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Economic efficiency of desalinated water to be used in agricultural production in the Kingdom of Saudi Arabia

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ABSTRACT

This study aimed to measure the economic efficiency of desalinated water used in agricultural production in general, and in the production of dates in particular. This study adopted the use of equations and econometric analysis to achieve its objectives. The prime findings of the study include: (1) desalinated water production increased from 1.13 billion m^3 in 2007 to 2.24 billion m^3 in 2016; (2) the amount of desalinated water used for drinking increased from 1.07 billion m^3, representing 53.97% of the total 1.98 billion m^3 of drinking water, in 2007 to 1.95 billion m^3, representing 62.22% of the total 3.13 billion m^3 of potable water, in 2016. (3) The cost of desalination exceeded the value of productivity per unit of water used in the production of cereals, fodder, olives, citrus, apricots, peaches, pomegranates, figs, mangoes, bananas, berries, and apples. Productivity exceeded the desalination cost per unit of water used in the production of vegetables, dates, grapes, figs, almonds, pears, plums, and papayas. (4) The trend towards the use of desalinated water in Saudi agriculture lead to a net economic loss of SR 10.86 billion, with a desalination cost of SR 6/m^3, in 2015. (5) The marginal return of water used in date production in Riyadh was estimated at SR 0.89/m^3. The marginal rate of return for the cost of desalination was 0.148, so the use of desalinated water in date production is not economically efficient. (6) Based on the economic analysis made in study, it is recommended not to expand the use of desalinated water in agricultural production, except when the use of modern desalination techniques (solar and atomic energy) reduces the cost of desalination to reach the value of the marginal output of water used in agricultural production.

Keywords: Economic efficiency; Water desalination; Dates; Economic gains and losses

1. Introduction

The Kingdom of Saudi Arabia is the largest producer of desalinated water, with a production of 2.24 billion m^3, accounting for 18% of the world's desalinated water production in 2016 (Ministry of Environment, Water and Agriculture, 2017). Most of the desalinated water produced in the Kingdom is specified for drinking purposes. The volume of desalinated drinking water is 1.95 billion m^3, representing 57.8% of the total 3.13 billion m^3 of drinking water in 2016 [1]. Due to the scarcity of water resources and the decrease in non-renewable groundwater levels, the Ministry of Environment, Water and Agriculture (MEWA) restructured the crop structure to stop the cultivation of wheat and fodder crops. Consequently, area under crop decreased from 1.05 million hectares in 2015 to 614.74 thousand hectares in 2016. Using modern technologies for water desalination, the Kingdom can return to growing wheat and fodder crops and thus increase the area under crops and the economic growth of the agricultural sector.

Some studies have dealt with the economic dimension of water desalination. Beltrán and Koo-Oshima [7] concluded

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that the application of water desalination in agriculture is limited to small areas, only for certain high-value crops and with government subsidies on capital costs. Distillation plants treat large volumes of water (55,000 m^3/d), almost exclusively seawater, and they are often built together with power plants (dual purpose). Seawater distillation costs (US$1.00–1.50/$m^3$) are designated mainly for industry and drinking-water, although would include agriculture within the range of large plants [8].

Shaffer et al. [9] introduced the concept of an integrated forward osmosis and reverse osmosis process for seawater desalination. The integrated process produces good quality water with the acceptable levels of boron and chlorides and is considered suitable for irrigation purposes while consuming less energy than a conventional two-pass reverse osmosis process. The challenges to further development of an integrated forward and reverse osmosis desalination process and its potential benefits beyond energy savings are also discussed by the authors.

Zarzo et al. [10] described the Spanish experience in desalination for agriculture from an historic point of view. They also discuss the economic aspects such as the price of water obtained from desalination plants compared with other sources such as superficial or reused water as well as the percentage of water costs in agriculture production and other beneficial aspects such as increased production.

Toim [11] studied the productive efficiency of the General Corporation for Desalination of Saline Water in the Kingdom of Saudi Arabia. The study showed that seven stations achieved full technical efficiency, while eight stations did not achieve full technical efficiency. The study recommended the use of modern methods and advanced technologies in desalination plants to make them economical and, to achieve an index of production efficiency in quality specifications to determine the relationship between inputs and outputs of production.

