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The application of virtual water in order to escape the drought crisis in line with water resources management

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Abstract

Being located in arid and semi-arid area and increasing water consumption, Iran is going to face the threat of water crisis in the coming years. So, in order to deal with this problem care must be taken in treating different types of water consumption. Virtual water is one of the issues to be considered. The water being used in production processes is called virtual water a part of which is kept in product. When the goods enter the global market, the virtual water trade occurs. It is expected that trade in virtual water would decrease water consumption in national and international level due to a more efficient and professional use of water. It is possible to calculate productivity at different levels, namely crop, livestock, forestry, aquaculture and production units, farms, irrigation system, irrigation basins and natural supplies (pasture and green). Increased productivity, especially from the perspective of the value of production per unit of water consumed directly or indirectly, could be an important strategy for improving the livelihoods of local communities. The results of this study indicate that during the years under study, the virtual water trade balance was negative in Iran, and this country has become an importer of virtual water.

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Introduction

Over the past decade, the excessive population and economic activities increase, consequently an increase of water allocation leaded to the worldwide scarcity of the fresh water sources. More than 94 percent of water sources in Iran, which possesses dry and semiarid weather, are utilized in an agricultural section. Virtual water can be considered as a prominent means for calculating the actual water of every country and if we take virtual water exchange which is due to the export and import of the goods, into account, then we can determine the actual water demand of the country in effect of the use patter of the people via an ecological footprint index. Self-sufficiency of water sources refer to the supply of required water for producing, services and direct consume within the same country boundaries. If the required water of the country is being provided through wide virtual water imports, then self-sufficiency will be closer to zero. In practice, the countries which import virtual water is depended on other countries water sources. The water dependency of a country is equal to the ratio of the country, ecological footprint of the external water to the country ecological footprint of the total water.

Water is one of the most important factors in the growth and development of countries. Shortage of drinking water on one hand, and the growing need for food, on the other hand, has caused the available water resources face a serious crisis. The decrease in the level of underground aquifers and the water crisis in more than 120 Plain of fertile plains of the country the number of which is increasing every year is one of the problems of agriculture sector. Agriculture is one of the foundations of economic development (Manouri *et al.2009*).

Despite the considerable investments made in the water sector, pollution and the destruction of many of the country's water resources continues due to the fact like: High extraction costs per cubic meter of water resources in the country, indiscriminate exploitation of some existing water resources, Lack of proper underground aquifers and surface water nutrition, non-compliance with the principles relating to the preservation and conservation of soil and water resources, development of industry and urbanization and the drought crisis in recent years. As a result, the water supply in some areas is unable to meet the growing demands for it in such a way that water has changed into a competitive product for various purposes and this restriction has become more prominent regarding the 90% consumption of the agricultural sector (Khalidi and Ehsani 2012).

One of the most important factors that influence the quality of water resources is reported as the increasing population and focus groups. This is one of the most important factors in too much pressure on water resources in arid regions(Lefroy*et al.*2000).

The low quality of crops and qualitative and quantitative resource reduction are the first consequence of the increased and concentrated population and the mismanagement of resources (Shangguam*et al.*2002).

There have been two definitions of water scarcity index. The first is by Chpagain and Hoekstra "The ratio of total volume of extracted water to the total renewable water resources". Based on this definition if the demand for water in one country is met through the import of water consuming products, or by using a small amount of domestic water, the water scarcity index would be zero (Chapagain and Hoekstra 2006).

One of the major requirements of careful planning regarding water issues is predicting demand and understanding the factors and materials affecting demand. Establishing balance between supply and demand for water is one of the important water management issues. Increasing needs for water due to population growth, Limitation of recoverable resources in the country, high cost of developing new water resource projects and other environmental and social impacts are among the issues that make the water production and demand management as two effective strategies on the general water management(Franklin Hadley and EbrahimiAsl 2013).

