American Journal of Water Resources, 2019, Vol. 7, No. 1, 16-22
Available online at http://pubs.sciepub.com/ajwr/7/1/3
Published by Science and Education Publishing
DOI:10.12691/ajwr-7-1-3

Estimating Virtual Water Trade in Crops for Saudi Arabia

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Received December 22, 2018; Revised January 23, 2019; Accepted January 29, 2019

Abstract Using the concept of virtual water introduced by Allan 1994 and developed by Hoekstra and Hung (2002), we estimate virtual water trade for 20 crops of Saudi Arabia during 2000-2016. Our result shows the average virtual water trade was 12.6 billion m^3/year. Saudi had net virtual water imports, with the most significant virtual water import for cereals & alfalfa and vegetable; and there is a virtual water export of fruit. Saudi virtual water trade reduced pressure on water resources by 54%. Distance plays a role in Saudi virtual water export; we found that more than 90% of exports go to neighboring countries, including 45% to GCC countries. On the other hand, more than 40% of virtual water imports came from Asia.

Keywords: *virtual water, import, export, Saudi Arabia, crops*

Cite This Article: Yosef Alamri, and Michael Reed, “Estimating Virtual Water Trade in Crops for Saudi Arabia.” *American Journal of Water Resources*, vol. 7, no. 1 (2019): 16-22. doi: 10.12691/ajwr-7-1-3.

1. Introduction

Water requirements have increased steadily as the population increased by 23% in 2017 compared to 2007 [1]. Saudi Arabia counts on three primary sources of water: groundwater, desalinated seawater, and recycled water (usually used for power generation). Saudi Arabia's arable land is estimated at 173.6 million hectares in 2016 [1]. The agricultural sector was the largest consumer, accounting for more than 80% of the total water consumption in Saudi Arabia. This proportion is significantly higher than in the world, where the agriculture sector accounts for 65% of freshwater use [2]. Saudi Arabia relies almost entirely on groundwater for irrigating crops; 83% of crop irrigation came from groundwater. This irrigated groundwater totaled 22.9 billion cubic meters in 2016 [3].

Groundwater resources in Saudi Arabia are being depleted at a very rapid rate. Most of the water withdrawals come from deep fossil aquifers, and some predictions suggest that these resources may not last more than 12 years [4,5,6].

Many studies have called for the government to stop subsidies for the cultivation of crops that use water intensively. The water policy gaps, legislation to promote agricultural production of water-intensive crops, and general inefficiencies in use of water within the agricultural sector have led to an increase in water consumption from nonrenewable groundwater [5,6]. Recently, there have been some government initiatives aimed at rationalizing Saudi Arabia's water supplies and uses. In 2008, the government issued a policy to reduce wheat cultivation by stopping subsidies to farmers gradually. In 2010, the government supported investors interested in agricultural investment outside the Kingdom of Saudi Arabia. In 2018, it was expected to stop the cultivation of alfalfa based on a new government resolution [6]. In the long term, these policies are expected to help the agricultural sector move towards the cultivation of high-value products through rationalization of water consumption [4,5,6].

Water problems are not going to go away from Saudi Arabia. The country must find ways to rationalize its water use so that it can deal with its limited amount of renewable water. Saudi Arabia, as one of the most water-scarce countries, faces challenges related to its water resources from population growth, climate change, pollution and degradation of water quality. Because water is consistently mispriced, Allan developed the concept of virtual water to address the water gap and achieve water security in 1994. Allan discussed the idea that water-scarce countries can import high water consumption crops from countries that have abundant water resources, creating a virtual water market through trade in agricultural and food crops [7,8,9]. Saudi Arabia should consider importing crops (importing virtual water) instead of using scarce local water. The virtual water trade could be key to improving water security.

Virtual water is defined as the amount of water needed to produce a good [10]. Virtual water trade calculates the amount of virtual water imported or exported through goods. For example, when Saudi Arabia imports a ton of rice, it saves the water needed to produce this ton of rice locally. The idea of virtual water trade is to transform the production of agricultural commodities into the corresponding quantity of water consumed to produce these agricultural commodities.

Virtual water trade allows Saudi Arabia to increase its water supplies through imports. The objective of this research is to present the benefits of using the concept of virtual water trade as a bridge to overcome the gap between local water sources and food demand in Saudi Arabia.

