Water International
Vol. 33, No. 1, March 2008, 19–32

Routledge
Taylor & Francis Group

The global component of freshwater demand and supply: an assessment of virtual water flows between nations as a result of trade in agricultural and industrial products

Ashok K. Chapagain[a] and Arjen Y. Hoekstra[b]*

[a]*WWF, Godalming, Surrey, UK;* [b]*University of Twente, Enschede, The Netherlands*

(*Received 12 May 2005; final form 7 January 2006*)

Where the river basin is generally seen as the appropriate unit for analysing freshwater availability and use, this paper shows that it becomes increasingly important to put freshwater issues in a global context. International trade in commodities implies flows of 'virtual water' over large distances, where virtual water should be understood as the volume of water required to produce a commodity. Virtual water flows between nations have been estimated from statistics on international product trade and the virtual water content per product in the exporting country. With increasing globalization of trade, global water interdependencies and overseas externalities are likely to increase. At the same time liberalization of trade creates opportunities to increase physical water savings.

Keywords: water demand; virtual water transfer; globalization; water footprint; international water dependency

Introduction

In the world of today, people in Japan indirectly affect the hydrological system in the United States and people in the Netherlands indirectly impact on the regional water systems in Brazil. Much has been reported about the expected effects of past and ongoing local emissions of greenhouse gasses on the future global temperature, evaporation and precipitation patterns. Little attention has been paid, however, to a second mechanism through which people affect water systems in other parts of the world. This second mechanism, which is actually much more visible already today, is through global trade. International trade in agricultural and industrial commodities creates a direct link between the demand for water-intensive commodities (notably crops) in countries such as Japan and the Netherlands and the water use for production of export commodities in countries such as the United States and Brazil. The water use for producing export commodities to the global market significantly contributes to the change of regional water systems. Through their consumption of American products, Japanese consumers exert an indirect pressure on water resources in the US, contributing to the mining of aquifers and emptying of rivers in North America. We know the examples of the mined Ogallala Aquifer and emptied Colorado River. In a similar way Dutch consumers contribute to a significant degree to the water demand in Brazil.

While it is generally argued that the river basin is the appropriate unit for analysing freshwater availability and use, this paper argues that it becomes increasingly important to

*Corresponding author. Email: a.y.hoekstra@ctw.utwente.nl

ISSN 0250-8060 print/ISSN 1941-1707 online

DOI: 10.1080/02508060801927812
http://www.informaworld.com

put freshwater issues in a global context. Although other authors have already argued so earlier (Postel *et al.* 1996, Vörösmarty *et al.* 2000), this paper adds a new dimension to the argument. International trade in commodities implies large-distance transfers of water in virtual form, where virtual water is understood as the volume of water that is required to produce a commodity and that is thus virtually embedded in it (Allan 1993, 1994). Knowledge on the virtual water flows entering and leaving a country can put a completely new light on the actual water scarcity of a country. Jordan, as an example, imports about 5–7 billion cubic metres (BCM) of virtual water per year (Chapagain and Hoekstra 2003, Haddadin 2003), which is in sheer contrast with the 1 BCM of annual water withdrawn from domestic water sources. As another example, Egypt, with water self-sufficiency high on the political agenda and with a total water withdrawal inside the country of 65 BCM per year, still has an estimated net virtual water import of 10–20 BCM per year (Yang and Zehnder 2002, Chapagain and Hoekstra 2003, Zimmer and Renault 2003).

In the past few years a number of studies have become available showing that the virtual water flows between nations are substantial. The studies indicate that the global sum of international virtual water flows must exceed 1000 BCM per year (Hoekstra and Hung 2002, 2005, Chapagain and Hoekstra 2003, Zimmer and Renault 2003, Oki and Kanae 2004, De Fraiture *et al.* 2004). However, all studies show limitations in the scope of traded commodities considered. Hoekstra and Hung (2002, 2005) considered 38 primary crops; Chapagain and Hoekstra (2003) looked at trade in livestock products from eight animal types (beef cattle, dairy cows, swine, sheep, goats, poultry/fowls, laying hens and horses); Zimmer and Renault (2003) accounted for 29 primary crops and 20 processed crop products; Oki and Kanae (2004) looked at five primary crops (maize, wheat, rice, barley, soybean) and three livestock products (chicken, pork, beef); and De Fraiture *et al.* (2004) analysed trade in cereals only. None of the studies included trade in industrial products.

The aim of this paper is to come up with a comprehensive estimate of international virtual water flows in the period 1997–2001 and to analyse what these virtual water flows mean in terms of water import dependency of regions. The paper considers international trade in 285 crop products (covering 164 primary crops) and 123 livestock products (covering eight animal categories). Trade in industrial products is dealt with all-inclusively as well, but in a more crude way, with the average virtual water content per dollar of traded industrial product as a key parameter.

