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Assessment of Virtual Water Flows in Morocco's Foreign Trade of Crop Products

Abdeslam Boudhar [1,*], Said Boudhar [2], Mohamed Oudgou [3] and Aomar Ibourk [4]

[1] Economic and Management Sciences Studies and Research Laboratory (LERSEG), Polydisciplinary Faculty, Sultan Moulay Slimane University, Beni Mellal 23000, Morocco
[2] Department of Economics, Faculty of Law, Economics and Social Sciences, Cadi Ayyad University, Marrakech 40000, Morocco
[3] Economic and Management Sciences Studies and Research Laboratory (LERSEG), National School of Business and Management, Sultan Moulay Slimane University, Beni Mellal 23000, Morocco
[4] Social and Solidarity Economy, Governance and Development Laboratory (LARESSGD), Faculty of Law, Economics and Social Sciences, Cadi Ayyad University, Marrakech 40000, Morocco
* Correspondence: a.aboudhar@usms.ma

Abstract: As a semi-arid/arid country located in the northwest of Africa, Morocco is facing serious water scarcity driven by the dual stresses of decreasing availability of water resources and increasing water demands. Virtual water trade could be an effective tool to alleviate water scarcity. The paper presents an analysis of the relationships between agrarian productions, foreign trade, and the water sector in Morocco by deriving a comprehensive estimate of virtual water export and import in Morocco's foreign trade of 40 crop products during the period from 2000 to 2017. Our objectives include determining the intensity of water consumption of exported and imported crop products and quantifying the water consumed and saved, respectively, by locally producing and importing these products. To this end, FAO's Penman-Monteith climate model was used to estimate crop water requirements based on data on meteorological factors. The results show that Morocco was a net virtual water importer during the study period. The deficit was 595.74 Gm^3. The tendency of total virtual water export was on a rising trend, while the total virtual water import was on a downward trend. The main exported virtual water was from vegetables (68.87 Gm^3, 72.47%) and the main imported virtual water was from cereals (679.68 Gm^3, 98.4%). Regarding crop product's water intensity, we found that the exported crop products were excessively concentrated on water-intensive products such as mandarins and clementines, figs, oranges, apricots, plums, citrus fruits, olives, tomatoes, asparagus, peas, and artichokes. On the other hand, the agricultural policy of 2009–2020 increased the production of water-intensive products. This finding seems to be going against the virtual water trade theory, which states that water-poor countries should import water-intensive products and produce local products with lower water requirements.

Keywords: virtual water trade; water scarcity; agricultural products; Penman-Monteith climate model; Morocco

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1. Introduction

We might start by saying that there is nothing more essential for life on earth than water. Human health, urban and rural settlements, food security, energy production, economic development, and healthy ecosystems are all water-dependent. Water is an essential input to undertake productive activities. Economic sector performance and growth depend heavily on water in every production process, either directly or indirectly. Nevertheless, it is far more than a production factor. Water has characteristics that make it a special economic good: it is essential for life and health, scarce, non-substitutable, not freely tradable, fugitive, and a complex system [1,2]. These characteristics make water a scarce economic good that cannot meet all demands.

Over the past 100 years, because of population increase, accelerating urbanization, new consumption habits, and economic growth, global water use has increased six-fold and continues to grow at a rate of around 1% per year [3]. Consequently, an increasing number of countries are reaching the limit at which water services can be sustainably provided. The United Nations estimated that about 2.3 billion people live in water-stressed countries, of which 733 million live in high and critically water-stressed countries [4]. As a result, 700 million people worldwide could be displaced by intense water scarcity by 2030 [5]. Under the current trend, the gap between global water supply and demand will reach 40% by 2030 [6]. Under the business as usual scenario, around 40% of the world's population will live in areas with severe water scarcity by 2035 and ecosystems will become increasingly unable to provide fresh water [7].

Morocco's freshwater scarcity is deeply linked to its location in the northwest of Africa (Figure 1), in that its per capita available freshwater resource is only 650 m^3 [8]. From 1960 to 2019, the available per capita renewable water resource in Morocco decreased from 2560 m^3 to 650 m^3. Moreover, water resource in Morocco is characterized by an uneven spatial-temporal distribution. The hydrographical map of the country is composed of nine hydrological basins. The two largest river basins, Sebou and Loukkos, are situated in the north of the country and contain about 47% of the total water resource, while they are home to only 19% of the total population and cover only 7.43% of the country's area (Table 1).

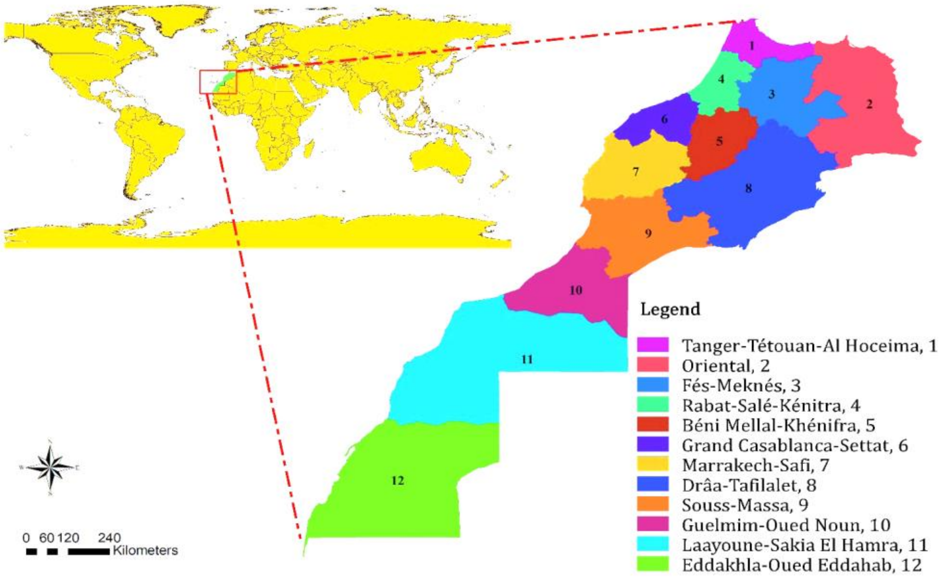

Figure 1. Geographic location and regional division of Morocco. Source: author's own.

Agriculture is the largest water-consuming sector in Morocco. It absorbs more than 87% of total water withdrawal. The definition of « Total water withdrawal » adopted in this study is that provided by FAO: Total water withdrawal is the annual quantity of water withdrawn for agricultural, industrial, and municipal purposes. It can include water from renewable freshwater resources, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of agricultural drainage water, direct use of (treated) wastewater, and desalinated water (https://www.fao.org/faoterm/en/?defaultCollId=7 (accessed on 26 March 2022)). Furthermore, irrigated agriculture is mainly export-oriented. Morocco's foreign agricultural trade value has been booming since 2010. In 2017, exports of agricultural products represented more than 22% of Morocco's total exports. The export volume increased by 59% since 2010. The international trade of agricultural products entails substantial flows of water in a 'virtual' form among countries. Therefore, assessing the impact of the international trade of agricultural commodities on water resources is helpful for understanding the driving forces behind water use and exploring new ways to mitigate the water scarcity problem in Morocco.

Table 1. Water resources (10^6 m^3), Population, and Area (10^3 km^2) by river basin.

River Basin	Surface Water (10^6 m^3)	Groundwater (10^6 m^3)	Total Fresh Water (10^6 m^3)	Cumulative Proportions	Population (10^4)	Cumulative Proportions	Area (10^3 km^2)	Cumulative Proportions
Loukkos	3600	146	3746	17	300	10	12.805	1.80
Sebou	5600	1123	6723	47	620	19	40	7.43
Moulouya	1300	610	936	55	250	40	74.145	17.86
Bouregreg	852	84	3880	59	700	63	20.47	20.74
Oum Er Rbia	3300	580	1780	77	500	80	48.07	27.50
Tensift	1140	640	1780	85	272.310	90	24.8	30.99
Ziz Guir Rheris	656	240	896	89	76.250	92	58.841	39.27
Sous Massa	1500	710	2210	98	190	99	126.48	57.06
Draa Sahara	300	40	340	100	41.649	100	305.239	100

Source: Boudhar et al. (2017) [9].

The aim of this paper is to analyze the relationship between agrarian production, the foreign trade of crop products, and the water sector in Morocco by deriving a comprehensive estimate of virtual water export and import in Morocco's foreign trade of 40 crop products during the period from 2000 to 2017. The main objectives include determining the status of Morocco's virtual water trade, calculating the intensity of water consumption of exported and imported crops, and quantifying the water consumed and saved, respectively, by locally producing and importing these products. The results of this research provide new insights to mitigate the water stress situation the country is suffering from through a virtual water trade strategy.

The original contribution of this study lies in the estimation method of the data used. This study is a critical analysis of Morocco's agricultural policy and foreign trade in agricultural products and in particular, the Green Morocco Plan, which aims to promote the production and export of agricultural products, with a focus on the effects of this policy on water resources. Although studies have been conducted on foreign trade in general, to our knowledge, no study has addressed the virtual water balance of Morocco. It is in this sense that our study aims to fill this gap through an empirical analysis of international flows of virtual water.

In order to assess the water intensity of the exported and imported crops, this paper uses "crop water requirements". Data is estimated according to climatic conditions and soil characteristics of the regions where they are cultivated and not crop water consumption data. In fact, the determinants of the agricultural orientation towards exports or local markets have historical roots. Therefore, the export-oriented sectors have benefited from great support and have become much more mechanized. Consequently, the irrigation techniques used in these sectors, and therefore water waste, are different compared to sectors oriented towards the local market. As a result, the use of crop water consumption data leads to erroneous conclusions. Thus, we can assert the advantage/disadvantage of locally producing, exporting, or importing an agricultural product only if we neutralize the effect of mechanization through the estimation of the crop water requirements according to the climatic conditions and soil characteristics.

The rest of the paper is organized as follows. Section 2 presents a literature review. Section 3 describes the method and databases used in the empirical application, and Section 4 contains the empirical results and discussions. A conclusion section ends the paper.

2. Literature Review

The impact of agriculture trade on water resources can be assessed using the "virtual water" concept. Since the 1990s, virtual water—or embedded water—has been emerging as a new perspective for water scarcity and water use management [10,11]. The virtual water concept was introduced by Allan in the 1990s [12,13]. It refers to the total volume of water used to produce a commodity. This volume depends on the production conditions including time and place of production and the efficiency of water use. The virtual water trade refers to virtual water transfers associated with the international trade of commodities. As a matter of fact, when a good is exported/imported, the virtual water used for the production of this good is also implicitly exported/imported. International trade is tied, therefore, to an indirect link between the water resources of a country and those of the countries with which it has trade relations.

In 1999, Allan [14] suggested that a country could implement the virtual water trade strategy by importing water-intensive products from another country and reducing the exports of products with high water consumption. For this purpose, the Virtual Water Trade analysis was developed to estimate the virtual water flow embodied in the trade of commodities. Many researchers have tried to assess the virtual water flow at global, regional, and national scales. At the global scale, virtual water trade research focuses more on the estimation of the global virtual water flows and the time series trends for virtual water trade [15–23], and investigates the drivers of trade pattern formation [24–29].

At the regional scale, virtual water trade has been largely conducted in order to explore the virtual water flows among multiple countries in a region or among countries in a basin. For example, Serrano et al. [30] Antonellia et al. [31], Fu et al. [32], Wang et al. [33] investigated the virtual water flows in the EU. Vanham [34] assessed the virtual water balance for agricultural products in EU river basins. Duarte et al. [35] analyzed the virtual water embodied in Mediterranean exports between 1910 and 2010. Hakimian [36], Antonellia and Tamea [37], Roson and Sartori [38], Saidi et al. [39], Antonellia et al. [40], Lee et al. [41] analyzed virtual water flows and virtual water trade patterns in the MENA region. Yang et al. [42] investigated food trade patterns in relation to water resources in the Southern and Eastern Mediterranean countries.

