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The economic dimension of directing treated wastewater to the production of green fodder in Saudi Arabia

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A B S T R A C T

This study aimed to identify the economic dimension of directing treated wastewater to the production of green fodder. To achieve its objectives, the study relied on economic equations, the method of using multiple criteria, and a scoring technique for prioritization. The study showed that green fodder is a crop that depletes water, as it consumes about 67.27% of the water used for agricultural purposes. In determining the priority of regions intending to use treated wastewater, the ranking put Riyadh region first, followed by the eastern region, the Qassim region, Hail, Makkah Al-Mukarramah, Tabuk, Asir, Al-Jawf, Jizan, Madinah, Najran, the northern borders, and Al-Baha, in this order. The area that can be cultivated with forage crops is estimated to be about 53.05 thousand hectares, with a production of 953.75 thousand tons. The cost of treating wastewater to make it usable amounts to 2126.22 million riyals, while the value of the benefits gained from its use is 2508.95 million riyals; thus, the Saudi agricultural economy achieves a net gain estimated at about 382.73 million riyals annually. Therefore, this study recommends the use of treated wastewater in the production of green fodder.

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1. Introduction

Water sources are confined to rainwater, surface water, renewable and nonrenewable groundwater, treated wastewater, desalinated water, and agricultural drainage water. Water resources are relatively scarce in the Kingdom of Saudi Arabia, as it is located in a very hot and dry area. Rainfall rates are highly irregular and fluctuate annually. As shown in Fig. 1, rainfall rates ranged between 55 and 99 mm during the period 2010–2019.

Despite the water scarcity in the Kingdom, the total water consumption increased from 17.79 billion m³ in 2008 to approximately 23.83 billion m³ in 2018 (Ministry of Environment, Water and Agriculture, 2020). To achieve the goal of preserving, developing, and rationalizing water resources, Resolution No. (335) was issued on 21/11/2007, which stipulates the following: (1) The General Organization for Grain Silos and Flour Mills will stop purchasing locally produced wheat within a maximum period of 8 years, at an annual rate of decrease of 12.5%. (2) The export of locally produced wheat will continue to be prevented. (3) The Ministry of Agriculture will continue to stop issuing licenses for the production of wheat, barley, and fodder. (4) The export of vegetables produced in open cultivation will be stopped gradually over the next 5 years (General Secretariat of the Council of Ministers, 2007). To implement the Cabinet’s decision, the Ministry of Agriculture issued a circular stopping the export of potatoes, onions, squash, and melons, as of 11/1/1433 AH. However, as most farmers continued to expand the cultivation of fodder and dates, the depletion of water resources increased. This is evidenced by the increase in the area planted with green fodder from 160.44 thousand hectares in 2009, to 195.6 thousand hectares, representing 28.2% of the total crop area in 2013. The Ministry of Environment, Water and Agriculture (2018) prepared the National Water Strategy 2030. The strategy stated
that forage crops alone consume about 79% of the volume of water used for agricultural purposes. Irrigation efficiency is currently 50%. In light of the current rates of water consumption, some regions in the Kingdom may face a depletion of the reserve stock during the next 12 years. In view of the continued wasting of water resources, the Council of Ministers Decision No. 66 was issued on 2/25/1437 AH to stop planting green fodder within a period not exceeding 3 years; then, the Council of Ministers decided in its meeting on October 17, 2016 to approve the application controls of Cabinet Decision No. (66) issued regarding stopping the cultivation of green fodder within a period not exceeding 3 years.

In the economic evaluation of the decision to stop the cultivation of fodder, the total current value of savings in groundwater amounted to 6.15 billion riyals, whereas the current value of the sacrificed production amounted to 5.03 billion riyals at a discount rate of 10%. The benefit-to-cost ratio was 1.22, and the net present value was 1.13 billion riyals, so the decision to stop planting green fodder was in the interest of the Kingdom of Saudi Arabia (Al-Ruwis et al., 2017).

