Open Journal of Social Sciences, 2023, 11, 162-189
https://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Virtual Water Trade in Egyptian Agricultural Sector in the Light of Scarcity of Water Resources

Gaber Ahmed Bassyouni Shehata[1*], Ahmed Hassan Ismaiel Srour[1], Shmoaa Awad Mohamed Soliman Oraby[2], Sahar El-Sayed El-Sayed El-Wakeel[3], Hanan Abd-Elmoneim Mohamed Zahran[1]

[1]Department of Agricultural Economics, Faculty of Agriculture (Saba Basha), Alexandria University, Alexandria, Egypt
[2]Department of Economics and Rural Development, Faculty of Environment Agricultural Sciences, Arish University, Arish, Egypt
[3]Agricultural Economics Institute, Agricultural Research Centre, Cairo, Egypt
Email: *dr-gaber2000@alexu.edu.eg, Ahis2010@yahoo.com, shmoaaawad@gmail.com, Dr_saharelwakeil22@yahoo.com, ha_hz2003@yahoo.com

How to cite this paper: Shehata, G. A. B., Srour, A. H. I., Oraby, S. A. M. S., El-Wakeel, S. E.-S. E.-S., & Zahran, H. A.-E. M. (2023). Virtual Water Trade in Egyptian Agricultural Sector in the Light of Scarcity of Water Resources. *Open Journal of Social Sciences, 11,* 162-189.
https://doi.org/10.4236/jss.2023.115013

Received: August 14, 2022
Accepted: May 21, 2023
Published: May 24, 2023

Abstract

Agricultural foreign trade has taken many recent trends in light of many changes and developments affecting the global economic environment. Countries have resorted to adjusting their trade policies and reconsidering the commodity structure of their exports to suit their resources, especially water resources, in order to maintain the efficiency of the use of these resources and at the same time increase the export return. The water issue in Egypt faces major challenges on the demand side of water in light of the relative stability on the supply side. The state is working to increase the supply side through the reuse of agricultural wastewater, seawater desalination, and wastewater treatment. On the demand side, it is working to develop systems Irrigation, reducing wastage in the use sectors, moving towards foreign trade by importing basic crops, and limiting the export of water-depleting crops to find a balance between the water balance and the agricultural trade balance, in which the deficit amounted to about LE 182.5 billion, representing about 23.5% of the deficit in the total trade balance of about LE 777.42 billion in 2019. The problem of the research is inefficiency of using the water resource in agricultural exports, as most components of the Egyptian agricultural exports structure are water-intensive fruit and vegetable crops, while the contribution of agricultural commodities that is less in the use of the water resource and the best in the export return is somewhat limited, which indicates the importance of working on modifying the structure of Egyptian agricultural exports and re-planning them in line with the variables related to the scarcity of water resources in Egypt. The main objective of the research is to propose different alternatives for the optimal planning of Egyptian agricultural exports, which are characterized by high export returns and low needs of water resources. The research depends on the linear programming method as a quantitative method to measure the phenomena and variables related to the research problem. Related to the research results, the following can be recommended: 1) Supporting the productive capacities of producers to export crops that use less water; 2) Reducing the expansion of exports that use the most water resource by limiting the volume of export support for these commodities; 3) Working to increase the Egyptian exports of dates, pomegranates, olives, grapes, fresh kernels, potatoes, eggplant, coriander, jasmine paste and marjoram, as they are among the agricultural exports with high export returns and the least in their needs for water resources; 4) Working to reduce or stabilize the exported quantities of bananas, citrus fruits, mangoes, onions, garlic, tomatoes, mint and fennel as they are among the agricultural exports with high average returns and the highest in their needs for water resources.

Keywords

Virtual Water, Supply Water, Demand, Egypt, Trade Water

1. Introduction

Agricultural foreign trade has taken many recent trends in light of many changes and developments affecting the global economic environment. Countries have resorted to adjusting their trade policies and reconsidering the commodity structure of their exports to suit their resources, especially water resources, in order to maintain the efficiency of the use of these resources and at the same time increase the export return.

The Egyptian agricultural foreign trade takes great importance in terms of the role of agricultural imports in achieving Egyptian food security and meeting the requirements of the local market, and the role of agricultural exports in increasing returns and supporting the national economy (Shehata et al., 2018).

In recent years, Egypt has faced many challenges related to Egyptian water security and contributed to increasing the risks of the scarcity of Egyptian water resources, the most important of which are the poor efficiency of the use of available water resources, population increase and threats related to the construction of El-Nahda Dam, which increased the importance of working to redraw agricultural and export policies to suit the scarcity Egyptian water resources.

In light of the repercussions of the water resource scarcity in Egypt, which takes many different dimensions, the importance of reconsidering the structure of Egyptian agricultural exports comes from the concept of virtual water, and virtual water is water "embodied" in a product, not in the real sense, but in the virtual sense. It refers to the water needed to produce the product. Virtual water is also called "embedded water" or "outside water", the latter referring to the fact that importing virtual water into a country means using the external water of the importing country. The external waters are thus added to the "original waters" of the country (Haddadin, 2003).

Egyptian agricultural exports are among the most important components of the Egyptian commodity exports structure, and contribute about 15% to the total Egyptian exports, mostly represented in fresh agricultural commodities of fruits and vegetables with high water consumption (Shehata & Zahran, 2021).

The water issue in Egypt faces major challenges on the demand side of water in light of the relative stability on the supply side. The state is working to increase the supply side through the reuse of agricultural wastewater, seawater desalination, and wastewater treatment. On the demand side, it is working to develop systems Irrigation, reducing wastage in the use sectors, moving towards foreign trade by importing basic crops, and limiting the export of water-depleting crops to find a balance between the water balance and the agricultural trade balance, in which the deficit amounted to about LE 182.5 billion, representing about 23.5% of the deficit in the total trade balance of about LE 777.42 billion in 2019 (Central Agency for Public Mobilization and Statistics, 2010-2020b).

The reality of Egyptian agricultural foreign trade under the concept of virtual water:

Foreign trade is one of the most important sectors supporting the national economy, as it needs to provide production requirements to produce export commodities suitable for world markets. As for agricultural exports, the most important production requirements are seeds that conform to specifications, chemicals and pesticides that are allowed to be used according to international standards, but the water component is one of the most important production requirements for commodities. Agricultural in general and export in particular, where it is important to provide hygiene conditions in irrigation water and not be polluted by agricultural drainage or soil pollutants.

Recently, the Egyptian agricultural foreign trade has taken many different dimensions into consideration, especially in light of the intensification of the repercussions of developments related to Egyptian water security during previous periods, which prompted the Egyptian side to redraw trade policies that are compatible with the preservation of Egyptian water resources.

Tony Allen is the first to launch this concept, and he definesd virtual water as: water used elsewhere to produce food that is exported to areas of water scarcity. He puts forward this concept with the aim of solving the problem of limited water resources in dry areas, especially the Middle East, where he believes that: "Since water is one of the important variables in the production of crops, so different countries should determine the amount of water needed to produce the food they need, When a country imports a ton of wheat and corn, it is also actually importing virtual water, that is, the water needed to produce those crops." This concept was introduced in 1993 by Allan, but it took a decade to be adopted as a resource for achieving water security at all levels (Allan 1996, 2002, 2003).

The virtual water perspective was initially proposed as a strategy for waterdeficient countries to import water-intensive goods produced in water-abundant countries to alleviate the current water stress. However, several studies show that this strategy is not affected by international trade data (Ramirez-Vallejo & Rogers, 2004).

But it is not always possible to reallocate water savings to other beneficial purposes (including mitigating environmental scarcity) to mitigate water scarcity, which means that economic and political considerations may have a greater influence than water scarcity in determining national trade strategies (Du Fraiture, 2004). Trading strategies based on a hypothetical water perspective are inconsistent with the economic concept of comparative advantage and cannot be used alone as a criterion for optimal policy development (Wichelns, 2010).

Similarly, a number of studies have found that more often, water-rich countries import water-intensive products, while water-scarce countries export water-intensive products due to the dominant influence of other factors such as land, labor costs and revenue (Kumar & Singh, 2005).

Virtual water contains three types of water, namely:

Green water:

It is the amount of rain water that evaporates during the production process, and this is represented in agricultural crops, that is, the total water evaporated from the field during the growth period of the crop, and this includes sweating of plants and other forms of evaporation.

