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The Role of Virtual Water Trade in Food Security: the Case of Ethiopia

Dr. Barış KARAPINAR – Research Fellow World Trade Institute / NCCR Trade

Abstract:

Following the global "food crisis" of 2008, the recent prices hikes in 2011 and successive seasons of droughts, more than 5 million Ethiopians are currently in need of emergency food relief. The country's chronic food insecurity is strongly connected to high vulnerability to water scarcity, while the sustainability of its water resources is increasingly exposed to the globalization of food and agriculture. In this context, based on the concept of "virtual water" – the total volume of water used to produce a commodity – the paper investigates how the patterns of "virtual water trade" affect the sustainability of water resources and food security. Our preliminary results suggest that negative virtual water flow arising from exports of water intensive commodities is not a major contributor to food insecurity – as the water used to produce these commodities by end large does not compete with water used to produce food staples. However, positive virtual water flow resulting from food aid and agricultural imports alleviates the impact of water deficiency caused by precipitation variability which is the main cause of food insecurity in the country. As such virtual water imports are an important channel through which international trade contributes to food security. Given that virtual water studies are at a relatively pioneering stage, this is one of the first empirical case studies on sub-Saharan Africa. It is envisaged that the results of the research will have policy relevance beyond Ethiopia, and shed some light on the heightened debate on food security, water scarcity and climate change adaptation in sub-Saharan Africa.

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I. Introduction

In early 2008, world prices of major agricultural commodities reached their highest levels in nearly three decades, a situation which turned into a "food crisis" (Karapinar and Haeberli, 2010). As a consequence, the number of undernourished people is estimated to have increased by around 100 million – exceeding more than 1 billion in total (FAO, 2009; Martin and Ivanic, 2010). In 2011, world prices of major agricultural commodities are about 40 percent above their levels a year ago and they remain close to their peak during the food crisis of 2008. The main driver of the price hikes are higher fuel costs connected to political instability in the Middle East and North Africa and severe weather events in key grain exporting countries. The World Bank estimates that and the number of people in extreme poverty increased by 44 million as a result of the recent price hikes. Climate change and growing population pressure on water and land resources make the task of achieving food security even more difficult (Parry et al., 2004; Bates et al., 2008; Schmidhuber and Matuschke, 2010). In particular, sub-Saharan Africa – where malnutrition and hunger are most prevalent – is expected to see its population double from the current 840 million to more than 1.75 billion by 2050 (UNPD, 2009). Hence feeding the population of the continent under the impact of climate change will be a major challenge.

Ethiopia is a landmark case in this context. The incremental progress the country had achieved in alleviating hunger and malnutrition in the past few years has been wiped out by the severe impact of the food crisis of 2008 and successive seasons of drought. In November 2009, the Government of Ethiopia and the United Nations World Food Programme (WFP) appealed for 159,410 tonnes of food – as more than 5 million Ethiopians urgently needed emergency food relief (WFP, 2009). The country ranked 80th in IFPRI's 2010 Global Hunger Index and it is among 29 countries with levels of hunger that are categorized as "extremely alarming" or "alarming." As of 2011, 7.8 million Ethiopians receive food or cash under an aid program administered by the WFP (WFP, 2011).

Ethiopia's chronic food insecurity is strongly connected to high vulnerability to water scarcity and precipitation variability (Sen, 1981a,b; Webb et al., 1992; Nellemann et al., 2009). Given that only three per cent of its arable land is irrigated, agricultural activities largely depend on erratic rainfall, which constitutes the most important limiting factor. The severity and the frequency of water shortages are estimated to have increased since the 1950s, and as a result, the country has been facing production shortages almost every other year (CEEPA, 2006). As such, the sustainable use of water resources is vital for Ethiopia's food security.

The latest episode of the food crisis, however, has shown that the context within which food security is defined has changed dramatically since Amartya Sen first analyzed the local aspects of Ethiopian famines in the early 1970s (Sen, 1981a,b). Its agricultural sector, like that of many other countries in sub-Saharan Africa, is now increasingly exposed to the globalization of agriculture and food – driven by factors such as growing volumes of international trade and foreign direct investment (FDI), surge in demand for crops suitable for biofuels production, and the changes of consumption patterns in densely populated emerging economies. For example, between 1998-2008, Ethiopia's exports of agricultural commodities - mainly water-intensive goods such as cut flowers, fruits and oil seeds - have risen rapidly (from US$ 500 million to US$ 1.320 million). And its imports of relatively less water intensive commodities - mainly food staples - grew 15-fold (from US$ 90 million to US$ 1,330 million). Ethiopia has also become an increasingly attractive destination for export-oriented FDI in agriculture. The country attracts substantial volumes of FDI in the labour-intensive horticultural sector. Similarly, there have been reports of foreign companies investing in the production of significant quantities of biofuels in the western and southeastern regions (Reuters, 2009 a,b,c).

In this context, this paper investigates the interface between food security and sustainability of water resources in Ethiopia in the context of its increasing exposure to globalization. The focus is on the impact of increasing volume of agricultural exports and imports on the sustainability of water resources. The assessment is based on the concept of "virtual water" – the total volume of water consumption throughout the stages of crop production, from planting to harvest and processing (Allan, 2001; Hoekstra and Chapagain, 2008). The effects of agricultural trade on Ethiopia's water systems will be identified by estimating the virtual water component of its major import and export commodities. By looking at the volumes of virtual water flows, the study examines (a) to what extent do exports of water-intensive crops affect drought-prone areas and food security? (b) To what extent is importing "virtual water", for example, through cereals imports, help alleviate the impact of water scarcity and precipitation variability?

As for the methods of analysis, the impact of virtual water trade on food security will be analyzed through four stages. The first stage will develop a drought index based historical precipitation data. The second stage will seek to establish a significant relationship between the incidence of droughts and trade volumes. The third stage will analyze crop level water requirements – "virtual water" – of major food staples, namely wheat, barley, maize and sorghum. It will examine whether or to what extent virtual water trade helps alleviate crop water deficits. The fourth stage will introduce three major climate change scenarios to evaluate the potential implications of future precipitation variability on crop water deficits. This will constitute the basis of analysis of the potential impacts of climate change on trade volumes on the one hand, and the role of trade in climate change adaptation on the other.

This paper is organised as follows. Section 2 describes the most salient current trends in Ethiopian agriculture. Section 3 maps out the food security profile of the country and describes the linkage between water scarcity and the prevalence of food insecurity at the regional level. Section 4 describes the methodology used and the related data requirements. Section 5 offers a preliminary analysis of the impact of virtual water trade on food security. Section 6 examines the potential implications of virtual water trade in climate change adaptation. Section 7 offers a brief conclusion.

