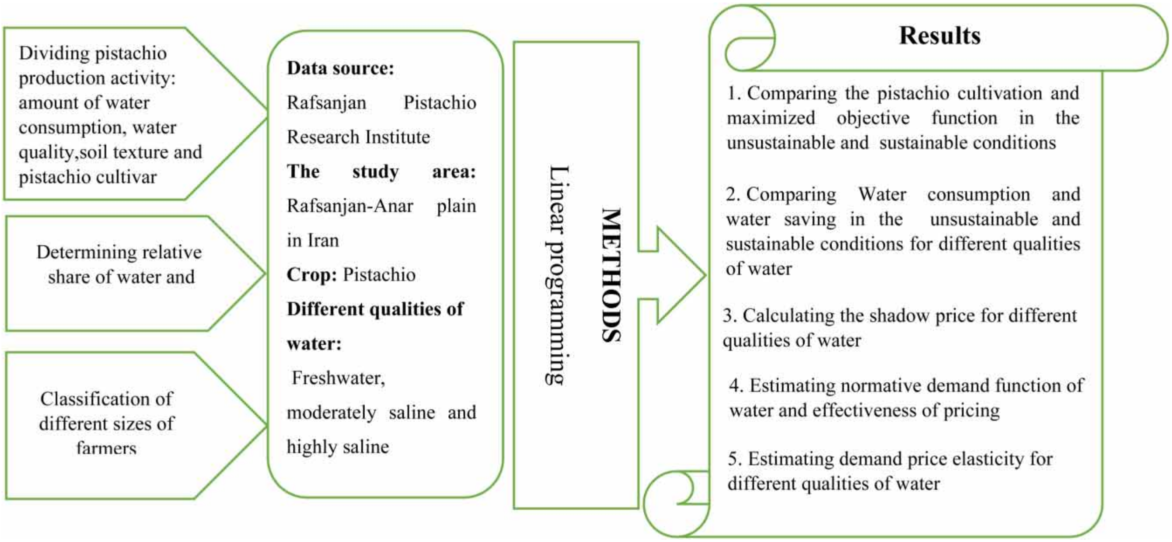
Serious constraints in increasing water supply have led countries around the world to seek solutions for managing water demand. Proper pricing of water is one of the foremost water demand management policies which can lead to the optimal water use. On the flip side, the quality of agricultural water is declining due to the uncontrolled abstraction of groundwater. In this regard, the present study aims to determine the economic value of different qualities of water throughout pistachio-growing regions of the Rafsanjan-Anar plain in Iran. Results reveal that the economic value and price elasticity of water demand differ among different groups. Freshwater, moderately saline water and highly saline water have the highest to lowest elasticity and shadow price, respectively. Additionally, comparison of the gross margin, which represents the profit from each activity, in two conditions including the unsustainable status quo and sustainable conditions intended by the Ministry of Energy, shows that although water use has declined by 50%, the gross margin has decreased by only 36%. This implies it is feasible to reduce water use in pistachio orchards by water re-allocation with a minimum decline in profit, which will both reduce water use and ensure high economic benefits for farmers.

Key words: Demand price elasticity, Irrigation water management, Pistachio, Water pricing, Water quality

HIGHLIGHTS

- The decline of water quality in many parts of the world has made water resource management a critical policy.
- In our study, different pricing policies are proposed for different water qualities so as to manage the demand for irrigation water.
- The water pricing policy will be accomplished successfully if it is intended to reduce the consumption of high-quality water resources.

GRAPHICAL ABSTRACT



INTRODUCTION

Nowadays, water and food supply are among the basic needs of human societies, although improving living standards and protecting the environment are also of great significance. In addition to increasing population growth, factors such as the deterioration of natural resources, unplanned abstraction of groundwater resources, expansion of saline lands and contamination of surface and groundwater resources have intensified the water and soil resource limitations (Nazemi, 2000).

Declining water quality and expanded awareness of water-related natural and social issues clarify why water resource administration has turned into a basic approach issue in numerous parts of the world (Tsur, 2004, 2005).

Management of water demand is one of the key issues in the management and utilization of water resources, in addition to its supply organization. This is of great importance because poor irrigation water management gives rise to a noteworthy increase in water demand and wastage of this scarce resource. There are various tools for implementing water demand management policies, including the re-allocation of water resources, improving the infrastructure, introducing the water market and pricing of water in the agricultural sector (Dinar *et al.*, 1997; Chakravorty & Zilberman, 2000; Gomez-Limon & Riesgo, 2004) which could work for distributing water among demandants commensurate with the benefit or value of the final product and could motivate users to conserve water (Easter *et al.*, 1999; Cortignani & Severini, 2009; Medellín-Azuara *et al.*, 2012; Dinar *et al.*, 2015; Bierkens *et al.*, 2019; Sapino *et al.*, 2020). Low water price may increase water consumption and encourage wasteful use, depriving other farmers and consumers. Conversely, if the price of water exceeds the output value of the crop, farmers tend to no longer exploit it; such a price for water negates the objectives of agricultural growth and increment in the income of farmers (Easter *et al.*, 1999; Bierkens *et al.*, 2019). Therefore, it is imperative that water users consider the actual cost of water when deciding on water demand and allocation of water between different activities. ‘An obvious way to achieve this is to charge water users the “right” price of water’ (Tsur, 2004, 2005). The pricing policies in managing water resources can promote its conservancy and sustainability, and water consumption will be optimized among consumers if the price of water resources is determined by considering the net value of water and the cost of its supply (Rogers *et al.*, 2002).