Blue water:

It is the amount of surface or groundwater that evaporated as a result of the productive process. In the case of crop cultivation, this type of water can be defined as the sum of the evaporation of irrigation water from the field and the evaporation of water from irrigation water channels and artificial storage places. In the case of the industrial process and local water supplies, it can be defined Blue water is an amount (used in production) equal to water evaporated from water extracted from the ground or surface water that does not belong to the ecosystem from which it came. That is, it is the water of fresh water bodies, rivers, as well as water located below ground level, i.e. groundwater.

The green water resource is water stored in unsaturated soil. It is the water source for rainfed agriculture. The source of blue water refers to the water found in rivers, lakes, reservoirs, ponds, and aquifers. Irrigated agriculture usually uses blue water as a supplement to the lack of rainfall. Currently, the data available at the country level includes only blue water resources. Information on green water resources is mostly absent. This is partly related to the technical and conceptual complexity in quantifying green water resources. For example, green and blue water resources are interrelated in the hydrological system. They are not two separate sources. Further complicating the assessment is that the green water resource is a stock, while the blue water resource is a flow (Falkenmark & Rockstrom, 2006).

Gray water:

It is the hypothetical amount of water that is polluted during the production process, and this can be determined by estimating the amount of water required to dilute the pollutants generated during the production process to the extent that the water quality is still according to the agreed standards in terms of water quality.

Virtual water trade:

It is the hidden flow of water if food or other commodities are circulated from one place to another. Where this concept is considered one of the means to increase the efficiency of water use in the world, as it indicates that countries that suffer from water scarcity can import high water consumption commodities to maximize the value of the limited water they have, and in this way the importing country achieves water savings at the same time, this savings can be used for other purposes and uses of high productivity, that is, to generate a greater multiplier value for each unit of water.

International trade is organized according to relative cost advantages. Because water prices in many countries are either non-existent or too low to in any way reflect the value of water, the current virtual water trade is regulated not by relative cost advantages, but by absolute water scarcity. They argued that if an economically appropriate value was attached to water or its supply, a hypothetical water trade strategy under a special promotion policy would not be needed because the trade would organize itself according to its comparative cost advantages (Yang & Zehnder, 2007).

The net import of virtual water in a water-scarce country can reduce pressure on the country's water resources, as virtual water can be considered an alternative source of water. And that the use of this additional source be a tool for achieving regional water security, and this is the political argument that Tony Allan has put forward since the beginning of the hypothetical debate on water, where the virtual trade of water can be a tool in solving geopolitical problems and even preventing wars over water (Allan, 1996, 2002, 2003). Next to the political dimension, there is the economic dimension, equally emphasized by "Tony Allen: The economic argument behind virtual water trade is that, according to international trade theory, countries must export products in which they have a comparative or comparative advantage in production, while they must import products that have It has a relative disadvantage (Wichelns, 2001).

Virtual water balance:

It is defined as the quantity difference between the exporter and the importer multiplied by the water footprint of this product during a specified period of time. Export is considered a negative sign because it means water loss with exported products, commodities and crops. If the state's exports exceeds the water it imports, this is calculated as a deficit, and if the import exceeds the estimate, there will be a surplus of virtual water, and the global water availability depends on the difference between the productivity of a cubic meter of water in importing and exporting countries.

The amount of water used in production = the amount of crop production × water needs per ton

The amount of exported virtual water = the amount of exports of the crop × water requirements per ton

The amount of imported virtual water = the amount of imports of the crop × water requirements per ton

Net virtual water balance = volume of virtual water imports − volume of virtual water exports

The reality of Egyptian agricultural exports under the concept of virtual water

Virtual water is defined as the water inherent in the product, not explicitly, but by default, and it is referred to as the water needs of the product, as it is called in some cases the water that includes embodied water or exogenous water, and its importance has increased in the recent period, where the importance of virtual water is in contributing to the formulation of water, agricultural and export policies in countries, especially those that suffer from a shortage of water resources, including Egypt.

In recent years, Egyptian exports have been affected by many changes and developments. Water determinants consider from the most important developments that have affected the structure of Egyptian agricultural exports through the trade policies taken by the Egyptian state to limit exports with high water needs such as rice, and through the rational use of water in production. In order to export to ensure the quality of irrigation water in the exported products and not cause these exports to be rejected in world markets due to the repercussions of pollution of irrigation water.

1.1. Research Problem

The problem of the research is the inefficiency of using the water resource in agricultural exports, as most components of the Egyptian agricultural exports structure are water-intensive fruit and vegetable crops, while the contribution of agricultural commodities that is less in the use of the water resource and the best in the export return is somewhat limited, which indicates the importance of working on modifying the structure of Egyptian agricultural exports and re-planning them in line with the variables related to the scarcity of water resources in Egypt.

1.2. Research Objectives

The main objective of the research is to propose different alternatives for the optimal planning of Egyptian agricultural exports, which are characterized by high export returns and low needs of water resources. This main objective is achieved through a set of sub-objectives, including the following:

1) Studying of the reality of Egyptian water resources.

2) Identifying the general features of the reality of Egyptian agricultural exports and imports under the concept of virtual water.

3) Suggesting appropriate policies to develop agricultural exports that have

the lowest water needs and higher export returns, and stabilize or limit agricultural exports with large water needs.

1.3. Research Methodology and Data Sources

To achieve objective of the research, it depends on both descriptive and quantitative statistical analysis methods, where some economic indicators were used to explain virtual water balance, in addition to use linear programming approach for optimal planning of Egyptian agricultural exports in light of the scarcity of available water resources.

The research depends on both descriptive and quantitative analysis methods, where the descriptive method was used to explain some concepts and variables related to the research, while the research relied on the linear programming method as a quantitative method for optimal planning of Egyptian agricultural exports in light of the scarcity of available water resources.

The linear programming problem can be formulated as follows:

$$
\begin{aligned}
\text{Maximize} \quad & c_1x_1 + c_2x_2 + \cdots + c_nx_n \\
\text{Subject to} \quad & a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \le b_1 \\
& a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \le b_2 \\
& \vdots \\
& a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \le b_m \\
& x_1, x_2, \cdots, x_n \ge 0
\end{aligned}
$$

Linear programs formulated this way as linear programs in standard form; we use m to denote the number of constraints, and n to denote the number of decision variables. A proposal of specific values for the decision variables is called a solution. A solution (x_1, x_2, ..., x_n) is called feasible if it satisfies all of the constraints. It is called optimal if in addition it attains the desired maximum (Vanderbei, 2020).

The research depends on the published and unpublished secondary data issued by the component authorities such as Ministry of Irrigation and Water Resources, Ministry of Agriculture and Land Reclamation, Central Agency of Public Mobilization and Statistics, in addition to some data published on the internet, as well as the publications of the Food and Agriculture Organization of the United Nations (FAO) were also relied upon. Use the international web to obtain information related to the research studies, publications and information that issued by various research and institutes, as well as studies related to the subject of the research.

The research depends on collecting data on agricultural foreign trade on the Egyptian customs tariff issued by Republican Decree No. 39 of 2007, the Egyptian Customs Authority and the Ministry of Finance, and according to the Standard Commodity Classification related to Harmonic System (H.S), which is the most widely used commercial classification in the world for foreign trade data for commodities (Countries are obligated according to the rules of the World Customs Organization to define the exported and imported goods within the framework of the decisions of the World Customs Organization according to the commodity classification (H.S), which is the most widely used classification in the world, where the commodities are classified on the basis of the raw material, and according to the degree of processing, use, and more details from the Food and Agriculture Organization of the United Nations website http://www.fao.org/statistics/standards/ar/).

It is worth noting that what is meant by fresh agricultural commodities in the research is the components of fresh Egyptian agricultural exports of vegetables, fruits, medicinal and aromatic plants, and grain products, at the level of the 4 digits customs chapters contained in the Egyptian customs tariff issued according to the Harmonic System (H.S) Standard Commodity Classification. The commodity structure of agricultural exports was divided into the following:

- **Vegetable exports:** it includes merchandise exports of vegetable crops in their fresh and raw form. The items of these commodities fall under the customs chapter (07) according to the commodity classification (H.S).
- **Fruit exports:** it includes commodity exports of fruit crops in their fresh and raw form, and the items of these commodities fall under the customs chapter (08) according to the commodity classification (H.S).
- **Exports of medicinal and aromatic plants**: it includes commodity exports of medicinal and aromatic plants, whether in the form of leaves, roots, stems or seeds. The items of these commodities fall under the customs chapter (09), and the customs item (12), according to the commodity classification (H.S).
- **Grain exports:** it includes merchandise exports of grain crops of all kinds, and the items of these commodities fall under the customs chapter (10), according to the commodity classification (H.S).