Ouda [12] reviewed the Kingdom of Saudi Arabia (KSA) desalination industry performance since inception to date. The study forecast desalination water demands up to year 2040 in the context of three scenarios optimistic, moderate, and pessimistic. It further discussed the future of the desalination industry as a strategic domestic water supply source and highlighted its challenges. Results show that KSA will need about 2.0, 3.2, and 4.5 billion m^3/y of desalinated water in the year 2040 based on optimistic, moderate, and pessimistic scenarios, respectively. The review of Saudi initiatives shows that the KSA government effectively considered seawater desalination as a strategic option, and implemented a comprehensive set of initiatives to realize this option. Moreover, the on-going desalination industry initiatives, coupled with some improvements, will satisfy the desalinated water demand on a short-term basis. However, the long-term ability of the desalination industry to meet the ever-increasing domestic water demand remains a valid concern, especially, if the moderate or pessimistic scenario is realized.

The study of Bouazem and Wennon [13] examined the revenues and costs of desalination in Saudi Arabia. Desalination is not only a technique that transforms salt water into fresh water that can be consumed by humans. It is a strategic option to achieve the economic and political stability of countries suffering from a scarcity of conventional water resources. Desalinated water not only contributes to the provision of drinking water but also reduces stress on the non-renewable groundwater resources. Therefore, Saudi Arabia has been successful in matching the revenues and costs of desalination and making water resources available and sustainable.

Bouazem and Wennon [14] also studied the General Corporation for Desalination of Saline Water in Saudi Arabia. The study showed that the company has become a pioneer in water desalination and electricity production. The foundation also adopted a strategy to support scientific research in desalination techniques and to expand the circle of cooperation and partnership with parties interested in desalination technology at the internal and external levels. Finally, Martínez-Alvarez et al. [15] analyzed the development of agricultural desalinated seawater (DSW) supply as a pivotal means to securing crop production in the Segura River Basin (SRB). The study evidenced that DSW can be a supplementary supply contributing to effectively remove the hydrological constraints for crop production in the SRB.

The results of the previous studies indicate that some were interested in studying the techniques used in water desalination and their differentiation, while others addressed the importance of using desalinated water in agricultural production without specifying economic efficiency or the net gains and losses in monetary values resulting from the use of desalinated water in agricultural production.

Due to the high cost of conventional, oil and gas based water desalination, the Al Khafji solar desalination plant was established with a production capacity of 300,000 m^3/d. Water produced by this plant is used in agricultural production, especially for the cultivation of salt-tolerant crops such as wheat, barley, dates and fodder crops. The use of solar energy in water desalination will reduce the use of petroleum. It is expected to reduce the dependence on oil for desalination by 50%, which means saving 200,000 barrel/d by 2025 [2]. The use of current desalination technologies, raises several questions like: (1) Is the use of desalinated water in agricultural production economically rewarding or not? (2) What is the value of economic gains and losses resulting from the use of desalinated water in agricultural production?

2. Research objectives

This study aimed to measure the economic efficiency of desalinated water to be used in agricultural production in general, and in the production of dates in particular with the following objectives:

1. To study the production and use of desalinated water in the Kingdom of Saudi Arabia during the period 2007–2016.
2. To estimate the economic return of water used in agricultural production in 2015.
3. To conduct the comparative economic analysis between the value of productivity and the cost of desalination per unit of water to be used in plant production.

4. To estimate the values for gains and losses resulting from the use of desalinated water in agricultural production.
5. To measure the economic efficiency of desalination water to be used in the production of dates in Riyadh.

3. Methodology of the study

This study is based on the following economic equations:

1. Water unit productivity = Average productivity per hectare ÷ Water needs per hectare.
2. Value of the productivity of the unit of water = Productivity of the water unit × the farm price of the unit of production.
3. Ratio of value of production to desalination cost = Value of water unit productivity ÷ desalination cost of water unit.
4. Value of economic gains and losses = (value of water unit productivity – desalination cost of water unit) × Quantity of water used in production.
5. Net gains and losses = Value of economic gains – Value of economic losses.