There are two international water resources Acts approved by the governments namely: Helsinki Act, which was published in 1967 by the International Law Association and the 1997 Convention on the rights of non-strategic use of drains International waters that has been developed by the International Law Commission of the United Nations(Chenoweth 2000).

The 1997 Convention has introduced the social and economic needs of the people living in the margins of international waters as one of the most important factors in determining the fair use of an International water supply(Howard and Bartram, 2003).

The resources are classified into blue water and green water supplies in the hydrologic cycle. Groundwater and surface waters are blue, while the soil moisture in the unsaturated zones is called green water. The rainwater before infiltration into water and reaching the saturated zone is called green water. Rainfed agriculture feeds from mainly green water. Based on the definition the grey water is the kind of water contaminated by human activities such as urbanization, agriculture or industry and has become lower than the applicable standard. The term in the context of virtual water refers to the kind of water than cannot return to the applicable cycle quickly cycles or its return to the application standard demands a lengthy and costly process(Ingh*et al.*2001).

World merchandise trade creates international flows of virtual water that is called virtual water trade. In other words the virtual water is the water used in product manufacturing process from the beginning to the end. With the beginning of international trade of goods, virtual water flows from one region to another region in the world. (Allan 2003).

Virtual water and water productivity are inversely related to one another. By definition, water productivity is the amount of product produced per unit of water and it is usually defined as kilograms per cubic meter, but virtual water is the amount of water used to produce a certain amount of the product and its units are (Lit/ kg) or (m^2/ kg). In other words in productivity the emphasis is on the amount of production of water and by contrast in virtual water the emphasis is on the amount of water used in production. Thus, by increasing the productivity of water, the virtual water of the product or item will decrease and vice versa(Mousavi*et al.* 2010).

Keshavarz and Dehghan (2012) analyzed the Productivity Indices in order to the optimal water resource management. In this research the water productivity of various provinces and agricultural crops was studied through virtual water approach (Keshavarz and SanychDehghani 2012).

Sarshar and Masoumi (2013) discussed the impact of virtual water on the water resource management. In this investigating the impact of water inside and outside of Iran, the definition of virtual water and its impact on water resource management were discussed and explored.

Mousavi*et al* (2014) presented the impact of virtual water, the new solution to the water crisis. In this study, the average virtual water index of a product was used as a method of estimating the amount of virtual water.

Poorjafari*et al.* (2012) analyzed Ecological footprint of virtual water and virtual water indices of pistachio and dates in Kerman. In this study in order to investigate the ability of the region to supply water needed for domestic production, the ecological footprint of water in strategic crops of nuts and dates in the province in 2009. In order to perform the calculations the method of Hoekstra and Hang and Hoekstra *et al.* was used.

Bulsink*et al.* (2010) claimed that the total water use within a single country is not a proper criterion of water use of that country from the world's water resources. In fact in order to have a true picture of a country's real needs the world's water resources requires the addition of the imported virtual water to the total domestic water consumption. Also the exported virtual water must be deducted from the domestic water consumption.

Yang *et al.* (2010) have added Iran into the list of countries with water shortage since 2000 and it will have less than 1500 m² recoverable water resources per an individual until 2030.

Alcamo *et al* (2000) found out that based on the critical ratio, i.e. the amount of water use to the amount of access to water, Iran has the critical ratio of 0.8 and it will be among countries with serious water crisis until 2025.

If the increase of sub cultivation surface products is within the refrained crops framework, it means more use of green water (solid moisture in unsaturated areas). If such increase is within the irrigated agriculture, then more use of blue water can be inferred. It is expected that by increase of sub cultivation surface, we notice an increase of producing, extension of exports and decrease of imports. In this research, we will investigate the special water demand of the agricultural elected products, virtual water of agricultural import products, the contents of the virtual water associated with elected agricultural export products and the sheer volume of import virtual water will be calculated.