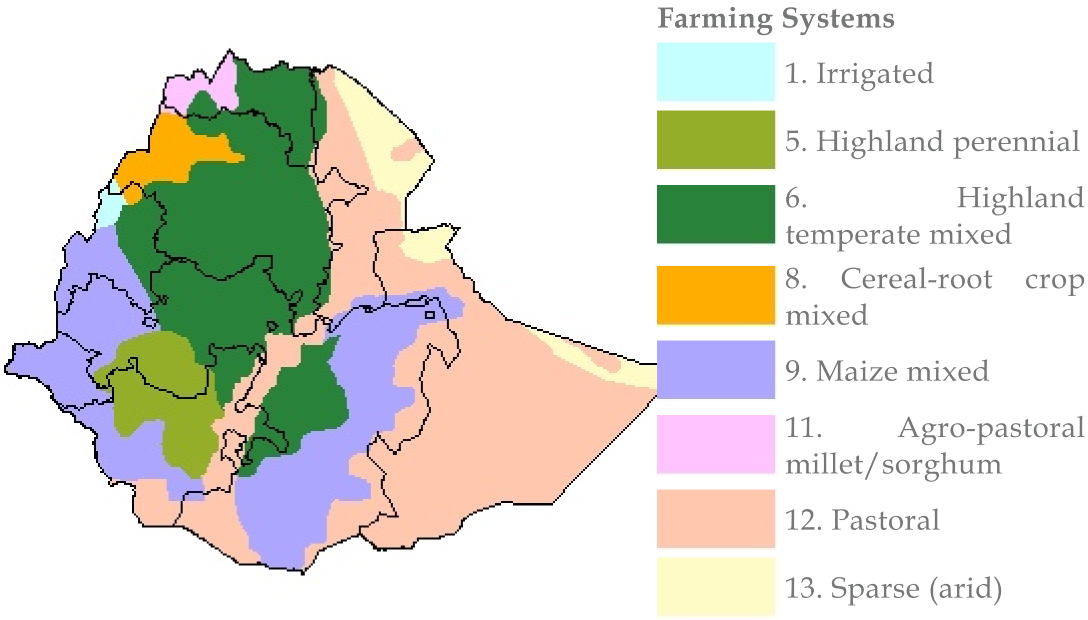
II. Structure of Ethiopian Agriculture

Agriculture accounts for almost half of the gross domestic product (GDP) and it is the primary source of income for more than 85 per cent of the country's approximately 80 million inhabitants.

The type of farming systems vary significantly across the country (see figure).

About one third of all rural households live in pastoral or drought-prone areas in the south-east, east and north-east parts of the country. They live largely by primary staple production in densely populated areas. They are often exposed to fluctuations in rainfall damaging staple production and leading to high mortality of livestock. On the other hand, there are highland mixed farming systems in the central and north-west regions of the country. These are largely areas of relatively high productivity due to high precipitation. These regions offer agro-ecological conditions that are favorable to cash crop production, such as coffee, sesame seed and vegetables. For example, there is a large coffee livelihood zone in the east, Gedeo, and a major sesame seed production zone in the north-west. In addition, an export-oriented greenhouse horticultural production zone has been flourishing around the capital Addis Ababa. These cash crop farming systems provide substantial employment to poor people as laborers and bring in crucial financial in-flows that help Ethiopia pay for its imports of staple food.

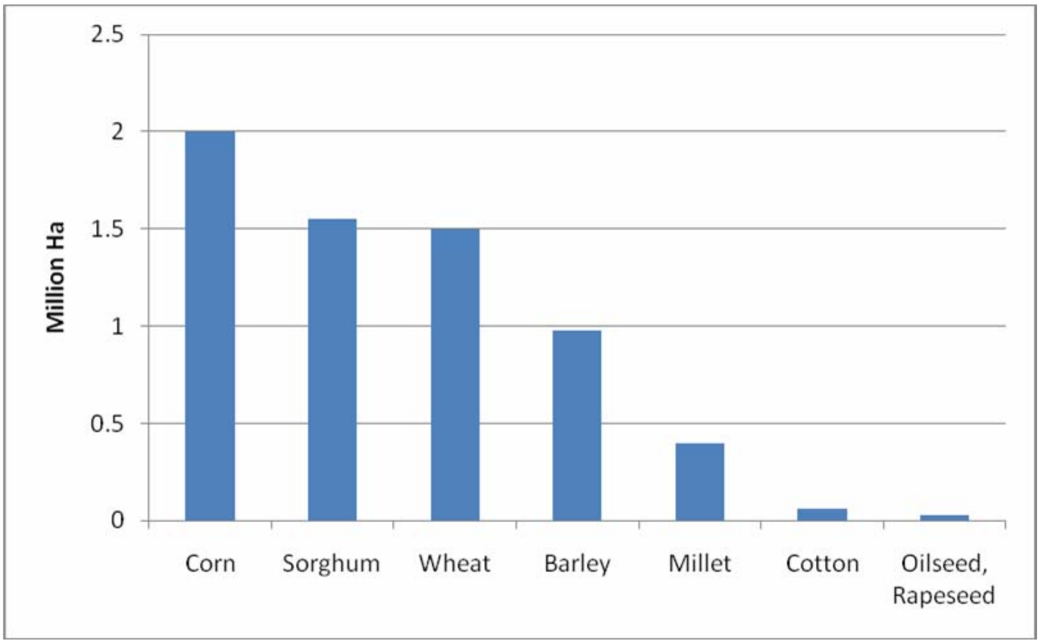
Figure. Major Farming Systems, Ethiopia



Source: FAO

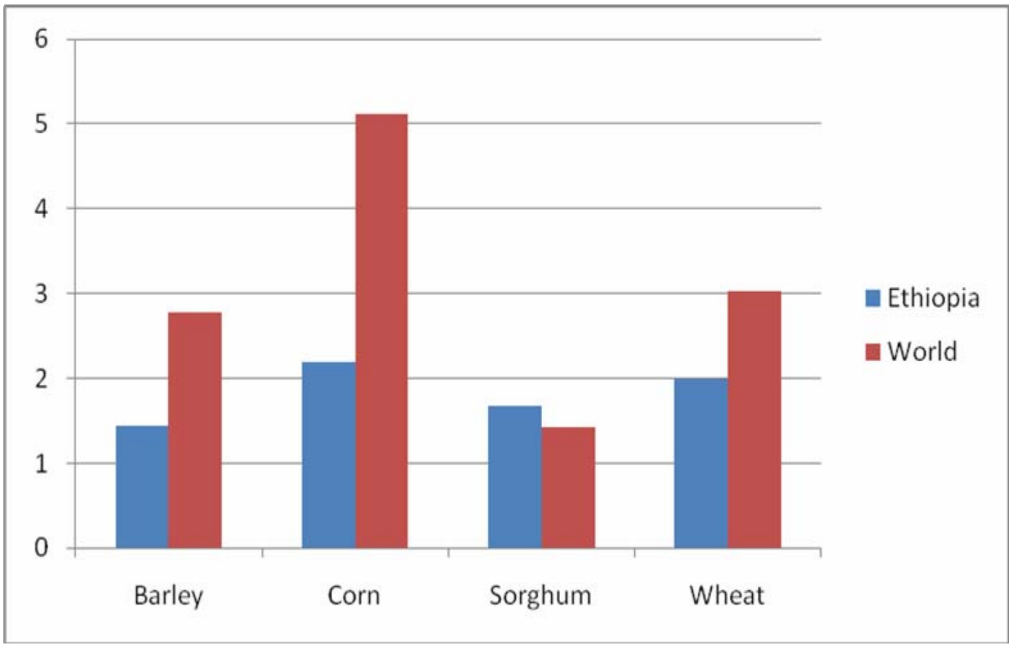
Although there are regional variations, the Ethiopian agriculture is dominated by semi-subsistence farming systems with low productivity. The total amount of agricultural land is around 35 million hectares (FAOSTAT). In 2010/11, maize covered approximately 2 million ha of the harvested area, sorghum and wheat covered around 1.5 million ha, and barley covered approximately 1 million ha. Agricultural yields are substantially lower than world averages. For barley and maize, yields in Ethiopia are almost half of the world averages whereas for wheat the yields are around 2/3 of world averages. Poor infrastructure, lack of technological diffusion, high population pressure which leads to fragmentation of land holdings, land degradation and water scarcity are some of the structural causes of low productivity in agriculture.