Water pricing is considered an effective and significant economic tool for achieving more efficient water use, in which users are made aware that water is a resource that can be scarce and that protecting water quality and ensuring water availability have their own costs (Dinar & Mody, 2004; Chebil *et al.*, 2010; Bogaert, 2012). Moreover, knowing the economic value of water and its price elasticity could help policymakers design water policies that promote more efficient use of this scarce resource (Vásquez-Lavín *et al.*, 2020).

Given the importance of using pricing tools to achieve a balance in the use of water resources, the present study evaluated the possibility of using this tool to achieve sustainable development. In this regard, this possibility should be investigated so carefully because a major problem in water management is that water prices are socially constructed to a large extent, rather than being based on the principles of efficient water pricing that reflect resource scarcity. In many areas, water resource management is highly political and increasing water prices tends to be a sensitive and complicated policy matter (Olmstead, 2010; Kejser, 2016).

Considering the importance of water pricing in achieving sustainable development, as well as the various political, social and economic consequences of this issue, the present study attempted to estimate a general perspective into the volume of water price changes to achieve the desired goals of the Ministry of Energy. Such estimation helps policymakers and planners to be more careful in selecting the appropriate tools and policies for achieving their goals.

Studies in developing countries suggest that water pricing is helpful in demand management policies to control the consumption of water resources (Ahmad *et al.*, 2017). Water users in these countries pay for only 29% of total cost and the main objectives of the pricing system are to develop equality in water distribution and efficiency in irrigation (Seagraves & Easter, 1983). Moreover, a number of studies in India demonstrate that the appropriate electricity tariff policy and electricity replacement with direct benefit transfer to farmers could help maintain the income without overexploiting water resources (Fosli *et al.*, 2021; Parween *et al.*, 2021). Also, the treatment of water resources and its services, and property rights have a significant impact on pricing and costs, including service, resources and environment, which are difficult to recover (Shen & Reddy, 2016).

Due to the climatic conditions of the Rafsanjan-Anar plain and the low quality and quantity of water in the region and the impossibility of economic cultivation of other crops, the predominant product of this plain is pistachio and pistachio cultivation in this region has economic and logical justification. One of the limitations of the paper is the small scope of product selection. Also, due to the fact that this plain is a single product, we could not expand the scope to overcome this limitation in linear programming. We divided pistachio production into several activities which included the amount of water consumption in different ranges, water quality in different ranges, soil texture and pistachio cultivar to be able to use the linear programming model.

Pistachio is one of the main export commodities in Iran and constitutes 71% of the export value of farming products, 47% of the export value of the agricultural sector and 11% of non-oil export. This product, which earns more than $900,000,000 for the country (Clearance, 2019; FAO, 2019), is mainly produced in Rafsanjan and Anar, Kerman Province, Iran, with a cultivated area of more than 100,000 ha. The shares of these cities in terms of the fertile cultivated area for pistachio are 24, 34 and 60% in the world, Iran and Kerman Province, respectively (Iran Agricultural Statistics, 2021).

Pistachio is a drought-tolerant and profitable product; therefore, it is considered as the final agricultural option in many parts of Iran and the world. In other words, pistachio cultivation becomes popular when there is no possibility for growing any other products, economically and technically. Even when the water quality is low and drainage depth is high, profit gained from planting pistachio exceeds the cost of water extraction. Thus, destruction of water resources is indispensable. In the past, pistachio was planted in a limited number of regions in Iran and the globe. However, due to the reduced water quality and quantity as well as lack of cost-effectiveness in terms of producing other agricultural products, pistachio is currently cultivated in 27 of 31 provinces of Iran (Iran Agricultural Statistics, 2021). In the USA, there was no export of pistachio until 1981; however, it has transformed into the leading pistachio exporter in the world at present. Moreover, pistachio cultivation has been expanded in numerous countries such as, China, Turkey, Syria, Greece, Italy, Afghanistan, Tunisia, Spain, India, Turkmenistan, Uzbekistan, Chile, etc. (FAO, 2020). Although the current study is done in a small geographical area, its results could be used in the areas that enjoy an appropriate climate for pistachio cultivation.

As stated, many studies have been carried out on water pricing; nevertheless, different pricing policies have been suggested in a few studies for different qualities of water. In the current study, different prices are proposed for different water quality levels (fresh water, moderately saline water and highly saline water), recruiting a mathematical programming method and considering four electrical conductivity (EC) constraints, the amount of water consumption, soil texture and the type of pistachio. (It is worth noting that the measurement of EC of water was conducted in the Rafsanjan Pistachio Research Institute.)

The rest of this paper is organized as follows. First, we calculated the pistachio cultivation optimal model and maximized objective function in the current unsustainable and the desired sustainable conditions. Next, we estimated water shadow prices for different qualities of water. Afterwards, we assessed the ability to pay for water to different size classes of farmers. Then, to examine the effectiveness of pricing, we estimated the water normative demand function and demand price elasticity. Afterwards, data and empirical results were analyzed. The last section is devoted to the conclusion and recommendations.

STUDY SITE

Iran, with an area of 1,648,195 km^2 and a population of 80 million people, is located in the Middle East in the southwest of Asia. This country is divided into 31 provinces of which Kerman in the southeast is the largest, covering an area of 183,285 km^2. The Rafsanjan-Anar plain is located in the north of Kerman province. Due to the warm and dry climatic conditions as well as low quality and quantity of water, pistachio is the only agricultural crop that is presently cultivated in this plain. Kerman province is the world's largest producer of pistachio with an average of 129 mm annual amount of water, and more than 212,000 ha of pistachio (Iran Agricultural Statistics, 2021). In addition, the Rafsanjan-Anar plain is one of the most prominent areas of pistachio cultivation, known as the cradle of pistachio. Figure 1 shows the location of the study area.