Spatial and temporal limits of the study

The study focused on identifying the general features of the Egyptian agricultural foreign trade with world markets as spatial limits for research, during the period (2010-2020) as time limits for the study.

The research depends on both descriptive and quantitative analysis methods, where the descriptive method was to explaining some concepts and variables related to the research, while the research relied on the linear programming method as a quantitative method to measure the phenomena and variables related to the research problem.

2. Research Results

First: The reality of the Egyptian water resources.

Table 1 shows that the total water resources in Egypt amounted to about 80.25 billion m^3, of which about 59.6 billion m^3 were from traditional water resources, namely the Nile River, groundwater and rain, and about 20.6 m^3 from non-traditional resources, the most important of which are shallow groundwater and treated wastewater during the year 2020. It was also found that the agricultural sector consumes about 61.65 billion m^3, representing about 76.8% of the

Table 1. Egypt's water balance in billion m³ during the period (2017-2020).

Water source	2017	2018	2019	2020
The Nile River	55.50	55.50	55.50	55.50
Deep ground water	2.10	2.40	2.45	2.45
Rain and torrential	1.30	1.30	1.30	1.30
Sweetening	0.21	0.25	0.35	0.35
Total conventional water resources	59.11	59.45	59.60	59.60
Shallow groundwater (delta)	7.39	7.05	7.15	7.00
Wastewater reuse	13.50	13.50	13.50	13.50
Unconventional water resources	20.89	20.55	20.65	20.65
Total water resources	80.00	80.00	80.25	80.25
Water resources uses				
Drinking water	10.65	10.65	10.70	10.70
Industry water	5.40	5.40	5.40	5.40
Farming water	61.45	61.45	61.65	61.65
Evaporation losses	2.50	2.50	2.50	2.50
Total uses	80.00	80.00	80.25	80.25

Source: Central Agency for Public Mobilization and Statistics (2010-2020b), Issues (2017-2020), Irrigation and Water Resources Annual Bulletin, Issues (2017-2020).

total uses, followed by drinking water with about 10.7 billion m³, at a rate of 13.3%, then industry with about 5.4 billion m³, at a rate of 6.7%, and in the last place evaporation losses about 2.5 billion m³, representing 3.1% of the total uses.

Table 1 also shows that there is a relative stability in the volume of Egyptian water resources despite the increase in the population, the increase in factories and the expansion of agricultural projects, which indicates the existence of a scarcity in Egyptian water resources, and therefore the importance of working to reduce the low efficiency of water use in various fields, the most important of which are activities agricultural. It is worth noting that the average per capita share of water in Egypt is about 560 m³ of water annually, which is lower than the global average of about one thousand m³ annually.

Contribution of the most important agricultural commodities to Egyptian exports:

Through the data of Figure 1 and Table 1 in the appendix, it is clear that the most important components of the commodity structure of fresh Egyptian agricultural exports are fruit exports, which represented about 47.6% of the amount of agricultural commodity exports, vegetables, which represented about 42.7%, and medicinal and aromatic plants, which represented about 2.4% of the amount of agricultural commodity exports as an average for the period 2010-2021.

Contribution of the most important agricultural commodities to Egyptian exports:

Through the data of Figure 1 and Table 1 in the appendix, it is clear that the most components of the commodity structure of fresh Egyptian agricultural exports are fruit exports, which represented about 47.6% of the amount of agricultural commodity exports, vegetables, which represented about 42.7%, and medicinal and aromatic plants, which represented about 2.4% of the amount of agricultural commodity exports as an average period 2017-2020.

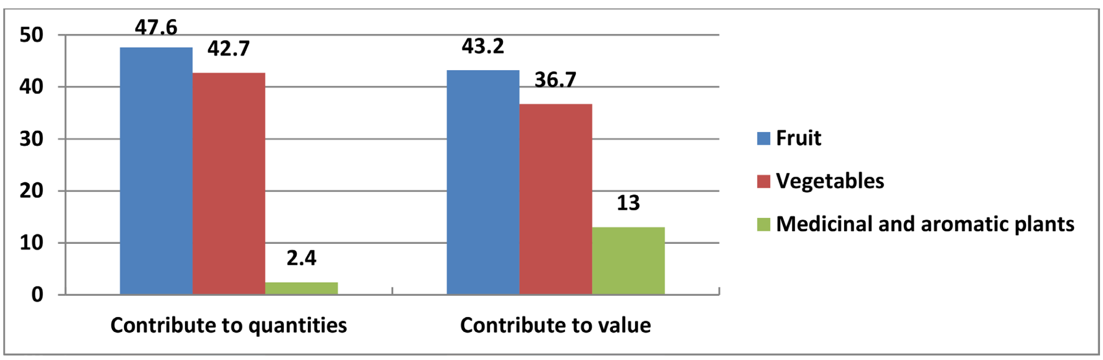
It also appears from Table 2 in the appendix that the most important components of the commodity structure of fruit exports are citrus, which contribute about 51% to the total fruit exports, then grapes, strawberries and mangoes, and their contribution to fruit exports is about 19%, 14%, 6%, for each of them respectively.

While Table 3 in the appendix shows that the most important components of the commodity structure for vegetable exports are potatoes and onions, as each of them represented about 21% of the total vegetable exports, as well as frozen vegetables by 15.8%, and fresh tomatoes and pulses with a contribution of 4.6%, 5.5% for each of them respectively.

Table 4 in the appendix shows that the most important components of the commodity structure for exports of medicinal and aromatic plants are sunflower seeds, which contribute about 26% to the total exports of medicinal and aromatic plants, then fruits and oilseeds by 16%, then dried peppers by 12%.

Second: Contribution of the most important agricultural commodities to Egyptian imports:

It is clear from the data of Figure 2 and Table 1 in the appendix that the most important components of the commodity structure of fresh Egyptian agricultural imports are grain imports, which represented about 89% of the amount of agricultural commodity imports, fruit, vegetables, where each represented about 7%, and medicinal and aromatic plants which represented about 3% of the amount of imports of agricultural commodities as an average for the period 2010-2021.



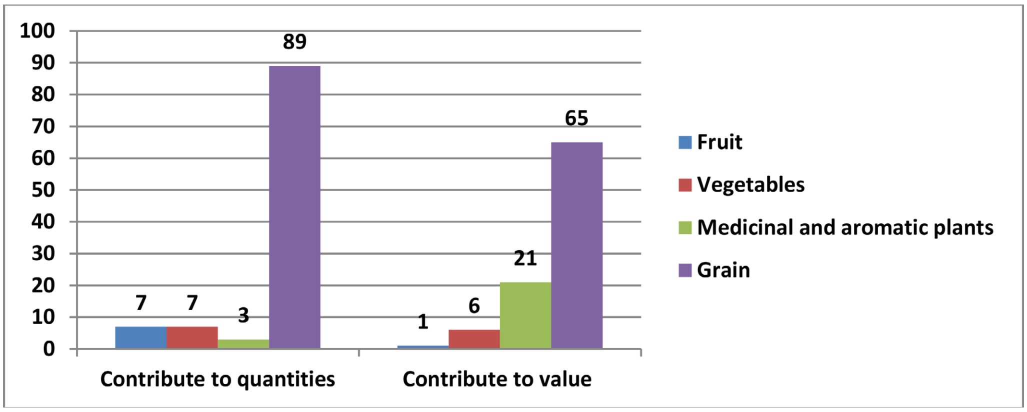
Source: Table A1 in Appendix.

Figure 1. The contribution of the most important agricultural commodity groups Egyptian agricultural exports as an average for the period 2010-2021.

Third: The reality of the Egyptian agricultural trade balance under the concept of virtual water:

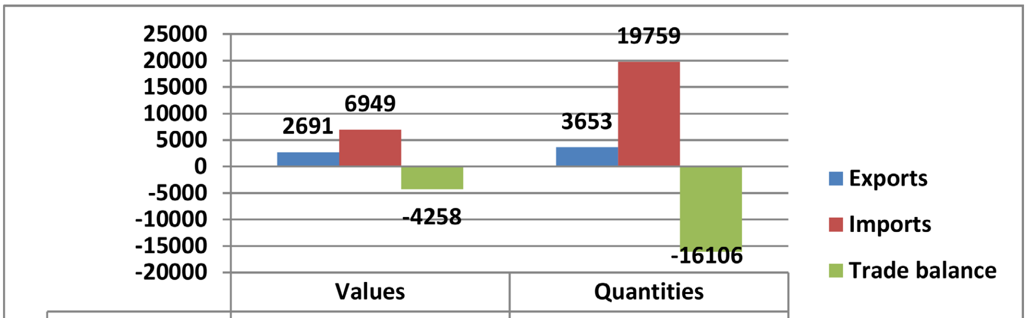
It is clear from the data of Figure 3 and Table 1 in the appendix that Egypt suffers from a deficit in the agricultural trade balance of fresh agricultural commodities in both quantity and value, mainly due to the increase in Egypt's imports of grains, fruits and oilseeds, where this deficit amounted to about 16.1 million tons of imported commodities with a total value of about $4.2 billion.

