Asia Pacific Academy of Science Pte. Ltd.

Advances in Modern Agriculture 2025, 6(1), 3098.
https://doi.org/10.54517/ama3098

Article

Proposed water valuation scheme for a more sustainable agricultural water productivity

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CITATION

Peyghan K, Raja O, Parsinejad M, Karandish F. Proposed water valuation scheme for a more sustainable agricultural water productivity. Advances in Modern Agriculture. 2025; 6(1): 3098. https://doi.org/10.54517/ama3098

ARTICLE INFO

Received: 26 November 2024
Accepted: 8 January 2025
Available online: 14 January 2025

Abstract: Growing depletion of groundwater resources is a global threat and intensified under improper water valuation systems. Here, we proposed an irrigation water valuation framework based on the opportunity cost concept (IWVF), to better differentiate the value of surface water, renewable, and nonrenewable groundwater. In this study, a 10-years dataset was used in Marvdasht-Kharameh irrigation networks (MKINs) in southern Iran, where groundwater depletion overshoots the sustainable level with an annual average rate of 1.42 m y^{-1}. Irrigation water use, net incomes and losses, and economic water productivities (EWP) were estimated under the common and newly developed valuation methods. The reflections of adopting IWVF on EWPs were assessed under current condition and the proposed WP improvement scenarios, including removing irrigation efficiency gaps, changing the cropping calendar, and application of different levels of deficit irrigation. Results showed that the value of irrigation water supply ($436.91 million) exceeds gross income through crop production ($139.01 million) under current condition, which results in a net loss of $297.9 million in the study area. Hence, economic WP loss will be −0.33 $ m^{-3}, meaning that consuming a unit of blue water causes $0.33 income loss under current condition. Applying WP improvement scenarios can reduce value of irrigation water by 27%, and gross income by 5.3%. Accordingly, common WP can increase by 6.6% from 1.81 to 1.93 kg m^{-3}. However, the negative sign of EWP loss under management scenarios (−0.22 $ m^{-3}) indicates that crop production in the study area is not viable due to its considerable environmental damages. Hence, current irrigation system should be revisited when sustainable agriculture is considered. The proposed water valuation method can help decision makers to better assess the consequences of WP improvement strategies, if the true value of different water resources is ignored.

Keywords: nonrenewable groundwater resources; opportunity cost; irrigation water valuation; environmental deterioration; economic water productivity

1. Introduction

In most countries, the agricultural sector is the main user of freshwater resources [1]. In semi-arid and arid regions, like Iran, with increasing area under cultivation, decreasing rainfall, continuation of recent droughts and, most importantly, scarcity or severe decrease in surface runoff has led to uncontrolled overexploitation of groundwater resources as an auxiliary source for agricultural water supply [2,3]. These factors have resulted in a sharp decline in both surface and groundwater resources in most plains of Iran [4–6]. Decreased water levels in groundwater are followed by problems such as drying of wells, reduced flow of rivers, reduced water quality, increased pumping costs, deterioration of soils, and land subsidence [7–11]. These limitations have all contributed to reduced crop production [12–14].

While agricultural development has a key role in fulfilling food security for ever-increasing world population, it should, however, be both environmentally and economically sustainable. With the growing limitations on availability of water, more attentions are paid on improving water productivity, i.e., more crop per drop of water. Numerous definitions have been provided for agricultural water productivity, namely amount of agricultural production per unit volume or value of water used, consumed, depleted or diverted. The crop production can also be expressed in different terms (biomass, cash crop, or nutritional values of product per unit of water [15]. Many management schemes, such as deficit irrigation, fertigation, changes in planting date, optimizing irrigation scheduling, and conservation tillage, have variously contributed to higher and more stable water productivity [16–19]. Inasmuch as attentions are paid to improve the efficiency and productivity of the amount of water used, realizing the value of water based on the abstracted sources is often ignored. While water is the most precious natural resource, particular attention must be paid to valuing water in to assess alternative management and policy options when the availability and sustainability of water are at risk. Indeed, the valuation of water is a proper strategy to reduce water loss; however, estimating the real value of water is difficult. there are two main reasons for the lack of transparency in the value of water; first, benefits arise from services or goods for which there is no specific market or market prices; second, values vary in space and time. On the other hand, since farmers do not pay an impartial fare for water, therefore, the cost of agricultural productions often ignore the cost of water being used. As a result, the amount of water being used is not of their main concern [20,21]. In Iran, the asking price for irrigation water does not have a significant effect on the water tariff system. To address this problem, there is a need for proper valuation of water [22]. Reasons beyond inefficient allocation of irrigation water can provide guidelines to improve the economic performance of irrigated production [23]. To this end, economic efficiency of water should be differentiated from technical irrigation efficiency [24].

With growing water scarcity, water pricing mechanisms are increasingly proposed to improve management and allocation of water [25]. But no consensus exists among experts on how to price water. The water pricing methods are often based on the physical, social context. Nevertheless, as more real pricing of water is gradually replacing the previously free or underpriced systems, it can lead to a more rational economic value of water for decision-making and accounting strategies.