Virtual water trade has been largely analyzed at the national scale in China [43–52], Spain (e.g., [53–56]), Italy (e.g., [57–59]), Korea [60–63], and Brazil [64–67]. A few scholars have conducted quantitative studies on Morocco's virtual water flows. For instance, Hoekstra and Chapagain [68] assessed the water footprints of Morocco and the Netherlands from 1997 to 2001. They found that Morocco depends 14% on foreign water resources, while the Netherlands depends on 95%. Boudhar et al. [9] implemented the concept of virtual water within an input-output framework. The model is used to quantitatively assess the relationships between economic sectors and water use (direct use), intersectoral water relationships (indirect use), and the economic benefits of water use. Haddad and Mengoub [69] estimated the virtual water exchanged between the Moroccan regions and the rest of the world through the implementation of the concept of virtual water in an interregional input-output model. However, there is no scholar who has analyzed the virtual water export and import in Morocco's foreign trade of crop products and observed the changes over a long time. Therefore, the research on Morocco's international virtual water trade of agricultural products needs to be enriched.

3. Materials and Methods

3.1. Estimation of the Crop Water Requirements

The estimation process of the crop water requirements and virtual water is presented in Figure 2. In this study, the crop water requirements are estimated by using the FAO Penman—Monteith model and the CROPWAT software developed by the Food and Agriculture Organization of the United Nations (FAO).

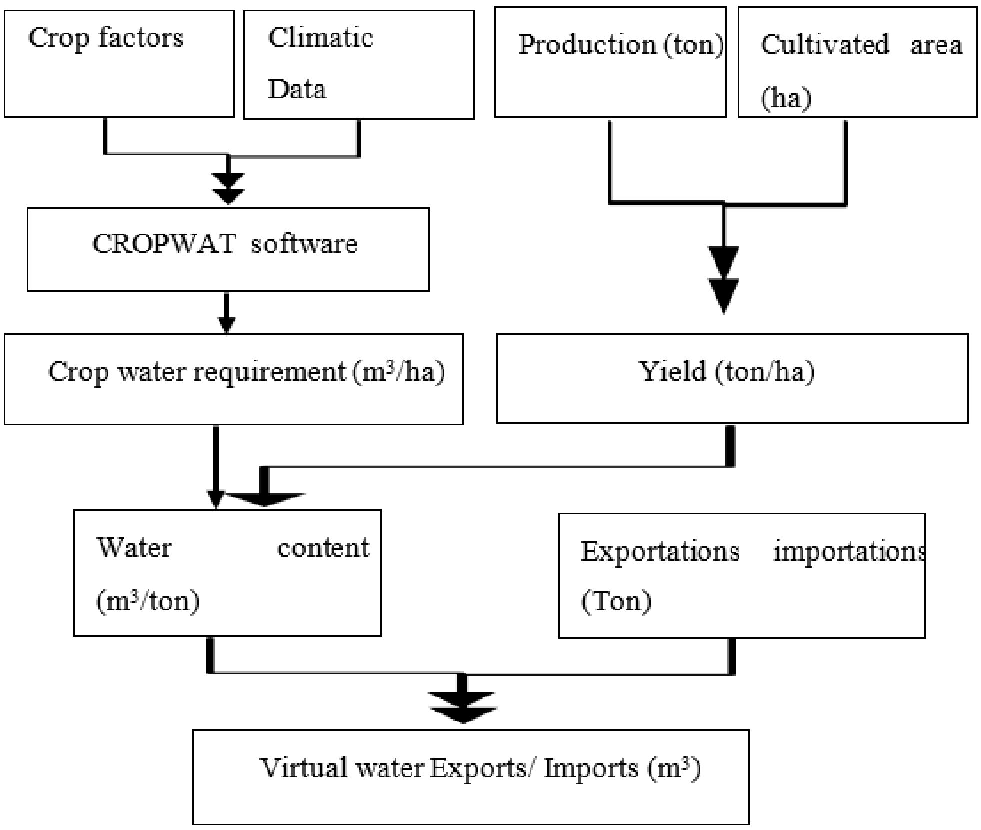

Figure 2. Crop water requirements and virtual water estimating process.

The crop water requirement is defined in Allen et al. [70] as the amount of water required by a crop achieving full production potential to compensate for the water lost through evapotranspiration. The same authors define evapotranspiration as a combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration. After irrigating a crop, liquid water enters the soil. Much of this water is absorbed by the roots of the plant, goes up into the leaves, and is evacuated as vapor through the stomata. This evacuation is called transpiration. Another quantity of water is evacuated as vapor from the soil. This second type of evacuation is called evaporation. The sum of evaporation and transpiration is evapotranspiration (ET_c). The share of evaporation and transpiration in ET_c varies according to the leaf area. At sowing, nearly 100% of the ET_c comes from evaporation, while in full plant cover; more than 90% of the ET_c comes from transpiration. Thus, the evapotranspiration and the crop water requirements are identical.

According to the FAO Penman-Monteith model, evapotranspiration (ETc) depends on the reference crop evapotranspiration (ET_0) and the cultural coefficient (Kc) [71,72]:

$$ET_c = K_c \times ET_0 \quad (1)$$

The cultural coefficient depends on the characteristics of the plants and their development phases. The reference evapotranspiration is calculated according to the following equation [73]:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \quad (2)$$

where ET_0 or ET_{ref} is the reference evapotranspiration; R_n is the net radiation at the crop surface; G is the soil heat flux density at the soil surface; T is the mean daily or hourly air temperature at 1.5 to 2.5 m height; u_2 is the mean daily or hourly wind speed at 2 m height; e_s is the saturation vapor pressure at 1.5 to 2.5 m height calculated for daily time steps as the average of saturation vapor pressure at maximum and minimum air temperature and for hourly time steps using hourly average air temperature; e_a is the mean actual vapor pressure at 1.5 to 2.5 m height; Δ is the slope of the saturation vapor pressure-temperature curve; γ is the Psychrometric constant; C_n and C_d are respectively the numerator and the denominator constant those change with calculation time step as shown in Table 2.

Table 2. Units of Penman-Monteith equation parameters, C_n and C_d values for different calculation time steps.

Time Step	C_n	C_d	Units						
			U_2; C_d	T	e_s; ea	Δ; γ	ET_o	C_n	R_n; G
Daily time step	900	0.34					mm d^{-1}	K mm s^3 Mg^{-1} d^{-1}	MJ m^{-2} d^{-1}
Hourly time step during daytime	37	0.24	m s^{-1}	°C	kPa	kPa °C^{-1}	mm h^{-1}	K mm s^3 Mg^{-1} h^{-1}	MJ m^{-2} h^{-1}
Hourly time step during nighttime	37	0.96					mm h^{-1}	K mm s^3 Mg^{-1} h^{-1}	MJ m^{-2} h^{-1}

Source: Author's own, based on Pereira et al. [74].

In 1992, FAO integrated the FAO-Penman-Monteith model into a software called CROPWAT in order to facilitate the calculation of crop water requirements and irrigation requirements [75]. In order to overcome the lack of data needed to compute the FAO-Penman-Monteith model variables, FAO has developed the CLIMWAT for CROPWAT database [76], which provides the necessary climatic data assembled from 146 countries.

3.2. Variables

This subsection aims to present the different variables used in this study and the calculation method of each variable. The international flows of imported virtual water (VWM_i) and exported virtual water (VWX_i) associated with a crop i, expressed in cubic meters, are calculated in this work, by multiplying the annual trade flows (exports (X_i) and imports (M_i)) of the crop i, expressed in ton/year, by the water content of the crop i (WC_i), expressed in m^3/tons:

$$VWM_i = M_i \times WC_i \tag{3}$$

and:

$$VWX_i = X_i \times WC_i \tag{4}$$

A crop's net exports of virtual water (NVW_i) are the value of its total virtual water exports minus the value of its total virtual water imports:

$$NVW_i = VWX_i - VWM_i \tag{5}$$

The water content (WC_i) associated with a crop i is defined as the volume of water required to produce one ton of this crop. It is obtained by dividing the crop water requirements (CWR_i) (m^3/ha) by the crop yield (Y_i) (Ton/ha):

$$WC_i = CWR_i / Y_i \tag{6}$$

The yield of each crop i is obtained by dividing the production (P_i) by the cultivated area (CA_i):

$$Y_i = P_i / CA_i \tag{7}$$

3.3. Data

In this study, we have taken into account the imported and exported virtual water embodied in trade from 2000 to 2017. A total of 40 crop products are considered. The crops' imports and exports data come from the United States Department of Agriculture (USDA) Global Agricultural Trade System Database. The yield of each crop is extracted from the FAOSTAT database of FAO.

Morocco's climatic data: The average daily maximum and minimum temperature, average relative humidity, average wind speed, the average daily sun hours, average solar radiation, and the monthly precipitations are extracted from the CLIMWAT 2.0 for CROPWAT 8.0 database. Twelve meteorological stations covering the territory of Morocco are available in this database.

Regarding the crop factors, CROPWAT contains a database of the variables that are needed. Nevertheless, this database does not contain all the crops considered in this paper. Therefore, we have created the files of the unavailable crops using data on crop planting times in Morocco from the FAO Crop Calendar database. Crop coefficients, crop development stages, and rooting depths of each crop are obtained from Doorenbos and Pruitt [77]. Table 3 presents a summary of data sources.

Table 3. Summary of data sources.

Variables	Sources
Exportation and importation per crop (Ton)	USDA Global Agricultural Trade System (GATS) database [78].
Yield per crop (Ton/ha)	FAOSTAT database of FAO [79].
Climatic data	CLIMWAT database [80].
Crop factors	CROPWAT database [81]. FAO crop Calendar database [82].
Crop coefficients, crop development stages and rooting depths of crops	Doorenbos and Pruitt.

Source: Author's own.

4. Results and Discussions

4.1. Analysis of Morocco's Import and Export

4.1.1. The Variation of Agricultural Products' Import and Export

To ensure its development, Morocco has adopted an economic and financial openness policy by joining GATT in 1987 and WTO in 1995, and exports of agricultural products continuously increased during the period from 2000 to 2017. Morocco's total export volume of agricultural products has achieved USD 33.583 billion during the study period. The export volume increased from USD 698.964 million in 2000 to USD 3399.168 million in 2017, by 4.9 times. Since 2012, this volume has experienced vigorous growth. The number increased by 12% from USD 1691 million in 2009 to USD 2458 million in 2010 (Figure 3).

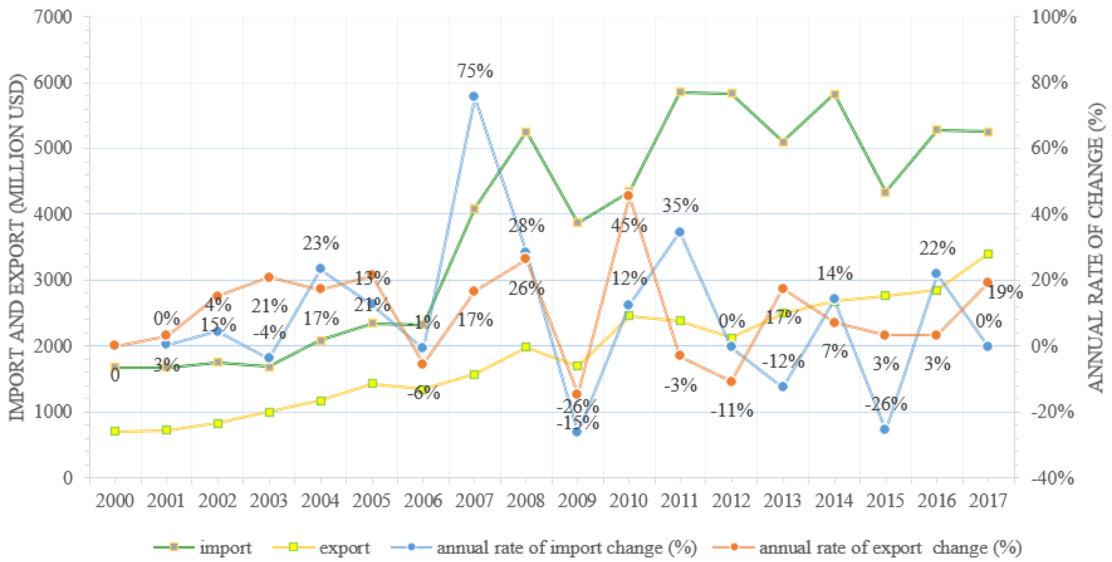

Figure 3. Variation in Morocco's agricultural products import and export.

