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Coping with water scarcity in Eastern Africa: the potential role of intra-regional virtual water trade

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Abstract Virtual water is the amount of water required for the production of a commodity. Trading commodities implies Virtual Water Trade (VWT). This study was conducted to determine the VWT derived from intra-regional trade of six cereals (maize, paddy rice, millet, sorghum, wheat and barley) for ten countries within Eastern Africa from 1998 to 2003. It involved quantifying the VWT, assessing the role of water scarcity in shaping VWT and determining the quantity and nature of water savings generated. Quantifying the VWT included delineating major crop growing zones and calculating Crop Water Requirement (CWR) using a model, CropWat. Virtual water contents derived from CWR were multiplied with intra-regional cereal trade flows to obtain the VWT. Results show that virtual water contents vary significantly within the region, being higher in the arid countries than the humid countries, partly because of water scarcity in these countries. Virtual water flows for the region averaged 150 Mm^3 $year^{-1}$ of water whilst "water savings" averaged 31 Mm^3 $year^{-1}$. Sudan, Uganda and Tanzania are the only net virtual water exporters, exporting a combined volume of 110 Mm^3 $year^{-1}$, whilst the other seven countries are net importers, the largest importer being Ethiopia. No correlation was found between a nation's water scarcity status and virtual water imports, suggesting that intra-regional cereal-derived VWT is not a conscious choice but arises for other reasons like comparative advantage. Sorghum and maize trade accounted for the largest virtual water flows, 36% and 38%, respectively, the former due to the high unit virtual water content of the major exporting countries and the latter due to the large tonnage traded. In a regional virtual water policy, Kenya, Sudan, Djibouti, Eritrea and Somalia can be potential virtual water importers, whilst Tanzania, Uganda, Rwanda, Burundi and Ethiopia can be potential virtual water exporters. It was concluded that VWT had a big role in water savings in water scarce countries. This has been considered as a change in water resources systems, and hence maintenance in water security and insurance in integrated management.

Key words virtual water trade; water scarcity; water security maintenance

INTRODUCTION

Eastern Africa faces a water scarcity crisis. This crisis is further compounded by the issue of food security and trade. An intimate link exists between water, foodstuffs and trade. Food production is the most water intensive activity in the world, and increasingly more water is required to produce more food to feed an ever-growing population. Even as more water is withdrawn to produce more food, the rate of trade that is occurring among countries is increasing due to the rapid rise of the globalization phenomenon. The concept of virtual water links all three aspects of water, foodstuffs and trade by showing that trade in foodstuffs is actually a trade in virtual water (Turton *et al*., 2002). The implications of this have a direct bearing on Eastern Africa. As the water scarcity problem prevails, globalization in the form of regional integration is increasing trade among individual countries and therefore the intra-regional water trade finds its applicability in coping with the water scarcity. The objectives of the study were to quantify the VWT, assess the role of water scarcity in shaping VWT, and determine the quantity and nature of water savings generated.

METHODOLOGY

Description of study area

Eastern Africa is comprises of 10 countries (Tanzania, Uganda, Kenya, Rwanda, Burundi, Ethiopia, Eritrea, Djibouti, Somalia and Sudan), see Fig. 1.

These countries, located within Eastern Africa, constitute the region called the Great Horn of Africa. Although these countries have a wide range of physical and cultural features, they share some geographical and environmental similarities. More significantly, all have suffered serious crises over the past two decades: widespread hunger and famines, violent conflict, environmental devastation, and severe poverty. As such, they pose major challenges and opportunities for regional cooperation among stakeholders (Thrupp & Megetali, 1999).