Area Harvested (Million hectares), major agricultural products, Ethiopia **2010/11**



Source: FAOSTAT

Average yields (t/ha) of major agricultural products, Ethiopia vs. World



Source: FAOSTAT

In this context, Ethiopia's agricultural trade has increased substantially in the last decade. Between 1998 and 2008, the value of its imports grew 15-fold, from US$ 90 million to US$ 1,330 million (UNcomtrade, 2009) . Cereals imports amounted to almost 45 per cent of the total imports in 2008. The international price hikes substantially inflated the country's import bill in that year. The value of agricultural exports, on the other hand, rose from US$ 500 million in 1998 to US$ 1,320 million in 2008. Although coffee is still the most significant export commodity, its share in total export revenues has declined from almost 80 per cent to 40 per cent – as the country has diversified its exports towards other secondary products such as oilseed crops, cut flowers and vegetables.

Table 1: Ethiopia's major agricultural exports and imports, 2008

Export Commodities	*Export Value (Million US$)*	**Share (%)**
1. Coffee	556	42.1
2. Oil seeds	250	18.9
3. Cut flowers	105	7.9
4. Fresh	83	6.3
Group total	**994**	**75.2**

Source: UNcomtrade, 2009

Import Commodities	*Import Value (Million US$)*	**Share (%)**
1. Wheat	465	35.4
2 .Palm oil	202	15.4
3. Coffee	85	6.5
4. Grain	85	6.4
5. Raw sugar	55	4.2
Group total	**892**	**67.8**

III. Food security and water deficiency

Ethiopia's chronic food insecurity is strongly connected to high vulnerability to water scarcity and precipitation variability (Sen, 1981a,b; Webb et al., 1992; Nellemann et al., 2009). Given that only three percent of its arable land is irrigated, agricultural activities largely depend on erratic rainfall, which constitutes the most important limiting factor. As such the areas of severe food insecurity largely overlap with areas where erratic rainfalls are the most constraining factor in agriculture. As indicated by the maps of major environmental constraints and food insecurity below, large parts of the Herari, Somali and Tigray region which suffer from seasonal water shortages due to precipitation variability are largely areas of chronic food insecurity. These regions are also the priority areas for food relief operations of the World Food Programme (WFP, 2011).

In this context, temporary production deficits - which are caused by precipitation variability - against local food requirements are the main channel through which the relationship between water and food insecurity is investigated in this paper. Undertaking a full account of the household economy which determines a household's food security profile is beyond the scope of this study. Nevertheless given that the majority of poor rural households heavily dependent upon crop production - as they produce 60 percent to 90 percent of the food they consume - which makes them highly vulnerable to water scarcity and precipitation variability (FEWSNet, 2006), [1] our analysis is likely to capture a significant proportion of the prevalence of food insecurity in Ethiopia.

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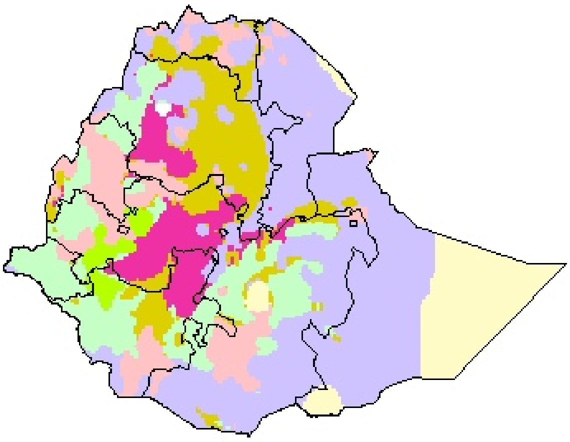
[1] See USAID (2006), Southern Nation, Nationalities and People's Region, Ethiopia

Figure: Major environmental constraints, Ethiopia



Environmental Constraints

🟨 Dry and/or cold areas with low production potential

🟥 Low soil suitability

🟪 Erratic rainfall and cold stress risk

🟨 Steep slopes and mountains

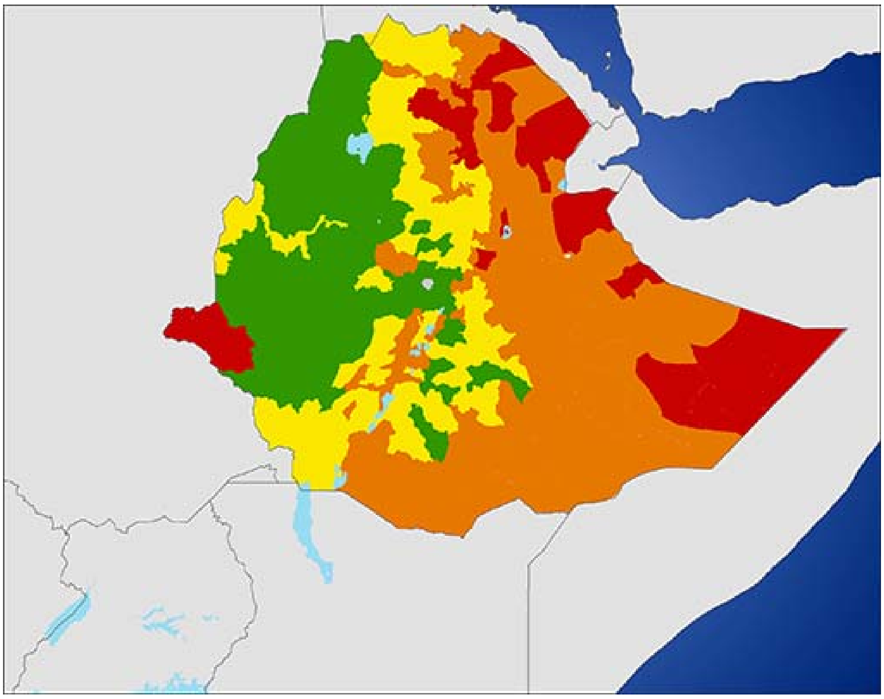
🟥 Severe and very severe land degradation

🟩 Low to medium climatic production potential

🟩 High climatic production potential

Source: FAO

Figure: Map of food security, Ehiopia



Source: USAID

IV. Methodology and Database

The study of the impact of virtual water trade on food security is based on four stages of analysis. The first stage will develop a drought index based historical precipitation data. The second stage will seek to establish a significant relationship between the incidence of droughts and trade volumes. The third stage will analyze crop level water requirements – "virtual water" – of major food staples, namely wheat, barley, maize and sorghum, to examine whether or to what extent virtual water trade helps alleviate water deficits at the crop level. In the fourth stage, we will introduce three major climate scenarios to evaluate the potential implications of change in the amount and variability of future precipitation on water deficits. This will constitute the basis of analysis of the potential impacts of climate change on trade volumes on the one hand, and the role of trade in climate change adaptation on the other.