Volumetric pricing, for example, requires accurate measurement of water use. World Bank recommends volumetric pricing for efficient use of irrigation water, based on opportunity costs [26]. Otherwise, water can be priced by flow rate or as commonly practiced by a fixed charge based on land area, or crop production. The latter charging methods are easy to administer and more feasible in continuous flow irrigation systems [27].

Opportunity costs are defined as the waived benefits from alternative uses of water resources. Agricultural water demands often compete with water rights to preserve sustainability of ecosystems. For which, opportunity costs are hard to measure and to base for water rationing. “Getting prices right” is important [28]. However, experiences suggest that allocation mechanisms should be designed with pricing irrigation water and with careful consideration of physical and political background [27].

Many studies have tried to address the importance of valuing (not pricing) of water. For example, Eldeeb and Zelenakova [29] assessed the economic value of irrigation water based on self-sufficiency of main crops in Sharqiya province of Egypt. They evaluated wheat, cotton, and rice products with the peak economic value of 1.23 EGP[1] m^{-3}, 0.98 EGP m^{-3}, and 0.41 EGP m^{-3}, respectively. Ren et al. [30] conducted research on the valuation and pricing of agricultural irrigation water based on space scaling in Heilongjiang province, the main grain-producing region in China. According to the results, the water price of the macro-agricultural irrigation was priced at 1.023 Yuan[2] m^{-3}, and the micro-agricultural irrigation water prices for surface water and groundwater ranged from 0.993 to 1.008 Yuan m^{-3} and from 2.343 to 2.358 Yuan m^{-3}, respectively. Even though they differentiated between price for surface and groundwater, they stated that the current agricultural irrigation water price does not reflect the true value of water source. Al-Karablieh et al. [31] used the Residual Imputation Method (RIM) to determine the average economic value of irrigation water in Jordan. Crop production gross income became the basis for calculating the value of water. Their results indicated that the weighted average of water value was 0.44 JD[3]/m^{-3} for field crops, 1.23 JD m^{-3} for vegetable crops and 0.23 JD m^{-3} for fruit trees. Among orchards, banana with 0.79 JD m^{-3} had the highest water value. Therefore, the decision from some farmers in using Reverse Osmosis units to desalinize water and use it for irrigation of bananas was still economically justified, because the value of water productivity was still twice as much as the cost of desalination. Bierkens et al. [32] determined the shadow price of irrigation water for some groundwater-depleting countries and for five crops during 2006 to 2010. They defined the shadow price of water as reflecting the value of products that can be produced by the marginal unit of water supply given the number of other inputs. For Iran, they calculated shadow price of irrigation water for wheat, maize, rice, potato, and citrus were 0.041, 0.258, 0.014, 0.034, and 0.162 \$ m^{-3}, respectively.

Opportunity cost, a key concept in economics, is defined as the foregone benefit of options not chosen. Opportunity costs of resource depletion and degradation, known as marginal opportunity cost (MOC), are an important and useful tool for conceptualizing and measuring the physical effects of resource depletion and degradation in economic terms. The opportunity cost approach has been widely used in water related research [33–36]. Neglecting opportunity costs in decision-making can have consequences such as ignoring the best alternatives and misallocation of resources [37].

Based on the concept of opportunity cost, we developed a new method for estimating real value of water being used in the agricultural sector while distinguishing between different types of water resources. While many earlier researches ignored such distinguishments, we showed that consuming groundwater in agriculture has a higher opportunity cost than surface water and a unit volume of depleted nonrenewable groundwater can only be valued based on the cost of replacing the water from alternate sources. Hence, valuing different sources of water in the same way misleads policy and decision makers to go on the wrong track. In this regard, we used our developed water valuation conceptual framework to estimate real economic water productivity of different crops, and then compared them with those estimated based on the common method to show the actual gaps between real and apparent values.

2. Materials and methods

We built upon the earlier study carried out by Raja et al. [4] on alternate irrigation management to improve water productivity in Marvdasht-Kharameh in southern Iran (**Figure 1**). In this region, local groundwater resources have increasingly depleted in the last two decades at an average rate of 142 cm per year, equivalent to 96.33 million cubic meters. Hence, Raja et al. [4] estimated water productivity of the main crops cultivated in the study area and then, introduced practical and low-cost scenarios for improving agricultural water productivity through reducing water consumption. Their proposed pathways included removing irrigation efficiency gaps, changing the cropping calendar, and application of different levels of deficit irrigation. In other words, the water-saving strategies with the minimal additional expense were suggested so that they do not affect the livelihoods of farmers. The results of their study showed that by adopting the management scenarios, crop water productivity can improve from 1.81 kg m^{-3} to 1.93 kg m^{-3}. The analysis is adopted based on the amount of crop production and total volume of water being used for crop production irrespective of the source. However, such common assumption of similar values for water regardless of the source is plausible and needs further examination. More detailed information could be found in Raja et al. [4].