The study also measures the economic efficiency of the water used in the econometric analysis of the estimation of the production function for dates in the Riyadh area in the form of ordinary least squares and can be expressed as follows:

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + e_i$$

where Y: dates production in tons; X_1: the amount of water used in thousand m^3; X_2: the amount of farm labor per man/d; X_3: the amount of chemical fertilizers in tons; X_4: the amount of organic fertilizer in tons; X_5: the number of years of experience in date production.

Additionally, a, b_1, b_2, b_3, b_4, and b_5 represent parameters for the model, and e_i represents error term [3]. The economic efficiency of desalinated water to be used in date production was measured by estimating marginal water productivity and comparing it to marginal cost (desalination cost of water unit).

Finally, this study relied on secondary data, presented as under: (1) Detailed results of the agricultural census for 2015 conducted by the General Authority for Statistics [4], (2) Studies that focused on estimating the water needs of various crops [5]. Also the study was based on preliminary data collected through the administration of questionnaires distributed to the sample population of 50 palm farmers in Riyadh region in 2017. Dates were chosen as the main crop due to its prime significance in Saudi agriculture, where the date production value represents 52.87% of the value of all plant production, which reached SR 30.59 billion in 2015 [6].

4. Results and discussion

4.1. Production and use of desalinated water in Saudi Arabia

Ten companies are currently engaged in desalinating water in Saudi Arabia. The most important are: the General Establishment for Desalination of Salt Water, Shuaiba Water and Electricity Company, Jubail Water and Electricity Company, Electricity and Water Utility Company in Jubail, Yanbu, and other companies. The data presented in Table 1 show that the production of desalinated water increased from 1.13 billion m^3 in 2007 to 2.24 billion m^3 in 2016, with an annual average of 1.64 billion m^3 during the period 2007–2016. In 2016, the General Corporation for Saline Water Conversion ranked first in the production of desalinated water, its production reached 1.38 billion m^3, representing 61.37% of the total desalinated water production in 2016, followed by Shuaiba Water & Electricity Company at 12.62% and Jubail Water & Electricity Company at 12.44%. Al-Shaqeeq Water & Electricity Co. contributed 3.39%, followed by Electricity and Water Utilities Company in Jubail and Yanbu at 3.12%. From the above information, it becomes clear that the contribution of the five companies referred to above reached 92.94%, while the contribution of other companies did not exceed 7.06% in 2016.

At present, desalinated water is the prime source of drinding (potabke) water in Saudi Arabia. The data shown in Table 2 illustrates that the amount of desalinated water used for drinking increased from 1.07 billion m^3, representing 53.97% of the total of potable water (1.98 billion m^3), in 2007 to 1.95 billion m^3, representing 62.22% of the total quantity of potable water (3.13 billion m^3), in 2016. The annual average was 1.46 billion m^3, representing 57.80% of the average quantity of drinking water of (2.51 billion m^3), during the period 2007–2016. The amount of groundwater and dam water used for drinking increased from 910 million m^3, representing 46.03% of the total quantity of potable water (1.98 billion m^3), in 2007 to 1.18 billion m^3, representing 37.78% of the total quantity of drinking water (3.13 billion m^3), in 2016. 1.05 billion m^3 represents 42.20% of the average quantity of drinking water (2.51 billion m^3) during the period 2007–2016.

4.2. The economic return of water used in plant production in 2015

4.2.1. Economic return of water used in grain and feed production

The economic value per water unit used in crop production in the cropping structure was estimated in 2015. The data shown in Table 3 demonstrates the following: (1) the productive efficiency of the water resources used in the production of grain crops varies. The productivity of the water resources ranged from a minimum of 0.23 ton/thousand m^3 with a value of 322 riyals/thousand m^3 for millet to a maximum production reached of 1.03 ton/thousand m^3, with a value of 1190 riyals/thousand m^3 for barley production in 2015. It is obvious that wheat crop is the first in the grain group according to the value of the water unit, followed by the sesame, barley, yellow corn and other grains. (2) The productive efficiency of the water resources used in feed production also varies. Between a minimum of 0.58 ton/thousand m^3, with a value of 1112 riyals/thousand m^3 for alfalfa crop, and a maximum of 0.61 ton/thousand m^3 with a value of 917 riyals/thousand m^3 for other fodder crops. From the above information it

