Globalization of Water Resources through Virtual Water Trade

by

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15 April 2008

1. Introduction

With the continuous population growth and related developments, water resources have become increasingly scarce in a growing number of countries and regions in the world. As the largest water user, accounting for over 80% of the global total water withdrawal, food production is directly affected by water scarcity. In many water scarce countries, an increasing amount of food is being imported to meet the domestic food demand. For these countries, importing food is virtually equivalent to importing water that would otherwise be needed for producing the food locally. Allan (1993) termed the water embodied in food import as “virtual water”. In recent years, the concept of virtual water has been extended to refer to the water that is required for the production of agricultural commodities as well as industrial goods (Hoekstra and Hung, 2005). Nevertheless, discussions on virtual water issues have so far focused primarily on food commodities due to their large share in total water use. With the intensification of water scarcity in many areas of the world and looming impacts of climate change, the role of virtual water trade in balancing local water budget is expected to increase.

This study examines global virtual water flows associated with international food trade. The role of virtual water trade in redistributing global water resources and compensating for water scarcity is assessed, and opportunity costs of green and blue water uses and environmental impacts are discussed. The analysis is made on two dimensions: the global and country levels, and the exporting and importing countries.

2. Virtual water flows associated with international food trade

2.1 Quantification of virtual water flows

The amount of water required for producing a unit of crop is termed “virtual water content” (m^3/kg). It is in essence the inverse of crop water productivity (kg/m^3). Multiplying virtual water content of a crop by its trade quantity derives the volume of virtual water flow associated with the trade of the crop. Allan (1997) estimated that the virtual water embodied in cereal import into the Middle Eastern and North African countries exceeded the total annual water use for food production in Egypt. Following Allan, many other studies have quantified virtual water flows at various geographical levels (Hoekstra and Hung, 2005; Yang et al., 2003; Oki and Kanae, 2004; Zimmer and Renault, 2003; Fraiture et al., 2004; Hoekstra and Hung, 2005). Globally, the virtual water flows between nations stood at about 1000 km^3/year at the turn of the last century (from the perspective of exporting countries). Of which, about 650 km^3/year was attributed to crop related trade. The volume of virtual water associated with food trade was about 15% of total water use in food production.

Variations are however rather large in the estimated virtual water flows at the global level as well as at the country level among different studies. The variations mainly stem from the inconsistency in the following four aspects: the value of virtual water content used in calculating virtual water flows, the coverage and aggregation of crops, the period considered, and the source of trade data. For these reasons, the results from different studies are often difficult to compare.

In the global food trade system, the volume of total food export is approximately equal to the volume of total food import to achieve the market clearance. This is especially so when averaged over a period of time as the effect of yearly stock exchange is smoothed out. Concerning the global virtual water trade, however, this equilibrium does not apply. Crop water productivity, and virtual water content, is a function of climate conditions, agronomic practices and field management, etc. For a given crop, water productivity varies across regions. The virtual water “value” of a given amount of food may not be identical on the importing and exporting sides. When virtual water imports and exports for all the countries are summed up separately, a gap between the two volumes occurs.

Table 1. Global virtual water import and export, average over 1997-2001

Crops	Global gross virtual water import (km3 year-1)	Global gross virtual water export (km3 year-1)	Global water sa		
				Ratio of virtual water saving to total virtual water import	

*. Others refer to other crops.
Source: Yang et al., 2006.

Table 1 shows the gross virtual water import and export at the global level estimated by Yang et al. (2006). Total volume of virtual water export associated with the food crops is about 644 km3/year. The corresponding volume for import is 981 km3/year. The difference is 337 km3/year. This volume is the global water saving resulting from the food trade. It means that this volume of additional water would otherwise be required if the imported amount of food were produced in the importing countries. At the global level, 34.3% of the water is 'saved' in producing the traded volume of food through virtual water trade.

