CHAPTER 2

Global agricultural green and blue water consumptive uses and virtual water trade

Junguo Liu
School of Nature Conservation, Beijing Forestry University, Beijing, China

Hong Yang
Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland

ABSTRACT: An accurate estimate of global water uses with high spatial resolution is crucial for assessing global water scarcity and for understanding human's interference with the ecosystems. As agricultural production is the single largest water user in most of the areas of the world, it is especially important to have a spatially explicit assessment of both green and blue water uses in agriculture and virtual water flows associated with international food trade. In this chapter, we estimated consumptive water use (CWU) in cropland on a global scale with a spatial resolution of 30 arc-minutes. A GIS-based version of the EPIC model, GEPIC, is used for the estimation. The results show that in crop growing periods, global CWU was 5,938 km^3/yr in cropland around the year 2000, of which green water contributed to 84%. On an annual basis, global CWU was 7,323 km^3/yr in cropland, of which green water contributed to 87%. Almost 95% of the world crop related virtual water trade has its origin in green water. High levels of net virtual water import (NVWI) generally occur in countries with low CWU on a per capita basis. A virtual water trade strategy could be an attractive water management option to compensate for domestic water shortage for food production for these countries. However, NVWI is constrained by income. Low-income countries generally have a low level of NVWI. Strengthening low-income countries economically will allow them to develop a virtual water trade strategy to mitigate malnutrition of their people.

Keywords: water scarcity, consumptive water use, virtual water trade, GEPIC

1 INTRODUCTION

Agriculture is the single largest water user amongst all the economic sectors in most of the countries in the world. There is an intrinsic linkage between water availability, food production and food trade. The virtual water concept, emerged in the mid 1990s, specifically addresses this linkage from the perspective of food trade as a means of redistributing global water resources and as a possible policy option in managing local water resources, particularly in water scarce countries and regions (Allan, 1994). This study takes a green and blue water perspective in the investigation of water-food-trade relations across different geographical regions and on a high spatial resolution with a global coverage.

The concept of green water was first introduced by Falkenmark (1995), referring to the total crop evaporation during crop growth. Later, green water resource has been generally used to refer to the water that comes from precipitation, is stored in the soil, and subsequently released to the atmosphere through crop evaporation. In contrast, blue water refers to the water in rivers, lakes, reservoirs, ponds and aquifers. Both green and blue water resources are important for food production. Rainfed agriculture uses green water only, while irrigated agriculture uses both green and blue water.

In many water scarce countries, an increasing amount of food is imported to meet domestic food demand (Yang *et al.*, 2006). For these countries, importing food is equivalent to importing virtual water to mitigate the physical lack of water for domestic food production. With population growth and economic development, water resources are under pressure in an increasing number of countries. Unravelling the relationship between a country's consumptive water use (CWU) in crop production and virtual water trade can improve the understanding of water-food-trade relationship, and help formulate appropriate policies to deal with water scarcity.

In this study, we quantify CWU in crop production and investigate CWU–virtual water trade relations. CWU at the global level is assessed with a spatial resolution of 30 arc-minutes (about 50 km × 50 km in each grid near the equator). Special attention is given to the green water component of CWU for the production of 22 major crops. Virtual water trade is quantified for each crop and is summed up as a common yardstick in investigating CWU–virtual water trade relations. The green water proportion in both domestic crop production and virtual water trade is calculated, and the virtual water trade and CWU for low-, middle- and high-income countries are examined.

2 CALCULATION OF CROP YIELD, EVAPORATION AND CROP WATER PRODUCTIVITY

2.1 *Methodology*

A GEPIC model is used to simulate crop yield, CWU (defined as evapotransporation, ET, in this study), and crop water productivity (CWP) for individual crops in each grid cell at the spatial resolution of 30 arc-minutes covering the entire world. The GEPIC model is a GIS-based EPIC model designed to simulate the spatial and temporal dynamics of the major processes of the soil-crop-atmosphere-management system (Liu *et al.*, 2007a; Liu *et al.*, 2007b; Liu *et al.*, 2008). CWU in a country is calculated as the sum of the CWU of all grid cells within this country. CWP is calculated as the ratio of crop yield to ET.

