ETHIOPIAN INSTITUTE OF WATER RESOURCES

ADDIS ABABA UNIVERSITY

Sustainable use of irrigation water, water footprint and virtual water in advancing transboundary water policy in the Nile Basin countries

By

Amanuel Abate Ararssa

A Dissertation Submitted

to

Ethiopian Institute of Water Resources

Presented in Fulfillment of the Requirements for the

Degree of Doctor of Philosophy

in

Water Resources Engineering and Management

Addis Ababa University
Addis Ababa, Ethiopia
July 2020

Sustainable use of irrigation water, water footprint and virtual water in advancing transboundary water policy in the Nile Basin countries

by

Amanuel Abate Ararssa

A Dissertation Submitted

to

Ethiopian Institute of Water Resources

Presented in Fulfillment of the Requirements for the

Degree of Doctor of Philosophy

in

Water Resources Engineering and Management

Main Advisor:	**Dr. Mesfin M. Mekonnen** University of Nebraska, USA
Co-Advisor:	**Dr. Azage G. Gebremariam** Addis Ababa University (AAU), EiWR
Co-Advisor:	**Dr. Worku L. Mulat** Wollo University

Addis Ababa University
Addis Ababa, Ethiopia
July 2020

Addis Ababa University
School of Graduate Studies

This is to certify that the dissertation presented by Amanuel Abate entitled "**Sustainable use of irrigation water, water footprint and virtual water in advancing transboundary water policy in the Nile Basin countries**" and submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Water Resources Engineering and Management) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Advisor: Dr. Mesfin M. Mekonnen Signature _______________ Date: ______________

Advisor: Dr. Azage G. Gebremariam Signature _______________ Date: ______________

Advisor: Dr. Worku L. Mulat Signature _______________ Date: ______________

External Examiner: Dr. Mekonen Ayana Signature _______________ Date ______________

Internal Examiner: Dr. Amare Haileslassie Signature _______________ Date ______________

Internal Examiner: Dr. Zeleke Agide Signature _______________ Date ______________

Chairman: Dr. Tekalegn Ayele Signature _______________ Date ______________

____

Chair of Department or Graduate Program Coordinator

Acknowledgments

Above all, I glorify my Almighty God and his mother St' Mary for everything in my life and for giving me the courage to go on and finish my Ph.D. work successfully. I believed all the solution to pass the challenges or my strength to reach to this point came from my God.

Firstly, I want to express my sincere and profound gratitude to my supervisors Dr. Mesfin M. Mekonnen, Dr. Worku L. Mulat, and Dr. Azage G. Gebrmariam for their great support, professional guidance, and encouragement during my Ph.D. work. I was extremely lucky to have advisors who cared so much about my research work and replied very swiftly to my questions. They have been so informative and compassionate whenever I needed their support, regardless of the time limits. Thank you, Dr. Mesfin, for encouraging me to do my Ph.D. work with him and to provide a good study environment for me. I thank you for giving me the opportunity for a research visit in the Netherlands to make my Ph.D. experience productive. I have learned a great lesson from his solid research experiences and like the discipline. Dr. Azage's contribution to winning awards and securing grants was immense. His assistance in training, conferences, and administrative facilitation was highly appreciated. Once again, I am very thankful to all my beloved Ph.D. supervisors. This research work would not have been realizable without their support, encouragement, and supervision. I wish them a long life to all!

I would also like to thank the late Prof. Arjen Hoekstra, who passed away in his productive age, in late November 2019 for what he has done for me. Prof. Arjen, thank you for his kind help, and guidance by approving the request of Dr. Mesfin, May God rest his soul in peace in heaven. I would also like to thank Dr. Joep Schyns at the University of Twente, the Netherlands, for helping me to spend productive time during my study visit. I want to thank for his technical advice, encouragement, & support. It has been my pleasure to work with them. My Ph.D. dissertation has greatly benefited from their comments & suggestions. Thank you in particular to Dr. Befkadu Esayas, Dr. Abebe Chukala, Dr. Hatem Chouchane, Dr. Rick Hogeboom, Dr. Achenafi T., Shannon B., Kasish, Werk, Endawek A., Habtamu M., Dereje G., Solomon, & Joke.

I am very grateful to EiWR, Addis Ababa University, and Gondar University for funding my Ph.D. study and for providing testing instruments for the irrigation fieldwork. I would also like to thank the Ethiopian minister of water, irrigation, and energy for the financial support, without the financial help that the research work could not have finished. My thanks to the staff at EiWR who have always been able to provide administrative support. I am also grateful to ILRI Campus for providing info center facilities throughout the study period.

I am very grateful to my mother and father for their moral support that has played a pivotal role throughout my life. I am profoundly grateful to my beloved Geni, who has been with me on all my Ph.D. academic journeys and shared my joy with me. I want to thank my wonderful kid Hemi who made me smile and happy. Thank you all who helped me directly or indirectly.

Dedication

I dedicated this dissertation work for my family and parents!

Abstract

The world faces a huge challenge in balancing water demand for the growing populations and economic development while protecting the environment with declining freshwater supply. Deficit irrigation (DI) and organic mulching (OM), understanding the water footprint (WF), and virtual water will play a key role in sustainable water management in water-scarce regions. The main objective of the study is to provide policy-relevant information by estimating the virtual water flows and water footprint of major crops produced in the Nile Basin. The research consists of four main components: first, a case study aimed to evaluate deficit irrigation management and its impacts on yield and water productivity of barley; second, evaluating of the blue water-saving potential through deficit irrigation and mulching; third, a spatial analysis of the WF of major crops in the Nile Basin; and, finally, an assessment of the annual variability and long-term changes in WF and virtual water flow of selected crops in the Nile Basin countries. For the case study, the barley has been selected as a target plant for multiple reasons. Firstly, barley is the fourth most important annual cereal crop grown globally; secondly, the crop grows under a different agro-ecological zone; thirdly, barley is both irrigated and rain-fed crop and commonly cultivated across upstream and downstream countries. To determine the irrigation amount of barely, the irrigation field experiment was arranged in a randomized complete block design (RCBD) with four replicates and five irrigation treatments (fully irrigated treatment (FIT), 90% FIT, 85% FIT, 80% FIT, & 75% FIT). The AquaCrop model & the global WF accounting standard were used to calculate the WF of crops. For barley production at 80% FIT, the largest yield was recorded at 1700 kg/ha. The provision of a certain level of water stress (80% FIT) throughout the growing season, translates to a better yield relative to full irrigation. The reason for the application of less water to provide a better yield might due to, Kc value, soil, and the regional crop variety respond well to water stress. The FIT (2.01 kg/m^3) and 80% FIT (2.95 kg/m^3) treatments had the lowest and highest water productivity, respectively. The finding indicates that barley production using DI offers great potential in improving water use. The blue water-saving potential of DI and OM, the spatial and temporal variability of WF was modeled using the AquaCrop-OS plugin at a spatial resolution of 5x5 arc-minute grid cells for the year 1986-2015 based on a global data source. The blue WF of the selected crops was highest in Egypt, Sudan, South Sudan, and Tanzania. For the current situation, the total blue WF was 48.5 km^3/y per crop, 89% of which falls in Sudan (55%), and Egypt (34%). Production of sorghum account for the largest share of the blue WF (50%) followed by maize (21%), and rice (16%). DI combined with OM showed to reduce the current blue WF by as much as 42%. Egypt and Sudan exclusively rely on irrigation water while the rest are based on rainfed in which other countries need to use irrigation for better production. Rainfall and evapotranspiration are highly variable in all production regions, which are the main drivers affecting the availability and distribution of water resources. Likewise, the findings show that there is a substantial difference in green and blue WF among crops across the Basin countries. The largest average blue WF (m^3/y) in crop production was found in Sudan, South Sudan, and Egypt. In Sudan, the crops with large WF are maize (6046m^3/tonne), rice (5175m^3/tonne), sorghum (2644m^3/tonne), and millet (2160m^3/tonne) and in Egypt, groundnut (3138m^3/tonne). Egypt is the largest exporter of rice with an average net virtual water export of 810 Mm^3 per year followed by 19 Mm^3 in Sudan and 16 Mm^3 in Egypt for groundnuts production. The results of this study have some relevant policy implications and may be of great use in policy formulation. This research provided empirical evidence of the potential blue water-saving; WF of crops and virtual water trade across the Nile Basin countries. Water-scarce countries like Egypt and Sudan can increase imports of water-intensive crops from relatively water abundant countries (upstream countries), and vice versa. It is important to know the national virtual water trade with internal and external virtual water flows in order to establish a sound national water policy. Virtual water trading can therefore help to sustain the water use of the regions in a sustainable manner. It is therefore necessary to use evidence that satisfies the various criteria for the design, planning and implementation of sustainable water resource management.

***Keywords*:** Sustainable, water use, water footprint, virtual water, water policy, Nile Basin countries

Lists of acronyms

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CRU	Climate Research Unit
CWP	Crop Water Productivity
CWR	Crop Water Requirement
DAP	Diammonium Phosphate
DI	Deficit Irrigation
EIWR	Ethiopia Institute of Water Resource
ET	Evapotranspiration
Eta	Actual crop evapotranspiration (m^3/ha)
ETo	Initial evapotranspiration
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statics
FC	Field Capacity
FIT	Fully Irrigated Treatment
GIS	Geographic Information System
IWMI	International Water Management Institute.
IWRM	Integrated Water Resource Management
ISRIC	International Soil Reference and Information Center
LNB	Lower Nile Basin
MASL	Meter Above Sea Level
NBI	Nile Basin Initiative
NVW	Net Virtual Water
NVWE	Net Virtual Water Export
NVWI	Net Virtual Water Import
OM	Organic Mulching
PWP	Permanent Wilting Point
RAW	Readily Available Water
RCBD	Randomized Complete Block Design

Sb-I	Blue soil moisture from irrigation
Sb-CR	Blue soil moisture from capillary rice
TAT	Total Available Water
Ton	Tonne
Tmax	Maximum Temperature
Tmin	Minimum Temperature
TN	Total Nitrogen
UNB	Upper Nile Basin
UNEP	United Nation Environmental Program
UNESCO	United Nation Educational Scientific and Cultural Organization
UNSD	United Nations Statistical Division Database
VW	Virtual Water
WF	Water Footprint
WFA	Water Footprint Assessment
WP	Water Productivity

Table of contents

List of Figures

List of Tables

1. Introduction

1.1 Background

In the face of complex climate change and the ensuing reduction in freshwater availability, the world is facing huge water crises in balancing the demand and supply of water for the growing population. Globally, people in many parts of the world face severe water shortages (Seckler *et al*., 2003). The increasing pressure on these freshwater has been due to population growth, climate change, and economic development to improve the quality of life. As development increases, the water demand could increase for different sectors, under which the pressure would aggravate (Stephens & Couzens, 2016). Studies on sustainable and efficient use of water, water footprint, and virtual water are so vital to alleviate the water scarcity problems. Enhancing irrigation methods and technology by implementing the best water management technique and interventions in policy needed to mitigate the water shortage through efficient and equitable water use and improved water allocation. Unless water mgt improves to balance supply and demand, it would be difficult to support an ever-increasing population (Multsch *et al*., 2017).

Water scarcity can be alleviated through the potential solution of water footprint reduction in agriculture (Nouri *et al.,* 2019); virtual water which can fill the gap between the demand and supply (Hatem *et al*., 2018) and deficit irrigation as an alternative strategy to save water and irrigate more area (Mekonen, 2011). The equitable share of water benefits in the transboundary basin is important in solving disputes among riparian countries (Arjoon *et al*., 2016). Water footprint and virtual water flows are directly related concepts that have been introduced by Hoekstra and Hung in 2002 for better water management. By linking the concept of virtual water, water footprint analyses, and efficient use of water through irrigation techniques, it can provide an appropriate framework to find potential solutions to contribute to better water management (Aldaya *et al*., 2010). Sustainable, efficient, and equitable use of water is necessary to mitigate the water shortage (Mekonnen *et al*., 2015). Studying the water footprint and the virtual flow of crops have been increasingly emerged recognized as a mechanism for improving national water security (Mekonnen &Hoekstra, 2014). Water management strives to achieve optimal &efficient allocation of available water for various uses within the Basin countries.

Bluewater shortage is a concern in the Nile Basin countries, which needs to reduce the blue water footprint. Regional water savings could achieve in a water-scarce Basin like the Nile Basin by implementing deficit irrigation and organic mulching. Moreover, incorporating water footprint and virtual water into water policy is one possible mechanism for introducing better water management and can avoid potential water use disputes. Water management through water footprint and virtual water could be an instrument to alleviate water scarcity (Mekonnen &Hoekstra, 2011; Qasemipour &Abbasi, 2019). Many nations save domestic water resources by importing water-intensive products and exporting less water-intensive commodities. On the other way, a water-scarce country might wish to import products that require more water in their production and export products that require less water (Mekonnen & Hoekstra, 2011). This will alleviate the pressure on the nation's water resources. Sustainable and efficient irrigation water use including awareness of water footprint and virtual water for advancing resources policy in the transboundary Bain can therefore play a vital role in sustainable water management.

The water footprint concept

The water footprint concept has developed to have an indicator of water use in relation to the consumption of people. It was introduced by Hoekstra and Hung in 2002 to have a consumption-based indicator of water use that could provide useful information. It refers to all forms of freshwater use that contribute to the production of goods and services consumed by inhabitants of certain geographic areas (Chapagain & Hoekstra, 2004). The water footprint can be regarded as a comprehensive indicator of freshwater appropriation, next to a restricted measure of water withdrawal (Hoekstra *et al*., 2011).

The 'water footprint' concept has emphasized the global dimension of water use and the importance of considering water use along the supply chain (Chapagain &Hoekstra, 2003; Hoekstra, 2017). A water footprint is defined as the amount of water used to produce a product or service i.e. no longer available for immediate reuse (Mekonnen &Hoekstra, 2011). The idea of 'water footprint' introduces an analytical framework to investigate the correlation between goods and services consumption and water resource use (Hoekstra, 2017). It is an indicator of the consumption of fresh water, which explores both the direct and indirect use of water for different use. The water footprint within a geographically delineated area is equal to the sum of the water footprint of all processes taking place in that area (Hoekstra *et al*., 2011). The water footprint of crop production is the sum of all the water required to produce the particular crop production (Mekonnen & Hoekstra, 2010; Wang *et al*., 2019).

According to Hoekstra and Chapagain (2008), the water footprint of national consumption is defined as the total volume of freshwater that is consumed by the inhabitants of the nation used to produce goods and services. The water footprint has three components, (blue, green, and grey) water (Hoekstra *et al*., 2011). Bluewater footprint is the amount of surface or groundwater, which evaporated incorporated into the products. A greywater footprint is also, the volume of polluted freshwater that is required to assimilate a load of pollutants in the existing ambient water quality standards. The green water could be either efficiently used for plants transpire or unproductively evaporated from the soil or vegetation (Hoekstra *et al*., 2011; Falkenmark & Karlberg, 2014).

Virtual water flows

International trade of commodities implies flows of virtual water over long distances. According to Mekonnen and Hoekstra (2010), with increasing trade between nations and continents, water is more frequently used to produce exported goods. International trade in commodities implies distance transfers of water in virtual form (Chapagain *et al*., 2008). The virtual water flow among the nation is the volume of virtual water that is being transferred from one to the other as a result of product trade (Zhang *et al*., 2018). Virtual water is the volume of water required to produce a commodity or service. Virtual water import is become an alternative water source, next to internal water sources. Virtual water imports allow nations to save scarce domestic water resources by importing water-intensive products and exporting commodities that require little water (Allan, 2003 & Chapagain *et al*., 2006a).

In addressing inadequate water problems, most governments may focus on expanding supply through dams, reservoirs, and Basin transfers. Since real water transfers over long distances are economically infeasible; it can offer a more efficient way of reduction of water pressure in water-scarce regions (Gerbens *et al*., 2008). The idea of ‘virtual water import’ as a means of reducing the burden on domestic water was introduced by Allen *et al*., (1998).

Knowing the virtual water flows entering and leaving a country can put a completely new light on the actual water problems of a country (Chapagain & Hoekstra, 2003). For example, Egypt, with water self-sufficiency high on the political agenda and with a total water withdrawal inside the country of 65 billion cubic meters per year, still has an estimated net virtual water import of 10 to 20 billion cubic meters per year (Chapagain &Hoekstra, 2003). The nations, on the other hand, faces water shortage and low water import dependency, aiming at consuming the Nile water to achieve food self-sufficiency.

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 abundantly available within the country for products that need resources that are scarcely available (Chapagain *et al*., 2006). People in countries where water is comparatively scarce could thus aim at importing products that require much water in their production and exporting products that require less water (Mekonnen &Hoekstra, 2014). This import of virtual water will reduce the pressure on the nation's water resources. Many goods consumed by the inhabitants of a country are produced in other countries, which means that the real water demand of a population may be much higher than the national water withdrawals do suggest (Chapagain *et al*., 2008). Even though the national water withdrawals have been substantial, a large amount of the products are being exported for consumption elsewhere (Chapagain *et al*., 2006).

International trade involves transfers of water for long-distance in virtual form, where virtual water has been understood as the volume of water that has been used to produce a commodity. Along these lines, virtual water flows analysis concerning agricultural commodity trade is very useful to investigate the extent to which a revision of trade agreements at the regional and global levels can improve the water balance (Kuiper *et al*., 2011). Virtual water trade as a component of water polices is contingent on the rules of the international market. Including virtual water as a policy option requires a thorough understanding of the impact and interactions of virtual water trade on the local, social, economic, cultural, and environmental situations (Van Hofwegen, 2004).

Currently, there is high recognition that the water footprint has led many researchers and academicians to research water management. Several studies have been conducted on global water use in different areas. Numerous national water footprints have been published recently. The first study on water footprints of nations was carried out by Hoekstra and Hung (2002). A more extensive assessment was done by many researchers. Studies have also shown that large amounts of virtual water flows occur as a result of global trade in agricultural and industrial products (Hoekstra, 2013).

The global water footprint has developed the statistics covering water footprints of crops, animals, water footprints of domestic and industrial sectors, and virtual water flows between nations due to international trade (Chapagain & Hoekstra, 2004). Mekonnen and Hoekstra (2011) updated the green, blue, and grey water footprint for agriculture, industry, and domestic globally at a high spatial and temporal resolution. The Spanish government ratified a regulation to incorporate water footprint in the process of developing river Basin management plans starting from 2010 (Aldaya *et al.*, 2010). Zhang *et al.* (2013), studied the sustainability of national consumption from a water resources perspective.

In the past few years, many studies have become available that show that the virtual water flows between nations are important. Because of global trade in both agricultural and industrial goods, many consumers have no longer any idea about natural resource use. Many counties have virtual water imports while some have exported (Chapagain *et al.*, 2008). From a water resources perspective, one may expect that countries with net virtual water import have purposely adopted this as a strategy to alleviate their water management problem. It is clear that virtual water flows between nations could be used as a means to improve global water management and to achieve water resource problems in water-stressed countries (Gerbens *et al.*, 2008; Hoekstra, 2011).

In recent years, there have been various attempts to assess global water consumption in agriculture at high spatial resolution. More recently, a few studies have separated global water consumption for crop production into green and blue water. Mekonnen and Hoekstra, (2011) made a global estimate of agricultural green and blue water consumption in a grid-based approach with a spatial resolution of 5x5 arc minute without showing the water use per crop and applying crop categories in the underlying model. Virtual water imports can save global water if water-intensive products are traded internationally from highly water productive areas to low water productive areas (Hoekstra *et al.*, 2011). Mekonnen and Hoekstra (2014), quantifies and maps the water footprint of Kenya from both production and consumption perspectives and estimates the country's virtual water export and import consumption perspectives and estimates the country's virtual water export and import.

There are various ongoing and completed research projects in the Nile Basin, which has implemented by several research organizations that are pertinent to the region. Hoekstra and Mekonnen (2011) allow a deeper look at the nature of water use in the Nile Basin could undertake a closer analysis of the types of water use. In the Nile Basin, the largest green water footprint is in the Southern parts of the Basin. On the other hand, the largest blue water footprint occurs in the Northern part of the Basin. Based on the various studies done elsewhere, the current study attempts to improve the assessment water footprint and virtual water trade in the Nile Basin by using more data that are accurate, covering more products than before, and refining the methodology where it appeared necessary.

According to Kuiper *et al*., (2011), the traditional water policy approach has always been supplied and producer oriented. The water footprint approach shifts the previous emphasis on supply towards demand management, where demand management is not limited to promoting water use efficiency at field level but extended to wise water governance in supply chains as a whole, thus also addressing trade and consumption patterns (Hoekstra *et al*., 2011). Governments and international organizations should include 'virtual water' accounts as an instrument in any national or regional water and agricultural policy analysis (Verkerk, 2007). Basin-wide cooperation is the optimal solution to the problem of managing international Basins. The national water policy can characterize by several strategies, planning processes, and integration to ensure the coherence of resource allocation is a major challenge.