Research on the virtual water content of various agriculture crops increases the awareness of the impact of producing these products with local water resources. This encourages the reduction of water use on the cultivation of crop products that are heavy consumers of water and importing those crops from water-abundant countries. For example, to produce a kilogram of wheat requires about 1000 liters of water, so the virtual water of this kilogram of wheat is 1000 liters [11]. Knowing the virtual water content of each agricultural enterprise and determining how much virtual water is traded can help countries know their net import balance for virtual water, and help them assess ways to use water more efficiently in the agricultural sector. It also gives a clearer picture of ways to track and increase virtual water availability when developing future development plans.

1.1. Water Use in the Agricultural Sector:

Water demand for agricultural production is influenced by various factors such as cultivated area, climatic conditions, crop type, irrigation method, and soil quality. Saudi Arabia has problems with all of these factors.

To understand the effect of virtual water on Saudi Arabia groundwater, we use the idea of consumption water from [12-16]. Figure 1 shows the supply and demand for groundwater in Saudi Arabia. For the supply curve, the part from 0 to Q1 represents the yearly recharge of groundwater (which is priced at zero). S^c is the highest amount of renewable water available for agricultural use (it will vary by year, but we assume it constant and non-responsive to water price). If water is withdrawn from the ground at more than the recharge rate, there is no price charged in Saudi Arabia, but there is an opportunity cost because the water is not available for future use. The supply curve ($a+bQ$) represents increasing opportunity cost as more water is withdrawn. The demand curve (for instance c-dQ) is the marginal benefit to farmers from using the water.

Two types of equilibrium can emerge from Figure 1: one is where the demand for water falls within the renewable water constraint (S^c); the other is where nonrenewable groundwater is used to meet water demands (beyond S^c). Net social welfare is the area of consumer and producer surplus from using groundwater:

$$SW = \int \left(c - dQ\right) dQ - \int \left(a + bQ\right) dQ.$$

Social welfare is maximized where

$$\frac{\partial SW}{\partial Q} = 0 \rightarrow \left(c - dQ\right) - \left(a + bQ\right) = 0$$

Which is at Pd=Ps→P*. The supply curve represents the marginal cost of extraction plus the marginal cost of consuming the water today rather than in the future. Fluctuations in the supply of water depend on physical storage availability and yearly recharge amounts. Q_c represents the total amount of renewable and nonrenewable groundwater. At a price of P_1 farmers increase their water use from the optimum to Q_2. Current farmers gain from this low price for water, but social welfare is lost because future water users value this extra water used more than current water users.

At P* and Q* the marginal benefit is equal to marginal cost in the domestic market, and social welfare is maximized. In most situations, water is not priced at the socially optimum level but instead is much lower priced [17]. This encourages current use and delays issues with future water shortages. However, virtual water imports can mitigate this situation if policies are followed to encourage such imports [17]. Virtual water imports shift the water demand curve to the left (D` for instance). In the case of Saudi Arabia where increasing consumption of crops can increase water demand, shifting production from Saudi Arabia to other countries (through crop imports) can help improve the situation.

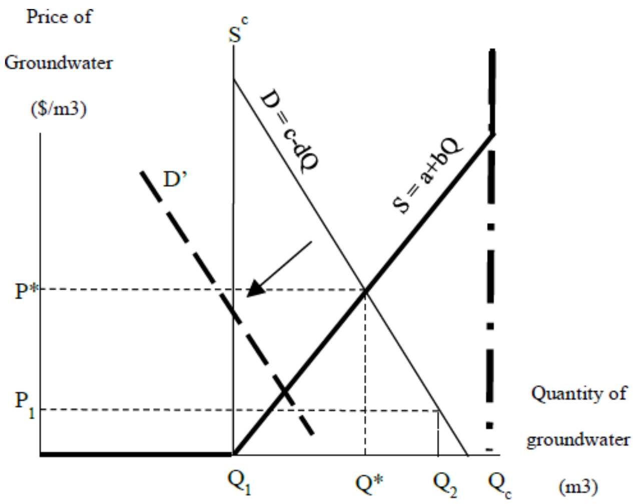

Figure 1. Demand and Supply of groundwater use

2. Methodology

Our research methodology is divided into two parts:

First, the data were classified into general categories such as Cereals & alfalfa, Vegetables, and Fruits taking into account the classification of GASTAT (General Authority for Statistics in Saudi Arabia). The categories are then classified into specific products: Wheat, Millet, Sorghum, Corn, Barley, Sesame, Tomato, Potato, Marrow, Eggplant, Okra, Carrot, Dry Onion, Cucumber, Melon, Watermelon, Alfalfa, Dates, Citrus, and Grapes. Further, products were classified as either exports or imports.