Despite the decisions related to limiting the cultivation of green fodder, the area planted with green forage crops increased to 418.93 thousand hectares in 2019, representing about 48.84% of the total crop area of 857.76 thousand hectares (Ministry of Environment, Water and Agriculture, 2019). Green fodder is known to be one of the most important fodder resources for livestock in the Kingdom of Saudi Arabia, amounting to 13.47 million head, of which about 9.06 million head are sheep (67.23%), about 3.56 million head are goats (26.45%), about 354.28 thousand head are cows (2.63%), and about 24.36 thousand head are draft, riding, and other animals (0.18%) (General Authority for Statistics, 2015).

To preserve the number of livestock in the Kingdom of Saudi Arabia while limiting the consumption of nonrenewable water resources with limited regeneration, treated wastewater can be used in the production of green fodder. Milad et al.’s (2019) study confirmed that triple treated wastewater is an important source and tributary that can be used to improve water scarcity, as well as increase the area of wheat, fodder, and crop production for sustainable agriculture in the Sultanate of Oman.

The increase in the Kingdom’s population, which reached 33.41 million people in mid-2018, resulted in the country moving toward urban expansion. Through the proportional distribution of household sanitation sources at the Kingdom level, presented in Fig. 2, the main source of sanitation in homes in 2019 was found to be the public network at 61.65%, followed by the pit at 37.67%, and the private network at 0.67%. To ensure the availability of water and sanitation services, the value of official development assistance related to water and sanitation increased from 287.69 million riyals in 2010 to 3277.75 million riyals in 2016.

Despite the water scarcity in the Kingdom, treated wastewater has not been used adequately because of limited infrastructure and the challenges related to the acceptability of this water in some areas. In this regard, this study raises several questions, the most important of which are as follows:

1. What are the priority areas for using treated wastewater to produce green fodder?
2. What is the amount of area that can be cultivated with fodder crops and how is it distributed among the productive areas?
3. What are the benefits and economic costs of directing treated wastewater to produce green fodder?

1.1. Research objectives

This study mainly aimed to determine the economic dimension of directing treated wastewater to produce green fodder in the Kingdom of Saudi Arabia, by studying the following objectives:

1. The current status of green forage area and its water consumption in the Kingdom of Saudi Arabia.
2. Determining the priority of production areas in the use of treated wastewater.
3. Determining the area that can be cultivated with fodder crops in light of the volume of treated wastewater and its distribution to the productive areas.
4. Estimating the benefits and economic costs of using treated wastewater in the production of green fodder.
2. Materials and methods

This study is based on determining the priority of production areas for the use of treated wastewater, by using the multiple criteria method and the scoring technique for prioritization. A set of criteria was used, the most important of which are as follows:

1. The cumulative total of the lengths of the sewage networks, where priority is given to the regions with the longest sewage networks.
2. The volume of treated wastewater, where priority is given to the regions that produce the largest volume of treated wastewater.
3. The number of wastewater treatment plants, where priority is given to regions with the largest number of stations.
4. The cumulative total of the numbers of household connections for sewage, where priority is given to the regions with the highest cumulative number of household connections.
5. The relative importance of the number of livestock in the production regions, where priority is given to the regions that have the largest number of livestock (sheep, goats, camels, cows, and other animals).
6. The relative importance of the area planted with green forage crops, where priority is given to the regions that grow the largest area of green forage crops.
7. Productivity efficiency per unit area (hectare), expressed as the average productivity per hectare, where priority is given to regions with higher productivity.
8. The efficiency of using the water unit, expressed as the average productivity of the water unit (thousand m³), where priority is given to the regions with the highest water use efficiency.
9. Water needs of the terrestrial unit, where priority is given to regions with the lowest water needs.

A gradation rating between zero and 100 was used, and then the scores for each region were combined and prioritized in the use of treated wastewater.

2. The value of the productivity of the water unit = the productivity of the water unit × the farm price of the unit produced.
3. Return value of water used = value of productivity per unit of water × volume of water used in the production of green fodder.
4. The value of the saving of groundwater = the cost of extracting the water unit × the volume of the groundwater used in the production of green fodder.
5. Total value of benefits gained = value of return for water used + value of savings of groundwater.
6. The value of the wastewater treatment costs that can be used = the cost of treating the water unit × the volume of wastewater that can be used.
7. The value of economic gains and losses = the total value of the benefits gained – the value of the wastewater treatment costs that can be used.