Although increasing the cultivated area of pistachio in Iran has boosted economic growth, exports and currency import, it has triggered some instability in the abstraction of water resources, in such a way that the unsustainable use of water resources has resulted in reducing water quality in the region in addition to the drop in the groundwater table. The minimum and maximum salinity levels in the Rafsanjan-Anar plain are 1,100 and 19,000 μmho/cm, respectively (Iranian Pistachio Research Center, 2019). According to the data reported by Kerman province Regional Water Company, 540 million m^3 of water is currently abstracted from underground aquifers in the Rafsanjan-Anar plain. However, the annual water withdrawal equilibrium in this plain is 270 million m^3/year based on the reports of the same company. In other words, it is necessary to reduce water exploitation from the agricultural wells of the region by half to have sustainable water withdrawal of these resources. In this regard, the Ministry of Energy designed a scheme called Water Equilibrium Scheme, in which the withdrawal of these resources should achieve a sustainable level at the end of the project.

METHODS

In this study, the optimal cultivation model and shadow prices for different qualities of water were calculated using the linear programming method. Moreover, by plotting the normative water demand function, the rate of increase in water prices was calculated to achieve a sustainable withdrawal of water resources in the study area.

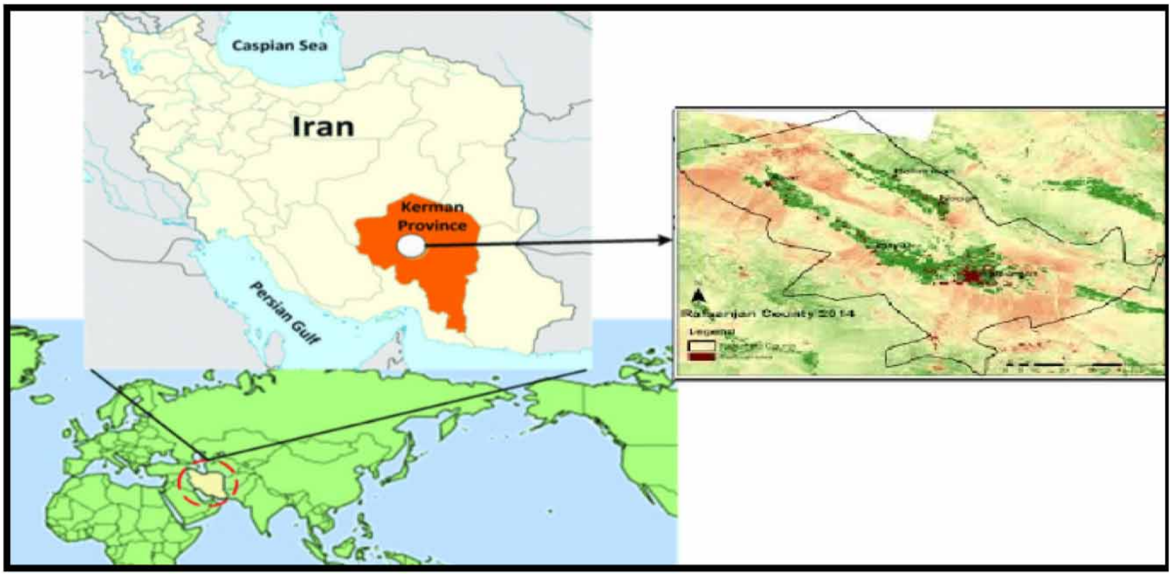


Fig. 1 | The location of the study area.

The methodology was based on the mathematical programming technique in which profits from agricultural production are maximized under conditions constrained by the availability of water and land. Gross margin represents the profit from each activity (Rial/ha) which is calculated by multiplying the price of the product by its yield minus variable costs other than the cost of water supply. The mathematical forms of the objective function with maximizing gross margin and constraints are provided as follows:

$$\max\ Z = \sum (\pi_{ijkv} - PI_{ijkv})X_{ijkv} \qquad i = 1, 2, 3 \quad j = 1, 2, 3 \quad k = 1, 2 \quad v = 1, 2 \tag{1}$$

$$s.\ t.$$
$$\sum I_{ijkv}X_{ijkv} \leq b_i$$
$$\sum X_{ijkv} \leq b_k$$
$$\sum X_{ijkv} \leq b_v$$
$$X_{ijkv} \geq 0$$

To calculate the annual amount of water per hectare of pistachio orchards, the number of orchard irrigation hours per year was multiplied by the well discharge rate and number 3.6. The calculated value was estimated in m^3/ha/year. The net profit per hectare was calculated after deducing all production costs from income. The income was calculated according to pistachio yield (kg/ha) and the pistachio price (Rial). Since Ahmad Aghaei, Akbari, Kaleh Quchi and Ohadi are currently being produced in the region, these four pistachio cultivars were used in the present work. Based on the statistical results obtained at the Pistachio Research Institute, two cultivars of Ahmad Aghaei and Akbari were placed in one group and two cultivars of Kaleh Quchi and Ohadi were placed in the second group. To estimate the normative demand function of water, the water costs were separated from other production costs, as presented in Table 1. The soil texture of pistachio orchards was divided into three groups including light, medium and heavy. Due to the similar yield, pistachio orchards with light

Table 1 | Definitions of variables.