In this study, we proposed a method for estimating the value of irrigation water to distinguish between different types of water resources. We used this framework for estimating real economic water productivity of different crops, and then compared the calculated values with those reported by Raja et al. [4]. The concept of opportunity cost (OC) was adopted when developing our water valuation framework. OC is defined as the value of a resource in its best alternative use, i.e., other than the purpose currently being considered. In most studies, the OC of groundwater resources is often ignored, as they are treated as an open-access resource. In addition, OC can be assigned to nonrenewable water resources (overdraft from the aquifers), based on the availability and cost of future substitutes. Expensive alternatives, such as transfer of desalinized seawater, can be proposed to compensate for replacement of the highly valuable and crucial nonrenewable water used. The challenge in irrigated agriculture is to govern that farmer consider opportunity costs of the type of water into cost-benefit analysis of water being used, which are often much higher than current charges.

2.1. Study area

The Marvdasht-Kharameh irrigation networks are located in southern Iran with an area of 3941 km^2 in the center of the of Bakhtegan-Maharloo basin (**Figure 1**). There are two irrigation and drainage networks, including Dorodzan (with 64,000 ha in the northern area), and Korbal (with 48,000 ha in the southern area) networks.

In the study area, irrigation water is supplied conjunctively from both surface and groundwater resources. Over the period 2006–2016, data on the volume of abstracted water for irrigation from surface water, renewable and non-renewable groundwater resources were collected (**Table 1**). The Surface water was allocated from the Dorodzan dam to the downstream area of the irrigation network, and was then supplemented by groundwater for irrigation (deep and semi-deep wells, springs, and aqueducts). Information on the amounts of water used from different sources were obtained from local official sources [38]. The amount of excessive groundwater extracted (nonrenewable) was determined as the change in the volume of aquifer (ΔV) based on the average drops of the water table (Δh), aquifer storage coefficient (S_y), and using the following (**Table 1**):

$$\Delta V = \Delta h \times S_y \times A \quad (1)$$

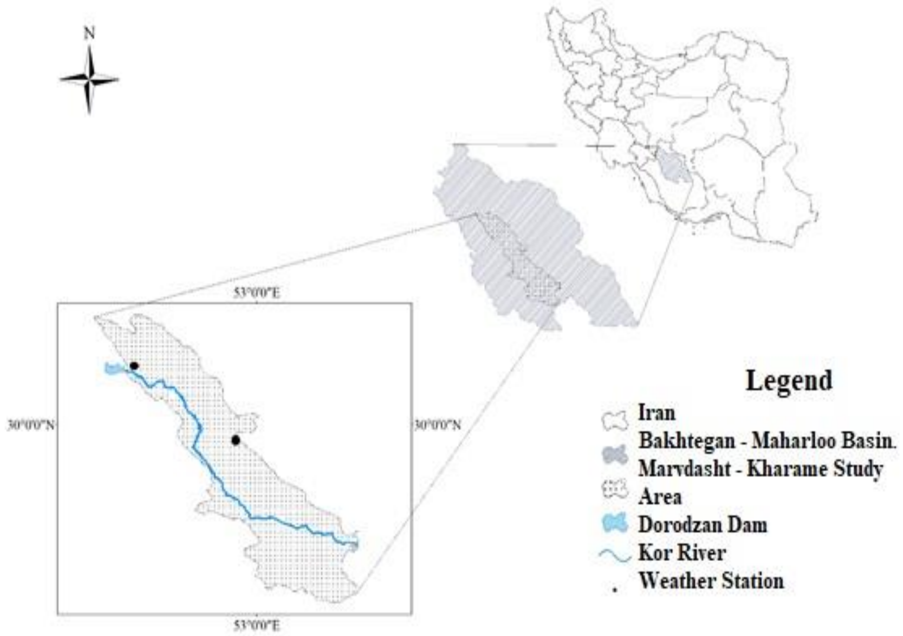

Figure 1. Location of Marvdasht-Kharameh study area in Bakhtegan-Maharloo basin.

Table 1. Surface and groundwater supplied for irrigation in Dorodzan network.

Water supply (million m^3)			Groundwater overdraft (million m^3)
Groundwater	**Surface water**	**Total**	
750	424	1174	96.33

The cropping pattern in Dorodzan irrigation network is presented in **Figure 2**. Alternate field management scenarios namely different levels of deficit irrigation, change in cropping calendar and removing irrigation efficiency gaps were examined to improve crop water productivity. More information on water saving scenarios, can be obtained from reference [39]. The results of adopted scenarios are briefly explained in **Table 2**.

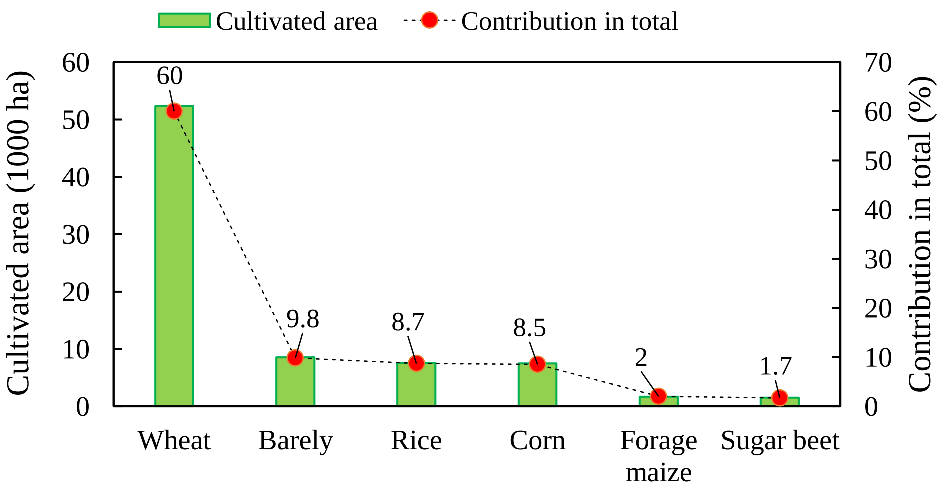

Figure 2. Cropping pattern Dorodzan network.