Finally, in achieving its objectives, this study relied on data issued by the General Authority for Statistics, especially the statistical yearbook data and the detailed results of the 2015 agricultural census. This study also relied on the data of the statistical book issued by the Ministry of Environment, Water and Agriculture, in addition to the data contained in the National Water Strategy 2030 Studies and research related to the subject of study.

3. Results

3.1. The current status of green forage area and its water consumption during the period 2014–2019

By studying the development of the area cultivated with fodder crops and its water consumption during the period 2014–2019, the data presented in Tables 1 and 2 evidently show that the area planted with fodder crops decreased from 501.21 thousand hectares, representing 47.84% of the total cropped area in 2014, to 464.06 thousand hectares, representing 48.52% of the total cropped area in 2019. In light of the cultivated area and the water needs of green fodder crops in the sedimentary shelf areas of 28.65 thousand m³/hectare, the volume of water used in the production of green fodder decreased from 14.36 billion m³, representing 73.22% of the volume of water used for agricultural purposes in 2014, to 12.0 billion m³, representing 59.66% of the volume of...
Green fodder area and its ratio to the total crop area during the period 2014–2019.

| Year | Total fodder area (thousand hectares) | Crop area (thousand hectares) | Ratio of fodder area to crop area (%) |
|------|--------------------------------------|------------------------------|-------------------------------------|
|      | Alfalfa | Other fodder | Total | 2014 | 432.13 | 69.08 | 501.21 | 1047.77 | 47.84 |
|      |        |              |       | 2015 | 432.66 | 69.06 | 501.72 | 1038.12 | 48.33 |
|      |        |              |       | 2016 | 433.20 | 69.04 | 502.23 | 1026.91 | 48.91 |
|      |        |              |       | 2017 | 434.11 | 3.86  | 437.97 | 900.60  | 46.66 |
|      |        |              |       | 2018 | 420.84 | 1.48  | 422.32 | 869.91  | 48.55 |
|      |        |              |       | 2019 | 418.37 | 0.56  | 418.93 | 857.76  | 48.84 |
|      | Average | 428.55 | 35.31 | Total | 464.06 | 956.76 | 48.52 |

Source: General Authority for Statistics (2019), Statistical Yearbook.

### 3.2. The priority of production regions for using treated wastewater

The priority of production regions for using treated wastewater has been determined based on a set of criteria listed in Table 3. These criteria are as follows: (1) the cumulative total length of the sewage networks, as it ranged from a minimum of 317 km for the Al-Baha area to a maximum of 1,163 thousand km for the Riyadh region by the end of 2019 (Ministry of Environment, Water and Agriculture, 2019); (2) the volume of treated wastewater, which ranged from a minimum of 492.42 thousand m³ for the Al-Baha region to a maximum of 1,443.11 million m³ for the Riyadh region in 2019 (Ministry of Environment, Water and Agriculture, 2019); (3) the number of wastewater treatment plants, which ranged from a minimum of two stations for the Hail and Al-Jawf regions to a maximum of 17 stations for the Asir region in 2019 (Ministry of Environment, Water and Agriculture, 2019); (4) the cumulative total number of household connections related to sanitation, which ranged from a minimum of 325 connections in the Al-Baha region to a maximum of 407.71 thousand connections in the Riyadh region in 2019 (Ministry of Environment, Water and Agriculture, 2019); (5) the relative importance of the wealth of livestock in the Kingdom of Saudi Arabia, which ranged between a minimum of 0.11% for the northern border region and a maximum of 24.90% for the Riyadh region in 2019 (General Authority for Statistics, 2019); (6) the relative importance of the area cultivated with green fodder crops in the Kingdom of Saudi Arabia, which ranged between a minimum of 0.003% for the northern border region and a maximum of 35.35% for the Riyadh region in 2019 (General Authority for Statistics, 2019); (7) the productivity per unit area expressed as the average productivity per hectare, which ranged from a minimum of 15.64 tons/hectare for the Al-Baha region to a maximum of 23.97 tons/hectare for the Al-Jouf region. As for the Asir region, it ranked seventh, followed by Al-Jawf, Jizan, Madinah, Najran, the northern border, and Al-Baha, in this order.