Method

International virtual water flows have been calculated by multiplying commodity trade flows by their associated virtual water content:

$$VWF\,[n_e, n_i, c] = CT\,[n_e, n_i, c] \times VWC\,[n_e, c] \qquad (1)$$

in which VWF denotes the virtual water flow (m^3yr^{-1}) from exporting country n_e to importing country n_i as a result of trade in commodity c; CT the commodity trade (ton yr^{-1}) from the exporting to the importing country; and VWC the virtual water content (m^3 ton^{-1}) of the commodity, which is defined as the volume of water required to produce the commodity in the exporting country. We have taken into account the trade between 243 countries for which international trade data are available in the Personal Computer Trade Analysis System of the International Trade Center. It covers trade data from 146 reporting countries disaggregated by product and partner countries (ITC 2004). We have carried out calculations for 285 crop products and 123 livestock products.

The virtual water content (m^3 ton^{-1}) of primary crops has been calculated as the crop water requirement at field level (m^3 ha^{-1}) divided by the crop yield (ton ha^{-1}). The crop water requirement is defined as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate region, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield. Crop water requirements have been calculated per crop and per country using the methodology developed by the Food and Agriculture Organization (FAO) (Allen *et al.* 1998).

If a primary crop is processed into a crop product (e.g. seed cotton processed into cotton lint), there is often a loss in weight, because only part of the primary product is used. In such a case we calculate the virtual water content of the processed product by dividing the virtual water content of the primary product by the so-called product fraction. The product fraction denotes the weight of crop product in ton obtained per ton of primary crop. If a primary crop is processed into two different products or more (e.g. soybean processed into soybean flour and soybean oil), we need to distribute the virtual water content of the primary crop to its products. We do this proportionally to the value of the crop products. If during processing there is some water use involved, the process water requirement is added to the virtual water content of the root product (the primary crop) before the total is distributed over the various root products. In summary, the virtual water content of a crop product is calculated as:

$$VWC[p] = (VWC[r] + PWR[r]) \times \frac{vf[p]}{pf[p]} \tag{2}$$

in which $VWC[p]$ is the virtual water content of product p (m^3/ton), $VWC[r]$ the virtual water content of the root product r (m^3/ton), $PWR[r]$ the process water requirement when processing the root product into processed products (m^3/ton), $pf[p]$ the product fraction (dimensionless) and $vf[p]$ the value fraction (dimensionless). The latter is the ratio of the market value of the product to the aggregated market value of all the products obtained from the primary crop:

$$vf[p] = \frac{v[p] \times pf[p]}{\sum_{p=1}^{n} (v[p] \times pf[p])} \tag{3}$$

in which $v[p]$ is the market value of product p (US$/ton). The denominator is totalled over the n products that originate from the primary crop. In a similar way we can calculate the virtual water content for products that result from a second or third processing step. The first step is always to obtain the virtual water content of the input (root) product and the water necessary to process it. The total of these two elements is then distributed over the various output products, based on their product fraction and value fraction.

The virtual water content of live animals has been calculated based on the virtual water content of their feed and the volumes of drinking and service water consumed during their lifetime. Eight major animal categories were included in the study: beef cattle, dairy cows, swine, sheep, goats, fowls/poultry (meat purpose), laying hens and horses. The calculation of the virtual water content of livestock products has again been based on product fractions and value fractions, following the above described methodology.

Data on trade in industrial products have been taken from the World Trade Organization (WTO 2004). Virtual water imports and exports have been calculated by multiplying monetary data on international trade in industrial products ($/yr) by country specific data on the average virtual water content per dollar of industrial products (m^3/$). The latter has been calculated per country by dividing the water withdrawal in the industrial sector (FAO 2003) by the added value in the industrial sector (World Bank 2004). In this approach, all industrial products are included implicitly.

International virtual water flows

The calculations show that the global virtual water flows during the period 1997–2001 added up to an average of 1625 BCM/yr. The major share (61%) of the virtual water flows between countries is related to international trade in crops and crop products. Trade in livestock products contributes 17% and trade in industrial products 22%. The total volume of international virtual water flows includes virtual water flows that are related to re-export of imported products. The global volume of virtual water flows related to export of domestically produced products is 1197 BCM/yr (Table 1). With a total global water use of 7451 BCM/yr, this means that 16% of the global water use is not meant for domestic consumption but for export. In the agricultural sector, 15% of the water use is for producing export products; in the industrial sector this is 34%.