Table 2. Impact of management scenarios on water savings in the Dorodzan region [39].

Scenario		Description	Water saving (million m^3)
1)	Removing irrigation efficiency gaps	The higher existing irrigation efficiency was selected from observed measures was selected as the achievable efficiency in the region for similar irrigation systems. The resulted water saving, from improved irrigation efficiency scenario, was estimated for each of the major crops.	131.6
2)	Change in cropping calendar	Changing the planting dates for each crop can lead to a shorter growing period and increased effective rainfall quota, and result in reduced irrigation water requirement during the growing season. The planting date was changed in such a way that consecutive winter and spring crops' growing seasons would not overlap. The water saving was calculated based on the selecting the optimum planting date for major crops in Dorodzan region.	32.1
3)	Deficit irrigation	Water savings for major crops in Dorodzan region were examined for deficit irrigation scenarios by reducing percentage of irrigation depths (IRR80, IRR60 and, IRR40) and increasing days of irrigation intervals (F9, F12, F15, F20, F25, and F30).	91.5

2.2. Economic analysis

Surface water resources are often available seasonally and are subject to evaporation and runoff losses. The groundwater resources, on the other hand, are securely stored underground and can be extracted on demand basis throughout the year. They can even be restored for being used in the years to come. Groundwater, therefore, has a higher opportunity value. On the contrary, if excessive groundwater is overexploited, negative consequences should be expected such as reduced water supply due to aquifer depletion, increased groundwater pumping costs, and additional expenses on well deepening or replacement. When groundwater exploitation goes beyond sustainable cap or at a point that cannot be naturally replaced, then the water supply is termed as "nonrenewable groundwater resource", having significantly higher opportunity costs. Hence, we tried to consider such differences when developing our new irrigation water valuation framework.

All calculation were done for the current situation and under different management scenarios (**Table 2**). In this study, we used the price of crop products for calculating economic productivity [40]. Considering the price of water supply, the net income was calculated as follows:

$$Net\ Income\ (\$) = \ Crop\ Production\ Gross\ Income\ - Price\ of\ Water\ Supply \quad (2)$$

The economic productivity (EP) of each crop is calculated by considering the amount of water supplied using the following equation [29]:

$$EP = \frac{Crop\ Price\ (\$/ton) \times Crop\ Production\ (\frac{ton}{ha})}{Supplied\ Water\ (m^3/ha)} \quad (3)$$

The proportion of water used, for different crops, from surface, groundwater and nonrenewable sources, were assumed to be as the proportion of these resources used in the entire plain. Namely, 36.1% of water were supplied from surface, 55.7% from ground and 8.2% of nonrenewable resources (**Table 1**).

Water productivity was, then, reevaluated, by modifying the value of different water resources as follows:

Surface water valuation: Since water demand of wheat is entirely supplied from surface water resources, the value of surface water was determined based on wheat's economic productivity using the available water allocated through the irrigation network, Hence, the real price of a unit of irrigation water being used from surface water resources is considered 0.17 $\$\ m^{-3}$.

Renewable groundwater valuation: the value of groundwater is assumed to equal to the highest economic productivity among all crops, including longer growing season crops that cannot be fully irrigated and sustained unless groundwater is used. Hence, the real price of a unit of irrigation water being used from renewable groundwater resources is considered 0.52 $\$\ m^{-3}$.

Nonrenewable groundwater valuation: the opportunity cost of nonrenewable groundwater resources could be equal to the most environmentally damaging and economically expensive alternatives for supplying water demands, such as inter-basin water transfer or transfer of desalinized seawater. In Iran, Persian Gulf Water Desalination and Transfer project (PGP) is a very expensive project which is adopted to supply water demand in water scarce regions; where improper agriculture is the main source of the emerged water shortage for the other water consumers (i.e., domestic, industry, and environment). Indeed, modifying cropping systems and managements in these regions could save large amount of blue water and consequently, stop adopting such an environmentally damaging project [41]. Hence, we considered the opportunity cost of nonrenewable groundwater resources to be equal to the cost of desalination and transfer of one cubic meter of water from the most feasible port in the Persian Gulf (Siraf) to the Dorodzan dam (**Figure 3**).