3.3. The area that can be cultivated with green fodder crops, based on the treated wastewater volume and its distribution to productive areas

The area that can be cultivated with forage crops was estimated and determined according to the volume of treated wastewater used, based on the following assumptions:

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### Table 3
Criteria used to determine the priority of production areas in the use of treated wastewater.

| Region                  | Length Rank | Volume of treated wastewater (million m$^3$) | Number of wastewater treatment plants | Cumulative total number of household connections | Relative importance of livestock numbers (%) | Relative importance of fodder area (%) | Average yield per hectare (tons) | Water requirements (thousand m$^3$/ha) | Productivity of water unit (tons/thousand m$^3$) |
|-------------------------|-------------|-----------------------------------------------|--------------------------------------|-------------------------------------------------|-------------------------------------------|------------------------------------|-------------------------------------|--------------------------------------------|-----------------------------------------------|
| Al-Riyadh               | 11,634      | 1                                             | 540.11                               | 15                                              | 3                                         | 409,707                            | 24.9                               | 35.35                                    | 19.12                                        |
| Al-Qassim               | 3533        | 5                                             | 79.89                                | 3                                               | 7                                         | 141,253                            | 14.55                              | 10.3                                      | 15.78                                        |
| Eastern Region          | 6528        | 3                                             | 423.12                               | 16                                              | 2                                         | 279,160                            | 6.01                                | 8.89                                      | 18.3                                         |
| Al-Jouf                 | 613         | 11                                            | 16.46                                | 2                                               | 10                                        | 17,974                             | 2.61                                | 29.29                                    | 23.97                                        |
| Hail                    | 1731        | 7                                             | 24.45                                | 2                                               | 10                                        | 37,687                             | 8.06                                | 11.44                                    | 17.61                                        |
| Tabuk                   | 1417        | 8                                             | 46.29                                | 3                                               | 9                                         | 43,819                             | 5.01                                | 3.47                                      | 20.34                                        |
| Northern Region Borders | 538         | 12                                            | 7.22                                 | 3                                               | 9                                         | 19,041                             | 0.11                                | 0.03                                      | 16.07                                        |
| Makkah Al-Mukarramah    | 8202        | 2                                             | 456.26                               | 7                                               | 6                                         | 293,190                            | 9.64                                | 0.23                                      | 16.6                                         |
| Al-Madinah Al-Monawarah | 2952        | 6                                             | 105.12                               | 4                                               | 8                                         | 73,462                             | 7.35                                | 0.4                                       | 44.24                                        |
| Jizan                   | 962         | 10                                            | 21.75                                | 13                                              | 4                                         | 237,674                            | 6.84                                | 0.32                                      | 15.86                                        |
| Asir                    | 3974        | 4                                             | 76.48                                | 17                                              | 1                                         | 98,369                             | 5.73                                | 0.06                                      | 38.42                                        |
| Najran                  | 1310        | 9                                             | 4.24                                 | 3                                               | 9                                         | 21,272                             | 5.21                                | 0.19                                      | 38.89                                        |
| Al-Baha                 | 317         | 13                                            | 0.49                                 | 9                                               | 5                                         | 325                                | 2.18                                | 0.05                                      | 43.58                                        |
| Kingdom of Saudi Arabia | 43,729      | –                                             | 1801.87                              | 99                                              | –                                         | 1,458,933                         | –                                   | –                                         | –                                             |

Sources:
- Ministry of Environment, Water and Agriculture (2019), Statistical Book.
- General Authority for Statistics (2019), Bulletin of Agricultural Production Survey 2019.
- Al-Amoud et al. (1431 AH).