The first level of analysis is going to develop the Standardized Precipitation Index (SPI) for selected food insecure regions in Ethiopia. SPI is a probability index that uses precipitation data. This index is based on standardized probabilities of amount of precipitation in a given area. Median precipitation amount is indicated by the index measure of zero. (Hence half of the historical precipitation amounts are below the median, and half are above the median). The index is negative for below- the-median precipitation amounts which indicate drought conditions (more negative for more severe droughts). The index is positive for above- the-median precipitation amounts which indicate wet conditions (more positive for more wet conditions). A period during which SPI is continuously negative can be identified as a drought event (McKee et al., 1993).[2] The SPI can be calculated for different time scales, ranging from one week to one year to capture the various scales of both short-term and long-term drought. By identifying interval values for SPI, drought intensity can be arbitrarily defined based on a range of severity categories:

SPI Values	Drought Category
0 to -0.99	mild drought
-1.00 to -1.49	moderate drought
1.50 to -1.99	severe drought
≤ -2.00	extreme drought

Source: (McKee et al., 1993)

Once the first level of analysis using SPIs, as described above, has identified the historical periods of droughts for selected food deficit regions in Ethiopia, then the second stage will examine whether or to what extent these periods overlap with higher volumes of trade and food aid. Through regression analysis, the relationship between droughts and trade (and food aid) will be established. This will constitute the background of the virtual water analysis which will be undertaken in the third stage.

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[2] See Thomas B. McKee, Nolan J. Doesken and John Kleist, 'The Relationship of Drought Frequency and Duration to Time Scales' Eighth Conference on Applied Climatology,17-22 January 1993, Anaheim, California

In the third stage, the assessment of virtual water requirements will be undertaken by estimating actual crop water requirements in specific local contexts at the regional level. The empirical estimation of the virtual water component of the selected crops will be based on a methodology developed by the Land and Water Development Division of the Food and Agriculture Organization of the United Nations (FAO). Using a software tool called CROPWAT, evapotranspiration (ETo) values and actual water requirements will be calculated for each crop by factoring in local climate, crop, farming practices and soil data.

Table: Crop Water Requirements

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for Crop evapotranspiration under standard conditions (ETc) and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration.

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the Reference evapotranspiration (ETo). Experimentally determined ratios of ETc/ETo, called Crop coefficient (Kc), are used to relate ETc to ETo, therefore we can express crop evapotranspiration as ETc = Kc * ETo. This is known as the crop coefficient approach to calculate crop evapotranspiration.

Differences in leaf anatomy, stomatal characteristics, aerodynamic properties and even albedo cause ETc to differ from ETo under the same climatic conditions. Due to variations in the crop characteristics throughout its growing season, Kc for a given crop changes from sowing till harvest.

In CROPWAT 8.0 the calculation of crop water requirements is carried out per decade. For the calculations of the Crop Water Requirements (CWR), the crop coefficient approach is used.

Crop evapotranspiration per decade is calculated by multiplication of the number of effective crop days. To convert monthly rainfall data to decade values, a linear interpolation is carried out. Values for first and third decades of each month are calculated by inter-polation with the preceding and successive month respective-ly. To compensate for deviations in the maximum and minimum months, a reiteration is carried out to ful-fil the condition that the 3 decade values average the given monthly aver-age.

Crop water requirements are then calculated as the difference between crop evapotranspiration and effective rainfall.

Source: FAO

Database

The empirical part of the research project will make use of three different databases combining data on climate variables, plant physiology and local farming practices, and international trade.

- For each of the selected fields of production, climate data is needed to calculate the reference evapotranspiration (ETo) under base vegetation (i.e. grass) (Allen et al., 1998). For Ethiopia, time series are available through

FAO's CLIMWAT 2.0 database which offers observed agroclimatic data from 100 stations across the country. The data provides long-term monthly mean values of the required climatic parameters – such as daily temperatures, humidity, wind speed, solar radiation and rainfall. It covers the period 1971–2000. We are in the process of gathering the data for the period since 2000 from the Department of Meteorological Affairs in Ethiopia.

- For each crop, data on actual plant physiology and local farming practices will be incorporated into the model to calculate the Crop Coefficient which integrates the effect of characteristics that distinguish a specific crop from the base crop that is used to calculate the reference evapotranspiration. For the selected fields of production, information on plant physiology (rooting depth, plant height etc.) and the timing of the relevant farming practices (planting date, harvest date and irrigation schedules etc.) and data on soil characteristics, such as maximum available soil moisture and rain infiltration rate, are needed. We are in the process of gathering the data from the World Food Programme in Ethiopia.

- For international trade data, UNComtrade database is used.

Feeding these three data components into CROPWAT 8.0 will produce the output on the actual water requirements for each crop. This will then be divided by yields observed in the selected fields of production.

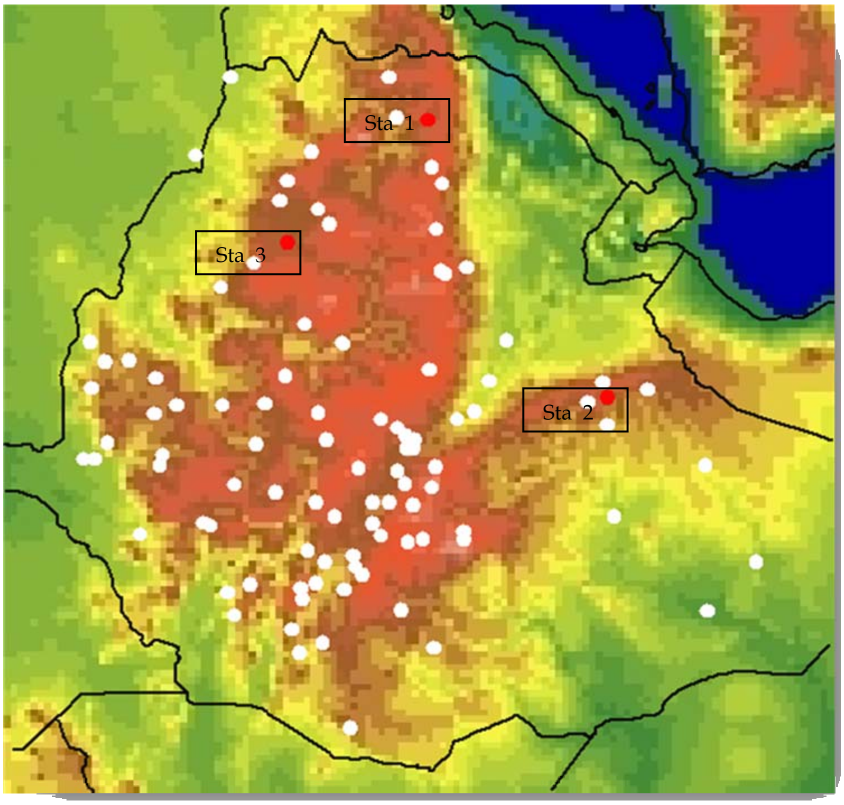
Given that virtual water studies are at a relatively pioneering stage (De Fraiture et al., 2004; Oki and Kanae, 2004; Hoekstra and Hung, 2005; Hoekstra and Chapagain, 2008), the literature on sub-Saharan Africa is scant. To our knowledge, there has as yet been no empirical study on flows of virtual water in Ethiopia. The most comprehensive study on global virtual water flows by Hoekstra and Chapagain (2008) looks at 146 countries, including Ethiopia. However it has serious shortcomings in relation to the accuracy of its estimates. First, the calculation of crop water requirements – from planting to harvest – is largely based on international averages for specific crop varieties grown under "ideal conditions". It does not factor in the effects of local farm practices, soil characteristics, ground cover and other agro-physical constraints which lead to substantial variations in crop physiology, and hence in actual water requirements. Local varieties of a certain crop might also have significantly different water requirement from the standard variety included in the analysis. Second, the study estimates the volume of virtual water flows at the national level. Yet this is not informative in relation to the impact of virtual water trade on water scarcity at the local level – as the availability of water resources varies markedly across the regions of Ethiopia. Third, both the trade and climate data used in that study cover the period between 1996 and 2001, which is highly outdated given that Ethiopia's trade volumes have increased rapidly since 2001, and some of its climate trends might have changed.