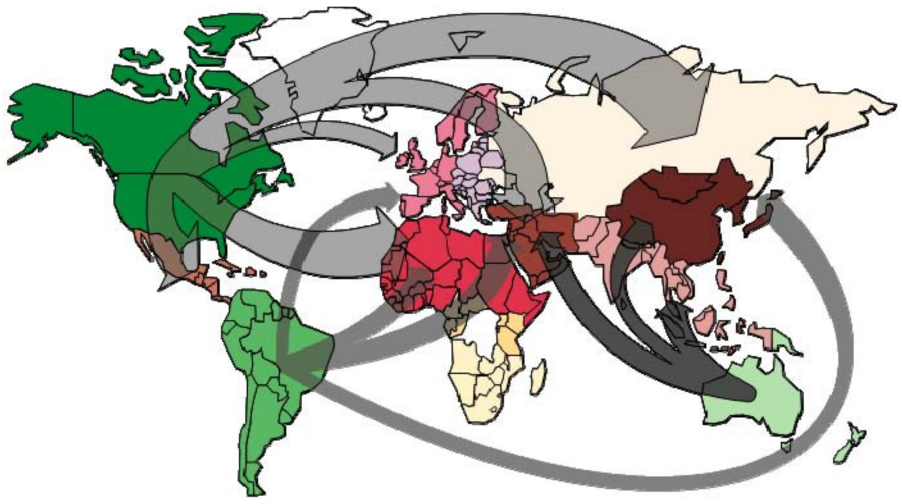
For individual crops, the scale of 'water saving' varies. For wheat and maize, the trade has resulted in a 41% and 59% reduction in the global water use in producing the traded amounts of the respective crops. The trading of these two crops contributes greatly to the total global water saving. An exception, however, is rice where the volume of virtual water embodied in rice export is larger than that in rice import. This implies that the rice production in the exporting countries requires more water than the production in the importing countries.

The water saving achieved at the global level reflects a relatively high water productivity in the major exporting countries. The study by Hoekstra and Hung (2005) shows that water productivity for the respective crops is generally high in North America and the Western European countries. Other countries with high water productivity include Argentina, China, Australia, and some countries in the Middle East. In contrast, water productivity is manifestly low in the poor Sub-Saharan African countries. This situation is expected because water productivity is closely related to the agronomic practices and water management at both regional and farm-levels. Efforts to raise water productivity are often associated with greater inputs and improved agronomic practices and water management, which are generally lacking in poor countries. The opposite situation for rice may partly be explained by the relatively high crop evapotranspiration in the major rice exporting countries, such as Vietnam and Thailand.

2.2. Virtual water flows across regions

As water productivity is generally lower in importing countries than in exporting countries, a given amount of food commodities is worth more virtual water in the former than in the latter. This leads to an amplification of virtual water flows from source to destination. Figure 1 illustrates the amplification visually. The net virtual water flows are viewed from the exporting and importing sides, respectively, for the 14 regions of the world. The net volume of virtual water export is the net export quantities multiplied by crop virtual water content in the corresponding exporting countries. The net volume of virtual water import is the net import quantities multiplied by crop virtual water content in the corresponding importing countries. The two volumes represent the virtual water “values” of a given amount of traded food commodity measured at source and destination. Each individual country’s net virtual water export/import is calculated first. All the countries are then grouped into 14 regions.

Figure 1. Virtual water flows by regions, average over 1997-2001



Exporter	VW km^3	Importer	VW km^3	Exporter	VW km^3	Importer	VW km^3	Exporter	VW km^3	Importer	VW km^3
N-America	73	E-Asia	149	S-America	30	W-Europe	26	Oceania	15	E-Asia	20
	30	C-America	64		21	E-Asia	25		11	S+E- Asia	24
	22	N+W-Africa	58		18	M-East	35		10	M- East	14
	17	M-East	55		12	N+W-Africa	21		13	Others	24
	12	W-Europe	17		15	Others	38				
	27	Others	71								

North America, South America and Oceania are the net exporting regions of virtual water. All other regions are net importers. East Asia, Central America, North and West Africa and Middle East are the major destinations of virtual water. It can be seen that the volumes of virtual water differ largely on the exporting and importing sides. For example, the volume of 73 km3 of virtual water exported from North America is worth 149 km3 of virtual water in East Asia. In the Middle East, the corresponding volumes are 17 km3 and 55 km3, respectively. One exception is the virtual water export from South America to Western Europe. The virtual water exported from South America is worth less in Western Europe because of the lower water productivity in the former region than in the latter.