Variables	Explanation	Variables	Explanation
z	Total gross margin (Rial[a])	j	Water consumption (m^3/ha/year)
π_{ijkv}	The profit from one hectare of each activity before deducting the cost of water (Rial)	K	Pistachio cultivar
P	The cost of pumping water (Rial/m^3)	V	Soil texture
I_{ijkv}	Water consumption per activity (m^3/ha)	b_i	Maximum available water with different salinities
X_{ijkv}	The cultivated area of each activity (ha)	b_k	The maximum cultivated acreage of different cultivars (Ahmad Aghaei, Akbari, Kaleh Quchi and Ohadi)
i	Water salinity (µmho/cm)	b_v	The maximum cultivated area of gardens with light, medium and heavy soil textures

[a]Rials is the currency of Iran (1 USD=240,000 Rials).

and medium soils were classified in one group and heavy soil texture was placed in another due to its significantly lower yield. Finally, according to Pistachio Research Institute's recommendations, water quality was divided into three EC groups of less than 8,000; 8,000–12,000 and more than 12,000 µmho/cm. Also, water consumption was divided into three groups of less than 6,000; 6,000–12,000 and more than 12,000 m^3/ha. Accordingly, we examined 36 activities.

DATA REQUIREMENT

The required data included the amount of inputs used in pistachio production per hectare (cultivated area, labor (person/day), machinery (h), animal manure (kg), fertilizer (kg), pesticide (l) and water (m^3)), their cost (Rial/m^3), pistachio yield (kg/ha) and pistachio price (Rial). In total, 286 pistachio farmers in the Rafsanjan-Anar plain were randomly selected to complete a questionnaire by the Rafsanjan Pistachio Research Institute during the crop year 2018–2019. Excel software was used to estimate the models.

RESULTS AND DISCUSSION

As mentioned earlier, 36 variables are applied in the current study; the variables and some of their features are demonstrated in Table 2.

According to the results in Table 2, 69.8% of water used by farmers is obtained from fresh water (EC $<$ 8,000), 20.3% from fairly saline water (8,000 $<$ EC $<$ 12,000) and 9.9% from extremely saline water. Based on another classification, 35.3% of consumed water is used for Akbari and Ahmad Aghaei cultivars and 64.7% for Kale Quchi and Ohadi cultivars. Water share is the same for the currently stable and unstable conditions. In fact, as long as water's shadow price is higher than the water price, there would be no change in water consumption share for different activities. As shown in Table 3, the pistachio cultivation optimal model and maximized objective function was compared in the currently unsustainable and desired sustainable conditions of the Ministry of Energy.

Results of the pistachio cultivation optimal model in the currently unstable conditions are as follows: 3,270 ha x_{1111}; 41,057 ha x_{1121}; 28,215 ha x_{2212}; 6,100 ha x_{3221} and 4,515 ha x_{3312}. Also, results of pistachio cultivation optimal model in stable conditions are as follows: 3,270 ha x_{1111}; 18,731 ha x_{1121}; 14,108 ha x_{2212}; 3,050 ha x_{3221} and 18,622 ha x_{3312}. Here, x_{1111} indicates the under-cultivation area with EC of less than 8,000 µmho/cm, water consumption of less than 6,000 m^3/ha, as well as Akbari and Ahmad Aghaei cultivars,

Table 2 | Variables and relevant features.

Variables	Water quality	Water consumption (m^3/ha)	Pistachio cultivar	Soil texture	Relative share of water (%)	Average yield (kg/ha)
x_{1111}	EC<8,000	<6,000	Akbari and Ahmad Aghaei	Light and medium	3.7	824
x_{1112}	EC<8,000	<6,000	Akbari and Ahmad Aghaei	Heavy	0.7	253
x_{1121}	EC<8,000	<6,000	Kaleh Quchi and Ohadi	Light and medium	4.2	624
x_{1122}	EC<8,000	<6,000	Kaleh Quchi and Ohadi	Heavy	0.9	561
x_{1211}	EC<8,000	6,000–12,000	Akbari and Ahmad Aghaei	Light and medium	8.4	627
x_{1212}	EC<8,000	6,000–12,000	Akbari and Ahmad Aghaei	Heavy	1.7	543
x_{1221}	EC<8,000	6,000–12,000	Kaleh Quchi and Ohadi	Light and medium	16.1	645
x_{1222}	EC<8,000	6,000–12,000	Kaleh Quchi and Ohadi	Heavy	4.9	594
x_{1311}	EC<8,000	>12,000	Akbari and Ahmad Aghaei	Light and medium	8.2	1,356
x_{1312}	EC<8,000	>12,000	Akbari and Ahmad Aghaei	Heavy	1.4	539
x_{1321}	EC<8,000	>12,000	Kaleh Quchi and Ohadi	Light and medium	12.4	1,100
x_{1322}	EC<8,000	>12,000	Kaleh Quchi and Ohadi	Heavy	7.2	461
x_{2111}	8,000<EC<12,000	<6,000	Akbari and Ahmad Aghaei	Light and medium	0.1	324
x_{2112}	8,000<EC<12,000	<6,000	Akbari and Ahmad Aghaei	Heavy	0.1	267
x_{2121}	8,000<EC<12,000	<6,000	Kaleh Quchi and Ohadi	Light and medium	0.2	324
x_{2122}	8,000<EC<12,000	<6,000	Kaleh Quchi and Ohadi	Heavy	0.1	194
x_{2211}	8,000<EC<12,000	6,000–12,000	Akbari and Ahmad Aghaei	Light and medium	0.8	589
x_{2212}	8,000<EC<12,000	6,000–12,000	Akbari and Ahmad Aghaei	Heavy	1	1,802
x_{2221}	8,000<EC<12,000	6,000–12,000	Kaleh Quchi and Ohadi	Light and medium	1.9	467
x_{2222}	8,000<EC<12,000	6,000–12,000	Kaleh Quchi and Ohadi	Heavy	0.8	139
x_{2311}	8,000<EC<12,000	>12,000	Akbari and Ahmad Aghaei	Light and medium	3.9	1,040
x_{2312}	8,000<EC<12,000	>12,000	Akbari and Ahmad Aghaei	Heavy	1.6	1,140
x_{2321}	8,000<EC<12,000	>12,000	Kaleh Quchi and Ohadi	Light and medium	8.4	866