V. Virtual water and Food Security: Preliminary tests

We have conducted some preliminary tests on variations of crop water requirement at the local level. Before the full set of data is available, three meteorological stations have been identified, Mekele, Harar and Dahr-Bar. The first two stations are located in food deficit zones, while the third station is located in a food surplus zone (see figure below). For each station data on the following long-term monthly mean values of seven climatic parameters have been gathered:

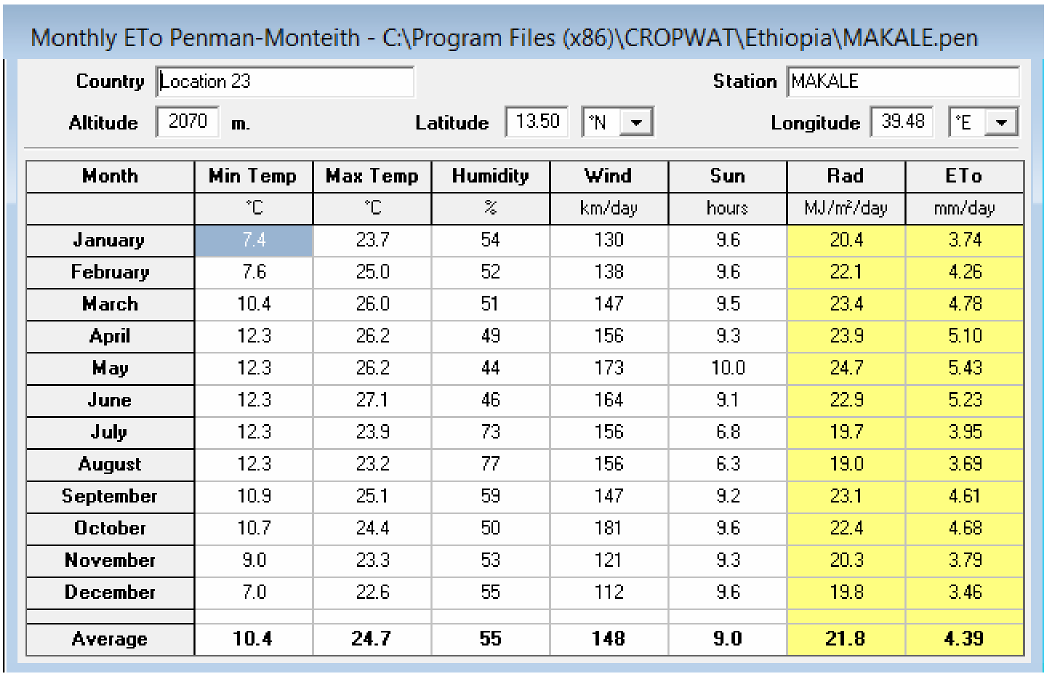
- Mean daily maximum temperature in °C
- Mean daily minimum temperature in °C
- Mean relative humidity in %
- Mean wind speed in km/day
- Mean sunshine hours per day
- Mean solar radiation in MJ/m2/day
- Monthly rainfall in mm/month
- Monthly effective rainfall in mm/month
- Reference evapotranspiration calculated with the Penman-Monteith method in mm/day

Figure: Location of 100 meteorological stations where time series are available



Source: FAO CLIMWAT

Station 1: Mekele



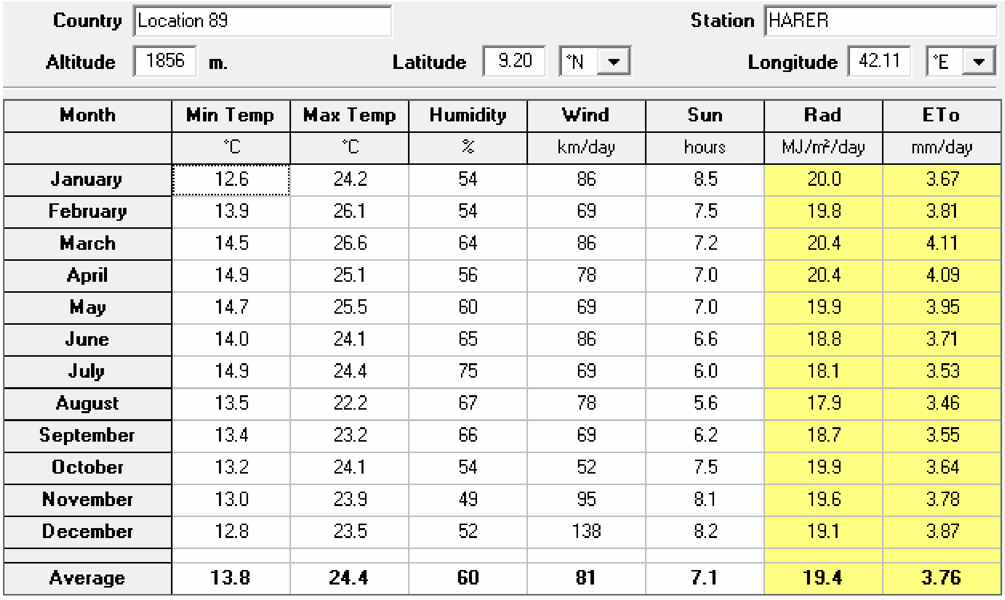
Monthly ETo Penman-Monteith - C:\Program Files (x86)\CROPWAT\Ethiopia\MAKALE.pen

Country Location 23 **Station** MAKALE

Altitude 2070 **m.** **Latitude** 13.50 °N **Longitude** 39.48 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m^2/day	mm/day
January	7.4	23.7	54	130	9.6	20.4	3.74
February	7.6	25.0	52	138	9.6	22.1	4.26
March	10.4	26.0	51	147	9.5	23.4	4.78
April	12.3	26.2	49	156	9.3	23.9	5.10
May	12.3	26.2	44	173	10.0	24.7	5.43
June	12.3	27.1	46	164	9.1	22.9	5.23
July	12.3	23.9	73	156	6.8	19.7	3.95
August	12.3	23.2	77	156	6.3	19.0	3.69
September	10.9	25.1	59	147	9.2	23.1	4.61
October	10.7	24.4	50	181	9.6	22.4	4.68
November	9.0	23.3	53	121	9.3	20.3	3.79
December	7.0	22.6	55	112	9.6	19.8	3.46
Average	**10.4**	**24.7**	**55**	**148**	**9.0**	**21.8**	**4.39**