The estimations of virtual water trade are highly sensitive to the values of crop water productivity used in the estimation. The crudeness of the data can also affect the accuracy of the estimation. Therefore, the estimated volumes of virtual water trade here and in all other studies should be only viewed as approximations.

3. The role of virtual water in compensating for water scarcity

While water scarcity has been at the center of virtual water discussion, it has been widely recognized that not all virtual water trade is driven by water scarcity (Yang et al., 2003; Fraiture et al., 2004; Oki and Kanae, 2004). Japan is an example in point. The country imports 75 percent of the cereals consumed domestically (FAO, 2004). The import, however, has no direct relation with its water resources, which stood at 3380 m^3/capita in 2000. It is more the scarcity of land resources that shapes the country's food import policies (Oki and Kanae, 2004).

To examine the significance of virtual water trade in compensating for water scarcity, we divide all the net virtual water importing countries into three groups. The water threshold of 1700 m^3/capita defined by Falkenmark and Withstand (1992) is used as a scarcity indicator. A minimum of 2500 m^3/capita is set for non-water scarce countries. This is based on the observation that above this level, a country is very unlikely to endure a nationwide physical water resources scarcity, though some regions may experience water stress. The countries with water resources availability between 1700 m^3/capita and 2500 m^3/capita are at the margin, which may or may not endure a widespread water scarcity. Table 2 shows the shares of the three country groups in total net virtual water import.

Table 2. Net virtual water import by country groups, average of 1997-2001 (viewed from the importing side).

	Total	Countries with water availability below 1700 m^3/capita	Countries with water availability between 1700 and 2500 m^3/capita	Countries water ava larger tha m^3/capita
Total net virtual water import (km^3/year)	715.5	145.8	82.1	487.1
Percentage of total net virtual water import	100	20.4	11.5	68.1

The total net virtual water import of all net importing countries is around 715 km^3 annually. Of this volume, about 20.4% occurs in the countries with water resources below 1700 m^3/capita, 11.5% is in the countries with water resources between 1700m^3/capita and 2500m^3/capita. The rest of 68.1% is in the non-water scarce countries. Based on these figures, one can conclude that water scarcity has a relatively limited role in shaping the global virtual water trade flows. For developed countries, such as Japan, Switzerland, Italy, etc., pursuing comparative advantages would have been an important drive for food import (Fraiture et al., 2004). Water saving *per se* would be of little benefit to them.

Nevertheless, for water scarce countries importing food effectively reduces the domestic water use for food production. This reduced amount may be viewed as a 'saving' of domestic water. For these countries, virtual water import plays an important role in balancing the water budget and alleviating water stress. Table 3 shows the net virtual water import in the Middle Eastern and North African countries (MENA). It can be seen that many of them have extremely high ratio of virtual water import to renewable water resources. In Libya, the volume of virtual water import is more than five times its own available water resources.

Table 3. Net virtual water import in MENA countries (million m^3) (1998-2002)

COUNTRY	Cereal import	Vegetable oil import	Sugar impor	Vegetable export	Fruit export	Sum of net virtual water import	Net virtual water import as a percentage of water resources
Algeria	7540	2418	1276	-10	-99	11342	79.21
Cyprus	439	71	45	1	28	526	67.47
Egypt	10049	2840	1006	124	44	13727	23.55
Israel	2701	436	430	40	63	3464	207.40
Jordan	1250	326	248	120	-18	1722	195.69
Lebanon	834	274	188	-18	48	1266	28.73
Libya	2214	729	248	-138	-13	3343	557.09
Morocco	3945	1935	695	109	121	6344	21.88
Syria	-315	553	809	76	28	943	3.59
Tunisia	3486	1019	411	60	12	4845	96.91
Turkey	622	2447	-451	371	647	1600	0.70
Sum of the region	32764	13049	4906	735	861	49123	13.26

Cereal import takes the lion's share in total virtual water import in the MENA countries, except for Syria and Turkey. For the region as a whole, about 67% of the virtual water import is attributed to cereal, 27% to vegetable oil, and about 10% to sugar. The volume of virtual water embodied in the export of fruits and vegetables is small. This is partly due to relatively low virtual water content of these crops.

