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Virtual water strategy and its application in optimal operation of water resources

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ABSTRACT

The water used in the production process of an agricultural or industrial product is called "virtual water". In Iran with low average annual precipitation also lack of available water resources, concept of the virtual water and its trade is used as a strategy for optimal operation of water resources in many fields such as water scarcity, drought and so on. This concept, also, could hold some interesting new opportunities for the field of sustainable consumption. Recently, in Iran, net virtual water import reached to (15-20)*10^9 m^3 per year and is one out of the top ten virtual importing countries. In this research, after virtual water applicable concepts expressing, virtual water content in some of the agricultural products in the world have been compared with products existence in Iran. Additionally, we selected some strategic agricultural products, which export and import to the country, and used an algorithm called "Genetic Algorithm", to optimize virtual water usage and trade according to demands, agricultural situation, production cost and environmental condition. Results showed which products how could help optimal water resources operation and effect of virtual water usage in economic growth.

1. Introduction

Iran has arid and semi-arid climate with 250 mm mean precipitation that it is one out of three global mean precipitation, although, it has the mean evaporation equal to three times of world mean. 94 percent of whole available water in country belongs to agriculture and 5 percent to healthy and urban usage. Just remained one percent is related to industrial usage. So, water scarcity is considered as a serious challenge in agriculture part, which is the biggest consumer of water. According to water resources scarcity and their high values as the "economical commodity", countries with crucial water conditions have introduced a new concept as "virtual water" to their strategic agricultural and industrial products.

Producing goods and services generally require water. The water used in the production process of an agricultural or industrial product is called the "virtual water" contained in the product. The concept of 'virtual water' has been introduced by Tony Allan in the early nineties (Allan 1993; 1994).

For producing 1 kg of grain we need for instance 1000-2000 kg of water, equivalent to 1-2 m^3. Producing livestock products generally requires even more water per kg of product. For producing 1 kg of cheese we need for instance 5000- 5500 kg of water and for 1 kg of beef we need in average 16000 kg of water (Chapagain and Hoekstra 2003). According to a recent study by Williams et al. (2002), the production of a 32-megabyte computer chip of 2 grams requires 32 kg of water.

If one country exports a water-intensive product to another country, it exports water in virtual form. In this way some countries support other countries in their water needs. Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic. For water-scarce countries it can therefore be attractive to achieve water security by importing water-intensive products instead of producing all water-demanding products domestically. Reversibly, water-rich countries can profit from the abundance of water resources by producing water-intensive products for the export.

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2. Core concepts: virtual water

There are some important and main introductions and equations which are clues in virtual water comprehensive concept. Some of the most intrinsic of them are as follows:

2.1. Virtual water conceptual parameters

In the hydrology cycle, water resources are divided into two categories: "blue" and "green" water. "Blue water" is the component of the rainfall that moves through the hydrological cycle and ends up in rivers, lakes and groundwater. This is the water that we primarily manage and use. "Green" water in the hydrological cycle, is the rainfall that is intercepted by vegetation and by the soil, and is taken up by plants to create biomass, and then evaporated back into the atmosphere. This part of the hydrological cycle has not been given much attention and is poorly managed. The blue virtual water content (BVW) was calculated as follows:

$$BVW = \frac{10 \times CIR \times CA_{irr}}{CP_{total}} \quad (1)$$

where CIR is the crop irrigation requirement (mm), CA_{irr} is the area (ha) of crop under irrigation and CP_{total} is the total amount of maize (tonnes) produced. Estimates of the area of maize under irrigation for each SADC country were obtained from the FAO Aquastat survey (FAO, 2005). Green virtual water content (GVW) was calculated as follows**:**

$$GVW = \frac{10 \times (CWR - CIR) \times CA_{total}}{CP_{total}} \quad (2)$$

where CWR is the crop water requirement (mm) and CA_{total} is the total area under maize (ha). So, the total virtual water content is equal to the sum of the green and blue virtual water content for maize in the country.

2.2. Specific water demand

The virtual water content [VWC] of a crop, c, in a country (m^3/ton) is calculated as the ratio of total water used for the production [CWU] to the total volume of production by that country (Chapagain and Hoekstra 2004).

$$SWD_c = \frac{CWR_c}{CY_c} \tag{3}$$

where, CWR is the crop water requirement measured at field level (m^3/ha), and Y_c the total volume of crop c produced per hectare in the country (ton/ha).