It is certain that this deficit is largely reflected in the trade balance of virtual water in the Egyptian foreign trade of the fresh agricultural commodities under study, as the results of Table 2 show the amount of virtual water imported through the fresh agricultural commodities under study amounted to about 54 billion m^3, mostly due to cereals. The same table shows that the amount of virtual water exported from fruit crops amounted to about 530 million m^3, mostly citrus, while the amount of virtual water exported from vegetables amounted to 417 million m^3, mostly potatoes, onions and garlic.



Source: Table A1 in Appendix.

Figure 2. The contribution of the most important agricultural commodity groups to the Egyptian agricultural imports as an average for the period 2010-2021.



	Values	Quantities
Exports	2691	3653
Imports	6949	19759
Trade balance	-4258	-16106

Source: Table A1 in Appendix.

Figure 3. The agricultural trade balance of fresh agricultural commodities as an average for the period 2010-2021.

Table 2. The commercial water balance of Egypt's virtual water million m³ according to the commodity groups of the most important Egyptian agricultural exports as an average for the period 2010-2020.

Commodity group	Exported commodity	Quantity of virtual water exported (thousand m³)	Quantity of imported virtual water (thousand m³)	Commercial water balance of virtual water million cubic meters
Fruit	citrus	453.0	0.9	0.5
	grapes	11.9	0.7	0.01
	strawberry	9.3	0.4	0.01
	mango	28.2	1.5	0.03
	olive	4.1	0.6	0.00
	pomegranate	26.6	0.02	0.03
	dates	0.8	0.1	0.001
Vegetable	potato	89.2	33.3	0.1
	onions and garlic	85.2	12.5	0.1
	tomatoes	6.1	0.03	0.01
	eggplant	4.5	0.04	0.00
	fresh kernel seeds	277.9	0.1	0.3
Medicinal and aromatic plants	sunflower seeds	38.7	222.8	−0.2
	oil fruits and seeds	4.3	14.4	−0.01
	jasmine	1.8	0.2	0.00
	dried and ground pepper	8.4	42.1	−0.03
	marjoram	0.8	0.1	0.00
	coriander	11.0	9.5	0.00
	mint	21.4	0.01	0.02
	fennel	9.7	0.01	0.01
Grains	Wheat	0.0	54,503.6	−54.5
	maize	0.0	13.4	−0.01
	rice	0.0	245.0	−0.3
General total		1092.9	55,101.2	−54,018
Total fruit group		533.9	4.3	530.0
Total vegetable group		462.9	45.9	417.0
Total group of medicinal and aromatic plants		86.5	289.0	−203.0
Total grain group		0.02	0.02	−54.8

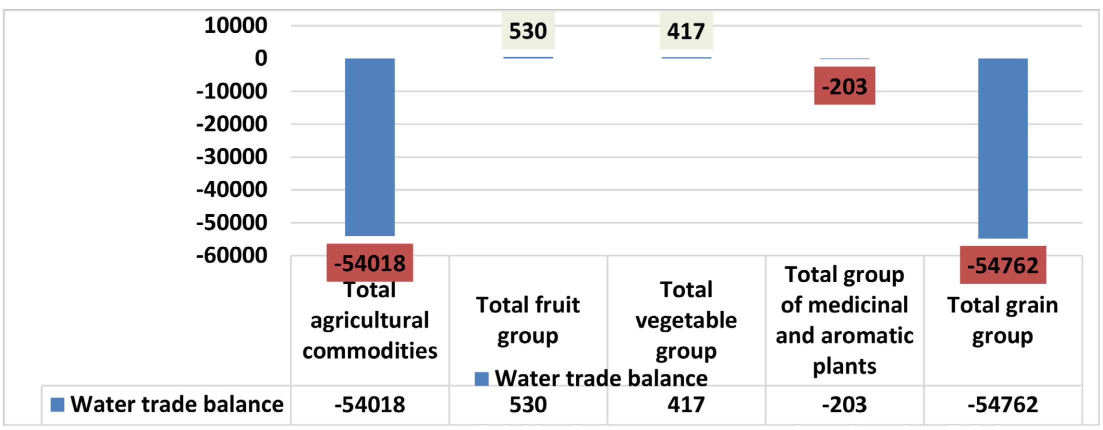
Source: Compiled and calculated from: 1) Central Agency for Public Mobilization and Statistics (2010-2020b), Annual Bulletin of Irrigation and Water Resources Statistics, issues (2010-2020); 2) FAO database, available at https://www.fao.org/faostat/ar/; 3) Central Agency for Public Mobilization and Statistics (2010-2020a), Agricultural Statistics Yearbook, issues (2010-2020).

Fourth: Optimal planning for Egyptian agricultural exports in light of the scarcity of available water resources:

Planning Egyptian agricultural exports in an optimal manner that is commensurate with the scarcity of Egyptian water resources is of great importance, especially in light of the growing dangers of Egyptian water security and raising awareness of the concept of virtual water, in the context of implementing the state's efforts aimed at achieving sustainable development and preserving Egyptian water resources and not depleting them, and in view of the distribution The current merchandise of the most important Egyptian agricultural exports as an average for the period 2016-2020 for global markets, which is shown in Table 3. It appears that the most important fresh Egyptian agricultural exports are vegetables, fruits, medicinal and aromatic plants. The average exported quantities of the most important fresh agricultural commodities during the period 2016-2021 amounted to about that the annual average of the amount of Egyptian exports to the world amounted to about 2909 thousand tons, with a total value of about 1419 million dollars, and the average water needs of the cultivated acre of these exportted commodities amounted to about 3074 m^3/feddan. The most important agricultural commodities exported by Egypt are 20 different commodities that can be divided into three main groups:

The first group: It includes fruit crops, as it includes seven crops: oranges, grapes, strawberries, mangoes, olives, pomegranates and dates. The annual Egyptian exports of this group are estimated at 2114 thousand tons, which is equivalent to 74% of the total quantity of the most important fresh Egyptian agricultural commodities exported to the world during that period. The average water requirement per feddan for these exported commodities is about 2359 m^3/feddan, and dates are one of the least crops in terms of water needs per feddan.

The second group: It represented by vegetable crops, which includes five crops, namely potatoes, onions, garlic, tomatoes, eggplants and fresh horny seeds. The annual Egyptian exports of this group are estimated at 697 thousand tons, equivalent to 29% of the total quantity of the most important fresh Egyptian agricultural commodities exported to the world during that period. The average water requirement per acre for these exported commodities is about 3195



Source: Table A5 in Appendix.

Figure 4. The agricultural trade water balance from the virtual water of fresh agricultural commodities as an average for the period 2010-2021.

Table 3. Quantitative and quantity distribution and average price of the most important Egyptian exports according to water needs during the period (2016-2020).