In this study, CWU refers to the total amount of water consumed by crops in terms of evapotranspiration. In each grid cell, CWU is calculated as:

$$CWU = CWU_r + CWU_i \tag{1}$$

$$CWU_r = \sum_c CWU_r^c = 10 \times \sum_c (ET_r^c \times A_r^c) \tag{2}$$

$$CWU_i = \sum_c CWU_i^c = 10 \times \sum_c (ET_i^c \times A_i^c) \tag{3}$$

Where *CWU* is consumptive water use in m^3/yr in one grid cell, subscript *r* and *i* refer to rainfed and irrigated agricultural systems, respectively. The subscript *c* represents the crop code. *ET* is evapotranspiration of crop *c* under rainfed conditions (*r*) or irrigated conditions (*i*) in mm/yr, while *A* is area of crop *c* under rainfed or irrigated conditions in ha. The constant 10 converts mm into m^3/ha.

For rainfed crops, CWU_r is all from green water. For irrigated crops, CWU_i is partly from green water and partly from blue water. In order to estimate the proportion of green and blue water uses in irrigated agriculture, two different soil water balances are performed for irrigated crops according to FAO (2005).

1) Soil water balance I is carried out by assuming that the soil does not receive any irrigation water. Seasonal evapotranspiration computed using this soil water balance is referred to as *SET1*.
2) Soil water balance II is carried out by assuming the soil receives irrigation water. Seasonal evapotranspiration computed using this soil water balance is referred to as *SET2*.

For a specific crop under irrigated conditions, according to FAO (2005), green water use is equal to *SET1*, while blue water use is equal to the difference between *SET2* and *SET1*, or *SET2-SET1* in crop growing periods. Hence, for a specific crop under irrigated conditions, the proportion of blue water in crop growing periods is calculated as (Liu *et al.*, 2009; Liu & Yang, 2010):

$$b_i^c = \frac{SET2^c - SET1^c}{SET2^c} \tag{4}$$

Where b is the blue water proportion of crop c under irrigated conditions i.

In a grid cell, consumptive blue water use ($CBWU$) for all crops can be estimated as:

$$CBWU = \sum_c (b_i^c \times CWU_i^c) \tag{5}$$

The blue water proportion (B) and green water proportion (G) in each grid cell are calculated as follows:

$$B = \frac{CBWU}{CWU} \tag{6}$$

$$G = 1 - B \tag{7}$$

With *Eq. 6*, blue water proportion in both crop growing periods and in the entire year is calculated. It is assumed that irrigation is not applied in non-growing periods. Hence, $CBWU$ remains the same for the crop growing periods and the entire year. CWU during the growing periods differs from that during the entire year, leading to different blue water proportion in the two calculations.

2.2 *High-resolution data of harvested area*

In this study, 22 crop categories in rainfed and irrigated areas are considered (Table 1). The four crop types ("citrus", "date palm", "grapes/vine", and "others perennial") are combined into one category "fruits". Grape is the most planted fruit in terms of harvested area (FAO, 2006); hence, it is used as a representative crop for the simulation of fruits by the GEPIC model. Similarly, tomato is the most planted vegetable in terms of harvested area (FAO, 2006), and it is selected as a representative crop type for the simulation of vegetables. Fruits and vegetables only account for 3.7% and 3.4% of the total cropland (Ramankutty *et al.*, 2008). They account for 6.0% and 6.4% of the total irrigated cropland. Hence, the use of representative crops will not significantly affect the simulation results of CWU. For the assessment of virtual water trade, data for trade quantities of some minor crops are not always available for the period the study covers. Hence, only 17 most important crops (marked with * in Table 1) are considered in the calculation of virtual water trade.

Two data sources are used in this study for the harvest area of crops. One source is the Center for Sustainability and the Global Environment (SAGE) of the University of Wisconsin at Madison, USA (Ramankutty *et al.*, 2008). The SAGE dataset provides harvested area of 175 primary crops in the year 2000 with spatial resolutions of 30 arc-minutes. In this dataset, the harvested area is the sum of the rainfed and irrigated crop area. Another source is the Institute of Physical Geography of the University of Frankfurt (Main), Germany (hereafter referred to as "MIRCA2000 dataset"). The MIRCA2000 dataset provides harvested area of 26 irrigated crops around 2000 with a spatial resolution of 30 arc-minutes (Portmann *et al.*, 2008). The harvested area of these irrigated crops are calculated mainly based on the SAGE harvested area data and the global map of irrigated areas (Siebert *et al.*, 2007). The harvested area (rainfed plus irrigated) of the 26 crops is also integrated from the SAGE dataset by Portmann *et al.* (2008). For these crops, the harvested area of a rainfed crop is assumed to be the difference between the harvested area and the irrigated harvested area of the corresponding crop in each grid cell. In case that the irrigated harvested area is higher than the total harvested area, we assume there is no rainfed harvested area for the corresponding crop.