Material and methods

The method of calculating stored virtual water in agriculture

In order to determine countries' net virtual water import and exports, major exported or imported horticultural and agricultural crops are selected and examined. The following equations are used to calculate the consumed virtual water:

$$SWD_{ij} = \frac{CWR_{ij}}{CY_{ij}} \quad (1)$$

In equation (1) $(m^3 ton^{-1}) SWD$ (Specified Water Demand) is the special water used by product i in the j area. Due to different climate of the countries any product may exist at different areas that uses specific amount of water. Thus for eachproduct in each area SWD is calculated separately and the weighted average is calculated.

CWR_{ij} is the Crop Water Requirement product i in the j area $(m^3 ha^{-1})$.

Hoekstra and other researchers used ET_C in order to calculate CWR. They calculated the value of CWR after deducting the amount of effective irrigation and applying irrigation efficiency.

$$ET_C = K_C \times ET_0 \quad (2)$$

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_a - e_d)}{\Delta + \gamma(1 + 0.34 U_2)} \quad (3)$$

$ET_0\ [mm\ day^{-1}]$ = Reference plant evapotranspiration.

$R_n\ [MJ\ m^{-2} day^{-1}]$ = Net radiation of the plant.

$G\ [MJ\ m^{-2} day^{-1}]$

$T\ [{}^0C]$ = Wind speed at a height of 2 meters above ground level.

$e_a\ [KPa]$ = Saturated vapor pressure

$e_d\ [KPa]$ = Actual vapor pressure

$e_a - e_d\ [KPa]$ = The difference in vapor pressure

$\Delta\ [KPa^0C^{-1}]$ = *vapor pressure* curve slope

$\gamma\ [KPa^0C^{-1}]$ = Moisture meter constant

CY_{ij} the performance of the product i in the area j. After calculating SWD the following equation will calculate the weighted average of SWD_i .

$$SWD_i = \left(\sum_{j=1}^{m} SWD_{ij}.TP_{ij} \right) \Big/ TP_i \qquad (4)$$

Where SWD_i is the consumed water per the ith unit in the jtharea.

TP_{ij} = The total production of the ith unit in the jth area.

TP_i = The total production of the ith unit in the country.

In this way SWD_i is calculated for all products. SWD_i is the water consumption index for a ton of the ith m² product. In fact it represents the whole water to be consumed to produce a ton of ith product which is called the water footprintfor the ith product. Water footprint is the total consumed water by a product, crop, an activity, the whole country or even an individual (including actual and virtual water).

Calculating the discharge of virtual water

In order to determine the total virtual water for the export of a product $TSWD_{i\exp}$ the following equation is used:

$$TSWD_{i\,\exp} = SWD_i.TP_{i\,\exp} \qquad (5)$$

Where $TP_{i\,\exp}$ is the total export of the ithproduct. The total imported virtual water to the country by the ith product the $TSWD_{i\,imp}$ is calculated as follows:

$$TSWD_{i\,imp} = SWD_i.TP_{i\,imp} \qquad (6)$$

Where $TP_{i\,imp}$ is the total import of the ithproduct. It should be noted that these measures are based on cubic meter.

The total amount and value of currency of $TP_{i\,\exp}$ and $TP_{i\,imp}$ for the ith product are presented in FAO website. It is assumed that the total dollar value of exported and imported products is in virtual water content attributed to it. However each product has other production factors as well, but based on the topic of this study which is about water and its importance in our country this assumption is considered(Obuobie*et al.*2005).

In order to calculate the total exported virtual water $TVWT_{\exp}$ the following equation was used:

$$TVWT_{\exp} = \sum_{i=1}^{n} TP_{i\exp} \qquad (7)$$

In order to calculate the total imported virtual water $TVWT_{\exp}$ the following equation was used:

$$TVWT_{imp} = \sum_{i=1}^{n} TP_{i\,imp} \qquad (8)$$

The total value of the imported and exported selected products equals the total value of the imported and exported value of virtual water. In order to calculate the dollar value of each cubic meter of the exported the following equation is used:

$$VWV_{\exp} = \frac{TVTP_{\exp}}{TVWT_{\exp}} \qquad (9)$$

Where $TVTP_{\exp}$ is the total value of the export of the exported products. The value of each cubic meter of imported virtual water is also calculated by the above equation. Now it is possible to economically evaluate the role of virtual water trade in fighting against drought and decrease the pressure on water reservoirs in the country through comparing the imported and exported virtual water and the value of each cubic meter and based on the combination of exported products (Obuobie*et al.* 2005).

