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Water footprint and virtual water trade in Qatar

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ABSTRACT

This paper analyzes the relationship between virtual water and domestic food-water security in Qatar. The total virtual water traded between 1998 and 2015 was 24,470 Mm^3, average of 1,360 Mm^3y^{-1}. Green water and blue water account 69 and 31% of total virtual water import. On average, 70% of the total water requirement is from virtual water import and Qatar's dependence on virtual water for agricultural products increased to 90% in 2015. The paper examines the virtual water flow from the major river basins in India, Pakistan, Australia and groundwater aquifers in Saudi Arabia and policy implications of virtual water on food security of Qatar.

Keywords: Virtual water, Qatar, Arid lands, Food security, Agriculture, Water footprint

1. Introduction

Freshwater scarcity is increasingly becoming a global concern, various sectors competing for scarce water resources. Even the water-rich countries are struggling to cope with the growing freshwater scarcity causing impediments to economic prosperity and human security[1].According to the last four global risk reports published by the World Economic Forum, water scarcity remains one of the top five risks for the last four consecutive years [2]. Old and new problems intensify water scarcity such as increasing cost of developing new water (treated wastewater, desalination), depletion of ground water, water pollution, degradation of water-related ecosystems, and economically inefficient use in the form of subsidies and climate change [3]. Nearly two-thirds of global population experience conditions of severe water scarcity at least for a month, and half a billion population face year-round scarcity [4]. Approximately 20% of renewable water resources will decline for every degree of global warming. Population dependent on river basins for livelihoods and freshwater will experience acute water scarcity [5]. Some countries (or regions) are naturally endowed with freshwater while others not. The Arab region is one of the water scarcest regions in the world with the very limited renewable freshwater availability of 1200 $m^3\,y^{-1}$ compared to world average of 7000 $m^3\,y^{-1}$ [6]. Freshwater distribution within the Arab states is disproportionate —very severe in Kuwait, UAE, and Qatar and moderate in Syria and Egypt. The per capita renewable water resources in the Arab world are continuously falling due to shrinking resources, increased consumption (in all sectors) and steady growth in population [7]. Despite severe water shortages, the Gulf Cooperation Council (GCC)[1] countries do not suffer from water conflicts or food shortages. The domestic water requirement met by large-scale fossil-fuel powered desalination technologies, whereas the food is imported from the global market and a small quantity produced domestically (10% of total production, in the case of Qatar). The domestic food production limited to high-value crops such as vegetables and fruits, which is consumed locally and exported to neighboring countries. Kuwait, Qatar, and UAE importnearly 100% of cereals from the international supply chain [8]. Groundwater is the major source of irrigation in the GCC countries. Because of three decades of unsustainable water extraction, groundwater aquifers are depleted, and rising salinity of water makes it unfit for direct agricultural use. The water level in some of the aquifers in Saudi Arabia drops at a rate 3–6 m/y for the past 20–30 y. It is estimated that in 10 to 15 y, a portion of the Wajid aquifer, bordering Saudi Arabia and Yemen

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will be exhausted [9]. The worrying concern with the groundwater is, along with the exhaustion of renewable groundwater shallow aquifers, most of the nonrenewable groundwater aquifers are depleted (two-thirds of fossil groundwater aquifers depleted in Saudi Arabia). This is not only the case of Saudi Arabia but other countries in the region. In United Arab Emirates (UAE), the water table dropped one meter per year in last three decades, causing seawater intrusion making it unfit for agricultural and domestic use [9,10].

The lack of freshwater availability, fertile soil and favorable climatic conditions pushes the Arab countries to depend heavily on international food trade. Recently, experts show the growing relation between international trade and freshwater scarcity, which is now commonly known as virtual water. Virtual water refers to 'invisible' water embodied in agricultural and industrial commodities. The concept of the virtual water trade was initially proposed by Tony Allan suggesting that the surprising lack of water conflicts in the water-scarce region (Arab world) was due to increase in reliance on food imports, resulting in domestic water savings and minimum friction between neighboring countries (concerning water). Virtual water in most of the water-scarce countries acts as a major relief [11,12]. The idea quickly gained popularity among academics and was extended to another level by Arjen Hoekstra and his team [13]. Since the inception of the idea, virtual water (or water footprint) finds its use in many applications especially in assessment of national water needs and "flows" [14–17]. There is an intense drive for the water-scarce countries to reduce or reallocate the water for economically profitable commodities by importing the water-intensive commodities like cereals and livestock. Over the last two decades, the volume of virtual water trade more than doubled [18].Nearly one-third of the global water withdrawal is embodied in international trade [19]. The majority of the countries in the region depend heavily on the import of water-intensive crops particularly cereals and sugar. The scarce water resources are allocated to irrigate high-value crops like vegetables and fruits for domestic use and partially exported to the neighboring states. The total virtual water import in the Middle East and North Africa (MENA)[2] region (which includes Iran, Turkey, and Israel) in 2010 was 273 km^3 y^{-1} and exports 480 km^3 y^{-1}. Between 1998 and 2002, the average volume of net virtual water import trade of South and Eastern Mediterranean countries was 49,123 Mm^3. Cereals occupy a major share of 67%, followed by vegetable oil 27%, and 10% goes for cereal, vegetable oil and sugar respectively. Some of the countries have a high ratio of virtual water import to renewable water resources. For instance, Libya's virtual water import share was five times, and Jordan's share was two times its own available renewable resources [20,21].

The present research evaluates the significance of virtual water in Qatar's food and water security. This paper estimates the virtual green and blue water for most of the food commodities consumed within Qatar between 1998 and 2015. The first section of the paper provides a brief background of food production, water resources,and food trade pattern in Qatar. The second section discusses research methodology and data sources. The third section explained the results and examined the relationship between river basins in India/Pakistan, Australia and groundwater aquifers in Saudi Arabia and its implications. The final section ends with conclusions and its implications for policy making in Qatar.

2. Background

Qatar is a semi-arid country with all basic characteristics like limited annual precipitation, poor soil quality and unfavorable climatic condition that makes unfit for agricultural production. In the past, the population was extremely small and relied heavily on their local production and imported food from the neighboring Saudi Arabia. In the last two decades, the social and economic dynamics of the country transformed significantly. Qatar's population quadrupled from 0.56 million in 1998 and increased to 2.4 million in 2015 [22]. This significant increase in less than 15 y is from the expatriate population (all non-Qatari population) resulting in growing food demand. The diversity of the expatriate population and affluent lifestyle of the local population continue to shape the diverse range of food imports from different countries. The majority of the population is from South Asia, followed by the Arab world (primarily Egypt, Jordan, Lebanon, Syria) and Europeans. The three household surveys (2001, 2006, 2013) indicate, there is a consistent increase in average spending on food commodities and increase in per capita consumption of basic food products such as rice, wheat, meat and dairy products. Household consumption of meat, dairy and high value products is twice in Qatari households compared to non-Qatari households [23–25]. The dietary habits of the local citizens changed considerably over time because of the rise in household income, availability of different commodities, lower prices, and exposure to diverse cultures.

2.1. Food production and self-sufficiency by trade

High temperature, depleting groundwater aquifers, lack of freshwater bodies and poor soil quality (lack of organic nutrients) are the major biophysical constraints for food production in Qatar. Agriculture is not the primary source of the economy (0.1% of GDP) and employment (1.6% of total labor force) [26,27]. Only 6% of the Qatar's total land mass is arable, of which only 11,216 ha used for cultivation. The total domestic production (for human consumption) in 2014 was 20 kilotons, representing only 13% of the total consumption [28]. The self-sufficiency ratio was 20% in the early 1990s and fell to 9% in 2012 and in 2015, it reached 13%. The recent modest increase in self-sufficiency is attributed to increasing in investment and policy support for new and existing agricultural farmers. Fig. 1 shows the self-sufficiency ratio of various food commodities. There is a declining trend of food commodities and in the last few years, the downward trend is much faster because of rapid population growth. In 2003, over 95% of the local fish catch was sufficient for local consumption, but in 2014, it fell to 34%. The national effort to increase self-sufficiency is observed only in the dairy sector. Because of increase in fodder production (237% up in 2014, compared to 1995),

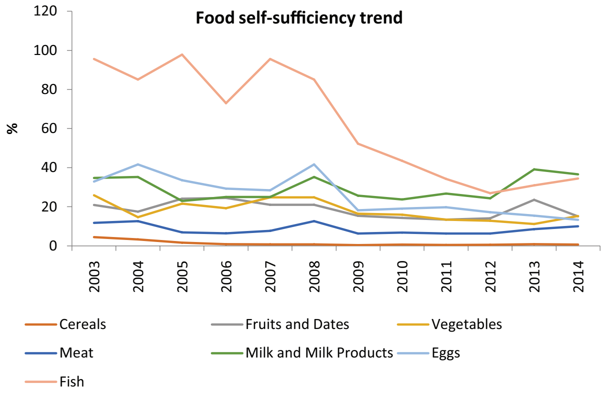


Fig. 1. Food self-sufficiency of Qatar (Source: Author construction based on the Annual Reports, MDPS).

the dairy output increased modestly contributing to 36% of total dairy consumption in 2014. Over 99% of the cropped area is an open field, and there is a growing trend of using greenhouses for vegetable production. The total domestic production in 2014 was 561,618 tons of which 88, 5, 7%, is for fodders, date palms, and vegetables respectively. Cereals and other fruits both combined contribute less than 1% of total production [28]. Land allocation for various food and non-food commodities remains fluctuating over time. There is a regional trend in shifting from cereal to vegetable/fruits production because of dwindling groundwater resources [8]. In Qatar, land for cereal production dropped 450% in 2005 compared to 2004 and remained constant ever since. Similarly, the land for vegetable production increased 41% in 2007 compared to 2006 [24]. In the past, Saudi Arabia was one of the major exporters of green fodder to Qatar. However, in the last five years, the green fodder export ban [29] increased the area for green fodder in Qatar. We observed the agricultural productivity in the last two decades was abysmally low and modestly increased, except cereals, the productivity was doubled.