Morocco has established trading relationships with most countries and areas in the world. The top ten export destinations of Morocco's agricultural products during the period 2000–2017 are France (USD 11.03 billion), Spain (USD 4.04 billion), Russia (USD 2.65 billion), the Netherlands (USD 2.23 billion), the United States of America (USD 1.5 billion), the United Kingdom (USD 1.1 billion), Italy (USD 939 million), Germany (USD 926 million), Belgium (USD 819 million), and Canada (USD 629 million). The top ten countries accounted for 77% of total exported agricultural products during the study period.

From the perspective of import, Morocco's total import volume of agricultural products was USD 57.9 billion during the period from 2000 to 2017. This volume has increased from USD 1674 million in 2000 to USD 5254 million in 2017, by 3.13 times. During the period 2000–2006, the import volume increased steadily from USD 698.964 million to USD 2328 million, at an average rate of 6% per year. Since 2007, Morocco's imports have been booming, reaching the highest value (5853 million USD) in the year 2011. The top ten import sources of Morocco during this period are France, the United States of America, Brazil, Argentina, Canada, Spain, Germany, China, Ukraine, and the Netherlands. The imported volume of the agricultural products of Morocco from the above ten countries accounted for approximately 88% of its total import volume from 2000 to 2017.

Agricultural exports have been steadily increasing between 2000 and 2017. This is explained by the free trade agreements signed between Morocco and several Mediterranean countries. On the contrary, imports have experienced strong variations during this period. Indeed, Moroccan agricultural imports are mainly composed of cereals whose national production is conditioned by rainfall marked by recurrent droughts.

4.1.2. The Variation of Studied Crops Import and Export

Figure 4 presents the variation in Morocco's exports by crop category from 2000 to 2017. It appears clearly that the crop categories that have significantly pulled the agricultural products import are fruits and vegetables. The study period exhibits a rising trend. Morocco's fruits and vegetables exports increased respectively from 2.76 million tons and 2.73 million tons in 2000 to 7.02 million tons and 8.11 million tons in 2017. During the period 2000–2017, the above-mentioned crop categories were responsible for respectively 78.81 and 104.36 million tons of export. The highest values of fruits and vegetables exports were in 2010 (8.29 and 10.22 million tons respectively).

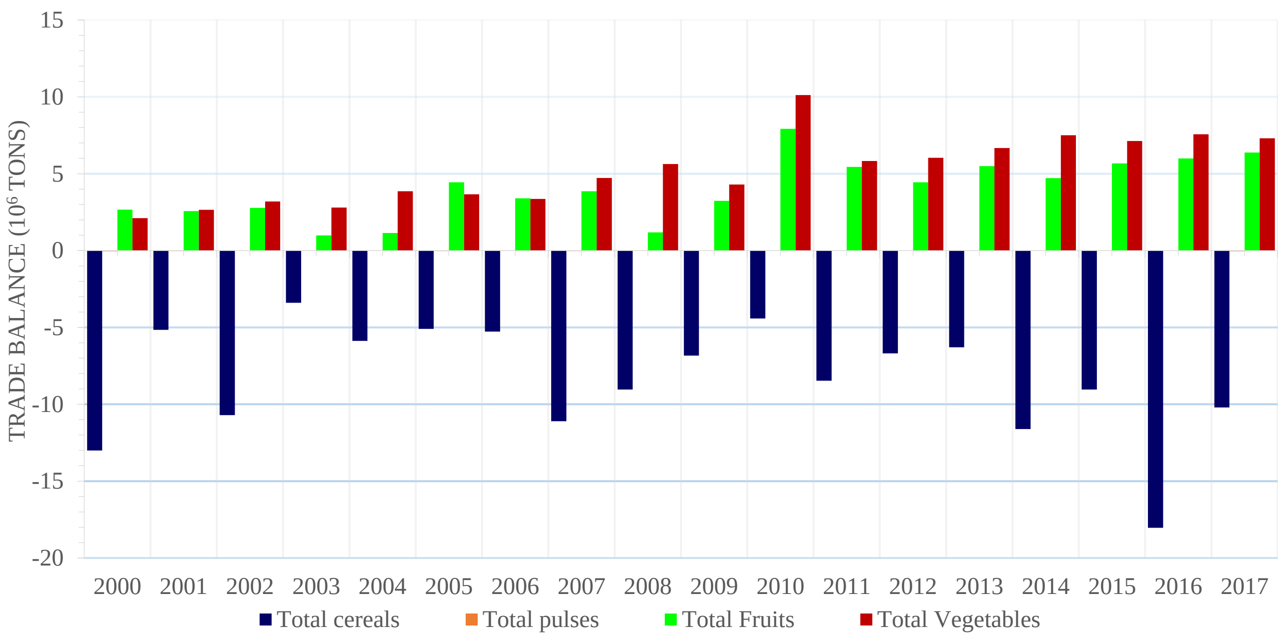

Figure 4. Morocco's trade balance (X–M) by crop category from 2000 to 2017.

Meanwhile, cereals were the main imported crops. The tendency of cereals imports is basically on an irregular trend. The period from 2000 to 2017 suffers ups and downs. Morocco's imports of cereals reached the highest value in 2016 (18 million tons). The lowest value was recorded in 2003 (3 million tons) and Morocco had accumulatively imported 150 million tons of cereals during the study period (Figure 4).

Comparing the exports by crop category with the imports from 2000 to 2017, it can be found that fruits and vegetables are net exporter crop categories. Their net exports were in a rising trend year by year and increased from 2.67 and 2.11 million tons respectively in 2000 to 6.38 and 7.31 million tons in 2017 (Figure 3). Their aggregate net exports in the seventeen years achieved respectively 72.32 and 94.46 million tons.

Cereals and pulses show a negative balance, which means that the imported volume is higher than the exported volume. Cereals are the highest net importer crop category. They had a total net import of 150.24 million tons during the study period, while pulses had a total net import of 0.27 million tons.

4.2. Analysis of the Virtual Water Exports and Imports in Morocco's International Trade of the Studied Crop Products

4.2.1. Total Virtual Water Imports and Exports

Our calculations show that the virtual water that Morocco exported to the world during the period 2000–2007 was 95.03 Gm^3. The amount was 1.73 Gm^3 in 2000 and 7.86 Gm^3 in 2017. The exported virtual water flows had little inter-annual changes and the tendency of total virtual water export was on a rising trend (Figure 5). The highest volume was recorded in 2017. That is because fruit and vegetable exports, which are water-intensive agricultural commodities, significantly increased during the period 2010–2017 (Figure 4). Therefore, there was a significant pulling effect of these crop products on Morocco's virtual water export.

Figure 5. The trend of virtual water imports and exports in Morocco's foreign trade of the studied crop products.

Regarding virtual water imports, Morocco had accumulatively imported 690.77 Gm^3 from 2000 to 2017. The total virtual water that Morocco imported during the study period was basically on a downward trend (Figure 5). Morocco's virtual water imports were 151.60 Gm^3 in 2000 and 26.66 Gm^3 in 2017. The annual average was 38.38. The highest volume of water imports (151.60 Gm^3) and the lowest volume (10.96) were reached respectively in 2000 and 2010.

Virtual water imports were steadily increasing in 2006 and 2015 due to the increase in imports of agricultural products, particularly cereals, during this period of drought.

It can be seen from Table 4, which demonstrates the virtual water exported by crop category, that the main exported virtual water was from vegetables. Virtual water exported by Morocco's vegetable exports was approximately 68,872.17 Hm^3 from 2000 to 2017, accounting for about 72.47% of the total volume of exported virtual water. The second was fruit products (25,773.69 Hm^3, 27.12%), then cereals (250.79 Hm^3, 0.26%), and pulses (137.29 Hm^3, 0.14%).

Table 4. Exported and imported virtual water by crop category from 2000 to 2017.

	Virtual Water Exports (Hm^3)	Percent (%)	Virtual Water Imports (Hm^3)	Percent (%)
Total cereals	250.79	0.26	679,681.71	98.4
Total pulses	137.29	0.14	2073.37	0.3
Total Fruits	25,773.69	27.12	7569.30	1.1.
Total vegetables	68,872.17	72.47	1445.50	0.2
Total	95,033.94		690,769.87	

Source: Author's own.

4.2.2. The Variation of Virtual Water Exports by Crop Category

As shown in Figure 6, the tendency of the exported virtual water was on a rising trend as a whole in all crop categories except pulses. The detailed trend of the exported virtual water through the exports of vegetables and fruits is as follows: From 2000 to 2011, exported virtual water experienced ups and downs every year. The highest exported virtual water volumes of fruits and vegetables during this period were respectively, 4325.50 hm^3 reached in 2010 and 6133.24 hm^3 reached in 2004, while the lowest exported virtual water volumes were respectively 356.22 hm^3 recorded in 2003 and 982.60 hm^3 recorded in 2000.

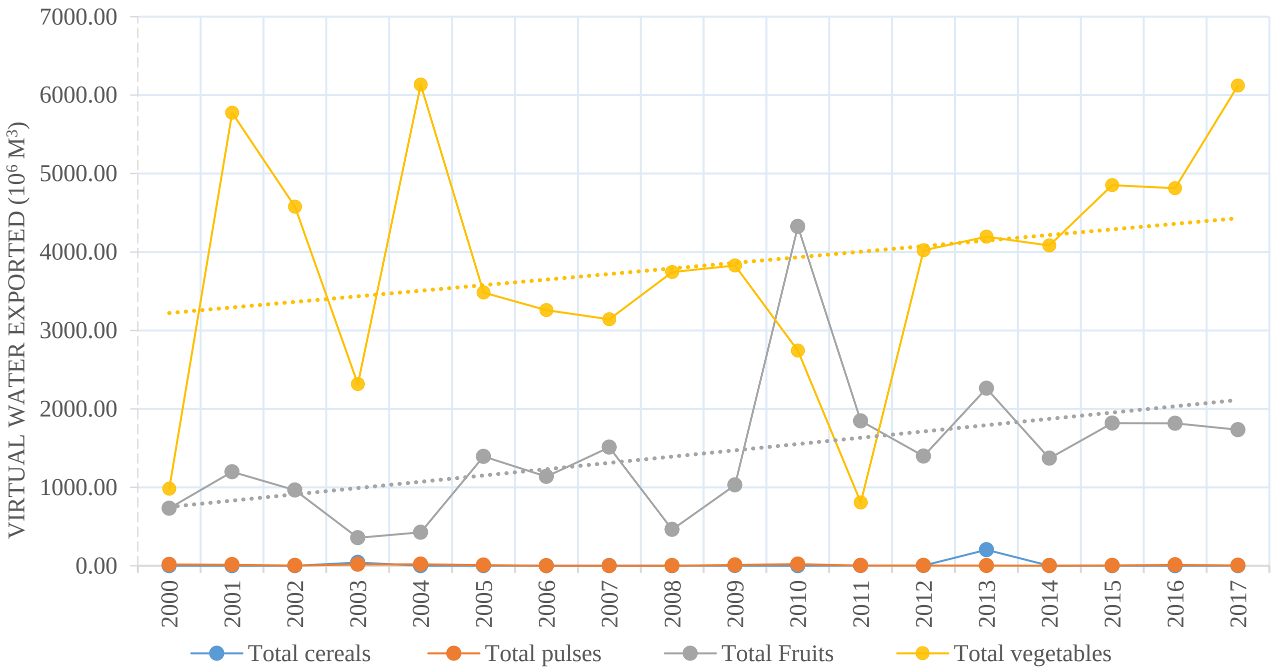

Figure 6. Trend of exported virtual water of Morocco by crop category.