Deficit irrigation for water management

Water management and water productivities rely on irrigation. Sustainable water management comes as a response to the challenge of avoiding resources unsustainable water use while increasing food production for an increasing demand from a growing global population (Karimi *et al*., 2013). One of the greatest challenges to increase food production with less water, particularly in countries with limited water is the lack of proper use of the available water.

Deficit irrigation practices and the application of mulching could be a sustainable crop production strategy in water-scarce areas. For example, the application of different systems of irrigation water use for crop production could improve the efficient use of water. In many areas with increasing water scarcity, deficit irrigation is a vital water-saving strategy (Temesgen *et al*, 2018).

The shortage of soil moisture in the dry rain-fed areas occurs during the most sensitive growth stages of cereal and legume crops. As a result, rain-fed crop growth is poor and yield is consequently low. Different irrigation techniques can the limited amount of water, if applied during critical crop growth stages, result in substantial improvement in yield and water productivity (Deng *et al*., 2006). In the water-scarce region of the world, sustainable, efficient, and effective use of irrigation water for crop production has become a worldwide concern, which needs an urgent and immediate solution. Water stress at the mid-season stage is minimized and different deficit irrigation strategies using pond water are possible, depending on the amount of water available (Ambachew *et al*., 2014).

Evaluations of Irrigation make it possible to identify problems or lacks in the irrigation systems, which have to solve to improve irrigation productivity. The application of different irrigation systems needs to be evaluated. Water management through irrigation can be achieved by irrigation scheduling, including information about the irrigation set time (Pereira, 2005). Most studies investigate that the availability of water for agriculture is under threat. Water demanded irrigation at a farm level depends on the condition on when and which crop to produce, the volume and the frequency of irrigation, and the selection of irrigation method and technology (Marques *et al*., 2005).

One of the greatest challenges in this era is to increase food production with the available small amount of water, particularly in countries with inadequate water resources. Improved crop irrigation management is supposed to contribute to efficient water management and can alleviate water resource challenges.

1.2 The rationale of the study

In improving the efficient use of shared water resources in the water-scarce regions, it has paramount importance to conduct scientific research and development activities on the efficient and sustainable water use, water footprint, and virtual water to advance water policy. Water footprint assessment is getting wider acceptance as a comprehensive water use indicator. In Nile Basin, countries there are limited blue and green water footprint and scarcity studies at the national level irrespective of the existing significant climate variability. The innovative aspect of the current research is blue water-saving potential through deficit irrigation and organic mulching and long-term inter-annual variation assessment of blue and green water footprint in Nile Basin countries for the first time. Such a study could use by the governments to formulate and implement effective and appropriate water policies and strategies to reduce potential water resource conflicts. It also provides baseline data for policymakers to put appropriate remedial actions to develop an appropriate water management plan. Moreover, the study could provide inputs on effective water management strategies and foster transboundary water cooperation in the Nile Basin. It is important to quantify the green and blue water availability and use it to allocate for various demands. Unequal distribution of climate and water needs innovative solutions. E.g. in Egyptians to produce a kg of wheat it requires about 930m^3 /tonne from the total 0% green & 100% blue for Australia is vice-versa (Hoekstra, 2017). Despite the problem, this calls for an alternative perspective to deal with the problems.

It has been increasingly recognized among states cooperation on the development and management of Nile water for the welfare of the inhabitants (Mohamed &Loulseged, 2008). Since, as increased irrigation efficiency will not be enough to meet potential water demand in the Nile Basin (Multsch *et al*., 2017). Despite the challenges of water issues, the measure to resolve the challenge should be dealt with technically. A new school of thought emerged that water should not be seen as a source of conflict, instead it should be a source of cooperation and peace (Levy & Sidel, 2011; Salman, 2015). One of the pressing problems facing in such transboundary nations today is water resource management, particularly linked to efficient use of water, water footprint, and virtual water trade. The lack of a comprehensive and advancements in water resources policy in nations has caused adverse impacts on its management (Raskin *et al*., 2017).

The hydro politics of the Nile River Basin is missing a scientific approach, cooperative work, hydro-diplomacy, and equitable distribution hindering the sustainable development of the region. This scientific research on water footprint and virtual water has a significant contribution in enhancing the win-win cooperation of the shared water resources.

Parts of the findings of this research have been published in reputable scientific journals and could support various stakeholders, scientific societies, local communities, and decision-makers by developing the water policy on the transboundary Basin by guiding hydro diplomacy, peace, and cooperation on shared water resource development and management. The study will contribute to water conservation, water footprint, and virtual water to mitigate water scarcity and provide useful knowledge for policy formulation to manage water sustainable manner throughout the Nile transboundary basin. Furthermore, the study benefits to quantify the volume of virtual water transfer among the Nile Basin countries and estimate the water footprint of major agricultural products in Nile Basin countries. The study also highlights the value of efficient water usage, a policy mechanism that will strengthen and maintain the sustainability of shared water supplies.

1.3 Problem statement

The world faces an era of increased water scarcity. According to Arjoon *et al*., (2016), the discourse on transboundary water management has developed and changed significantly over the past decades. The fact that nations that are unable to domestically produce the food they need would be able to solve their food demand through trade in the global market was either not well understood or ignored (Paul &Wahlberg, 2008). Although the Nile River is one of the most important river Basins in the world, the Nile Basin countries face the challenge of water resource management. In the Nile Basin, there has been a strong emphasis on the national sovereignty of countries that allows governments to decide on their national development plans and develop natural resources available for their national socio-economic development (Williams, 2003; Abawari & Security, 2011).

A significant issue in the transboundary river Basin like the Nile is the equitable sharing of common resources such as water among Basin countries. However, the issues, concepts, and implementation of an equitable share of water could be a major challenge (Baten & Titumir, 2016). For water managers and political decision-makers in the transboundary Basin, the lack of concepts on water footprint and virtual water trade is a very useful tool that provides a useful strategy, appropriate policy, and solution for political stress in the regions (Tian *et al.*, 2018). Therefore, these studies analyze the efficient use of water, the water footprint, and virtual water trade of selected crop product that provides to develop equitable and appropriate water policy.

The Nile Basin countries experiencing water shortages due to aridity and man-made problems, and mismanagement of the available water (Di Nunzio, 2013). There is an uneven distribution of water resources in the region. Improved water management is required to balance water demand and supply, particularly in irrigated agriculture through saving water (Horst *et al.*, 2005; Multsch *et al*., 2017). One main issue is demand management by reducing the farm irrigation water demand by improved crop irrigation management (Perea *et al.*, 2018). Evaluation of the existing irrigation condition and the potential for water savings by improving the farm irrigation and yield at the field level is also essential (Horst *et al*., 2005). For instance, deficit irrigation for maize production is reported as an alternative means of improving water use in irrigated agriculture (Mekonen, 2011).

The export of products from a water-efficient region to water inefficient region can save water globally (Mekonnen & Hoekstra, 2011). In the Nile Basin the largest green water footprint is in the southern parts of the basin, In contrast, the largest blue water footprint occurs in the northern part of the basin, the majority being in Egypt and Sudan. There is a relative abundance of water resources, which can be controlled for development and trade. In the transboundary river Basin, virtual water trade on water resources is essential. Even though research on virtual water trade and water footprint has done globally, no research was carried out in Nile basin countries concerning the deferent scenarios.

The water-saving that could be achieved if most of the production was done in the upstream countries compared to the current situation where Egypt and Sudan produce large amounts of crops and where the crop water requirement is very high and more evapotranspiration per unit of cultivated area implies larger water footprint. But currently, Egypt has a relatively large yield compared to the rest of the Nile basin countries which lowers there water footprint. They have already reached their maximum productivity level with little room for improvement. The question is then as follows:

1.4 Research questions

The core research questions emerged from the statement of the problems:

1) How does deficit irrigation improve water management in the upper Blue Nile Basin?
2) What will be the overall water saving with the water footprint reduction by implementing deficit irrigation and organic mulching relative to the reference case?
3) What is the spatial extent of the green and blue water footprint in the Nile Basin countries?
4) How does the change in water footprint and virtual water trade help to reduce water scarcity in Nile Basin countries?

1.5 Objectives of the study

The overall goal of this study was to study the sustainable use of water, water footprint, and virtual water trade to advance water policy in the transboundary River Basin of Nile.

Here are the specific objectives of the study:

1) To evaluate deficit irrigation management and its impacts on yield and water productivity of barley
2) To evaluate the blue water-saving potential through deficit irrigation and organic mulching in Nile Basin countries
3) To analyze the spatial variability in the blue and green water footprint of selected and commonly used crops in Nile Basin countries.
4) To develop the long-term changes in water footprint and virtual water flows of selected crops in Nile Basin countries.

1.6 Limitations of the study

The data provided in this research used from the global data source based on some uncertainty. Other sources of uncertainty in the results presented in this dissertation include data that has been used as a course scale global source of data. Since the largest parts of the essential data sources are global, it has limitations that take account of uncertainties and possible errors. The deficit irrigation level was obtained by simulating different scenarios. It has demanding to obtain the optimum level of deficit irrigation. This study was limited to a few selected and commonly used Basin countries crops for virtual water trade among nations. To get a better view of the overall virtual water flows, more additional crops and other agricultural products should take into account. In simulating the model, assumptions were made like soil salinity was not taken into account. Eritrea was removed from among the eleven countries in which the data was obtained because the selected crops have not grown in that specific country. The other limitation was the irrigation field experiment was a one-season experiment. Given several uncertainties, the findings of the study provide a good basis for a rough comparison to guide further research.

1.7 Organization of the dissertation

This Ph.D. dissertation was divided into eight sections, consisting of four independent outputs contributions from four to seven sections. A brief overview of the content outline to ease the understanding of the relationship between all sections has been provided.

- ☞ Section one provides the general background of the study, problem statement, research questions, research objectives, limitations, and conceptual framework of the study (Introduction and background). This Section also presents the literature review and some concepts on the water footprint and virtual water.

- ☞ Section two presents the material and methods which consist of the general approach, data sources, and the conceptual framework of the study.

- ☞ Section three outlines the effects of irrigation management on yield and water productivity of Barley ‘*Hordeum vulgare'* in the Upper Blue Nile Basin: a case study in northern Gondar covered by the study (Research objective 1).

- ☞ Section four presents the blue water-saving potential through deficit irrigation and mulching in Nile Basin countries (Research objective 2).

- Section five assesses the spatial annual variability in the blue and green water footprint of selected crops in Nile Basin countries at high temporal resolution (Research objective 3).
- Section six precisely deals with analyzing long-term changes in water footprint (green and blue) and virtual water flows of selected crops in the Nile Basin countries over thirty years (Research objective 4).
- Section seven presents the general conclusion and recommendations, describes scientific contributions of the study, and potential policy implications.

2. Material and Methods

2.1 Description of the study area

This study was conducted in Nile Basin, which is located in North-East Africa and is shared by eleven countries, namely: Burundi, Congo, Egypt, Eritrea, Ethiopia, Kenya, Sudan, South Sudan, Tanzania, Uganda, and Rwanda (Figure 2.1).

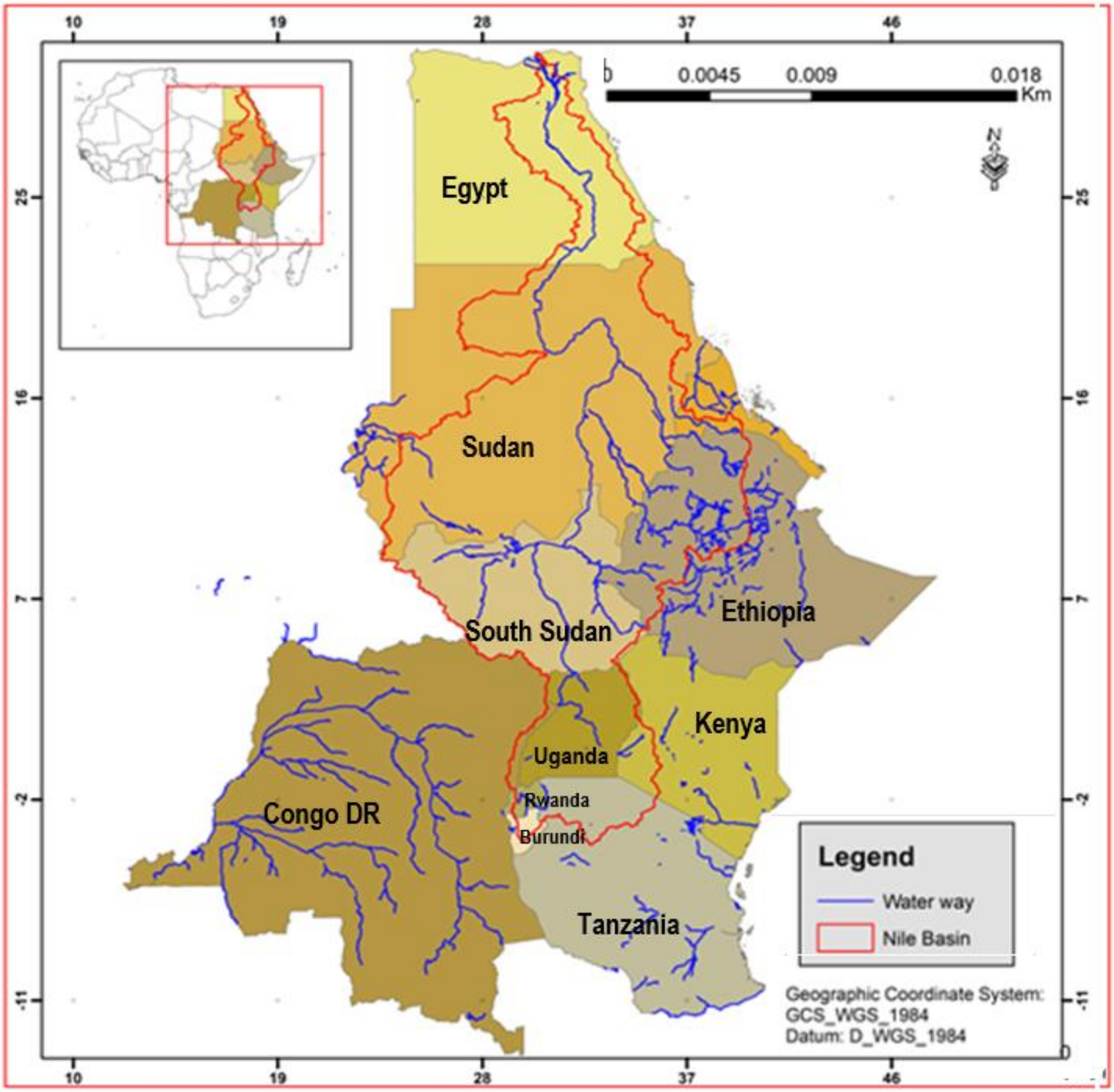


Figure 2. 1 The study area of the Nile River Basin countries

2.1.1 Rainfall climatology of the Basin

The Basin's area extends across the different geographical, climatological, and topographical regions with a different environment, social and economic aspects of the Basin. The vegetation cover in the Basin is strongly associated with the amount of precipitation. The precipitation amount is more than 1,000 mm/yr in the southern part and is almost zero in the northern part of the Sahara Desert (Mohamed & Loulseged, 2008). The precipitation and river-flow also encompass sharp seasonal and spatial variability across the Basin.

The Nile Basin covers various geographical, climatologically, and topographical regions with different environmental, social, and economic aspects (Mohamed & Loulseged, 2008). The Nile Basin has also characterized by high climatic diversity and variability, a low percentage of rainfall reaching the main river, and an uneven distribution of its water resources. The potential evaporation rate is high in the Northern part of the Nile Basin. Evaporation from Lake Nasser is currently high because the level of the lake is high after almost two decades of above-average rainfall in Ethiopia (Zeitoun *et al*., 2010).

2.1.2 Water resource of the Basin

The water resource of the Nile River is under increasing pressure due to rapid population growth and socio-economic development in the region (Ali *et al*., 2014). The Nile Basin is one of the world's largest basins extending 3.35 million km^2, equal to 10 percent of Africa's land and the world's longest river of 6700 km (Karimi *et al.*, 2011). The Nile River Basin occupies the African continent at around 10 percent. Nearly all Nile water is provided into an area that encompasses 20 percent of the Basin, while the rest is in arid or semi-arid regions (Zeitoun *et al.*, 2010). Egypt and Sudan are almost entirely dependent on the Nile for their water uses and, almost all other Nile countries are subject to water stress, or already below the $1000m^3$ water shortage thresholds per inhabitant per annum (Georgakakos, 2010). Water stress is exacerbated by rapid population growth, economic development, and climate change, which are double the global average rate. Therefore, extreme conditions of water shortages are emerging over most countries throughout the Nile. Irrigated agriculture can cause soil erosion, overflow, and sedimentation in downstream bodies of water (NBI, 2011).

2.1.3 Irrigation developments in the Nile

Irrigation development has to change the Nile River countries. Irrigation developments are planned and several are under construction. The irrigation developments could have a direct effect on the Basin populations, and governments as negotiate for water resources. Agriculture has been the main feature of Nile Basin countries for a hundred years (Awlachew *et al*., 2012).

According to Awlachew *et al.* (2012), the total irrigated area in the Nile Basin is 4.3 million ha, based on GIS measurements. Total irrigated area in the basin range from 4.9 million to 6.4 million ha (Johnston, 2012). Egypt and Sudan are dependent almost entirely on Nile water for irrigated farming. The arable land of Sudan is estimated at 105 million ha, with approximately 18 million hectares under cultivation, most of which are rain-fed (Awlachew *et al*., 2012). Irrigation development in Egypt and Sudan are being planned and executed. This expansion is to be maintained by the shifted water, but if there is no spill water available to return to the lakes it may mean catastrophe in the future.

Irrigated agricultural expansion over the last hundred years, often driven by foreign powers, and maintain to be the main influence on the decisions around the Nile River utilization (Awlachew *et al*., 2012). Upstream Nile countries have experienced a higher frequency of droughts, depending on rainfall, and cannot neglect the need to grow more food and increase demand, even at great cost; this includes irrigation. Ready to demand its share of Nile water, Tanzania plans to build a 170-km-long pipeline that will take water from Lake Victoria south to the Kahama irrigation project in an arid poverty-stricken area, benefiting thousands of people. Many upstream Nile countries that also feel more secure and motivated to find ways to tackle hunger and poverty will want to use their Nile water 'share' (Awlachew *et al*., 2012).

2.1.4 Nile water and agriculture

The economies of the Nile Basin are highly dependent on farming which accounted for more than half of the GDP and employs more than 80% of the working population. Nevertheless, the lack of water resources, significant climate change, and unsustainable agricultural practices have significantly reduced the economic development of the nations (Georgakakos, 2010).

Agriculture is the economic base of all the Nile Basin countries and the major consumers of water except in Uganda (Kloos & Legesse, 2010). The actual consumption (blue water footprint) is 5% of the water withdrawn for industrial purposes and the remaining fraction is the return flow (Mekonnen & Hoekstra, 2011). Although, agriculture has been a dominant feature of Nile Basin countries for centuries, irrigated agricultural expansion over the last hundred years, often driven by foreign powers, has caused a significant change in the use of the Nile water, and continues to be a major influence on the decisions around the Nile River use today (Awlachew *et al*., 2012).

The main dominant crops produced and harvested in the Basin are rice, sorghum, millet, maize, and groundnut. The high growth rate of the population in the Basin imposes pressure on water, the most precious common natural resources. Poverty, food shortage, and water scarcity, and environmental degradation are the most serious challenges facing the Nile Basin countries (Sulser *et al*., 2010).

2.1.5 Population of the Nile Basin

The study area focuses on the Nile Basin, which is the longest north-flowing river in the world, and located in North-Eastern Africa and shared by eleven countries (Melesse *et al*., 2014). Though the Nile Basin water is scarce, it is one of the transboundary Basins in which millions of people rely on its water resources (Melesse *et al*., 2014)**.** The high rate of population growth in the Basin rests pressure on its natural resources, including water. The population in the Nile Basin is estimated at around 202 million in 2005 and is expected to reach 336 million by 2030, suggesting that water scarcity could reach a crisis point if water needs cannot be met timely (Kloos & Legesse, 2010). As the demand for water increases, the link between the river and the watershed becomes a cause of conflict (Melesse *et al*., 2014).

Even though the Nile Basin is endowed with extraordinary natural resources, its inhabitants face considerable challenges. The region is considered one of the poorest regions of the world. More than 70% of the Nile population depends directly or indirectly on farming for their incomes and livelihoods (Mohamed &Loulseged, 2008).

2.2 General methodological approaches

The annual water footprint for the selected five crops was estimated in all the eleven Nile Basin countries for the years 1986 and 2015 following the global water footprint assessment standard (Hoekstra *et al*., 2011). The AquaCrop-OS plugin model, which is the open-source of FAO's AquaCrop model, was applied to evaluate the green and blue water footprint of crops in the Nile Basin countries. The model was implemented at 5x5-arc minute grids spatial resolution for all grid cells for all selected dominant crops for all the Basin countries.