Because of limited production; most of the food is imported. Increasingly, food trade serves as an effective tool for national food security for the water-scarce (and fertile land) Middle Eastern countries. Before five decades, the food trade is restricted to dry and non-perishable commodities and the local production was sufficient to cater the small population. The increase in trade liberalization, openness to the market, huge financial reserves managed to import from all over the world and maintain a constant supply of food commodities to the local market meeting the needs of growing population [30]. The bilateral trade relation between two main regional blocks: GCC and South Asian Association for Regional Cooperation (SAARC)[3] countries have increased several folds in the last few years because of the increase in population throughout the GCC countries primarily due to an influx of migrant workers from the neighboring region. The GCC-Asia trade doubled within four years from $480 billion in 2008 to $814 billion in 2012. The GCC countries with limited labor, fertile land, freshwater, and abundant capital, geographical and cultural proximity made SAARC countries—a natural trade ally. The SAARC countries rich with fertile soil, fresh water (though depleting at a faster rate), cheap labor coupled with trade liberalization made it possible to export agricultural products to the GCC countries. Cereals, meat and poultry, sugar cane and processed tobacco are the major agricultural products imported by the GCC countries. Most of these products mentioned above are imported primarily from India and Pakistan. Of all the SAARC countries, India accounts for 80% of the total exports to GCC. India occupies a major share of primary commodities like rice (62%), the meat of bovine animals (55%), sugar cane and beet sugar (28%) and Pakistan supply nearly 24% of total rice to the GCC market [31]. The food import in Qatar increased four times between 1998 and 2015, from 433 kilotons in 1998 to 1662 kilotons in 2015 as shown in Table 1. Cereals continue to maintain a huge share (26%) of food import, followed by vegetables (18%), fruits (10%), dairy (9%) and meat products (8%) respectively. The share of cereals as follows: rice – 40%, wheat – 33%, barley – 22% and maize – 5%. The average import share of food and live animals (categorized as food) between 2004 and 2014 was 7%, reaching $2.68 billion in 2014 from $0.3 billion in 1998. In last four years, the food import share remained 9% consistently, which is doubled than the import share during 2006–2007 [32]. Further breaking down, meat, cereals, and dairy products were the high value import commodities in 2014 [28]. On average, the per capita food import in terms of value is 2,574 Qatari Riyal and in quantity is 707 kg, respectively.

The geographical proximity, strong bilateral relations, and political stability play a major role in the selection of importing countries. This heavy reliance on the international market comes with risks of market instability and price volatility. The insecurity and vulnerability are often tied-up with the heavy reliance on food from the international market [33]. Qatar situated in geopolitical hotspot—bordering to its troubled neighbor (Saudi Arabia) and contested sea-route Strait of Hormuz. The food entering from Strait of Hormuz and Saudi Arabia is 46 and 41%, respectively. Besides the geopolitical crisis, the food crisis and export restrictions in 2008 emerged as a second shock to the Gulf countries (the first shock in the 1970s led to increasing domestic production, in the case of Saudi Arabia). In the wake of food price hike, the Gulf countries reacted swiftly by increasing agricultural investment abroad (by leasing lands), and increase domestic food storage and local pro-

Table 1
Food import in Qatar for selective years (Source: FTP)

(000 metric tons)	1998	2005	2010	2014	2015
Cereals	125.44	151.56	428.03	439.08	480.16
Meat	25.92	58.47	125.37	130.01	129.82
Vegetables	46.06	103.06	260.78	333.86	311.58
Fruits	58.24	74.40	130.83	160.21	154.75
Flour	9.52	29.40	44.85	50.45	25.52
Sugar	16.62	18.10	39.53	42.56	52.78
Dairy	24.52	63.34	109.82	149.07	132.20
Others	127.48	162.93	295.73	411.91	376.06
Total	433.81	661.26	1434.94	1717.14	1662.87

duction [30]. One such case is the establishment of Qatar National Food Security Program (QNFSP) to survey the opportunities for increasing domestic food production. Despite renewed interest in increasing food production, an increase in investment, subsidies and technical assistance to farm owners; aim to achieve decent levels of food self-sufficiency is remain distant. Qatar's reliance on international food trade will remain significant at least for next decade.

2.2. Water resources in Qatar

Qatar is one of the world's water-scarce countries; the total renewable water resources per capita is less than 200 cubic meters [16]. With limited renewable freshwater resources and annual precipitation, the fossil-based energy-intensive desalination technologies serve domestic and industrial water consumption. With the increase in population and industrial activities, the installations of desalination units are continuously increasing. The desalinated water increased from 97 million cubic meters (Mm^3) in 1995 to 516 Mm^3 in 2015 [22]. The per capita residential water consumption is 222 $m^3\ y^{-1}$ in 2014, which is above the regional standards [34]. The continuous expansion of desalination units poses severe stress on the shallow Gulf. The increasing salinity of the Gulf and the steady decline of marine species could disrupt the fishing population and severely impair long-term usage of seawater for desalination. Despite awareness among all the regional consumers of the Gulf seawater, the actions are weak and fragmented [35,36]. In the last decade, treated sewage effluent (TSE) considered as a strategic water resource. The domestic wastewater treatment capacity increased from 67,235 m^3/d in 2004 to 545,201 m^3/d in 2015 and the total TSE volume in 2015 was 163 Mm^3, which constitutes 18% of the total domestic water budget. The usage of TSE is increased from 5% in 2004 to 18% in 2015. The utilization of TSE is visible in different activities primarily in fodder production (37%), landscaping (16%), and aquifer recharge (23%), all values are for 2013. The share of TSE in fodder production increased from 6% to 19% between 2004 and 2013. In 2011, only 53% of the TSE was used, and excess TSE dumped into lagoons because of lack of infrastructure to transport the water to different activities [37]. Because of strict regulations, the current TSE use for food crops seems to be a distant option, yet the TSE is of high quality. Lately, TSE finds its use in sand washing and district cooling; nonetheless, full utilization of TSE remains a challenge because of inadequate infrastructure.

Rainfall is unlikely alliance to grow food because of its erratic and unpredictable nature. Groundwater is the primary and reliable source of irrigation. Nearly 92% of the groundwater abstraction is used to irrigate the farms, and this remains constant since 1990 peaking highs and lows in 1995 (99%) and 1999 (80%). The mean annual evaporation is 2,232 mm; and it is very high during the summer months (June to August) due to high temperature, low relative humidity and lack of rainfall. The minimum precipitation recharges the ground and fills the aquifers. The natural recharge from rainfall and inflow from Saudi Arabia is only 65 Mm^3. In 2012, the total water deficit was 108 Mm^3, of which 85.8% is for agricultural abstractions. The domestic and industrial groundwater abstraction is minimal, but an increase in delivery of piped water by the State displaced the use of groundwater [37]. A new report laments the steady decline of fresh groundwater lenses. In 1971, the freshwater lens in the north-central part of the Qatar occupies 15% (1683 km^2) of the country's area while it declined to only 2% (275 km^2) in 2009 as shown in Fig. 2. Additionally, freshwater with TDS less than 1000 mg/l will exhaust within nine years [38]. Three-fourths of the wells in the country are used for farm irrigation. In last few years, brackish water (Total Dissolved Solids < 2000–3000 ppm) declined markedly. About 75% of the groundwater used for irrigation is highly saline [38], requires further treatment. Consequently, the capital and operational cost for irrigation increased. The high-income farm owners managed to deploy sophisticated brackish water reverse osmosis for irrigation and low-income farm owners abandon the farm altogether. In last few years, there is another emerging trend; the number of registered farms has increased and increased in the utilization of farm area. We noticed these new farms are well-equipped with advanced brackish water treatment technologies to reduce salinity. Agricultural water-use efficiency was abysmally low because of its heavy reliance on international food market that has led to the unsustainable use of groundwater. Because of rapid declining of fresh groundwater, there is a growing stress to increase the water-use efficiency of the agricultural and other sectors. In last few years, the drilling permits were restricted, and groundwater withdrawal should not exceed the limits imposed by the Ministry of Environment, leading to saturation of groundwater withdrawal. The water use for per unit ton of agricultural produce is steadily declining, for example, in 1995, 940 m^3 to produce one ton and in 2013 it requires only 437 m^3. In other words, the water use efficiency doubled between 1995 and 2013. Notwithstanding, the water use efficiency, and crop yield are extremely low compared to the international and regional standards. In last two decades, several field studies attempted to improve the water use efficiency, however, there are mixed results [39]. Based on our estimations, the water use per agricultural GDP halved in less than a decade, from 1.04 m^3 in 2005 to 0.56 m^3 in 2013. Despite major gains in efficiency; the sectoral water allocation has become a contested issue—to save the depleting groundwater aquifers as a strategic water reserve as an alternative to desalination or to use for food production to increase self-sufficiency. Striking a balance between the two has been a challenge and no coherent long-term policy is formalized.