Table 1. The 22 crop categories used in this study.

Crop category in this study	Corresponding crop category in MIRCA 2000	Representative crop for simulation	Potential heat unit (°C)
Wheat*	Wheat	Wheat	1,750
Maize*	Maize	Maize	1,000
Rice*	Rice	Rice	1,500
Barley*	Barley	Barley	1,000
Rye*	Rye	Rye	1,750
Millet*	Millet	Millet	1,500
Sorghum*	Sorghum	Sorghum	1,500
Soybeans*	Soybeans	Soybean	1,800
Sunflower*	Sunflower	Sunflower	1,500
Potatoes*	Potatoes	Potato	1,500
Cassava*	Cassava	Cassava	1,500
Sugar cane*	Sugar cane	Sugar cane	1,500
Sugar beets*	Sugar beets	Sugar beet	1,500
Oil palm	Oil palm	–	–
Rapeseed/canola*	Rapeseed/canola	Rapeseed	1,500
Groundnuts/peanuts*	Groundnuts/peanuts	Groundnut	1,500
Cotton*	Cotton	Cotton	1,500
Pulses*	Pulses	Peas	1,600
Coffee and cocoa	Coffee, cocoa	Coffee	1,700
Fruits	Citrus, date palm, grapes/vine, others perennial	Grape	2,223
Vegetables	Others annual	Tomato	1,700
Managed grassland/pasture	Managed grassland/pasture	Pasture	2,000

* The 17 major crops

3 CWU AND GREEN WATER PROPORTION

3.1 *CWU of crops*

Spatial patterns of CWU during the growing period are demonstrated in Figure 1a. The global CWU in crop growing periods was 5,938 km^3/yr in cropland around the year 2000 (the average of the years 1998–2002). The highest CWU per grid cell (e.g. > 400 Mm^3/yr) was found in most part of India, Eastern part of China, some countries in Southeast Asia such as Indonesia, Mid Central of the USA, part of Argentina and Brazil, and very few countries in Africa (e.g. Nigeria, Ghana, and Ivory Coast). These regions represent the most intensive agricultural production area in the world. In Europe, CWU in most grid cells is between 300 and 400 Mm^3/yr. In other parts of the world, CWU was generally lower than 100 Mm^3/yr.

Spatial pattern of annual CWU in the entire year is similar to that of CWU in the crop growing periods (Figure 1b). The highest CWU per grid cell (e.g. >300 Mm^3/yr) was found in most part of India, in the river basins of the Yellow River, the Huai River, the Hai River, and the Yangtze in China, in the Mississippi river basin in North America, and some part of the Parana and Sao Francisco river basins in South America. These regions mainly contained grid cells with high fraction of arable lands and permanent crops. At the global level, CWU was 7,323 km^3/yr in cropland around the year 2000. This means that 81% of the annual CWU was used in the crop growing periods, while the remaining 19% occurred in the non-growing periods. At the river basin level, Mississippi, Yangtze, Ganges and Nile are the four river basins with the highest CWU both during the growing periods and for the entire year (Table 2). These four river basins account for around 20% of the global CWU.

Of the global CWU of 5,938 km^3/yr, over two thirds can be attributed to cereal crops. Wheat and rice account for two thirds of the CWU of cereal crops.