In this regard, the available cost analysis of water desalination for the PGP in Bandar Abbas and its transfer to Gol Gohar Company is used as a reference here. In this project, desalinated water is transferred with a flow rate of 4 $m^3\ s^{-1}$ to a distance of 300 km [42]. The reverse osmosis method was used to desalinate the seawater to 1.5 dS. m^{-1}, for drinking purposes. The cost of water desalination and transfer was reported to be 1.01 $\$\ m^{-3}$, and 0.45 $\$\ m^{-3}$, respectively. To accommodate the needs of the present study, the transfer cost was increased by 20% for a longer distance of 360 km. The desalination costs for irrigation purpose can be adjusted for a higher target salinity based on crop's salinity tolerance thresholds. Although different crops have different salinity tolerance, it is not practicable to desalinate water at different EC[4] levels. Therefore, a common target EC_w was defined for desalinating water for agricultural use. This target must be set to the salinity threshold of the most sensitive crop. Based on these adjustments, the total cost of desalination and water transfer were determined as 1.55 \$ m^{-3} [42]. The proposed route for water transfer pipeline is presented in **Figure 3**.

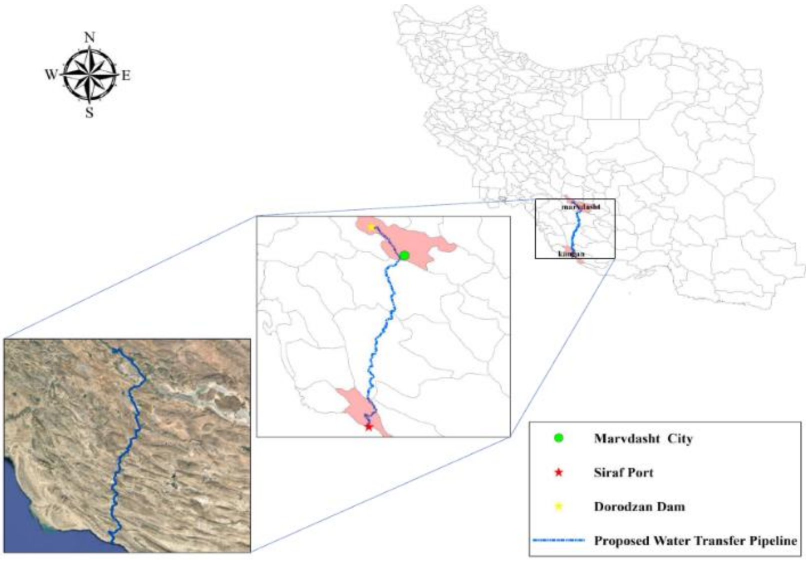

Figure 3. The proposed water transfer pipeline.

Using the real value of water for crop production is not economically viable. The cost of water supply is much higher than the gross income from crop production. However, the value of saved water by adopting management scenarios will compensate for some of the loss. In this study, we are suggesting that the higher income from the most "economically" productive crop can be analogous to opportunity cost as calculated in the following equations:

$$\text{Net income (\$)} = \text{Crop Production Gross Income} - \text{Value of Water Supply} \tag{4}$$

$$\text{OP} = \text{Net income After Applying Management Scenario} - \text{Net income in Current situation (\$)} \tag{5}$$

3. Results

3.1. Original water productivity

The results of reference studies [4,39,43] showed that management scenarios, such as changing planting dates, removing irrigation efficiency gaps and applying different levels of deficit-irrigation for major crops, can reduce irrigation requirements by about 91.5 million m^3 (**Table 3**). In addition, the weighted average water productivity in the entire network, which was calculated based on the harvested area of individual crops, increased by 6.6%, from 1.81 kg m^{-3} to 1.93 kg m^{-3}, when adopting proposed water-saving scenarios. It is assumed that such increase in water productivity is mainly due to the lowered water use and can eventually amount to reduced abstraction from nonrenewable water resources.

Table 3. Water savings and water productivity for different crops in Dorodzan region.

Crop	Water savings (million m^3)	WP (Kg m^{-3})	
		Current situation	After applying management scenarios
Wheat	46.60	1.36	1.92
Barley	8.63	1.17	1.58
Forage maize	11.34	3.62	4.52
Corn	2.62	1.03	1.49
Sugar beet	2.80	2.08	2.26
Rice	19.50	2.16	2.65
Entire plain	91.50	1.81	1.93

3.2. Economic productivity of crops

Original gross production income for individual crops was calculated, for the current situation and after applying the management scenarios, and results are summarized in **Figure 4**. The results indicate that gross income in current situation and after applying the management scenarios did not change significantly. While adopting management scenarios resulted in noticeable water saving and in a higher water productivity, it did not positively affect crop's gross income. This is mainly due to crop's yield reduction under deficit irrigation scenarios. Overall, crop's gross income is reduced from $139.01 million under current situation, to $133.73 million after applying management scenarios, which shows a decrease of $5.28 million (3.79%).