3. Methodology and data

The present study estimates virtual water trade of Qatar considering green and blue water for all the major crops. We calculated the virtual water flow for agrifood products based on the well-established methodology developed by [40]. We estimated the virtual water flow for following products: cereals, vegetables, fruits, flour (processed), sugar, meat, and dairy (see App.1). These commodities represent 80% of the total food import. WE used the similar definitions given in the reference [43]. The water footprint of a product refers to…" volume of freshwater used to produce the product, measured over the full supply chain"

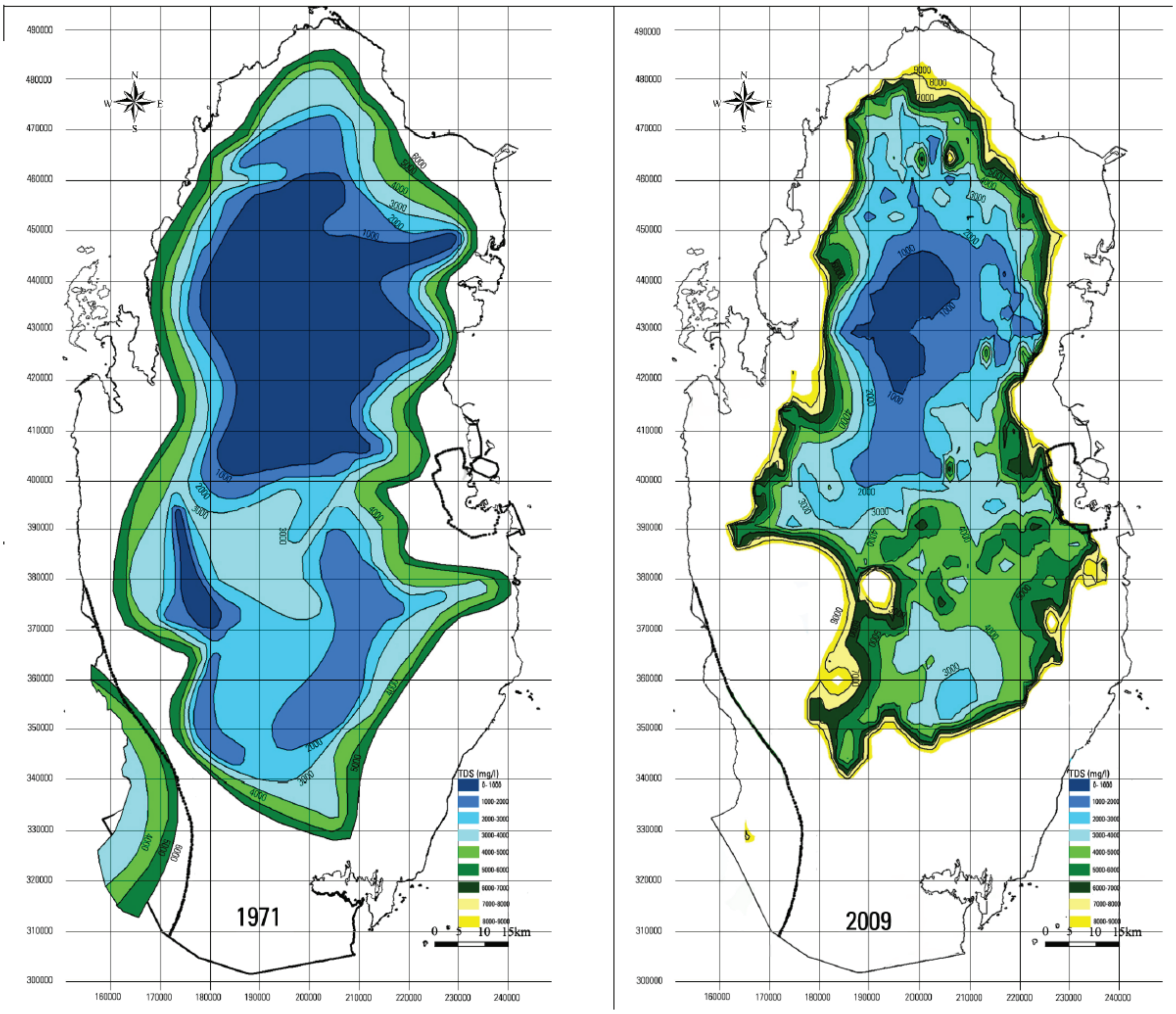


Fig. 2. Groundwater salinity Isoconcentration Maps – 1979 and 2009 [38].

(pp. 2) Blue water footprint defined as "consumption of blue water resources (surface and groundwater) along the supply chain of a product. 'Consumption' refers to the loss of water from the available ground-surface water body in a catchment area. Green water footprint defined as "consumption of green water resources (rainwater in so far as it does not become run-off) [43].

The green component in the process water footprint of growing a crop or tree ($WFproc,green$, m^3/ton) is calculated as the green component in crop water use ($CWUgreen$, m^3/ha) divided by the crop yield (Y, ton/ha). The blue component ($WFproc,blue$, m^3/ton) is calculated in a similar way:

$$WF_{proc,\,green} = \frac{CWU_{green}}{Y}\left[volume\ /\ mass\right] \qquad 1$$

$$WF_{proc,\,blue} = \frac{CWU_{blue}}{Y}\left[volume\ /\ mass\right] \qquad 2$$

The water footprint is calculated by dividing the green and blue water use by the crop yield. The latter one has been derived by [43] from statistical data [FAOSTAT]. Crop water use has been simulated with an approach similar to the Cropwat model by [43] on a 5 by 5 arc minute spatial resolution for the time period between 1996 and 2005. Finally, [43] provide a database with average crop water footprints over this time period for national and sub-national administrative units [WATERSTAT] which have been used in this study.

The water footprint of national consumption ($WF_{cons,nat}$) is calculated as the water footprint within the nation ($WF_{area,nat}$) plus the virtual water import (V_i) minus the virtual water import V_e.

$$WF_{cons,nat} = WF_{area,nat} + V_i - V_e\,[\text{volume/time}] \qquad 3$$

The gross virtual water import is calculated as

$$V_i = \sum_{ne}\sum_{p}\left(T_i\left[n_e,p\right]\times WF_{prod}\left[n_e,p\right]\right. \qquad 4$$

in which represents the imported quantity of product p from exporting nation n_e (product units/time) and WF_{prod} $[n_e,p]$ the water footprint of product p as in the exporting nation n_e(volume/product unit).

The virtual water import dependency defined as the ratio of external to the total water footprint as shown in Eq. (6). It is calculated based on the formula given by [40]

$$WD = \begin{cases} \dfrac{NVWI}{WU + NVWI} \times 100 & \text{if } NVWI \geq 0 \\ 0 & \text{if } NVWI < 0 \end{cases} \qquad 5$$

WU denotes the total water use in the country ($m^3\,y^{-1}$), and NVWI is net virtual water import or external water footprint.

The water requirement differs significantly for different crops in different regions and sometimes within the region. The global average water footprint for crops varies from 200 $m^3\,ton^{-1}$ (sugar crops) to 4000 $m^3\,ton^{-1}$ (pulses) [42]. We used the values of water demand for each crop product (and its derived products) of each country provided by [43]. We used each country's average water demand instead of the different cities or regions. The water intensity or water footprint of crop products were obtained from [43]; and animal products from [44].The virtual water content of animal products is based on the water content to produce feed and volumes of drinking and other services. In the case of Qatar, the food export in 2015 was negligible (<3000 tons) and the food import in the same year was 0.81 million tons. The total virtual water flow out of Qatar is negligible. Therefore, the total virtual water flow is equal to the virtual water flow in Qatar through imports.

