Measuring the impact of water scarcity on agricultural economic development in Saudi Arabia

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Article info

Article history:
Received 3 November 2019
Revised 16 September 2020
Accepted 17 September 2020
Available online 24 September 2020

Keywords:
Agricultural economic development
GDP
Saudi Arabia
Water resources

Abstract

This research measures the impact of water scarcity on agricultural economic development and economic development indicators in the Kingdom of Saudi Arabia during 1995–2018. By examining the current status of available water resources and their uses, and estimating a model to study the impact of water scarcity on agricultural economic development. The study relied on descriptive and standard economic analysis to estimate the proposed regression model. It found that a 10% change in the amount of water resources available leads to a 5.1% change in the same direction of the crop area. A 10% change in the estimated crop area results in a 1.5% change in the same direction of the total agricultural output value. A 10% change in employment and agricultural loans leads to a change in the same direction of the aggregate agricultural output value of 5.1% and 7.2%, respectively. A 10% change in the total value of the estimated agricultural output leads to a 2.9% change in the same direction of GDP. Thus, a lack of water resources will decrease the crop area and have a negative impact on the value of agricultural output, thereby impacting GDP. We therefore include policy recommendations for the conservation of water resources: The government should stop the export of virtual water, particularly for water-depleting products; an economic accounting framework for water should be introduced to monitor the amount of water in excess of the water codification for various crops prevailing in the crop composition.

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1. Introduction

The Kingdom of Saudi Arabia is located in a very hot and arid region where the annual rainfall typically ranges between 50 and 150 mm. However, the rainfall rate fluctuates. It decreased from 86 mm in 2010 to 62 mm in 2012 and 2014, increased to 99 mm in 2016, then decreased to 72 mm in 2017 (GAS 2018). Thus, Saudi Arabia has limited water resources. However, these resources are constantly in demand to meet the needs of the agricultural, municipal, industrial, and other sectors. Despite Saudi Arabia’s water scarcity, there has been a significant expansion in the cultivated area and production of green fodder, a water-depleting crop, and in the production of fresh milk. Moreover, despite decisions to stop the export of virtual water (Ministry of Economy and Planning, 2010–2014), some companies still export fresh milk products to the Gulf Cooperation Council (GCC) countries. According to the concept of virtual water, the export of fresh milk products also involves the export of water that contributed to its production, which constitutes an economic loss for Saudi Arabia. Husain and Ahmed (2009) showed that Saudi Arabia has low rainfall rates, particularly in sedimentary shelf areas. Therefore, renewable surface and groundwater are not sufficient to meet the increasing demand for water resources for domestic, industrial, and agricultural purposes.

To cover the deficit in the water balance, the State has focused on the reuse of treated wastewater for irrigation, industry, and groundwater recharge, considering the environmental, economic, and social impacts. The cost of triple treatment of wastewater in Jeddah was estimated at 1.1 riyals/m3. The Ministry of Environment, Water and Agriculture (2014) prepared the National Pasture Strategy and Plan for Saudi Arabia through to 2034. This

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Peer review under responsibility of King Saud University.