(*Continued.*)

Table 2 | Continued

Variables	Water quality	Water consumption (m^3/ha)	Pistachio cultivar	Soil texture	Relative share of water (%)	Average yield (kg/ha)
x_{2322}	8,000<EC<12,000	>12,000	Kaleh Quchi and Ohadi	Heavy	1.4	1,680
x_{3111}	EC>12,000	<6,000	Akbari and Ahmad Aghaei	light and medium	0.3	326
x_{3112}	EC>12,000	<6,000	Akbari and Ahmad Aghaei	heavy	0.1	326
x_{3121}	EC>12,000	<6,000	Kaleh Quchi and Ohadi	Light and medium	0.2	326
x_{3122}	EC>12,000	<6,000	Kaleh Quchi and Ohadi	Heavy	0.4	290
x_{3211}	EC>12,000	6,000–12,000	Akbari and Ahmad Aghaei	Light and medium	1.9	807
x_{3212}	EC>12,000	6,000–12,000	Akbari and Ahmad Aghaei	Heavy	0.2	286
x_{3221}	EC>12,000	6,000–12,000	Kaleh Quchi and Ohadi	Light and medium	4.2	852
x_{3222}	EC>12,000	6,000–12,000	Kaleh Quchi and Ohadi	Heavy	0.2	286
x_{3311}	EC>12,000	>12,000	Akbari and Ahmad Aghaei	Light and medium	1.1	1,021
x_{3312}	EC>12,000	>12,000	Akbari and Ahmad Aghaei	Heavy	0.1	750
x_{3321}	EC>12,000	>12,000	Kaleh Quchi and Ohadi	Light and medium	1.1	357
x_{3322}	EC>12,000	>12,000	Kaleh Quchi and Ohadi	Heavy	0.1	286

Table 3 | Comparing the pistachio cultivation and maximized objective function in the currently unsustainable and desired sustainable conditions.

Activity	x_{1111} (ha)	x_{1121} (ha)	x_{2212} (ha)	x_{3221} (ha)	x_{3312} (ha)	Maximized objective function (Rial)
Unsustainable conditions	3,270	41,057	28,215	6,100	4,515	111,155,277,881,759
Sustainable conditions	3,270	18,731	14,108	3,050	18,622	71,087,912,253,267

and light and medium soil texture. x_{1121} represents the under-cultivation area with EC of less than 8,000 μmho/cm, water consumption of less than 6,000 m^3/ha ,Kaleh Quchi and Ohadi cultivars as well as light and medium soil texture. x_{2212} designates the under-cultivation area with EC of 8,000–12,000 μmho/cm, water consumption of 6,000–12,000 m^3/ha, Akbari and Ahmad Aghaei cultivars as well as heavy soil texture. x_{3221} exhibits the under-cultivation area with EC of more than 12,000 μmho/cm, water consumption of 6,000–12,000 m^3/ha, Kaleh Quchi and Ohadi cultivars as well as light and medium soil textures. Subsequently, x_{3312} shows the under-cultivation area with the EC of greater than 12,000 μmho/cm, water consumption of more than 12,000 m^3/ha, Akbari and Ahmad Aghaei cultivars as well as heavy soil texture.

Due to the unsustainable water abstraction from underground aquifers in the pistachio-producing areas of Iran, especially in Kerman province, the Iranian government has decided to implement a water equilibrium plan in these areas. Since about 95% of the water abstracted from underground aquifers is used in the Rafsanjan-Anar plain in Kerman province, this study aimed to investigate the feasibility of implementing the water equilibrium plan and its consequences in this area, employing linear programming and water pricing policy. With respect to the objectives of this plan, the amount of water withdrawal from underground resources in these two counties should be reduced from the annual rate of 540–270 million m^3/year.

Comparing the maximized objective function (gross margin) in both current and equilibrium conditions indicated that the optimal objective value only decreased by 36% although water consumption decreased by 50%, indicating that water consumption can be decreased by re-allocating water in pistachio orchards with the minimum reduction in activity efficiency, which is possible by removing low-quality orchards and retaining high-yield pistachio orchards. This will both reduce water consumption and abstraction and ensure high economic benefits for farmers. Therefore, we will achieve the following two goals: first, sustainable water level (we will achieve from unsustainable water use to sustainable water use) and second, optimal allocation of water resources.

After determining the optimal cultivation model and maximized objective function, water consumption was calculated in two conditions. First, the current water consumption was determined, and second, the amount of water consumption in the equilibrium plan proposed by the Ministry of Energy was calculated. Then, the amount of water saving was determined by considering these two cases in the linear programming model. The results are presented in Table 4.

The current unsustainable water consumption was 200,000,000 m^3 for $EC < 8{,}000$; 281,248,000 m^3 for $8{,}000 < EC < 12{,}000$ and 58,752,000 m^3 for $EC > 12{,}000$. In addition, sustainable water consumption in the equilibrium plan of the Ministry of Energy was 100,000,000 m^3 for $EC < 8{,}000$; 140,624,000 m^3 for $8{,}000 < EC < 12{,}000$ and 29,376,000 m^3 for $EC > 12{,}000$.