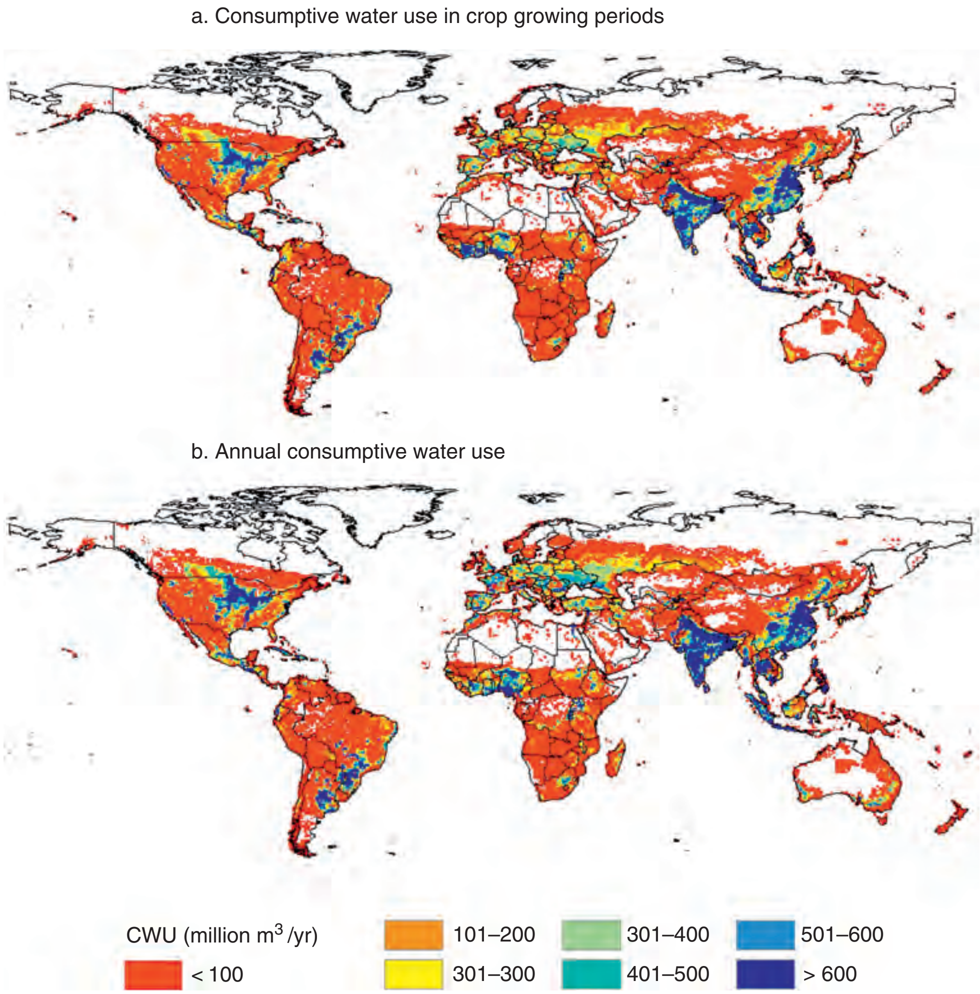

Figure 1. Spatial distribution of consumptive water use (CWU) for crop production per grid cell of 30 arc-minutes (average over 1998–2002).

There have been several estimates of global CWU in the literature. These estimates range from around 3,500 km^3/yr (Zehnder, 1997) to 7,400 km^3/yr (Postel *et al*., 1996), depending on the land types and the methods used for the estimation. Postel *et al*. (1996) provided a CWU value of 7,370 km^3/yr in cultivated land in 1990. Cultivated land area refers to arable land and land under permanent crops. Cultivated land area is almost equal to cropland area; hence, the above estimate can be regarded as CWU for cropland. The estimation by Postel *et al*. (1996) is very rough with several strong assumptions. Rockström *et al*. (1999) calculated global CWU at 6,800 km^3/yr for the period 1992–1996 by using crop production and crop water productivity of 18 crop groups, with differentiation of tropical and temperate climate zones. Crop water productivity of various crop groups was based on extensive literature review. Chapagain & Hoekstra (2004) calculated the global CWU as 6,390 km^3/yr for 164 crops based on national average crop production and national average crop water productivity (CWP) for the period 1997–2001. This estimate considered crop production and crop water productivity in individual countries, but it did not take into account the variations within a country.

Table 2. Consumptive water use and blue water proportion in major river basins (average over 1998–2002).

Name of river basin	Annual consumptive water use (km^3/yr)	Consumptive water use in crop growing periods (km^3/yr)	Consumptive blue water use (km^3/yr)	Blue water proportion in the entire year (%)	Blue water proportion in crop growing periods (%)
Mississippi	538.3	445.6	58.4	10.8	13.1
Yangtze	441.7	338.5	65.0	14.7	19.2
Ganges	407.0	296.7	57.0	14.0	19.2
Nile	144.2	114.1	19.1	13.2	16.7
Danube	104.2	77.8	2.0	1.9	2.6
Yellow	94.7	73.3	24.5	25.9	33.4
Murray–Darling	56.1	37.0	9.3	16.6	25.1
Amazon	55.6	48.8	1.4	2.5	2.8
Orange	25.4	19.5	1.4	5.3	6.9
Mackenzie	7.2	5.5	0.002	0.0	0.0
Lena	0.24	0.19	0.043	17.9	22.6