https://doi.org/10.1016/j.sjbs.2020.09.038
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strategy suggested that Saudi Arabia can compensate for the water shortage by suspension of green fodder cultivation and implementation of the Natural Pasture Development Strategy. The amount of water needed to grow one hectare of alfalfa is enough to grow 48 ha of improved pastoral plants, which produce more than 56% of the digestive feed per hectare. This would be in addition to the positive effects on animal production, ecotourism, combating desertification, conservation of water resources, biodiversity, water quality, and the standard of living of breeders. The Ministry of Environment, Water and Agriculture (2017) conducted a study of Saudi Arabia’s proposed crop composition. This study shows that the agricultural sector's total water consumption can be reduced from 21.23 billion m³ to 6.95 billion m³ following the implementation of the proposed crop composition in light of the regulations to stop the cultivation of green fodder. Given the scarcity of water resources and the trend toward sustainable development, it was necessary to restructure the crop composition and install meters on wells and water sources of all kinds to control the amount of non-renewable groundwater. The Ministry of Environment, Water and Agriculture (2018) also prepared the National Water Strategy. This strategy showed that the Kingdom has a limited reserve of non-renewable groundwater, due to the low rates of groundwater recharge given the arid climate. The agricultural sector consumes about 84% of the total water demand, making it the largest sectoral consumer of water. Water use in the agricultural sector is therefore an environmental challenge, as it relies on non-renewable groundwater. Given current water consumption rates, some regions of the Kingdom may face depletion in the coming years. Despite the scarcity of water, treated wastewater is underutilized, given the limited infrastructure, challenges regarding its acceptability in some areas, limited legislative oversight, and pricing incentives. Also Mu’azu, N. Dalhat et al. (2020) investigated the socio-demographic variables influencing public perceptions of reusing grey and mixed wastewater for non-domestic uses: firefighting, swimming pools, and car washing. Data were collected from 624 households in the Dammam Metropolitan Area, Saudi Arabia using a structured questionnaire and analyzed using descriptive and inferential statistics. The results from logistic regression indicates that the likelihood of a household to accept reusing treated mixed wastewater is influenced by gender with odds ratio (OR) of 2.71–2.18, residential location (OR = 1.32–1.03), age (OR = 1.22–0.18) and educational level (OR = 1.33–0.98), with a tendency for more acceptance of treated grey wastewater than mixed wastewater. These findings showcase the difficulty that the country could face concerning the public acceptance of treated wastewater for non-domestic uses to augment current freshwater sources even among the educated class. This study is significant because sustainably meeting the country's rising water demands requires the stringent implementation of strategic wastewater reuse policy, including bold steps towards wastewater streams segregation, and intensive public awareness campaigns to change negative perceptions on treated sewage effluent. This study concluded that a substantial reduction in the country's reliance on costly desalinated water and fast depleting non-renewable groundwater requires complete reuse and recycling of treated. Finally Elena Vallino et al. (2020) explored whether it can represent a valid metric for economic water scarcity (EWS) measurement. They first showed that a high level of water management was neither necessarily associated to high economic power of the country nor to low physical water availability. Then they made the first attempt to quantify the strengths of this relation at a global scale for different crops in climatic diverse countries. They detected a positive and significant association between integrated water resource management (IWRM) level and yield, and consequently a negative and equally significant association between the IWRM level and the crop water footprint. Statistical significance holds also when potentially confounding variables are included in a multiple regression analysis. They infer from this analysis that good water management, as detectable through the IWRM indicator, improved land productivity and water saving, in turn mitigating EWS. Their findings paved the way toward the use of the IWRM indicator as a valuable tool for measuring EWS in agriculture, bridging the measurability gap of economic water scarcity, with straightforward policy implications in favour of investments in water management as a lever for enhancing food security and development.

Research objectives

This research aims to measure the impact of water scarcity on agricultural economic development during the period 1995–2017 by:

1. Studying the current status of available water resources and their use in Saudi Arabia.
2. Study the development of economic development indicators in the Kingdom of Saudi Arabia.
3. Estimating a model to study the impact of water scarcity on agricultural economic development.

2. Materials and methods

This study relied on econometric analysis to estimate the proposed regression model to study the impact of water scarcity on agricultural income and GDP during 1995–2017. The proposed regression model consists of the following behavioral equations:

\[
\begin{align*}
1_t &= a_0 + a_1 X_{1t} + e_{1t} \\
2_t &= b_0 + b_1 X_{2t} + b_2 X_{3t} + b_3 + e_{2t} \\
3_t &= c_0 + c_1 X_{4t} + c_2 X_{5t} + e_{3t}
\end{align*}
\]

The proposed model's equations include the following variables: (1) three endogenous variables: \(\text{Y}_{1t}\) Total crop area, \(\text{Y}_{2t}\) The value of agricultural output in million riyals and \(\text{Y}_{3t}\) GDP in million riyals; (2) four exogenous variables: the quantity of water available to the agricultural sector in million m\(^3\)(\(X_{1t}\)), agricultural employment per thousand workers \(X_{2t}\), the value of agricultural investments in million riyals \(X_{3t}\), and local income for the rest of the economic sectors in million riyals \(X_{4t}\). It is clear from the proposed model that water resources affect the crop area, which, in turn, affects agricultural income and, consequently, the gross domestic product (GDP). Therefore, the causal line runs in one direction. Models that follow this pattern are called the recursive model. The proposed model is estimated using the ordinary least squares (OLS) method (Greene, 2003; Gujarati, 1979). In order to achieve its objectives, this study relied on the inventory of studies and research related to the scarcity of water resources in addition to secondary data obtained from the bulletins of the General Authority for Statistics and the statistical books issued by the Ministry of Environment, Water and Agriculture.