4. "Green" vs "blue" water in agricultural production and virtual water trade

4.1 Green and blue water in food production

Rainwater that falls on a watershed could be partitioned into "green" and "blue" water. The concept of green water was first introduced by Falkenmark (1995) to refer to the return flow of water to the atmosphere as evapotranspiration (ET) which includes a productive part as transpiration (T) and a non-productive part as direct evaporation (E) from the surfaces of soils, lakes, ponds, and from water intercepted by canopies. Later, green water has been generally used to refer to the water stored in the unsaturated soils (Savenije, 2000). Green water is the water source of rainfed agriculture. Blue water refers to the water in rivers, lakes, reservoirs, ponds and aquifers (Rockström et al., 1999). Irrigated agriculture typically uses blue water as a supplement to rainfall.

Earlier studies of water-food-trade relations had mainly focused on addressing constraint of blue water scarcity on irrigated agriculture. Recent years have seen a growing attention on rainfed systems which rely on green water stored in unsaturated soils (Falkenmark and Rockström, 2006).

Green and blue water have different characteristics, leading to different opportunity cost of the use of these resources. Table 4 summarized some of the features of green and blue water. Green water comes from rainfall. It is a 'free good' in terms of supply. Plants other than food crop (which often have lower direct economic value of water use) are the major competitive users of this water (Yang and Zehnder, 2002). Compared with blue water, the opportunity cost of green water use is lower. In contrast, blue water has many functions. Irrigation often yields the lowest economic value among all the functions (Zehnder et al., 2003). Thus, the opportunity cost of irrigation water is high. Meanwhile, blue water requires facilities for storage and distribution before it can be delivered to users. The supply of water involves cost. Moreover, excessive irrigation can cause severe salinization, water logging and soil degradation, which are evident in many areas of the world (Postel, 1999). From the viewpoint of opportunity cost of the use of water resources, trading green virtual water is overall more efficient than trading blue virtual water, holding other factors constant.

Table 4. Characteristics of the Blue and Green Water

Type of water	Blue	Green
Sources	rivers, lakes, reservoirs, ponds, aquifers	water that is stored unsaturated soil and used for evapotranspir
Mobility	highly mobile	highly immobile
Substitution of sources	Possible	impossible
Competitive uses	Many	few
Conveyance facilities	Required	not required
Cost of use	High	low