Crop water requirement is defined as the total water needed for evapotranspiration from planting to harvest for a given crop in a specific region, when adequate soil water is maintained by rainfall and/or irrigation, so that it does not limit plant growth and crop yield. Under standard conditions when a crop grows without any shortage of water, the crop evapotranspiration is equal to the CWR of a crop (Allen et al. 1998). The crop water requirement is calculated by accumulation of data on daily crop evapotranspiration, ETc (mm/day), over the complete growth period as following:

$$CWR_c = 10 \times \sum_{d=1}^{lp} ET_{c,d} \tag{4}$$

where the factor 10 is meant to convert mm into m^3/ha and where the summation is done over the period from day 1 to the final day at the end of the growth period (lp stands for length of growth period in days). The crop evapotranspiration per day follows from multiplying the reference crop evapotranspiration, ET0, with the crop coefficient, Kc, as following:

$$ET_c = K_c \times ET_o \tag{5}$$

The reference crop evapotranspiration, $ET_{0,}$ is defined as the rate of evapotranspiration from a hypothetical reference crop with eight assumed crops of 12 cm, a fixed crop surface resistance of 70 sec/m and an albedo of 0.23.

2.3. Calculation of virtual water trade flows and national virtual water trade balance

Virtual water trade flows between nations have been calculated by multiplying international crop trade lows by their associated virtual water content. The latter depends on the specific water demand of the crop in the exporting country where the crop is produced. Virtual water trade is thus calculated as:

$$VWT_{(ne,ni,c,t)} = CT_{(ne,ni,c,t)} \times SWD_{(ne,c)} \tag{6}$$

in which VWT denotes the virtual water trade (m^3/yr) from exporting country, $n_{e,}$ to importing country, $n_{i,}$ in year, t, as a result of trade in crop, c. CT represents the crop trade (ton/yr) from exporting country, $n_{e,}$ to importing country, $n_{i,}$ in year, t, for crop c.
The gross virtual water import (GVWI) to a country, $n_{i,}$ is the sum of all imports:

$$GVWI_t = \sum_{ni,c} VWT_{(ni,c,t)} \tag{7}$$

The gross virtual water export (GVWE) from a country, n_e, is the sum of all exports:

$$GVWE_t = \sum_{ne,c} VWT_{(ne,c,t)} \tag{8}$$

The net virtual water import of a country is equal to the gross virtual water import minus the gross virtual water export. The virtual water trade balance of country, x, for year, t, can thus be written as:

$$NVWI_t = GVWI_t - GVWE_t \tag{9}$$

where NVWI stands for the net virtual water import (m^3/yr) to the country. Net virtual water import to a country has either a positive sign or a negative sign. The latter indicates that there is net virtual water export from the country.

2.4. The water footprint of a country

The total water use within a country itself is not the right measurement of a nation's actual appropriation of the global water resources. In the case of net import of virtual water into a country, this virtual water volume should be added to the total domestic water use in order to get a picture of a nation's real call on the global water resources. Similarly, in the case of net export of virtual water from a country, this virtual water volume should be subtracted from the volume of domestic water use. The sum of domestic water use and net virtual water import can be seen as a kind of 'water footprint' of a country, on the analogy of the 'ecological footprint' of a nation. In simplified terms, the latter refers to the amount of land needed for the production of the goods and services consumed by the inhabitants of a country. The 'water footprint' of a country (expressed as a volume of water per year) is defined as:

$$\text{Water Footprint} = WU + NVWI \tag{10}$$

in which WU denotes the total domestic water use (m^3/yr) and NVWI the net virtual water imports of a country (m^3/yr). As noted earlier, the latter can have a negative sign as well.

2.5. National water scarcity, water dependency and water self-sufficiency

As an index of national "water scarcity" we use the ratio of total water use to water availability:

$$WS = \frac{WU}{WA} \times 100 \tag{11}$$

In this equation, WS denotes national water scarcity (%), WU denotes the total water use in the country (m^3/yr) and WA denotes the national water availability (m^3/yr). Defined in this way, water scarcity will generally range between zero and hundred percent, but it can be above hundred percent in exceptional cases (e.g. groundwater mining).
The "water dependency", WD of a nation is in this paper calculated as the ratio of the net virtual water import into a country to the total national water appropriation:

$$WD = \begin{cases} \dfrac{NVWI}{WU + NVWI} \times 100 & if \quad NVWI \geq 0 \\ 0 & if \quad NVWI \prec 0 \end{cases} \tag{12}$$

The value of the water dependency index will in each definition vary between zero and hundred percent. A value of zero means that gross virtual water import and export are in balance or that there is net virtual water export.
The counterpart of the water dependency index, the "water self-sufficiency" index is defined as follows:

$$WSS = 1 - WD \tag{13}$$

The level of water self-sufficiency (WSS) denotes the national capability of supplying the water needed for the production of the domestic demand for goods and services. Self-sufficiency is hundred per cent if all the water needed is available and indeed taken from within the own territory. Water self-sufficiently approaches zero if a country extremely relies on virtual water imports.