Commodity group	exported commodity	Code	Water Needs (m^3/fed)	Contribute to the quantity of the most important agricultural exports	Exported quantity		Export value		Export price ($/ton)	Import capacity (10^3/ton)	% of Egypt's exports of import energy
					10^3 (ton)	%	10^6 $	%			
Frut	citrus	X_1	3500	18	1553	53.4	490	34.5	315.52	6962	7.81
	grapes	X_2	1200	7	128.6	4.4	184	13.0	1430.79	4538	5.09
	strawberry	X_3	1450	4.7	225.5	7.8	126	8.9	558.76	4497	5.05
	mango	X_4	6912	2.1	61.2	2.1	56	3.9	915.03	1020	1.14
	olive	X_5	1500	1.3	13.7	0.5	16.7	1.2	1218.98	1110	1.25
	pomegranate	X_6	1400	1.2	133	4.6	69.5	4.9	522.56	1547	1.74
	dates	X_7	550	1.1	25.6	0.9	96	6.8	1718.75	950	1.07
Vegetable	potato	X_8	2972	7	255	8.8	166.3	11.7	722.35	13674	15.34
	Onions and garlic	X_9	3200	6	213	7.3	14.2	1.0	80.28	10831	12.15
	tomatoes	X_{10}	4265	1.3	50.2	1.7	34.2	2.4	681.27	7629	8.56
	eggplant	X_{11}	2986	0.2	15.4	0.5	12.8	0.9	831.17	2114	2.37
	fresh kernel seeds	X_{12}	2554	1.7	163.2	5.6	55.6	3.9	289.22	6290	7.06
Medicinal and aromatic plants	sunflower seeds	X_{13}	3026	0.3	25.6	0.9	9.7	0.7	378.91	2327	2.61
	Oil fruits and seeds	X_{14}	2300	1.2	4.3	0.1	40.9	2.9	9046.51	1391	1.56
	jasmine	X_{15}	2010	0.6	5.4	0.2	30.2	2.1	4511.63	8302	9.31
	Dried and ground pepper	X_{16}	4158	0.1	7.5	0.26	3.2	0.2	744.19	1594	1.79
	marjoram	X_{17}	2012	0.1	9	0.31	3.1	0.2	720.93	1132	1.27
	coriander	X_{18}	1650	0.1	8	0.27	5	0.4	697.67	2394	2.69
	mint	X_{19}	7704	0.1	8.9	0.31	2.9	0.2	426.47	2625	2.95
	fennel	X_{20}	6121	0.1	3	0.1	2.8	0.2	1647.06	8204	9.20
General total		-	3074(*)	100	2909	100	1419	100	27,458	89,131	100
Total fruit group		-	2359(*)	74	2141	74	1038	73	6680	20,624	23
Total vegetable group		-	3195(*)	24	697	29	283	20	2604	40,538	45
Total group of medicinal and aromatic plants		-	3623(*)	24	71.7	2.5	283	20	2604	40,538	45

(*) The amount average of water requirements for crops. **Source:** Table A5 in the Statistical Appendix.

m^3/feddan. Potatoes are considered one of the least crops in terms of water needs per acre.

The third group: It represented by medicinal and aromatic plants, which includes eight crops: sunflower seeds, fruits, oil seeds, jasmine paste, dried and ground pepper, marjoram, coriander, mint and fennel. The annual Egyptian exports from this group are estimated at about 71.7 thousand tons, which is equivalent to 2.5% of the total amount of the most important fresh Egyptian agricultural commodities exported to the world during that period. The average water requirement per feddan for these exported commodities is about 3195 m^3/feddan. Potatoes are considered one of the least crops in terms of water needs per feddan.

Objective function:

It aims to increase the amount of exports of crops with less water needs during the period (2016-2020). To formulate this function, the water needs of crops were used during the study period, and the average quantity that could be exported to the world was used, so the target function can be formulated as follows:

$$\begin{aligned}\text{Max} = {} & 3500X_1 + 1200X_2 + 1450X_3 + 6912X_4 + 1500X_5 + 1400X_6 \\ & + 550X_7 + 2972X_8 + 3200X_9 + 4265X_{10} + 2986X_{11} + 2554X_{12} \\ & + 3026X_{13} + 2300X_{14} + 2010X_{15} + 4158X_{16} + 2012X_{17} + 1650X_{18} \\ & + 7704X_{19} + 6121X_{20}\end{aligned}$$

Table 4 shows the export constraints of the linear programming model for the most important fresh agricultural exports during the period 2016-2020.

Alternative activities: They are represented in the commodity structure of the most important crops exported by Egypt.

Export constraints: It represented by the average import capacities in thousand tons of importing countries, as well as the current export quantities during the study period.

The results of the proposed alternatives shown in Table 5 indicated the following:

As for the current model, the Egyptian exports of fruit crops amounted to about 73.56%, for vegetable crops about 23.94%, and for medicinal and aromatic plants about 1.91%, with a total virtual water exported of about 1092.9 million m^3.

As for the first alternative, it achieved an export proceeds, as shown in Table 5, estimated at about $1160 million, with a decrease of $(−259) million, which represents about −18.2% from the current model, with a total virtual water exported amounting to about 834.5 million m^3. This decrease is due to the reduction of fruit exports, which are characterized by a high export return compared to vegetables and medicinal and aromatic plants. This quantity was distributed among 15 crops and the rest of the crops were excluded. The fruit group, through this alternative, as shown in Table 5, acquired 66.8% of the total exported quantities, while the vegetables group acquired 29.8%, while the medicinal and aromatic plants group accounted for about 3.4% of the total exported quantities.

Table 4. Export constraints of the linear programming model for the most important fresh agricultural exports for the period 2016-2020

Restrictions (for current export quantities)		Alternative activities		Restrictions (for import capacities)
1553	≤	X_1	≤	6962
128.6	≤	X_2	≤	4538
225.5	≤	X_3	≤	4497
61.2	≤	X_4	≤	1020
13.7	≤	X_5	≤	1110
133	≤	X_6	≤	1547
25.6	≤	X_7	≤	950
255	≤	X_8	≤	13,674
213	≤	X_9	≤	10,831
50.2	≤	X_{10}	≤	7629
15.4	≤	X_{11}	≤	2114
163.2	≤	X_{12}	≤	6290
25.6	≤	X_{13}	≤	2327
4.3	≤	X_{14}	≤	1391
5.4	≤	X_{15}	≤	8302
7.5	≤	X_{16}	≤	1594
9	≤	X_{17}	≤	1132
8	≤	X_{18}	≤	2394
8.9	≤	X_{19}	≤	2625
3	≤	X_{20}	≤	8204
2909		≥		$\sum_{1}^{20} X_i$

As for the second alternative, it achieved an export earnings, as shown in Table 5, estimated at about $1437 million, an increase of $17.8 million, representing about 1.3% from the current model, and with a total exported virtual water of about 874.6 million m^3, the fruit group acquired in this alternative About 63% of the total exported quantities, while the vegetables group accounted for about 33.5%, and the medicinal and aromatic plants group accounted for about 3.6% of the total exported quantities.

As for the third alternative, it achieved an export proceeds, as shown in Table 5, estimated at about $1517 million, an increase of $98.1 million, representing about 7% over the current model, and with a total exported virtual water amounting to about 1335.8 million m^3, and the fruit group acquired in this alternative About 71.5% of the total exported quantities, while the vegetables group

Table 5. Results of the linear programming model for the most important fresh agricultural exports for the period 2010-2020.

Commodity group	Exported quantity	Code	Exported commodity water Needs of exported ton of water (m^3)	The first alternative					The second alternative					The third alternative				
				Exported quantity		Export value		Amount of virtual water exported	Exported quantity		Export value		Amount of virtual water exported	Exported quantity		Export value		Amount of virtual water exported
				10^3 ton	%	10^6 $	%	(10^6 m^3)	10^3 ton	%	10^6 $	%	(10^6 m^3)	10^3 ton	%	10^6 $	%	(10^6 m^3)
Fruit	citrus	X_1	292	776.5	37.7	245	21.1	226.7	776.9	36.2	245.1	17.1	226.9	1679.6	51.8	529.9	34.9	490.4
	grapes	X_2	92	139.1	6.7	189.5	16.3	12.8	132.5	6.2	284.4	19.8	12.2	139.1	4.3	199	13.1	12.8
	strawberry	X_3	41	243.9	11.8	129.8	11.2	10	232.4	10.8	194.8	13.6	9.5	243.9	7.5	136.3	9	10
	mango	X_4	461	30.6	1.5	28	2.4	14.1	30.6	1.4	28	1.9	14.1	66.2	2	60.6	4	30.5
	olive	X_5	300	15.8	0.8	18.4	1.6	4.7	15.1	0.7	27.6	1.9	4.5	15.8	0.5	19.3	1.3	4.7
	pomegranate	X_6	200	143.8	7	71.6	6.2	28.8	137.1	6.4	107.4	7.5	27.4	143.8	4.4	75.2	5	28.8
	dates	X_7	32	28.2	1.4	100.8	8.7	0.9	26.9	1.3	151.3	10.5	0.9	28.2	0.9	105.8	7	0.9
Vegetable	potato	X_8	350	289.2	14	179.6	15.5	101.2	262.8	12.2	171.4	11.9	92	413.7	12.8	179.9	11.9	144.8
	onions and garlic	X_9	400	106.5	5.2	7.1	0.6	42.6	219.5	10.2	14.6	1	87.8	111.8	3.5	7.5	0.5	44.7
	tomatoes	X_{10}	122	25.1	1.2	17.1	1.5	3.1	51.7	2.4	35.2	2.5	6.3	26.4	0.8	18	1.2	3.2
	eggplant	X_{11}	293	17.8	0.9	14.1	1.2	5.2	16.5	0.8	13.7	1	4.8	26	0.8	14.4	0.9	7.6
	fresh kernel seeds	X_{12}	1703	176.5	8.6	57.3	4.9	300.6	168.2	7.8	57.3	4	286.4	264.8	8.2	60.1	4	451
Medicinal and aromatic plants	sunflower seeds	X_{13}	1513	28.2	1.4	10.2	0.9	42.7	26.9	1.3	10.2	0.7	40.7	28.2	0.9	10.7	0.7	42.7
	oil fruits and seeds	X_{14}	1000	5	0.2	45	3.9	5	4.7	0.2	44.6	3.1	4.7	4.9	0.2	46.8	3.1	4.9
	jasmine	X_{15}	335	6.2	0.3	33.2	2.9	2.1	5.9	0.3	32.9	2.3	2	6.2	0.2	34.6	2.3	2.1
	Dried and ground pepper	X_{16}	1124	4.3	0.2	1.8	0.2	4.8	8.2	0.4	3.5	0.2	9.2	8.6	0.3	3.7	0.2	9.7