The major water exporters are the US, Canada, France, Australia, China, Germany, Brazil, the Netherlands and Argentina. The major water importers are the US, Germany, Japan, Italy, France, the Netherlands, the UK and China. Table 2 presents the virtual water flows for a number of selected countries. Import of water in virtual form can substantially contribute to the total “water supply” of a country. The Netherlands imports, for instance, a net amount of (virtual) water, equivalent to the annual net precipitation in the country. Jordan imports a volume of water in virtual form equivalent to *five times* its own annual renewable water resources.

A national virtual water flow balance can be drafted by subtracting the export volume from the import volume. Figure 1 shows the virtual water balance for all countries of the world. Most of the Americas, Australia, most of Asia and Central Africa have net export of virtual water. Net import of virtual water can be found in most of Europe, Japan, North and South Africa, the Middle East, Mexico and Indonesia. It appears that developed countries generally have a more stable virtual water balance than the developing countries. Countries that are relatively close to each other in terms of geography and development level can have a rather different virtual water balance. Germany, the Netherlands and the UK are net importers whereas France is a net exporter. The US and Canada are net exporters whereas Mexico is a net importer. Although the US has more than three times as much gross virtual water export as Australia, Australia is the country with the largest *net* export of virtual water in the world.

Table 1. International virtual water flows and global water use per sector, 1997–2001.

	Gross virtual water flows			
	Related to trade in agricultural products (BCM/yr)	Related to trade in industrial products (BCM/yr)	Related to trade in domestic water (BCM/yr)	Total (BCM/yr)
Virtual water export related to export of domestically produced products	957	240	0	1,197
Virtual water export related to re-export of imported products	306	122	0	428
Total virtual water export	1,263	362	0	1,625
	Water use per sector			
	Agricultural sector	Industrial sector	Domestic sector	Total
Global water use (BCM/yr)	6,391	716	344	7,451
Water use in the world not used for domestic consumption but for export (%)	15	34	0	16

Virtual water flows between world regions

Gross virtual water flows between and within 13 world regions are presented in Table 3. The regions with the largest virtual water export are North and South America. The largest importers are Western Europe and Central and South Asia. The single most important intercontinental water dependency is Central and South Asia (including China and India) annually importing 80 BCM of virtual water from North America. This is equivalent to one seventh of the annual runoff of the Mississippi. Ironically, the African continent, not known because of its water abundance, is a net exporter of water to the other continents, particularly to Europe. This can be seen in Figure 2, which shows average virtual water balances over the period 1997–2001 at the level of the 13 world regions. The figure shows the biggest virtual water flows between the different regions insofar as they are related to trade in agricultural products.

Dependence on external water resources

From a water resources point of view one might expect a positive relationship between water scarcity and water import dependency, particularly in the ranges of high water scarcity. Water scarcity is defined here as the country's water footprint – the total water volume needed to produce the goods and services consumed by the people in the country – divided by the country's total renewable water resources (Chapagain and Hoekstra 2004). Water import dependency is defined as the ratio of the external water footprint of a country

Table 2. Virtual water flows for a few selected countries, 1997–2001.

	Gross virtual water flows ($10^6 m^3/yr$)								Net virtual water import ($10^6 m^3/yr$)			
	Related to the trade in crop products		Related to the trade in livestock products		Related to the trade in industrial products		Total		Related to trade in crop products	Related to trade in livestock products	Related to trade in industrial products	Total
	Export	Import	Export	Import	Export	Import	Export	Import				
Argentina	45,952	3,100	4,178	811	499	1,732	50,629	5,643	–42,853	–3,367	1,233	–44,987
Australia	46,120	3,864	26,377	745	501	4,399	72,998	9,007	–42,256	–25,633	3,898	–63,991
Bangladesh	771	3,670	652	86	162	415	1,585	4,171	2,899	–566	254	2,586
Brazil	53,713	17,467	11,911	1,907	2,211	3,694	67,835	23,068	–36,246	–10,003	1,483	–44,767
Canada	48,321	16,190	17,424	4,952	29,573	14,289	95,318	35,430	–32,132	–12,472	–15,284	–59,888
China	17,429	36,260	5,640	15,247	49,909	11,632	72,978	63,139	18,831	9,608	–38,277	–9,839
Egypt	1,755	11,445	221	1,466	729	711	2,705	13,622	9,690	1,245	–18	10,917
France	43,410	40,577	13,222	11,829	21,873	19,761	78,505	72,166	–2,833	–1,393	–2,112	–6,338
Germany	27,630	59,751	17,432	16,062	25,416	29,757	70,478	105,570	32,121	–1,370	4,341	35,092
India	32,411	13,941	3,406	343	6,748	2,945	42,565	17,228	–18,470	–3,063	–3,803	–25,337
Indonesia	24,750	26,917	371	1,666	310	1,822	25,430	30,405	2,167	1,296	1,512	4,975
Italy	12,920	47,164	14,912	28,295	10,402	13,498	38,234	88,957	34,244	13,383	3,096	50,723
Japan	954	59,015	955	20,328	4,605	18,883	6,513	98,227	58,061	19,374	14,279	91,714
Jordan	97	4,103	165	462	25	228	287	4,794	4,006	297	203	4,506
Korea Rep.	997	24,801	3,930	6,097	2,219	8,344	7,146	39,242	23,804	2,166	6,126	32,096
Mexico	11,784	26,956	5,757	13,418	3,790	9,710	21,331	50,084	15,173	7,661	5,920	28,754
Netherlands	34,529	48,607	15,146	7,852	7,885	12,293	57,561	68,753	14,078	–7,294	4,408	11,192
Pakistan	7,381	8,879	612	98	1,526	579	9,518	9,555	1,498	–514	–947	37
Russia	8,297	30,925	2,503	12,243	36,932	2,899	47,732	46,067	22,627	9,740	–34,032	–1,665
South Africa	6,326	7,752	1,312	1,019	912	1,924	8,550	10,695	1,426	–293	1,011	2,145
Spain	18,252	30,483	8,541	5,972	3,753	8,520	30,545	44,975	12,231	–2,569	4,767	14,430
Thailand	38,429	9,761	2,856	1,761	1,655	3,596	42,940	15,117	–28,668	–1,096	1,941	–27,823
United Kingdom	8,773	33,742	3,786	10,163	5,113	20,321	17,672	64,226	24,968	6,378	15,208	46,554
USA	134,623	73,129	35,484	32,919	59,195	69,763	229,303	175,811	–61,495	–2,564	10,568	–53,491