We collected the agrifood import dataset from the foreign merchandiser trade database co-managed by the Ministry of Development Planning and Statistics (MDPS) and General Customs Authority of Qatar. Detailed data recorded only from 1998. The merchandiser data classified in different formats such as HS and SITC. We used Harmonized System (HS) data at eight-digit level. The database is dynamically updated every month recording up to date trade volume. The database records the quantity, price and the origin of the product. The data processed into a standard format and grouped them into manageable categories. To illustrate, there are eight kinds of rice categories recorded in the database atan HS-8 level such as semi-milled rice, broken rice, rice in the husk and the like. All of them grouped into a single commodity- rice. We repeated the process for major commodities. We used water footprint values for each commodity based on the import quantity. For instance, the water footprint values of rice and wheat are taken for HS product—rice, semi-milled or wholly milled (which is 97% of the total rice import in 2015), and durum wheat, wheat nes, and meslin (which is 91% of the total wheat import in 2015). We did a similar exercise for various categories (raspberries, blueberries are grouped them into strawberries). We believe this grouping will not substantially influence the overall virtual water flow. We ignored the virtual water trade for live animals. Because it is difficult to determine whether the animals imported were at the full age for slaughtering or at tender age aimed to grow in Qatar. This assumption will influence the total virtual water because of varying water footprint intensities in importing and the host country. Therefore, we ignored the virtual water content of live animals import in this study. We calculated the virtual water content of the country for each product exceeding 100 tons for the combined period, 1998–2015. The partnered country recorded in the database is from the last consignment of the global supply trade routes. According to the database, the second largest agrifood trading partner is the United Arab Emirates (UAE), totaling 0.15 million tons of food commodities traded in 2015. However, UAE is itself a net food importer. Since it is impossible to trace the origin of the product, we equally distributed the products originating from UAE to other major trading partners such as rice from India, Pakistan and Thailand, sugar from Brazil and India, and wheat from Russia, Australia, and Canada.

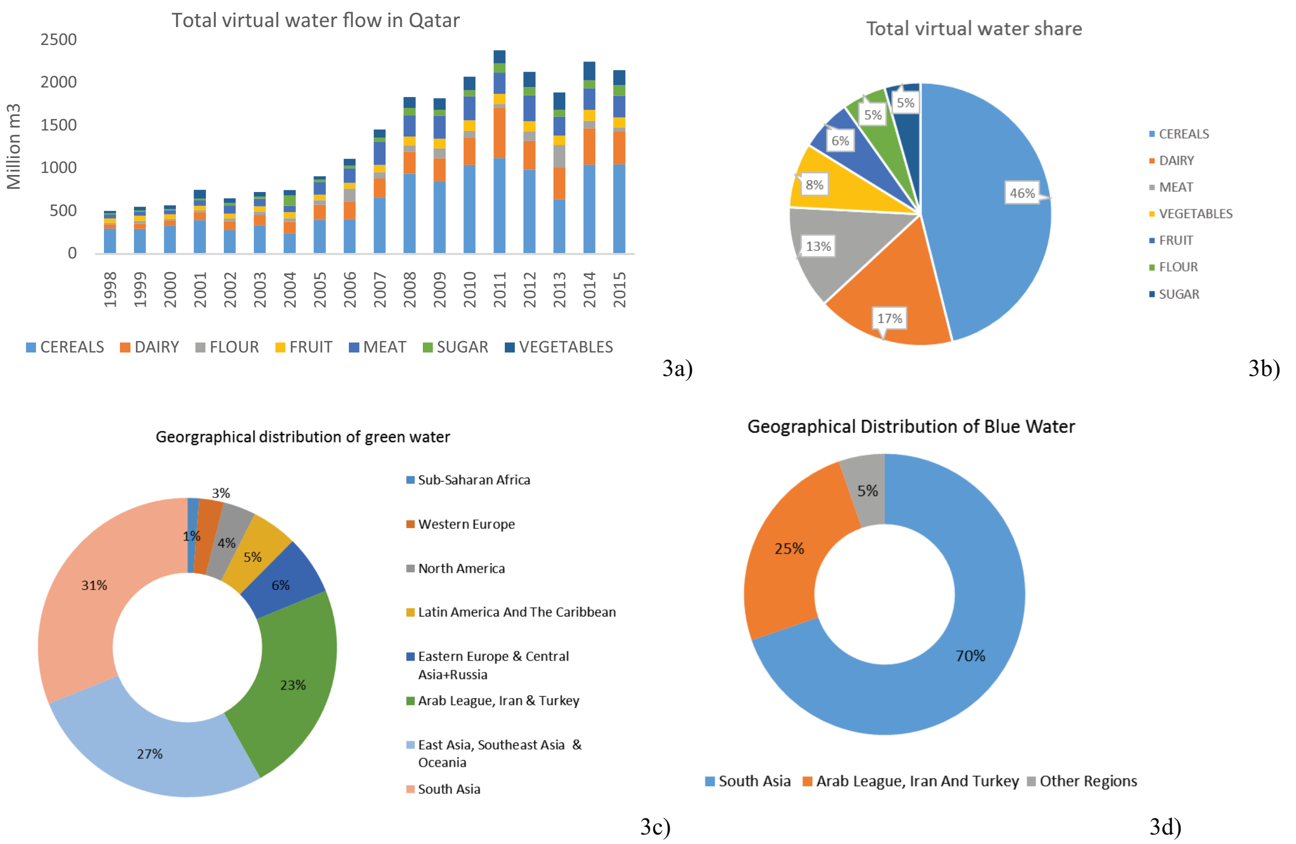
A simple multiple regression model was used to assess the key driving factors of virtual water import in Qatar.

$$\begin{aligned} VW = \alpha + \beta_1(\text{Income}) + \beta_2\,(\text{Population}) + \beta_3\,(\text{GDP}) \\ + \beta_4\,(\text{GWW}) + \beta_5\,(\text{IWW}) + \varepsilon \end{aligned}$$

where VW is the total virtual water import in million m^3 (Mm^3), income is the per capita income (in \$), GDP is real GDP (in constant 2005\$), GWW is groundwater withdrawal (Mm^3) and IWW is the total internal water withdrawal including desalination and treated wastewater effluent (Mm^3). The number of observations in the regression is 18 for each variable. The selection of the independent variables is based on the results of correlation analyses of factors that are more likely to influence virtual water import.

4. Results and discussion

Qatar is a net virtual water importing country. The total virtual water flow was 24,470 Mm^3 for the period 1998–2015, with an average virtual water flow of 1,350 Mm^3/y. The total virtual water flow into Qatar increased from 500 Mm^3 in 1998 to 2147 Mm^3 in 2015 (Fig. 3). Green and blue water represent 69% (16,795 Mm^3) and 31% (7,676 Mm^3) of the total virtual water. This shows the strategic importance of green water. Between 1998 and 2015, the green and blue water import increased 372 and 225% respectively. By far, cereals has the largest water (green and blue) footprint, accounting 46%, followed by dairy 17%, meat 13%, vegetables 8%, fruits 6%, flour, and sugar 5% each. Cereal import constitutes the largest share (41%) of green water, followed by dairy (21%), meat (18%), vegetables (8%), fruits (5%), flour (4%) and sugar (3%).The largest contributor of blue water is cereals (56%), fruits (10%), dairy and flour (9% each), sugar and vegetables (7%, each) and meat (2%). Nearly 10% of the water demand for agricultural commodities is met by domestic sources, whereas 90% of outside water used for producing agricultural products. On average, the total volume of the water used for overall food consumption is ten times more than the volume of water used in Qatar. In other words, the actual water use in the agricultural sector from a production and consumption perspective is 0.25 $km^3\,y^{-1}$ and 2.57 $km^3\,y^{-1}$ (the global water footprint), respectively. Qatar's dependence on virtual water for agricultural products increased from 63% in 1998 to 90% in 2015. In other words, the virtual water is five times more than the domestic water for overall food consumption. The water dependency index shows that, on average, 70% of the water requirement is from virtual water import, reaching an all-time high of 77% in 2011. Qatar's per capita water footprint is 1,554 $m^3\,y^{-1}\,cap^{-1}$, which is slightly



3a) 3b)

3c) 3d)

Fig. 3. Clockwise direction from top left: 3a) Time series of virtual water flow in Qatar for all products; 3b) Total virtual water share; 3c) Geographical distribution of blue water; 3d) Geographical distribution of green water.

higher than the global average (1240 $m^3 y^{-1} cap^{-1}$). However, far less than the USA (2,480 $m^3 y^{-1} cap^{-1}$) and other European countries such as Italy and Spain (2300–2400 $m^3 y^{-1} cap^{-1}$) [45]. The per capita virtual import is 1058 $m^3 y^{-1} cap^{-1}$, and it is considerably higher compared to the MENA average of 601 $m^3 y^{-1} cap^{-1}$ (2010). Nonetheless, in the last few years, there is a declining trend, it is not because of shrinking in import, but increase in low-income expatriate population [13] estimated Qatar's net virtual water import was 49 Mm^3, and water dependency was 17.8% for 1995. Whereas, our results show a tenfold increase in net virtual water import (500 Mm^3) and water dependency was 55.4% for 1998. The difference in population and food import between 1995 and 1998 was minimal. A possible explanation for this inconsistency is the data taken from the international datasets for domestic freshwater renewable resources, and food import is not complete. Also, the new datasets we employed has a high resolution virtual water content of crops.