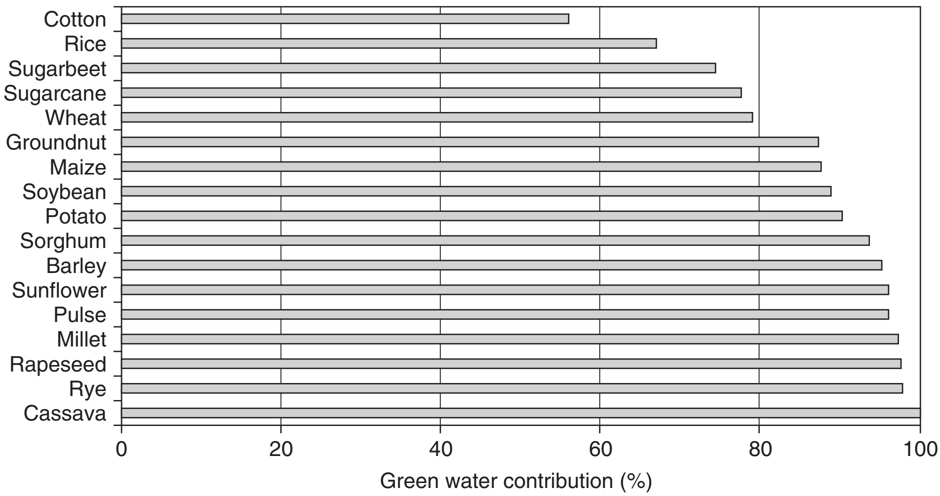

Figure 2. Global average green water portion for individual crops (average over 1998–2002).

3.2 *Green water proportion in CWU*

On global average, green water accounts for 84% of CWU during the crop growing period. For most crops, green water accounts for more than two thirds of the consumptive water use except for cotton (Figure 2). Cotton has the green water proportion of 56%, the lowest among all crops. This portion closes to the value of 48% reported by Chapagain *et al*. (2006). Globally, about 73% of the cotton production is from irrigated fields. The main cotton producers are arid regions such as Egypt, Uzbekistan, Pakistan, and Northwest China. Rice has a green water proportion of 67%, which represents the lowest green water proportion next to cotton. Cassava is a highly drought tolerant crop, and thus is less dependent on irrigation. With almost 100%, it has the highest green water proportion of all crops.

At the national levels, agricultural production greatly depends on green water (Figure 3). In Canada, Brazil, Argentina, many African and European countries, and Australia (90%), no less

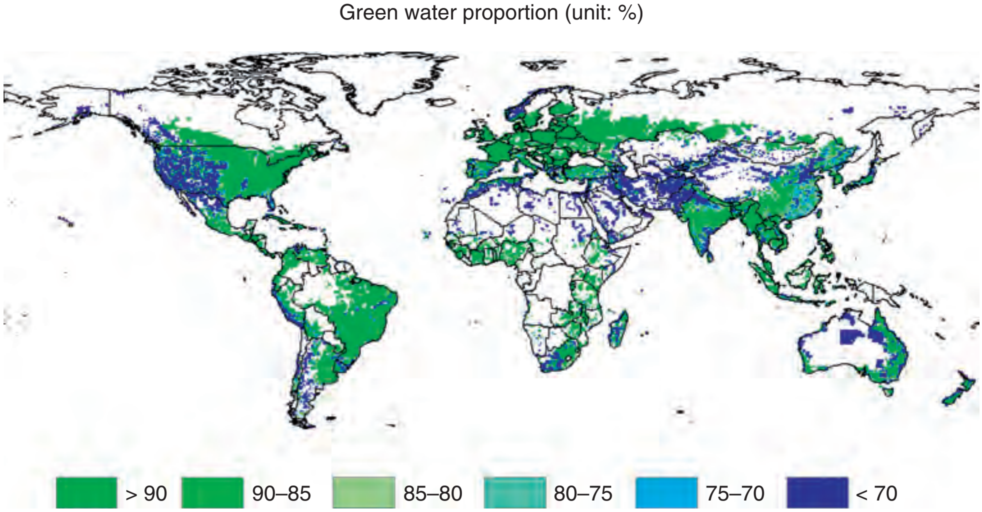

Figure 3. Green water proportion at the grid cell level (average over 1998–2002).

than 90% of CWU has its origin in green water. Arid and warm zones such as many countries in the MENA region show a low green water proportion. About 80% of the MENA region has annual rainfalls of less than 100 mm/yr. The lack of rainfall coupled with high evaporation makes irrigation crucially important for agriculture production.