Second, using the methods developed by [11], we calculate total virtual water trade using the following stages:

Stage 1: Estimate total net virtual water trade:

1. Estimating virtual water of the crop (VWC) per ton using crop water requirements:

$$VWC_{ct} = \frac{CWR_c}{YE_{ct}}$$

Where the subscript ct is crop c in year t, CWR is crop water requirement, and YE is the crop yield.

2. Estimating virtual water trade (VWT):

$$VWT_{n_e n_i ct} = CT_{n_e n_i ct} \times VWC_{n_e c}$$

Where $CT_{n_e n_i ct}$ denotes the crop c trade from n_e exporting country to n_i importing country in year t. $VWC_{n_e c}$ is the virtual water of the crop c for the exporting country.

3. Net virtual water trade of a country (NVW):

To calculate the NVW, we need to calculate gross virtual water imports and exports for Saudi Arabia, as follow:

$$GVWI_{n_i t} = \sum_{n_i t}[CT_{n_i ct} \times VWC_{n_e c}]$$

Gross virtual water import (GVWI) is the sum of $CT_{n_i ct}$, the crop c import from n_i country in year t, times $VWC_{n_e c}$ the virtual water of the crop c in the importing country.

$$GVWE_{n_e t} = \sum_{n_e t}[CT_{n_e ct} \times VWC_{n_e c}]$$

Gross virtual water export (GVWE) is the sum of $CT_{n_e ct}$, the crop c export from n_e country in year t, times $VWD_{n_e c}$ the virtual water of the crop c in the exporting country n_e.

The net virtual water trade of a country, NVW, is:

$$NVW = GVWI - GVWE$$

Stage 2: Estimate the water footprint of a country (WF):

$$WF = WU + (GVWI - GVWE) = WU + NVW$$

WF is total domestic water use, WU plus the difference between gross virtual water imports and exports. To find total domestic water use, we include the water used by the agricultural, industrial, and municipal sectors. We recalculated the amount of virtual water using the water requirements for each crop under [18,19].

Stage 3: Estimate water index:

1. Virtual water dependency (WD):

$$WD = \frac{NVW}{WU + NVM} \times 100$$

The WD reflects the country dependence on international water resources. A value of zero mean GVWI is equal to GVWE (virtual water trade is in balance); a value of one hundred percent means the country totally depends on virtual water imports.

2. Water Self-Sufficiency (WSS):

$$WSS = \frac{WU}{WU+NVW} = \frac{WF}{WU+NVW} - \frac{NVW}{WU+NVW}$$
$$= \frac{(WU + NVW)}{WU + NVW} - \frac{NVW}{WU + NVW} = 1 - WD$$

The WSS reflects the country's ability to provide the water required for domestic production. Values closer to zero mean the country depends greatly on importing virtual water, while values closer to one hundred mean the country provides its water requirements domestically.

3. Data

We estimate virtual water flows from 2000 through 2016. Production data came from the General Authority for Statistics (GASTAT) in Saudi Arabia. However, most of the trade data came from GATS: Global agricultural trade system online from the United States Department of Agriculture (USDA). Marrow and watermelon trade data came from the General Authority for Statistics (GASTAT) in Saudi Arabia and the Food and Agriculture Organization of the United Nations (FAO). We used Harmonized codes for Sorghum, Barley, Tomato, Potato, Eggplant, Dry Onion, Cucumber, Dates, Alfalfa, Citrus, and Grapes. We are using BICO (USDA) codes for Wheat, Millet, Corn, Sesame, and Marrow. We used the World Trade Organization codes for Okra, Carrot, Melon, and Watermelon. The amount of virtual water for crops (the water footprint) calculated from [18] is more comprehensive, detailed, and accurate than other studies. The study on the water footprint of Saudi Arabia by [19], though, has newer data and is based on a similar approach to the study of [18]. It uses SPARE: WATER rather than the CropWat program[1]. We rely on [19] for Saudi Arabia, but [18] for the rest of the world. If the data are not available for the country from [18], we take the average global water footprint.

To obtain the water needs for heterogeneous groups of agricultural products (Cereals & alfalfa, Vegetables, and Fruits); we take the average of the water footprint for each category for each country. We omit Hong Kong, Gibraltar, Eswatini and Taiwan because the water footprint is not available from [18]. We add these countries to the Areas not Elsewhere Specified.