Table 1
Development of desalinated water production in Saudi Arabia in million m^3 during the period 2007–2016

Year	Saline Water Conversion Corporation	Shuaibah Water & Electricity Company	Jubail Water and power Company	Power and Water Utility Company for Jubail and Yanbu	Al Shuaiba Expansion Project Company	Rabigh Arabian Water & Electricity Company	Shuqaiq Water & Electricity Company	Other Companies *	Total
2007	1093	–	–	36	–		–	–	1129
2008	1096	–	–	38	–	8	–	–	1144
2009	1013	98	10	41	8	28	–	–	–1200
2010	883	296	151	40	43	35	34	–	1484
2011	932	302	263	40	50	32	61	–	1684
2012	997	292	273	43	52	38	66	–	1764
2013	1055	278	275	47	53	36	66	–	1812
2014	1139	288	269	49	52	39	71	–	1912
2015	1291	273	272	53	53	33	72	–	2049
2016	1376	283	279	70	53	36	76	69	2242
For the % year 2016	61.37	12.62	12.44	3.12	2.36	1.61	3.39	3.08	100

*Includes Al-Fath International Water and Electricity Works, Buarj International Desalination Co. Ltd., and Kandasat Water Services Company.

Source: Electricity and Cogeneration Regulatory Authority [16].

Table 2
Development of the quantity of drinking water according to its sources during the period 2007–2016

Year	Quantity of drinking water in million m^3			Relative importance %	
	Desalination water	Groundwater and dam water	Total	Desalination water	Groundwater and dam water
2007	1067	910	1977	53.97	46.03
2008	1063	942	2005	53.02	46.98
2009	1145	978	2123	53.93	46.07
2010	1258	1025	2283	55.10	44.90
2011	1476	947	2423	60.92	39.08
2012	1546	981	2527	61.18	38.82
2013	1594	1137	2731	58.37	41.63
2014	1685	1189	2874	58.63	41.37
2015	1835	1190	3025	60.66	39.34
2016	1947	1182	3129	62.22	37.78
Average	1461.60	1048.10	2509.70	57.80	42.20

Source: Ministry of Environment, Water and Agriculture [1].

becomes evident that alfalfa ranks first in the feed group according to the criterion of the unit value of water, followed by other fodder crops.

4.2.2. Economic return of water used in vegetable production

It is clear from the data presented in Table 4 that the productive efficiency of water resources used in the production of vegetables ranged from a minimum of 1.52 ton/thousand m^3 with a value of 25.87 thousand riyals/thousand m^3 for the okra crop to a maximum of 15.53 ton/thousand m^3 with a value of 48.46 thousand riyals/thousand m^3 of protected leafy vegetables. The figures presented in the Table reveal that the protected squash crop ranked first in the vegetables group according to the criterion of the unit value of water, followed by the protected cucumber, protected tomatoes, protected leafy vegetables, and okra, respectively.

Table 3
The economic yield of the unit of water used in the production of cereals and fodder in 2015

Crop	Productivity Ton/ha	Water needs thousand m^3/ha	Water unit productivity ton/thousand m^3	The sale price of the product SR/ton	Water unit productivity value	
					SR/thousand m^3	SR/m^3
Wheat	6.27	7.03	0.89	1605	1432	1.43
Barley	7.33	7.12	1.03	1155	1190	1.19
Sorghum	2.68	9.68	0.28	1365	378	0.38
Maize	3.66	9.85	0.37	1221	454	0.45
Millet	1.2	5.15	0.23	1383	322	0.32
Sesame	1.94	7.14	0.27	5026	1366	1.37
Yellow corn	4.15	8.67	0.48	1256	601	0.6
Other grains	2.62	7.56	0.35	1350	468	0.47
Average	3.73	7.78	0.49	1795	776	0.78
Alfalfa	21.66	37.65	0.58	1933	1112	1.11
Other fodder	21.32	34.86	0.61	1500	917	0.92
Average	21.49	36.26	0.6	1717	1015	1.02

Source: (1) General Organization for Statistics [6], (2) Al-Amoud et al. [5].