Continued

marjoram	X_{17}	88	10.4	0.5	3.4	0.3	0.9	9.8	0.5	3.4	0.2	0.9	10.3	0.3	3.5	0.2	0.9
coriander	X_{18}	1375	9.2	0.4	5.5	0.5	12.7	8.8	0.4	5.5	0.4	12.1	9.2	0.3	5.8	0.4	12.7
mint	X_{19}	2408	4.5	0.2	1.5	0.1	10.8	9.2	0.4	3	0.2	22.2	9.6	0.3	3.1	0.2	23.1
fennel	X_{20}	3222	1.5	0.1	1.4	0.1	4.8	3.1	0.1	2.9	0.2	10	3.2	0.1	3	0.2	10.3
General total		15351	2062.3	100.1	1160.3	100.1	834.5	2146.8	100	1436.8	100	874.6	3239.5	100.1	1517.2	100.1	1335.8
Total fruit group		1418	1377.9	66.9	783.1	67.5	298	1351.5	63	1038.6	72.3	295.5	2316.6	71.4	1126.1	74.3	578.1
Total vegetable group		2868	615.1	29.9	275.2	23.7	452.7	718.7	33.4	292.2	20.4	477.3	842.7	26.1	279.9	18.5	651.3
Total group of medicinal and aromatic plants		11065	69.3	3.3	102	8.9	83.8	76.6	3.6	106	7.3	101.8	80.2	2.6	111.2	7.3	106.4

Source: The results of the linear programming analysis of the data mentioned in **Tables A1-A5** in the Appendix.

accounted for about 26%, and the medicinal and aromatic plants group accounted for about 2.5% of the total exported quantities.

From the above, and by reviewing the results of **Table 6** from the point of view of the commercial water balance of virtual water, the second alternative is the best, as it is possible to increase the proceeds of agricultural exports by about $17.8 million annually, and at the same time reduce the amount of virtual water by about 20% from the current situation to become 874.6 million m^3 instead of 1092.9 million m^3, with an estimated saving of about 20%, not from the exported virtual water, which contributes to reducing the use of water in exports and raising the efficiency of its use, while at the same time increasing the export revenue.

3. Discussion

By reviewing the reality of the Egyptian water resources, it was shown that the Egyptian water resources are characterized by relative stability in terms of the resources of the Nile River or in terms of rainfall amounts. However, in light of the increase in the population and the increase in water uses in agricultural and industrial activities, the process of managing water resources in Egypt has become one of the processes that require proper planning in a manner that ensures the optimal use of Egyptian water resources. The water balance is one of the most important water management tools, especially in light of the multiple uses of water in agricultural and industrial activities, human consumption and other uses.

By reviewing the general features of the reality of fresh Egyptian agricultural exports, it becomes clear that the most important components of the commodity structure of these exports are agricultural commodities with large water needs and at the same time characterized by the lowest export price, such as citrus and mango in fruit, onions and tomatoes in vegetables, and fennel and mint in medicinal and aromatic plants. Compared to commodities with lower water needs and high export price.

From the above it is clear that the structure of Egyptian agricultural exports of

Table 6. The yield of virtual water and the value of Egypt's exports of the most important Egyptian agricultural exports in the current situation and in light of the various proposed alternatives.

Gurrent model and alternative models	Value exports 10^6 $	Virtual water exported 10^6 m^3	Savings (return achieved from the current situation from virtual water)		Savings (return from the current situation from the proceeds of exports)	
			10^6 m^3	%	10^6 $	%
Current model	1419	1092.9	-	-	-	-
First alternative	1160.1	834.5	−258.4	−23.6	−258.9	−18.2
Second alternative	1436.8	874.6	−218.3	−20.0	17.8	1.3
Third alternative	1517.1	1335.8	242.9	22.2	98.1	7

Source: Calculated and compiled from **Table 4** data.

fresh commodities includes many exported commodities with high water needs, which requires the necessity of working on setting appropriate policies to reduce water-consuming agricultural exports and working on re-planning Egyptian agricultural exports in light of the scarcity of Egyptian water resources.

From the above it is clear that the commodity structure of the most important fresh agricultural exports contributes in a large proportion to commodities with large water needs and lower export returns, while the contribution of agricultural commodities with lower water needs and high export returns is less, which indicates the need to work on re-planning for export development, and this goal can be achieved through the linear programming methodology in light of the constraints represented in the absorptive capacity of the world markets of the commodities under study, the current status model was designed with a set of alternatives and various restrictions for this current distribution according to the following:

Suggested alternatives:

Status current model: It is to shed light on the current situation of the exported quantities of the most important agricultural export commodities under study to the world, considering the determination of water needs and the export price for each commodity (**Figure 4**).

The first alternative: it is the free model, in which the commodity structure of exported agricultural commodities is proposed according to the following criteria:

- Reducing the amount of exports of agricultural commodities under study whose water needs exceed 3074 m^3/feddan as a general average of water needs by 50%.
- Increasing the export quantities of selected commodities to world markets according to the standards of water needs and the export price by about 5% to meet the needs the growth of world demand.

The quantities available from the previous criterion are directed to the other agricultural export commodities under study that have the lowest water needs and the highest export price.

The second alternative: in which the commodity structure of exported agricultural commodities is proposed according to the following criteria:

- Stability of the exported quantities of vegetables and medicinal and aromatic plants, while at the same time increasing the quantities exported for each crop of the fruit group by 50%, provided that the water need for any crop does not exceed 2359 m^3/feddan, which is the general average of the water needs of the group of fruit commodities.
- Reducing the exported quantities of fruit crops whose water need exceeds 2359 m^3/feddan to 50%.
- Increasing the export quantities of selected commodities to international markets according to the standards of water needs and the export price by about 5% to meet the needs of the growth of world demand.
- The quantities available from the previous criterion are directed to the other agricultural export commodities under study that have the lowest water needs

and the highest export price.

The third alternative: in which the commodity structure of exported agricultural commodities is proposed according to the following criteria:

- Stability of the exported quantities of fruits and medicinal and aromatic plants, while at the same time increasing the quantities exported for each crop of the vegetable group by 50%, provided that the water need for any crop does not exceed 3195 m^3/feddan, which is the general average of the water needs of the group of vegetable commodities.
- Reducing the exported quantities of vegetable crops whose water need exceeds 3195 m^3/feddan to 50%.
- Increasing the export quantities of selected commodities to international markets according to the standards of water needs and the export price by about 5% to meet the needs of the growth of world demand.
- The quantities available from the previous criterion are directed to the other agricultural export commodities under study that have the lowest water needs and the highest export price.

4. Recommendations

Related to the results obtained, the research recommends the following:-

- Supporting the productive capacities of producers to export crops that use less water.
- Reducing the expansion of exports that use the most water resource by limiting the volume of export support for these commodities.
- Working to increase the Egyptian exports of dates, pomegranates, olives, grapes, fresh kernels, potatoes, eggplant, coriander, jasmine paste and marjoram, as they are among the agricultural exports with high export returns and the least in their needs for water resources.
- Working to reduce or stabilize the exported quantities of bananas, citrus fruits, mangoes, onions, garlic, tomatoes, mint and fennel as they are among the agricultural exports with high average returns and the highest in their needs for water resources.