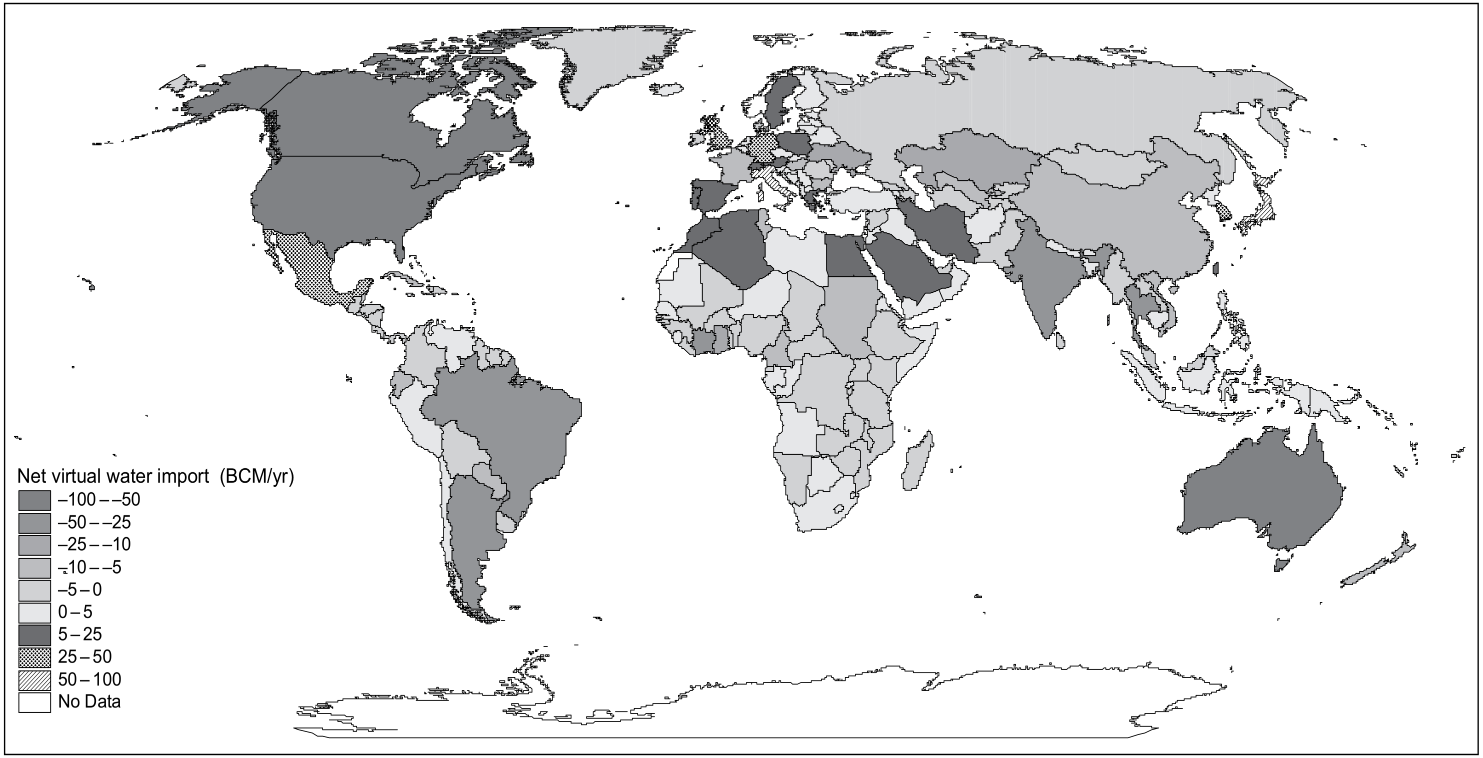

Figure 1. Virtual water balance per country over the period 1997–2001.

Table 3. Average annual gross virtual water flows between world regions related to the international trade in agricultural products in the period 1997–2001 (BCM/yr). The grey-shaded cells show the international virtual water flows within a region.

Exporter \ Importer	Central Africa	Central America	Central and South Asia	Eastern Europe	Former Soviet Union	Middle East	Northt Africa	North America	Oceania	South America	South-east Asia	Southern Africa	Western Europe	Total gross export
Central Africa	0.80	0.07	1.73	1.29	0.03	0.26	0.96	0.90	0.06	0.05	1.19	0.17	16.45	23
Central America	0.08	3.13	3.88	0.65	6.14	0.38	0.75	23.98	0.06	0.58	0.23	0.03	10.67	47
Central and South Asia	1.29	0.81	31.53	1.21	4.08	6.67	3.86	4.44	0.37	0.61	16.90	1.37	9.80	51
Eastern Europe	0.01	0.08	0.69	10.77	4.80	2.65	1.08	0.55	0.08	0.10	0.19	0.03	14.15	24
Former Soviet Union	0.01	0.07	3.06	4.47	16.67	5.38	1.26	0.05	0.00	0.30	0.41	0.00	10.54	26
Middle East	0.24	0.11	2.73	0.84	1.46	8.45	3.43	1.01	0.13	0.17	1.86	0.05	6.91	20
North Africa	0.10	0.24	7.09	6.15	2.11	4.32	5.87	8.37	0.17	2.29	3.49	0.52	63.22	98
North America	0.46	40.65	80.18	1.71	2.43	11.22	11.38	35.10	0.96	11.51	13.72	0.79	25.57	201
Oceania	0.34	1.24	29.32	0.33	0.33	6.22	2.13	11.33	12.63	0.67	14.64	1.11	7.76	75
South America	0.39	3.06	19.82	4.23	4.46	8.92	5.08	19.65	0.37	28.09	4.63	1.93	54.44	127
South-east Asia	1.96	0.50	35.57	2.43	1.52	7.75	8.00	10.89	2.49	0.93	26.87	2.54	18.14	93
Southern Africa	1.04	0.06	2.12	0.38	0.19	0.53	0.54	1.12	0.05	0.17	2.41	2.59	7.21	16
Western Europe	1.40	2.60	15.45	18.87	10.56	12.28	14.26	9.79	0.91	2.45	2.61	1.82	183.51	93
Total gross import	7	50	202	43	38	67	53	92	6	20	62	10	245	895