Table 4
The economic return of the unit of water used in the production of vegetables in 2015

	Productivity ton ha	Water needs Thousand m^3/ha	Water unit productivity ton/thousand m^3	The sale price of the product SR/ton	Water unit productivity value	
					SR/thousand m^3	SR m^3
Tomatoes open farm	17.37	9.21	1.89	5290	9977	9.98
Protected tomatoes	82.98	6.20	13.38	5290	70801	70.80
Eggplant	15.73	9.36	1.68	4320	7260	7.26
Squash open farm	17.29	9.25	1.87	5980	11178	11.18
Protected squash	86.97	6.20	14.03	5980	83884	83.88
Open cucumber farm	18.72	8.99	2.08	5000	10412	10.41
Protected cucumber farm	87.82	6.20	14.16	5000	70823	70.82
Okra	14.18	9.34	1.52	17040	25870	25.87
Carrot	17.08	8.83	1.93	4590	8879	8.88
Potato	25.80	7.88	3.27	3680	12049	12.05
Dry onion	30.32	8.66	3.50	3240	11344	11.34
Melon	20.30	8.91	2.28	4610	10503	10.50
Watermelon	21.51	8.88	2.43	2714	6583	6.58
Open farm vegetables	17.43	9.29	1.88	3120	5854	5.85
Protected paper vegetables	96.3	6.2	15.53	3120	48461	48.46
Average	37.99	8.23	5.43	5265	26259	26.26

Source: (1) General Organization for Statistics [6], (2) Al-Amoud et al. [5].

4.2.3. Economic return of water used in fruit production

It is clear from the data presented in Table 5 that the productive efficiency of water resources used in fruit production ranged between a minimum of 0.72 ton/thousand m^3 with a value of 1.84 thousand riyals/thousand m^3 for mulberry yield to a maximum of 4.49 ton/thousand m^3 with a value reached of 3.24 thousand riyals/thousand m^3 for pomegranate crops. It is also shown that the date crop is ranked first in the fruit group according to

Table 5
The economic yield of the unit of water used in fruit production in 2015

Crop	Productivity ton/ha	Water needs thousand m^3/ha	Water unit productivity ton/thousand m^3	The sale price of the product SR/ton	Water unit productivity value	
					SR/thousand m^3	SR/thousand m^3
Dates	10.86	10.16	1.07	13520	14451	14.45
Olive	4.91	5.83	0.84	4500	3790	3.79
Citrus fruit	8.0	9.41	0.95	3032	2881	2.88
Grapes	10.61	9.69	1.09	5830	6384	6.38
Ficus Caria	13.37	9.68	1.38	6194.2	8555	8.56
Apricot	10.48	8.37	1.25	2001.2	2506	2.51
Peaches	6.01	8.16	0.74	4973.2	3663	3.66
Pomegranate	14.86	9.98	4.49	2299.0	3423	4.42
Barbary Figs	20.81	10.27	2.03	1000.0	2026	2.03
Almonds	14.63	10.60	1.38	8295.2	11449	11.45
Mango	8.28	9.11	0.91	3045.8	2768	2.77
Banana	11.73	9.69	1.21	3552.4	4300	4.30
Pear	10.32	8.22	1.26	5215.1	6547	6.55
Mulberry	7.28	10.07	0.72	2538.2	1835	1.83
Plum	13.38	8.12	1.65	4938.3	8137	8.14
Apple	14.63	9.29	1.57	1994.0	3140	3.14
Papaya	13.04	9.46	1.38	4519.7	6230	6.23
Average	11.42	9.18	1.41	4556	6410	6.41

Source: (1) General Organization for Statistics [6], (2) Al-Amoud et al. [5].

the value of the unit of water, followed by the yield of ficus caria, figs, plums, pears, and grapes, respectively.