Station 2: Harar

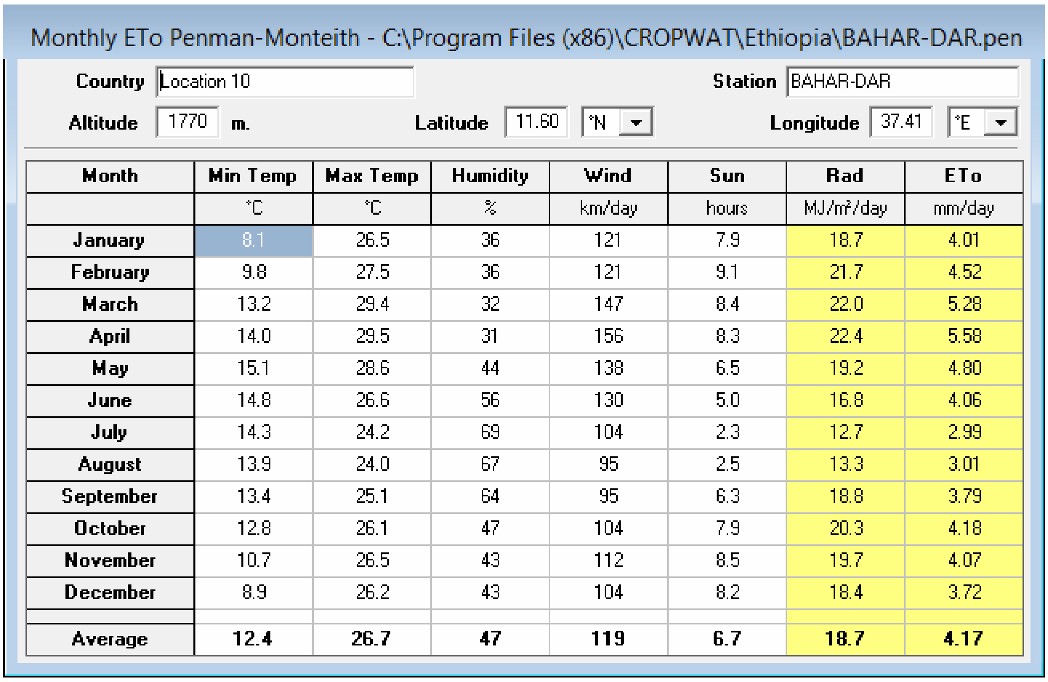


Country Location 89 **Station** HARER

Altitude 1856 **m.** **Latitude** 9.20 °N **Longitude** 42.11 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m^2/day	mm/day
January	12.6	24.2	54	86	8.5	20.0	3.67
February	13.9	26.1	54	69	7.5	19.8	3.81
March	14.5	26.6	64	86	7.2	20.4	4.11
April	14.9	25.1	56	78	7.0	20.4	4.09
May	14.7	25.5	60	69	7.0	19.9	3.95
June	14.0	24.1	65	86	6.6	18.8	3.71
July	14.9	24.4	75	69	6.0	18.1	3.53
August	13.5	22.2	67	78	5.6	17.9	3.46
September	13.4	23.2	66	69	6.2	18.7	3.55
October	13.2	24.1	54	52	7.5	19.9	3.64
November	13.0	23.9	49	95	8.1	19.6	3.78
December	12.8	23.5	52	138	8.2	19.1	3.87
Average	**13.8**	**24.4**	**60**	**81**	**7.1**	**19.4**	**3.76**

Station 3: Bahr-Dar



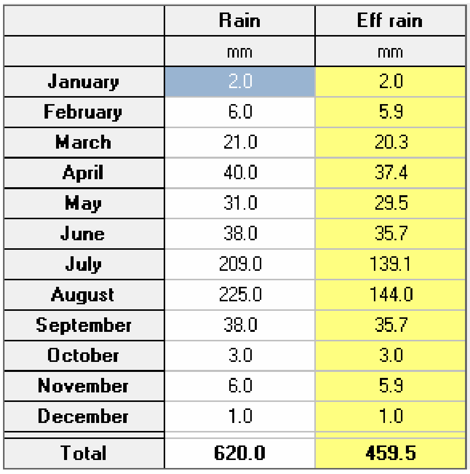
Monthly ETo Penman-Monteith - C:\Program Files (x86)\CROPWAT\Ethiopia\BAHAR-DAR.pen

Country: Location 10
Station: BAHAR-DAR
Altitude: 1770 m.
Latitude: 11.60 °N
Longitude: 37.41 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	8.1	26.5	36	121	7.9	18.7	4.01
February	9.8	27.5	36	121	9.1	21.7	4.52
March	13.2	29.4	32	147	8.4	22.0	5.28
April	14.0	29.5	31	156	8.3	22.4	5.58
May	15.1	28.6	44	138	6.5	19.2	4.80
June	14.8	26.6	56	130	5.0	16.8	4.06
July	14.3	24.2	69	104	2.3	12.7	2.99
August	13.9	24.0	67	95	2.5	13.3	3.01
September	13.4	25.1	64	95	6.3	18.8	3.79
October	12.8	26.1	47	104	7.9	20.3	4.18
November	10.7	26.5	43	112	8.5	19.7	4.07
December	8.9	26.2	43	104	8.2	18.4	3.72
Average	**12.4**	**26.7**	**47**	**119**	**6.7**	**18.7**	**4.17**

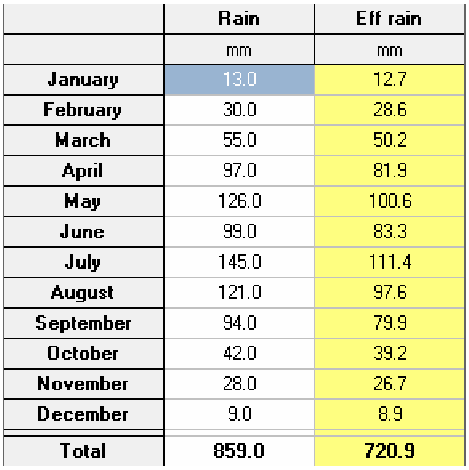
Next, the data on rainfall and effective rainfall have been introduced. For agricultural production, effective rainfall refers to that portion of rainfall that can effectively be used by plants. This is to say that not all rain is available to the crops as some is lost through Runoff (RO) and Deep Percolation (DP). How much water actually infiltrates the soil depends on soil type, slope, crop canopy, storm intensity and the initial soils water content. The most accurate method to determine effective rainfall is through field observation. Rainfall is highly effective when little or no RO takes place. Small rainfall amounts are not very effective as these small quantities of water are quickly lost to evaporation.

Station 1: Mekele



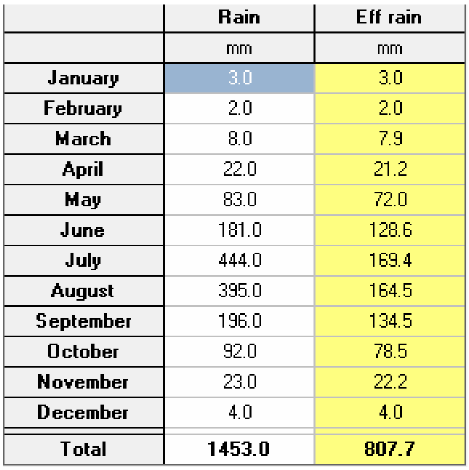
	Rain	Eff rain
	mm	mm
January	2.0	2.0
February	6.0	5.9
March	21.0	20.3
April	40.0	37.4
May	31.0	29.5
June	38.0	35.7
July	209.0	139.1
August	225.0	144.0
September	38.0	35.7
October	3.0	3.0
November	6.0	5.9
December	1.0	1.0
Total	**620.0**	**459.5**

Station 2: Harar



	Rain	Eff rain
	mm	mm
January	13.0	12.7
February	30.0	28.6
March	55.0	50.2
April	97.0	81.9
May	126.0	100.6
June	99.0	83.3
July	145.0	111.4
August	121.0	97.6
September	94.0	79.9
October	42.0	39.2
November	28.0	26.7
December	9.0	8.9
Total	**859.0**	**720.9**