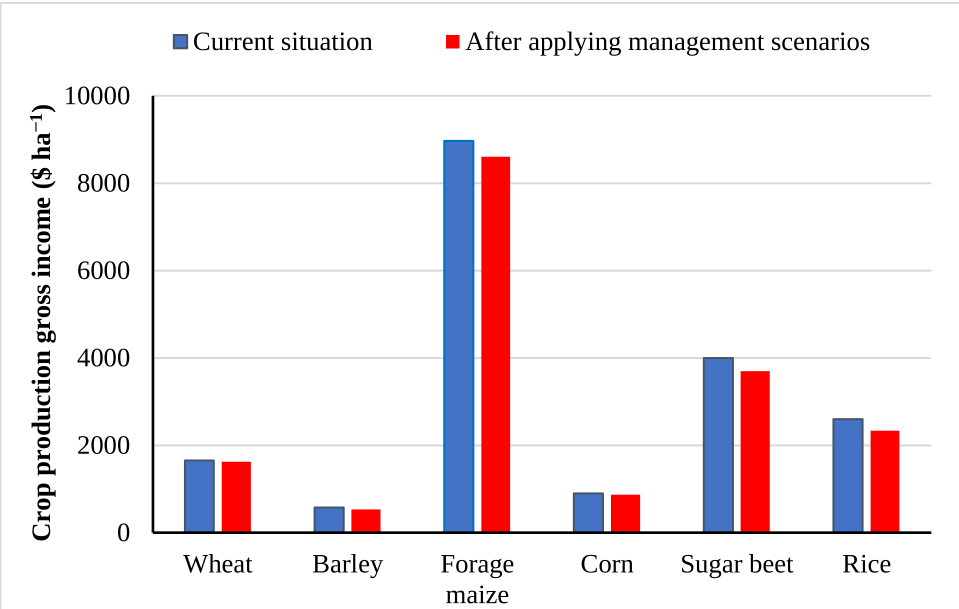

Figure 4. Production gross income for each crop and for the entire plain in current situation and after applying management scenarios.

The net income was then calculated for each crop and for the entire study area under current situation and after applying management scenarios considering the existing common water price, rather than those estimated based on our newly developed framework (**Table 4**). Forage maize and barley persistently had maximum and minimum production net income. The crop production net income for the entire plain in the current situation was calculated as $134.84 million, while it will decrease to $129.72 million after applying management scenarios. The reason of such reduction is that after applying management scenarios, the gross income for entire plain has decreased by $5.8 million, and the price of water supply has decreased from $4.17 million to $4.01 million ($0.16 million). In fact, due to the low price of water, saving water consumption has not significantly reduced production costs.

Table 4. Production net income for each crop and for the entire plain in current situation and after applying management scenarios (considering common water price).

Crop	Crop production net income ($ ha^{-1})			
	Current situation		**After applying management scenarios**	
	The price of water supply ($ ha^{-1})	**Net income ($ ha^{-1})**	**The price of water supply ($ ha^{-1})**	**Net income ($ ha^{-1})**
Wheat	49.60	1603.85	48.65	1573.01
Barley	17.30	559.29	16.00	517.34
Forage maize	269.00	8697.80	258.24	8349.89
Corn	26.90	869.78	26.00	840.79
Sugar beet	119.92	3877.40	110.93	3586.60
Rice	77.88	2518.10	70.09	2266.69
Entire plain ($ million)	134.84		129.72	

Economic productivity for all crops was also calculated in the current situation and after applying management scenarios (**Figure 5**). In current conditions, economic productivity ranged from 0.06 $ m^{-3} for barley to 0.52 $ m^{-3} for forage maize. After applying management scenarios, economic productivity increased for three crops (wheat, barley and forage maize); however, it did not change for the other three crops, because the rate of yield reduction and water supply was proportionally the same for these crops.

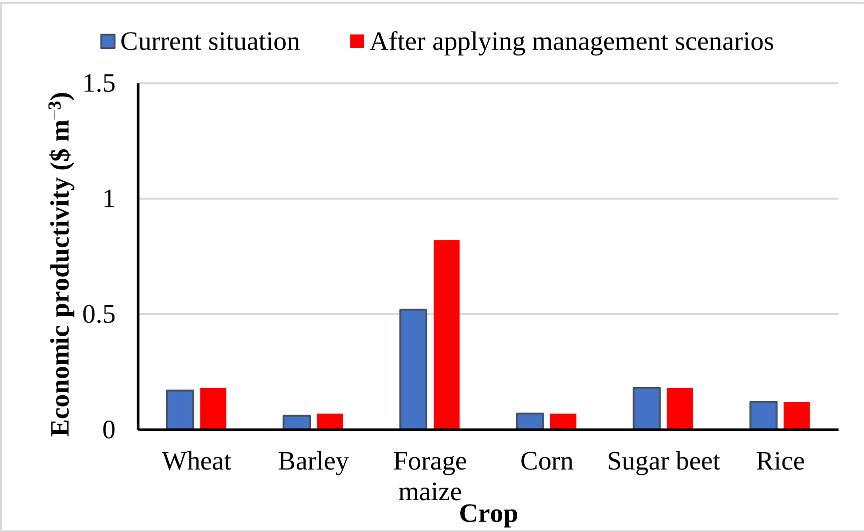

Figure 5. Economic productivity for each crop in current situation and after applying management scenarios.

3.3. Water valuation

Water use and its corresponding value was calculated for each crop separately and for the entire plain area in current situation and after management scenarios (**Tables 5** and **6**). By adopting management scenarios, it was assumed that the amount of water saved would be deducted from the share of nonrenewable water. However, if the amount of water saved for a crop was greater than the total water used from nonrenewable sources, the remaining amount would be reduced from groundwater and surface sources, respectively.