3. Results and discussion

3.1. The current situation regarding available water resources and their uses

Saudi Arabia’s water resources consist of rainwater, surface water, renewable and non-renewable groundwater, treated wastewater, desalinated water, and agricultural wastewater. It is clear from the data in Table 1 that the total amount of water avail-
available to Saudi Arabia decreased from 20.74 billion m³ during the Sixth Development Plan to 16.31 billion m³ during the Ninth Development Plan. Water resources are used for agricultural, industrial, and municipal purposes. Data from Table 2 show that the amount of water used for municipal purposes increased from 2.01 billion m³ in 2008 to approximately 3.39 billion m³ in 2018. This was an increase of 138.5 million m³ per year, representing 6.90% of the amount of water used for municipal purposes in 2008. The amount of water used for industrial purposes also increased from 698 million m³ in 2008 to approximately 1.4 billion m³ in 2018, an increase of 70.2 million m³ per year, representing 10.06% of the amount of water used for industrial purposes in 2008. The agricultural sector relies on both non-renewable (deep) and renewable (non-deep) groundwater. The amount of water used for agricultural purposes increased from 15.08 billion m³ in 2008 to approximately 21.2 billion m³ in 2018. This was an increase of 611.7 million m³ per year, representing 4.06% of the total amount of water used in 2008. Water consumption in the Kingdom increased from 17.79 billion m³ in 2008 to approximately 25.99 billion m³ in 2018, an annual increase of 820.4 million m³ and representing 4.61% of the total amount of water used in 2008.

### Table 1
| Water resources                              | Development plans |
|----------------------------------------------|-------------------|
|                                              | Sixth 1999 | Seventh 2004 | Eighth 2009 | Ninth 2014 |
| Surface water and renewable underground water | 8000      | 5410         | 5541        | 4644       |
| Non-renewable underground water              | 11,769    | 13,490       | 11,551      | 8976       |
| Sea desalinated water                        | 791       | 1070         | 1048        | 2070       |
| Treated agricultural wastewater              | –         | 40           | 42          | 47         |
| Treated wastewater                           | 180       | 260          | 325         | 570        |
| **Total resources available**                | **20,740** | **20,270**   | **18,507**  | **16,307** |

Source: Ministry of Economy and Planning, Economic and Social Development Plans 6 to 9.

### Table 2
| Year | Municipal | Industrial | Agricultural | Total |
|------|-----------|------------|--------------|-------|
| 2008 | 2007      | 698        | 15083        | 17788 |
| 2009 | 2123      | 714        | 14747        | 17584 |
| 2010 | 2284      | 753        | 14410        | 17447 |
| 2011 | 2423      | 800        | 15970        | 19193 |
| 2012 | 2527      | 843        | 17514        | 20884 |
| 2013 | 2731      | 890        | 18639        | 22260 |
| 2014 | 2874      | 930        | 19612        | 23416 |
| 2015 | 3025      | 977        | 20831        | 24833 |
| 2016 | 3129      | 1015       | 19789        | 23933 |
| 2017 | 3150      | 1000       | 19200        | 23350 |
| 2018 | 3392      | 1400       | 21200        | 25992 |
| **Average** | **2696.8** | **910.9**  | **17908.6**  | **21516.4** |
| **Relative importance %** | **12.53** | **4.23**   | **83.23**   | **100**  |

Source:
1. Ministry of Water and Electricity, Statistical Report for the fiscal year (2015).
2. General Authority for Statistics, environmental indicators.

3.3. Estimating the proposed regression model to study the impact of water scarcity on agricultural economic development

**Descriptive statistics of the proposed model’s internal and external variables:**

We refer to the descriptive statistics of the proposed model’s internal and external variables to evaluate the impact of water resource scarcity on GDP as an indicator of economic development. Table 4 shows that the crop area ranged between a minimum of 694.5 thousand hectares in 2013 and a maximum of 1,302.4 thousand hectares in 1995 with an annual average of about 1,055.1 thousand hectares, and a difference of 16.6% during the 1995–2017 period. The value of agricultural output ranged from a minimum of 31.6 billion riyals in 1995 to a maximum of 65.29 billion riyals in 2017, with an annual average of about 45.41 billion riyals, and a coefficient of variation that reached 26.5% during the study period. The gross domestic product ranged from a minimum of 1.3682 billion riyals in 1995 to a high of 2,836.31 billion riyals in 2014, with an annual average of about 1,517.48 billion riyals, and a coefficient of variation that reached 56.9% during the study period.