The exported virtual water of fruits and vegetables followed a rising trend. In 2008, Morocco launched the Green Morocco Plan (GMP) 2008–2020, which is a comprehensive development strategy aimed at transforming the agricultural sector into a source of growth and employment. Regarding export development, this strategy aimed to increase agricultural exports from 1.35 million tons in 2008 to 4.6 million tons in 2020 (that is +254%). As shown in Figure 4, the GMP promoted the export of agricultural products in Morocco. As a result, from 2011 to 2017, the tendency of virtual water exports of fruits and vegetables was on a rising trend.

With regard to cereals and pulses, the exported virtual water through the exports of these crop categories had slight inter-annual variations. The tendency of the total virtual water exported through the export of pulses per year was on the decline as a whole, while the tendency of the total virtual water exported through cereal exports was on a rising trend.

The top five crop products in terms of virtual water export from 2000 to 2017 were olives (61,201.13 Hm^3), mandarin and clementine (19,819.31 Hm^3), tomatoes (5126.37 Hm^3), apricots (1572.86 Hm^3), and strawberries (1479.36 Hm^3). The exported virtual water embedded in these crop products accounted for 94% of the total volume of exported virtual water through the exports of the crop products studied.

In the cereals category (Table 1 in Appendix A), the main exported virtual water was from corn. The amount was 205.22 Hm^3 from 2000 to 2017, accounting for approximately 82% of the total virtual water embodied in the cereals category. The second was wheat (45.21 Hm^3, 18%), then barley, millet, and oats.

With regard to the virtual water embedded in the pulses category (Table 1 in Appendix A), chickpeas were the main virtual water exporter. The amount was approximately 117 Hm^3 from 2000 to 2017, accounting for 85% of the total volume of virtual water exported in the pulses category. The second was dried lentils with approximately 20.30 Hm^3, accounting for 15% of the total volume of virtual water exported in this category.

As is illustrated in Table 1 in Appendix A, the top five fruits in terms of virtual water exports were mandarin and clementine (19,819.31 Hm^3, 77%), apricots (1572.86 Hm^3, 6%), strawberries (1479.36 Hm^3, 6%), oranges (1104 Hm^3, 4%), and melons (578.60 Hm^3, 2%). The virtual water embedded in these products accounted for approximately 26% of the total volume of the exported virtual water embedded in the crop categories studied.

In the vegetables category (Table 1 in Appendix A), the top four crop products that pulled Morocco's virtual water exports are olives, tomatoes, beans, and potatoes. From 2000 to 2017, the total virtual water exported by the above-mentioned 5 crop products were respectively 61,201.13 Hm^3, 5126.37 Hm^3, 1034.60 Hm^3, and 843 Hm^3, accounting for 89%, 7%, 2%, and 1% of the total exports of virtual water in the vegetables category. The proportion of the virtual water exported by these four crop products in the total exported virtual water embedded in the 41 crop products studied had been kept above 72% (Table 1 in Appendix A).

4.2.3. The Variation of Virtual Water Imports by Crop Category

We see in Table 4 that the main imported virtual water was from the cereals category during the period 2000–2017. The total amount of virtual water imported by Morocco's cereals import was approximately 679.68 Gm^3 from 2000 to 2017, accounting for about 98.4% of the total volume of imported virtual water. The second was fruit products (7.57 Gm^3, 1.1%), then pulses (2.07 Gm^3, 0.3%), and vegetables (1.45 Gm^3, 0.2%).

The trend that Morocco imported virtual water per year through the imports of cereals was on the decline while the exports were on a rising trend (Figure 7). The annual average water imports of cereal were 37.76 Gm^3. The highest volume was 150.60 Gm^3 reached in 2000 and the lowest volume was 10.40 reached in 2010. Concerning the pulses category, the tendency of the total virtual water imported as well as that of the total virtual water exported through the exports of this category per year was on the decline as a whole. The year 2000 had the highest water imports with a figure of 813.69 Hm^3. The lowest volume was 5.91 Hm^3 reached in 2015. The annual average was 115.19 Hm^3.

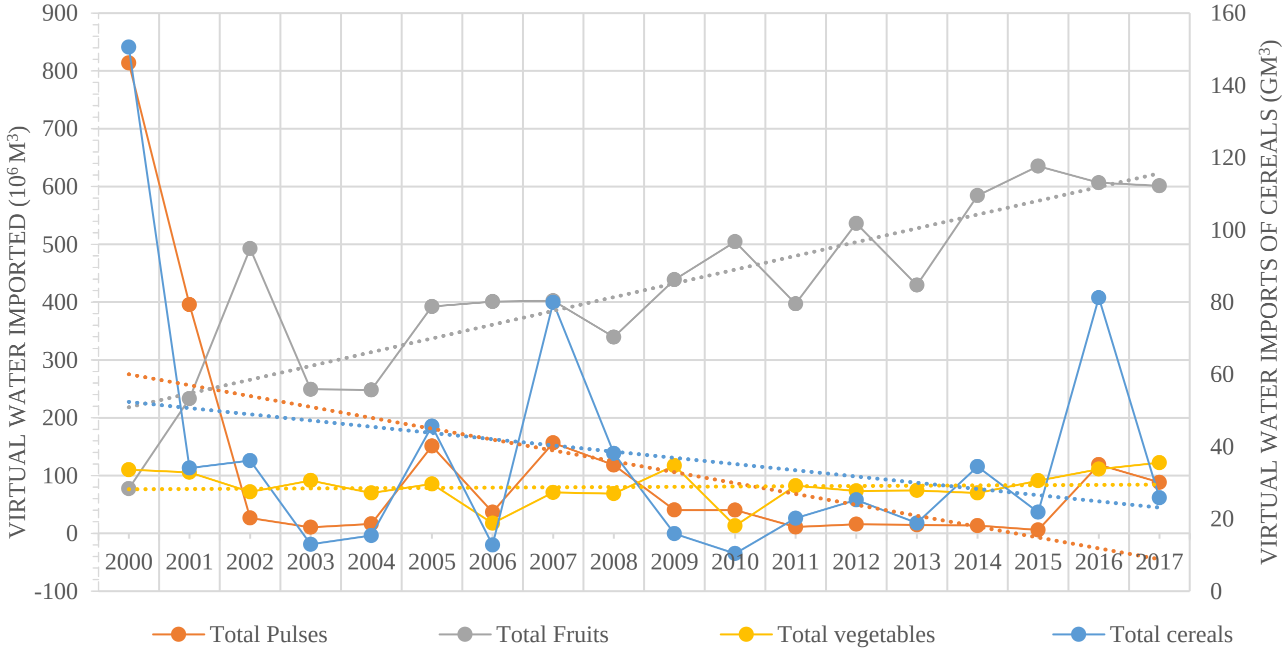

Figure 7. Trend of imported virtual water of Morocco by crop category.

The tendency of imported virtual water was on a rising trend as a whole in the fruits and vegetables categories. The highest imported virtual water volumes of fruits and vegetables during this period were respectively 635.27 Hm^3 reached in 2015 and 122.22 Hm^3 reached in 2017. The lowest volumes were respectively 77.39 Hm^3 reached in 2000 and 12.94 Hm^3 reached in 2010 (Figure 7). In addition, as is reflected in Figures 8 and 9, the virtual water imports and exports through the imports of vegetables increased at a growing rate. However, the average annual growth rate of virtual water imports (45%) was higher than that of virtual water exports (26%). Regarding fruits, the exported virtual water through fruit exports rose at an increasing rate, and the virtual water imports rose at a decreasing rate. The average annual growth rate of virtual water imports of fruits was 22% while that of virtual water exports was 33%.

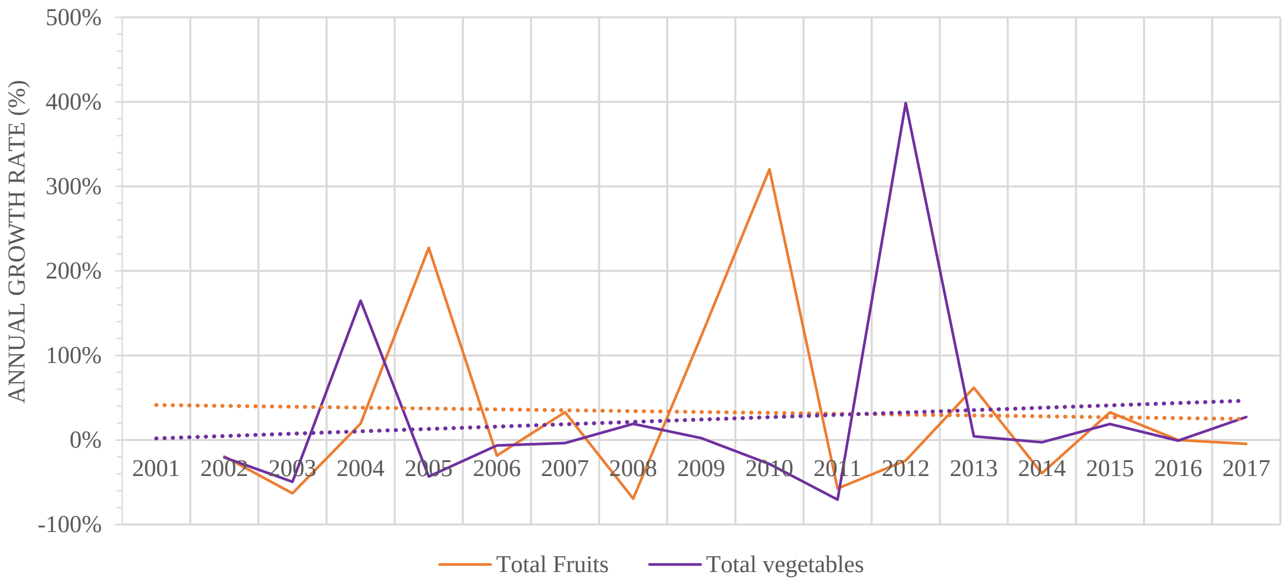

Figure 8. Annual growth rate of vegetable and fruit imports.

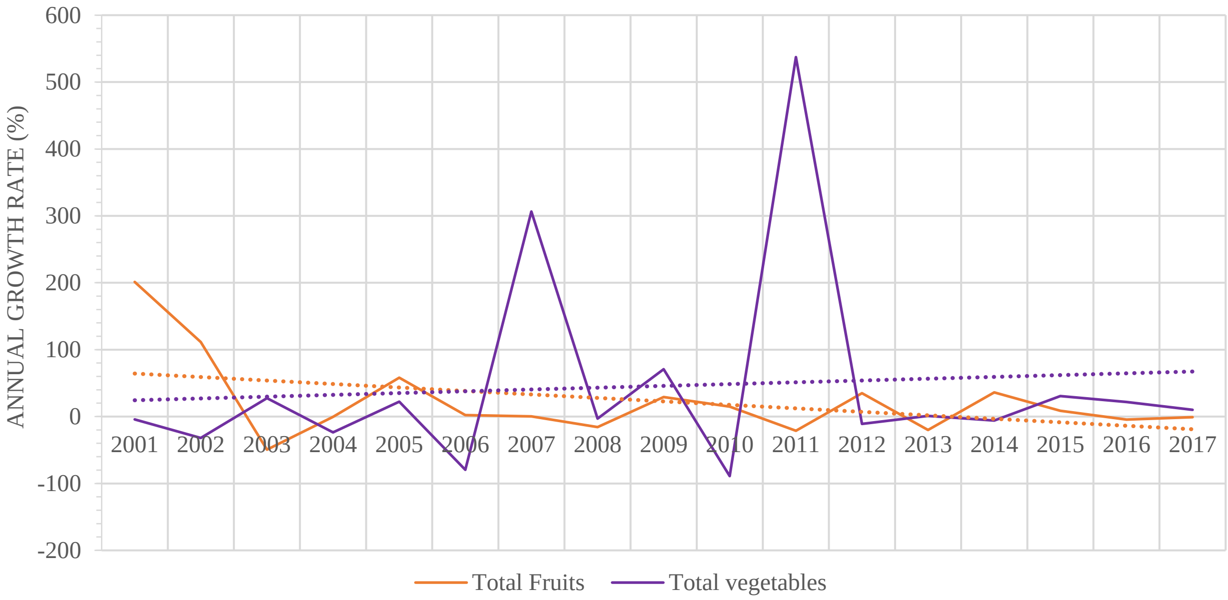

Figure 9. Annual growth rate of vegetable and fruit exports.