### Table 4
Results of priority criteria for production areas in the use of treated wastewater.

| Region                  | Cumulative total length of sewage networks (km) | Volume of treated wastewater (million m$^3$) | Number of wastewater treatment plants | Cumulative total number of household connections | Relative importance of livestock numbers (%) | Relative importance of fodder area (%) | Average yield/ha (tons) | Water requirements of ground unit (thousand m$^3$/ha) | Productivity of water unit (tons/thousand m$^3$) | Total number of points | Priority order of areas |
|-------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------------------|-------------------------------------------------|-------------------------------------------|------------------------------------|-------------------------------------|-------------------------------------------------|-----------------------------------------------|-------------------------------|------------------------|
| Al-Riyadh               | 100                                          | 100                                           | 80                                   | 100                                             | 100                                       | 80                                 | 50                                  | 60                                             | 770                                          | 1                           | 3                      |
| Al-Qassim               | 60                                           | 60                                            | 40                                   | 70                                              | 90                                        | 70                                 | 10                                  | 100                                            | 60                                           | 560                                         | 5                      |
| Eastern Region          | 80                                           | 80                                            | 90                                   | 30                                              | 30                                        | 60                                 | 70                                  | 70                                             | 60                                           | 630                                         | 2                      |
| Al-Jouf                 | 10                                           | 20                                            | 10                                   | 10                                              | 10                                        | 90                                 | 90                                  | 100                                            | 100                                          | 440                                         | 8                      |
| Hail                    | 40                                           | 30                                            | 10                                   | 30                                              | 30                                        | 70                                 | 80                                  | 60                                             | 80                                           | 500                                         | 4                      |
| Tabuk                   | 30                                           | 40                                            | 20                                   | 40                                              | 20                                        | 50                                 | 90                                  | 100                                            | 90                                           | 480                                         | 6                      |
| Northern Region Borders | 10                                           | 10                                            | 20                                   | 10                                              | 0                                         | 0                                  | 20                                  | 60                                             | 40                                           | 170                                         | 12                     |
| Makkah Al-Mukarramah    | 90                                           | 90                                            | 50                                   | 80                                              | 80                                        | 40                                 | 40                                  | 20                                             | 10                                           | 490                                         | 5                      |
| Al-Madinah Al-Monawarah | 50                                           | 70                                            | 50                                   | 50                                              | 50                                        | 40                                 | 30                                  | 0                                              | 0                                             | 320                                         | 10                     |
| Jizan                   | 20                                           | 30                                            | 20                                   | 30                                              | 30                                        | 10                                 | 10                                  | 80                                             | 50                                           | 350                                         | 9                      |
| Asir                    | 70                                           | 50                                            | 100                                  | 60                                              | 60                                        | 10                                 | 50                                  | 40                                             | 20                                           | 460                                         | 7                      |
| Najran                  | 30                                           | 30                                            | 10                                   | 10                                              | 10                                        | 20                                 | 20                                  | 30                                             | 30                                           | 240                                         | 11                     |
| Al-Baha                 | 0                                            | 0                                             | 60                                   | 60                                              | 10                                        | 10                                 | 10                                  | 10                                             | 10                                           | 60                                          | 13                     |

Sources: Data provided in Table 3.
1. *Direct guidance of the volume of treated wastewater to each area to grow fodder crops:* The data presented in Table 5 reveal clearly that, based on the volume of treated wastewater available and the water needs of fodder crops, the area that can be cultivated was estimated to range from a minimum of 0.01 thousand hectares for the Al-Baha region to a maximum of 16.18 thousand hectares for the Riyadh region, with a total area of 53.05 thousand hectares. Based on the average productivity per hectare and the area that can be cultivated with fodder crops, the production of fodder was estimated, ranging from a minimum of 0.18 thousand tons for the Al-Baha region to a maximum of 309.37 thousand tons for the Riyadh region, with a total of 953.75 thousand tons.