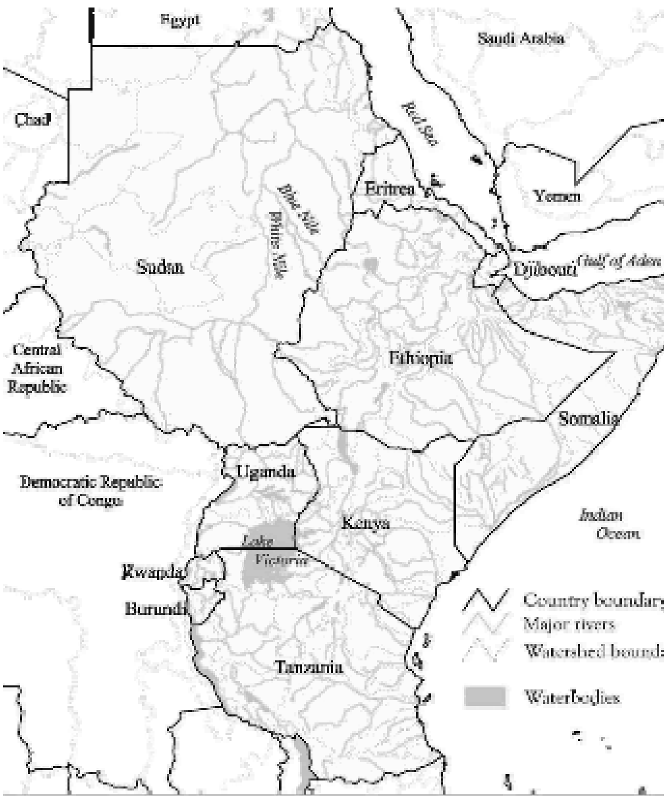

Fig. 1 Map showing the Eastern Africa region.

Quantification of virtual water flows

Prior to quantification of virtual water flows, climate data was combined with the main cropping zones by use of Arc-View GIS. Maps depicting the main cereal growing regions were digitized and thematic maps were produced. The co-ordinates for the climate stations were mapped onto the thematic maps, whereby only the climate stations within the main crop growing zones were used for calculations by CropWat. The first step in quantifying virtual water flows was to determine the specific water requirement for each crop traded for each nation. Specific water demand was calculated separately for each relevant nation on the basis of FAO data on CWR and crop yields:

$$SWD_{(n,c)} = \frac{CWR_{(n,c)}}{CY_{(n,c)}} \tag{1}$$

where *SWD* denotes the specific water demand ($m^3\ t^{-1}$) of crop *c* in country *n*, *CWR* the crop water requirement ($m^3\ ha^{-1}$) and *CY* the crop yield ($t\ ha^{-1}$).

The crop water requirement *CWR* (in $m^3\ ha^{-1}$) was calculated by use of the CropWat model. The next step was to calculate the virtual water contents properly. *VWT* flows between nations were calculated by multiplying international crop trade flows by their associated *SWD* (Specific Water Demand). *VWT* was thus calculated as:

$$VWT_{(ne,\ ni,\ c,\ t)} = CT_{(ne,\ ni,\ c,\ t)} \times SWD_{(ne,\ c)} \tag{2}$$

VWT denotes the *VWT* ($m^3\ year^{-1}$) from exporting country n_e to importing country n_i in year *t* as a result of trade in crop *c*. *CT* represents the crop trade ($t\ year^{-1}$) from exporting country n_e to importing country n_i in year *t* for crop *c*. *SWD* represents the specific water demand ($m^3\ t^{-1}$) of crop *c* in the exporting country.

The gross virtual water import to a country n_i is the sum of all imports:

$$GVWI_{(ni,\ t)} = \sum_{ni,\ c} VWT_{(ni,\ ne,\ c,\ t)} \tag{3}$$

The gross virtual water export by a country n_e is the sum of all exports:

$$GVWI_{(ne,\ t)} = \sum_{ne,\ c} VWT_{(ne,\ ni,\ c,\ t)} \tag{4}$$

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

$$NVWI_{(x,\ t)} = GVWI_{(x,\ t)} - GVWE_{(x,\ t)} \tag{5}$$

where *NVWI* stands for the net virtual water import ($m^3\ year^{-1}$) to the country. Net virtual water import to a country has either a positive or a negative sign. The latter indicates that there is a net virtual water export from the country. A schematic diagram illustrates the whole process (Fig. 2).