### Table 4
| Year | Municipal | Industrial | Agricultural | Total |
|------|-----------|------------|--------------|-------|
| 2008 | 2007      | 698        | 15083        | 17788 |
| 2009 | 2123      | 714        | 14747        | 17584 |
| 2010 | 2284      | 753        | 14410        | 17447 |
| 2011 | 2423      | 800        | 15970        | 19193 |
| 2012 | 2527      | 843        | 17514        | 20884 |
| 2013 | 2731      | 890        | 18639        | 22260 |
| 2014 | 2874      | 930        | 19612        | 23416 |
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| 2017 | 3150      | 1000       | 19200        | 23350 |
| 2018 | 3392      | 1400       | 21200        | 25992 |
| **Average** | **2696.8** | **910.9**  | **17908.6**  | **21516.4** |
| **Relative importance %** | **12.53** | **4.23**   | **83.23**   | **100**  |
period. As for the proposed model’s external variables, the amount of available and used water in the agricultural sector ranged from a minimum of 14.41 billion m³ in 2010 to a maximum of 20.83 billion m³ in 2015, with an annual average of about 17.60 billion m³, and a coefficient of variation that reached 10.7% during the 1995–2017 period. Agricultural employment ranged from a minimum of 317.0 thousand in 2004 to a maximum of 866.0 thousand in 2017, with an annual average of about 487.23 thousand, and a coefficient of variation that reached 33.3% during the study period. As for the domestic income of the rest of the non-agricultural economic sectors (GDP minus the value of agricultural output), it ranged from a minimum of 694.5 billion riyals in 1995 to a maximum of 700 billion riyals in 2017, with an annual average of about SR 908.78 million, and a coefficient of variation that reached 27.8% during the 1995–2017 period. Agricultural employment ranged from a minimum of 14.41 billion m³ in 2010 to a maximum of 20.83 billion m³, with an annual average of about 17.60 billion m³, and a coefficient of variation that reached 10.7% during the study period.

To study the impact of scarcity of water resources on GDP as an indicator of economic development, the proposed model’s equations were estimated by the application of the OLS method. The proposed model’s first behavioral equation in Table 5 shows that

Table 3
The most important indicators of economic development in the Kingdom during the period 2005–2017.

| Year | Economic development | Growth rate % | Pern capita income in 000 riyals | Worker productivity in 000 riyals |
|------|-----------------------|---------------|----------------------------------|----------------------------------|
|      | Domestic income in billions riyals | Minimum | Maximum | Current | Real | Minimum | Maximum | Current | Real |
| 2005 | 1302.4 | 91.60 | 536.8 | 14.82 | 422 | 630 | 505.2 |
| 2006 | 1106.7 | 52.30 | 1230.8 | 18.59 | 583 | 896.01 | 1191.1 |
| 2007 | 806.7 | 492.7 | 1980.8 | 12.30 | 392 | 1112.22 | 675.7 |
| 2008 | 1036.3 | 39.64 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| 2009 | 1023.1 | 59.64 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| 2010 | 1014.4 | 59.64 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| 2011 | 1015.3 | 15.41 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| 2012 | 1016.3 | 64.95 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| 2013 | 2015 | 1980.8 | 19.79 | 581 | 455.49 | 2353.6 |
| 2014 | 2015 | 1980.8 | 19.79 | 581 | 455.49 | 2353.6 |
| 2015 | 2015 | 1980.8 | 19.79 | 581 | 455.49 | 2353.6 |
| 2016 | 2015 | 1980.8 | 19.79 | 581 | 455.49 | 2353.6 |
| 2017 | 2015 | 1980.8 | 19.79 | 581 | 455.49 | 2353.6 |
| Average | 1216.1 | 10.87 | 78.69 | 75.40 | 186.15 |
| Standard deviation | 566.04 | 14.64 | 14.53 | 10.14 | 30.33 |
| Coefficient of variation | 26.19 | 167.44 | 19.09 | 12.30 | 15.15 |

Source: Saudi Arabian Monetary Agency, Annual Statistics 2017, May 31, 2018.

Table 4
Descriptive statistics of the variables used to measure the impact of scarcity of water resources on GDP during 1995–2017.