2.4. Process of global virtual water calculation

According to mentioned contexts, commonly calculating process of virtual water is as the Fig. 1.

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2.5. Trading of global virtual water

In this part we investigated virtual water trade and subsequent benefits in Iran compared with other different countries. Virtual water calculating and trade identities in these countries are shown in Table 1. In this paper, we selected two kinds of agricultural products in Iran. First, 16 agricultural products studied which allocate 33.8*10^9 cubic meter of water export. On the other hand, virtual water importance for 9 studied agricultural products is 46.1*10^9 cubic meter. Utilized amount of virtual water in mean per ton is 2869.6 m^3 for exports and 3893 m^3 for imports. Imported and exported total virtual water by selected products and its values are shown in Table 2 and 3, respectively. Table 1 indicates that Iran is one of the biggest users of imported virtual water.

3. Virtual water exchange, trade and optimization in Iran

According to Table 2 and Table 3, in order to optimization of virtual water exchange, we calculated two parameters by dividing (consumed water ⁄ Yield) with (m^3/Kg) dimension and (Value ⁄ Amount) with ($/Kg) dimension which is used as cost and benefit. After that, we made object function to optimization by "Genetic Algorithm" based on mentioned cost and benefit indexes.

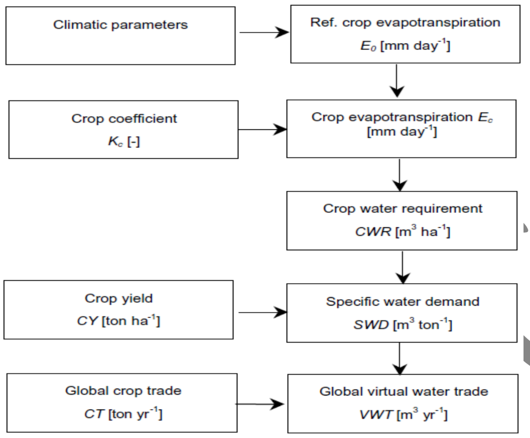

Fig. 1. Calculating process of virtual water.

Table 1. Vitual water index calculating and subsequent trade in export and import (Cubic Million Meter per Year).

Country	Water Availability	GVWE	GVWI	NVWI	Water Footprint	WS (%)	WSS (%)	WD (%)
Iran	117500	803.4	6623.1	5819.7	1457	72.9	93.6	6.4
Australia	343000	30130.3	1011	-29119.3	1085	8	100	0
Germany	171000	9671.3	13589.1	13589.1	742	27.7	77.7	22.3
Japan	547000	188.4	59443.6	59443.6	1196	16.8	60.7	39.3
Brazil	6950000	32161.8	23161.6	-9000.2	225	0.7	100	0
Cameron	268000	187.9	175.3	-12.6	33	0.2	100	0

Table 2. Total exported virtual water, amount and value by selected products (1996-2004), Iran.

Product	Amount (Ton)	Value (1000 $)	Virtual Water Volume (m^3)	Consumed Water (m^3/ha)	Yield (kg/ha)
Grape	4452290	549390	2174514799	8000	4091
Nut	19610	21200	115352941	850	5000
Pistachio	1100790	3757700	20408621090	431.5	8000
Onion	658970	57230	434922685	21212	14000
Tea	90130	61140	179707055	1630	3250
Date	991600	305790	1967460317	6300	12500
Cucumber	69060	17800	7847727	22000	25000
Apple	1590020	273630	636008000	13000	5200
Potato	612550	74140	320731180	25000	13090
Garlic	30070	4730	14729881	14290	7000
Walnut	25350	35260	131688311	1155	6000
Tomato	1851550	260550	608366428	35000	11500
Beans	5390	1120	2964500	10000	5500
Citrus	36440	6060	31617058	170000	14750
Sum	11782850	5520500	33812343300	-	-

3.1. Optimization

Object function determined as:
Maximum obtained benefit ((Benefit Index: β) * Production Amount) and Minimum virtual water usage ((cost Index: α) * Production Amount).