A simple multiple regression analysis was calculated to show the major factors that influence virtual water import. The regression results show a statistically significant coefficient for per capita income ($p < 0.05$), population ($p < 0.1$), and total internal water withdrawals ($p < 0.05$). Table 2b shows per capita income, population and GDP have high correlations with the virtual water import. This shows that population and per capita income contributes substantially to the increase in the virtual water. In other words, for every 100,000 increase in population, 127 Mm^3 of virtual water increases. Over the last two decades, the population quadrupled from 0.56 million in 1998 to 2.42 million in 2015, on average, the growth rate was 9%. During 2005–2009, the average growth rate was 17%. Similarly, on average, the virtual water growth rate was 10%, with the exception of 20% between 2005 and 2009. This suggests that there is a strong relationship between population growth and virtual water import.

South Asia remained the major (31%) green water exporter, followed by East Asia, Southeast Asia and Oceania (27%), Arab League, Iran & Turkey (23%), and the rest 19% was from other regions. Similarly, South Asia occupies the major share (70%) of blue water, followed by Arab League, Iran & Turkey (25%) and the rest 5% from other regions. We noticed the green water import is spread more geographically than blue water. Fig. 4 shows the geographic distribution of virtual water inflow (consumption of food commodities) to Qatar. At a country level, India (22.6%), Australia (19.6%), Saudi Arabia (16.8%), Pakistan (8%) and Brazil (3.4%) are the five major green water imports, accounting 70% of the total green water import. Similarly, Pakistan (46.5%), India (23%), Saudi Arabia (12.5%), Egypt (3%) and Iran (2.2%) are the five major blue water imports, accounting 87% of the total blue water import. For more details, check supplementary figures. Rice, wheat, red meat, and dairy products are the major influencers of the virtual

Table 2a
Descriptive statistics

	Virtual Water (million m^3)	Per capita income (USD)	Population	Real GDP (2005 prices, bn)	Local groundwater withdrawal (Mm^3)	Total internal withdrawal (Mm^3)
Mean	1359.54	58700.94	1267021.1	72.84	252.68	571.47
Median	1283.88	61545.65	1133972.0	61.24	248.24	527.28
Standard Deviation	695.37	27053.44	625680.3	42.40	24.81	187.12
Minimum	500.63	18680.30	560990.0	26.70	217.99	352.73
Maximum	2379.76	96735.40	2423175.0	140.97	307.44	927.56

Correlation matrix of possible factors influencing virtual water import

	1	2	3	4	5	6
Virtual water (Million m^3)	1					
Per capita income (USD)	0.933	1				
Population	0.949	0.898	1			
Real GDP (2005 prices, bn)	0.958	0.917	0.989	1		
Local groundwater withdrawal (Mm^3)	–0.246	–0.304	–0.219	–0.206	1	
Total internal withdrawal (Mm^3)	0.920	0.881	0.984	0.980	–0.090	1

Table 2b
Correlation matrix

Regression statistics	
Multiple R	0.978
R square	0.956
Adjusted R square	0.938
Standard error	173.51
Observations	18

Table 2c
Regression results

	Coefficients	Standard error	*t* stat	*P*-value
Intercept	–189.2125	544.9153	–0.3472	0.73
Per capita income (USD)	0.0099	0.0042	2.3738	0.04
Population	0.0013	0.0006	1.9959	0.07
Real GDP (2005 prices, bn)	11.0628	7.7330	1.4306	0.18
Local groundwater withdrawal (Mm^3)	4.3074	2.6790	1.6078	0.13
Total internal withdrawal (Mm^3)	–4.4519	1.9614	–2.2698	0.04

water footprint. In the next section, we investigate the dependence of these basic commodities on the river basins and ground water aquifers in India/Pakistan, Australia, and Saudi Arabia.

5. Globalization of water resources

The globalization of water resources (copied the title from the paper [40]) helped to ameliorate the food security crisis in water-scarce countries. On average, 695 G m^3 y^{-1} of virtual water flowed between countries over the period 1995–1999 [40]. In this section, we address two elements – virtual water of commonly consumed food commodities, secondly relationship between Qatar's food security and river basins in India/Pakistan (Indus/Ganges), Australia (Murray-Darling) and groundwater aquifers in Saudi Arabia. We briefly discuss the global impact of these river basins, water withdrawal for domestic production, global exports and amount of virtual water exported to Qatar in the form of four major commodities – rice, wheat, meat and dairy products. Indus/Ganges river basin (India/Pakistan) for rice/wheat, Murray-Darling Basin (Australia) for wheat and livestock; and Wajid and Umm er Radhuma-Dammam Aquifers (Saudi Arabia) for dairy products. In India and Pakistan, wheat is grown only near the Indus (98% in Pakistan, 27% in India), GBM basin (62% in India), whereas in Australia, 48% of the wheat is grown in the MBD basin (Arjen Y. Hoekstra, 2013, ABS, 2008). We assumed that all the wheat and livestock imported from Australia produced in Murray-Darling Basin (MDB). Whereas in the case of rice, a substantial amount of rice is grown in the North India especially in the Indus/Ganges basin, whereas the rest of the rice imported from India produced in southern states such as Tamil Nadu, Kerala, Andhra Pradesh and Karnataka. Additionally, the majority of dairy farms grew in three provinces which cover Wajid and Umm er Radhuma-Dammam aquifers. The recent household survey indicates the monthly average of food quantity for a Qatari household was about 56 kg of rice (all types), 33 kg of bread (all types),

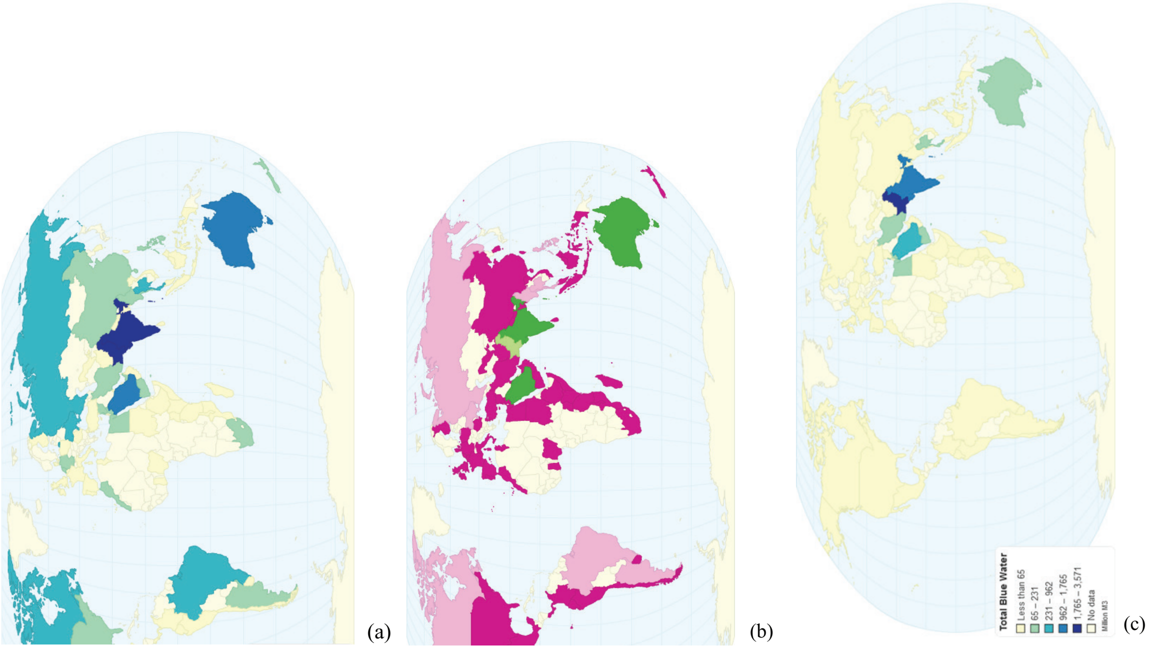


Fig. 4. a) Total virtual water flows b) Green water c) Blue water. All the values are from 1998 to 2015, Million m^3.

38 kg of meat, 33 kg of poultry, 24 liters of fresh milk, 17 liters of concentrated milk, 8 liters of milk (all types of Laban "yogurt"), and 16 kg of other dairy products [25]. Rice, wheat, meat and milk alone contributes 63% and 64% of total green and blue water.