The AquaCrop earth alternatives model built around on the plug-in version of AquaCrop 4.0 has been used which is set up by Hogeboom *et al*., (2019). To simulate the model, it has been used as the main AquaCrop papers of the FAO crop model to simulate yield response to water (Hsiao *et al.*, 2009; Raes *et al.*, 2009 and Steduto *et al*., 2009).

Finally, the model was executed by selecting the best rule. ET and crop yield were simulating the dynamic soil water balance during the study period based on the (Hoekstra *et al*., 2011). Blue and green water accounting in a soil water balance was separated following Hoekstra, (2019).

The output of the model had been processed to separate the soil water content and the number of ingoing and outgoing water into green and blue components. Furthermore, the blue soil water content was further separated into blue water originating from irrigation water (Sb-I) and blue water originating from capillary rise (Sb-CR). This partitioning allows us to track which fractions of ET originate from rainwater, irrigation water, and capillary rise, respectively (Chukalla *et al*., 2015). Changes in the green (Sg), blue from irrigation (Sb-I), and capillary rise (Sb-CR) soil water stocks described in the following three equations:

$$\frac{dS_g}{dt} = R - (Dr + ET)\left(\frac{S_g}{S}\right) - RO\left(\frac{R}{I + R}\right) \tag{3.1}$$

$$\frac{dS_{b,i}}{dt} = I - (Dr + ET)\left(\frac{S_{b,i}}{S}\right) - RO\left(\frac{I}{I + R}\right) \tag{3.2}$$

$$\frac{dS_{b,CR}}{dt} = CR - (Dr + ET)\left(\frac{S_{b,i}}{S}\right) \tag{3.3}$$

Where dt is the calculation for the time of one day, R precipitation (mm), I irrigation applied (mm), RO surface runoff (mm), ET is the evapotranspiration (mm), Dr drainage or percolation (mm), and CR capillary rise from the groundwater (mm). Bluewater forms part of the soil moisture since it is fresh surface and groundwater, that is, water in lakes, rivers, and freshwater in the soil. Separating green and blue components of ET is useful, as this split indicates the origin of the water that evaporates or transpires.

Sg is the content of green soil water (mm) and Sb is the content of blue soil water (mm). During the growing period, the green and blue parts of crop water use (CWU, m^3/ha) were calculated by aggregating the green and blue evapotranspiration (ET, mm/day).

$$\mathrm{CWU}_{\mathrm{green}} = 10\mathrm{X}\sum_{d=1}^{lgp} ET_{green} \tag{3.4}$$

$$\mathrm{CWU}_{\mathrm{blue}} = 10\mathrm{X}\sum_{d=1}^{lgp} ET_{blue} \tag{3.5}$$

Where ET green represents evapotranspiration of green water and ET blue is evapotranspiration of blue water. The water footprint of crop production is expressed as in m^3/tonne. Factor 10 is intended in the equation to convert water depths in millimeters into volumes of water per m^3/ha per land surface. The summation is done from the planting day (day 1) to the harvest day (lgp is the length of the growing period in days). Because different crop varieties can have significant variations in the length of the growing period, this factor can have a significant effect on the use of crop water. The green element in growing crops water footprint (WFgreen, m^3/tonne) is calculated as the use of green water in CWU green m^3 divided by crop yield (Y, t/ha). The blue part is calculated using the same technique (WFblue, m^3/tonne):

$$\mathrm{WF}_{\mathrm{green}} = \frac{CWU_{green}}{\mathrm{Y}} \tag{3.6}$$

$$\mathrm{WF}_{\mathrm{blue}} = \frac{CWU_{blue}}{\mathrm{Y}} \tag{3.7}$$

Yield has taken from the simulated yield of the model for all annual crops. For the method of crop water use, the average annual crop water use over the life span of the crop is taken. According to Hoekstra *et al.*, (2011), the total water footprint of the process of growing crops (WF) is the sum of green and blue water:

$$\mathrm{WF_{total}} = \mathrm{WF_{blue}} + \mathrm{WF_{Green}} \tag{3.8}$$

2.3 Conceptual framework of the study

In this study, the methodology was used as it set out the global standard for the water footprint of the AquaCrop model, which is developed by the water footprint network (Hoekstra *et al.*, 2011). The water footprint measures the amount of water used to produce each of the goods and services use. To calculate the water footprint of crops, one method of measurement is using the AquaCrop, which is the best model to use. The model was applied at a global scale using a resolution of 5x5 arc minutes.

For efficient water use for the transboundary Nile river basin, irrigation water management and water-saving practices were implemented for the better water management for shared water resources.

The required input data for water footprint and agricultural trade data was obtained from various global databases. The volume of crop-related to virtual water trade between nations average over the study period was calculated. To estimate the water footprint of crop simulations have done. Inter-regional and international virtual water trade was calculated. The calculation was made based on the method used by Chouchane *et al.*, 2018. Estimation methods have been applied using the standard of global conventional methods on water footprint and virtual water trade. Based on the finding of the study, by incorporating the water footprint and virtual water, the result could be input in developing water policy for Nile Basin countries. The overall framework is irrigation management, water footprint assessment, virtual water, and water-saving practices. In the study, it has to explore alternative management that could reduce crop water footprint and achieve more effective use of water. The framework for the study has shown in Figure 2.2. The framework for efficient water use of transboundary Nile River basin.

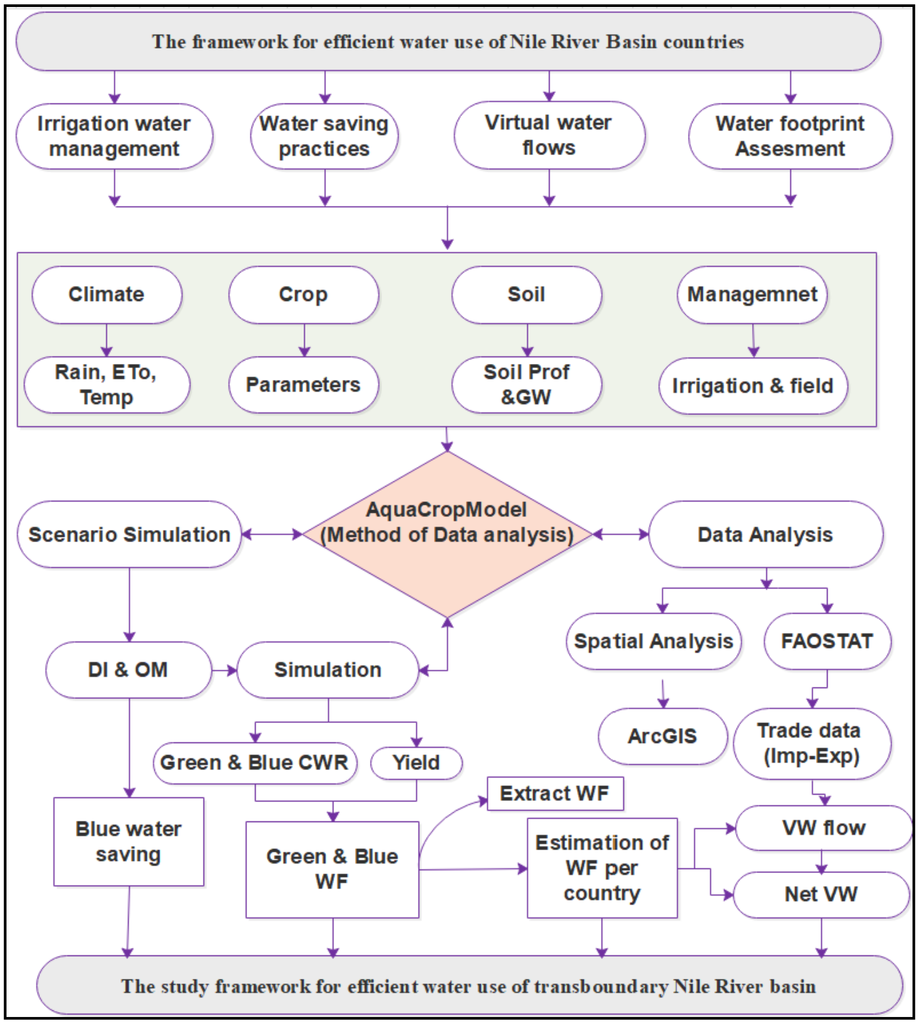


Figure 2. 2 Conceptual framework of the study

To achieve the efficient water use of Nile River basin countries various options have been used: irrigation water management, water-saving practices, water footprint assessment, and virtual water flows. Different water management strategies were used for efficient and improved water management. For the case study, an irrigation field experiment was done in the North Gondar which is the upper Nile basin catchment for the barley crop. Concerning the water footprint estimations of the selected crops, the global input data source from the FAOSTAT was used. AquaCrop model was used as a method of data analysis. From the model simulation, the blue and green CWR and yield data were obtained and based on the resulting green and blue water footprint was estimated. The net virtual water flow was obtained by multiplying the green and blue water footprint resulted from the simulations with the import and exported trade data obtained from the FAOSTAT based on the method used by Chouchane *et al.*, 2018.

2.4 Implementing the model

2.4.1 Model Set up

To define the best rules for the simulation result of water-saving scenarios of deficit irrigation; several simulations were implemented for specific crops with certain station data for the different agro-ecological zone. Based on those results the rule has been defined and implemented for the entire simulations. The following is the setup of the simulation effort. Since deficit irrigation and mulching can help in water footprint reduction or increasing crop water productivity, the production of three crops were selected in three climate stations (zones) in one year were considered. The management practices were with irrigation techniques (furrow), Irrigation strategies (full (FI) and different forms of deficit irrigation (DI) from 90%, 85%, 80%, and lesser of full irrigation, with mulching practices organic (OML) and without mulching.

Under full irrigation, the soil moisture was full to the field capacity when the root zone soil moisture depletion reaches 30% TAW. In the deficit irrigation conditions, sustained deficit irrigation strategies have been used. It has been expected that at different climatic zone, we could have different optimal irrigation levels. In most cases, the yield from full irrigation to deficit irrigation up to some depletion level could sustain the production. Nevertheless, after a certain level of depletion, it starts to decline swiftly.

The net irrigation has run in the initial condition when determining the rule. After running the net irrigation, then applies different rates of irrigation by reducing water application from full irrigation. Once the simulation has been done for the selected crop production, the optimal condition of applied irrigation, which has higher water productivity with a relatively higher yield has been selected. Once the simulation has done the relationship between yield and water footprint alongside applied irrigation amount in allegro climate zones has been implemented for selected crops using the mulching and without mulching with full irrigation and deferent levels of deficit irrigation.

2.4.2 Data

The water footprint of crops was estimated for all Nile basin countries for the period 1986-2015 following the method and using the same underlying datasets as (Hogeboom *et al.*, 2019). Various global data sources such as CRU for climate and ISRIC-WISE for soil datasets were used for the study. Data on crop yields and crop water requirements were obtained from simulation.

To estimate the crop water use of growing crops requires several input data for different combinations of crop, soil, and climate for soil water balance using the AquaCrop model. The climate data includes daily precipitation, daily reference evapotranspiration (ET_0), and maximum and minimum daily temperature. These climatic data were collected with a spatial resolution of 5x5 arc-minute grid daily from CRU TS-3.20 (Harris *et al.*, 2014).

Different global data sources were used to estimate crop water footprint. These five crops (rice paddy, maize, millet, sorghum, and groundnuts) were selected based on the FAO (2019) database on both the largest in production and area harvested. Monthly precipitation, daily reference evapotranspiration (ET_0), and daily maximum and minimum temperature were obtained from CRU TS-3.20 with a 5x5 arc-minute grid spatial resolution (Harris *et al.*, 2014).

Soil data with 5x5 arc minute resolution were obtained from the ISRIC dataset (Batjes, 2014). The MIRCA 2000 dataset was used for the irrigated and rain-fed harvested area for each crop at 5x5 arc minutes resolution (Portmann *et al.*, 2010) which made to fit FAO's national level total harvested area. The 'scaling coefficients' were adjusted to the MIRCA2000 reference map to meet the annual harvested area values. The yearly harvested area at the 5x5-arc minute was derived by multiplying the reference MIRCA2000 map by the scaling coefficients.

To get the initial soil moisture in the first year, the model was run over the whole period with initial soil moisture at field capacity, and then the average values were used. The results of a second run for the whole period, initialized in 1986 with derived average soil moisture, were used for the crop water requirement calculation. In calculating the crop water requirement, few assumptions were made. Some of the assumptions are soil water salinity was not taken into account. The yearly percentages of rain-fed and irrigated areas specific per crop were obtained from the FAO.

The crop trade data were obtained from FAOSTAT, (2019). The global averages of the water footprint of traded crops were obtained from Mekonnen & Hoekstra, (2011). To estimate the virtual water trade of the crops the calculation method was used which is developed by Chapagain and Hoekstra (2003). The full method has been indicated in the seventh chapter.

3. Effects of irrigation management on yield and water productivity of Barley ‘*Hordeum vulgare'* in the Upper Blue Nile Basin: A case study in Northern Gondar

Abstract

Deficit irrigation practices could be a sustainable crop production strategy in water scarce-regions. This paper presents the relationship between barley yield and various irrigation treatments based on a field-level experiment. This study aims to evaluate deficit irrigation management and its impacts on yield and water productivity of barley, *‘Hordeum vulgare’*. The field experiment was arranged in a randomized complete block design (RCBD) with four replications and five irrigation treatments (fully irrigated treatment (FIT), 90% FIT, 85% FIT, 80% FIT, and 75% FIT). The study showed yields of barley were significantly ($p < 0.05$) affected by the irrigation amount. At 80% FIT, the largest yield was recorded at 1700 kg/ha. The decrease in yield with increasing irrigation levels might characteristic to the variety of the barley in the region that performs well under water stress. Therefore, the highest yield is obtained at a lower irrigation volume than the full irrigation level. The provision of a certain level of water stress (80% FIT) throughout the growing season, translates to a better yield relative to full irrigation. The FIT (2.01 kg/m^3) and 80% FIT (2.95 kg/m^3) treatments had the lowest and highest water productivity, respectively. The finding indicates that barley production using deficit irrigation offers great potential in improving water use. Therefore, a deficit irrigation strategy that increases barley production in water-scarce areas is recommended to use water efficiently.

Keywords: Barley yield, water depth, water productivity, deficit irrigation, Ethiopia.

3.1 Introduction

In the face of climate change and the ensuing water scarcity problems in sub-Saharan Africa, increasing crop production is facing considerable challenges (Gebrehiwot and Gebrewahid, 2016). Many areas of the world are facing severe water scarcity (Seckler *et al*., 2003). Globally around 4 billion people live under severe water scarcity (Mekonnen& Hoekstra, 2016). Freshwater scarcity is a major problem for crop production in arid and semi-arid regions (Cavazza *et al.*, 2018). Without enhancing irrigation methods and technology in these regions, the goal of producing more crops tends to become a moving target (Usman and Kundiri, 2016). Better water productivity can increase in the irrigated area (Grafton *et al.*, 2018). Countries have been successful in using new irrigation technology to increase agricultural production (Perry *et al.*, 2017). Different field management strategies, such as mulching and deficit irrigation could use to minimize unproductive evaporation loss from the soil. Furthermore, careful scheduling and proper planting are among the various ways to improve water usage (Evans & Sadler, 2008). To make sound decisions, crop water requirement estimation is an important tool to ensure sustainable crop production (Irmak, 2015).

The pressure to produce more food to meet the requirements of the ever-increasing global population is expected to further strain the already limited water resources (Falkenmark & Karlberg, 2014). Given the fact that agriculture is the highest water user (Mila *et al*., 2017), freshwater stress may constrain global food production. In particular, crop production in water-scarce regions could be challenging due to climate disparity, longer dry environments, and associated problems (Kang *et al.*, 2009). Agricultural production is very difficult unless irrigation is well-managed in response to the challenges of water shortages and water scarcity (Kruashvili *et al*., 2016). Such water-related problems could be minimized by implementing the best water management techniques available (Amador &Jose, 2018). For irrigated crops, understanding the optimum crop water requirement in areas where water is a limiting factor is important to increase water productivity (Molden *et al*., 2010). In places where rainfall is low, increasing irrigation could help to raise crop yield (Irmak, 2015). Nevertheless, maximum yield does not always mean the highest water productivity and a reduced amount of applied irrigation water (Carvalho *et al*., 2016). In most agricultural regions, water shortage is becoming a challenge due to the increasing competition for limited water resources. Therefore, adjustment of water usage properly and increasing water productivity for proper water management is a must (Kang *et al*., 2009 & Molden *et al*., 2010).

Studies on barley crop water needs have taken place in Ethiopia and other regions. The response to irrigation levels for the production of barley and investigation into the yield under various water depths and schedules were studied (Araya *et al*., 2010). The effects of agronomy and soil on barley yield were examined (Bayeh & Berhane, 2011). The effects of fertilizer were analyzed (Shafi *et al*., 2011). Strategies for improving the productivity of water, enhancing management, and advancing irrigation technologies at the farm or field level were studied (Evans & Sadler, 2008). Field level study in irrigated agriculture revealed that for many crops, yield increases occurred without increasing the amount of water used (Molden *et al*., 2010; Bayeh & Berhane. 2011). Sustainable water management is vital to maximizing the production of crop products (Amador & Jose, 2018). Information on proper irrigation is essential to maximize yield per unit area and for sustaining crop production.

Even though research on different barley crops has been extensively conducted, the relationship between yield and crop water use has never been established in the study region. This work is new because it demonstrates the effects of various inputs at different treatment levels of water application to create improved water management for barley production. In this study, the barley *’Hordeum vulgare'* has been selected as a target plant for multiple reasons. Firstly, barley is the fourth most important annual cereal crop grown globally; secondly, the crop grows under a different agro-ecological zone; thirdly, it is the major food source in many African countries (Shafi *et al*., 2011). Consequently, in areas that experience water shortages, deficit irrigation could be an alternative strategy to maintain crop production (Sarwar & Perry, 2002). Deficit irrigation could allow growers to save water and irrigate more areas (Yenesew & Tilahun, 2009). For better crop water productivity, knowledge of the crop water requirement helps to raise production and results in enhanced water savings (Yenesew, 2015).

More advanced irrigation technologies lead to local water savings with less water applied. Studies suggest that water is not lost if the irrigation system is inefficient instead it remains in the hydrological system (Hoekstra, 2014; Usman & Kundiri, 2016; Grafton *et al*., 2018). Deficit irrigation could allow to reduce the amount of applied water and irrigate more area (Sarwar & Perry, 2002). One way of alleviating water insufficiency could be by increasing water use efficiency (Seckler *et al*., 2003). For better crop water productivity, knowledge of the crop water requirement helps to raise production and results in reducing the amount of applied water (Yenesew, 2015). Sustainable water use can be achieved by setting the water volume that can be consumed (Hoekstra, 2014). Effective management of water can save water by increasing the water availability for reallocation to the other use, such as the industries. For example, studies in biorefinery processes use large volumes of water and chemicals that could impact the sustainability of the industry (Pan *et al*., 2016).

The Ethiopian national barley yield average is low (Araya *et al*., 2010). The yield of barley has a strong relationship with the different levels of water depth. Therefore, proper irrigation scheduling or water management is needed. The yield of barley was reported to reduce when the water level was high in the study region (Feyisa, 2016). The increase in yield and water productivity was not significantly different compared to the water stress conditions (Araya *et al*., 2010). Since soil moisture conditions affect nutrient availability to the crops, optimum irrigation could maximize water productivity and higher yield (Hussain *et al*., 2007).

Barley is highly sensitive to waterlogging and the regional variety responds well to water stress (Araya *et al*., 2010). The crop water productivity values depend on crop yield (which fluctuates with factors such as variety, diseases, soil fertility, drought, and overall management practices), and evapotranspiration (ET) (which depends on factors such as climate, soil moisture, cropping calendars, mulching, rainfall, and irrigation (Bastiaanssen & Steduto, 2017). Crop water requirements tend to be highly location-specific with different management strategies, therefore studies conducted in some other areas cannot be directly adopted in this region. Deficit irrigation provides the means to optimize plant water use and to increase crop production. Therefore, the objective of this study was to determine the irrigation amount and its effect on the yield and water productivity of barley.

3.2 Methodology

3.2.1 Study area descriptions

The field experiment was conducted at the University of Gondar agricultural research station (experimental farm), located in the upper Blue Nile sub-catchment of 37^{0}26.105E longitude and 12^{0}35.96'N latitude (Figure 3.1). The map indicates the irrigation field experiment boundary. The experiment has done at the University of Gondar research site, which is part of the Upper Nile basin sub-catchment. The study area location map shows the specific irrigation field experiment for a better understanding.