Figure 2. Regional virtual water balances and net interregional virtual water flows related to the trade in agricultural products, 1997–2001. Only the biggest net flows (>10 BCM/yr) are shown.

to its total water footprint. The external water footprint of a country refers to the use of water resources in other countries to produce commodities imported into and consumed within the country. Figure 3 shows that the relation between water scarcity and water import dependency is not as straightforward as one would expect, although indeed a number of countries – e.g. Kuwait, Qatar, Saudi Arabia, Bahrain, Jordan, Israel, Oman and Lebanon – combine very high water scarcity with very high water import dependency. The water footprints of these countries have largely been externalized.

The reason that the overall picture is more diffuse than one would expect from a water resources point of view, is that under the current trade regime water is seldom the dominant factor determining international trade in water-intensive commodities. The relative availability of other input factors – notably land and labour – play a role as well, and also existing national policies, export subsidies and international trade barriers.

Various countries have high water scarcity but low water import dependency. There are different explanatory factors. Yemen, known for overdrawing their limited groundwater resources, for instance has a low water import dependency for the simple reason that they do not have the foreign currency to import water-intensive commodities in order to save domestic water resources. Egypt on the other hand combines high water scarcity and low water import dependency intentionally, aiming at consuming the Nile water to achieve food self-sufficiency.