We optimized object function by Genetic Algorithm (G.A). “G.A” is a non-linear method to optimize, which is used for evolution rules to complete the process. Ability of “G.A” in finding global optimization by acceptable iteration makes it an elite method between other algorithms. Specified characteristics of “G.A” change it to a flexible method to use in different fields of engineering sciences. According to mentioned explanation, we run “G.A” with 1000 initial population and 0.001 accuracy. In 100 iterations, evolution parameters were 0.03 for mutation coefficient and crossover coefficient equal to 0.8.

Results showed optimum possible cultivation pattern for exported product. With this pattern, we can minimize exported virtual water content and maximize obtained benefit. On the other hand, “G.A” gives another pattern for importing products which causes reduction in cost despite reduction in virtual water import. So, by this pattern, we have

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165 million dollars per year increase in benefits, and economize 4150 million cubic meter in virtual water usage for exported products. For imported product, pattern results in 2140 million dollars providence per year for imported products, even though amount of imported virtual water reduced. Optimum patterns for importing and exporting products based on "G.A" results are shown in Fig. 2 and Fig. 3, respectively. In Fig. 4, convergence trend of program has shown after 100 iterations. as it shows results start to converge after approximately 70 iterations.

Table 3. Imported total virtual water, amount and value selected by products (1996-2004), Iran.

Product	Amount (Ton)	Value (1000 $)	Virtual water volume (m^3)	Consumed Water (m^3/ha)	Yield (kg/ha)
Sunflower	3934100	1075550	59382641610	530	8000
Peanut	77830	27710	133752296	3375	5800
Rice	10699380	2556230	61139314290	3500	20000
Barely	5245260	783370	9618310000	3000	5500
Tea	112440	310750	224190184	1630	3250
Sorghum	13986640	215420	21221108970	7250	11000
Soya	36906730	5516570	246044866700	1500	10000
Sugar	7669600	1947241	18782693880	4900	12000
Wheat	38135230	5325450	43855514500	5000	5750
Banana	1689470	721240	1013682000	25000	15000
Sum	118520500	20400361	461414074300	-	-

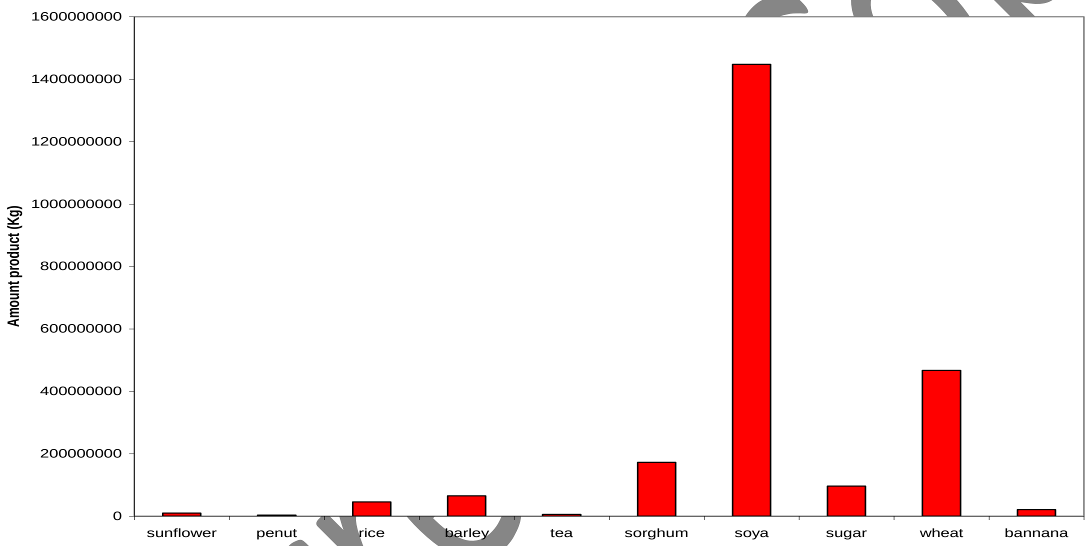

Fig. 2. Optimum pattern for importing agricultural products.