Results and discussions

The existing status of agricultural water productivity

The average water productivity in irrigated farming based on the total crops (Irrigated agriculture and horticulture) and the total water used in agriculture regardless of the composition of the different crops and difference in precipitations was calculated as 0.7 Kg per 1 cubic meter of irrigation. The status of agricultural water productivity is presented in table 1 based on the 4th Agricultural Development Plan in the country.

Table 1. The status of agricultural water productivity based on the 4th Agricultural Development Plan in the country.

Year of the plan	Total irrigated and rain fed farming and gardening products (thousand tons)	Total irrigated farming and gardening products (thousand tons)	The total production of irrigated gardening and horticultural crops after conversion of feed into sugar beets and TDN based on the Sugar cane by sugar (thousand tons)	Water for farming and gardening (billion cubic meters)	WP compared to the total production of horticultural crops and water (kg /m3)	WP to the total production of irrigated horticultural crops and forage plants after conversion of the feed into sugar beet and cane according to TDN (kg /m3)
2003-2004	77145	68741	52233	88.3	0.778	0.591
2005	84844	76131	57898	89.2	0.835	0.649
2006	86809	76643.3	54119	90	0.818	0.601
2007	89664	80126	60946.6	90.9	0.881	0.670
2008	-	-	-	91.8	-	-
2009	-	-	-	92.6	-	-
Target year	99131	89376	62814	92.6	0.965	0.678

The results of table (1) indicate that the exported crops demand higher average water than imported crops. After calculating water demand, based on the volume of foreign trade in goods, virtual water trade is calculated.

In Table (2) the productivity of some major products of the country is compared with its amount in Egypt. Based on the results the only product with more efficiency than Egypt is corn.

Table 2. The comparison of water efficiency (products per 1 cubic meter) in major products of Iran and Egypt (2007).

Product	Iran			Egypt		
	Performance (Kg)	The average water consumption (cubic meters)	Production per unit of one cubic meter of water (kg)	Performance (Kg)	The average water consumption (cubic meters)	Production per unit of one cubic meter of water (kg)
Wheat	Grain 3801 Straw 1200	6500	0.77	Grain 6478 Straw 2000	6200	1.36
Rice	4326	12000	0.36	10288	17000	0.61
Cotton	3535	15000	0.16	4545.47	16000	0.28
Corn	7698	15000	0.51	4558	14000	0.32
Sugar beet	5415	16000	0.34	8988	17000	0.53
Cane	8707	28000	0.31	11975	28000	0.43

Sugar production is calculated per hectare.

Table 3. Evaluation of water demand for selected agricultural products (cubic meters per ton).