2. *Estimation of the area that can be cultivated with green fodder crops:* Based on the total volume of treated wastewater at 1.80 billion m$^3$ and the average water requirement of 33.72 thousand m$^3$/hectare, the area that can be cultivated is estimated to be about 53.44 thousand hectares, distributed to the productive regions according to their rank of using water from treated sewage. The data presented in Table 4 show that the regions garnered a total of 5500 points. By multiplying the average share of one point out of the total cultivable area of about 0.00972 by the number of points obtained by each region, the area that can be cultivated ranged from a minimum of 0.87 thousand hectares for the Al-Baha region to a maximum of 7.48 thousand hectares for the Riyadh region. Based on the average productivity per hectare and the area that can be cultivated with fodder crops, fodder production was estimated to range from a minimum of 13.68 thousand tons for the Al-Baha region to a maximum of 143.04 thousand tons for the Riyadh region, with a total of 965.09 thousand tons (Table 5).

3.4. *Estimating the economic benefits and costs of using treated wastewater in the production of green fodder*

Of the studies that have estimated wastewater treatment costs, the most important is Zahid’s (2007) study, where the total costs of wastewater treatment according to drip filtration methods, wastewater mixed completely with aerobic microorganisms, and the method of oxidative disposal of aerobic microorganisms were found to reach SAR 1.06, 1.23, 1.25/m$^3$, respectively. The data in Table 6 show clearly that based on the average treatment cost of SAR 1.18/m$^3$ for wastewater and the volume of treated wastewater that can be used, the value of treated wastewater ranges from a minimum of 0.58 million riyals for the Al-Baha region to a maximum of 637.33 million riyals for the Riyadh region, and a total of 2126.22 million riyals for all the regions. The efficiency of water use in the production of green fodder was measured to range from a minimum of 0.359 kg/m$^3$ with a value of SAR 0.617/m$^3$ for the Al-Baha region to a maximum of 0.871 kg/m$^3$ with a value of SAR 1.498/m$^3$ for the Al-Jouf region. Based on the productivity of a unit of water and the volume of treated wastewater that can be used in each region, the return value of the water used ranges between a minimum of 0.30 million riyals for the Al-Baha region and a maximum of 532.12 million riyals for the Riyadh region, and a total of 2126.22 million riyals for all the regions. The use of treated wastewater in the production of green fodder also results in the saving of nonrenewable groundwater equivalent to the volume of treated wastewater that can be used. Considering the average cost of extracting groundwater of SAR 0.482/m$^3$ at a discount rate of 10% (Nashwan, 2016), the value of groundwater savings ranges from a minimum of 0.24 million riyals for the Al-Baha region to a maximum of 532.12 million riyals for the Riyadh region, and a total of 2126.22 million riyals for all the regions.
From the above data, the value of the benefits resulting from the use of treated wastewater in the production of green fodder ranges from a minimum of 0.54 million riyals for the Al-Baha region to a maximum of 792.46 million riyals for the Riyadh region, with a total of 2508.95 million riyals for all the regions. The difference between the total benefits gained and the total costs incurred means that the Saudi agricultural economy achieves net gains from the use of treated wastewater in the production of fodder, estimated at about 382.73 million riyals annually.

4. Conclusions and recommendations

The results of this study showed that green fodder is one of the crops that deplete water, using about 67.27% of the total water used for agricultural purposes during the period 2014–2019. Green fodder cultivation is concentrated in the sedimentary shelf areas (Riyadh, Qassim, Sharkia, Al-Jawf, Hail, and Tabuk) that depend on nonrenewable groundwater. Green fodder is known to be an important fodder resource for livestock, which amounted to 13.47 million head in 2019. In the context of sustainable development and achievement of the Kingdom’s 2030 vision, it is necessary to preserve nonrenewable groundwater for future generations. In light of water scarcity in the Kingdom, 1.8 billion m³ of treated wastewater can be used in the production of green fodder. The available volume of treated wastewater can support the growth of green fodder in an area of 53.05 thousand hectares, with a total production of 953.75 thousand tons of fodder. The costs of wastewater treatment and the benefits gained from using treated wastewater also resulted in net gains for the Saudi agricultural economy, estimated at about 382.73 million riyals annually. Therefore, this study recommends the use of treated wastewater for the production of green fodder.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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