Water Scarcity Indicator and water dependency

The scarcity indicator developed by Chapagain & Hoekstra (2005) was employed for this study. They defined a Water Scarcity Indicator as:

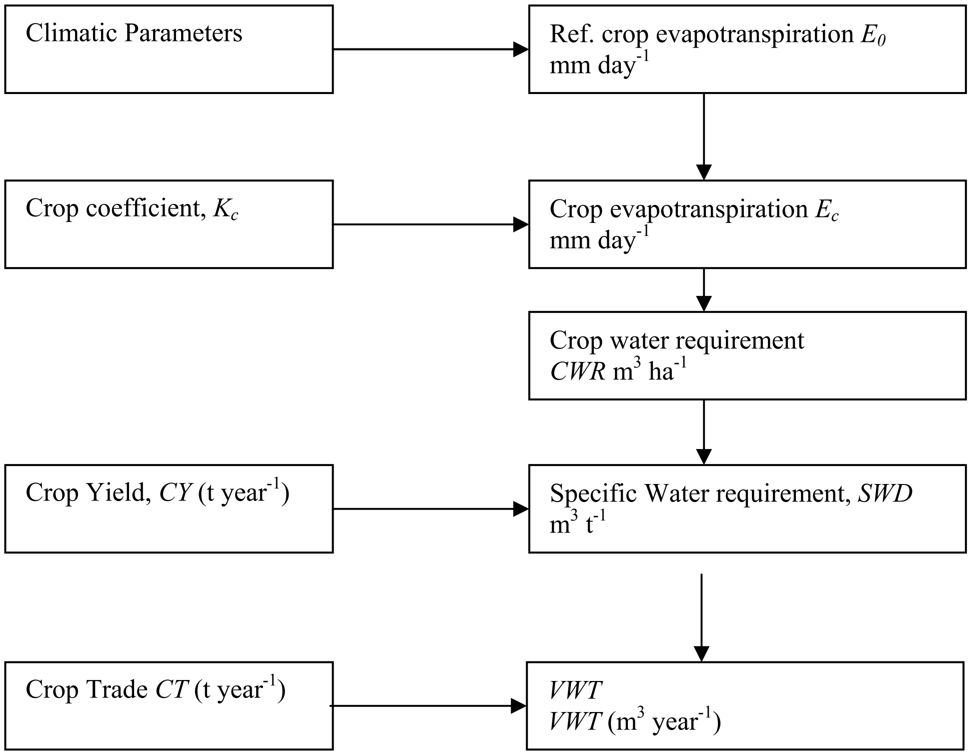

Fig. 2 Schematic representation of calculations for virtual water flows.

$$WS = \frac{WU + NVWI}{WA} \tag{6}$$

In this equation, *WS* denotes national water scarcity (percent), *WU* the total water use in the country (m^3 year^{-1}), *NVWI* the net virtual water import into a country and *WA* the national water availability (m^3 year^{-1}).

The "virtual water import dependency" or "water dependency" will act as an indicator of the net virtual water flow of a country. The indicator reflects the level to which a nation relies on foreign water resources (through import of water in virtual form). The water dependency *WD* of a nation is calculated as the ratio of the net virtual water import into a country to the total national water appropriation:

$$WD = \frac{GVWI}{WU + NVWI} \quad \text{if } NVWI \geq 0 \tag{7}$$

$$WD = 0 \quad \text{if } NVWI \leq 0$$

Water savings

Taken from Hoekstra & Hung (2003a), the national water saving ΔSn (m^3 year^{-1}) of a country n_i as a result of trade of product *p* is:

$$\Delta S_{n\,(ni,\,p)} = V_{(ni,\,p)} \times I_{(ni,\,p)} - V_{(ni,\,p)} \times E_{(ni,\,p)} \tag{8}$$

where V is the virtual water content (m^3 t^{-1}) of the product, p in country n_i, I the amount of product p imported (t $year^{-1}$) and E is the amount of product exported (t $year^{-1}$). ΔS_n can have a negative sign, which means a net water loss instead of a saving. By definition, the total regional water savings is also equal to the sum of the national savings of all countries ΔS_n.

RESULTS AND DISCUSSION

Net virtual water imports

The net virtual water imports (NVWI) for the countries for all the cereals are displayed in Table 1 below. As noted in the methodology, a negative sign implies a net export of virtual water for a country for the specified cereal, whilst a positive value indicates a net import of virtual water for a country for the specific cereal.

Table 1 Net virtual water imports per country per crop Mm^3 $year^{-1}$.