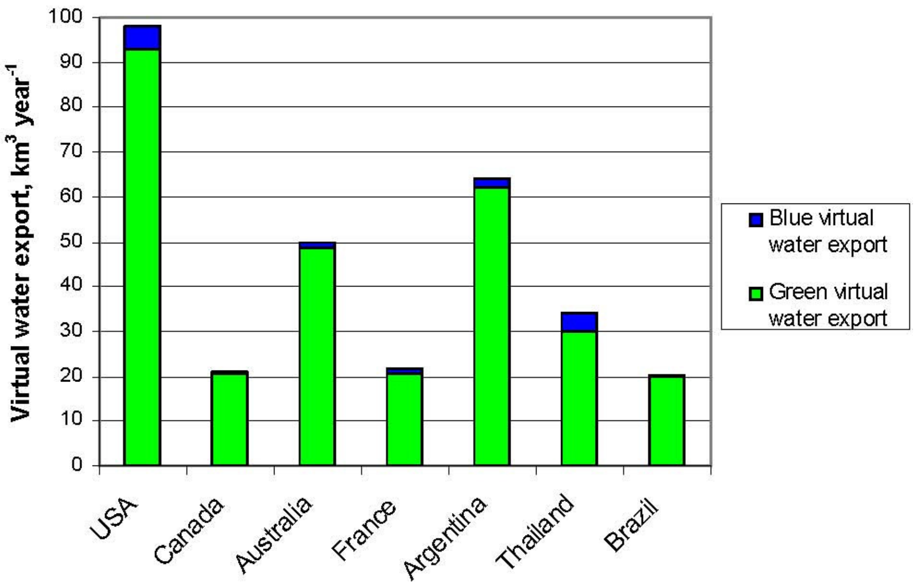
The ratio of irrigated areas to total crop areas indicates the dependence of a country's agricultural production on blue water. In major food exporting countries, especially Canada, France, Australia and Argentina, the irrigation ratio is low. Food production in these countries is dominantly rainfed. This means that food exporting countries generally export their green virtual water. In food importing countries, irrigation ratio varies widely. Many water scarce food importing countries have a high dependence on blue water for agricultural production. This is not surprising given the close links between low precipitation, need for irrigation and the demand for virtual water import. For water scarce countries, the opportunity cost of irrigation is high as there are many competing uses. However, the high opportunity cost is often taken as a trade-off for easing other more pressing concerns, typically food security, rural employment and political stability (Wichelns, 2001). It is also noticed that in many poor countries, the irrigation ratio is low irrespective of their water resources. This situation is no doubt related to the lack of financial capacity in these countries to bring blue water into irrigation.

4.2. Proportion of blue and green water in global virtual water trade

Figure 2 shows the blue and green virtual water proportion in the seven largest food exporting countries. These countries account for about 80 percent of the total net virtual water export. It can be seen that the proportion of the blue virtual water export in these countries is considerably small. In Canada, it is negligible. This means that the global virtual water export is overwhelmingly "green". Exporting green water constitutes a lower opportunity cost in water use as opposed to irrigated food production, holding other factors constant.

Figure 2. Net blue and green virtual water export in major exporting countries,

average over 1997-2001



It should be noted that green and blue waters are not completely independent in the hydrological cycle. For example, changes in land use can affect the green and blue water partitioning in a watershed (Rockström, et al., 1999). Also, there are "grey areas", such as water harvesting, where deliberate local interventions are made to capture local runoff. The separation of green and blue water resources here is mainly for illustrating the opportunity cost of the water use in irrigated and rainfed production and the virtual water trade associated with the different water uses.

5. Effects of virtual water trade on the water use efficiency in source and destination countries

5.1 Impact on importing countries

Virtual water import effectively reduces the water use for food production in food importing countries. For the countries where water resources are scarce, virtual water import helps alleviate water stress. For many of them, it has been often cheaper and less ecologically destructive to import food, especially the water intensive cereal crops, than to transport water to produce the same commodity locally (Qadir et al., 2003). Over the last 30 years prior to 2006, the world prices for major cereal crops had declined by about 50 percent (Yang et al, 2003). Water deficit countries had been able to access the virtual water at the advantageous prices. However, recent years have witnessed a significant increase in food prices in the world market. The price raises pose a disincentive to food import. The rapid expansion of bioeneragy industry has been widely considered to be partly responsible for the food price hikes. It can be expected that furture energy policies in major food exporting countries will have significant impacts on the future food price and food trade of the world.

For poor countries with abundant water resources, however, viewing food import from a water saving perspective is not meaningful. For these countries, agriculture is an important economic sector and a large proportion of the population relies on farming for living. The flux of food import to these countries often undermines local food production as farmers cannot compete with the cheap and often subsidized food surpluses from the major exporting countries. The food dumping to poor countries depresses local prices and reduces domestic production (Rosegrant et al., 2002). Poor and small farmers are hit the most. In this case, virtual water import could be detrimental to the local food security. Increasing food production by better agronomic practices and field management, including bringing water resources into use, is of importance for these countries to improve the rural income and livelihood (Rockström et al., 1999; Rosegrant et al., 2002).