5.1 Rice

India is one of the largest green water users for rice production, accounting 136.3 km^3/y (54% of rice water footprint), and Pakistan's blue water footprint was 16.3 km^3/y (81% of rice water footprint). Of the top 10 virtual water exporters (of rice), India (5.1km^3/y) and Pakistan (2.9 km^3/y) occupy the second and fourth position respectively [47]. Indus River Basin accounts for 98% of wheat production in Pakistan, 62% in the Ganges, and 27% in the Indus Basin and 48% of the wheat is grown in the Murray-Darling Basin in Australia. The total water footprint of wheat production from Indus (78.36 G m^3/y), Ganges/Brahmaputra/Meghna (95.95 G m^3/y), and Murray-Darling Basin (22 G m^3/y) accounts 18% of the total WF of wheat production. The blue WF for wheat production in India and Pakistan is 81.3 G m^3/y and 27.7 G m^3/y respectively. These two basins alone account for 47% of the global blue water footprint.

Rice is the most common staple food in Qatar. The local population and expatriate population (especially from the Asian continent, which forms a majority of the total population) are the major consumers of rice. Between 1998 and 2015, the total rice imported was 1.88 million tons with an average annual growth of 9.3%. Basmati (long grain white rice) is the most common rice consumed in Qatar. India and Pakistan are the major exporters of Basmati rice. In India, Basmati is primarily grown in Punjab, Haryana and Uttar Pradesh (96% of total Basmati production) (AIREA, 2016); and in Pakistan, it is primarily grown in Punjab and Sindh (accounts 88% of total rice production) [48]. The total virtual water of rice product in the same period was 6.4 km^3, accounting for 26% of the total virtual water flow in Qatar. Nearly 50% of the total blue water is from rice, whereas, the green water accounts only 16% of total green virtual water. The top five green water exporters (rice consumption) is India (1305 Mm^3, 49%), Pakistan (971 Mm^3, 36%), Thailand (348 Mm^3, 13%), Vietnam (21.77 Mm^3, 0.81%) and Australia (10.86 Mm^3, 0.4%) respectively. These five countries account for 99% of total green water for rice consumption. Pakistan (3189 Mm^3, 84%) and India (423 Mm^3, 11%) alone account for 95% of total blue water for rice production. However, in the last few years, the blue water from Pakistan declined steadily, whereas the green water from India increased because of a shift in importing countries. India's rice import increased consistently after the Pakistan floods that ravaged the nation in 2010. The cereals import from Pakistan dropped to 28 kilotons in 2015 from 130 kilotons in 2010, whereas, the India's cereal import increased from 19 kilotons in 2010 to 117 kilotons in 2015 respectively. This import decline from Pakistan is concurrent with its export values. Pakistan's exports of basmati rice have declined by 40% in the past four years, from 1.1 MT in 2011 to 676,630 tons in 2015 [49]. Another factor influenced the decline in blue water is the difference in virtual water content of India and Pakistan. The green water footprint for rice production in India and Pakistan is 2011 m^3/ton and 963 m^3/ton, and blue water footprint is 652 and 3162 m^3/ton respectively[43].

5.2 Wheat

Wheat is the second most common food in Qatar. Between 1998 and 2015, the total wheat import was 1.54 million tons, with an average annual growth of 7.4%. Australia (37%), Canada (14%), India (14%), Russia (9%), and Pakistan (7%) are the five major importers of wheat, accounting 82% of total wheat import. Nearly 12% of the total virtual water was from wheat and 25% of total virtual water for cereals. The total virtual water for wheat contributes 34% of the total green and 10% of the total blue water for cereals. The top five green water exporters (wheat production) is Australia (1154 Mm^3, 48%), Russia (523 Mm^3, 22%), Canada (289 Mm^3, 12%), India (133 Mm^3, 6%), and Pakistan (69 Mm^3, 3%) respectively. These five countries account 90% of green water for wheat imports. Whereas in the case of blue water, Pakistan (246 Mm^3, 55%) and India (35Mm^3, 35%) contributes 90% of total blue water export for wheat consumption. The blue water footprint for India and Pakistan is 1171 m^3/ton and 1469 m^3/ton, far higher than Australia (16 m^3/ton) and Canada (5m^3/ton).

5.3 Meat

Compared to global averages, Qatar's per capita red meat consumption is considerably low. The per capita red meat and poultry consumption, in 2015, was 17.2 kg, and 42.7 kg respectively. This trend is upward because of obvious reasons, increase in wealth and change in lifestyle. Nearly 1.4 million tons of meat imported between 1998 and 2015, of which, poultry takes a huge share of 73%, and lamb/sheet/goat combined 18% and beef 8.8%, respectively. In this section, we focus on the virtual water flow of red meat (including lamb/sheep/goat and beef, swine consumption is negligible contributing less than 0.3% of overall meat import). Brazil, USA, Australia, India, and Saudi Arabia are the five major exporters of meat to Qatar. These five countries alone contribute 87% of total meat import. However, India and Australia are two major importers of red meat. For instance, 36%, 23%, 45%, 38% of beef, goat, lamb and sheep imported from Australia. Also, Australia exports 55% of live animals (sheep, lamb, goat and bovine animals) to Qatar. We estimated virtual water only for the meat not for the live animals imported. Meat accounts for 13% of total virtual water, green and blue water shares are 18% and 2%, respectively. The total green virtual water for red meat for the period 1998–2015 is 2972 Mm^3, of which, bovine meat takes a huge share of 46% (1380 Mm^3), followed by lamb and sheep 22% (643 Mm^3) each, and goat 9% (277 Mm^3) respectively. Australia is the second largest exporter of virtual green water for beef (278 Mm^3, 20%), trailing behind India of 35% (478 Mm^3), Brazil (11%, 150 Mm^3), and Saudi Arabia (12%, 166 Mm^3). These four countries alone share 78% of total green water for beef. The green water for other red meat (goat/lamb/sheep), Australia takes a significant share of 39% (621 Mm^3), followed by Brazil 22% (344 Mm^3), and India 15% (239 Mm^3). These countries account three-fourth of total green water. The blue water consumption for meat consumption is very low, accounting only 146 Mm^3 of overall blue water import. The blue water consumption remains high for bovine meat accounting 41% and other red meat shares 59%. Australia's total green and blue virtual water are 899 Mm^3 and 27 Mm^3 representing 30% and 19% of total virtual water for meat consumption.

5.4. Dairy products

Saudi Arabia is a major producer of dairy products, vegetable and fruits and also a major exporter in the Gulf region. In 2013, 1.94 million tons of milk was produced. Dairy is a significant share of food exports, in 2014, 720 kilotons were exported representing 58% of total food export [50]. In our study, we limit the water withdrawal for green forage production for animal feed, as most of the green and blue water came from dairy consumption. There is very limited accessible data about the breakdown of groundwater consumption in Saudi Arabia. Some of the information published were outdated, incomplete and contradictory. It is very difficult to distinguish the forage consumption for dairy cattle and cattle for meat production. Considering the total output of dairy products, we assume three-fourths of the forage is used for dairy cattle and rest for meat production. The dairy farms partially produce the feed (forage crops) within the country and rest is sourced from the international market. Nearly 7.7 million MT of barley imported in 2013/2014, of which 5.39 million MT used as animal feed. Since wheat and barley production reduced significantly, there is a shift in green forage production throughout the country. The total area for green forage production increased from 151,301 ha in 2007 to 195,605 ha in 2014. In 2014, 4 million MT of green forage was produced, a 60% increase compared to production level in 2007 [51].

During 1980–1990s, wheat was the main crop grown in the area, but from the 1990s, the wheat crops were replaced by green forage crops. Nearly 65 % of the total irrigated area in the Wajid aquifer is forage crops and rest of the area used for growing fruit and vegetables. The central section of the Umm er Radhuma-Dammam aquifer system is one of the heavily exploited systems for agricultural development projects. The annual abstraction increased from 20 Mm^3/y in 1975 to 1000 Mm^3/y in 2010, accounting the cumulative abstraction of 24.3 km^3. Over 80 % of the abstraction used for irrigation. Three provinces cover these two aquifer systems – Riyadh, Eastern, and Najran. The total area of fodder crop in these three provinces accounts 55% and 57% of total forage area and production. In 2013, 96% of the milking cows was grown in the Eastern and Riyadh provinces, where most of the Umm er Radhuma-Dammam aquifer is situated. The irony of reducing of wheat production and replacing with green forage production is equally detrimental to the water resources. The water consumption increased for foraged production because of three harvests in a year. Recently, the Saudi government announced to phase out producing green fodder production and rely on international imports because of exhaustion of aquifers in some regions[9].

Saudi Arabia exported 2463 kilotons of food commodities to Qatar between 1998 and 2015, making the largest exporting partner. Over 63% of total dairy products (70% milk, 26% cheese, and 8% butter) were imported from Saudi Arabia between 1998 and 2015. Saudi Arabia is the third largest virtual water exporter to Qatar accounting 3.7 km^3 of which green water and blue water share are 2,834 Mm^3 and 962 Mm^3 respectively. Over 90% of the green water (2.55 km^3) is consumed in dairy products. The blue water consumption share is as follows – 513 Mm^3 (53.3%) for dairy products, 253 Mm^3 (26.2%) for fruits and 179 Mm^3 (18.6%) for vegetables. By far, milk consumption has the largest virtual water share of 78% and 46% of total green and blue water.