In this study, the value of surface water was considered equal to the economic productivity of wheat (0.17 $ m^{-3}) under current situation (**Figure 5**). In addition, the value of groundwater was assumed to be equal to the economic productivity of the crop with the highest productivity in the current situation, which was for forage corn with 0.52 $ m^{-3} (**Figure 5**). Sugar beet and rice are water-intensive crops. They have, therefore, a very high-water cost, since their water demand is mostly supplied from groundwater resources. Corn is the only crop that even after applying management scenarios consumes part of its water requirements from valuable nonrenewable water (**Table 6**). The total value of water supply was reduced by 27.45%, from $436.91 million in the current situation, to $316.96 million after applying management scenarios (or by 27.45%). The reason for such water savings is the significant reduction in the use of nonrenewable water (97.3 %), which is a highly valuable outcome from the present analysis, and is often ignored in most studies (**Figure 6**). After applying management scenarios, the yield performance of crops is slightly reduced (3.79%), while the reduction in the cost of water supply is significant (27.45%).

Table 5. The volume and value of water supply in current situation per unit area.

Crop	Water supply volume (m^3 ha^{-1})			Water supply value ($ ha^{-1})			
	Surface water	**Groundwater**	**Nonrenewable water**	**Surface water**	**Groundwater**	**Nonrenewable water**	**Total**
Wheat	3575.47	5512.21	812.32	607.83	2866.35	1259.10	4733.28
Barley	3259.45	5025.02	740.53	554.11	2613.01	1147.82	4314.93
Forage maize	6211.93	9576.77	1411.31	1056.03	4979.92	2187.53	8223.47
Corn	4333.90	6681.47	984.63	736.76	3474.36	1526.18	5737.31
Sugar beet	8017.72	12,360.71	1821.57	1363.01	6427.57	2823.44	10,614.02
Rice	7945.49	12,249.35	1805.16	1350.73	6369.66	2798.00	10,518.40

Table 6. The volume and value of water supply after applying management scenarios per unit area.

Crop	Water supply volume (m^3 ha^{-1})			Water supply value ($ ha^{-1})			
	Surface water	**Groundwater**	**Nonrenewable water**	**Surface water**	**Groundwater**	**Nonrenewable water**	**Total**
Wheat	3575.47	5434.05	0.00	607.83	2825.70	0.00	3433.53
Barley	3259.45	4755.83	0.00	554.11	2473.03	0.00	3027.14
Forage maize	6211.93	4317.49	0.00	1056.03	2245.09	0.00	3301.12
Corn	4333.90	6681.47	633.33	736.76	3474.36	981.67	5192.79
Sugar beet	8017.72	12,294.22	0.00	1363.01	6392.99	0.00	7756.01
Rice	7945.49	11,484.67	0.00	1350.73	5972.03	0.00	7322.76

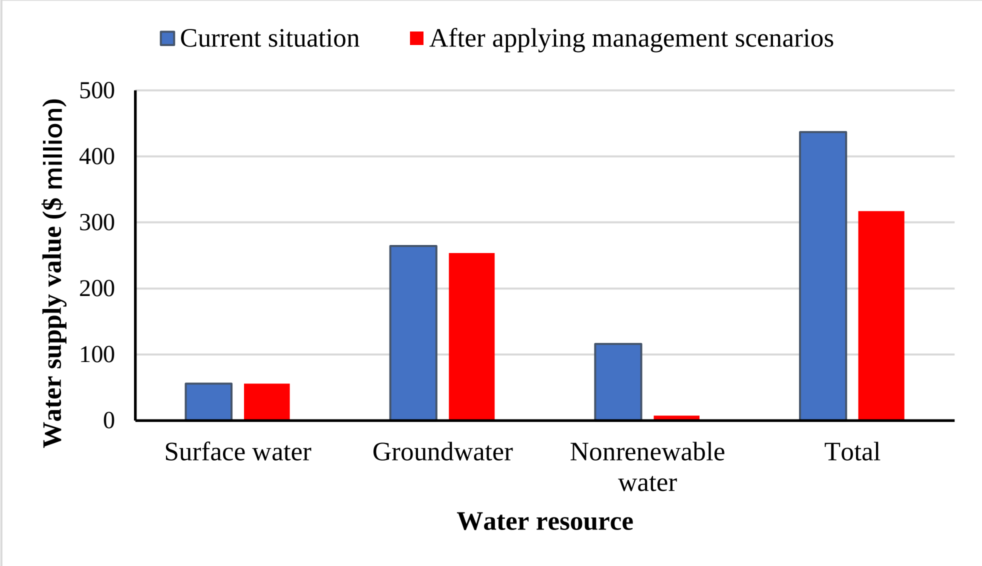

Figure 6. Water supply value in the current situation and after applying management scenarios for the entire plain.