The amount of water saving in the optimal model of equilibrium plan of Ministry of Energy compared to the optimal model of current water consumption was 100,000,000 m^3 for $EC < 8{,}000$, which was equal to 140,624,000 m^3 and 29,376,000 m^3 for $8{,}000 < EC < 12{,}000$ and $EC > 12{,}000$, respectively.

The shadow price (economic value) of water represents the rate of profit change among the farmers in the region per one unit of increase in the amount of available water resources. The results of water shadow price for different qualities of water are displayed in Table 5.

As shown in Table 5, the shadow price was IRR 161,851 for $EC < 8{,}000$; IRR 148,269 for $8{,}000 < EC < 12{,}000$ and IRR 103,213 for $EC > 12{,}000$. Furthermore, the freshwater produced the highest economic value for pistachio orchards. The next ranks in the economic value were for moderately saline and highly saline water, respectively. Considering the available data in the questionnaire, pistachio farms are divided into three groups in terms of cultivated area; the associated information is given in Table 6.

Table 4 | Water consumption and water saving in two cases of unsustainable conditions of water resource withdrawal and sustainable equilibrium model of the Ministry of Energy.

	Water consumption (m^3)		
Water saving (m^3)	**Desired sustainable conditions in the Ministry of Energy**	**Current unsustainable conditions**	**Constraints**
100,000,000	100,000,000	200,000,000	$EC < 8{,}000$
140,624,000	140,624,000	281,248,000	$8{,}000 < EC < 12{,}000$
29,376,000	29,376,000	58,752,000	$EC > 12{,}000$

Table 5 | Water shadow price (Rial/m^3).

Water shadow price	Constraints
161,851	EC $<$ 8,000
148,269	8,000 $<$ EC $<$ 12,000
103,213	EC$>$12,000

Table 6 | Classification of different sizes of farmers and their characteristics.

	Different size class of farmers		
	Less than 5 ha	Between 5 and 10 ha	More than 10 ha
Relative share of cultivated area (%)	19	41	40
Average pistachio crop yield (kg/ha)	577	750	770
Average water consumption (m^3/ha)	10,153	9,916	10,511
Gross profit (Rial/ha)	534,654,942	481,347,746	802,341,295
Profit per cubic meter of water (Rial)	52,660	48,543	76,333
Water shadow price (Rial/m^3)	52,660	48,543	76,333

Results of Table 6 proved that no matter how big the farm is, water's shadow price equals the profit per m^3 of water. In other words at the proposed prices to reduce water demand up to the balanced level, farmers are still able to pay for different levels of the garden; therefore, it is practically feasible to execute the pricing policy.

Estimating normative demand function of water and effectiveness of pricing

A normative demand function was estimated to determine a proper price that could effectively reduce water demand. Figure 2 shows the statistical results for the water normative demand for the three qualities of water (freshwater, moderately saline water and highly saline water) and their total.

As Figure 2 illustrates, rising water prices reduce the amount of water demand. Based on the results, the price of 1 m^3 of water should increase to 150,270 IRR/m^3 to reduce the water demand rate from the current rate (540 million m^3/year) to the equilibrium plan of Ministry of Energy (270 million m^3/year). In addition, the cost of water withdrawal, i.e., the maximum amount of money paid by farmers for water under the current conditions, is only 2,000 IRR/m^3. In other words, the price of water should increase by 75 times that of the current cost of water withdrawal in the region to achieve sustainable equilibrium in the region, only through implementing economic methods and increasing price.

Demand price elasticity

The price elasticity of demand for water with different qualities shows that when the water price is increased from IRR 2,000 to 105,213 the amount of water use does not change and the elasticity is zero for highly saline water (EC$>$12,000). Since poor quality water has a low price, 1% increase in its price has no impact on reducing water consumption. Furthermore, since this water has a low price, on the one hand, and its higher consumption has no significant effect on increasing yield, on the other hand, a further decrease in its price will not motivate its further consumption. In other words, the demand for low-quality water does not