Country/Crop	Maize	Rice	Millet	Sorghum	Barley	Wheat
Tanzania	–68.46	–20.06	–5.93	–4.58	–12.89	–47.09
Kenya	40.81	16.37	21.21	–4.149	5.034	–7.79
Uganda	–259.59	–1.11	–17.65	–13.27	7.81	41.75
Burundi	123.19	0	0	0	0.021	10.35
Rwanda	105.59	4.36	1.53	7.98	0.035	5.46
Somalia	18.79	0	0	24.33	0	–2.19
Sudan	39.12	0.45	0.23	–299.24	0	0
Ethiopia	–13.03	0	–25.92	208.31	–0.32	94.358
Eritrea	0.56	0	0.62	24.66	0	–0.0080
Djibouti	13.01	0	25.92	55.96	0.32	–94.84
Total	0	0	0	0	0	0

From this Table the virtual water flows, as opposed to net virtual water imports, can be determined by summing up either the negative or positive the overall flows. The calculation results show that the volume of crop-related intra-regional *VWT* flows amounted to 898.19 Mm^3 over the period 1998–2003. The annual average refers to the average over the 6-year period and is found by dividing the total 6-year value by six and amounts to 149.69 Mm^3 $year^{-1}$. Coincidentally, results from the IHE study by Chapagain & Hoekstra (2005) rank Sudan within the top 30 largest net water exporters (Table 2). Sudan ranked the 21st largest net virtual water exporter exporting 1151 Mm^3 $year^{-1}$ globally. Chapagain & Hoekstra (2005) classified Uganda as a net exporter but found Tanzania to be a net importer of water (Table 2). For all the countries within the region the study classifies them as net water importers, the same with this study. However, since they were focusing on 38 food crops for international trade, numerical comparisons are meaningless.

Table 2 Comparison of the nature of *VWT* per country between this study and Chapagain & Hoekstra (2005) (IHE-study).

	IHE study	This study
Tanzania	Importer	*Exporter*
Kenya	Importer	Importer
Uganda	*Exporter*	*Exporter*
Burundi	Importer	Importer
Rwanda	Importer	Importer
Somalia	Importer	Importer
Sudan	*Exporter*	*Exporter*
Ethiopia	Importer	Importer
Eritrea	Importer	Importer
Djibouti	Importer	Importer

Thus it can be seen that intra-regional *VWT* within the region mirrors international *VWT*. This is due to the fact that intra-regional trade is a sub-component of international trade and as such will not differ much in *nature.* A country with a large export base internationally will most likely have a large export base regionally, whilst a country with a net international import structure will also probably have a net import structure regionally.

Virtual water balance and water scarcity

An analysis was done to determine the role of water scarcity on the *VWT* balance of the countries considered. From a water management point of view it is plausible to think that a positive relationship between water scarcity and water dependency exists, because high water scarcity will make it attractive to import virtual water, and thus become water dependent. Using water dependency and water scarcity ratios defined in the methodology section, a scarcity-dependency graph (Hoekstra & Hung 2003b) was plotted and the results are shown in Fig. 3.

The results show no discernable link between water scarcity and virtual water imports. The role of water scarcity in determining virtual water imports in Eastern Africa is therefore small. Hoekstra & Hung (2003b) found similar results when considering all the countries of the world. Similar results were observed by de Fraiture (2003), focusing on the global cereal trade. The results show that cereal trade in Eastern Africa occurs for reasons unrelated to water. Thus other factors such as comparative advantage in other sectors, labour constraints or political reasons may be the driving force in trade patterns.

NET WATER SAVINGS

Savings per country

Intra-regional trade in cereal crops for the period 1998–2003 resulted in water savings for all the countries except Uganda, Tanzania and Sudan (Table 3). These countries