3.4. Opportunity cost

Net loss for each crop in the current situation and after applying management scenarios are presented in **Table 7**. In the current situation, the net revenue for rice production, considering the real value of water, would equal to a net loss of 7922.42 $ ha^{-1}. The amount of water used for rice production is much higher than those for the other crops, even though its production gross income is high as well. Therefore, the cultivation of rice in the study area is not economically viable when the real value of irrigation water is considered. Wheat has the lowest net loss of 3079.83 $ ha^{-1}. Forage maize production results in higher gross income than the real value of the used water, and therefore, it is the only crop with positive gross income without net loss, even when the real values of water use is considered. After applying the proposed management scenarios, the net loss for all crops was reduced due to the reduction in water consumption and consequently in the total value of water consumption. In practice, however, wheat and rice still have the lowest and the highest net loss, respectively. After applying management scenarios, the net income from forage maize has increased significantly, by about 714%.

Table 7. Net loss for each crop in the current situation and after applying management scenarios.

Crop	Current situation			After applying management scenarios		
	Crop production gross income ($ ha^{-1})	**The value of water supply ($ ha^{-1})**	**Net loss ($ ha^{-1})**	**Crop production gross income ($ ha^{-1})**	**The value of water supply ($ ha^{-1})**	**Net loss ($ ha^{-1})**
Wheat	1653.45	4733.28	−3079.83	1621.66	3433.53	−1811.88
Barley	576.59	4314.93	−3738.34	533.34	3027.14	−2493.80
Forage maize	8966.80	8223.47	+743.33	8608.13	3301.12	+5307.01
Corn	896.68	5737.31	−4840.63	866.79	5192.79	−4326.00
Sugar beet	3997.32	10,614.02	−6616.70	3697.52	7756.01	−4058.48
Rice	2595.98	10,518.40	−7922.42	2336.38	7322.76	−4986.38

In the entire plain, the net loss for the current situation is $297.90 million, which means that the real value of water supply is much higher than the gross income from crop production. Management scenarios can reduce the net loss by 38%; from $297.9 million to $183.23 million in the study area, crop production, in this region, is still not economically viable, if the real value of water is considered (**Table 8**). It can also reduce water prices by 27% from $436.91 million to $316.96 million, and causes a 5.3% reduction in gross income, mainly due to the considerable yield losses under deficit irrigation scenarios. Hence, EWP loss (i.e., the amount of money lost through a unit of water use; $ m^{-3}) will reduce from −0.33 $ m^{-3} to −0.22 $ m^{-3} under the adaptation of management scenarios. Negative signs indicate that crop production is not still viable in the study area. One cannot drive such information when simply considers common WP values. Indeed, while applying management scenarios can increase WP by 6.6% (from 1.81 kg m^{-3} to 1.93 kg m^{-3}) in the study are; its application is still along with net loss with a total rate of 0.22 $ m^{-3}. Our assessment reveals that applying management scenarios in the study area causes a net opportunity cost of $114.67 million when IWVF is considered.

Table 8. Net loss and opportunity cost for entire plain in the current situation and after applying management scenarios.

	Current situation				**After applying management scenarios**			
	Crop production gross income ($ million)	The value of water supply ($ million)	Net loss ($ million)	Economic WP loss ($ m^{-3})	Crop production gross income ($ million)	The value of water supply ($ million)	Net loss ($/ha) ($ million)	Economic WP loss ($ m^{-3})
	139.01	436.91	−297.90	−0.33	133.73	316.96	−183.23	−0.22
Opportunity cost ($ million)	114.67							

4. Conclusion

Significant water savings can be achieved by applying various field management scenarios without equally jeopardizing crop production. Therefore, crop's water productivity (WP) can be improved with more crop per drop. Common WP values have led to unsustainable water use policies when the real value of different types of water resources are not considered. The irrigation water valuation framework (IWVF), proposed in this study, differentiate between the value of surface water, renewable, and nonrenewable groundwater resources. The refinement in common WP values based on the opportunity cost concepts can provide a more sustainable framework on WP strategies. Our results show that removing irrigation efficiency gaps, changing the cropping calendar, and application of different levels of deficit irrigation can improve existing WP by 6.6% in the study area. Applying our IWVF shows that even under the above management scenarios, crop production is not viable in the study area since it results in an economic WP loss of −0.22 $ m^{-3}. A unit of blue water use under these scenarios can result in $0.22 income loss when real valuation of irrigation water is considered. We can conclude that our proposed refinements in WP values can help policy/decision makers with implementing actual effective scenarios for moving toward sustainable agriculture in water-scarce regions.

Author contributions: Conceptualization, OR, KP and MP; methodology, OR, MP, KP and FK; validation, OR, MP, KP and FK; investigation, OR, MP, KP and FK; resources, OR and KP; writing—original draft preparation, OR and KP; writing—review and editing, MP and FK; supervision, MP and FK; project administration, MP; All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The authors express their gratitude to the Agricultural Organization of Fars and, Regional Water Company of Fars that provided access to data required for the preparation of this article.

Consent to participate: All authors have read and understood the provided information and have had the opportunity to ask questions. All authors share equal responsibility for errors of commission or omission.

Consent to publish: All authors give their consent for the publication of the paper to be published in this Journal.

Conflict of interest: The authors declare no conflict of interest.

Notes

[1] National currency of Egypt (1 US$= 15.7 EGP).
[2] National currency of China (1 US$= 6.37 Yuan).
[3] National currency of Jordan (1 US$= 0.71 JD).
[4] Electrical Conductivity.

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