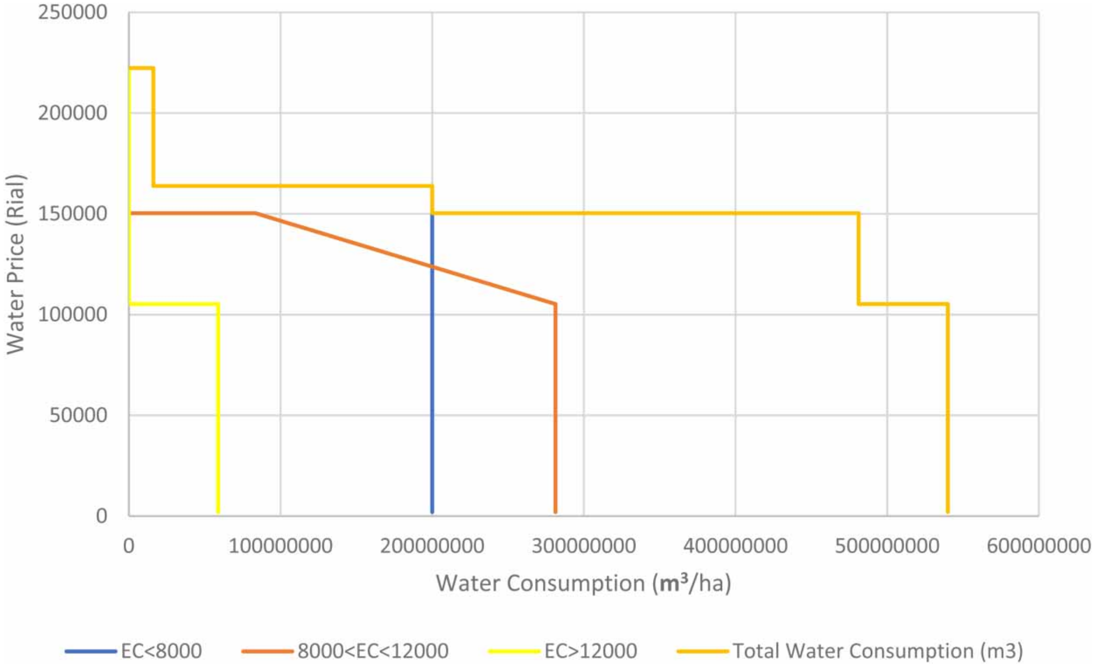


Fig. 2 | Water normative demand with the optimal model in current water consumption (540,000,000 m^3/ha).

depend on its price and is dependent on other factors, e.g., pistachio cultivar, orchard management, soil quality and so on.

At 8,000 < EC < 12,000, the elasticity is −2.4. When the water price is increased from 2,000 to 150,269 IRR, the amount of water use decreases from 281,248,000 to 83,376,000 m^3. This implies low elasticity of the water demand function. In other words, farmers do not merely respond to water price increase with less water consumption; rather, their response might be in the form of water re-allocation or a change in the cropping pattern.

Elasticity is −11.52 for water with EC < 8,000 and farmers are more responsive to an increase in the freshwater price so that when it is increased from IRR 2,000 to 222,379, the amount of water decreases from 200,000,000 to 16,104,750 m^3.

Eventually, elasticity is highest for the total of water with different qualities. One percent increase in the price results in reducing the demand by 32.83%. Since high-quality water is more expensive, it will be of higher price elasticity. On the contrary, low-quality water has lower price elasticity; hence, the total of water which is composed of different water qualities has higher elasticity.

CONCLUSIONS

This study aimed to manage irrigation water demand by emphasizing water pricing policy for its various qualities. In this regard, the economic value for each cubic meter of freshwater, moderately saline water and highly saline water was estimated as IRR 161,851; 148,269 and 103,213, respectively, which was much higher than the amount of water that farmers paid for in the Rafsanjan-Anar plain IRR 2,000/m^3 of water, revealing the great difference between the economic and market values of water input. Therefore, in order to improve and sustain the agricultural production system, it is suggested to form motivating forces for saving and properly using water among farmers via adjusting water-rate based on its economic value. Given the gap between the real prices and the agricultural water-rate in the short term, this policy may cause dissatisfaction among farmers and can negatively affect their incentive to produce crops, but in the long run, the gradual increase in the price of water bears more optimal social and economic effects, aiming to balance the benefits and costs of implementing this policy. Also, the price elasticities of the water input demand for freshwater, moderately saline water and highly saline water were −11.52, −2.4 and 0, respectively, hence the demand for moderately and highly saline water.

As a result, the sustainable exploitation of water resources in the region cannot be achieved using solely water pricing tools. In addition to pricing tools, it is necessary to employ other methods such as law enforcement and prohibition of users, recommendation methods, public participation and so forth. Also, the results revealed that the water pricing policy will be well accomplished if it is intended to reduce the consumption of high-quality water resources by the agricultural sector and allocate them to the drinking and industrial sectors. In contrast, if it is intended to protect the water and soil resources and accomplish sustainable development, this policy will fail because price increase will direct farmers towards low-quality water resources and will aggravate the degradation of water and soil resources. In other words, coordination should be made between consumption of water resources reduction and water conservation policies to ensure sustainable development.

Since it is not possible to suddenly increase the water price or set immediate limitations on water usage up to 50% of the current consumption, which may cause socio-economic consequences, it is recommended to execute the policies in several steps. In the first step, if there are no proper water user associations, they should be formed in different regions and employed to encourage farmers to implement the recommended policies. In the second step, minimum water share and, consequently, the minimum cultivated area which could provide the required income should be determined considering the minimum living expenditure per rural family. Afterwards, the farmers with the whole ownership of different agricultural wells less than the minimum expenditure cost should be determined. In the third step, the farmers who encounter subsistence and economic problems after executing pricing policies and restricting water consumption should be led towards non-agricultural jobs and the government should support them. In the fourth step, the optimal economic level of pistachio farms should be determined considering the amount of equitable water and pistachio farms which should be removed are technically specified. In the fifth and final steps, water price should increase (up to the extent that leads to reducing water consumption to the equilibrium level). Furthermore, the number of permits issued for water exploitation wells should be reduced to achieve the equilibrium level.

ACKNOWLEDGMENT

We thank the Rafsanjan Pistachio Research Institute for helping us with the data, particularly the questionnaires.

FUNDING

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Ahmad, S., Ali, S. H., Mirza, M. U. & Lotia, H. (2017). The limits of water pricing in a developing country metropolis: empirical lessons from an industrial city of Pakistan. *Water 9*(7), 533.

Bierkens, M. F. P., Reinhard, S., Bruijn, J. A., Veninga, W. & Wada, Y. (2019). The shadow price of irrigation water in major groundwater depleting countries. *Water Resources Research*. https://doi.org/10.1029/2018WR023086.