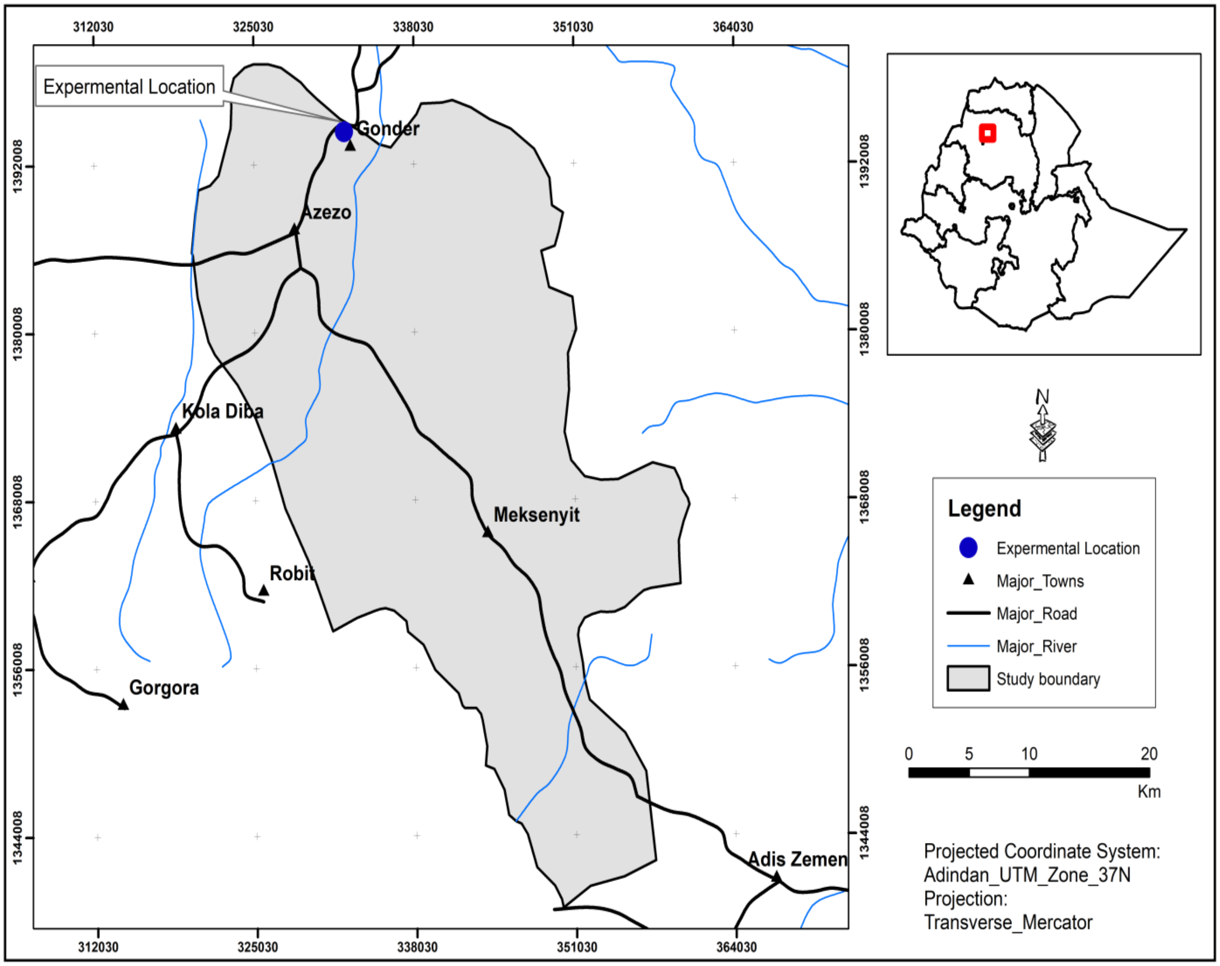


Figure 3. 1 Location map of the irrigation field experiment area

The experimental site is at about 2111 m.a.s.l altitude. The experimental site is located around 720km from Addis Ababa. The area receives annual average precipitation of 920 mm with maximum rainfall occurring from June to September. The average daily mean temperature value is about 21^{o}c. The laboratory analysis result revealed that the soil texture of the experimental area is clay loam. The area is generally characterized by poor drainage, with slow infiltration and permeability associated with heavy clay texture, flat topography, and a shallow groundwater table (Feyisa, 2016).

3.3.2 Experimental design and procedures

Ethiopia is one of the largest barley producers in Africa. It is a relatively dry heat-resistant grain and the fourth-ranked quantity produced in the world after maize, rice, and wheat as well as one of the main food sources in many African countries (Shafi *et al*., 2011). Moreover, barley is also found to be one of the major products around the study area (Bayeh & Berhane, 2011). Barley is one of the first food crops in the region in terms of area coverage and production. Recognition of the study district as one of the centers of diversity is another factor that made barley a suitable crop for investigating irrigation amount and its effect on the yield and water usage in the study area (Tadesse *et al*., 2018).

The field experiment was conducted during the dry season from 15th December 2016 to 15th May 2017 (a one-season experiment). The experiment was arranged in a factorial randomized complete block design (RCBD) with four replications. The RCBD design study was chosen for the field experiment because it has been applied with comparable experimental units of different treatments, which are grouped into blocks. Within each block, five irrigation regimes (Figure 3.2) were randomly distributed. Each treatment had a plot size of 3m x 3m with spacing between plots at 1m, and between blocks at 1.5m. A 1m border was left to separate plots, as it is useful, in avoiding border effect and facilitating management operations. Barley '*Hordeum vulgare'* seeds were planted on prepared plots in rows with 30cm spacing between them. Each plot consisted of 10 furrows that have diked to contain the irrigation water and eliminate runoff. The layout of the experiment has represented in Figure 3. 2.

75% FIT	80% FIT	FIT	90% FIT	85% FIT	Block 1
FIT	75% FIT	90% FIT	85% FIT	80% FIT	Block 2
80% FIT	FIT	85% FIT	75% FIT	90% FIT	Block 3
85% FIT	90% FIT	75% FIT	80% FIT	FIT	Block 4

Figure 3. 2 Schematic representation of the layout of the experimental plot

All standard plant management practices including fertilizer application, weed, and pest management were carried out. Fertilizer was applied based on the agronomic recommendation in the study area (69 kg/ha Urea and 57 kg/ha of diammonium phosphate, DAP). 69 kg/ha quantity of Nitrogen fertilizer was used with half applied at sowing and the remaining half at the mid-season stage, while the full P fertilizers were also applied at sowing. Crop water and yield data were taken from the central areas of each plot.

3.3.3 Amount of water under different treatments

As shown in Figure 3.3, a long, dry season occurred from October to May while maximum rainfall between June and August which reflects that the dry months in the study area were longer than the rainy season. For the dry season irrigation experiment, no effective rainfall was recorded. The irrigation amounts for different treatments are shown in Table 4.1. Below refers to different treatments under various combinations of the four growth stages (I to IV) and irrigation applications starting from full irrigation treatment FIT to 90% FIT, 85% FIT, 80% FIT, and 75% FIT. In the experimental season, irrigation was applied at 5-day intervals. Water was applied using garden watering cans with a fixed interval for all treatments.

Table 4. 1 Summary of irrigation amount (m^3/ha) for each treatment in the total growing season

	Treatments				
Date	FIT	90% FIT	85% FIT	80% FIT	75% FIT
15-December	7.1	6.7	6.3	5.9	7.9
20- December	7.1	6.7	6.3	5.9	7.9
25- December	7.1	6.7	6.3	5.9	7.9
30- December	16.2	15.3	14.4	13.5	18.0
4- January	16.2	15.3	14.4	13.5	18.0
9- January	16.2	15.3	14.4	13.5	18.0
14-January	16.2	15.3	14.4	13.5	18.0
19-January	16.2	15.3	14.4	13.5	18.0
24-January	16.2	15.3	14.4	13.5	18.0
29-January	29.3	27.7	26.0	24.4	32.5
3- February	29.3	27.7	26.0	24.4	32.5
8- February	29.3	27.7	26.0	24.4	32.5
13- February	29.3	27.7	26.0	24.4	32.5
18- February	29.3	27.7	26.0	24.4	32.5
23- February	29.3	27.7	26.0	24.4	32.5
28- February	33.9	32.1	30.2	28.3	37.7
5- March	33.9	32.1	30.2	28.3	37.7
10- March	33.9	32.1	30.2	28.3	37.7
15- March	33.9	32.1	30.2	28.3	37.7
20- March	33.9	32.1	30.2	28.3	37.7
25- March	33.9	32.1	30.2	28.3	37.7
30- March	36.3	34.3	32.3	30.3	40.4
4- March	14.2	13.4	12.6	11.8	15.8
9-April	14.2	13.4	12.6	11.8	15.8
14-April	14.2	13.4	12.6	11.8	15.8
19-April	14.2	13.4	12.6	11.8	15.8
24-April	14.2	13.4	12.6	11.8	15.8
29-April	14.5	13.7	12.9	12.0	16.1
4-May	14.5	13.7	12.9	12.0	16.1
9-May	14.5	13.7	12.9	12.0	16.1
Total	**648.7**	**612.6**	**576.6**	**540.6**	**720.8**

3.3.4 Crop water requirement and irrigation application

As previously, noted barley was selected because it is one of the dominant crops cultivated in the area and has considerable adaptability to the agro-ecological zone of the region. The growing season of the crop was mainly divided into four major growth periods: initial, development, mid-season, and late-season stages. Fully grown crops consume more water than just planted crops.

Crop water requirements of barley over the growing period were determined by multiplying the reference evapotranspiration and crop coefficient for each of the four growth stages. Lengths of the four growth stages and the respective crop coefficients were taken from FAO. A selected combination of irrigation depth, water application, and the barley's growth stage was used in the experimental design to determine the optimum water application depth at specific growth stages to determine optimum crop water depth. The determination of the crop water requirement has been based on established methods. Five different levels of irrigation water supply were scheduled. These were full crop water requirements with full irrigation at 90% FIT, 85% FIT, 80% FIT and, 75% FIT level application. Since there is no site-specific estimated crop coefficient in the region, the respective crop coefficient for initial, middle, and late growth stages was taken from (Allen *et al*., 1998).

Based on the climate of the study area, crop water requirements of the barley were determined using the AquaCrop model. Thirty-four years (1980-2014) of meteorological data obtained from the Ethiopian National Meteorological Services Agency and the crop coefficient from the Food and Agriculture Organization (FAO) were used. The crop parameters used for the estimation of crop evapotranspiration, water balance calculations, and yield reductions due to stress were the crop coefficient (Kc) and length of the growing season. The FAO Penman-Monteith method was used to calculate evapotranspiration (Allen *et al*., 1998). The following equation shows the crop water requirement for barley crops.

$$CWR = ET_O X K_C \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (4.1)$$

CWR = Crop water requirement (mm/day), ETo = Initial evapotranspiration (mm/day), and Kc = Crop coefficient (constant).

3.3.5 Crop Water Productivity (CWP)

Crop water productivity (CWP) is defined as the measure of the economic or biophysical gain from the use of a unit of water consumed in crop production (Bastiaanssen & Steduto, 2017). Generally, it can be defined as the output, yield (kg/ha) over the water consumed (m^3/ha). This means the output may be expressed either as physical production in kilograms per unit area or economic return in dollars per unit area. The water input is the amount of water applied to the cropped area per season. In this study crop, water productivity was estimated as the ratio of crop yield to the total irrigation depth applied to during the season (Temesgen *et al.*, 2018). It is expressed as:

$$CWP = {}^{Y}\!/_{W} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.2)$$

Where CWP = expressed in kg/m^3 on a unit water volume basis
Y = grain yield (kg/ha)
W = irrigation depth applied during the season (m^3/ha).

3.3.6 Data collection and analysis

Soil samples were collected from a depth of 0-40cm to analyze its physical characteristics such as initial soil moisture content and its chemical characteristics including, electrical conductivity (EC), pH, and organic matter. Soil samples were collected from the field based on the root depth of the experimental barley crop during the irrigation season. The soil parameters were analyzed in the Bahir Dar soil-testing laboratory.

Weather data including daily rainfall, maximum and minimum temperature, relative humidity, solar, and wind speed were obtained from the meteorological station 5 km away from the experimental field. The study area is characterized by a semi-arid climate in which the majority of rainfall occurs from June to September. The rainfall intensity showed marked spatial and temporal variations and no rainfall was recorded at the experimental station during the growing season.

The mean monthly rainfall, reference evapotranspiration distribution for the study area of the study period is shown in Figure 3.3. A comparison of those graphs explicitly shows that there was no source of moisture other than irrigation for the study period. There was massive rainfall during the extended summer, which occurs between June and September. The dry season followed summer from October to April.

The soil pH was determined based on the H_2O (1:2.5) Potentiometer method, texture (%) was based on the hydrometer method, organic matter (%) following Walkley black, and for the total nitrogen, Kejeldahl methods were used.

Crop water requirements of each treatment were calculated by multiplying the reference evapotranspiration values with the barley crop coefficients for the whole growing season (Allen *et al*., 1998). Irrigation water was applied at 5-day intervals on a total of six days per month. All treatments were devised according to the initially-planned framework and each received the required irrigation depth. The mean monthly rainfall and reference evapotranspiration of the study area is shown in Figure 3.3.

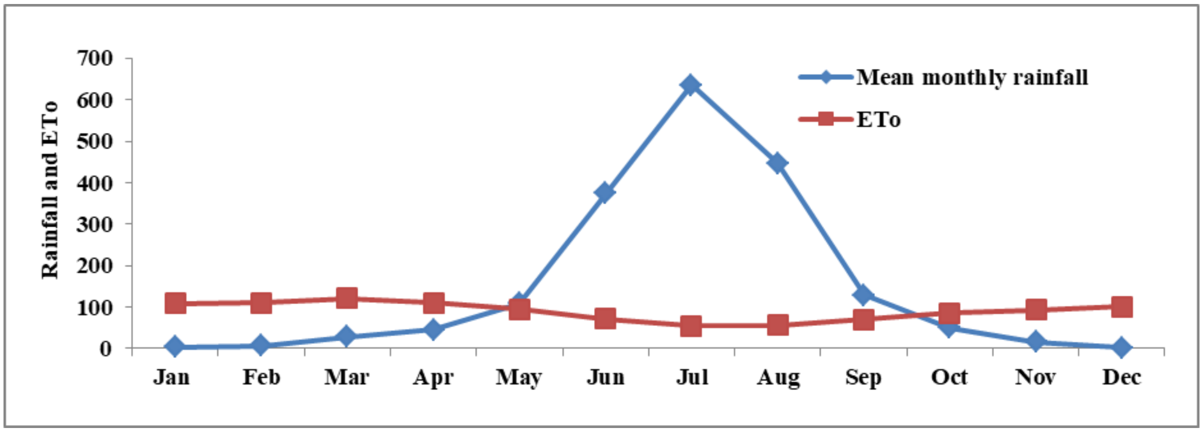


Figure 3. 3 Mean monthly rainfall and reference evapotranspiration (1980-2014).

Table 3.2 Mean monthly meteorological data of the study area (1980-2014).

Months	Tmin (^{O}c)	Tmax (^{O}c)	Humidity (%)	Wind speed (m/s)
January	10.7	29.1	33	2
February	12.4	30.8	28	2
March	14.2	31.7	30	2
April	15.5	31.7	32	2
May	15.4	29.8	45	1
June	13.6	25.4	70	1
July	12.8	20.2	90	1
August	12.3	20.1	92	1
September	11.3	23.8	81	1
October	11.8	26.4	59	1
November	11.3	28.6	43	1

Months	Tmin (^{O}c)	Tmax (^{O}c)	Humidity (%)	Wind speed (m/s)
December	10.6	28.7	35	1
Average	12.7	27.2	53	1

3.3 Results and discussions

3.3.1 Soil analysis

In the laboratory, soil samples were analyzed for pH, OC%, TN%, and texture%. The soil pH of the experimental field also varied with depth. From Table 4.3, the pH of the experimental site ranged from 6.5 to 6.6 in the 0-40 cm depth. The average pH of the soil is 6.6, which indicates that the soil at the site is within the recommended range, making it suitable for barley crop production.

According to the laboratory result, soil properties of the experimental site are within the recommended ranges. The threshold of organic carbon necessary for sustaining soil quality is widely suggested to be about 2%. Soil productivity may be affected by organic matter (OM) in various ways. Soil organic matter is the portion consisting of plant or animal tissue in various stages of decomposition. Cations are positively charged ions such as calcium (Ca2+), magnesium (Mg2+), and potassium (K+), and sodium (Na+). The capacity of the soil to hold on to these cations is called cation exchange capacity (CEC). Cations are held by the negatively charged clay and OM particles in the soil through electrostatic forces. The CEC cations in the soil particles are easily exchangeable with other cations and as a result, are plant-available. Soil characteristics are shown in Table 4.3.

Table 4. 3 Results of soil laboratory analysis for samples from the experimental site

Depth (cm)	PH H_2O (1:2.5)	Texture (%)			Classes	OC%	TN %	FC (%)	PWP (%)	TAW (%)
		Sand	Silt	Clay						
0-20	6.51	23	38	39	Clay loam	2.35	0.21	35.0	17.2	17.8
20-40	6.62	23	44	33	Clay loam	1.92	0.17	34.5	16.6	17.9

3.3.2 The effects of water depth on yield and water productivity (WP)

The effect of water depth on grain yield for the same seeding rates and management practice has shown in Table 4.4. The analysis of variance (ANOVA) showed that the effects of irrigation amount on yield had a substantial effect on levels at $p < 0.05$ (Table 4.4). For yield analysis, grain was considered because it was the best predictor of treatment response. A one-way ANOVA test showed that there is a statistically significant difference between the groups in at least two of the treatments applied (F=22.88). Using the least significant difference (LSD) test, the F-test was significant at level 0.05. The effect of different levels of irrigation on barley grain yield showed a notable variation ($p < 0.01$) between the treatments.

Table 4. 4 Yield, irrigation amount(mm/total growing period) and WP (from the field experiment)

Treatments	Irrigation amount(m^3/ha)	Yield (kg/ha)	WP (kg/m^3)	Yield rank	WP rank
FIT	721	1450 ± 21^a	2.01	5	5
90% FIT	649	1510 ± 24^b	2.33	3	4
85% FIT	612	1680 ± 32^c	2.75	2	2
80% FIT	577	1700 ± 16^c	2.95	1	1
75% FIT	541	1480 ± 24^a	2.74	4	3
CV (%)	3.13				

Nb: a, b, and c show the noteworthy difference between treatments where a corresponds to full irrigation treatment (FIT) and 75% FIT, b to 90% FIT, and c to 85% FIT and 80% FIT.

The LCD test also showed that a substantial difference in the means of yield exists at 0.05 significant levels. The result displayed in Table 4.4 indicated that the yield of barley depends on the amount of water depth with different levels of deficit irrigation. The results revealed that the higher barley yield was obtained under 80% FIT (1700 kg/ha) treatment with an irrigation amount of 577 m^3/ha that was subjected to 80% FIT application (Table 4.4) water stress, whereas, after 80% FIT application, the yield declined. Accordingly, the minimum yield was obtained under the FIT application (1450 Kg/ha). A similar result was reported when a lesser amount of irrigation water was required to improve barley yield (Feyisa *et al.*, 2016). By contrast, the high yield was found under full irrigation (Araya *et al.*, 2010).

Since barley is a shallow-rooted crop, it demands less water during the growing seasons, up to a certain water limit. In other words, if the amount of water applied decreased to a certain level (80% FIT), the yield would increase under the best crop management conditions. The yield drops with any further increase in the applied irrigation amount, which could be due to a water logging problem (Araya *et al.*, 2010). There was no notable difference between the yield of 85% FIT (1680 kg/ha) and 80% FIT (1700 kg/ha) although it was applied with 90% FIT and 80% FIT level differences throughout the growing season. This clearly shows that the application of water to the crop down to 80% FIT is important in improving the yield while simultaneously enhancing water productivity. However, reducing the irrigation application beyond 80% FIT adversely affects the yield of barley; any reduction in 80% FIT irrigation significantly affects the yield. Any increase in irrigation, say to 90% FIT, reduces the yield slightly. Yield drops after 80% FIT due to waterlogging and a crop variety that requires less water.

The difference in yield when compared with the harvest obtained in (Araya *et al.*, 2010), could be due to the crop water requirement which itself depends on factors such as climate, soil, cropping calendars, soil treatment, mulching, rainfall patterns, irrigation scheduling, and irrigation systems. Moreover, the crop water productivity was influenced by yield, which changes with variety, diseases, soil fertility, and overall management practices. Grain yield of barley reportedly fell when the crop was waterlogged at the early growth stage and the mid or late period (Araya and Stroosnijder, 2010 and El-Wahed *et al.*, 2015). Tied ridging markedly improved the barley yield since low yield is attributed to waterlogging problems (Araya *et al.*, 2010). The variability of deficit irrigation can be attributed to climate, irrigation water management, and soil management among others.