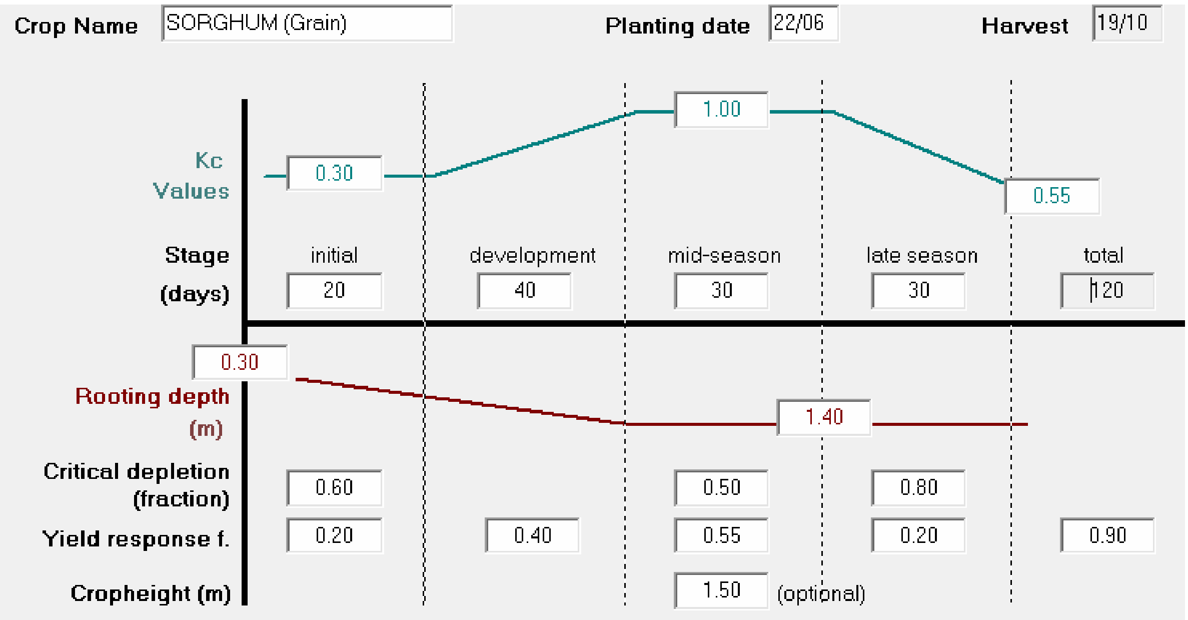
Station 3: Bahr-Dar



	Rain	Eff rain
	mm	mm
January	3.0	3.0
February	2.0	2.0
March	8.0	7.9
April	22.0	21.2
May	83.0	72.0
June	181.0	128.6
July	444.0	169.4
August	395.0	164.5
September	196.0	134.5
October	92.0	78.5
November	23.0	22.2
December	4.0	4.0
Total	**1453.0**	**807.7**

Then for sorghum, which is a main staple crop, the data input (including the parameters of planting date, crop coefficient (Kc), rooting depth, critical depletion fraction (p), yield response factor (Ky), maximum Crop height) were inserted into the Crop module of CROPWAT. As we do not have exact data on farming practices on the ground we assume a fixed harvest date which is automatically calculated on the base of the Planting date and the total duration of the crop cycle according to the length of the stages inputted for the crop (crop data refer to the four stages of crop cycle: initial stage, crop development stage, mid-season stage, late season)

Crop: Sorghum



Crop Name SORGHUM (Grain) **Planting date** 22/06 **Harvest** 19/10

	initial	development	mid-season	late season	total
Kc Values	0.30		1.00		0.55
Stage (days)	20	40	30	30	120
Rooting depth (m)	0.30		1.40		
Critical depletion (fraction)	0.60		0.50	0.80	
Yield response f.	0.20	0.40	0.55	0.20	0.90
Cropheight (m)			1.50 (optional)		

Based on this data, we run the CROPWAT to calculate the sorghum's crop water requirements in the selected three areas.

Station 1: Mekele

Station 1: Mekele

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	3	Init	0.30	1.46	13.1	18.3	0.0
Jul	1	Init	0.30	1.29	12.9	38.0	0.0
Jul	2	Deve	0.38	1.46	14.6	51.0	0.0
Jul	3	Deve	0.56	2.13	23.4	50.0	0.0
Aug	1	Deve	0.74	2.75	27.5	51.0	0.0
Aug	2	Deve	0.92	3.29	32.9	53.3	0.0
Aug	3	Mid	0.99	3.90	42.9	39.5	3.40
Sep	1	Mid	0.99	4.27	42.7	21.6	21.2
Sep	2	Late	0.99	4.57	45.7	8.3	37.4
Sep	3	Late	0.90	4.17	41.7	5.9	35.8
Oct	1	Late	0.75	3.57	35.7	2.6	33.0
Oct	2	Late	0.62	2.95	26.6	0.0	26.6
					359.7	339.6	157.3

* red highlights indicate water deficit

Station 2: Harar

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	3	Init	0.30	1.10	9.9	26.5	0.0
Jul	1	Init	0.30	1.08	10.8	35.3	0.0
Jul	2	Deve	0.37	1.31	13.1	39.1	0.0
Jul	3	Deve	0.54	1.88	20.7	36.9	0.0
Aug	1	Deve	0.70	2.44	24.4	34.2	0.0
Aug	2	Deve	0.86	2.97	29.7	32.7	0.0
Aug	3	Mid	0.93	3.24	35.6	30.7	5.0
Sep	1	Mid	0.93	3.27	32.7	29.3	3.4
Sep	2	Late	0.93	3.29	32.9	27.7	5.2
Sep	3	Late	0.83	2.98	29.8	22.8	7.0
Oct	1	Late	0.68	2.47	24.7	16.7	8.0
Oct	2	Late	0.54	1.98	17.8	10.6	6.0
					281.9	342.3	34.6

* red highlights indicate water deficit

Station 3: Bahr-Dar

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	3	Init	0.30	1.11	10.0	43.1	0.0
Jul	1	Init	0.30	0.98	9.8	53.4	0.0
Jul	2	Deve	0.37	1.08	10.8	58.6	0.0
Jul	3	Deve	0.55	1.60	17.6	57.4	0.0
Aug	1	Deve	0.72	2.15	21.5	56.1	0.0
Aug	2	Deve	0.88	2.65	26.5	56.0	0.0
Aug	3	Mid	0.95	3.12	34.3	52.3	0.0
Sep	1	Mid	0.95	3.37	33.7	49.0	0.0
Sep	2	Late	0.95	3.61	36.1	46.0	0.0
Sep	3	Late	0.86	3.37	33.7	39.4	0.0
Oct	1	Late	0.72	2.90	29.0	32.4	0.0
Oct	2	Late	0.58	2.42	21.8	23.5	0.0
					285.0	567.2	0.0

The test results suggest that, in the first two stations, sorghum's water requirements are not met by average precipitation patterns. Especially in August and September, there are significant levels of crop water deficits (highlighted in red in Tables above). Hence these periods are those when the crop requires irrigation. However given the unavailability of irrigation facilities, these periods of water deficits lead to yield losses and crop failure. However, in Dahr-Bar the levels of effective rainfall are at levels that balance crop evapotranspiration, hence crop water requirements are satisfied and no irrigation is needed for sorghum produced in average conditions.

Using the same method, we will calculate crop water requirements for wheat, barley, maize and sorghum (when the full set of data is available). Then the results will be compared with the import volumes of these commodities. We expect to find a significant correlation between crop water deficiency levels (under actual conditions) and import volumes. If a relationship between crop water deficiency and trade could be established, this will be a major contribution to the literature in relation to the impact of trade on food security. In a following stage, we will introduce various climate change scenarios (developed by the Intergovernmental Panel on Climate Change) to evaluate the potential implications of future precipitation variability on crop water deficits. This will constitute the basis of analysis of the potential impacts of climate change on trade volumes on the one hand, and the role of trade in climate change adaptation on the other.