5. Conclusion

Agricultural foreign trade has taken many recent trends in light of many changes and developments affecting the global economic environment. Countries have resorted to adjusting their trade policies and reconsidering the commodity structure of their exports to suit their resources, especially water resources, in order to maintain the efficiency of the use of these resources and at the same time increase the export return.

- The water issue in Egypt faces major challenges on the demand side of water in light of the relative stability on the supply side. The state is working to increase the supply side through reuse of agricultural wastewater, seawater desalination, and wastewater treatment. On the demand side, it is working to develop systems Irrigation, reducing wastage in the use sectors, moving towards foreign trade by importing basic crops, and limiting the export of water-depleting crops to find a balance between the water balance and the agricultural trade balance.

The problem of the research is inefficiency of using the water resource in agricultural exports.

The main objective of the research is to propose different alternatives for the optimal planning of Egyptian agricultural exports, which are characterized by high export returns and low needs of water resources.

The research depends on the linear programming method as a quantitative method to measure the phenomena and variables related to the research problem.

By reviewing the reality of the Egyptian water resources, it was shown that the Egyptian water resources are characterized by relative stability in terms of the resources of the Nile River or in terms of rainfall amounts. However, in light of the increase in the population and the increase in water uses in agricultural and industrial activities, the process of managing water resources in Egypt has become one of the processes that require proper planning in a manner that ensures the optimal use of Egyptian water resources. The water balance is one of the most important water management tools, especially in light of the multiple uses of water in agricultural and industrial activities, human consumption and other uses.

By reviewing the general features of the reality of fresh Egyptian agricultural exports, it becomes clear that the most important components of the commodity structure of these exports are agricultural commodities with large water needs and at the same time characterized by the lowest export price, such as citrus and mango in fruit, onions and tomatoes in vegetables, and fennel and mint in medicinal and aromatic plants compared to commodities with lower water needs and high export price.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Allan, J. A. (1996). Water Use and Development in Arid Regions: Environment, Economic Development and Water Resource Politics and Policy. *Review of European Community & International Environmental Law, 5,* 107-115. https://doi.org/10.1111/j.1467-9388.1996.tb00258.x

Allan, J. A. (2002). Hydro-Peace in the Middle East: Why No Water Wars?: A Case Study of the Jordan River Basin. *SAIS Review, 22,* 255-272. https://doi.org/10.1353/sais.2002.0027

Allan, J. A. (2003). Virtual Water—The Water, Food, and Trade Nexus. Useful Concept or Misleading Metaphor? *Water International, 28,* 106-113. https://doi.org/10.1080/02508060.2003.9724812

Central Agency for Public Mobilization and Statistics (2010-2020a). *Agricultural Statistics Yearbook, Issues.*

Central Agency for Public Mobilization and Statistics (2010-2020b). *Annual Bulletin of Irrigation and Water Resources, Issues.*

de Fraiture, C., Cai, X., Amarasinghe, U., Rosegrant, M., & Molden, D. (2004). *Does International Cereal Trade Save Water? The Impact of Virtual Water Trade on Global Water Use.* IWMI.

Falkenmark, M., & Rockström, J. (2006). The New Blue and Green Water Paradigm: Breaking New Ground for Water Resources Planning and Management. *Journal of Water Resources Planning and Management, 132,* 129-132. https://doi.org/10.1061/(ASCE)0733-9496(2006)132:3(129)

FAO Database. https://www.fao.org/faostat/ar/

Haddadin, M. J. (2003). Exogenous Water: A Conduit to Globalization of Water Resources. In: A. Y. Hoekstra, Ed., Proceedings of the International Expert Meeting on Virtual Water Trade, Value of Water Research Report Series No. 12, 2003. UNESCO-IHE.

ITC Database. https://www.trademap.org

Kumar, M. D., & Singh, O. P. (2005). Virtual Water in Global Food and Water Policy Making: Is There a Need for Rethinking? *Water Resources Management, 19,* 759-789. https://doi.org/10.1007/s11269-005-3278-0

Ramirez-Vallejo, J., & Rogers, P. (2004). Virtual Water Flows and Trade Liberalization. *Water Science & Technology, 49,* 25-32. https://doi.org/10.2166/wst.2004.0407

Shehata, G. A. B., & Zahran, H. (2021). Eeconomic Importance of Egyptian Agricultural Foreign Trade with European Union Markets. In *5th International European Forum on System Dynamics and Innovation in Food Networks.* https://www.fooddynamics.org/

Shehata, G. A. B., El-Gabry, A., Elseify, E., & Saleh, O. (2018). E-Marketing and Means to Develop Egyptian Agricultural Exports. *Menoufia Journal of Agricultural Economic and Social Sciences, 3.*

Vanderbei, R. J. (2020). *Linear Programming.* Springer International Publishing. https://doi.org/10.1007/978-3-030-39415-8

Wichelns, D. (2001). The Role of 'Virtual Water' in Efforts to Achieve Food Security and Other National Goals, with an Example from Egypt. *Agricultural Water Management, 49,* 131-151. https://doi.org/10.1016/S0378-3774(00)00134-7

Wichelns, D. (2010). Virtual Water: A Helpful Perspective, but Not a Sufficient Policy Criterion. *Water Resources Management, 24,* 2203-2219. https://doi.org/10.1007/s11269-009-9547-6

Yang, H., & Zehnder, A. (2007). "Virtual Water": An Unfolding Concept in Integrated Water Resources Management. *Water Resources Research, 43,* Article No. W12301. https://doi.org/10.1029/2007WR006048

Abbreviations

(H.S) Harmonic System

Appendix

Table A1. Egyptian agricultural trade balance for the most important agricultural commodities during the period (2010-2021).

Commodity group	Item		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	average
Fruir	exports	Value 10^6 LE	955	1021	990	1010	1053	1117	1210	1282	1397	1417	1454	1499	1200
		Quantity 10^3 ton	1957	906	1582	1651	1819	2077	2146	2502	2712	1237	1270	1309	1764
	imports	Value 10^6 LE	248	445	388	489	713	559	335	431	651	552	515	510	486
		Quantity 10^3 ton	171	224	177	168	159	151	144	137	130	123	115	114	151
	Trade balance	Value 10^6 LE	707	576	602	521	340	558	875	851	746	865	939	989	714
		Quantity 10^3 ton	1786	682	1405	1483	1660	1926	2002	2365	2582	1114	1155	1195	1613
Vegetable	exports	Value 10^6 LE	834	986	804	1040	1240	1128	967	1070	911	1105	1034	1139	1022
		Quantity 10^3 ton	1574	939	1526	1725	1516	1466	1977	1885	2298	1371	1282	1413	1581
	imports	Value 10^6 LE	574	527	592	571	536	617	456	476	548	444	341	238	493
		Quantity 10^3 ton	603	535	10424	1125	488	200	0	987	1	528	405	283	1298
	Trade balance	Value 10^6 LE	260	459	212	469	704	511	511	594	364	661	693	902	528
		Quantity 10^3 ton	970	404	−8898	600	1028	1267	1977	898	2296	843	877	1131	283
Medicinal and aromatic plants	exports	Value 10^6 LE	328	384	312	332	357	341	374	335	336	353	382	403	353
		Quantity 10^3 ton	186	33	91	104	56	89	58	81	88	81	88	92	87
	imports	Value 10^6 LE	1170	1377	1285	1327	1001	918	1166	1780	2075	1949	1824	1698	1464
		Quantity 10^3 ton	1236	2021	1225	1578	326	136	115	121	513	123	115	107	635
	Trade balance	Value 10^6 LE	−842	−993	−973	−995	−644	−577	−792	−1445	−1739	−1596	−1442	−1295	−1111
		Quantity 10^3 ton	−1050	−1988	−1134	−1474	−270	−47	−57	−40	−425	−42	−27	−14	−547
Grains	exports	Value 10^6 LE	500	395	28	93	206	35	83	32	3	8	5	5	116
		Quantity 10^3 *ton*	697	637	462	138	355	90	180	56	3	8	7	13	220
	imports	Value 10^6 LE	2434	3484	5453	5349	4729	5052	4343	4146	4432	4759	5257	4628	4506

Continued

		Quantity 10^3 ton	16041	15255	16993	18486	16301	13461	15469	17477	19485	21493	23501	18139	17675
	Trade balance	Value 10^6 LE	−1934	−3089	−5425	−5256	−4524	−5017	−4260	−4115	−4430	−4751	−5252	−4623	−4390
		Quantity 10^3 ton	−15344	−14618	−16531	−18348	−15945	−13371	−15289	−17421	−19482	−21485	−23494	−18127	−17455
Total agricultural commodities	exports	Value 10^6 LE	2617	2786	2134	2475	2856	2621	2634	2719	2647	2883	2875	3046	2691
		Quantity 10^3 ton	4414	2515	3661	3618	3746	3722	4361	4524	5101	2697	2647	2827	3653
	imports	Value 10^6 LE	4426	5833	7718	7736	6979	7146	6300	6833	7706	7704	7937	7074	6949
		Quantity 10^3 ton	18051	18035	28819	21357	17274	13948	15728	18722	20129	22267	24136	18643	19759
	Trade balance	value	−1809	−3047	−5584	−5261	−4124	−4525	−3666	−4115	−5060	−4821	−5062	−4028	−4258
		quantity	−13637	−15520	−25158	−17739	−13527	−10226	−11367	−14198	−15028	−19570	−21489	−15817	−16106

Source: ITC database: https://www.trademap.org.