4. Result and Discussion

4.1. Saudi Arabia Production Using the Concept of Virtual Water:

Agricultural policies played an important role in the growth of crop production in Saudi Arabia. The government has provided subsidies, soft loans, and various services for the sector. In recent years, however, these policies have changed to incorporate water preservation policies, moving the country to import crops that are intensive users of water. Production of cereals, vegetables, and fruit crops decreased by 55%, 34%, and 10%, respectively, from 2000 to 2017 [20]. Alfalfa production increased by 71% during the same period because many wheat farms turned to alfalfa after government support for wheat fell in 2008.

Virtual water consumption for agriculture increased by 38% between 2000 and 2017. Virtual water consumption for cereals and fruit decreased by 111% and 18%, respectively, during this period, but virtual water consumption for vegetables and alfalfa increased by 9% and 78%, respectively. Saudi farmers moved to more water-intensive vegetable crops during the period. Wheat has the highest consumption of virtual water, potatoes have the highest water consumption among vegetables,

[1] [19] used 55% of irrigation efficiency in Saudi Arabia while [18] used 100% (no losses with irrigation). As we mention in the beginning of this study, Saudi Arabia uses a great deal of nonrenewable ground water, [19] modified the calculation of the blue water footprint with the low efficiency and methods of irrigation (surface and sprinkler irrigation).

and dates have the highest water consumption among fruit crops.

4.2. Virtual Water Trade in Saudi Arabia:

The water footprint of Saudi Arabia (WFSA) was 503.1 billion m^3 during the study period (which is 289.2 billion m^3 of WU and 213.9 billion m^3 in net virtual water trade). The average WFSA was 29.65 billion m^3/year (17.0 billion m^3/year as WU +12.6 billion m^3/year for NVWSA), this result was higher than [11] found.

The water dependency statistic for Saudi Arabia is equal to 42.5% =[213.9/(213.9+289.2)], which means that 43% of Saudi Arabia's water comes from virtual net imports (notice that we only calculate the virtual water for crops). We found that Saudi Arabia was heavily dependent on virtual water import for all cereals crops. The self-sufficiency ratio of water was 57.5 %, which shows the problem of using scarce domestic water resources rather than import (higher than [11] found which was 33.2%).

Figure 2, Figure 3, and Figure 4 show virtual water imports and exports of crops between Saudi Arabia and the world during the period 2000 to 2016. In 2013, Saudi Arabia's imports of virtual water peaked at 21.8 billion m^3, which is the last year before the Saudi Arabia government issued the policy to stop exporting dairy products. Increasing virtual water imports was related to the government's tendency to import cereals and alfalfa (these products had high water consumption) instead of relying on local production to save water. The results show that annual average virtual water imports for Saudi Arabia are 12.6 billion m^3/year.

The cereal and alfalfa group accounted for a significant percentage of gross virtual water imports, followed by vegetables and fruit. The fruit group was the highest for gross virtual water export, followed by vegetables and then cereals and alfalfa. Saudi Arabia was a positive net importer of virtual water over the entire period. Net imports totaled 21.4 billion m^3 in 2013 but fell to 8.9 billion m^3 in 2016. This fall was due to a drop in grain exports from Australia, Canada, Germany, Russia and Ukraine to Saudi Arabia due to lower prices and lower production in these countries. Also, political problems between Russia and Ukraine during that period (both account of 28% of total virtual water imports of Saudi Arabia) also depressed exports to Saudi Arabia. These figures are higher than [5], but they studied a different period and used the [18] method to calculate the virtual water.

Total virtual water imports of Saudi Arabia increased from 7.6 billion m^3 in 2000 to 9.4 billion m^3 in 2016. Much of the virtual water imports come from cereals and alfalfa. These imports increased from 7.5 to 8.5 billion m^3 during the study period. Vegetables were the second-leading group for virtual water imports, increasing from 28 million m^3 to 845 million m^3 over the period to reflect the impact of declining domestic production of vegetables and increasing consumption. Virtual water from fruit imports increased from 13 million m^3 to 43 million m^3 during the study period. The slower (but still high) growth reflects the impact of increased domestic production as a result of government support for fruit crops, especially dates.