The total virtual water flow from these three hydrological systems was 11,162 Mm^3, of which 40% and 58% is green and blue water as shown in Fig. 5. These basins and aquifers export significant volumes of virtual water not only to Qatar but other countries as well. However, these river basins and groundwater aquifers are facing severe water shortages in last few years. The river basins in India/Pakistan are dry during summer because of precipitation changes, excessive withdrawal, and pollution in the upstream. In the last two decades, there is a shift in water withdrawal from surface water to groundwater. In 2000–01, 10.3 million ha of Punjab province of Pakistan was irrigated by groundwater and 3.7 million ha of surface irrigation. The negative effect of this shift is clearly visible these years because of declining groundwater tables and increase in salinity. The blue water consumption in the Indus basin and its growing negative impacts mentioned elsewhere [52]. In 2007, Murray-Darling Basin faced one of the worst droughts in the history. Water inflow in the Murray River declined to half of the historic average [61]. To conserve the shrinking groundwater aquifers (renewable and non-renewable), in 2008, the Saudi government decided to phase-out wheat production by 2016 citing reasons of groundwater exhaustion across the country. In 2015, the total wheat production was 30,000 MT falling from the peak 4.1 million MT in 1992. Similarly, the barley (for animal feed) production dropped from 2.2 million MT in 1993 to 15,000 MT in 2014 [51]. A dedicated analysis is required to assess the hydrological and climate change impacts on river basins and its implication on Qatar's food security. Nevertheless, the volume of the food import is not significant compared to global and regional countries. Therefore, the implications will not be worse as imagined, as the global food supply chain is well established [54]; cereals such as wheat and barley can be imported from any major producing countries if the current countries are experiencing water scarcity or other climate-related damages.

6. Policy implications

As noted above, many countries are increasingly looking virtual water trade as a source of policy criterion. One such case is the British Columbia in Canada. Brown et al. [55] estimated virtual water on a watershed level in dry and wet regions. In the wet region of Lower Fraser Valley, the virtual water use for crops was 32 Mm^3, with an average value of $95 million, whereas in the Okanagan region require 63 Mm^3 to grow berries and livestock. Virtual water estimation helped the decision makers to utilize the water resources better and expected to make strategic choices of reallocation and conservation of water use [55]. A similar case is observed in the Mancha Occidental Region, Spain. Aldaya et al. estimated virtual water and economic value for different products and observed vineyards have low virtual water content, yet produces high economic value. In contrast, the virtual water content of wheat is high, yet low economic value. The farmers continue to grow cereals despite environmental challenges because of continuous

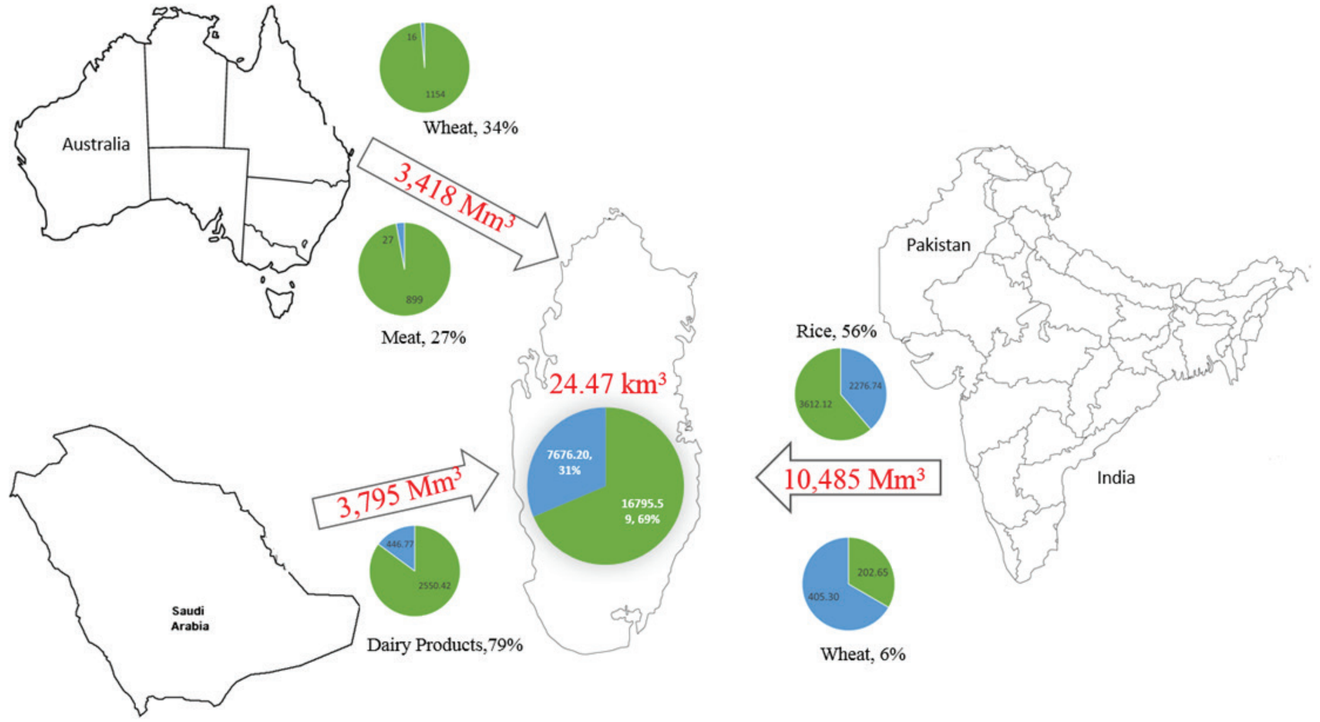


Fig. 5. Virtual water inflow from three major river basins and groundwater aquifers (the values in red shows the total VW flow from each country between 1998 and 2015. The values in % shows the virtual water share of each product from the respective countries.

support under the framework of European Unions' Common Agricultural Policy (CAP) subsidies. The political and economic challenges impede the effective utilization of virtual water concept from the policy perspective [56].

Managing shrinking water resources is becoming a major challenge in arid and semi-arid countries. The GCC countries are pursuing rigorous policies in saving domestic water and finding alternative ways to ensure long-term water security. Apparently, the effort to increase self-sufficiency will be limited to water-extensive, high value crops like vegetables and fruits. Import dependence on cereals such as wheat, rice and barley will be significant for the coming years. As outlined before, Saudi Arabia was self-sufficient for wheat and became a sixth largest exporter of wheat in the 1990s [33], and in 2016, the government decided to phase out wheat production completely and depend entirely on food imports [51]. Most of the food importing countries in the region has a serious concern of geopolitics of food trade. The residual memory of 1970s food embargo is still very much in the minds of regional leaders. The recent food crisis in 2007–2008 has led the GCC countries to look for various alternatives, and one of the strategic choices is to procure large farms in countries with abundant arable land and water resources [30]. As the water scarcity deepens, the Qatar government is actively looking for ways to conserve water resulting in the creation of committees to develop a new Water Policy Act. This will be expected to come into force by the end of this year which regulates the water production, distribution, consumption, and reuse. Groundwater allocation to agricultural sector remains a fundamental challenge because of its strategic importance as freshwater for domestic use when there are unforeseen circumstances such as oil spill and algal blooms. Even long before the concept of virtual water emerged, the arid countries in the region follow this principle – "what-we-cannot-grow-let's-buy-it." Though virtual water helps to identify the total water requirement besides domestic consumption, it is difficult to make any impact in policymaking. We doubt whether the concept of virtual water will be officially integrated into the national policy or national water balance despite its significant share in total water footprint. It is also unlikely we can see any shift in policy because of higher blue or green water import from countries that are struggling with water scarcity. Additionaly, there will not be a shift in food import countries where the blue/green water footprint (m^3/ton) is lower. The food trade will be based on the economics and accessibility rather than virtual water content [14]. To illustrate, can Qatar substitute Saudi Arabia to another country because of its depleting groundwater aquifers or shift its rice import from India/Pakistan to Thailand because of high blue water content? This may happen only when the exporting country changes its export policies (Saudi government banning forage production [29]) or struck by adverse circumstances such as floods/droughts.