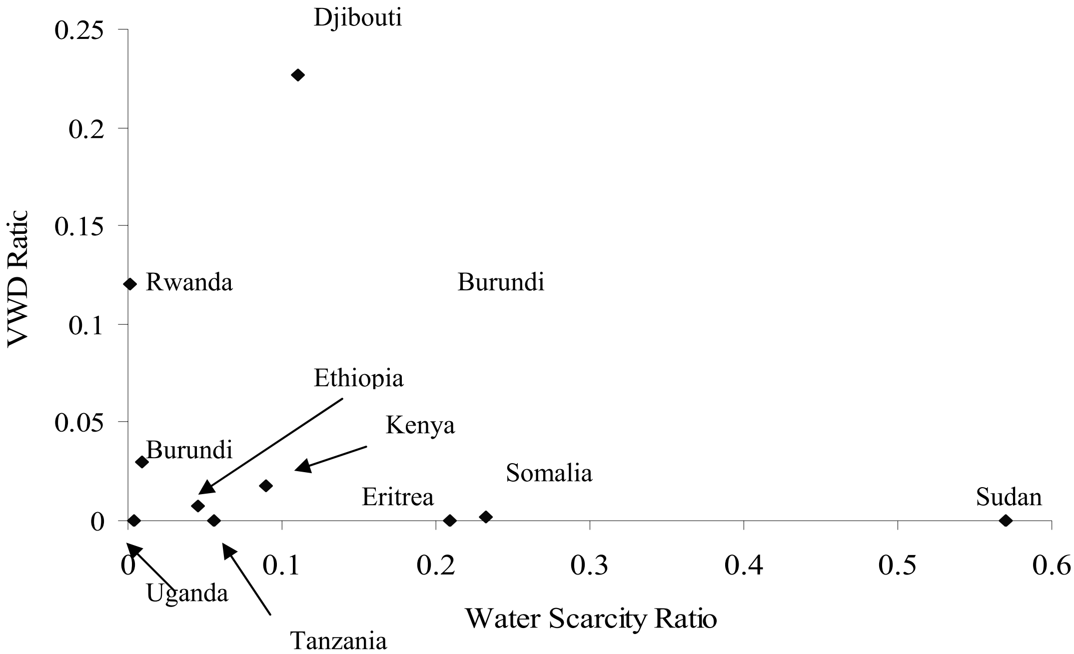

Fig. 3 Graph plot of virtual water dependency to water scarcity.

Table 3 Water savings and losses per country.

Water loss		Water savings	
Country	Mm^3 $year^{-1}$	Country	Mm^3 $year^{-1}$
Uganda	–33.877	Burundi	30.70527
Sudan	–29.2573	Rwanda	36.88163
Tanzania	–28.5558	Ethiopia	23.03683
		Kenya	17.08953
		Somalia	13.48306
		Eritrea	4.784585

Table 4 Water savings per crop.

Crop	Net water savings (Mm^3 $year^{-1}$)
Maize	42.9057
Rice	0.511957
Millet	9.506347
Sorghum	–25.5318
Barley	–0.70755
Wheat	4.484345
Total savings	31.16902

experienced a net loss of water totalling 99.83 Mm^3 $year^{-1}$. Net water savings per country amounted to 31.169 Mm^3 $year^{-1}$. Thus intra-regional trade in cereals in the region potentially saves 31.169 Mm^3 $year^{-1}$.

In percentages this is 21% of the virtual water flows, a significant amount. Water savings per crop are illustrated in Table 4. Intra-regional trade in maize saves the largest amount of water, 42.90 Mm^3 $year^{-1}$, whilst trading sorghum results in the highest losses of –25.53 Mm^3 $year^{-1}$.

CONCLUSIONS

From the analysis of the results generated within this study the following conclusions can be drawn. Intra-regional trade within the Great Horn of Africa is occurring for reasons unrelated to water scarcity. Given the water scarcity scenario within the region this represents unsustainable and inefficient water utilization within the region. As such, national and regional strategies should be implemented on virtual water. Water savings due to intra-regional trade are significant (representing 20.6% of total virtual flows). However, the losses and savings at a country level are high and low, respectively. A virtual water policy at a national or regional level will undoubtedly increase the water savings drastically, whilst cutting down on losses at a national level. The major crops to be targeted by any strategy, national or regional, are maize and sorghum, as their trade results in significantly larger virtual water flows.

There is a significant variation in virtual water contents of cereal crops owing to the great variation of climate within the region. The countries typically referred to as the Horn of Africa (Eritrea, Djibouti, Ethiopia, Somalia and Sudan) have high cereals containing high virtual water contents. This is due to high *CWR* and low average cereal yields. These countries can maximize benefits (save water) from the *VWT* by reducing the virtual water contents of their exports.

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