The highest and least water productivity was observed in 80% FIT (2.95 kg/m^3) and FIT (2.01 kg/m^3), respectively. Similar results were reported (El-Wahed *et al.*, 2015) when applying 80% FIT water level which demonstrates better water productivity than applying the highest and the lowest irrigation amount with 75% FIT application and no deficit irrigation, respectively.

The rank of all treatments with regards to the highest yield and water productivity is presented in Table 4.4. 80% FIT obtained the highest (1700 kg/ha) rank while the FIT is placed in the lowest (1450 kg/ha) yield category. Applying 577 m^3/ha irrigation water at 5-day intervals offered a relatively higher yield than the application of 721 m^3/ha irrigation water at 5-day intervals (Table 4.4). Similar studies (Feyisa, 2016) also reported, that for barley crops, the highest yield is achieved during irrigation of less water from its ideal crop water requirement while minimum yield was also observed with the highest water depth.

2.3.3 Barley yield and reduced amount of applied irrigation water

During the field experiment, using FIT as a control, (maximum crop water requirement base) for all treatments, the highest and lowest reduced amount of applied irrigation water was recorded at 75% FIT (25%) and under FIT (0%), respectively. The amount of reduced applied irrigation water in 75% FIT was 25%, which is higher than the other four treatments (FIT, 90% FIT, 85% FIT, and 80% FIT). However, relative water productivity was better in the 80% FIT which ensures the highest yield. Results of relative WP are also presented in Table 4.5, which indicates that the highest and lowest values were obtained in 80% FIT(1.47) and FIT(1), respectively.

Table 4.5 Barley yield, reduced amount of applied irrigation water (water-saving), and relative water productivity

Treatments	Irrigation amount(m^3/ha)	Yield (kg/ha)	Water-saving (%)	Relative WP
FIT	721	$1450{\pm}21^a$	0	1.00
90% FIT	649	$1510{\pm}24^b$	10	1.16
85% FIT	612	$1680{\pm}32^c$	15	1.37
80% FIT	577	$1700{\pm}16^c$	20	1.47
75% FIT	541	$1480{\pm}24^a$	25	1.36
CV (%)	3.13			

Nb: a, b, and c show the significant difference between the treatments, where a corresponds to full irrigation treatment (FIT) and 75% FIT, b to 90% FIT, and c to 85% FIT and 80% FIT.

The average barley yield of the region between 2004 - 2014 varies from 1188 kg/ha to 1513 kg/ha (Samuel, 2016) which is similar to the current study. Comparable results were reported by other researchers (Araya &Stroosnijder, 2010; El-Wahed *et al*., 2015; Pan *et al*., 2017), showing that the progressive increase in barley yield with an optimum irrigation level of water depth could enhance water productivity. Barley production at Mezezo has been recorded up to 1926 kg/ha (Feyisa, 2016). Studies by Carter and Stoker (Carter & Stoker, 1985) and Hussain and Al-Jaloud (Hussain & Al-Jaloud, 1998) also reported the effect of irrigation amount on yield and yield components of barley, the results of which were in line with the current findings. Analysis of the results clearly shows that there is a high potential for enhancing water productivity of barley in the region through different levels of water application. In general, the application of an ideal amount of water was accompanied by increased barley yield and water productivity in the water-scarce region.

3.4 Conclusion

The application of different systems of irrigation water use for barley production improves water productivity by saving water while maintaining a better yield. The study showed barley can withstand a maximum level of irrigation water up to 80% FIT application level. The maximum yield of 1700 kg/ha was obtained under irrigation when barley was subjected to the aforementioned level of application. The lowest yield was observed under 75% FIT and FIT of irrigation application. Nevertheless, application beyond 80% FIT was found to produce lower yields indicating that too much water stress could decrease the yield. Generally, the study provides an optimal irrigation treatment of 80% FIT which results in better yields of barley production. Barley '*Hordeum vulgare'* is a good, drought-resistant crop that provides a better yield with less water. Hence, this method is recommended for application in the water shortage area.

4. Blue water-saving potential through deficit irrigation & mulching in Nile Basin countries

Abstract

Water scarcity is one of the critical challenges of the 21st century, mainly in arid and semi-arid regions, due to the consequences of the growing population and climate change. The present study evaluates the blue water-saving potential through deficit irrigation and mulching over the Nile Basin countries. It focuses on blue water savings in irrigated agriculture showing the effects of deficit irrigation and mulching on blue water footprint WF (excluding capillary rise). The AquaCrop model and the global WF accounting standard were used to calculate the blue water footprint of crops for current conditions and a water-saving scenario with deficit irrigation and organic mulching. The model was performed at a spatial resolution of 5x5 arc-minute grid cells in eleven Nile Basin countries for five selected crops from 2011-2015. The blue WF of the selected crops was the largest in Egypt, Sudan, South Sudan, and Tanzania. For the current condition, the total blue water footprint was 48.5 k m^3/y, largely located in Sudan (55%) and Egypt (34%). Production of sorghum accounts for the largest share of the blue WF (50%) followed by maize (21%), rice (16%), groundnut (9%), and millet (4%). The largest blue water footprint in Sudan is due to the large harvested area in the region. Deficit irrigation combined with mulching could reduce the current blue WF by 42%. Close to three-quarters of the reduction in the blue WF was in Sudan and more than two-third was related to sorghum. The findings underline that deficit irrigation combined with mulching could reduce blue WF and help in sustainable water use in water-scarce regions.

Keywords: Blue water-saving; water footprint; deficit irrigation; mulching; Nile Basin countries.

4.1 Introduction

Globally, about 4 billion people live in severe water scarcity at least one month a year (Mekonnen &Hoekstra, 2016). As population increases, then the development calls for increased allocations of water resources for agriculture, domestic, and industrial sectors, the pressure on the water would intensify, leading to tensions, conflicts among users, and excessive pressure on the environment (United Nations Water, 2006; Adeba *et al.*, 2015). The agricultural sector is the major water consumer globally (Hoekstra &Mekonnen, 2012). It accounts for 92% of the global blue water footprint (Hoekstra *et al*., 2012), thus with a significant contribution to the global blue water scarcity. The blue water footprint refers to the amount of surface and groundwater consumed as a result of agricultural production (Hoekstra *et al*., 2009). Bluewater scarcity generally results in reduced river flows and diminishing groundwater, streams, and lakes levels that affect ecosystems and people (Schyns *et al*., 2019). To reduce the blue water scarcity problem, there is a need to explore techniques that reduce the water footprint of crops (Rockstro *et al*., 2009; Hoekstra *et al.*, 2011; Mekonnen & Hoekstra, 2014; Schyns & Hoekstra, 2014).

There are various soil, water, and crop management practices that would help to improve crop water intake and improve water productivity (Perea *et al*., 2018; Pioufle & Declerck, 2018). Soil mulching could lower unproductive soil evaporation (Yunusa *et al*., 1994; Chukalla *et al*., 2015). Deficit irrigation strategy decreases consumptive water use and improves water productivity (Ararssa *et al.*, 2019; Molden *et al*., 2010; Du *et al*., 2015a; Karasu *et al*., 2015; Ali *et al*., 2017). According to Chukalla *et al*., (2015) an average reduction in the consumptive water footprint (WF) of 8–10 percent is achieved when it changes from the reference case (furrow full irrigation with no mulching) to drip irrigation system. 28 percent reduction in the consumptive WF is achieved while it shift from reference to drip or subsurface drip irrigation with synthetic mulching. When the available water is not enough to meet the full crop water requirement, deficit irrigation practices could be a viable option to optimize irrigation water application and crop yield (Du *et al*., 2015, Richter *et al*., 2017; Awel *et al*., 2018). Deficit irrigation and mulching could be used as a mechanism for reducing water footprint and achieving water security (Fereres & Rabanales, 2007).

Implementing deficit irrigation and mulching could be promising measures to implement by African farmers. Since blue water scarcity is a problem in most of the Nile Basin countries which could reduce the blue water footprint of crops. In a water-scarce Basin like the Nile Basin, regional water savings could be achieved through deficit irrigation and organic mulching. The water saved would share fairly among the different economic sectors and riparian countries reducing the competition for the limited water resources. For instance, Nouri *et al*., (2019), estimates the total water saving and water scarcity alleviation through drip irrigation and mulching at the catchment level. Potential water savings by partial relocation of crops to Basins where crops consume less water and reducing the water footprint of crops down to benchmark levels are important way outs (Hoekstra, 2013; Schyns & Hoekstra, 2014).

Many empirical studies examined the field level reduction of the water footprint in crops. Field level studies were carried out in different regions focusing on the effects of irrigation techniques, irrigation strategies, and mulching on the water footprint reduction of different crops (Fereres &Soriano, 2007; Igbadun *et al*., 2012; Chukalla *et al*., 2015; Razaq *et al*., 2019). All of the above-mentioned studies dealt at the field level. Regional/Basin studies were undertaken on the water footprint of crops in different parts of the world (Ghufran *et al*., 2015; Ababaei & Ramezani, 2016; Kayatz *et al*., 2019; Nouri *et al*., 2019). Santos *et al*., (2002) studied irrigation management under water scarcity by implementing improved farm irrigation systems and deficit irrigation to reduced water demand. Deficit irrigation as a strategy has emerged as potential ways to increase water savings (Costa *et al*., 2007) and it should become more prevalent in water-scarce areas (Fereres *et al*., 2003). All the studies have used either mulching, drip irrigation, or both to the water footprint of crops. Therefore, none of the studies have quantified the blue water footprint reduction for a scenario with both deficit irrigation and mulching at the national level. This particular study is unique in the region by evaluating the total blue water footprint reduction in the Nile Basin nations.

The blue water could use, besides in crop production, in many other economic sectors. Water resources in the Nile Basin have higher economic importance, particularly for agriculture (Whittington *et al*., 2005). All riparian countries should benefit from Nile water through equitable utilization for sustainable socio-economic development (Mohamed & Loulseged, 2008). However, the Basin has a high climate diversity and variability, low rainfall, and uneven distribution of water resources (Mohamed & Loulseged, 2008; Roth *et al*., 2018). Water scarcity in the region remains the major limiting factor for agricultural development in terms of both physical and economic water scarcity (Karimi *et al*., 2013). The Nile Basin is a region facing water scarcity primarily due to manmade problems and water resource mismanagement (Kloos & Legesse, 2010; Paulo *et al*., 2010). According to Karimi *et al*. (2013), the main constraint facing agricultural development in the Nile Basin has been water scarcity coupled with high population growth. Although the region is a water-scarce, it can improve water productivity (or reduce WF) and decrease the pressure on the limited water resources (Haileslassie *et al*., 2008). It is essential to improve water productivity to reduce the pressure in the Nile Basin region.

Yield in rainfed countries is low because it is difficult to meet the crop water requirement. The low yield in better-rainfall countries is due to high variability in rainfall and its unpredictable nature. Rainfed agriculture is subject to the occurrence of longer dry spells and droughts that highly affect crop productivity. Therefore, there is a need for supplementary irrigation during low rainfall. In rainfed crop production, adding a limited amount of irrigation water (supplementary irrigation) when rainfall fails to meet the crop water requirement would help to alleviate the negative effects of soil moisture stress on the crop yield. On the other hand, in irrigated crop production, different irrigation techniques and irrigation strategies would help to reduce the overall water demand (Chukalla *et al*., 2015). This study has evaluated the blue WF for the main irrigated crops namely: rice, maize, sorghum, millet, and groundnuts in the Nile Basin countries in both the current condition and a water-saving scenario with deficit irrigation and organic mulching. These five crops were selected based on the largest irrigated area harvested and produced in the Nile Basin, so the largest potential water savings through deficit irrigation and mulching can be achieved. The current study focused on water footprint reduction through deficit irrigation and organic mulching. The objective of this study is, therefore, to evaluate the potential blue water savings through deficit irrigation combined with mulching in irrigated agriculture in the Nile Basin countries.

4.2 Material and Methods

4.3 Description of the study area

The study area focuses on the Nile basin, which is the longest north-flowing river in the world, and located in North-Eastern Africa and shared by eleven countries (Melesse *et al.*, 2014). Though the Nile basin water is scarce, it is one of the transboundary basins in which millions of people rely on its water resources (Melesse *et al*., 2014)**.** The high rate of population growth in the basin rests pressure on its natural resources, including water. The population in the Nile basin is estimated at around 202 million in 2005 and is expected to reach 336 million by 2030, suggesting that water scarcity could reach a crisis point if water needs cannot be met timely (Kloos & Legesse, 2010). As the demand for water increases, the link between the river and the watershed becomes a cause of conflict (Melesse *et al*., 2014).

The basin's area extends across the different geographical, climatological, and topographical regions with a different environment, social and economic aspects of the basin. The vegetation cover in the basin is strongly associated with the amount of precipitation. The precipitation amount is more than 1,000 mm/yr in the southern part and is almost zero in the northern part of the Sahara Desert (Mohamed & Loulseged, 2008). The precipitation and river-flow also encompass sharp seasonal and spatial variability across the basin. The Nile basin is also characterized by high climatic diversity and variability, a low percentage of rainfall reaching the main river, and an uneven distribution of its water resources. The potential evaporation rate is high in the Northern part of the basin. Even though the Nile basin is endowed with extraordinary natural resources, its inhabitants face considerable challenges. The region is considered one of the poorest regions of the world. More than 70% of the Nile population depends directly or indirectly on farming for their incomes and livelihoods (Mohamed & Loulseged, 2008). Agriculture is the economic base of all the Nile basin countries and the major consumers of water except in Uganda (Kloos & Legesse, 2010). The actual consumption (blue water footprint) is 5% of the water withdrawn for industrial purposes and the remaining fraction is the return flow (Mekonnen & Hoekstra, 2011).

The main dominant crops produced and harvested in the basin are rice, sorghum, millet, maize, and groundnut. The high growth rate of the population in the basin imposes pressure on water, the most precious common natural resources. Poverty, food shortage, and water scarcity, and environmental degradation are the most serious challenges facing the Nile Basin countries (Sulser *et al.*, 2010).

4.4 Methods

The annual WF for the selected five dominant crops was estimated in all the eleven Nile Basin countries for the years 2011 - 2015 following the global water footprint assessment standard (Hoekstra *et al.*, 2011). To evaluate potential blue water savings the AquaCrop-OS plugin model, which is the open-source of FAO's AquaCrop model was applied in the Nile Basin countries. The model was implemented at 5x5 arc minute grids spatial resolution for all grid cells for all selected dominant crops. First, the simulation was done on the current agricultural practices (the reference case), that is without mulching and with standard full irrigation practice; second, simulate a scenario within irrigated areas deficit irrigation and mulching in irrigated areas. The water-saving was then computed as the difference between the blue water footprint in the reference and scenario. The type of mulching is 100% organic mulching which is natural origin materials that can decompose naturally (compost).

The AquaCrop earth alternatives model built around on the plug-in version of AquaCrop 4.0 has been used which is set up by Hogeboom *et al.*, (2019). To simulate the model, it has been used as the main AquaCrop papers of the FAO crop model to simulate yield response to water (Hsiao *et al.*, 2009; Raes *et al.*, 2009 and Steduto *et al.*, 2009).

After performed different levels of deficit irrigation to select an optimal deficit level, the deficit irrigation strategy with the lowest consumptive WF and reasonable yield reduction was selected after running in the model for different percentages of deficit irrigation levels across the Nile Basin countries. Simulations were done based on 80% surface wetting (furrow irrigation system) with sustained deficit irrigation strategies. Deficit irrigation was determined with just varying certain percentage depletion of available water (TAW), after which irrigation was triggered to fill the soil moisture back to field capacity (FC). Based on the rules, sustained deficit irrigation was applied. Finally, the model was executed by selecting the best rule i.e full irrigation was implemented to FC when soil moisture depletion reaches 30% of TAW and deficit irrigation to FC when soil moisture depletion reaches 60% of TAW.

Finally, the model was executed by selecting the best rule i.e full irrigation was implemented to FC when soil moisture depletion reaches 30% of RAW and deficit irrigation to FC when soil moisture depletion reaches 60% of TAW. ET and crop yield were simulating the dynamic soil water balance during the study period based on the global water footprint assessment standard (Hoekstra *et al*., 2011). Daily soil moisture was partitioned into a green and blue part. Bluewater accounting in a soil water balance was calculated following Hoekstra, (2019):

$$\mathrm{Sgt} = \mathrm{Sgt} - 1 + \mathrm{Pt} - \mathrm{ROt}\left(\frac{\mathrm{Pt}}{\mathrm{Pt} + \mathrm{It}}\right) - (\mathrm{Dt} + \mathrm{ET})\left(\frac{\mathrm{Sgt} - 1}{\mathrm{St} - 1}\right) \tag{1}$$

$$\mathrm{Sbt} = \mathrm{Sbt} - 1 + \mathrm{It} - \mathrm{ROt}\left(\frac{\mathrm{It}}{\mathrm{Pt} + \mathrm{It}}\right) - (\mathrm{Dt} + \mathrm{ET})\left(\frac{\mathrm{Sbt} - 1}{\mathrm{St} - 1}\right) \tag{2}$$

Where Sg is the content of green soil water (mm) and Sb is the content of blue soil water (mm). During the growing period, the green and blue parts of crop water use (CWU, m3/ha) were calculated by aggregating the green and blue evapotranspiration (ET, mm/day).

4.5 Data

Different global data sources were used to estimate crop WF. These five crops (rice paddy, maize, millet, sorghum, and groundnuts) were selected based on the FAO (2019) database on both the largest in production and area harvested. Monthly precipitation, daily reference evapotranspiration (ET0), and daily maximum and minimum temperature were obtained from CRU TS-3.20 with a 30 x 30 arc-minute grid spatial resolution (Harris *et al*., 2014). Soil data with 5x5 arc minute resolution were obtained from the ISRIC-WISE dataset (Batjes, 2014). The MIRCA 2000 dataset was used for the irrigated and rain-fed harvested area for each crop at 5x5 arc minutes resolution (Portmann *et al*., 2010) which made to fit FAO's national level total harvested area. The ‘scaling coefficients’ were adjusted to the MIRCA2000 reference map to meet the annual harvested area values. The yearly harvested area at 5×5 arc minute was derived by multiplying the reference MIRCA2000 map by the scaling coefficients. To get the initial soil moisture in the first year, the model was run with initial soil moisture at field capacity for the entire period and then we used the average values.

4.6 Results

4.3.1 The water footprint of selected crops in the reference period

The total blue WF in the Nile Basin countries in the reference period 2011-2015 for producing the five selected crops was 48.5 km^3/y (Figure 4.1). Sudan accounts for the largest share of the blue WF (55%) mainly related to the production of sorghum, which accounts for 79% of the blue WF in Sudan. The other major country with a large blue WF is Egypt, which accounts for 34% of the blue WF of the Nile Basin. The major crops in Egypt with a large contribution toward its blue WF are maize (53%) and rice (36%). Among the crops, the production of sorghum takes for half of the blue WF in the Basin, followed by maize (21%), rice (16%), groundnut (9%), and millet (4%). The current blue water footprint for five selected crops per country and crop has shown in Figure 4.1.

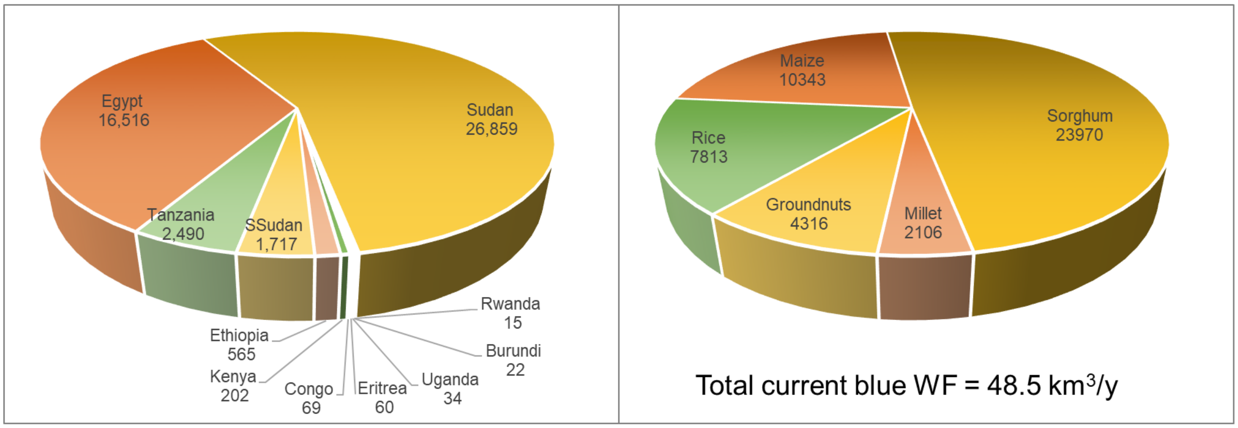


Figure 4. 1 The average blue water footprint of crops (million m^3/y per country) and crop in the reference period 2011-2015

4.3.2 Effects of deficit irrigation and mulching in reducing WF per tonne of crops

The blue WF reduction for five dominant crops in the entire Nile Basin countries was estimated by comparing the current agricultural practice and practice aimed at water footprint reduction (i.e., deficit irrigation and organic mulching). Because of the difference in climatic regions and soils, the result exhibited a significant difference in WF reduction across the Basin countries. It has been scaled Y back to reported Y in the reference (reflecting the Y limiting factors other than water that are not considered in the model) and applied the same factor in the deficit irrigation and mulching scenario. These scaling factors vary per country per year, so the soil also contributes to observing changes across countries. The results show for the total blue water saving (m^3/y) and the savings per ha (m^3/ha) per country, per crop. Based on the results in countries such as Egypt, Sudan, and Tanzania where rainfall is minimal and irrigation is extensive, the reduction in blue WF is large. However, in some countries, there is a smaller blue WFs reduction such as in Burundi and Congo. The reason for this could be crop production in these countries is mainly rainfed based on little irrigation according to the MIRCA2000 database (Portmann *et al*., 2010). Figure 4.2- Figure 4.6 shows, the blue WF for five selected crops in Nile Basin countries under the reference case and water-saving scenario in the period 2011–2015.