7. Conclusion

The purpose of the study was to draw the relationship between virtual water trade and food-water security in Qatar. No previous study has examined the virtual water flow in Qatar at a detailed level. The results provide the total water requirement to grow food in Qatar to maintain the current levels of food security. The study has shown that Qatar imported 24.4 km^3 of virtual water between 1998 and 2015. Qatar's green water dependence outweighs blue water. The green water import is twice than the blue water import, as most of the food imported from the rainfed irrigation areas. We calculated virtual water flow for 80% of the imported food commodities. Rice, wheat, meat and dairy products are the major source of virtual water, contributing 63 and 64% of green and blue water. Qatar is a net virtual water importer and its dependency on virtual water is about 68%. On average, 70% of the total water requirement is from virtual water import and Qatar's dependence on virtual water for agricultural products increased from 63% in 1998 to 90% in 2015. The regression results show the population, income growth, and declining domestic water withdrawal are the major factors that influence virtual water import in the country. Qatar's per capita water footprint is 1,554 $m^3\,y^{-1}\,cap^{-1}$, which is slightly higher than the global average (1240 $m^3\,y^{-1}\,cap^{-1}$). South Asia remains one of the key exporters of food and virtual water, especially, water-intensive cereals wheat, rice and livestock products. India, Australia, Saudi Arabia, Pakistan and Brazil are the major green water exporters, accounting 70 of the total green water. Pakistan, India, Saudi Arabia, Egypt, and Iran are the major blue water exporters accounting 83% of total blue water. Because of increase in import, the virtual water will be in upward trend. This study examined Qatar's dependence on river basins in India/Pakistan, Australia and groundwater aquifers in Saudi Arabia. The total virtual water flow from these three hydrological systems was 11,162 Mm^3, of which 40% and 58% is green and blue water. So far, the virtual water trade discourse was completely absent and never been considered part of the national water policy, this study may influence the local policymakers in taking account of virtual water and its implications on securing food and water security. This study substantiates previous studies that virtual water remains one of the major sources for domestic water security in arid countries such as Qatar.

Through virtual water, Qatar manages to secure its depleting aquifers from imminent and irreparable environmental damage. At the same time, too much of dependence on food import brings geopolitical risks such as the closure of Strait of Hormuz and Saudi Arabia's border or increase in food prices, embargoes, and the like. Additionally, it has undermined the prospects of improving water-use efficiency in the agricultural sector. However, it is virtually impossible for Qatar to grow all its food considering biophysical limitations, though, there is a huge potential to increase the production of less water-intensive and perishable crops. Already, many farms adopted new technologies such as hydroponics, greenhouses, and advanced brackish water treatment units. Compared to traditional practices, they are capital intensive. Unfortunately, very little attention is paid to the traditional agricultural methods that are adaptive to local dryland ecosystem both at a national and farm level. It is important to revive the traditional practices of crop cultivation and water harvesting methods [57–60].

Notes

1. GCC comprises of six countries – Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates
2. MENA comprises of Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, West Bank and Gaza, and Yemen. In the study [20,21], they included Iran, Turkey, and Israel.
3. SAARC includes Afghtsanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka

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Supplementary Figures and Tables

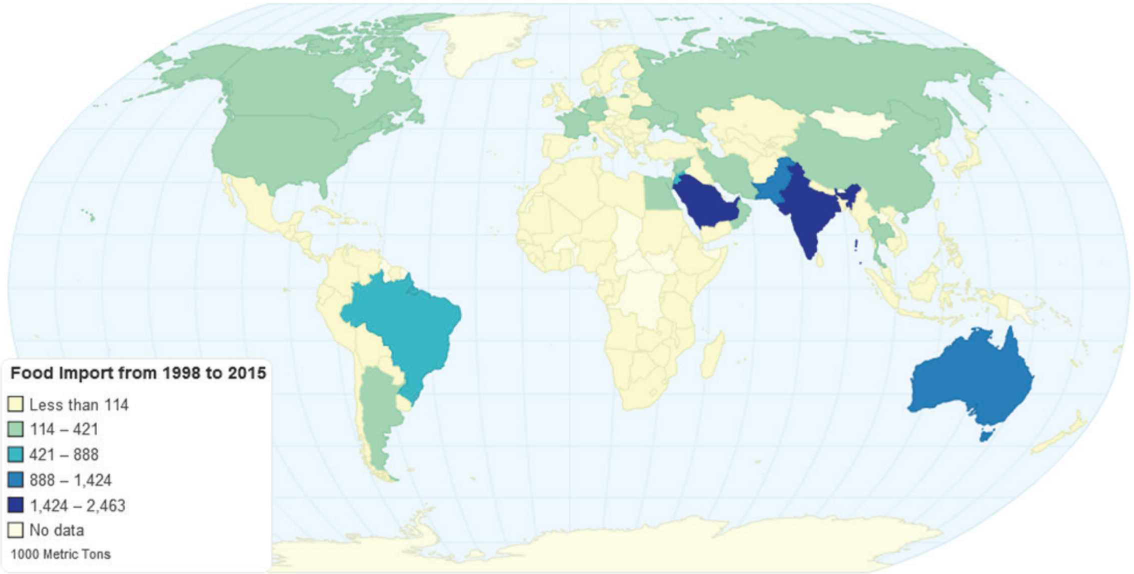

Fig. A1. Food import in Qatar from 1998 to 2015 (Source: Foreign Trade Merchandiser data).

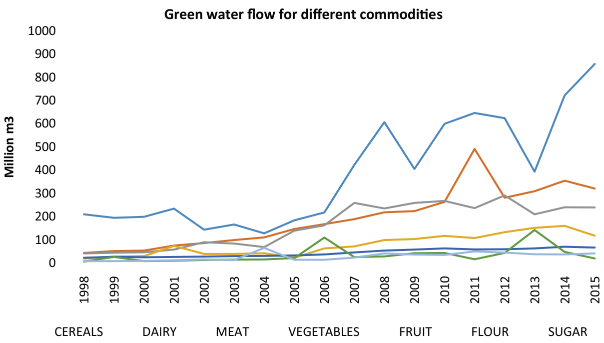

Fig. A2. Green water flow for different commodities.

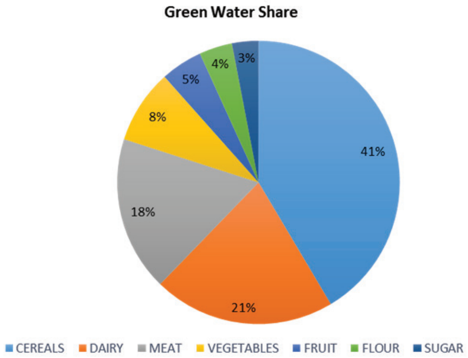

Fig. A4. Green water share for different commodities.

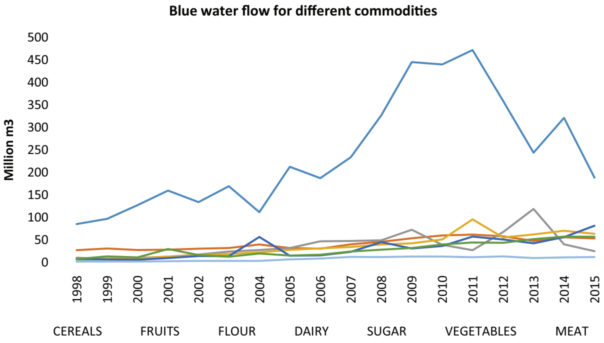

Fig. A3. Blue water flow for different commodities.

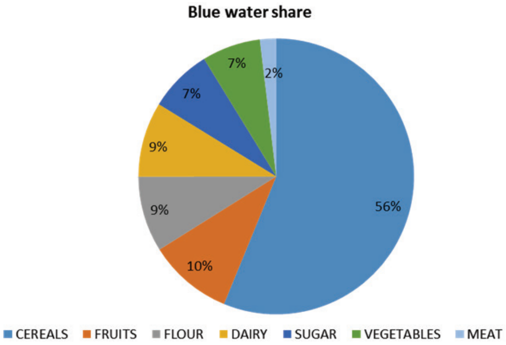

Fig. A5. Blue water share for different commodities.

CEREALS	VEGETABLES	FRUITS	DAIRY	MEAT	FLOUR & SUGAR
Barley	Beans	Almonds	Butter	Goat	Barley
Canary Seed	Beetroot	Apples	Cheese	Sheep	Maize
Grain Sorghum	Brussels Sprouts	Apricots	Milk	Bovine	Millet
Maize	Cabbages	Avocados		Lamb	Rice
Millet	Capsicum	Bananas			Wheat
Oats	Carrots	Nuts (Including All)			Sugar
Rice	Cauliflower	Cherries			
Rye	Chickpeas	Coconuts			
Wheat	Coriander	Dates			
	Corn	Dried Figs			
	Cucumbers	Fresh Figs			
	Egg Plants	Grapes, Fresh			
	Garlic	Guavas			
	Ginger	Lemons			
	Lentils	Mandarins			
	Lettuce	Mangoes			
	Mushrooms	Muskmelon			
	Okra	Nuts Edible			
	Olives	Oranges			
	Onions	Papayas			
	Parsley	Peaches Fresh			
	Peas	Pears			
	Potatoes	Pineapples			
	Pumpkins	Pistachios			
	Soya Beans	Plums Fresh			
	Squash	Pomegranates			
	Tomatoes	Prunes, Dried			
	Truffles	Quinces, Fresh			
		Raspberries			
		Strawberries			

Crops used in virtual water calculation