The consumptive blue water use (CBWU) was 927 km^3/yr in cropland on a global scale around the year 2000 for the 22 crops considered. During crop growing period, blue water accounts for 16% of the global CWU, while green water accounts for 84%. On an annual basis, the figures are 13% and 87% for blue water and green water, respectively. High CBWU (or low CGWU) occurs in Northern and Southern India, Eastern part of China, and the Mid Central of the USA (Figure 3). These regions are the major agricultural production regions in the world, and they also have very high CWU. When irrigation infrastructure exists, these regions often use a large volume of blue water, mainly due to the large agricultural area there. As for the blue water proportion, regions with high values are located in the Northern part of China, several West Asian countries, Middle East and North Africa, the Western part of the USA, and Chile. These regions mostly have arid or semi-arid climate with low precipitation. Precipitation can only meet part of the water required by crops. In order to achieve high crop yields, irrigation water has to be supplied in addition to precipitation. Largely due to the low precipitation, irrigation depth is generally very high, resulting in high blue water proportion.

At the river basin level, the Yellow River, Lena and Murray-Darling river basins had the highest blue water proportion (Table 2). These river basins are located in arid or semi-arid climates with low precipitation. For example, the mean annual rainfall in the Yellow river basin is 452 mm/yr. Meanwhile, this river basin is an important food producing region in China (Yang & Jia, 2008), and almost three fourths of the population lived in rural areas of the basin in 2000. Irrigation is vital to maintain high agricultural productivity, leading to relatively higher blue water proportion compared to other river basins. In contrast, the Mackenzie, Danube and Amazon river basins had the lowest blue water proportions (Table 2).

4 RELATIONS BETWEEN CWU AND VIRTUAL WATER TRADE

The global virtual water export is dominated by few countries. Ten major virtual water exporting countries shown in Figure 4 account for 94% of global total virtual water export. On global average,

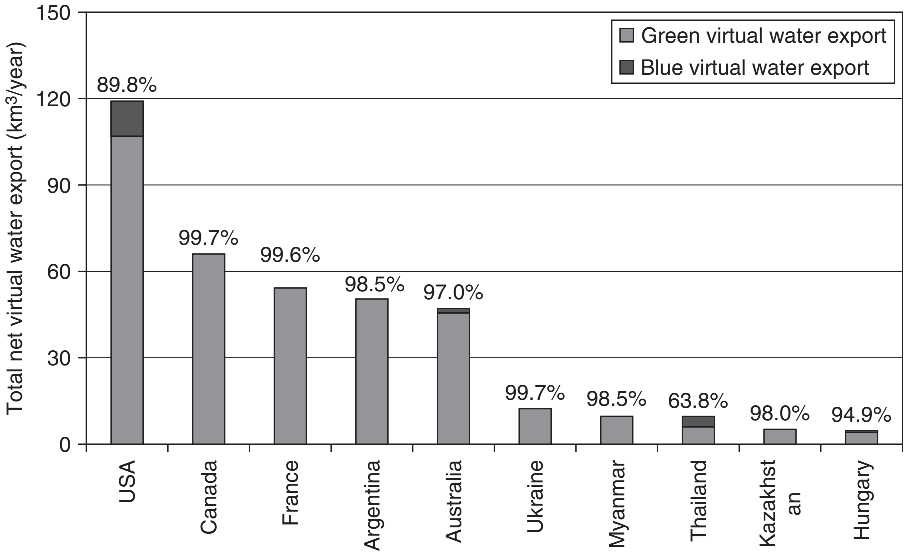

Figure 4. Total net blue and green virtual water export in major exporting countries, and green water proportion in total virtual water export (17 crops, average over 1998–2002). Green water proportions are marked as percentage above individual countries.