It is noteworthy that vegetables ranked first by attaining the average value for economic returns per water unit, which amounted to 26.26 riyals/m^3, followed by fruit crops, fodder, and grain with values reaching 6.41, 1.02, 0.78 riyals/m^3, respectively.

4.3. Comparative economic analysis between the value of productivity and the cost of desalination of water to be used in plant production

By studying the discrepancy between the average value of productivity and the desalination cost of the water unit to be used in plant production, the data in Table 6 shows that the desalination cost exceeds the value of productivity of the water unit to be used in the production of cereals and fodder. The ratio of the value of productivity to the desalination cost of the water unit ranged between a minimum of 0.05 for millet to a maximum of 0.24 for wheat therefore the use of desalinated water in the production of cereals and fodder causes the economic losses to the Saudi agricultural economy. In the case of the use of desalinated water in vegetable production, it is clear from the data in Table 7 that the value of the productivity exceeds the desalination cost of the water unit to be used in the production of vegetables; the ratio of the value of productivity to the desalination cost of the water unit ranged from a minimum of 0.98 for exposed leafy vegetables to a maximum of 13.98 for the protected squash crop. Therefore, economic logic dictates the possibility of using desalinated water in vegetable production. Finally, in the case of the use of desalinated water in fruit production, it is clear from the data in Table 8 that the value of the productivity exceeded the desalination cost of the water unit to be used in the production of dates, grapes, ficus caria, almonds, pears, plums, and papayas, while the cost of desalination exceeded the value of productivity of the water unit to be used in the production of the remaining fruit crops, where the ratio of the value of productivity to the desalination cost of the water unit was ranged between a minimum of 0.31 for strawberries to a maximum of 2.41 for dates. Therefore, it is economically logical to use desalinated water in the production of dates, grapes, ficus caria, almonds, pears, plums, and papayas.

4.4. Value of gains and losses on the use of desalinated water in agricultural production

The values for the gains and losses resulting from the use of desalinated water in agricultural production were estimated in light of the difference between the value of productivity and the cost of water desalination, in addition to the amount of water used in agricultural production. It is clear from the data presented in Tables

Table 6
Value of economic losses and percentage of value of production to the cost of desalination of water to be used in the production of cereals and fodder in 2015

Crop	Productivity value Water unit SR/m^3	Cost of desalination SR/m^3	Percentage of the value of production to the cost of desalination	Difference between the value of productivity and the cost of desalination in riyals	Quantity of water in million m^3	The value of losses in million riyals
Wheat	1.43	6	0.24	–4.57	805.20	3679.76
Barley	1.19	6	0.20	–4.81	666.08	3203.84
Sorghum	0.38	6	0.06	–5.62	610.02	3428.31
Maize	0.45	6	0.08	–5.55	194.53	1079.64
Millet	0.32	6	0.05	–5.68	20.76	117.92
Sesame	1.37	6	0.23	–4.63	14.68	67.97
Yellow corn	0.60	6	0.10	–5.40	78.62	424.55
Other grains	0.47	6	0.08	–5.53	10.41	57.57
Alfalfa	1.11	6	0.19	–4.89	2118.12	10357.61
Other Fodder	0.92	6	0.15	–5.08	325.28	1652.42

Source: Table 3 and Ministry of Water and Electricity [17].

Table 7
Value of economic gains and losses and the percentage of the value of productivity to the cost of desalination of water to be used in the production of vegetables in 2015