As is illustrated in Table 2 in Appendix A, the top five crop products in terms of virtual water imports during the study period were barley (304.95 Gm^3), corn (191.34 Gm^3), wheat (182.70 Gm^3), dates (5.52 Gm^3), and dried lentils (2.01 Gm^3). The imported virtual water embedded in these crop products accounted for 99% of the total volume of imported virtual water through the exports of the 40 crop products taken into account in this study.

The main imported virtual water in the cereals category was from barley. The imported virtual water through the imports of this crop product from 2000 to 2017 accounted for approximately 45% (304.95 Gm^3) of the total virtual water embodied in the cereals category. The second was corn (191.34 Gm^3, 28%), then wheat (182.70 Gm^3, 27%), millet, and oats. The imported virtual water embedded in cereal products accounted for approximately 68 % of the total volume of the imported virtual water embedded in the crop categories studied.

With regard to the virtual water embedded in the pulses category (Table 2 in Appendix A), dried lentils were the main virtual water importers. The amount was approximately 2.01 Gm^3 from 2000 to 2017, accounting for 97% of the total volume of virtual water exported in the pulses category. The second was chickpeas with 58.87 Hm^3.

The top five fruits from the perspective of virtual water imports were dates (5523.69 Hm^3, 73%), pears (554.66 Hm^3, 7%), apples (520.01 Hm^3, 7%), grapes (411.37 Hm^3, 5%), and bananas (333.97 Hm^3, 4%) (Table 2 in Appendix A). The imported virtual water through the import of the above-mentioned fruit products accounted for approximately 1% of the total volume of the imported virtual water embedded in the crop categories studied.

Concerning the vegetables category, during the period 2000–2017, the top five crop products from the perspective of virtual water import are potatoes (1177.17 Hm^3, 81%), olives (105.21 Hm^3, 7%), tomatoes (71.24 Hm^3, 5%) peas (55.61 Hm^3, 4%) and asparagus (16.76 Hm^3, 1%) (Table 2 in Appendix A).

4.2.4. The Net Exports of Virtual Water Driven

With regard to virtual water balance, the results show that Morocco was a net virtual water importer during the study period. The deficit was 595.74 Gm^3. At first glance, these findings seem satisfactory because the water situation in Morocco is alarming. Taking into account only these results, we can conclude that Morocco's foreign trade strategy is favourable to the country's water resources. However, pursuant to Figure 10, which shows the trend of the virtual water net exported from 2000 to 2017 through the trade of crop products, the tendency of the net imported virtual water was on a declining trend. The net imports of virtual water declined from 149.86 Gm^3 (2000) to 18.8 Gm^3 (2017). This is due to the trend that Morocco's exported virtual water increased while imports were on the decline. Compared to freshwater withdrawals in 2017, which was 10.43 billion m^3, the net imports of virtual water in 2017 accounted for 178%.

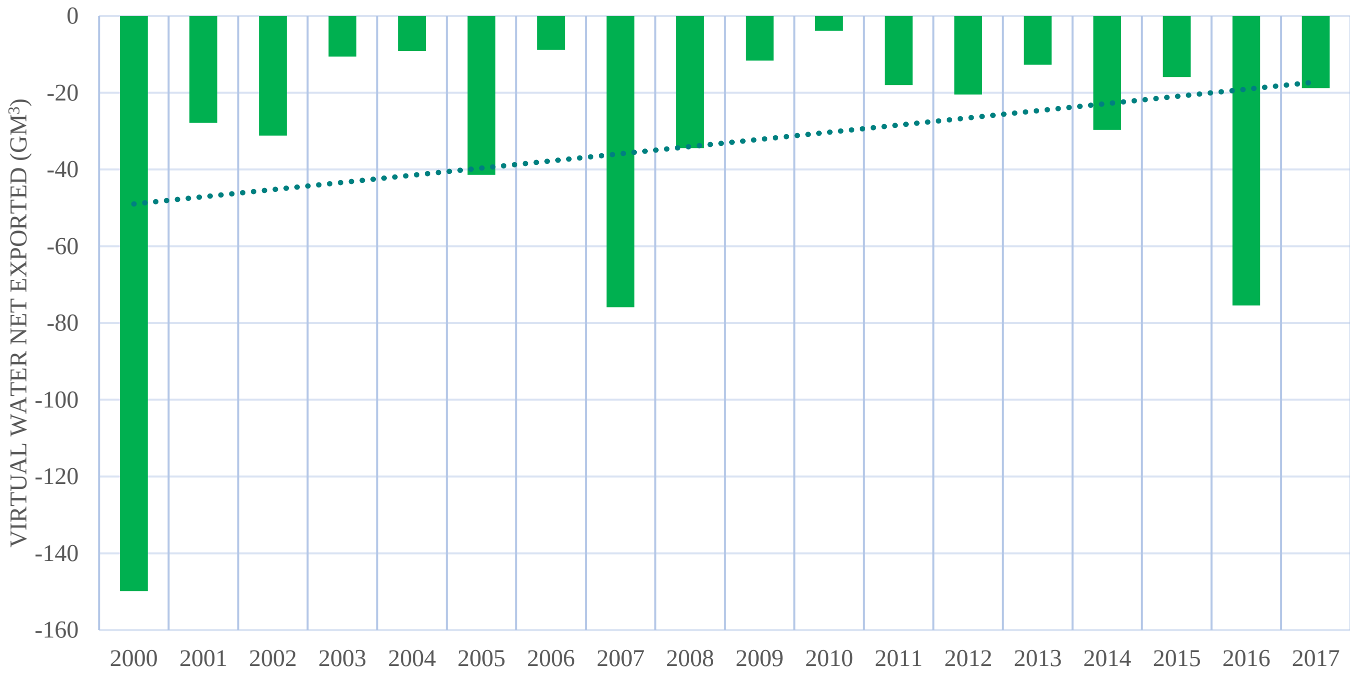

Figure 10. Net exports of virtual water per year.

As shown in Figure 11, cereals and pulses had a negative virtual water trade balance during 2000–2017, which means that the amount of water imported is higher than the water exported, while the fruits and vegetables categories had a positive virtual water trade balance due to the great volume of water exported when exporting these crop products. On the one hand, the main net imported virtual water during this period was from the cereals category, approximately 679.43 Gm^3 during 2000–2017, then pulses (2 Gm^3 from 2000 to 2017). On the other hand, the main net exported virtual water was from vegetables, approximately 6 Gm^3 from 2000 to 2017. The second was the fruits category with 1.13 Gm^3 (Table 3 in Appendix A). It is important to note that cereals and pulses are important in Moroccans' diet. Therefore, the satisfaction of the country's needs for these basic agricultural products through the external market and the lack of water needed to produce them locally because of its allocation to export-oriented crops causes Morocco to be in a situation of food and water dependency.

Comparing the trade balance of crop products with the crops' water content, it can be found that the exported virtual water through exports of vegetables is far higher than the imported virtual water because of the exportation of water-intensive products, mainly olives, tomatoes, asparagus, peas, artichokes, carrots, turnips, and cauliflowers (Figure 12). Olives had the highest water content and showed a significant exporting net balance. This finding strikes our attention since the Moroccan agriculture policy 2009–2020 "Green Morocco Plan" was intended to increase the areas under olive cultivation by 40% during the period 2009–2020. As a result, the area under olive trees increased from 720,000 ha in 2007 to 1,073,000 ha in 2019. The total production of the olives sector has increased from 549,000 tons in 2007 to 1,414,000 tons in 2019 [83].

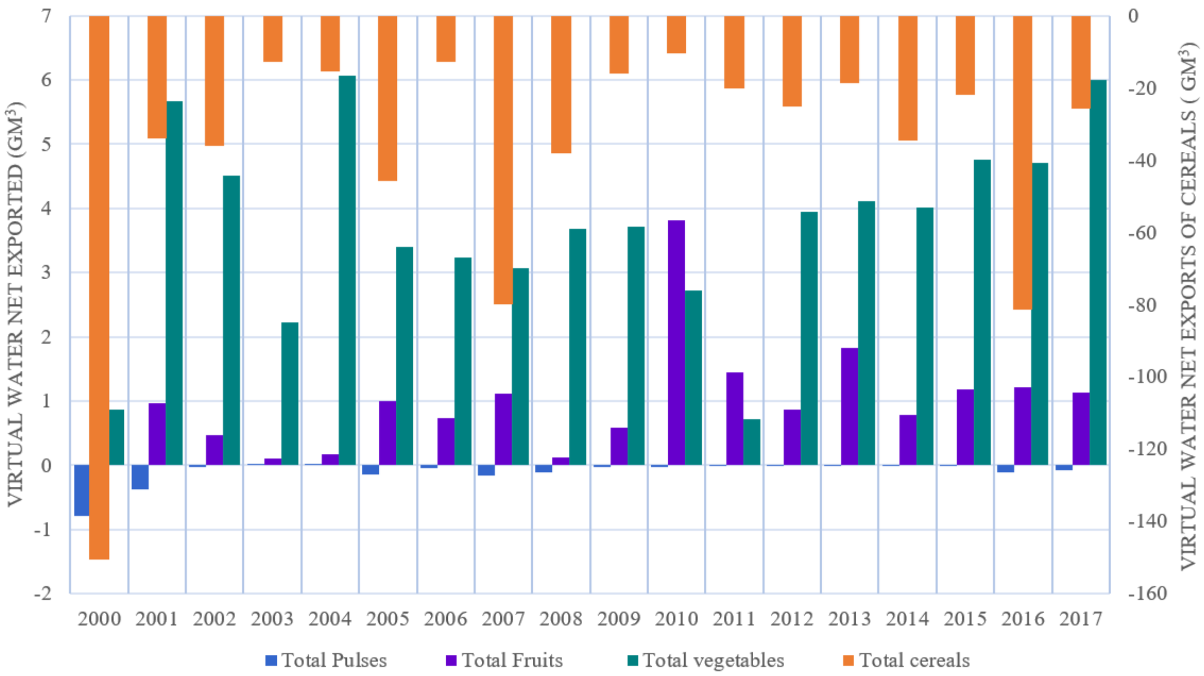

Figure 11. Virtual Water net exported by crop category per year.

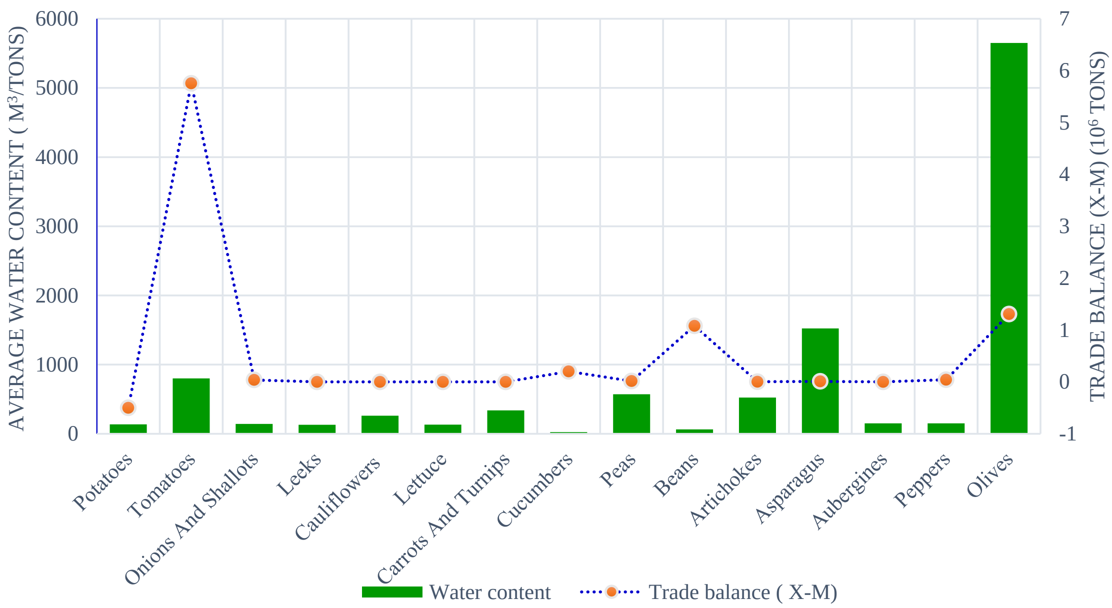

Figure 12. Trade balance and average water content of vegetables from 2000–2017.