There is a tendency for the Saudi government to enact agricultural policies to limit exports of intensive-water using crops, which lessens the pressure on non-renewable water resources, such as the decision to ban the export of alfalfa and the gradual lifting of subsidies for wheat producers in Saudi Arabia. Fruit exports continue, and their virtual water content increased from 88 million m^3 in 2000 to 475 million m^3 in 2016.

Kuwait, UAE, Yemen, Bahrain, and Qatar were the top five countries importing virtual water from Saudi Arabia during the study period, accounting for almost 70% of Saudi Arabia's virtual water exports (Figure 5). Ukraine, Russia, Australia, Argentina, and India were the top five countries exporting virtual water to Saudi Arabia, accounting 58% of the total Saudi Arabia imports (Figure 6).

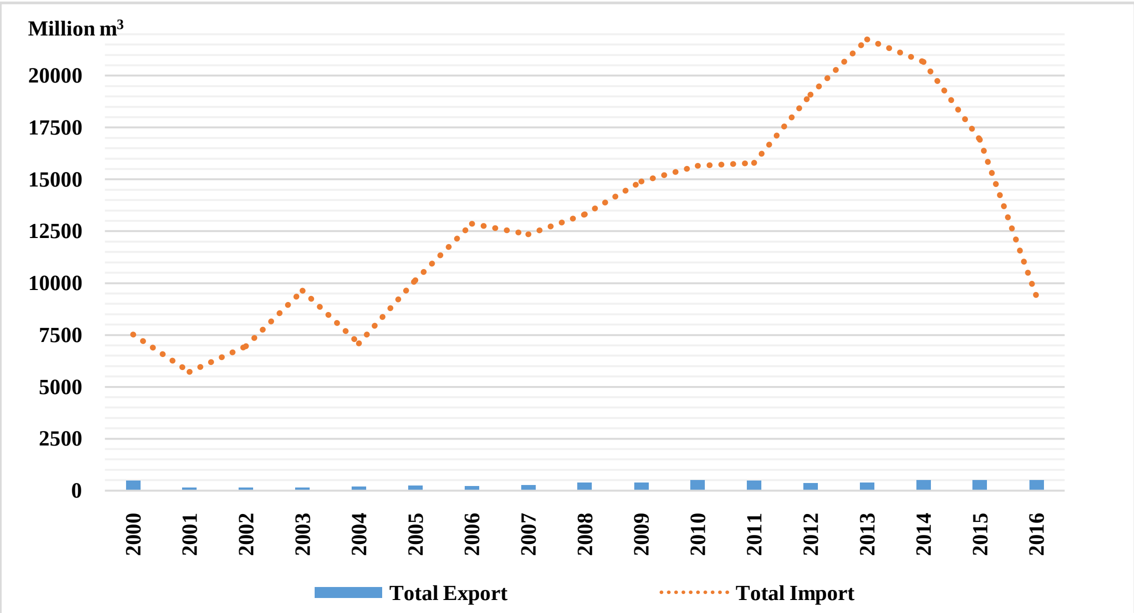

Figure 2. Total Virtual Water Trade for Saudi Arabia during the period 2000 to 2016