Crop	Productivity value Water unit SR/m^3	Cost of desalination SR/m^3	Percentage of the value of production to the cost of desalination	Difference between the value of productivity and the cost of desalination in riyals	Quantity of water in million m^3	The value of gains and losses in million riyals
Tomatoes open farm	9.98	6	1.66	3.98	91.34	363.53
Protected tomatoes	70.80	6	11.80	64.80	7.11	460.73
Eggplant	7.26	6	1.21	1.26	26.25	33.08
Squash open farm	11.18	6	1.86	5.18	110.74	573.63
Protected squash	83.88	6	13.98	77.88	1.04	81.00
Open cucumber farm	10.41	6	1.74	4.41	6.30	27.78
Protected cucumber farm	70.82	6	11.80	64.82	5.49	355.86
Okra	25.87	6	4.31	19.87	21.50	427.21
Carrot	8.88	6	1.48	2.88	32.76	94.35
Potato	12.05	6	2.01	6.05	276.34	1671.86
Dry onion	11.34	6	1.89	4.34	21.83	116.57
Melon	10.50	6	1.75	4.50	16.46	74.07
Watermelon	6.58	6	1.10	0.85	5.37	3.11
Open farm vegetables	5.85	6	0.98	–0.15	91.98	–13.80
Protected paper vegetables	48.46	6	8.08	42.46	5.07	215.27

Source: Table 4 and Ministry of Water and Electricity [17].

6–9 that the trend towards the use of desalinated water in the production of cereals and fodder resultedan economic loss of SR 24.07 billion. However, in the case of the use of desalinated water in the production of dates, grapes, ficus caria, almonds, pears, plums, and papayas, attained economic gains of 9.24 billion Riyals. Economic losses amounting to 524.14 million Riyals are realized when desalinated water is used in the production of olives,

Table 8
The value of economic gains and losses and the percentage of the value of productivity to the cost of desalination of water to be used in fruit production in 2015

Crop	Productivity value Water unit SR/m^3	Cost of desalination SR/m^3	Percentage of the value of production to the cost of desalination	Difference between the value of productivity and the cost of desalination in riyals	Quantity of water in million m^3	The value of gains and losses in million riyals
Dates	14.45	6	2.41	8.45	1085.78	9174.84
Olive	3.79	6	0.63	–2.21	101.90	–225.20
Citrus fruit	2.88	6	0.48	–3.12	39.14	–122.12
Grapes	6.38	6	1.06	0.38	78.82	29.95
Ficus Caria	8.56	6	1.43	2.56	8.46	21.66
Apricot	2.51	6	0.42	–3.49	5.38	–18.78
Peaches	3.66	6	0.61	–2.34	10.52	–24.62
pomegranate	4.42	6	0.74	–1.58	12.17	–19.23
Barbary Figs	2.03	6	0.34	–3.97	2.96	–11.75
Almonds	11.45	6	1.91	5.45	2.75	14.99
Mango	2.77	6	0.46	–3.23	27.36	–88.37
Banana	4.30	6	0.72	–1.70	5.94	–10.10
Pear	6.55	6	1.09	0.55	1.19	0.65
Mulberry	1.83	6	0.31	–4.17	0.54	–2.25
Plum	8.14	6	1.36	2.14	1.12	2.40
Apple	3.14	6	0.52	–2.86	0.60	–1.72
Papaya	6.23	6	1.04	0.23	1.03	0.24

Source: Table 5 and Ministry of Water and Electricity [17].

Table 9
Total value of economic gains and losses in million riyals resulting from the use of desalinated water in agricultural production

Statement	Gains	Losses	Net
Cereals and fodder	–	24069.59	–24069.59
Vegetables	4498.05	13.80	4484.25
Fruit	9244.73	524.14	8720.59
Total	13742.78	24607.53	–10864.75

Source: Data in Tables 6–8.

citrus, apricots, peaches, pomegranates, figs, mangoes, bananas, berries, and apples, with a net gain of 8.72 billion riyals when desalinated water is used for fruit production. In the case of the use of desalinated water in the production of all vegetables, except for open leafy vegetables, economic gains of 4.50 billion riyals were achieved. An economic loss of SR 13.80 million is realized when desalinated water is used to produce open leafy vegetables; the net gains are therefore SR 4.48 billion when desalinated water is used for vegetable production. Finally, in the case of the use of desalinated water in the production of all crops prevailing in the crop structure (cereals, fodder, vegetables, and fruits) the value of the economic losses (24.61 billion riyals) exceeds the value of the gains (13.74 billion riyals), thus achieving a net economic loss of 10.86 billion riyals.