Regarding fruits, the top ten crop products with a negative water trade balance in terms of water content, are mandarin and clementine, figs, oranges, apricots, plums, citrus fruits, grapefruits, watermelons, raspberries, and peaches and nectarines (Figure 13). It is outstanding that dates are a very water-intensive crop. Nevertheless, a significant investment has been made to increase production and exports in this sector. The Green Morocco Plan (GMP) had set the objective of increasing the production of dates from 68,000 tons (2007) to 160,000 tons (2020). As a result, the area cultivated with date palm crops increased by 25% to 60,000 ha in 2019. The production increased by 50%, from 68,000 tons to 102,000 tons over the same period [83]. The GMP was also intended to increase areas under citrus fruit and other fruits and vegetables cultivation by 52% and 76% respectively from 2009 to 2020. This suggests that the GMP did not aim to change agricultural specialization in crops with extremely high-water requirements. Instead, it aimed to intensify water-intensive crops that are primarily export-oriented (citrus, olives, other fruits, and vegetables).

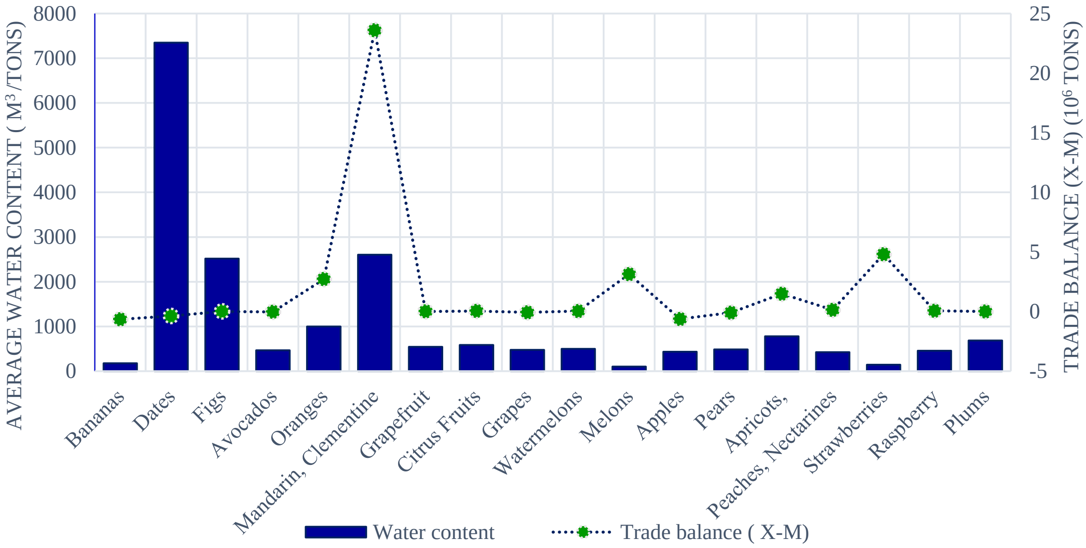

Figure 13. Trade balance and average water content of fruits from 2000 to 2017.

5. Conclusions and Policy Implications

This paper conducted a study of the relationship between international trade in crop products and water resources in Morocco by means of the concept of virtual water. For this purpose, we quantified the virtual water imported and exported through the trade of the 40 crop products from 2000 to 2017, with the aim of exploring new ways to alleviate the pressure on water resources in Morocco.

At the end of this research, we could make a summary of the main conclusions of our analysis as follows:

1. From 2000 to 2017, Morocco was a net virtual water importer. The net imported virtual water during this period was 595.74 Gm^3. However, the exported virtual water per year was on a rising trend while the imported was on the decline. As a result, the tendency of the net imported virtual water embedded in agricultural products was on a declining trend. The net imports of virtual water declined from 149.86 Gm^3 in 2000 to 18.8 Gm^3 in 2017. The main imported virtual water was from cereals (679.43 Gm^3), which are strategic agricultural products for Morocco's food security. This situation causes the country to be in a situation of food and water dependency on other world regions.
2. Fruits and vegetables are the major crop categories for pulling Morocco's virtual water exports. The main net exported virtual water during this period was from vegetables, approximately 6.8 Gm^3 from 2000 to 2017. The second was the fruits category (1.82 Gm^3). The exported virtual water through the export of vegetables is far higher than the imported virtual water because of the exportation of water-intensive products, mainly olives, tomatoes, asparagus, peas, artichokes, carrots, turnips, and cauliflowers. Concerning the fruits category, the top ten crop products in term of water content with a negative water trade balance are mandarin and clementine, figs, orange, apricots, plums, citrus fruits, grapefruit, watermelons, raspberry, and peaches and nectarines.
3. The agricultural policy of 2009–2020 increased the production of export-oriented crop products that require a lot of water, mainly dates, olives, and citrus and other fruits and vegetables.

From our findings, we could draw some interesting conclusions concerning the international trade of crop products in relation to water resources in Morocco. We could formulate our first conclusion as follows: Morocco, which is facing a difficult water situation, is a net exporter of products that intensively use water (mainly fruits and vegetables). This finding contradicts the virtual water trade theory, that is, water-poor countries should import water-intensive commodities and produce locally non-water-intensive commodities. These findings tend to reveal that Morocco has a trade structure of virtual water detrimental to its water resource.

The second conclusion is that the GMP has strongly encouraged the production and export of water-intensive products. This suggests that it did not include a virtual water trade strategy.

Based on the above conclusions, we are convinced that there is great potential to alleviate Morocco's water scarcity by adjusting its international trade structure of crop products. To achieve this goal, Morocco should review its productive structure and reduce exports of products that require a large amount of water and replace them with products that require a small amount of water. For example, if we imported vegetables and fruits, we would be able to save a lot of water. In addition, if the production of export-oriented vegetables and fruits was to be replaced by cereals, we would be able to mitigate the situation of food and water dependence on other world regions.

Nevertheless, it should not be overlooked that changes in productive specialization and international commercial relations are very difficult and can only be achieved in the long term. In the short term, Morocco should change the use of water in agriculture on a large scale. The modification of the agricultural specialization and the commercial dealings remains however an unavoidable option.

Based on the results of this study, we formulated recommendations concerning the international trade policy of agricultural products in Morocco in order to mitigate water stress in Morocco.

The agricultural policy within the framework of the Green Morocco Plan and the Green Generation must take into account the virtual water for the determination of the agricultural productions to promote. This implies that the State should only subsidize, within the framework of its agricultural policy, products that do not consume a lot of water.

In the same context, the State should not normally accept, within the framework of its agricultural policy, partnerships with foreign countries that wish to produce water-intensive products in Morocco.

Finally, the State must promote technology and scientific research in the agronomic field in order to establish crops adapted to the specificities of each region in terms of water resources and reduce the effect of evapotranspiration, or even opt for agricultural policies on a regional scale.

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Appendix A

Table 1. Virtual water exports, (10^6 m^3), Morocco, 2000–2017.