Table A2. Commodity distribution of fruit exports during the period (2010-2020).

Years	citrus		grape		Strawberry		mango, fig and guava		other		total fruit	
	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton
2010	518	1061	202	414	100	205	56	115	78	160	955	1957
2011	568	504	210	186	119	106	56	50	67	59	1021	906
2012	490	783	225	360	161	257	55	88	59	94	990	1582
2013	533	871	184	301	162	265	57	93	74	121	1010	1651
2014	475	821	246	425	150	259	83	143	100	173	1053	1819
2015	523	973	242	450	189	351	73	136	90	167	1117	2077
2016	575	1020	219	388	228	404	97	172	91	161	1210	2146
2017	635	1239	238	464	188	367	85	166	136	265	1282	2502
2018	770	1495	222	431	152	295	82	159	172	334	1397	2712
2019	748	653	235	205	160	140	81	71	192	168	1417	1237
2020	802	700	236	206	145	127	88	77	183	160	1454	1270

Source: ITC database: https://www.trademap.org.

Table A3. Commodity distribution of vegetable exports during the period (2010-2020).

Years	potato		Onion and gerlic		Frozen vegetable		tomato		Fresh legium		other		Total vegetable	
	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton
2010	132	249	239	450	131	247	26	49	78	147	229	432	834	1574
2011	251	239	228	217	174	165	19	18	63	60	252	240	986	939
2012	127	242	173	328	153	289	29	54	62	118	261	496	804	1526
2013	206	342	211	349	185	307	61	100	72	119	306	508	1040	1725
2014	327	400	170	208	145	177	71	87	63	77	464	567	1240	1516
2015	232	301	277	359	151	196	73	94	55	71	342	444	1128	1466
2016	147	301	217	444	155	316	68	138	56	113	325	664	967	1977
2017	272	479	235	414	154	271	32	57	46	81	331	583	1070	1885
2018	207	522	131	331	155	390	42	105	39	97	339	854	911	2298
2019	266	330	273	338	163	203	49	61	36	45	318	394	1105	1371
2020	222	275	213	265	183	226	40	50	39	48	337	417	1034	1282

Source: ITC database: https://www.trademap.org.

Table A4. Commodity distribution of medicinal and aromatic plants exports during the period (2010-2020).

Years	sunflower seeds		fruits and oil seeds		vegetable parts for aromatic purposes and seed		kernels dried and ground pepper		other	
	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton	value 10^6 LE	quantity 10^3 ton
2010	85.28	48.36	52.48	29.76	45.92	26.04	39.4	22.32	105	59.52
2011	99.84	8.58	61.44	5.28	53.76	4.62	46.1	3.96	122.9	10.56
2012	81.12	23.66	49.92	14.56	43.68	12.74	37.4	10.92	99.84	29.12
2013	86.32	27.04	53.12	16.64	46.48	14.56	39.8	12.48	106.2	33.28
2014	92.82	14.56	57.12	8.96	49.98	7.84	42.8	6.72	114.2	17.92
2015	88.66	23.14	54.56	14.24	47.74	12.46	40.9	10.68	109.1	28.48
2016	97.24	15.08	59.84	9.28	52.36	8.12	44.9	6.96	119.7	18.56
2017	87.1	21.06	53.6	12.96	46.9	11.34	40.2	9.72	107.2	25.92
2018	87.36	22.88	53.76	14.08	47.04	12.32	40.3	10.56	107.5	28.16
2019	91.78	21.06	56.48	12.96	49.42	11.34	42.4	9.72	113	25.92
2020	99.32	22.88	61.12	14.08	53.48	12.32	45.8	10.56	122.2	28.16

Source: ITC database: https://www.trademap.org.

Table A5. The commercial water balance of virtual water for the most important components of the commodity structure of foreign trade from Egyptian fresh agricultural crops, average for the period (2010-2021).

Commodity group	Exported commodity	Water requirements (m^3/feddan) in Egypt (1)	Average water needs at the world level (m^3/feddan) (2)	The difference in water needs per acre between Egypt and the world average (m^3/feddan) (3)	feddan productivity of export items ton/feddan (4)	The needs of the exported ton of water (m^3) (5)	Quantity of exports in ton (6)	Quantity of virtual water exported (10^3 m^3) (7)	Quantity of imports in ton (8)	Quantity of imported virtual water (thousand m^3) (9))	The commercial water balance of virtual water 10^3 m^3 (10)
	citrus	3500	3374	−126	12	292	1553000	452958	270	911	452
	grapes	1200	1255.2	55	13	92	128600	11871	562	705	11
	strawberry	1450	1368.8	−81	35	41	225500	9342	320	438	9
	mango	6912	7160.832	249	15	461	61200	28201	215	1540	27
	olive	1500	1446	-54	5	300	13700	4110	411	594	4
Fruir	pomegranate	1400	1450.4	50	7	200	133000	26600	10	15	27
Vegetable	dates	550	571.45	21	17	32	25600	828	255	146	1
	potato	2972	3043.328	71	8.5	350	255000	89160	10926	33251	56
	onions and garlic	3200	3020.8	−179	8	400	213000	85200	4150	12536	73
	tomatoes	4265	4132.785	−132	35	122	50200	6117	6	25	6
	eggplant	2986	3096.482	110	10.2	293	15400	4508	12	37	4
	fresh kernel seeds	2554	2594.864	41	1.5	1703	163200	277875	24	62	278
	sunflower seeds	3026	2947.324	-79	2	1513	25600	38733	75583	222768	-184
	oil fruits and seeds	2300	2389.7	90	2.3	1000	4300	4300	6020	14386	-10
Medicinal and	jasmine	2010	2086.38	76	6	335	5400	1809	80	167	2
aromatic plants	dried and ground pepper	4158	4316.004	158	3.7	1124	7500	8428	9750	42081	-34
Grains	marjoram	2012	2156.864	145	22.9	88	9000	791	44	95	1
	coriander	1650	1692.9	43	1.2	1375	8000	11000	5600	9480	2
	mint	7704	7187.832	−516	3.2	2408	8900	21427	2	14	21

Continued

fennel	6121	5833.313	−288	1.9	3222	3000	9665	1	6	10
Wheat	4500	4230	−270	3	1500	10	15	12885000	54503550	-54504
maize	1860	1610	−250	17.5	106	6	1	8298	13360	-13
rice	7120	6980	−140	4	1780	0	0	35106	245040	-345
General total	74950	73945.3	−1004.7	234.9	18735.481	2909116	1092939.2	13042645	55101207	−54018
Total fruit group	16512	16626.7	114.682	104	1418.5559	2140600	533910.44	2043	4349	530
Total vegetable group	15977	15888.3	−88.741	63.2	2866.916	696800	462860.7	15118	45912	417
Total group of medicinal and aromatic plants	22860	22777	−82.996	41.3	7842.144	68700	86487.671	97079	288991	−203
General total	13480	12820	−660	24.5	3386.2857	16	15.637714	12928404	54761950	−54762

Source: Compiled and calculated from data. 1) Central Agency for Public Mobilization and Statistics, Annual Bulletin of Irrigation and Water Resources Statistics, various issues. 2) FAO database, available at https://www.fao.org/faostat/ar/. 3) Central Agency for Public Mobilization and Statistics, Agricultural Statistics Yearbook, various issues. 4) ITC database: https://www.trademap.org.