| Statement | Internal variables | External variables |
|-----------|--------------------|--------------------|
| Crop area in thousand hectares | Agricultural output in billion riyals | GDP in billion riyals | Quantity of water resources in million m³ | Agricultural employment per thousand workers | Agricultural loans in million riyals | Total income for other sectors in billion riyals |
| 1995 | 1302.4 | 31.60 | 536.8 | 14.82 | 422 | 630 | 505.2 |
| 2000 | 1106.7 | 39.64 | 1230.8 | 18.59 | 583 | 896.01 | 1191.1 |
| 2005 | 806.7 | 52.30 | 1980.8 | 14.41 | 492.7 | 753.1 | 1928.5 |
| 2010 | 1036.3 | 64.95 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| 2015 | 1014.4 | 64.95 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| 2016 | 1015.3 | 15.41 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| 2017 | 1016.3 | 64.95 | 2418.5 | 19.79 | 581 | 455.49 | 2353.6 |
| Average | 1216.1 | 10.87 | 78.69 | 75.40 | 186.15 |
| Minimum limit | 694.5 | 31.60 | 536.8 | 14.41 | 422 | 630 | 505.2 |
| Maximum limit | 1302.4 | 31.60 | 536.8 | 14.41 | 422 | 630 | 505.2 |
| Standard deviation | 175.2 | 12.05 | 863.57 | 1.88 | 135.54 | 302.84 | 851.99 |
| Coefficient of variation | 16.6 | 26.5 | 56.0 | 10.7 | 19.09 | 12.30 | 57.9 |

Source: Compiled from:
1. Saudi Arabian Monetary Agency, Annual Statistics 2017, May 31, 2018.
2. Ministry of Environment, Water and Agriculture, Statistical Book, 2017.

Table 5
Equations of the proposed model to study the impact of water scarcity on GDP during 1995–2017.

| Statement | Equation |
|-----------|----------|
| Crop area | $\ln Y_1 = 5.411 + 0.51\ln X_1 + 0.74\ln X_2$ |
| Agriculture output value | $R^2 = 0.68$ |
| Total GDP value | $L_{\text{archtest}} = 0.35$ |

** Significant at 1% probability level, * Significant at 5% probability level.

Source: Calculated from data in Table 4.
a change of 10% in the amount of water resources available leads to a 5.1% change in the same direction for crop area. This means that in the absence of water resources in the agricultural sector, the crop area will be reduced, which will have a negative impact on the value of agricultural output and consequently, GDP. The second behavioral equation shows that a change of 10% in the estimated crop area leads to a 1.5% change in the same direction of total value of agricultural output. It was also found that a 10% change in employment and agricultural loans leads to a change in the same direction of aggregate agricultural output value to the tune of 5.1% and 7.2%, respectively.

The third behavioral equation shows that a change of 10% in the estimated value of agricultural output leads to a 2.9% change in the same direction of GDP. A 10% change in gross income for the rest of the economic sectors leads to a 9.6% change in GDP. This estimate was significant at the 1% level. It is also clear that the proposed model’s behavioral equations are free from the problem of serial correlation of residues according to the Breusch-Godfrey serial correlation LM Test. Additionally, there is no autocorrelation in the variation of the chain according to the Arch Test. The proposed model’s behavioral equations have good efficiency in the representation of the data used in the estimation. This is determined from the indicators used to measure the model’s efficiency, the most important of which is the unequal coefficient of (U) Theil, whose value is close to zero, as shown in Table 6.

4. Conclusion

Groundwater in Saudi Arabia has been continuously depleting over the past several years, exceeding recharge rates. The amount of water available decreased from 20.74 billion cubic metres during the Sixth Development Plan to 16.31 billion cubic metres during the Ninth Development Plan. As a result, the Kingdom faces considerable challenges in meeting the municipal, industrial, and agricultural demand for water due to the increasing population and economic growth. Despite the scarcity of water resources, there has been a significant expansion in the cultivated area and production of green fodder, a water-depleting crop. Additionally, despite the issuance of resolutions to stop the export of virtual water, some companies are still exporting fresh milk products to the GCC countries. The results of this study recommend the conservation of water resources through several mechanisms, the most important of which are the following: (1) The Ministry of Commerce and Investment should enforce the resolutions related to stopping the export of virtual water, particularly for water-depleting products; (2) The Ministry of Environment, Water and Agriculture should introduce a framework in the context of economic accounting for the amount of water used in excess of the water codification for the various crops prevailing in the crop composition.

CRediT authorship contribution statement

Khalid Nahar Alrwis: Conceptualization, Formal analysis, Visualization. Adel Mohamed Ghanem: Conceptualization, Writing - review & editing, Supervision. Othman Saad Alnashwan: Methodology, Data curation, Project administration. Abdul Aziz M. Al Duways: Software, Writing - original draft. Sharaf Aldin Bakri Alaagib: Validation, Investigation. Nageeb Mohammed Aldawdah: Validation, Resources.

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.

Acknowledgement

The authors extend their sincere appreciation to the Deanship of Scientific Research at King Saud University for supporting the work through the College of Food and Agricultural Sciences Research Center. Furthermore, the authors thank the Deanship of Scientific Research at King Saud University for their technical support.

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