Product	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2000–2017
Corn	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.54	0.02	203.56	0.91	0.00	0.00	0.02	205.22
Wheat	0.03	0.00	0.00	41.04	0.21	0.22	0.00	0.24	0.05	0.37	0.00	0.86	1.96	0.00	0.22	0.00	0.00	0.00	45.21
Millet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.12
Barley	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.14	0.07	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.25
Oats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Cereals	**0.03**	**0.00**	**0.00**	**41.20**	**0.22**	**0.24**	**0.00**	**0.38**	**0.12**	**0.39**	**0.00**	**1.40**	**2.00**	**203.56**	**1.24**	**0.00**	**0.00**	**0.02**	**250.79**
Chickpeas	5.56	12.05	3.11	15.63	17.77	8.12	0.25	0.18	0.39	10.16	20.65	2.86	0.41	0.41	0.00	3.28	10.99	5.19	117.00
Lentils Dried	10.80	1.21	0.00	1.34	1.22	0.04	0.01	0.00	0.00	0.00	0.00	0.00	2.39	1.31	0.84	0.96	0.01	0.14	20.29
Total Pulses	**16.36**	**13.26**	**3.11**	**16.97**	**18.99**	**8.17**	**0.26**	**0.18**	**0.39**	**10.16**	**20.65**	**2.86**	**2.80**	**1.72**	**0.84**	**4.25**	**11.00**	**5.33**	**137.29**
Mandarin. Clementine	386.27	836.62	614.13	58.90	73.80	1000.41	780.19	1067.60	127.33	761.48	4209.66	1555.52	1102.47	1903.38	1013.00	1445.20	1543.88	1339.48	19,819.31
Apricots.	150.16	164.20	153.14	120.59	136.84	110.11	92.87	106.96	64.96	64.69	30.64	54.31	50.36	68.99	80.64	61.24	8.80	53.35	1572.86
Strawberries	61.76	57.68	73.25	73.88	71.07	102.08	76.01	119.93	11.91	30.05	17.77	105.34	115.56	121.80	118.92	113.38	107.04	101.92	1479.36
Oranges	86.18	86.34	74.73	73.71	70.78	70.72	76.80	91.89	119.35	61.43	44.78	48.34	33.93	28.86	29.78	36.59	28.02	41.87	1104.10
Melons	25.95	28.01	23.58	1.76	24.44	46.01	36.00	40.48	50.89	38.62	10.21	41.41	38.66	41.64	3.86	35.53	39.41	52.12	578.60
Grapes	8.44	8.98	12.44	16.37	28.15	40.38	55.73	56.32	56.09	44.43	0.00	22.04	31.08	30.90	30.54	27.63	32.60	27.12	529.25
Raspberries	0.00	0.00	0.00	0.25	0.15	0.61	0.24	3.21	6.54	8.72	8.27	1.78	16.25	36.98	52.16	55.02	5.85	66.77	262.79
Peaches. Nectarines	9.26	9.57	6.19	5.06	10.31	14.79	10.57	10.97	1.20	11.87	0.04	9.86	1.33	19.96	24.37	17.26	26.10	17.14	205.86
Citrus Fruits	2.64	1.41	1.29	0.60	0.96	3.30	2.22	3.36	13.36	3.24	1.74	3.99	3.39	1.90	3.21	0.33	3.34	5.02	55.31
Watermelons	0.00	0.00	0.48	0.52	0.30	0.58	0.29	0.51	0.80	0.81	0.06	0.84	1.21	1.78	3.71	7.79	9.48	15.96	45.12
Figs	0.37	1.09	0.64	0.53	1.99	2.20	4.80	6.42	1.30	2.60	0.61	0.36	0.29	0.18	0.59	0.52	1.85	1.52	27.87
Pears	0.03	0.12	1.53	2.88	6.25	1.08	0.07	1.19	5.66	0.00	0.00	0.01	0.12	0.05	0.20	3.23	1.81	1.55	25.76
Avocados	0.03	0.06	0.16	0.30	0.02	0.05	0.04	0.59	1.22	0.87	0.32	1.56	0.38	1.15	3.27	3.12	2.90	7.14	23.16
Dates	0.36	0.67	1.80	0.81	0.54	0.48	1.30	0.12	0.01	0.01	0.08	0.11	0.10	1.35	1.17	5.36	2.42	0.98	17.68
Apples	0.21	2.24	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.02	0.10	0.14	0.82	3.92	4.14	1.34	0.66	13.63
Grapefruit	0.10	0.24	0.14	0.06	0.15	0.35	0.27	0.78	0.83	0.52	1.26	0.37	1.70	1.11	0.25	0.47	0.59	1.09	10.29
Plums	0.02	0.02	0.03	0.01	0.02	0.06	0.00	0.11	0.00	0.00	0.00	0.00	0.01	0.02	0.46	0.76	0.32	0.30	2.14
Bananas	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.07	0.04	0.02	0.00	0.11	0.24	0.04	0.07	0.00	0.60
Total Fruits	**731.80**	**1197.24**	**963.52**	**356.22**	**425.76**	**1393.24**	**1137.41**	**1510.43**	**461.47**	**1029.42**	**4325.50**	**1845.95**	**1396.99**	**2260.99**	**1370.30**	**1817.60**	**1815.84**	**1733.99**	**25,773.69**
Olives	603.81	5502.08	4252.29	2018.10	5784.91	3136.26	3003.35	2664.26	3313.27	3381.22	2041.83	321.60	3597.60	3750.77	3563.37	4362.04	4289.65	5614.73	61,201.13
Tomatoes	228.84	223.04	204.90	176.57	199.61	212.67	173.24	307.21	260.86	283.78	594.18	346.62	301.40	262.06	327.45	337.86	343.13	342.95	5126.37
Beans	18.48	27.46	35.16	39.75	45.37	47.81	41.52	59.77	64.53	95.17	82.94	78.41	48.03	67.67	69.95	68.72	75.05	68.81	1034.60
Potatoes	107.47	8.42	56.13	56.36	70.08	60.74	4.51	63.82	80.04	18.15	5.06	35.02	36.17	42.83	59.20	35.06	54.07	49.76	842.90
Onions And Shallots	0.52	2.23	3.83	1.87	3.36	3.91	7.36	8.28	3.79	1.86	0.31	5.25	8.67	25.38	35.32	18.69	24.93	13.45	169.02
Asparagus	8.50	1.30	12.86	7.82	9.24	8.70	13.21	17.41	2.60	31.58	0.21	2.15	12.86	8.87	2.43	2.03	2.51	5.23	149.51
Peppers	1.86	2.55	3.24	3.47	6.44	6.55	4.24	5.49	9.06	6.51	10.65	10.39	10.19	12.61	14.09	13.92	13.14	13.49	147.89
Peas	11.06	6.20	5.56	7.33	8.46	1.11	8.60	11.67	4.91	5.74	2.09	1.83	2.94	14.17	3.96	9.33	4.30	8.53	117.79
Artichokes	0.25	0.57	0.96	2.19	3.19	3.46	0.33	3.68	2.88	1.76	0.00	2.84	1.58	6.26	2.24	0.23	0.76	0.59	33.75
Cucumbers	1.77	1.08	1.66	2.49	2.29	1.71	1.26	0.13	1.03	1.65	1.63	0.87	1.89	1.87	2.68	2.97	2.80	0.19	29.96
Carrots And Turnips	0.03	0.06	0.07	0.02	0.08	0.17	0.14	0.12	0.10	0.29	2.78	1.60	0.85	1.46	1.41	1.51	2.36	1.97	15.00
Aubergines	0.00	0.01	0.02	0.01	0.14	0.04	0.00	0.00	0.01	0.00	0.08	0.06	0.09	0.11	0.08	0.37	0.55	0.25	1.82
Leeks	0.00	0.07	0.02	0.01	0.04	0.08	0.07	0.17	0.22	0.13	0.00	0.09	0.02	0.03	0.01	0.02	0.07	0.08	1.11
Lettuce	0.00	0.00	0.00	0.00	0.02	0.17	0.17	0.11	0.06	0.04	0.00	0.05	0.00	0.00	0.00	0.14	0.03	0.07	0.87
Cauliflowers	0.00	0.00	0.00	0.01	0.02	0.05	0.03	0.06	0.03	0.00	0.00	0.02	0.00	0.01	0.05	0.01	0.07	0.08	0.43
Total vegetables	**982.59**	**5775.08**	**4576.71**	**2316.00**	**6133.24**	**3483.43**	**3258.02**	**3142.18**	**3743.37**	**3827.87**	**2741.76**	**806.80**	**4022.32**	**4194.09**	**4082.23**	**4852.90**	**4813.41**	**6120.18**	**68,872.17**
Virtual water exports	**1730.78**	**6985.58**	**5543.34**	**2730.39**	**6578.21**	**4885.07**	**4395.69**	**4653.17**	**4205.35**	**4867.84**	**7087.91**	**2657.01**	**5424.10**	**6660.36**	**5454.62**	**6674.75**	**6640.25**	**7859.52**	**95,033.94**

Source: Author's own.

Table 2. Virtual water imports, (10^6 m^3), Morocco, 2000–2017.

Product	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2000–2017**
Barley	114,729.51	5522.01	20,796.01	330.40	4632.14	4477.40	4738.29	39,469.48	14,394.70	4336.42	677.75	6372.91	2385.61	3574.82	11,501.07	6056.72	51,705.56	9246.05	304,946.88
Corn	8949.06	18,315.00	5697.21	7998.01	5304.92	31,588.61	4683.12	18,108.19	12,198.39	7386.94	2482.45	6128.65	10,506.89	10,556.19	11,729.36	10,947.41	8678.97	10,084.97	191,344.35
Wheat	26,903.43	10,225.34	9648.72	4621.90	5439.09	9559.30	3335.00	22,265.27	11,517.43	4155.41	7228.75	7646.27	12,338.11	4688.89	11,205.58	4842.54	20,647.57	6435.33	182,703.93
Oats	11.86	17.89	5.35	4.02	1.49	32.13	2.77	49.71	7.30	4.40	11.49	9.67	11.53	1.37	10.21	6.58	144.81	31.04	363.64
Millet	0.06	5.45	0.99	5.94	8.51	13.83	17.41	20.62	14.29	13.56	2.34	22.18	25.78	42.40	33.84	3.36	45.59	46.76	322.91
Total cereals	**150,593.94**	**34,085.70**	**36,148.29**	**12,960.27**	**15,386.15**	**45,671.28**	**12,776.58**	**79,913.27**	**38,132.12**	**15,896.73**	**10,402.78**	**20,179.68**	**25,267.92**	**18,863.68**	**34,480.06**	**21,856.61**	**81,222.50**	**25,844.14**	**679,681.71**
Lentils Dried	803.19	354.79	26.40	10.28	16.14	150.91	36.44	156.44	118.10	40.45	40.33	10.60	15.62	9.27	12.89	5.91	118.65	88.10	2014.50
Chickpeas	10.50	40.99	0.22	0.18	0.11	0.03	0.18	0.01	0.07	0.00	0.00	0.27	0.17	5.37	0.47	0.00	0.19	0.13	58.87
Total Pulses	**813.69**	**395.78**	**26.62**	**10.46**	**16.25**	**150.93**	**36.62**	**156.45**	**118.16**	**40.45**	**40.33**	**10.87**	**15.79**	**14.64**	**13.36**	**5.91**	**118.83**	**88.23**	**2073.37**
Dates	27.28	145.84	425.62	189.75	176.07	335.00	315.13	299.69	257.93	298.81	401.87	259.47	399.61	296.83	426.95	489.59	392.89	385.35	5523.69
Pears	3.40	3.26	1.77	2.39	3.29	0.36	0.35	4.82	7.25	15.69	23.22	32.78	40.65	27.47	73.12	69.23	105.15	140.43	554.66
Apples	20.11	45.81	22.86	25.29	23.91	2.96	30.52	20.61	2.45	52.43	24.45	34.75	28.38	29.35	32.95	33.22	62.41	27.55	520.01
Grapes	22.30	28.98	34.50	24.03	35.20	34.06	36.41	36.17	29.46	52.46	29.24	20.11	8.27	6.29	4.11	2.28	3.67	3.84	411.37
Bananas	0.00	5.53	2.62	2.11	2.06	9.05	9.62	30.32	32.57	4.47	16.03	36.56	44.94	45.08	31.40	25.94	18.66	17.03	333.97
Citrus Fruits	0.53	0.54	0.27	0.27	0.43	0.61	0.45	0.57	0.57	2.76	0.33	0.59	6.90	12.05	10.51	7.52	11.95	13.61	70.49
Peaches. Nectarines	2.21	2.47	2.20	2.36	2.73	4.25	1.45	3.22	4.46	4.15	5.40	5.71	4.74	4.99	0.50	0.47	6.12	8.62	66.05
Avocados	0.30	0.29	0.32	0.42	1.27	2.78	2.72	3.04	3.77	2.92	0.01	2.62	1.73	5.23	3.22	2.80	1.85	1.92	37.22
Apricots.	0.72	0.05	2.22	1.98	2.27	2.51	3.31	3.08	0.39	4.60	2.32	3.44	0.05	0.47	0.64	0.38	1.96	1.50	31.88
Strawberries	0.00	0.04	0.00	0.14	0.05	0.45	0.52	0.06	0.26	0.04	0.79	0.18	0.37	0.94	0.38	3.30	1.45	0.87	9.83
Figs	0.45	0.27	0.31	0.31	0.61	0.30	0.33	0.59	0.16	0.32	0.36	0.52	0.17	0.30	0.15	0.00	0.03	0.10	5.29
Melons	0.01	0.01	0.02	0.00	0.06	0.10	0.01	0.11	0.11	0.08	0.40	0.08	0.11	0.10	0.10	0.13	0.14	0.02	1.59
Raspberries	0.01	0.02	0.01	0.01	0.03	0.01	0.04	0.04	0.01	0.02	0.01	0.20	0.22	0.18	0.22	0.34	0.01	0.11	1.49
Plums	0.03	0.02	0.03	0.05	0.06	0.05	0.04	0.04	0.06	0.13	0.11	0.10	0.08	0.07	0.08	0.03	0.06	0.06	1.09
Mandarin. Clementine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.29	0.16	0.46
Grapefruit	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.11
Watermelons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.00	0.01	0.00	0.01	0.09
Oranges	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
Total Fruits	**77.39**	**233.13**	**492.73**	**249.13**	**248.07**	**392.50**	**400.91**	**402.38**	**339.46**	**438.90**	**504.55**	**397.11**	**536.22**	**429.36**	**584.33**	**635.27**	**606.65**	**601.20**	**7569.29**
Potatoes	96.51	96.82	67.11	86.44	58.90	62.45	5.75	56.90	58.92	103.11	8.95	64.98	60.86	56.51	57.37	76.78	81.28	77.51	1177.16
Olives	4.11	4.59	1.86	0.94	4.59	8.23	0.17	3.79	0.57	2.41	0.19	7.07	0.17	8.21	10.87	5.31	10.96	31.18	105.21
Tomatoes	1.09	1.20	0.40	0.93	3.66	7.98	6.88	4.97	0.23	5.39	1.71	6.15	6.16	6.50	0.54	5.41	5.51	6.56	71.24
Peas	7.20	2.55	2.13	1.46	2.28	5.16	3.80	4.45	5.28	0.16	1.50	3.33	4.51	2.26	0.20	2.74	1.87	4.70	55.61
Asparagus	1.00	0.14	0.12	1.27	0.17	1.30	0.59	0.50	3.51	1.64	0.51	0.49	1.36	0.46	0.55	0.55	1.45	1.15	16.76
Onions And Shallots	0.17	0.14	0.00	0.07	0.03	0.15	0.04	0.01	0.04	3.34	0.00	0.05	0.03	0.04	0.04	0.05	9.71	0.84	14.76
Beans	0.03	0.05	0.05	0.05	0.02	0.01	0.08	0.07	0.01	0.36	0.07	0.15	0.15	0.14	0.10	0.21	0.15	0.16	1.85
Artichokes	0.00	0.00	0.00	0.27	0.00	0.00	0.01	0.01	0.03	0.83	0.00	0.17	0.16	0.05	0.05	0.08	0.05	0.01	1.72
Cucumbers	0.01	0.02	0.04	0.02	0.09	0.07	0.09	0.08	0.08	0.09	0.01	0.06	0.05	0.05	0.04	0.05	0.07	0.10	1.01
Carrots And Turnips	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.07
Peppers	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.05
Lettuce	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Leeks	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Cauliflowers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Aubergines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total vegetables	**110.12**	**105.50**	**71.72**	**91.47**	**69.82**	**85.38**	**17.42**	**70.79**	**68.67**	**117.33**	**12.94**	**82.45**	**73.45**	**74.22**	**69.79**	**91.18**	**111.06**	**122.22**	**1445.50**
Total VWM	151,595.14	34,820.10	36,739.35	13,311.33	15,720.28	46,300.09	13,231.54	80,542.89	38,658.41	16,493.41	10,960.60	20,670.12	25,893.37	19,381.90	35,147.54	22,588.98	82,059.04	26,655.79	690,769.87

Source: Author's own.