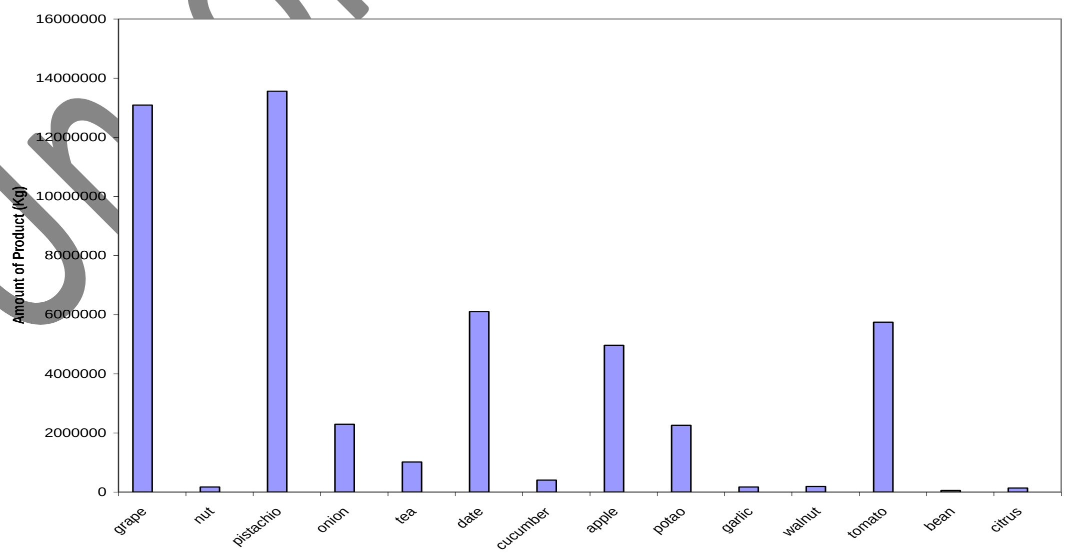

Fig. 3. Optimum pattern for exported agricultural products.

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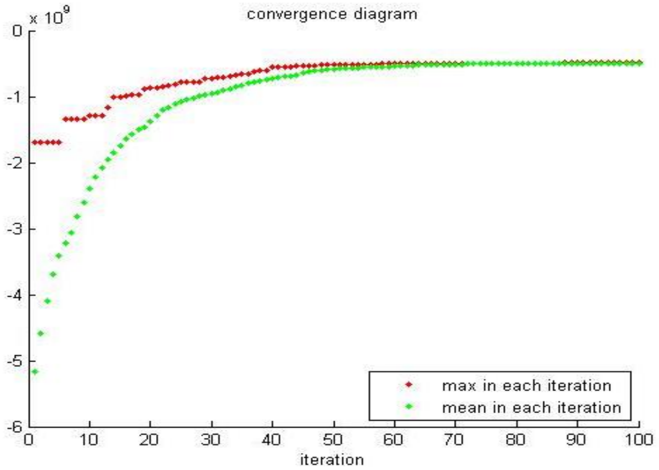

Fig. 4. Convergence diagram of "G.A" results after 100 iterations.

4. Conclusions

Finally, it seems that virtual water concept could be a useful and important factor for water scarcity in some countries or countries with arid or semi-arid climates. Additionally, its role in agricultural product trade and national economy exchange rate is considerable.

In this paper, we have studied some selected strategic agricultural products and their statistics in Iran. Virtual water parameters were also calculated and considered. Object function to optimize mentioned as a combination of cost and benefits functions. After all this, we have used "Genetic Algorithm" as an optimization algorithm and nominated a cultivation and import pattern which could optimize cost and benefits of virtual water trade in Iran. Optimization also had economical results by increasing revenues and decreasing cost of exported products. According to the optimum fitted pattern, import of "Soya" in imported product category should be increased to 32 % and "Pistachio" product for the export has been recommended to increase to 10 %. Recommended pattern for exports resulted in 4150 million cubic meter thrift each year.

References

Darowski J.M.E., Ashton P.Y., Analysis of Virtual Water Flows Associated With The Trade of Maize In The SADC Region, Hydrology and Environment System Science Jurnal 13 (2009) 1967-1977.

Hoekstra A.R., Hung P.Q., Virtual Water Trade: Proceedings of The International Expert Metting On Virtual Water trade, Value of Water Research Report Series, IHE, DELFT, (2003) 13-50.

Hoseini S.A., Arshadi M., Babai H., The First International Conference on Water Crisis, "Virtual Water: Concepts and Applications (In Persian), Zabol, IRAN, (2009).

Odularu G.O.E., Conceptual Explanat of Virtual Water Trade and Lessons For Africaion, Jurnal of Development and Agriculture Economicsl 1(2009) 162-167.

Schreier H., et al. Blue, Green and Virtual Water, for Walter and Duncan Gordon Foundation Toronto Canada, Ontario, (2008).

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