4.5. Economic efficiency of desalinated water to be used in the production of dates

4.5.1. Estimation of the date production function in Riyadh region

The production of dates ($\hat{Y}$) is determined by a number of factors, including the following: (1) the amount of water used per thousand m^3, (2) the amount of labor used in the implementation of plant operations (man/d) for dates, (3) the amount of chemical fertilizers used in tons, (4) the amount of organic fertilizers in tons, and (5) years of experience in date production. A multiple regression analysis to the specific explanatory variables of the research sample of date production showed an advantage of the double logarithmic model in the representation of the data used in the estimation as expressed by the following equation:

$$\text{Ln}\,\hat{Y} = 0.864 + 0.48\,\text{Ln}\,X_1 + 0.08\,\text{Ln}\,X_2 + 0.04\,\text{Ln}\,X_3$$
$$(3.64)^{**}\quad (2.83)^{**}\quad (3.12)^{**}\quad (9.82)^{**}$$
$$R^{-2} = 0.81 \qquad F = 87.77$$

It is clear from the estimated model that the increasing in quantity of water used (X_1), the quantity of labor (X_2), and the quantity of chemical fertilizers (X_3) by 10% leads to increased dates production by 4.8%, 0.8% and 0.4%, respectively. The estimated model is highly efficient according to the efficiency indicators of the models, the most important being the (R–2) and the U-Theil coefficient from zero. The Heteroscedasticity problem was detected by the White Heteroscedasticity test, so (F) reached 1.50, which is insignificant at the level of 5%. This confirms the absence of the problem of variance difference**.**

4.5.2. Estimation of marginal return for water used in date production in the Riyadh area

To estimate the marginal return of water used in date production, the marginal water output function was derived from the first differential of the date production function as follows:

$$\frac{dY}{dX_1} = 1.139\ X_1^{-0.52} X_2^{0.08} X_3^{0.04}$$

In light of the average farm price for dates (13.52 thousand riyals/ton), the quantity of chemical fertilizers (6.79 ton/farm), and the amount of employed labor (40.11 man/d), the marginal return function for water used in dates production can be derived as follows:

$$\frac{dY}{dX_1} \times P_y = 22280.96 X_1^{-0.52}$$

$$\frac{dY}{dX_1} \times P_y = 891.24\ Riyal / 1000M^3$$

In light of the average amount of water used (480.48 thousand m^3/farm), the marginal water return is estimated at 891.24/m^3, 0.89 riyals/m^3. With a water desalination cost of 6 riyals/m^3, the marginal return to desalination cost for date production is 0.148. Therefore, the use of desalinated water in date production is not efficient economically at the current cost of desalination.

5. Conclusion and recommendations

Saudi Arabia suffers from water scarcity and a sharp decline in non-renewable groundwater levels. Therefore, Resolution 335 was issued in 2007 on the rationalization of water consumption and the General Establishment of Silos and Flour Mills stopped purchasing locally produced wheat for up to eight years. In view of the continued waste of water, resolution 66 was issued in 2015 to stop the cultivation of green fodder for a period not exceeding three years. The Ministry of Environment, Water and Agriculture restructured the cropping pattern and resultantly cropland decreased from 1.05 million ha in 2015 to 614.74 thousand ha in 2016. Desalinated water has become a sustainable and prime source, of potable water. Although Saudi Arabia is the world's largest producer of desalinated water yet the cost of desalination reached as high as 6 riyals/m^3 in 2015.

The results of this study indicate that the trend towards the use of desalinated water in agricultural production is not economically rewarding at present because the desalination cost exceeds the value of the water unit. Therefore, the Saudi economy may suffer a net economic loss of SR 10.86 billion. This study does not recommend expansion of the use of desalinated water in agricultural production, unless more modern desalination techniques (solar and atomic energy) are being used, which could reduce the cost of desalination to reach the value of marginal water used in agricultural production. In terms of water alternatives to agriculture, it is known that the agricultural sector in the Kingdom depends on renewable and non-renewable surface and groundwater. The Ministry of Environment, Water and Agriculture has prepared a study of the proposed crop structure, which is based on renewable surface and groundwater only and is estimated at 8 billion m^3 ,thus there is no justification for the use of desalinated water in agricultural production

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