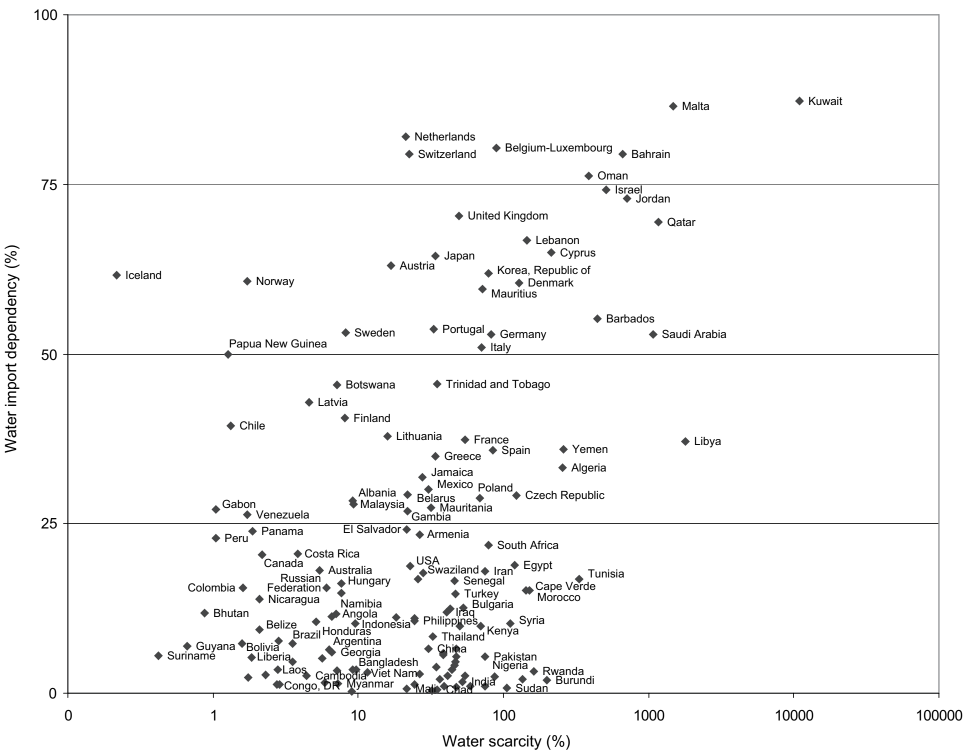

Figure 3. Water scarcity versus water import dependency per country. Water scarcity is defined as the ratio of the total national water footprint to the country's total renewable water resources. The water import dependency is defined as the ratio of the external water footprint to the total water footprint of a country.

The water scarcity and use of external water resources for some selected countries are presented in Table 4. India has a very high national self-sufficiency ratio (98%), which implies that at present India is only a little dependent on the import of virtual water from other countries to meet its national demands. The same is true for the people of China, who have a self-sufficiency ratio of 93%. However, India and China have relatively low water footprints per capita (India 980 m^3/cap/yr and China 702 m^3/cap/yr). If the consumption pattern in these countries changes to that like in the US or some Western European countries, they will be facing a severe water scarcity in the future and probably be unable to sustain their high degree of water self-sufficiency.

Discussion

International water dependencies are substantial and are likely to increase with continued global trade liberalization. The study shows that, today, 16% of global water use is not for producing products for domestic consumption but for making products for export. Assuming that, on average, agricultural production for export does not significantly cause more or less water-related problems (such as water depletion or pollution) than production for domestic consumption, this means that one sixth of the water problems in the world can be traced back to production for export. Considering this substantial percentage and the upward trend, we suggest that future national and regional water policy studies should include an analysis of international or interregional virtual water flows.

Globalization of freshwater brings both risks and opportunities. The largest risk is that the indirect effects of consumption are externalized to other countries. While water in agriculture is still priced far below its real cost in most countries, an increasing volume of water is used for processing export products. The costs associated with water use in the exporting country are not included in the price of the products consumed in the importing country. Consumers are generally not aware of and do not pay for the water problems in the overseas countries where their goods are being produced. According to economic theory, a precondition for trade to be efficient and fair is that consumers bear the full cost of production and impacts.

Another risk is that many countries increasingly depend on the import of water-intensive commodities from other countries. Already today, Jordan annually imports a virtual water volume that is five times its own annually renewable water resources. Although saving their own domestic water resources, it increases Jordan's dependency on other nations. Other countries in the same region, such as Kuwait, Qatar, Bahrain, Oman and Israel, but also European countries like the UK, Belgium, the Netherlands, Germany, Switzerland, Denmark, Italy and Malta, have a similar high water import dependency.