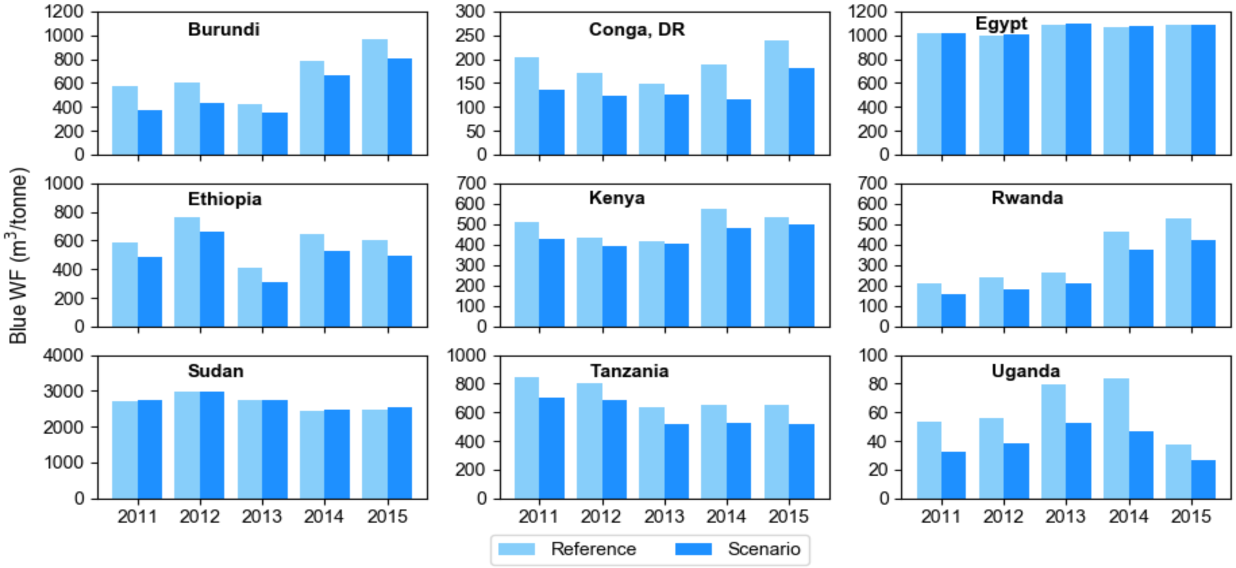


Figure 4. 2 The blue water footprint of rice in Nile Basin countries under reference and water-saving scenario in the period 2011–2015.

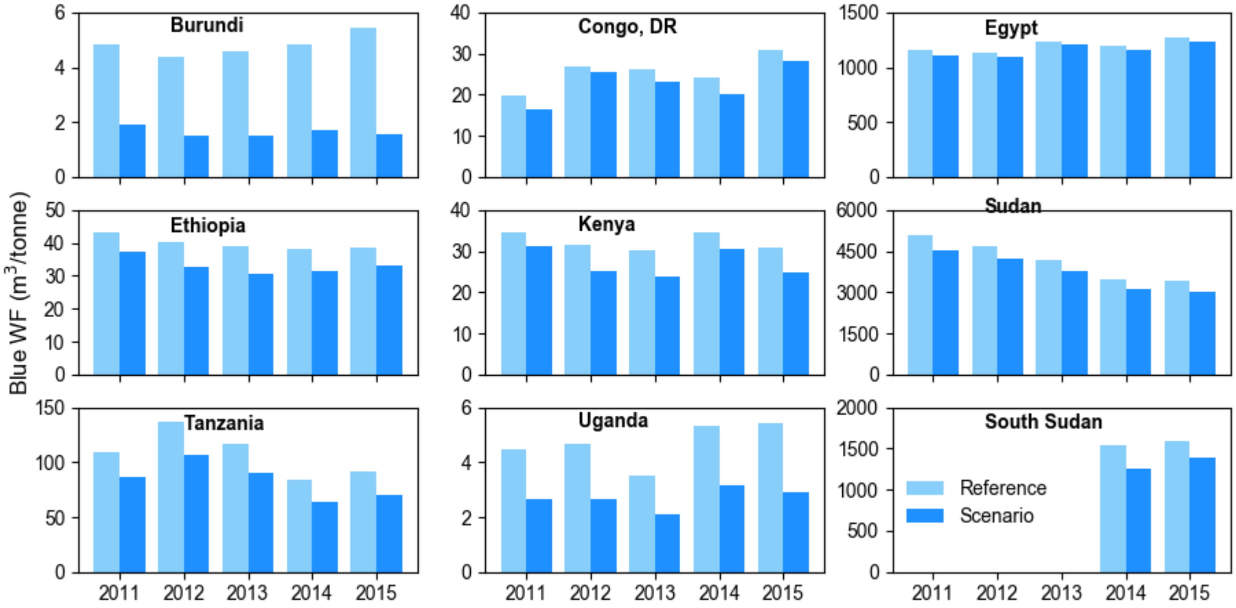


Figure 4. 3 The blue water footprint of maize in Nile Basin countries under reference and water-saving scenario in the period 2011–2015

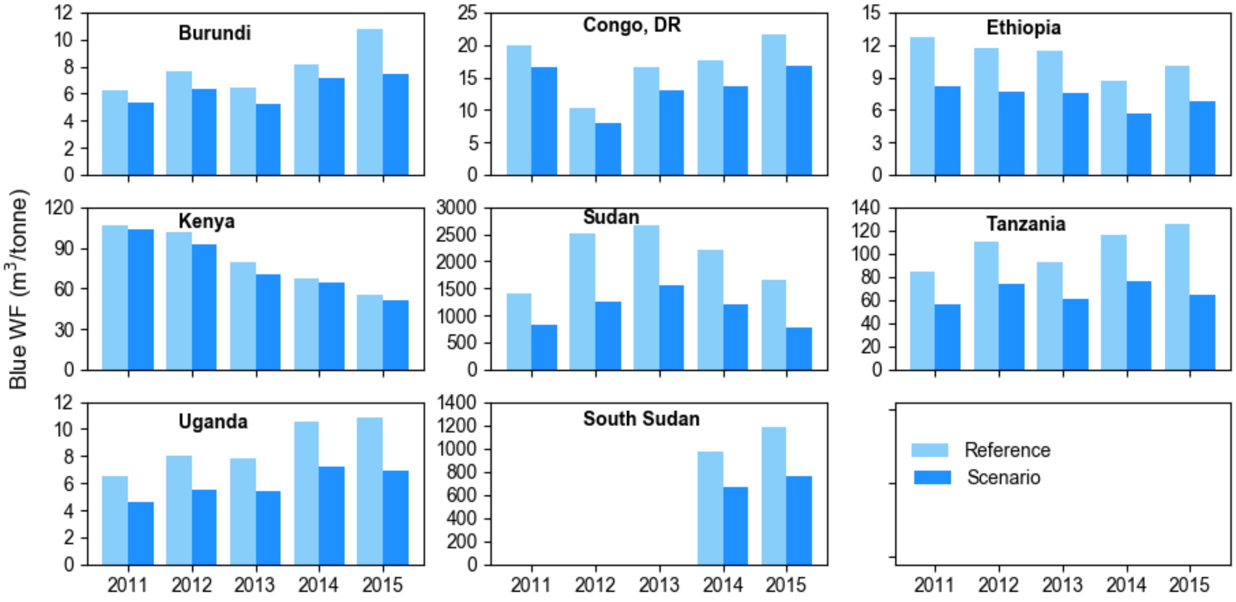


Figure 4. 4The blue water footprint of millet in Nile Basin countries under reference and water-saving scenario in the period 2011–2015

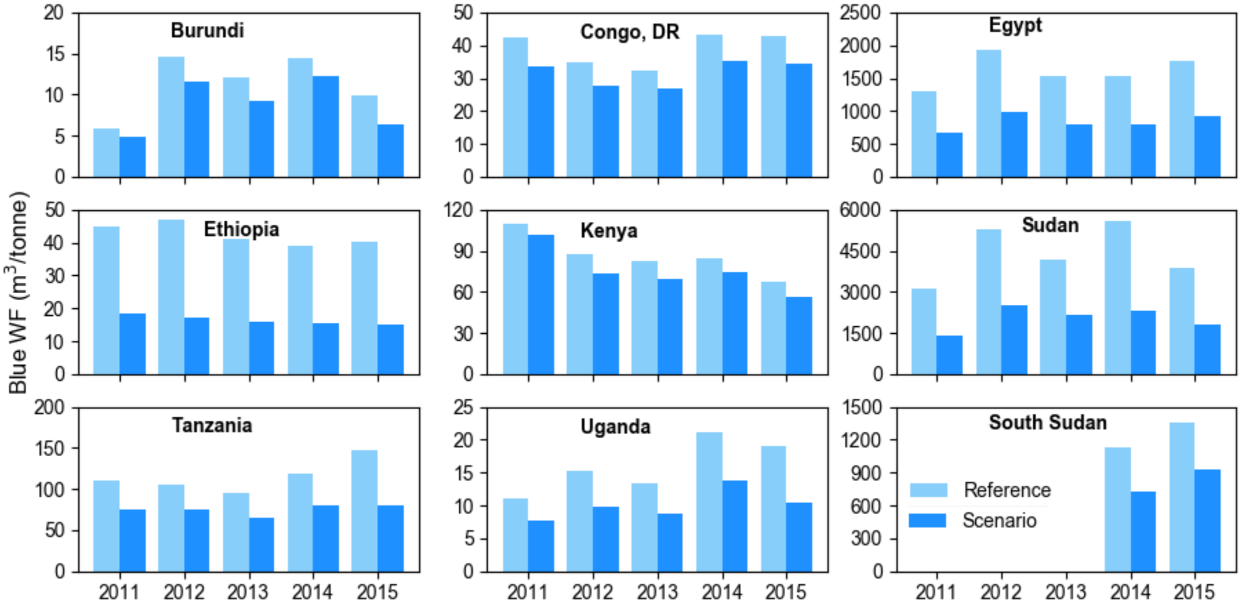


Figure 4. 5 The blue water footprint of sorghum in Nile Basin countries under reference and water-saving scenario in the period 2011–2015

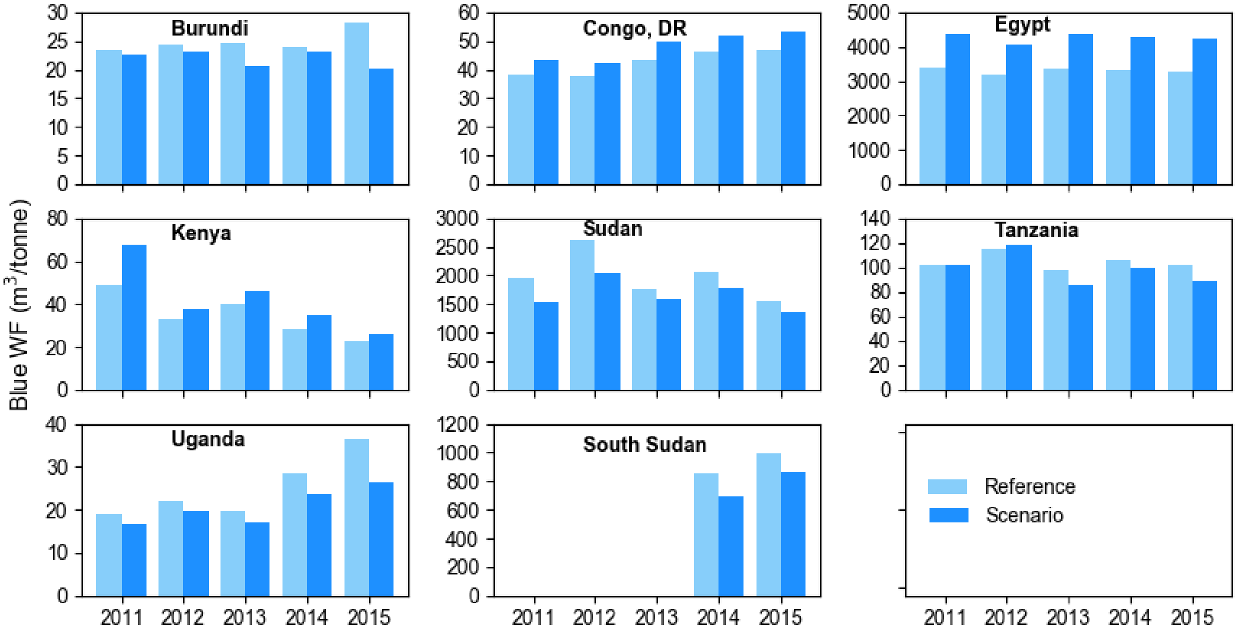


Figure 4. 6 The blue water footprint of groundnuts in Nile Basin countries under reference and water-saving scenario in the period 2011–2015

4.3.3 The production of crops under deficit irrigation and mulching in irrigated areas

The production of crops under deficit irrigation and mulching in irrigated areas varies from country to country and the production could reduce to some extent by applying deficit irrigation.

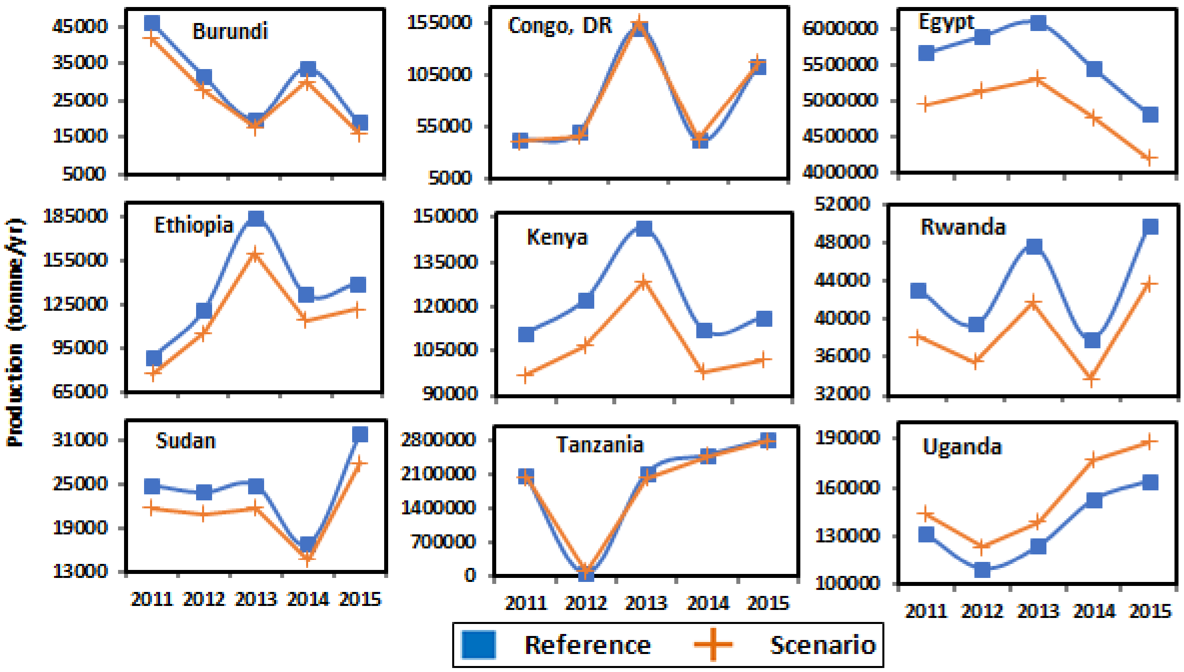


Figure 4. 7 Production of crops under deficit irrigation and mulching in irrigated areas

4.3.4 The total blue water saving

The blue WF reductions through deficit irrigation combined with mulching were estimated. The total blue water saving in the Basin under the water conservation scenario was 20.4 km^3/y or 42% of the current blue WF related to the production of the five selected crops. The largest water-saving was achieved in Sudan (74%), Egypt (18%), South Sudan (4%), and Tanzania (2.4%). The blue water saving for the other crops ranges between 5% for millet to 9% for maize and rice. Table 5.1. Shows blue water savings of crop production in irrigated agriculture showing the effects of deficit irrigation and mulching on blue WF (million m^3/y) for five dominant crops per country: Average for 2011-2015.

Table 5. 1 The total blue water savings of crop production per country in million m³/year: Average for 2011-2015

Country	Rice			Maize			Sorghum			Millet			Groundnuts		
	Ref	Sce	Save	Ref	Sce	Save	Ref	Sce	Save	Ref	Sce	Save	Ref	Sce	Save
Burundi	20.1	13.6	6.5	0.71	0.23	0.48	0.4	0.29	0.11	0.09	0.06	0.03	0.27	0.17	0.1
Congo	13.6	10.5	3.1	37.6	30.7	6.9	0.21	0.16	0.05	0.76	0.6	0.16	16.6	13.3	3.3
Egypt	5882	4303	1579	8761	7341	1420	1212	554	658			0	661	577	84
Ethiopia	77.9	55.3	22.6	276	249	26.8	202	63	139	9.16	5.3	3.86			0
Kenya	59.5	46.6	12.9	117	92.9	24.6	16.5	12.5	4	7.65	6.41	1.24	0.96	0.81	0.15
Rwanda	14.5	10.2	4.3												
Sudan	65.8	57.9	7.9	194	151	43	21156	8511	12645	2041	1121	920	3402	1940	1462
South Sudan			0	317	182	135	1282	652	630	11.4	6.96	4.44	106	58.8	47.2
Tanzania	1613	1366	247	626	461	165	95	61.7	33.3	34.1	20.8	13.3	121	82.7	38.8
Uganda	6.38	5.34	1.04	13	7.13	5.87	5.34	3.23	2.11	2.16	1.38	0.78	7.16	4.26	2.9
Total	7813	5915	1897	10343	8515	1828	23970	9858	14112	2106	1163	944	4316	2678	1638

4.3.6 Irrigation water savings in irrigated maize production

Irrigation water in the water-scarce area could save water by applying mulching and deficit irrigation. The simulation results for maize production in Figure 4.8 showed that the Absolute irrigation water savings (million m³/year) in irrigated maize production that can be achieved by applying deficit (instead of full) irrigation and organic mulching. Average for 1986-2015.