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
The main exported products												
Almond in shell	-	-	6676.1	8238.5	8952.9	5574.7	6309.2	-	-	-	-	7150.25
Apple	979.9	1004.5	1175.9	1014.4	966.8	550.3	648.9	643.3	901.1	778.7	792.8	859.26
Apricot	-	1637.4	-	1659.5	-	-	-	-	-	-	-	1648.48
Dates	3117	3753.2	4138.4	3513.5	3586	2188.5	2557.3	2631.3	2985.1	3010	2997.1	3134.3
Fig	-	6348.8	-	7116.3	6182.2	4467.7	4646.4	-	5334	5253.6	5243.1	5574
Grapes	1071.1	1108.8	1162.1	1108.5	981.1	614.3	680.7	9691	794	738.4	729.3	880.01
Walnut in shell	-	-	4417.3	5114.2	5579.1	-	-	-	-	-	-	5036.85
Watermelon	-	-	342.1	331/5	329/8	204.6	213.8	384.3	204.2	191.7	199.7	266.85
Orange	-	930.7	-	1000.7	-	-	-	-	592.6	602.7	529	731.16
Melons	604.7	617.4	-	-	-	-	-	-	-	-	-	611.06
Pistachio	6395.4	7452.7	15507.6	6994.5	19226.3	5457.1	6781.6	5419.6	10115.7	10699.1	11276	9557.07
The average	2432.6	2856.7	4774.2	3609.2	5726.8	2721	3119.7	1954.1	2989.5	3039.2	3109.6	-
The main imported products												
Rice	1392.5	1632.5	1529.4	1873/3	1989	1147.6	1148.1	1072.2	1299.5	1173.9	942.2	1381.8
Soybean	7330.5	5226	6130.3	6447.5	6044.2	4078.9	2917.1	2958.9	2897.4	2989.8	3001	4547.41
Sugar beet	-	-	-	-	-	-	250.3	-	-	-	-	250.3
Sugarcane	260.7	239.2	258.6	238.5	206.6	137.5	160.2	154	-	165.3	162.6	201.02
Sunflower Seeds	2912.9	4480.9	3247.6	4235.8	4691.7	-	1051.9	1337.6	1428.4	-	3795.4	3020.2
Tobacco	-	-	-	-	-	-	-	-	-	3843.3	4110.4	3976.86
Corn	1368.2	1313.3	1528.3	1537.4	1424	900	893.6	957.7	916.1	895.7	800.5	1139.5
Barley	955.2	1036.9	968/8	1328.3	1343.5	731.8	-	785.5	844.7	823.5	813.4	960.47
Wheat	1133.2	1249.3	1042.8	1207.3	1409.4	802.8	860.9	787.5	-	-	961.4	1020.5
The average	2193.3	2168.3	2104.7	2409.7	2444.04	1299.75	1040.3	1146.6	1477.2	1648.6	1789.6	-

Table 4. Virtual water for selected imported agricultural products (cubic meters per ton).

Crops	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
Wheat	4.32	7.42	3.61	7.43	7.91	5.44	2.41	0.51	-	-	0.69	4.42
Barley	0.3	0.63	0.2	0.56	1.41	0.68	1.52	0.14	0.71	1	0.31	0.68
Corn	1.98	0.2	1.23	1.55	1.75	1.54	-	2.52	1.83	1.89	2.33	1.68
Rice	1.27	0.2	1.23	1.55	1.75	1.54	-	2.52	1.83	1.89	2.33	1.68
Crude Soybean Oil	10.6	3.62	3.32	10.12	9.1	6.22	4.28	4.35	3.25	4.45	4.11	5.77
Sunflower oil	0.64	2.03	3.01	1.13	1.44	-	0.2	0.48	0.04	-	0.93	1.1
Raw sugar from sugar cane	1.76	2.33	2.04	2.6	1.56	1.05	0.86	0.26	0.18	0.96	2.51	1.46
Soybean meal	-	-	-	-	-	3.86	3.28	2.61	3.08	0.69	3.04	2.76
Palm Oil	-	-	-	-	-	-	-	1.42	2.69	4.61	5.2	3.48
Soybean oil	-	-	0.63	-	0.49	-	-	-	-	-	-	0.56
Tobacco	-	-	-	-	-	-	-	-	-	0.18	0.24	0.21
Raw sugar from sugar beet	-	-	-	-	-	-	0.31	-	-	-	-	0.31
Share	78.2%	83.8%	72%	80%	77.6%	82.2%	70.2%	62%	56.9%	64.7%	67.4%	-
The total imported virtual water	20.88	17.27	15.02	25.31	25.99	19.59	14.05	13.23	13.25	14.99	20.51	-

Average means the average imported virtual water of the product during this period and share means the total value of imports of the chosen product from the total value of agricultural imports in each year. This trend of net virtual water import shows that in all the years studied, the imported virtual water was more than its exports. The net imported virtual water is positive.