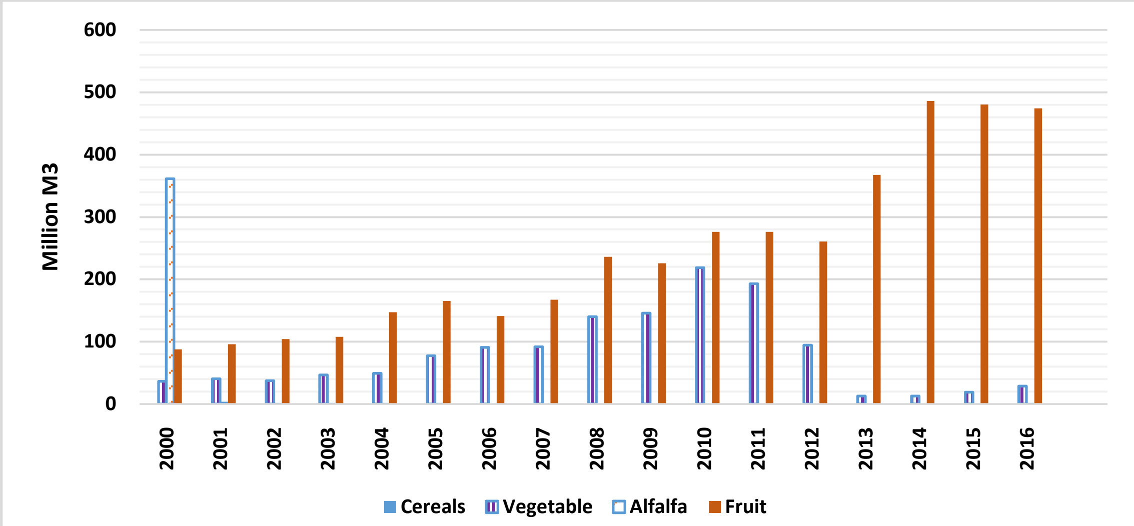

Figure 3. Total Virtual Water Exports from Crops in Saudi Arabia during the period 2000 to 2016

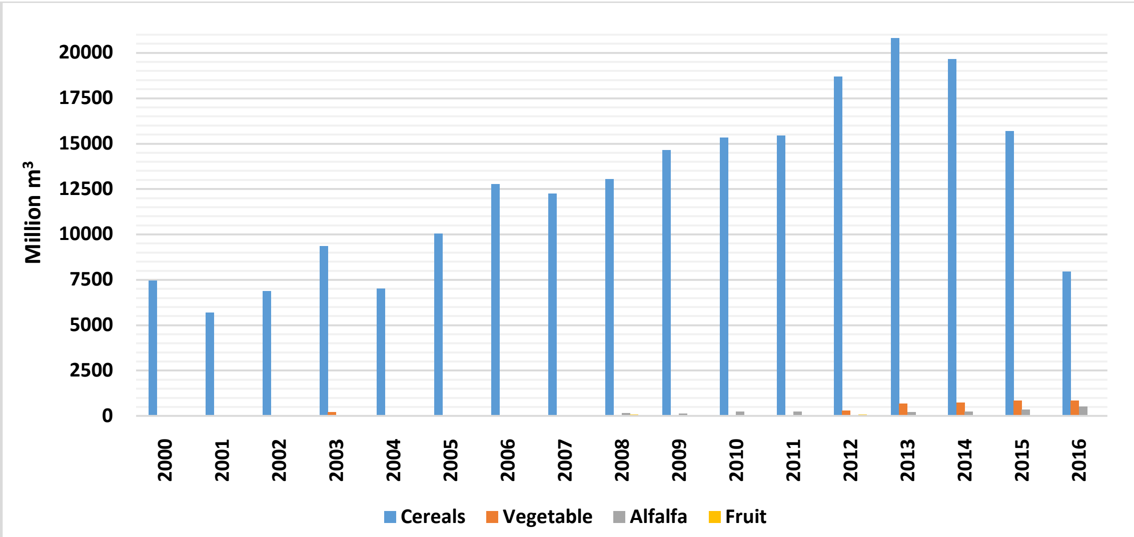

Figure 4. Total Virtual Water Imports of crops in Saudi Arabia from 2000 to 2016

Figure 5. Saudi Arabia virtual water export map (million m^3)