Bogaert, S. (2012). *The Role of Water Pricing and Water Allocation in Agriculture in Delivering Sustainable Water use in Europe*. ARCADIS Belgium, European Commission, Project Number 11589.

Chakravorty, U. & Zilberman, D. (2000). Introduction to the special issue on: management of water resources for agriculture. *Agricultural Economics 24*, 3–7. https://doi.org/10.1111/j.1574-0862.2000.tb00088.x.

Chebil, A., Frija, A. & Thabet, C. (2010). Irrigation water pricing between governmental policies and farmers' perception: implications for green-houses horticultural production in Teboulba (Tunisia). *Agricultural Economics Review 11*(2), 44–54.

Clearance, Official Broker of the Customs of the Islamic Republic of Iran (2019). Available at: http://www.tarkhisline.com/% D8 %AA%D8 %B1 %D8 %AE%DB%8C%D8 %B5-%DA%A9 %D8 %A7 %D9 %84 %D8 %A7/%D9 %BE%D8 %B3 % D8 %AA%D9 %87 (accessed 18 January 2022).

Cortignani, R. & Severini, S. (2009). Modeling farm-level adoption deficit irrigation using positive mathematical programming. *Agricultural Water Management 96*(1), 1785–1791.

Dinar, A. & Mody, J. (2004). Irrigation water management policies: allocation and pricing principles and implementation experience. *Natural Resources Forum 28*(2), 112–122.

Dinar, A., Rosegrant, M. W. & Meinzen-Dick, R. (1997). Water allocation mechanisms-Principles and examples. *Policy Research*, Working Pap. WPS 1779, World Bank, Washington, D.C.

Dinar, A., Pochat, V. & Albiac-Murillo, J. (2015). Water pricing experiences and innovations. *Journal of Economic Literature 53*(4), 1040–1043.

Easter, K. W., Rosegratant, M. W. & Dinar, A. (1999). Formal and informal markets for water: institutions, performance, and constraints. *The World Bank Research Observer 14*(1), 99–116. https://doi.org/10.1093/wbro/14.1.99.

Food and Agriculture Organization (2019). Available at: https://www.fao.org/faostat/en/#compare (accessed 17 January 2022).

Food and Agriculture Organization (2020). Available at: https://www.fao.org/faostat/en/#compare (accessed 17 January 2022).

Fosli, J. K., Reddy, A. A. & Rani, R. (2021). The policy of free electricity to agriculture sector: implications and perspectives of the stakeholders in India. *Journal of Development Policy and Practice 6*(2), 252–269.

Gomez-Limon, J. A. & Riesgo, L. (2004). Water pricing: analysis of differential impacts on heterogeneous farmers. *Water Resources Research 40*, W07S05. doi:10.1029/2003WR002205.

Iran Agricultural Statistics (2021). Available at: https://www.maj.ir/Dorsapax/userfiles/Sub65/Amarnamehj3-1399-sh.pdf (accessed 17 January 2022).

Iranian Pistachio Research Center (2019). Rafsanjan, Kerman, Iran. Available at: https://pri.ir (accessed 15 June 2019).

Kejser, A. (2016). European attitudes to water pricing: internalizing environmental and resource costs. *Journal of Environmental Management 183*(3), 453–459.

Medellín-Azuara, J., Howitt, R. E. & Harou, J. J. (2012). Predicting farmer responses to water pricing, rationing and subsidies assuming profit maximizing investment in irrigation technology. *Agricultural Water Management 108*, 73–82. https://doi.org/10.1016/j.agwat.2011.12.017.

Nazemi, A. H. (2000). Water resources in Iran, problems and plans. In *Proceeding of International Conference on Sustainable Development of Water Resources: Water Resource Sector in the Coming Decades*, Delhi, India, pp. 10–19.

Olmstead, S. (2010). The economics of managing scarce water resources. *Review of Environmental Economics and Policy 4*(2), 179–198.

Parween, F., Kumari, P. & Singh, A. (2021). Irrigation water pricing policies and water resources management. *Water Policy 23*(1), 130–141. https://doi.org/10.2166/wp.2020.147.

Rogers, P., Silva, R. D. & Bhatia, R. (2002). Water is an economic good: how to use prices to promote equity, efficiency, and sustainability. *Water Policy 4*, 1–17.

Sapino, F., Perez-Blancoa, C. D., Gutierrez-Martínb, C. & Frontutoc, V. (2020). An ensemble experiment of mathematical programming models to assess socio-economic effects of agricultural water pricing reform in the Piedmont Region, Italy. *Journal of Environmental Management 267*, 110645. 1–13.

Seagraves, J. A. & Easter, K. W. (1983). Pricing irrigation water in developing countries. *Water Resource Bulletin 19*(4), 663–672.

Shen, D. & Reddy, V. R. (2016). Water pricing in China and India: a comparative analysis. *Water Policy 18*(S1), 103–121.

Tsur, Y. (2004). Introduction to special section on irrigation water pricing. *Water Resources Research 40*, W07S01. doi:10.1029/2003WR002213.

Tsur, Y. (2005). Economic aspects of irrigation water pricing. *Canadian Water Resources Journal 30*(1), 31–46. doi:10.4296/cwrj300131.

Vásquez-Lavín, F., Vargas, O. L., Hernández, J. I. & Ponce Oliva, R. D. (2020). Water demand in the Chilean manufacturing industry: analysis of the economic value of water and demand elasticities. *Water Resources and Economics 32*, 100159. https://doi.org/10.1016/j.wre.2020.100159.

First received 22 October 2021; accepted in revised form 28 April 2022. Available online 18 May 2022