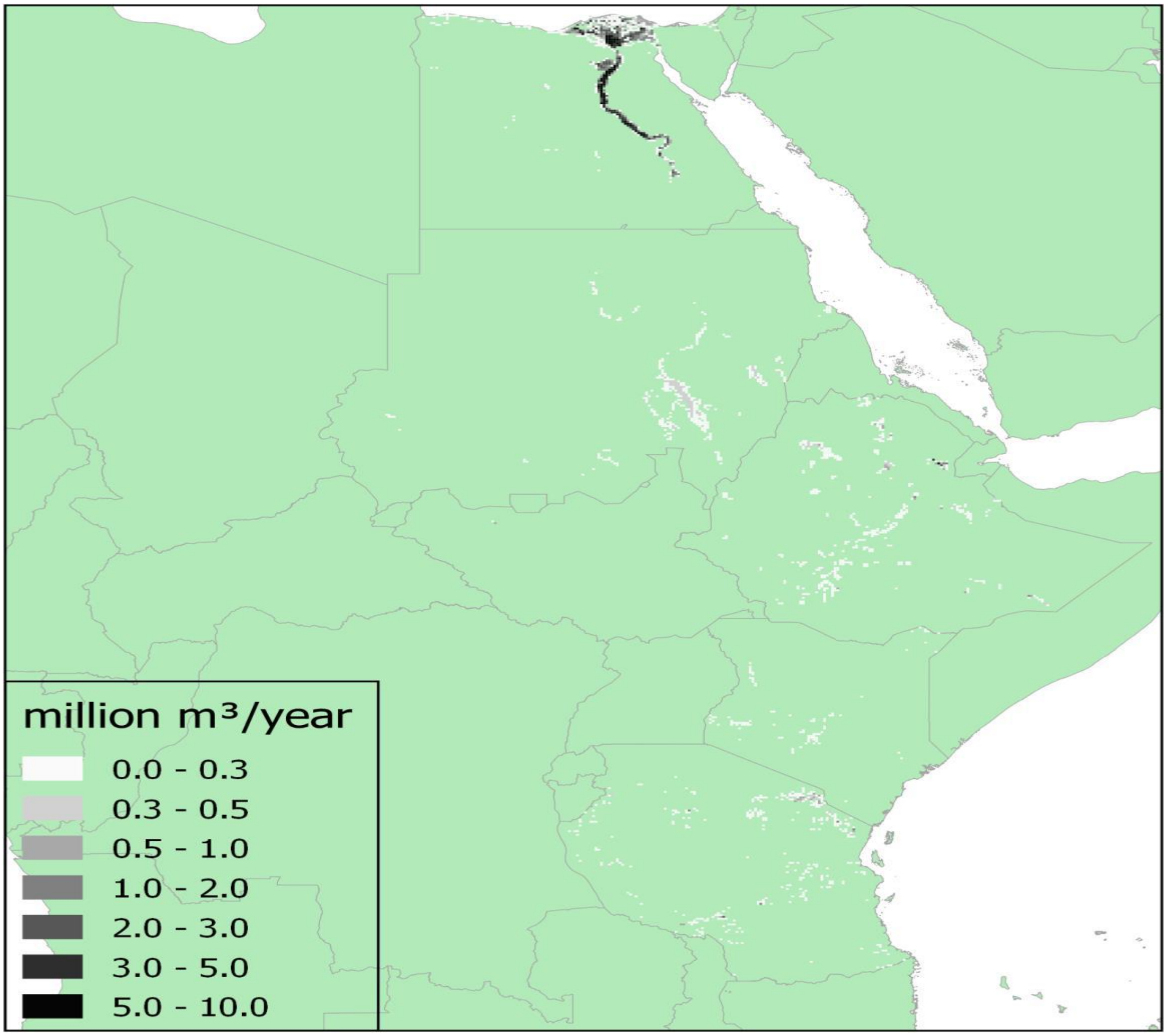


Figure 4. 8 Absolute irrigation water savings (million m³/year) in irrigated maize production achieved by applying deficit (instead of full) irrigation and mulching. Average for 1986-2015.

4.7 Discussion

In arid and semiarid regions of agricultural land which have the characteristics of low and variable rainfall and climate, implementing water-saving strategies is required to reduce the water footprint of crops. To alleviate water scarcity problems in the region, implementing deficit irrigation and mulching is vital, although the impacts might vary in different years from a country to country and from a crop to a crop. Therefore, it requires a regional and seasonal investigation. In the current study, five crops (rice, maize, millet, sorghum, and groundnuts) were observed to have a consistent WF reduction from deficit irrigation and organic mulching. For the current condition, the total blue water footprint was 48.5 km^3/y, 55% of which falls in Sudan, and 34% in Egypt.

Similar studies were carried out to reduce the water footprint of crops. The finding is in line with earlier studies. Nouri *et al*., (2019)found blue water saving of 5% from the combination of drip irrigation and mulching. Chukalla *et al*., (2015) tested the effect of irrigation techniques and mulching for water footprint reduction and found a reliable WF reduction. Jayakumar *et.al*. (2017) studied the field experiment on coconut in India and revealed an improvement in reducing consumptive water footprint under a combination of drip irrigation and mulching. The impact of different irrigation technologies on the water footprint of cotton in Greece was studied by Tsakmakis *et al*., (2018), which established a 5% reduction from total WF under drip irrigation. Gil *et al*., (2018) also assessed that mulching has water-saving effects to reduce the WF. Humphreys *et.al.* (2011) examined the impact of rice straw mulch with mulching and without mulching on the water productivity of wheat and found higher water productivity. Jabran *et al*., (2015) observed that mulching has improved the water productivity of rice.

Table 5.1 shows the national total average blue water saving in m³/year for the five dominant crops per country. Studies in Pakistan compare the water footprint values obtained in current and global average water footprint, which has been observed that sorghum, millet, and groundnut use high quantities of water in the local conditions as compared to the global averages of the same (Ghufran *et al*., 2015). The results found that there is substantial variation over the countries due to different climatic variability which is in line with Nouri *et al*. (2019) in the study for Lebanon.

Chapagain and Hoekstra (2004) estimated the global water footprint of crop production distinguishing between green and blue at the global level. For example, the global water footprint of rice production was 784 km^3/y with an average of 1325 m^3/tonne (Chapagain & Hoekstra, 2011). Mekonnen & Hoekstra (2011b) reported an average water footprint for cereals 1644 m^3/tonne and relatively small for maize (1222 m^3/tonne); the average WF of rice is close to the average for all cereals and groundnut 7500 m^3/tonne. The estimate of the water footprint by Mekonnen and Hoekstra, (2011b) is different from our estimate as indicated in Table 5. 1. The reason for this disparity might be due to climatic variability, soil, and management practices.

In the case of no data in the simulation output, for the crop failure, the reasons might be either the soil is not proper, climate or there is no crop in that region. Due to soil moisture deficit response, there is no blue WF in Eretria and for some crops in Rwanda because there is only rainfed crop production in these countries according to the global datasets that have been used (Portmann *et al*., 2010).

There is significant variation across the regions to generalize the water footprint reduction of the reference case with a water-saving scenario and the findings are case-specific. The different studies vary in many factors, such as crops, soil, climate, and management practices (such as fertilizer application, mulching, etc.). The current study assessed the effects of water footprint reduction due to deficit irrigation and organic mulching. The findings of the current study have generally shown that water-saving can be achieved using the two alternatives by lowering the water footprint. The total blue water savings of crop production per country in million m^3/year can be saved as shown in Table 5.1.

The water footprints of crops are sensitive to climatic factors. The results found that there is a substantial variation over the countries, which is in line with Nouri *et al*. (2019) a study in Lebanon. The current study measured the benefits of deficit irrigation and mulching in terms of water footprint reduction. Chukalla *et al*., (2015) explored the potential of reducing the water footprint of growing crops by using different management practices in different environments. Generally, the result of the current study has paramount importance to reduce water scarcity by lowering the water footprint.

4.8 Conclusion

To reduce the pressure on freshwater and enhance the sustainable use of blue water and ensure crop production, different solutions are required. Reducing the blue water footprint of crop production is a strategy to alleviate the problem of water scarcity and sustainable use of water. This paper estimated the potential saving of blue water in Nile Basin countries through deficit irrigation and mulching for five dominant crops. Under current conditions, the largest crop water footprints were found in Egypt, Sudan, South Sudan, and Tanzania. Upstream counties have a smaller water footprint. Deficit irrigation together with mulching can have a significant impact on blue water saving. Hence, it is imperative to promote water-saving scenarios. Further research is required to study the cost-benefit in implementing deficit irrigation and mulching at the national level. The study suggested that countries with a large proportion of blue water can save more water as deficit irrigation and mulching have significant impacts on total blue water footprint reduction in water-scarce regions for sustainable water use.

5. Spatial analysis of green and blue water footprint of selected crops in Nile Basin countries

Abstract

Improper allocation of water and mismanagement of water resources could put pressure on the overall freshwater in the Nile Basin countries. This study assesses spatial variability in the blue and green water footprint of selected crops in Nile Basin countries at high temporal resolution. The green and blue water footprint (mm/y) of crops was calculated as the water footprint in m^3/y divided by the entire grid cell area (m^2). The analysis was done for the temporal extent of the year 1986 and 2015 and spatial extent for the whole Nile Basin countries with the spatial resolution of 5x5 arc minutes. Precipitation and evapotranspiration are highly variable across the production regions which are the major drivers affecting the availability and distribution of water resources. The distribution of the water footprint of crops across the Nile Basin countries varies spatially and temporally. The distribution of the average water footprint of crops decreases from the initial year 1986 to the final year 2015. At the regional level, the Lower Nile Basin (LNB) countries have the largest consumptive water footprint (green+blue) compared to Upper Nile Basin (UNB) countries for all of the crops. This is due to Climate and the natural acidity of the region. Hence, it is vital to produce crops in the UNB countries and export to LNB countries.

Keywords: Spatial analysis, evapotranspiration, precipitation, water footprint, Nile Basin countries

5.1 Introduction

Freshwater is a limited and scarce resource in the world. This limited amount has been shared by many sectors that use more water. Agriculture alone accounts for 70% of all water withdrawn (UNESCO, 2012). As the demand for water increases, the availability of fresh water is likely to decrease. The unalterable rise in demand for water and the growing populations coupled with socio-economic developments and global change has led to the scarcity of freshwater and the big challenge for modern water management (Hoekstra *et al*., 2012). Likewise, the unstoppable rise in demand for water to produce food, and maintain economies has led to an increasing shortage of freshwater in many parts of the globe (Hoekstra *et al*., 2012). Unless the amount of food production improves, it would be difficult to support an ever-increasing population.

In the period 1996–2005, the global water footprint for crop production was 7404 billion m^3/y (Mekonnen & Hoekstra, 2011). Agriculture needs not only huge quantities of water but is also one of the most ineffective water users. There are substantial inequalities in water use and regional insecurity due to the unequal distribution of water resources across the globe (Mekonnen & Hoekstra, 2014). Water management is a challenging issue in most water-inefficient areas (Mekonnen & Hoekstra, 2014), where the Nile River Basin is one example. Water availability in the Nile Basin also varies considerably in space and time. Spatially, the Northern part of the Basin is arid and experiences high evapotranspiration, while the southern part is relatively wet with higher rainfall.

Though certain parts of the Nile Basin regions are with limited water availability, it is a severe climatic and economically disadvantaged region experiencing population increase, significant inequalities in water resources (Kloos & Legesse, 2010). The equitable sharing of common resources such as water among the Basin is an important issue in the transboundary river Basin. For water managers and political decision-makers in the transboundary Basin, the lack of concepts on water footprint which is a very useful tool that provides a useful strategy, appropriate policy, and solution for water scarcity alleviation.

The Nile Basin is a region that faces water scarcity in some parts due to aridity and man-made problems and mismanagement in the water-inefficient region. To reduce the disproportion between water demand and supply improved water management is required, particularly aimed at water-saving and conservation in irrigated agriculture (Mekonnen, 2011). Evaluation of the existing irrigation condition and the potential for water savings by improving the farm irrigation systems and irrigation development and yield at the field level is essential (Horst *et al.*, 2005). An effective and appropriate water management strategy is vital to maximize crop production (Ararssa *et al.*, 2019). Irrigated agriculture has played an important role in feeding the growing world population and is expected to continue in the future as well (Cai & Rosegrant, 2003). Excessive water supply results in lower water productivity in terms of yield per unit of water applied (Cho *et al.*, 2018). The major purpose of assessing annual variability in blue and green WF is to know the spatial extent of the WF in the Nile Basin countries and to improve water management.

Mekonnen and Hoekstra, (2011) made the first global grid-based assessment using the CropWat model for estimating water footprint in crop production. According to (Siebert & Döll, 2010), they have estimated the global green and blue water consumption for 24 crops and 2 additional broader crop categories applying a grid-based approach. Liu and Yang, (2010) made a global estimate of green and blue water consumption with a spatial resolution of 5x5 arc minutes. The evolvement of water footprint assessment (WFA) as an emerging and new research field over the past fifteen years in the different scenarios has been studied (Hoekstra, 2017). The AquaCrop model has also been used for green and blue water footprint reduction in irrigated agriculture (Chukalla *et al.,* 2015). Despite the several works made, there are very few studies for the Nile Basin concerning the water footprint of crop production. Coordinated use of the water for irrigation would maximize the benefits and require high levels of cooperation and clear mechanisms for benefit sharing. Benefits to the Nile Basin could optimize through cooperative management and development of the common water resources on a win-win basis. Estimating the water footprint of crops at such a river Basin is an important step by the Basin governments to formulate and implement effective and appropriate strategies. The aim of this study was, therefore, to evaluate spatial variability in the blue and green water footprint of selected crops in

Nile Basin countries. The study quantifies the blue and green water footprint related to selected major crops of the Nile Basin countries using the AquaCrop model. The model is the crop growth model developed by FAO to assess the effect of the environment and management on crop production.

5.2 Materials and Methods

5.2.1 Methods and data

To evaluate the spatial extent of the green and blue water footprint of selected crops the reference scenario was used. The method was used which is developed by (Hogeboom *et al.*, 2019). The AquaCrop model was used to estimate water footprints of selected crops (m^3/t) for the five selected crops in Nile basin countries. The Aqua21 FAO's crop growth model has been used to calculate crop water use and yields over the growing season on a 5×5 arc-minute grid for the period 1986-2015 (Steduto *et al.*, 2009; Raes *et al.*, 2009). The green and blue component of the resulting water footprint was separated by maintaining a water balance where the blue component consists of a blue irrigation water fraction and a capillary rise fraction as defined by Chukalla et al. (2015). Bluewater savings have been calculated as the difference between a reference and reduced use of blue water consumption. Resulting blue savings were mapped against average annual blue water scarcity levels as estimated by Mekonnen & Hoekstra (2016). The model was used with CRU climate data; soil layers the method by Hogeboom *et al.* (2019). Crop-specific harvested areas around the year 2000 were obtained from MIRCA2000 for the selected major crops (Portmann *et al.*, 2008).

Different global data sources were used to estimate crop WF. These five crops (rice paddy, maize, millet, sorghum, and groundnuts) were selected based on the FAO (2019) database on both the largest in production and area harvested. Monthly precipitation, daily reference evapotranspiration (ET0), and daily maximum and minimum temperature were obtained from CRU TS-3.20 with a 30 x 30 arc-minute grid spatial resolution (Harris *et al.*, 2014). Soil data with 5x5 arc minute resolution were obtained from the ISRIC-WISE dataset (Batjes, 2014). The MIRCA 2000 dataset was used for the irrigated and rain-fed harvested area for each crop at 5x5 arc minutes resolution (Portmann *et al.*, 2010) which made to fit FAO's national level total harvested area. The 'scaling coefficients' were adjusted to the MIRCA2000 reference map to meet the annual harvested area values. The yearly harvested area at 5×5 arc minute was derived by multiplying the reference MIRCA2000 map by the scaling coefficients. To get the initial soil moisture in the first year, the model was run with initial soil moisture at field capacity for the entire period and then we used the average values.

It has been used the raster's per crop for each year. Each raster contains two bands' water footprint for green and blue in mm/year. The variable band 1 indicates the green water footprint (mm/y), calculated as the water footprint in m^3/y divided by the entire grid cell area (m^2), and the variable band 2 indicates the blue water footprint (mm/y) and calculated as the water footprint in m^3/y divided by the entire grid cell area (m^2). The temporal extent was for the year 1986 and 2015 with a temporal resolution of per year and spatial extent for the whole Nile Basin countries with a spatial resolution of 5x5 arc minutes as estimated by Hogeboom *et al*., (2019). For these specific objectives, the data and methods have been used which is stated in the general methods section.

5.3 Results

5.3.1 Rainfall distribution

Rainfall over the Basin has characterized by uneven seasonal and spatial distribution. Most of the Basin region has only one rainy season i.e. in summer months. The amount of rainfall generally declines from upper to lower Nile Basin countries, with the arid regions of LNB receiving small annual rainfall. The spatial variability of rainfall is clearly illustrated by the spatial distribution of surface water bodies in the Basin. Large parts of the Nile Basin generate a very small amount of water. The main river water source producing areas are limited to the UNB of Congo DR, Rwanda, Uganda, Burundi, Ethiopian highlands, and the central plateau, with some contribution from western South Sudan. Areas in the Nile Basin located on or near the equator have a small amount of rainfall than the South. Therefore, the rainfall distribution in the LNB is typically dried while in the upper is relatively a smaller amount of rainfall. The high temporal and spatial variability of rainfall in the Basin could be demonstrated by the annual rainfall. The rainfall is the amount of water collected from the global weather station. The rainfall amount is directly proportional to the effective rainfall. The effective rainfall is different from among crops and across the Basin. The UNB has very limited rainfall which relying almost exclusively on irrigated agriculture that depends on Nile water. Figure 5.1 shows the average annual precipitation distribution in Nile Basin countries.

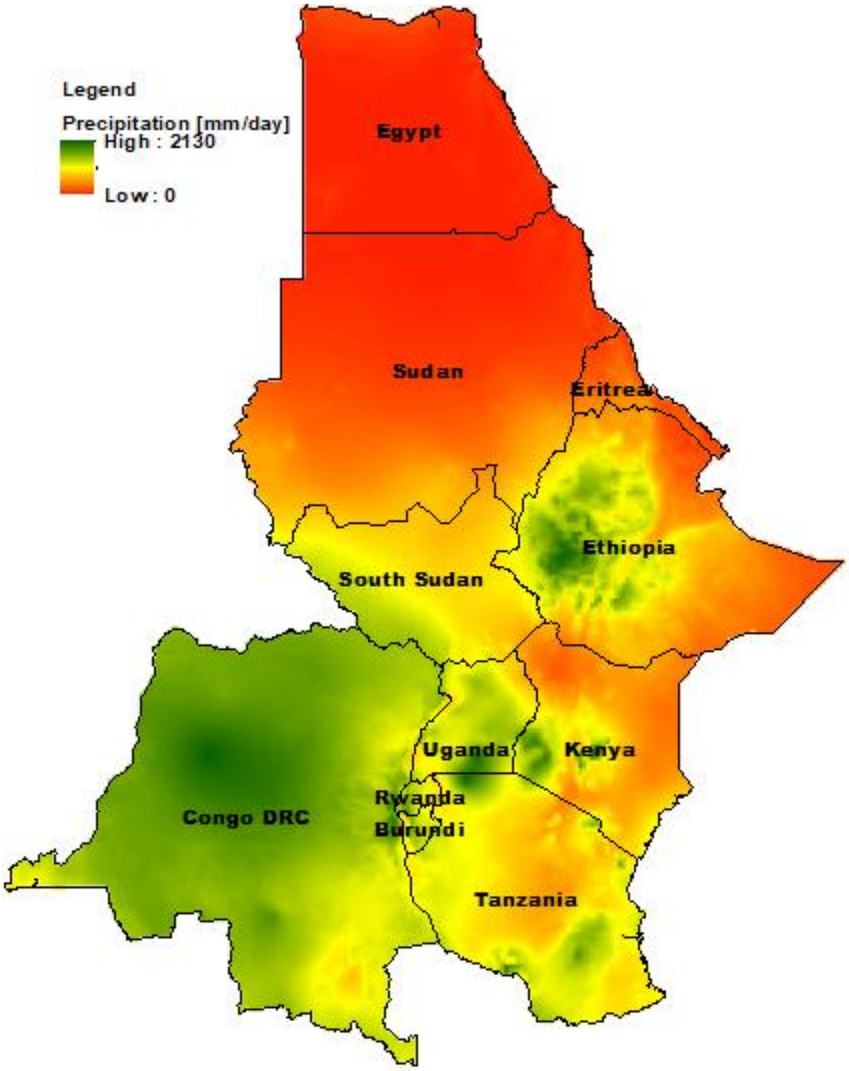


Figure 5. 1 Spatial pattern of mean annual rainfall (mm/year) in the Nile Basin countries: Data source CRU

5.3.2 Crop Evapotranspiration

A map showing the crop ET over the Basin could be good to show the spatial variability across the region. Across the Nile Basin region, the average evapotranspiration for the crops shows high spatial variation. The arid lands in the lower Nile Basin i.e. the Sudan and Egypt have higher evapotranspiration rates than the humid headwater regions of the Nile. Figure 5.2 shows the crops' annual average evapotranspiration across the Basin region. Maximum evapotranspiration is recorded in the LNB while relatively low in the UNB. the crop evapotranspiration has been decreased from the lower Nile Basin to the upper Nile Basin. The actual ET is highest in the lower Nile basin countries and low in the upstream basin countries due to climate variability in the region.