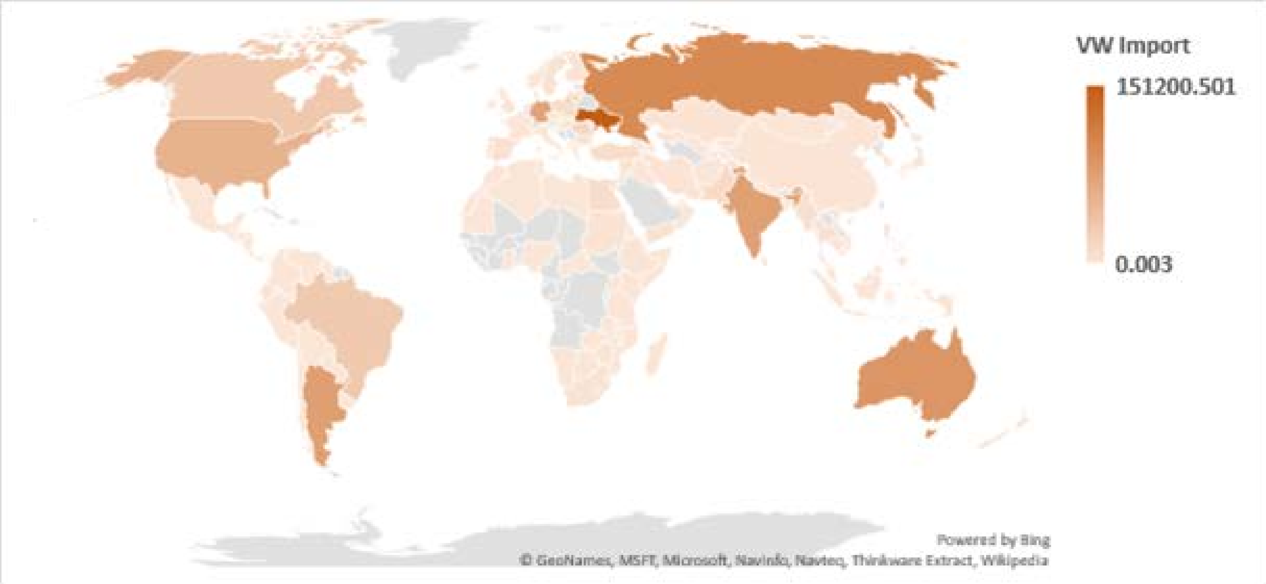

Figure 6. Saudi Arabia virtual water import map (million m^3)

Saudi Arabia received 214.5, 2.8, and 3.4 billion m^3 of virtual water through cereal & alfalfa, vegetable, and fruit trade, respectively, during the study period. It is clear from Figure 3 that Saudi Arabia's policies to stop exports of some agricultural products have produced remarkable water-saving results so that there are almost no exports of virtual water for the cereal and alfalfa group.

Wheat imports were where much of the virtual water was obtained for cereal & alfalfa, while tomato was the leading source of virtual water for vegetables, and grapes were the leading virtual water source for fruit.

Most of the virtual water exports from vegetables were from potatoes, and most of the virtual water exports from fruit were from dates. The government’s support for dates is the major reason that there is a net export of virtual water for fruits.

Overall, Saudi Arabia relies on agricultural imports to provide virtual water to overcome its scarcity. If Saudi Arabia did not import these crops during the study period and relied exclusively on local production (using the concept of virtual water), it would require an average of 12.9 billion m^3 of additional local virtual water, which is equivalent to 54% of the total local water resources (estimated at 23.9 billion m^3 in 2016).

5. Conclusion and Recommendation

This study calculates virtual water movements between Saudi Arabia and the world. The study compares the quantity of water consumed in three crop categories, cereals & alfalfa, vegetables, and fruits, by calculating the quantities of exports and imports for 20 crops and calculating the trade in virtual water. The goal is to present the benefit of using trade in virtual water as a means to bridge the shortage of local water sources for food demand in Saudi Arabia.

The results show that virtual water consumption by crops increased by 38% during 2000-2017. We found that consumption by cereals and fruit decreased by 111% and 18%, respectively, using the concept of virtual water, while consumption increased by 9% and 78% for vegetables and alfalfa, respectively, during the period. Wheat, potatoes, and dates were found to have the highest consumption of virtual water for these groups. The annual average of the virtual water received from crop imports by Saudi Arabia is 12.6 billion m^3/year. Cereals and alfalfa obtained the most significant percentage of gross virtual water from imports, and fruits accounted for the most virtual water from exports. Net virtual water imports reached 213.9 billion m^3 during the study period, and Saudi Arabia benefited by receiving 54% of its virtual water from outside the country, thus conserving local water resources.

The results of the study show that Saudi Arabia virtual water exports of fruits exceeded its imports. We also found that 1.4% of the virtual water production was used for exports, not used for domestic consumption. Ukraine is the top exporter of crops to Saudi Arabia, accounting for 18% of the total average Saudi Arabia imports of virtual water during the study period. On the other hand, Kuwait is the top beneficiary of Saudi Arabia's virtual water exports, accounting for 20%. The water footprint of Saudi Arabia (WFSA) totals 503.1 billion m^3 from 2000 through 2016. Saudi Arabia was 42.5% dependent on virtual water imports. However, the water self-sufficiency was high, which reflects that Saudi Arabia provides much of its water requirements domestically.

In the end, we recommend that the external agricultural investment activity needs to be directed towards some strategic commodities needed by Saudi Arabia which are challenging to produce domestically because of water scarcity, such as cereals and alfalfa products. The structure of foreign trade must be reconsidered so that goods with high water needs are imported, and limited water resources are used to provide fresh produce, such as vegetables. This study is just a beginning. More research on Saudi Arabai should focus on the impact many factors on virtual water trade, including relative water abundance, distance, free trade agreements, and other trade and water variables.

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