Table 5. The virtual water content of selected products in agricultural exports (tones per cubic meter).

Crops	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
Pistachio	0.9	0.43	1.94	0.708	0.2	0.65	0.1	0.94	1.4	1.5	1.95	0.97
Dates	0.19	0.22	0.305	0.355	0.39	0.26	0.3	0.3	0.28	0.37	0.435	0.31
Raisin	0.38	0.26	0.42	0.42	0.45	0.28	0.35	0.4	0.4	0.42	0.444	0.39
Apple	0.12	0.12	0.207	0.16	0.1	0.05	0.055	0.1	0.053	0.15	0.176	0.12
Watermelon	-	-	0.07	0.05	0.035	0.019	0.019	0.032	0.018	0.03	0.04	0.035
Fig	-	0.05	-	0.07	0.06	0.036	0.036	-	0.04	0.045	0.039	0.048
Tangerine	-	0.05	-	0.054	-	-	-	-	0.011	0.014	0.023	0.031
Almond	-	-	0.042	0.05	0.052	0.21	0.098	-	-	-	-	0.092
Walnut	-	-	0.028	0.025	0.02	-	-	-	-	-	-	0.025
Melons	0.092	0.079	-	-	-	-	-	-	-	-	-	0.086
Orange	-	-	-	-	-	-	-	-	0.011	0.012	-	0.012
Apricot	-	0.032	-	0.048	-	-	-	-	-	-	-	0.04
Share	93.3%	93.8%	94.2%	94.5%	95.3%	95.6%	94.3%	88%	94.7%	94.9%	92.3%	-
The total virtual water export	1.68	1.25	3.01	1.94	1.31	1.52	0.98	1.79	2.24	2.56	3.11	-

Table 6. Net volume of imported virtual water.

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Net imported virtual water	19.2	16.02	12	23.4	24.7	18.1	13.07	11.4	10.7	12.4	17.4

Table 7. Water and virtual water indices.

Index	Value
Total recoverable water reservoirs (Gm^3 Year^{-1})	137.5
Total consumed water (Gm^3 Year^{-1})	102.65
Water shortage (%)	75
Optimum supply of water (%)	82
Dependence on imported water (%)	18

Conclusion

Factors affecting the volume of virtual water trade can be divided into two general categories, controllable and uncontrolled factors. Uncontrolled factors include factors affecting plant water requirement (average minimum temperature, average maximum temperature, wind speed, sunshine hours, rainfall, potential crop evapotranspiration, crop coefficients and evapotranspiration). However, controlled factors include plant performance and performance of agricultural trade. This study has shown that variables such as income, population, and value added agriculture, irrigation and exports of goods and services have a significant effect on the variance of virtual water. Calculations of crop water requirements that products indicated that some plants have high water requirements, but due to high production yield, will have less special water appeal. Thus it is suggested that through increasing the performance of the products, while improving the production performance, the efficiency of water use would improve and demand for water by products, especially exported products decrease so that the export of virtual water decreases. The calculated results show that the water demand ofexported products was higher than imported products. In other words the agricultural export pattern was based on the water-based products. Also the results indicate that in terms of equal volume of trade, the export of virtual water manifolds the import of it. This is one of the considerable issues in determining the pattern of trade in virtual water. Since the countries with lack of water are socially less progressed, the danger of virtual water trade is higher for them. Paying attention to infrastructures, treatments of waste water, enhancing irrigation efficiency through sprinkler systems, paying attention to planting date and location of precipitation for higher utilization of green water, paying attention to the concept of comparative advantage with regard to the social and economic cost of water are recommended. Due to the fact that this study is the introductory to virtual water in Iran, it is suggested that future studies would be conducted with regard to the use of technical coefficients of water in the country and the results be compared to with results of the present study (which uses basic multiplication approach).

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