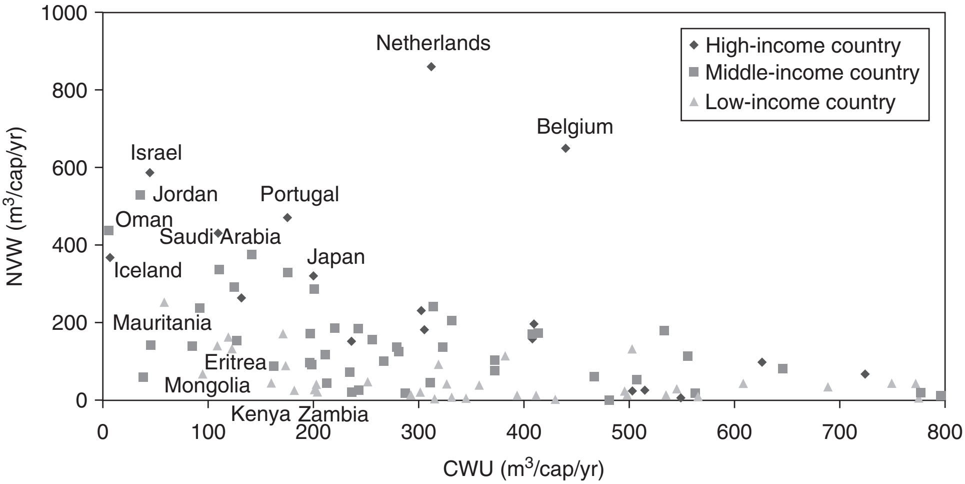

Figure 5. Relationship between net virtual water import (NVWI) and consumptive water use (CWU) in importing countries (17 crops, average over 1998–2002).

green water accounts for almost 95% of the global virtual water export. Hence, the international virtual water trade is dominantly *green*. With its almost 2,500 m^3/yr per capita, Australia is the most important net virtual water exporting country on a per capita basis. It is followed by Canada (2,137) and Argentina (1,372), and France, Paraguay, Hungary, the USA, and Denmark exporting between 350 and 900 m^3/yr per capita.

On the importing side, the Netherlands and Belgium are the two top net virtual water importing countries on a per capita basis. Net virtual water import (NVWI) into the two countries is about

860 and 650 m^3/yr per capita, respectively (Figure 5). Both countries are big meat exporters with over 120 kg/yr per capita, of meat exports. A large amount of imported crop products is used as feed for livestock (FAO, 2006).

Israel and Jordan are the third and fourth biggest importing countries with a NVWI of over 500 m^3/yr per capita. Both countries show a very low CWU of less than 50 m^3/yr per capita. Their NVWI is to compensate for the lack of water, a fact which is seen in all the MENA countries. Besides the 22 crops considered, Israel is importing also substantial amounts of meat and dairy products, which almost doubles the NVWI calculated here (Yang *et al*., 2007).

Countries respond to CWU differently when CWU is below 250 m^3/yr per capita. NVWI is affected by the levels of incomes. High- and middle-income countries generally have larger NVWI than low-income countries with a similar level of CWU (Figure 5). For example, CWU in Japan and Zambia is about 200 m^3/yr per capita. The NVWI in Japan is over 300 m^3/yr per capita, while it is negligible in Zambia. Apparently, the economic situation of a country is decisive to satisfy internal nutritional needs.

For some low-income countries, NVWI remains at a low level even with a low CWU. This means that part of the population is undernourished or obtains their calories from other sources than the 17 major crops considered. For instance, in Eritrea, the sum of CWU and NVWI is 261 m^3/yr per capita. The calorie intakes from animal products and other vegetal foods are also low. In fact, this country is being confronted with serious food security problem and 73% of its population is undernourished.

The countries with large per capita NVWI are mainly located in the regions where poor climatic conditions do not allow large area of agricultural production (as a result, CWU is also low in these countries), e.g. the arid MENA region, and the low-temperature countries, e.g. Northern Europe and Mongolia. Particularly in the MENA countries, the current NVWI already reaches or even exceeds combined green and blue water uses in domestic agriculture. Virtual water imports play a vital role in mitigating the regional water scarcity and in guaranteeing the regional food security. Given the strong agreement among climate models for less precipitation in the future in the MENA region, virtual water trade will become more important for the regional water and food security.

5 CONCLUDING REMARKS

We quantified CWU in cropland in a spatially explicit way by taking into account both green and blue water components. The results show that the global CWU was 5,938 km^3/yr in the crop growing periods and 7,323 km^3/yr in the entire year in cropland around the year 2000. Green water contributed to 84% of the global CWU in the crop growing periods, and 87% of the global CWU on an annual basis. The high proportion of green water was in part due to the dominance of rainfed agriculture, which consumed 4,068 km^3/yr of water in the crop growing periods and 5,105 km^3/yr of water in the entire year. In addition, in irrigated cropland, green water contributed to 50% of the total CWU in the crop growing periods, and over 60% of the annual total CWU.