Table 3. Net virtual water, (10^4 m^3), Morocco, 2000–2017.

Product	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2000–2017
Barley	−114,729.51	−5522.01	−20796.01	−330.4	-4632.13	-4477.39	−4738.29	−39,469.34	−14,394.63	−4336.42	−677.75	−6372.91	−2385.59	−3574.82	−11,501.07	−6056.72	−51,705.56	−9246.05	−304,946.6
Corn	−8949.06	−18,315	−5697.21	−7997.86	−5304.92	−31,588.61	−4683.12	−18,108.19	−12,198.39	−7386.93	−2482.45	−6128.11	−10,506.87	−10,352.63	−11,728.45	−10,947.41	−8678.97	−10,084.95	−191,139.13
Wheat	−26,903.4	−10,225.34	−9648.72	−4580.86	−5438.88	−9559.08	−3335	−22,265.03	−11,517.38	−4155.04	−7228.75	−7645.41	−12,336.15	−4688.89	−11,205.36	−4842.54	−20,647.57	−6435.33	−182,658.73
Oats	−11.86	−17.89	−5.35	−4.02	−1.49	−32.13	−2.77	−49.71	−7.3	−4.4	−11.49	−9.67	−11.53	−1.37	−10.21	−6.58	−144.81	−31.04	−363.62
Millet	−0.06	−5.45	−0.99	−5.94	−8.51	−13.83	−17.41	−20.62	−14.29	−13.56	−2.34	−22.18	−25.78	−42.4	−33.72	−3.36	−45.59	−46.76	−322.79
Total Cereals	**−150,593.91**	**−34,085.7**	**−36,148.29**	**−12,919.07**	**−15,385.93**	**−45,671.04**	**−12,776.58**	**−79,912.89**	**−38,132**	**−15,896.34**	**−10,402.78**	**−20,178.28**	**−25,265.92**	**−18,660.12**	**−34,478.82**	**−21,856.61**	**−81,222.5**	**−25,844.12**	**−679,430.9**
Lentils Dried	−792.39	−353.58	−26.4	−8.94	−14.92	−150.87	−36.43	−156.44	−118.1	−40.45	−40.33	−10.6	−13.23	−7.96	−12.05	−4.95	−118.64	−87.96	−1994.24
Chickpeas	−4.94	−28.94	2.89	15.45	17.66	8.09	0.07	0.17	0.32	10.16	20.65	2.59	0.24	−4.96	−0.47	3.28	10.8	5.06	58.12
Total Pulses	**−797.33**	**−382.52**	**-23.51**	**6.51**	**2.74**	**−142.78**	**−36.36**	**−156.27**	**−117.78**	**−30.29**	**−19.68**	**−8.01**	**−12.99**	**−12.92**	**−12.52**	**−1.67**	**−107.84**	**−82.9**	**−1936.12**
Dates	−26.92	−145.17	−423.82	−188.94	−175.53	−334.52	−313.83	−299.57	−257.92	−298.8	−401.79	−259.36	−399.51	−295.48	−425.78	−484.23	−390.47	−384.37	−5506.01
Pears	−3.37	−3.14	−0.24	0.49	2.96	0.72	−0.28	−3.63	−1.59	−15.69	−23.22	−32.77	−40.53	−27.42	−72.92	−66	−103.34	−138.88	−528.85
Apples	−19.9	−43.57	−22.86	−25.29	−23.91	−2.94	−30.52	−20.61	−2.45	−52.42	−24.43	−34.65	−28.24	−28.53	−29.03	−29.08	−61.07	−26.89	−506.39
Grapes	−13.86	−20	−22.06	−7.66	−7.05	6.32	19.32	20.15	26.63	−8.03	−29.24	1.93	22.81	24.61	26.43	25.35	28.93	23.28	117.86
Bananas	0	−5.53	−2.62	−2.11	−2.05	−9.05	−9.62	−30.32	−32.57	−4.4	−15.99	−36.54	−44.94	−44.97	−31.16	−25.9	−18.59	−17.03	−333.39
Citrus Fruits	2.11	0.87	1.02	0.33	0.53	2.69	1.77	2.79	12.79	0.48	1.41	3.4	−3.51	−10.15	−7.3	−7.19	−8.61	−8.59	−15.16
Peaches. Nectarines	7.05	7.1	3.99	2.7	7.58	10.54	9.12	7.75	−3.26	7.72	−5.36	4.15	−3.41	14.97	23.87	16.79	19.98	8.52	139.8
Avocados	−0.27	−0.23	−0.16	−0.12	−1.25	−2.73	−2.68	−2.45	−2.55	−2.05	0.31	−1.06	−1.35	−4.08	0.05	0.32	1.05	5.22	−14.03
Apricots.	149.44	164.15	150.92	118.61	134.57	107.6	89.56	103.88	64.57	60.09	28.32	50.87	50.31	68.52	80	60.86	6.84	51.85	1540.96
Strawberries	61.76	57.64	73.25	73.74	71.02	101.63	75.49	119.87	11.65	30.01	16.98	105.16	115.19	120.86	118.54	110.08	105.59	101.05	1469.51
Figs	−0.08	0.82	0.33	0.22	1.38	1.9	4.47	5.83	1.14	2.28	0.25	−0.16	0.12	−0.12	0.44	0.52	1.82	1.42	22.58
Melons	25.94	28	23.56	1.76	24.38	45.91	35.99	40.37	50.78	38.54	9.81	41.33	38.55	41.54	3.76	35.4	39.27	52.1	576.99
Raspberries	−0.01	−0.02	−0.01	0.24	0.12	0.6	0.2	3.17	6.53	8.7	8.26	1.58	16.03	36.8	51.94	54.68	5.84	66.66	261.31
Plums	−0.01	0	0	−0.04	-0.04	0.01	−0.04	0.07	−0.06	−0.13	−0.11	−0.1	−0.07	−0.05	0.38	0.73	0.26	0.24	1.04
Mandarin. Clementine	386.27	836.62	614.13	58.9	73.8	1000.41	780.19	1067.6	127.33	761.48	4209.66	1555.52	1102.47	1903.37	1013	1445.2	1543.59	1339.32	19,818.86
Grapefruit	0.07	0.24	0.14	0.06	0.15	0.34	0.27	0.77	0.83	0.52	1.26	0.37	1.7	1.1	0.24	0.46	0.58	1.07	10.17
Watermelons	0	0	0.48	0.52	0.3	0.58	0.29	0.51	0.8	0.8	0.04	0.84	1.21	1.76	3.71	7.78	9.48	15.95	45.05
Oranges	86.18	86.34	74.73	73.71	70.77	70.72	76.8	91.89	119.35	61.43	44.78	48.34	33.93	28.86	29.78	36.59	28.02	41.86	1104.08
Total Fruits	**654.4**	**964.12**	**470.78**	**107.12**	**177.73**	**1000.73**	**736.5**	**1108.07**	**122**	**590.53**	**3820.94**	**1448.85**	**860.76**	**1831.59**	**785.95**	**1182.36**	**1209.17**	**1132.78**	**18,204.38**
Potatoes	10.96	−88.4	−10.98	−30.08	11.18	−1.71	−1.24	6.92	21.12	−84.96	−3.89	−29.96	−24.69	−13.68	1.83	−41.72	−27.21	−27.75	−334.26
Olives	599.7	5497.49	4250.43	2017.16	5780.32	3128.03	3003.18	2660.47	3312.7	3378.81	2041.64	314.53	3597.43	3742.56	3552.5	4356.73	4278.69	5583.55	61,095.92
Tomatoes	227.75	221.84	204.5	175.64	195.95	204.69	166.36	302.24	260.63	278.39	592.47	340.47	295.24	255.56	326.91	332.45	337.62	336.39	5055.1
Peas	3.86	3.65	3.43	5.87	6.18	−4.05	4.8	7.22	−0.37	5.58	0.59	−1.5	−1.57	11.91	3.76	6.59	2.43	3.83	62.21
Asparagus	7.5	1.16	12.74	6.55	9.07	7.4	12.62	16.91	−0.91	29.94	−0.3	1.66	11.5	8.41	1.88	1.48	1.06	4.08	132.75
Onions and Shallots	0.35	2.09	3.83	1.8	3.33	3.76	7.32	8.27	3.75	−1.48	0.31	5.2	8.64	25.34	35.28	18.64	15.22	12.61	154.26
Beans	18.45	27.41	35.11	39.7	45.35	47.8	41.44	59.7	64.52	94.81	82.87	78.26	47.88	67.53	69.85	68.51	74.9	68.65	1032.74
Artichokes	0.25	0.57	0.96	1.92	3.19	3.46	0.32	3.67	2.85	0.93	0	2.67	1.42	6.21	2.19	0.15	0.71	0.58	32.05
Cucumbers	1.76	1.06	1.62	2.47	2.2	1.64	1.17	0.05	0.95	1.56	1.62	0.81	1.84	1.82	2.64	2.92	2.73	0.09	28.95
Carrots and Turnips	0.03	0.06	0.07	0.02	0.03	0.15	0.14	0.12	0.1	0.29	2.78	1.6	0.85	1.46	1.4	1.51	2.36	1.97	14.94
Peppers	1.86	2.55	3.24	3.47	6.42	6.54	4.24	5.49	9.06	6.51	10.65	10.39	10.19	12.61	14.08	13.92	13.14	13.49	147.85
Lettuce	0	0	0	0	0.02	0.17	0.16	0.1	0.06	0.04	0	0.05	0	0	0	0.14	0.03	0.07	0.84
Leeks	0	0.07	0.02	0.01	0.04	0.08	0.06	0.17	0.22	0.13	0	0.09	0.02	0.03	0.01	0.02	0.07	0.08	1.12
Cauliflowers	0	0	0	0.01	0.02	0.05	0.03	0.06	0.03	0	0	0.02	0	0.01	0.05	0.01	0.07	0.08	0.44
Aubergines	0	0.01	0.02	0.01	0.14	0.04	0	0	0.01	0	0.08	0.06	0.09	0.11	0.08	0.37	0.55	0.25	1.82
Total Vegetables	**872.47**	**5669.57**	**4504.98**	**2224.53**	**6063.43**	**3398.05**	**3240.61**	**3071.39**	**3674.72**	**3710.55**	**2728.82**	**724.35**	**3948.84**	**4119.88**	**4012.45**	**4761.72**	**4702.36**	**5997.96**	**67,426.68**
Net VWM	**−149,864.37**	**−27,834.53**	**−31,196.04**	**−10,580.91**	**−9142.03**	**−41,415.04**	**−8835.83**	**−75,889.7**	**−34,453.06**	**−11,625.55**	**−3872.7**	**−18,013.09**	**−20,469.31**	**−12,721.57**	**−29,692.94**	**−15,914.2**	**−75,418.81**	**−18,796.28**	**−595,735.96**

Source: Author’s own.

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