An opportunity of reduced trade barriers is that virtual water can be regarded as an alternative source of water. Virtual water import can be used by national governments as a tool to release the pressure on their domestic water resources. In an open world economy, according to international trade theory, the people of a nation will seek profit by trading products that are produced with resources that are (relatively) abundantly available within the country for products that need resources that are (relatively) scarcely available. People in countries where water is a comparatively scarce resource, could thus aim at importing products that require a lot of water in their production (water-intensive products) and exporting products or services that require less water (water-extensive products). This import of virtual water (as opposed to import of real water, which is generally too expensive) will relieve the pressure on the nation's own water resources. For water-abundant countries an argumentation can be made for export of virtual water.

Table 4. Water scarcity and water import dependency for some selected countries, 1997–2001.

Country	Total renewable water resources[1] (BCM/year)	Internal water footprint[2] (BCM/year)	External water footprint[2] (BCM/year)	Total water footprint[2] (BCM/year)	Water scarcity[3] (%)	Water self-sufficiency[4] (%)	Water import dependency[5] (%)
Argentina	814	48	3	52	6	94	6
Australia	492	22	5	27	5	82	18
Bangladesh	1,211	112	4	117	10	97	3
Brazil	8,233	216	18	234	3	92	8
Canada	2,902	50	13	63	2	80	20
China	2,897	826	57	883	30	93	7
Egypt	58	56	13	70	119	81	19
France	204	69	41	110	54	63	37
Germany	154	60	67	127	82	47	53
India	1,897	971	16	987	52	98	2
Indonesia	2,838	242	28	270	10	90	10
Italy	191	66	69	135	70	49	51
Japan	430	52	94	146	34	36	64
Jordan	0.9	1.7	4.6	6.3	713	27	73
Korea Rep.	70	21	34	55	79	38	62
Mexico	457	98	42	140	31	70	30
Netherlands	91	4	16	19	21	18	82
Pakistan	223	157	9	166	75	95	5
Russia	4,507	229	42	271	6	84	16
South Africa	50	31	9	40	79	78	22
Spain	112	60	34	94	84	64	36
Thailand	410	123	11	135	33	92	8
United Kingdom	147	22	51	73	50	30	70
USA	3,069	566	130	696	23	81	19

Notes: [1]Total renewable water resources as defined and given by FAO (2003).
[2]The water footprint of a nation is defined as the total amount of water that is used to produce the goods and services consumed by the inhabitants of the nation. The total water footprint of a country includes two components: the part of the footprint that falls inside the country (internal water footprint) and the part of the footprint that presses on other countries in the world (external water footprint). Definitions and data from Chapagain and Hoekstra (2004) and Hoekstra and Chapagain (2007).
[3]Defined as the national water footprint divided by the country's total renewable water resources.
[4]Defined as the ratio of the internal water footprint to the total water footprint of a country.
[5]Defined as the ratio of the external water footprint to the total water footprint of a country.

Finally, global virtual water trade can physically save water if products are traded from countries with high to countries with low water productivity. For example, Mexico imports wheat, maize and sorghum from the US, which requires 7.1 BCM of water per year in the US. If Mexico would produce the imported crops domestically, it would require 15.6 BCM of water per year. Thus, from a global perspective, the trade in cereals from the US to Mexico saves 8.5 BCM/yr. Although there are also examples where water-intensive commodities flow in the other direction, from countries with low to countries with high water productivity, Oki and Kanae (2004), De Fraiture *et al*. (2004), Chapagain *et al.* (2006a) and Yang *et al.* (2006) have shown that the resultant of all international trade flows works into the positive direction.

We would like to emphasize that in this paper we have quantified the international virtual water flows in the world as they are, but not *explained* them. We do not suggest that all countries that have net import of water in virtual form have so *because* they intend to save domestic water resources. The argument is rather that trade flows as they are result in international virtual water transfers. By importing virtual water the importing countries save domestic water resources, but this does not imply that the idea of water saving was necessarily the driving force behind the virtual water imports. International trade in agricultural commodities depends on a lot more factors than water, such as availability of land, labour, knowledge and capital, competitiveness (comparative advantage) in certain types of production, domestic subsidies, export subsidies and import taxes. As a consequence, international virtual water trade can most times not at all or only partly be explained on the basis of relative water abundances or shortages (De Fraiture *et al.* 2004, Wichelns 2004). Yang *et al.* (2003) demonstrated however that below a certain threshold in water availability, a relationship can be established between a country's cereal import and its per capita renewable water resources.

The results show that the current global trade pattern significantly influences water use in most countries of the world, either by reducing domestic water use or by enhancing it. We therefore recommend that future water policy studies at national level include an assessment of the effects of trade on water policy. The study shows that for water-scarce countries, it would also be wise to do the reverse: studying the possible implications of national water scarcity on trade. Finally, by showing virtual water flows, the study visualizes the connection between consumption in one place and water use for production in another place. When consumption of a certain good in one country relates to problems of water depletion or pollution in another country, as we show for instance for European cotton consumers and the desiccation of the Aral Sea (Chapagain *et al.* 2006b), this is an interesting starting point for an analysis of responsibilities and mechanisms that could possibly mitigate the environmental problem.