The important role of green water in crop production gives rise to the need for a better management of this water resource. However, in the past, water engineers and managers have mainly focused on expansion of irrigation infrastructure, particularly in many Asian countries. There is a general lack of green water management. Nowadays, further developing irrigation infrastructure becomes more and more difficult. There is not much potential to build large dams in most countries because water projects have been developed in the most suitable locations. Against this background, improving green water management should be an important option to guarantee world food security in the future.

Around 94% of the world crop-related virtual water trade has its origin in green water, which generally constitutes a low-opportunity cost of green water as opposed to blue water. High levels of net virtual water import (NVWI) generally occur in countries with low CWU on a per capita basis, where a virtual water strategy is an attractive water management option to compensate for domestic water shortage for food production. NVWI is constrained by income; low-income countries generally have a low level of NVWI. Strengthening low-income countries economically will allow them to develop a virtual water strategy to mitigate malnutrition of their people.

REFERENCES

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

Chapagain, A.K. & Hoekstra, A.Y. (2004). *Water footprints of nations*. UNESCO-IHE, Delft, the Netherlands.

Chapagain, A.K.; Hoekstra, A.Y.; Savenije, H.H.G. & Gautam, R. (2006). 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.

Falkenmark, M. (1995). Coping with water scarcity under rapid population growth. Paper presented at Conference of SADC Ministers, Pretoria, South Africa, 23–24 November 1995.

FAO (2005). *Review of agricultural water use per country*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2006). FAOSTAT: FAO statistical databases. Food and Agriculture Organization of the United Nations, Rome, Italy. [Available at http://faostat.fao.org/default.aspx].

Liu, J. & Yang, H. (2010). Spatial explicit assessment of global consumptive water uses in cropland: green and blue water. *Journal of Hydrology*, 384: 187–197.

Liu, J.; Wiberg, D.; Zehnder, A.J.B. & Yang, H. (2007a). Modelling the role of irrigation in winter wheat yield, crop water productivity, and production in China, *Irrigation Science*, 26(1): 21–33.

Liu, J.; Williams, J.R.; Zehnder, A.J.B. & Yang, H. (2007b). GEPIC – modelling wheat yield and crop water productivity with high resolution on a global scale. *Agricultural Systems*, 94(2): 478–493.

Liu, J.; Fritz, S.; van Wesenbeeck, C.F.A.; Fuchs, M.; You, L.; Obersteiner, M. & Yang, H. (2008). A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change, *Global Planetary Change*, 64(3–4): 222–235.

Liu, J.; Zehnder, A.J.B. & Yang, H. (2009). Global consumptive water use for crop production: the importance of green water and virtual water. *Water Resources Research*, 45: W05428

Portmann, F.; Siebert, S.; Bauer, C. & Döll, P. (2008). Global data set of monthly growing areas of 26 irrigated crops, version 1.0. Institute of Physical Geography, University of Frankfurt (Main), Frankfurt, Germany.

Postel, S.L.; Daily, G.C. & Ehrlich, P.R. (1996). Human appropriation of renewable fresh water. Science, 271(5250): 785–788.

Ramankutty, N.; Evan, A.T.; Monfreda, C. & Foley, J.A. (2008). Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. *Global Biogeochemical Cycles*, 22(1).

Rockström, J.; Gordon, L.; Folke, C.; Falkenmark, M. & Engwall, M. (1999). Linkages among water vapor flows, food production, and terrestrial ecosystem services. *Conservation Ecology*, 3(2): 5.

Siebert, S.; Döll, P.; Feick, S.; Frenken, K. & Hoogeveen, J. (2007). Global map of irrigation areas, version 4.0.1. University of Frankfurt, Main, Germany; and FAO, Rome, Italy.

Yang, H. & Jia, S. (2008). Meeting the basin closure of the Yellow river in China. *International Journal of Water Resources Development*, 24(2): 265.

Yang, H.; Wang, L.; Abbaspour, K.C. & Zehnder, A.J.B. (2006). Virtual water trade: an assessment of water use efficiency in the international food trade. *Hydrol Earth Syst Sc*, 10: 443–454.

Yang, H.; Wang, L. & Zehnder, A.J.B. (2007). Water scarcity and food trade in the Southern and Eastern Mediterranean countries. *Food Policy*, 32(5–6): 585–605.

Zehnder, A.J.B. (1997). Water – a commodity in short supply. *Eawag News*, 43: 3–4.