5.2. The environmental impact of virtual water trade on exporting countries

Food exporting countries are the source of virtual water. They are imperative players in the international virtual water trade. However, previous studies of virtual water issues have focused overwhelmingly on food importing countries. Little attention has been paid to food exporting countries concerning their water endowments and resource use efficiency, as well as environmental impacts associated with the virtual water export (Merrett, 2003). With the virtual water trade increasingly being emphasized in the global effort to combat regional water scarcity, the issues relating to exporting countries deserve much more attention.

As elaborated earlier, crop water productivity in major food exporting countries is generally higher than in many food importing countries. This is partly because the former have higher inputs, including fertilizers and pesticides, in food production. In the USA, for example, the average fertilizer application is about 140 kg/ha compared to the average of around 100 kg/ha in the developing countries (FAO, 2004). In many exporting countries, the excessive application of fertilizers and pesticides is rapidly becoming a major environmental hazard (Zehnder et al., 2003). What is not clear is how much of the high crop water productivity in the major exporting countries is due to better management and efficient use of water resources.

Although food production, especially cereal production, in the major exporting countries is dominated by rainfed agriculture, a significant increase in irrigation has been evident in some of these countries. In France, Australia and Brazil, for example, the increase between the early 1980s and the late 1990s was over 50%. In the United States, the rate was over 11% (FAO, 2004). Overexploitation of water resources has occurred in many regions of these countries. In the central and western United States, for example, many rivers and aquifers have been over-exploited, causing serious regional water resources depletion and environmental degradation (Postel, 1996; Gleick, 2003). It is estimated that under the business-as-usual scenario, about 17 percent increase in irrigation water supply would be needed worldwide to meet the demand for food in the coming 25 years (Rijsberman, 2002). Although most of the increase would be in food importing countries, an expansion in irrigated areas in food exporting countries could also be expected as a result of the increasing demand for their virtual water. This could aggravate the regional water resource depletion and environmental degradation in food exporting countries on the one hand and increase the opportunity costs of the virtual water trade on the other.

The above analysis suggests a complexity in assessing the water use efficiency in the virtual water trade when the perspective is extended to non-water scarce countries and to the exporting countries. Much more research is needed to address the trade-offs between gains and losses in the global virtual water trade for supporting policy making.

6. Summary

This study provided an assessment of virtual water flows associated with global food trade and discussed the water use efficiency embodied in such trade. The characteristics of green and blue water and their proportions in the global virtual water trade are elaborated.

At the global level, the volume of food crop related virtual water trade is about 650 km^3/year when viewed from the exporting perspective and 1000 km^3/year when viewed from the importing perspective. The difference is the result of generally higher water productivity in exporting countries in comparison to importing countries. Cereals account for a large share of total virtual water trade. Globally, the volume of virtual water associated with food crop trade is about 15% of the total water use in food crop production.

The quantification of virtual water embodied in the international food trade provides insights into the role of virtual water in redistributing (virtually) the global water resources. It is useful in raising the public awareness of water resources and environmental impacts through addressing virtual water embodied in the commodities they consume. For water scarce countries, virtual water import plays an important role in alleviating local water deficiency. However, for water abundant countries, viewing virtual water from water saving *per se* is little meaningful.

Major food exporting countries overall have a low irrigation intensity. The contribution of irrigation to food production is relatively small. The global virtual water trade is dominated by green water. Such a trade is efficient in terms of opportunity cost of water use. However, the high water productivity in the major exporting countries is partly due to the high inputs of chemical fertilizers and pesticides. The environmental impacts have been high.

It should be pointed out that the current global food trade is primarily among the countries with middle and high incomes. The low income countries have a much less participation in global food trade. Among many reasons, the low income and consequently the low ability to exploit natural resources and invest in agriculture are largely responsible. The lack of financial resources also deprives the poor countries' choice of purchasing food from the international market when the domestic food supply is in shortage. Therefore, one should be cautious to expect miracles from the virtual water trade in addressing the food security problems in poor countries. Greater efforts, particularly agricultural technologies and investment, should be devoted to the development of rainfed agriculture in these countries to improve food security. Given the increasing scarcity of the global blue water resources, more effectively utilizing green water may also have to be a direction to which the world agriculture will pursue in the future.

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