References

Allan, J.A., 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. *In: Priorities for water resources allocation and management*. London: ODA, 13–26.

Allan, J.A., 1994. Overall perspectives on countries and regions. *In:* P. Rogers and P. Lydon, eds. *Water in the Arab world: perspectives and prognoses*. Cambridge, Massachusetts: Harvard University Press, 65–100.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration – guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper 56*. Rome, Italy: FAO.

Chapagain, A.K. and Hoekstra, A.Y., 2003. Virtual water flows between nations in relation to trade in livestock and livestock products. *Value of Water Research Report Series No. 13.* Delft, the Netherlands: UNESCO-IHE.

Chapagain, A.K. and Hoekstra, A.Y., 2004. Water footprints of nations, *Value of Water Research Report Series No. 16*. Delft, the Netherlands: UNESCO-IHE.

Chapagain, A.K., Hoekstra A.Y. and Savenije, H.H.G., 2006a. Water saving through international trade of agricultural products. *Hydrology and Earth System Sciences,* 10 (3), 455–468.

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G. and Gautam, R., 2006b. The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. *Ecological Economics*, 60 (1), 186–203.

De Fraiture, C., Cai, X., Amarasinghe,U. Rosegrant, M. and Molden, D., 2004. Does international cereal trade save water? The impact of virtual water trade on global water use, *Comprehensive Assessment Research Report 4*. Colombo: IWMI.

FAO, 2003. *AQUASTAT 2002*. Rome, Italy: Food and Agriculture Organization.

Haddadin, M.J., 2003. Exogenous water: A conduit to globalization of water resources. *In:* A.Y. Hoekstra, ed. *Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade.* Value of Water Research Report Series No. 12, Delft, the Netherlands: UNESCO-IHE, 159–169.

Hoekstra, A.Y. and Hung, P.Q., 2002. Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade. *Value of Water Research Report Series No.11*. Delft, the Netherlands: UNESCO-IHE.

Hoekstra, A.Y. and Hung, P.Q., 2005. Globalisation of water resources: International virtual water flows in relation to crop trade. *Global Environmental Change*, 15 (1), 45–56.

Hoekstra, A.Y. and Chapagain, A.K., 2007. Water footprints of nations: water use by people as a function of their consumption pattern. *Water Resources Management*, 21 (1), 35–48.

ITC, 2004. *PC-TAS version 1997–2001*. [CD-ROM]. International Trade Centre, Geneva.

Oki, T. and Kanae, S., 2004. Virtual water trade and world water resources. *Water Science and Technology* 49 (7), 203–209.

Postel, S.L., Daily, G.C. and Ehrlich, P.R., 1996. Human appropriation of renewable fresh water. *Science*, 271, 785–788.

Vörösmarty, C.J., Green, P., Salisbury, J. and Lammers, R.B., 2000. Global water resources: Vulnerability from climate change and population growth. *Science*, 289, 284–288.

Wichelns, D., 2004. The policy relevance of virtual water can be enhanced by considering comparative advantages. *Agricultural Water Management,* 66, 49–63.

World Bank, 2004. *World development indicator data-query*. Washington, D.C.: The World Bank Group.

World Trade Organization (WTO), 2004. *Statistical database*. Geneva, Switzerland.

Yang, H. and Zehnder, A.J.B., 2002. Water scarcity and food import: A case study for Southern Mediterranean countries. *World Development,* 30 (8), 1413–1430.

Yang, H., Reichert, P., Abbaspour, K.C. and Zehnder, A.J.B., 2003. A water resources threshold and its implications for food security. *In:* A.Y. Hoekstra, ed. *Virtual water trade: proceedings of the International Expert Meeting on Virtual Water Trade*, Value of Water Research Report Series No. 12. Delft, the Netherlands: UNESCO-IHE, 111–117.

Yang, H., Wang, L., Abbaspour, K.C. and Zehnder, A.J.B., 2006. Virtual water trade: an assessment of water use efficiency in the international food trade. *Hydrology and Earth System Sciences*, 10 (3), 443–454.

Zimmer, D. and Renault, D., 2003. Virtual water in food production and global trade: Review of methodological issues and preliminary results. *In:* A.Y. Hoekstra, ed. *Virtual water trade: proceedings of the International Expert Meeting on Virtual Water Trade*, Value of Water Research Report Series No. 12. Delft, the Netherlands: UNESCO-IHE, 93–109.