VI. Relevance for Climate Change Adaptation

How the growing population of sub-Saharan Africa can be fed without further undermining the sustainability of the interaction between agricultural activities and the environment is a major challenge. Water, which is increasingly the most important limiting factor in agricultural production, faces additional competing demands for food, energy, health, and ecosystem services. Furthermore, climate change will make the task of achieving sustainable use of water even more difficult. In this context, this paper looks at how the globalization of food and agriculture affects the vital interaction between agricultural activities and water resources in a country, Ethiopia, where millions of people suffer from chronic food insecurity largely driven by vulnerability to water scarcity.

Given that precipitation variability is highly likely to increase as a result of climate change, the food security situation in areas where supply capacities are already weak and rural societies are vulnerable is likely to worsen. Hence the results of the project are highly relevant in the context of the role of international trade in climate change adaptation.

VII. Conclusion

Based on the concept of “virtual water” – the total volume of water used to produce a commodity – the paper investigates how the patterns of “virtual water trade” affect the sustainability of water resources and food security. Our preliminary results suggest that negative virtual water flow arising from exports of water intensive commodities is not a major contributor to food insecurity – as the water used to produce these commodities by end large does not compete with water used to produce food staples. However, positive virtual water flow resulting from food aid and agricultural imports alleviates the impact of water deficiency caused by precipitation variability which is the main cause of food insecurity in the country. As such virtual water imports are an important channel through which international trade contributes to food security.

References

ALDEN, C. & HUGHES, C. R. (2009) Harmony and Discord in China's Africa Strategy: Some Implications for Foreign Policy. The China Quarterly, 199, 563-584.

ALLAN, J. A. (2001) The Middle East Water Question: Hydropolitics and the Global Economy, London
New York, I.B. Tauris.

ALLEN, R. G., PEREIRA, L. S., RAES, D. & SMITH, M. (1998) Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and drainage Rome, FAO.

BATES, B. C., KUNDZEWICZ, Z. W., S., W. & PALUTIKOF, J. P. (2008) Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. Geneva, IPCC Secretariat.

COTULA, L., VERMEULEN, S., LEONARD, R. & KEELEY, J. (2009) Land Grab or Development Opportunity? Agricultural Investment and International Land Deals in Africa. London, Rome, IIED/FAO/IFAD.

DE FRAITURE, C., CAI, X., AMARASINGHE, U., ROSEGRANT, M. & 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.

FINANCIAL TIMES (2009) UN sees rise in land grab for food security. 17 September 2009.

HOEKSTRA, A. Y. & CHAPAGAIN, A. K. (2008) Globalization of Water: Sharing the Planet's Freshwater Resources, Oxford, Blackwell Publishing.

HOEKSTRA, A. Y. & HUNG, P. Q. (2005) Globalisation of water resources: international virtual water flows in relation to crop trade. Global Environmental Change, 15, 45-56.

KARAPINAR, B. (2010) Food Crises and the WTO. IN KARAPINAR, B. & HABERLI, C. (Eds.) Food Crises and the WTO. Cambridge, New York, Cambridge University Press.

KARAPINAR, B., AERNI, P., HABERLI, C., MEISTER, M., NEWMAN, S. & JUSOH, S. (2008) The Sustainability Impact Assessment of Swiss agricultural and trade policies in its developing country trading partners. World Trade Institute Consulting Paper, Funded Swiss Agency for Development and Cooperation, Bern, Switzerland.

KIRBY, W. C. (2006) China's Internationalization in the Early People's Republic: Dreams of a Socialist World. China Quarterly, 870-890.

LEE, H., SHALMON, D. & ROTBERG, R. I. (2008a) Searching for Oil: China's Oil Strategies in Africa. IN ROTBERG, R. I. (Ed.) China into Africa: Trade, Aid, and Influence. Brookings Institution Press and World Peace Foundation.

LEE, H., CLARK, W. C. & DEVEREAUX, C. (2008b) Biofuels and Sustainable Development. HKS Working Paper RWP08-049.

MARTIN, W. & IVANIC, M. (2010) The food price crisis, poverty and agricultural trade policy. IN KARAPINAR, B. & HABERLI, C. (Eds.) Food Crises and the WTO. Cambridge, New York, Cambridge University Press.

MITCHELL, D. (2008) A Note on Rising Food Prices. Washington, DC, World Bank.

NELLEMANN, C., MACDEVETTE, M., MANDERS, T., EICKHOUT, B., SVIHUS, B., PRINS, A. G. & KALTENBORN, B. P. (2009) The environmental food crisis - The environment's role in averting future food crises. United Nations Environment Programme.

OKI, T. & KANAE, S. (2004) Virtual water trade and world water resources. Water Science and Technology 49, 203-209.

ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD) (2007) OECD Environmental Performance Reviews: China. Paris, OECD.

PARRY, M. L., ROSENZWEIG, C., IGLESIAS, A., LIVERMORE, M. & FISCHER, C. (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environmental Change 14, 53-67.

REUTERS (2009a) Ethiopia to develop biofuels to cut oil imports. 01.11.2009.

REUTERS (2009b) FactBox: Foreign Forays into African Farming. 20.03.2009.

REUTERS (2009c) Saudi Investors Put $100 mln into Ethiopia. 06.04.2009.

SCHMIDHUBER, J. & MATUSCHKE, I. (2010) Shift and swing factors and the special role of weather and climate. IN KARAPINAR, B. & HABERLI, C. (Eds.) Food Crises and the WTO. Cambridge, New York, Cambridge University Press.

SEN, A. (1981a) Ingredients of famine analysis: availability and entitlements. Quarterly Journal of Economics, 96.

SEN, A. (1981b) Poverty and famines: an essay on entitlement and deprivation, Oxford, New York, Oxford University Press.

THE CENTRE FOR ENVIRONMENTAL ECONOMICS AND POLICY IN AFRICA (CEEPA) (2006) Climate Change and African Agriculture Policy Note No:31.

THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO) (2009) More people than ever are victims of hunger. Rome, FAO.

UNITED NATIONS COMMODITY TRADE STATISTICS DATABASE (UNCOMTRADE) (2009). United Nations Statistics Division, available at <http://comtrade.un.org/> (accessed November 2009)

UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT (UNCTAD) (2006) Challenges and opportunities for developing countries in producing biofuels. UNCTAD/DITC/COM/2006/15. Geneva.

UNITED NATIONS POPULATION DIVISION (UNPD) (2009) World Population Prospects, 2008 Revision. Population Estimates and Projections Section, available at < http://www.un.org/esa/population/unpop.htm > (accessed September 2009).

UNITED NATIONS WORLD FOOD PROGRAMME (WFP) (2009) Countries: Ethiopia, available at <http://www.wfp.org> (accessed November 2009).

VON BRAUN, J. & MEINZEN-DICK, R. (2009) ""Land Grabbing" by Foreign Investors in Developing Countries: Risks and Opportunities". Policy Brief No:13. International Food Policy Research Institute.

WEBB, P., VON BRAUN, J. & YOHANNES, Y. (1992) Famine in Ethiopia: policy implications of coping failure at national and household levels. Washington, D.C, International Food Policy Research Institute (IFPRI).

YANG, H., ZHANG, X. H. & ZEHNDER, A. J. B. (2003) Water scarcity, pricing mechanism and institutional reform in northern China irrigated agriculture. Agricultural Water Management 61, 143-161.