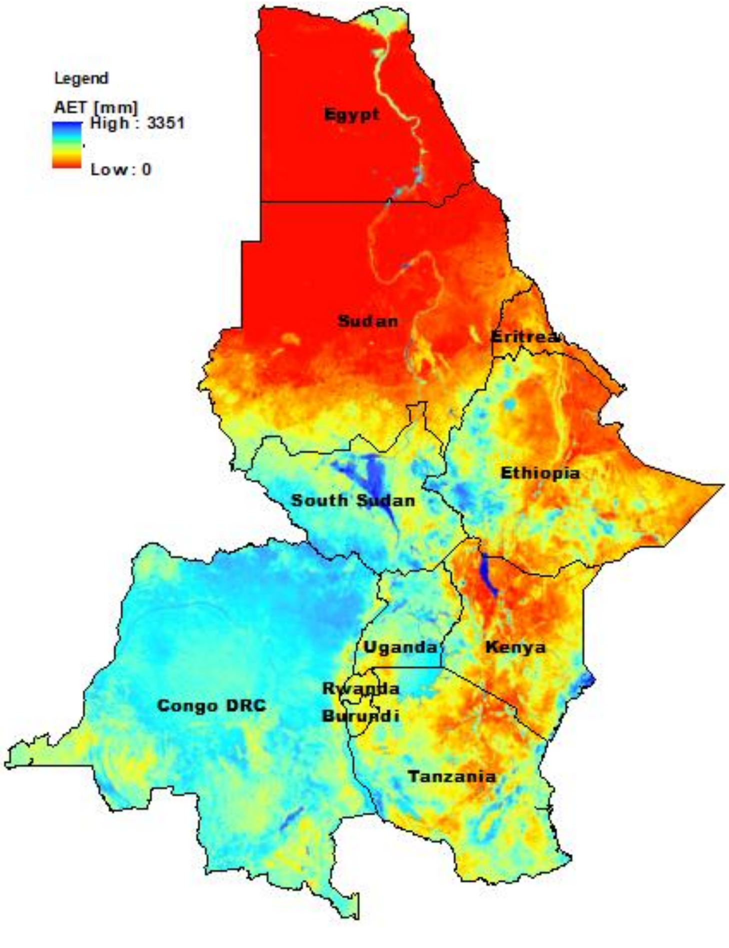


Figure 5. 2 Distribution map of evapotranspiration (in mm) for the Basin countries.

Data source: Allen *et al*, 2007

5.3.3 Distribution map of soil textural class for the Basin countries

The soil of the area is an important variable in maintaining the impacts of irrigation and soil moisture water holding capacity. The soil properties associated with the storage of water are crucial in a dry environment. Figure 5.3 indicates the distribution map of soil textural class for the Nile Basin countries.

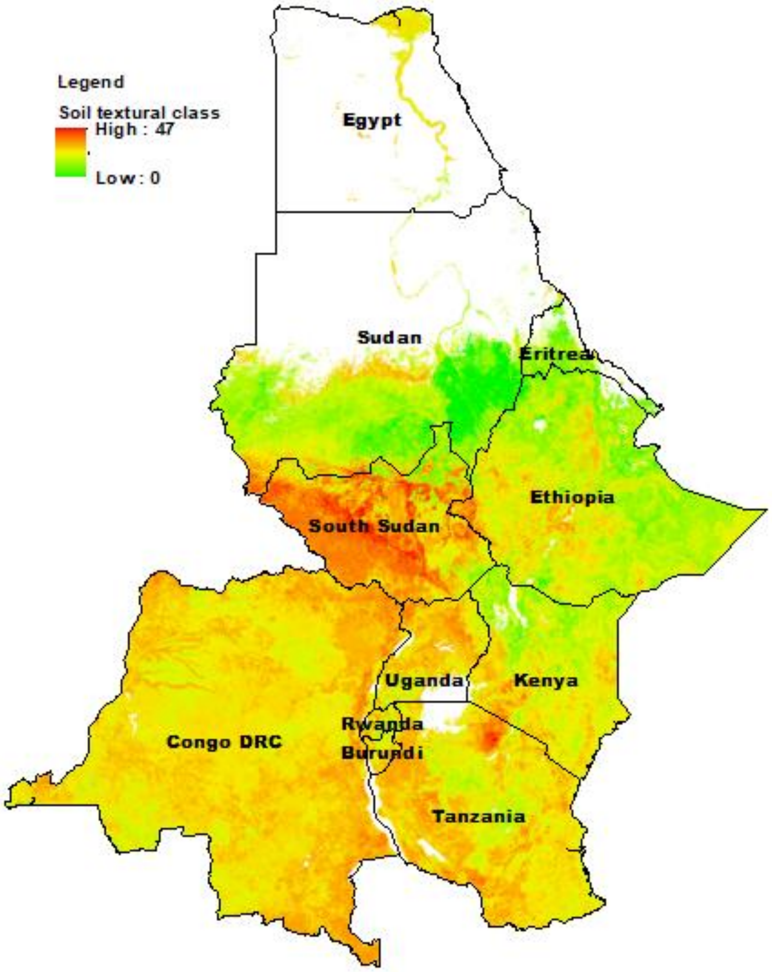


Figure 5. 3 Distribution map of soil textural class for the Basin countries in which the data source is ISRIC soil texture.

5.3.4 Spatial distribution of green and blue water footprint of crops (in mm/y)

Figure 5.4-5.8 illustrates the spatial and temporal distribution of the total (green + blue) water footprint of crops (in mm/y) for comparison between the initial and final periods 1986 and 2015. The distribution of the water footprint of crops across the Basin countries varies spatially and temporally. For example, from the initial year 1986 in the final year 2015 the distribution of the average water footprint of sorghum decreases from 1006 mm/y to 854 mm/y. In the drought year, the total water footprint of crops has been increased. Depending on the crops and countries, the water footprint of crops varies from time to time. The water footprint of crops decreases from the first year to the final year in all figures. This could be due to the growing technological advancement and the use of various techniques. The large water footprint associate with large production (harvested) area and the low water footprint correlate with low production areas. Due to the high proportion of blue water footprint that indicates the existence of irrigated farming in the Nile basin route, the highest crop production has been seen along the Nile basin routes.

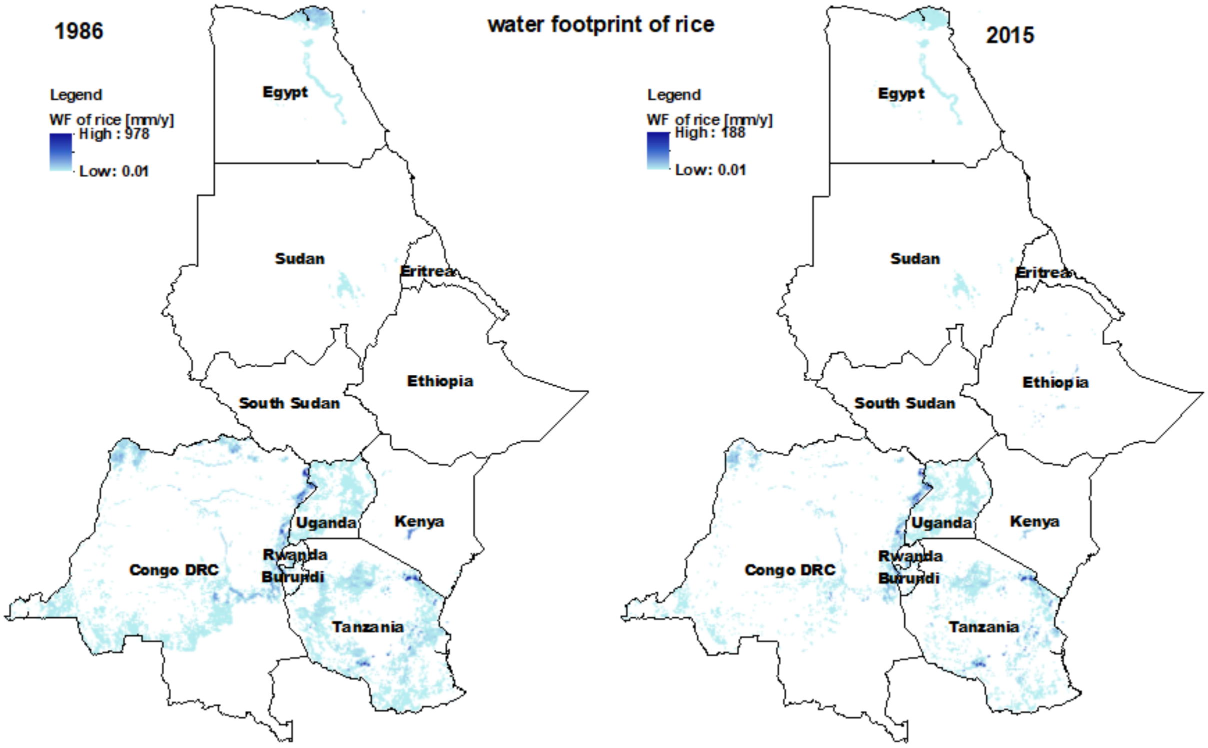


Figure 5. 4 Spatial distribution of the water footprint of rice for the year 1986 and 2015 at the spatial resolution of 5 arc-minute.

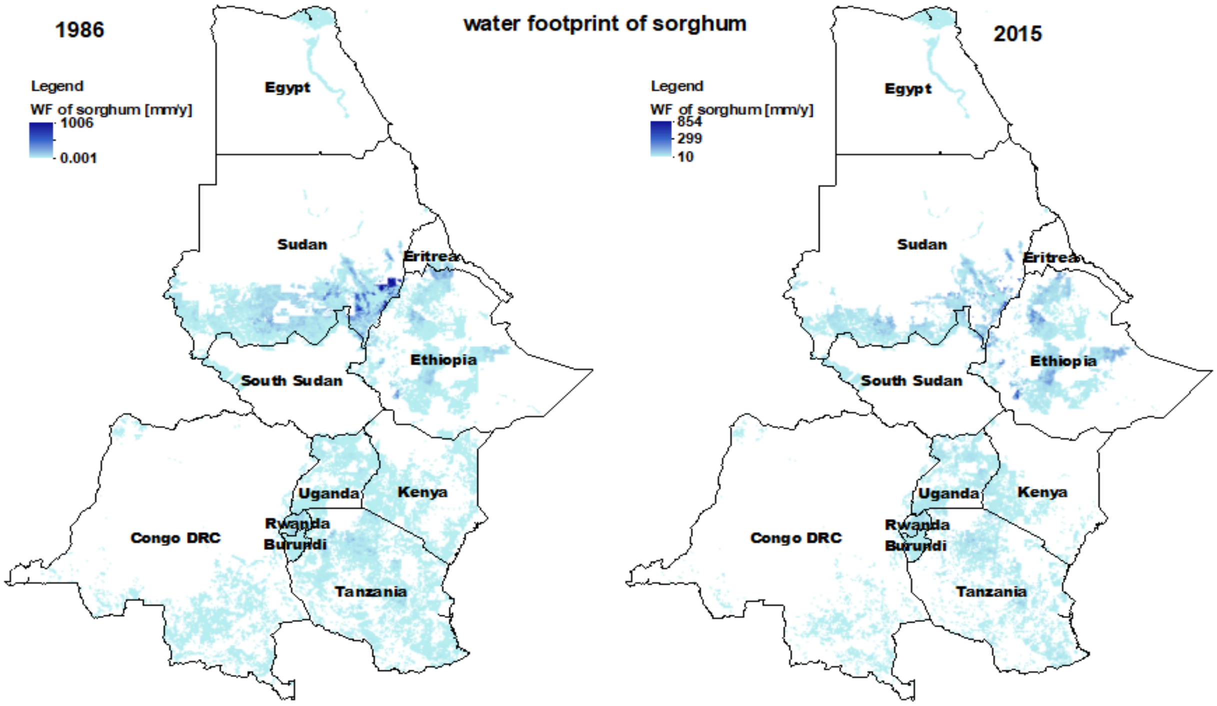


Figure 5. 5 Spatial distribution of the water footprint of sorghum for the years 1986 and 2015 at the spatial resolution of 5 arc-minute.

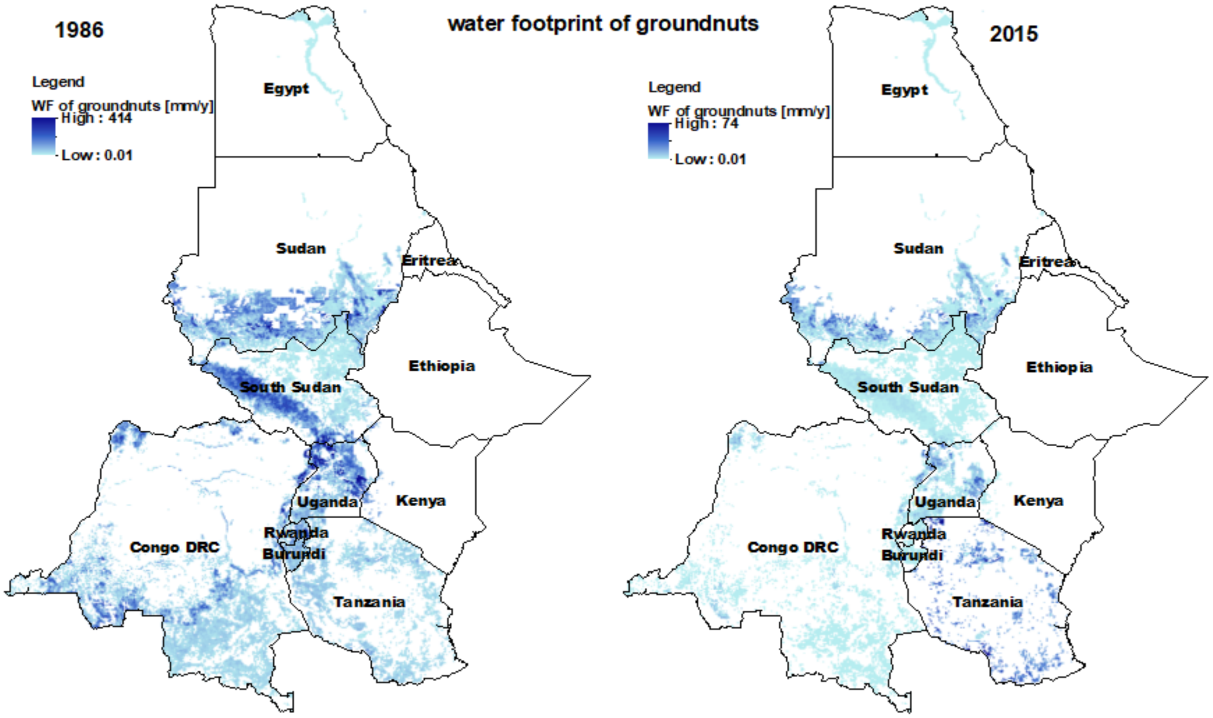


Figure 5. 6 Spatial distribution of the water footprint of groundnuts for the years 1986 and 2015 at the spatial resolution of 5 arc-minute.

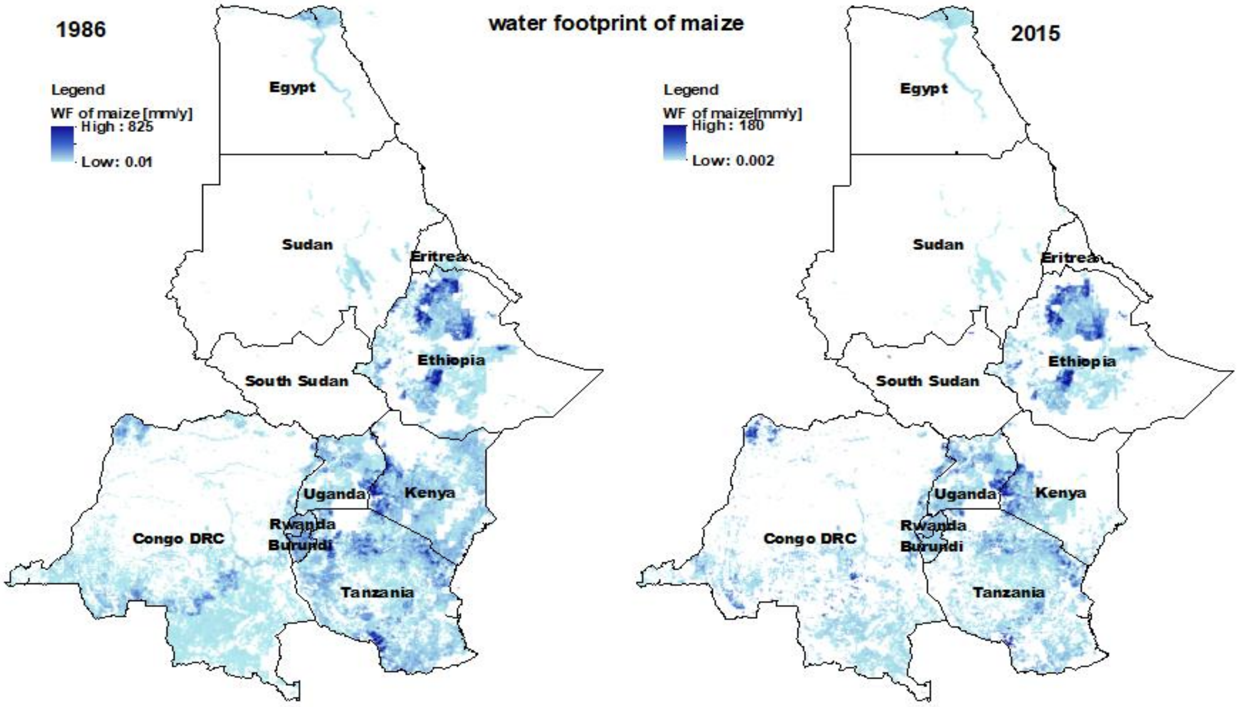


Figure 5. 7 Spatial distribution of the water footprint of maize for the years 1986 and 2015 at the spatial resolution of 5 arc-minute.

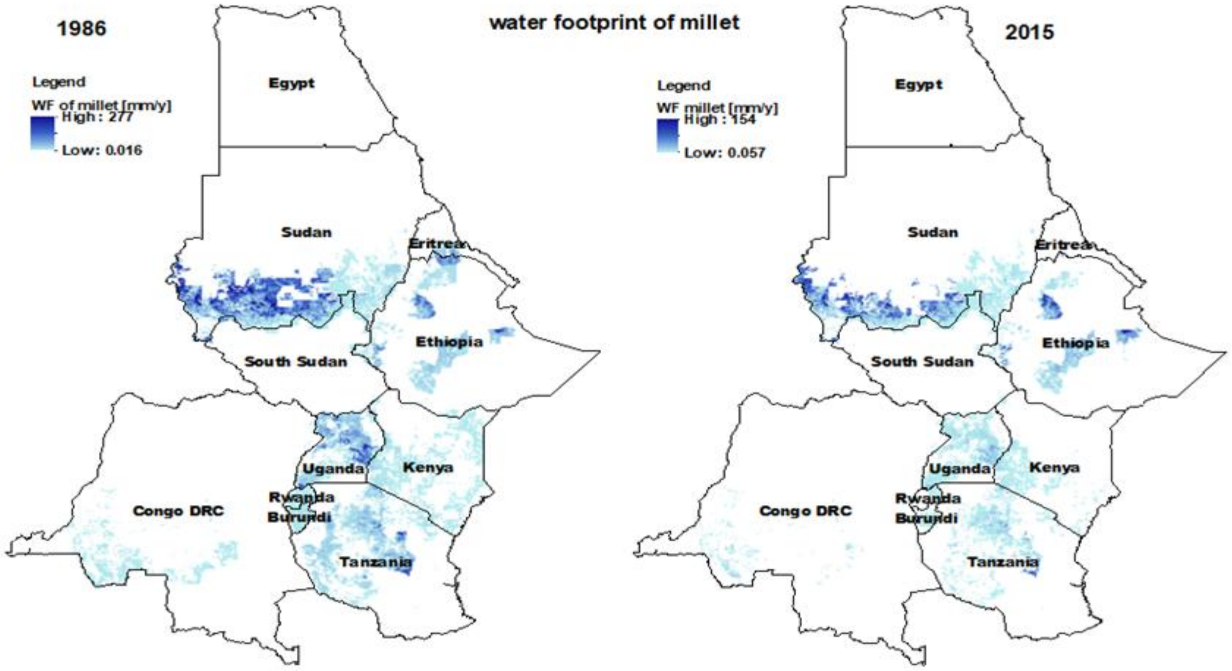


Figure 5. 8 Spatial distribution of the water footprint of millet for the years 1986 and 2015 at the spatial resolution of 5 arc-minute.

5.3.5 Spatial distribution of green & blue water footprint (in mm/y) of crops at Basin level

The water footprint of crops varies greatly across the Nile Basin region and within the different crops over its production systems. The green and blue footprint of some selected crop products in the Nile basin region has been presented in figure 5.9. In general terms, one can say that the green and blue water footprint can be determined by the climate, soil, the irrigation type, and the crop variety. Similarly, it can be observed that the country of production influences the water footprint of crop products related to existing country differences in irrigation development. This difference is in the fact that water footprints of crops vary across regions as a function of differences in climate, soil, irrigation type, and agricultural practice.

The result in figure 5.9 shows that much of the crop water footprint in the majority of the Basin, the green water is greater than the blue water footprint because most of the region use rain-fed agriculture than irrigated agriculture. The blue water footprint of crops is greater than green during the dry season whereas is less during the rainy season. At the regional level, a relatively, large green water footprint was measured for the upper Nile Basin region whereas small in the lower Nile basin (Figure 5.9). The lower region is under a very arid region and practices more in irrigated agriculture.

The differences can be partly explained by the different water requirements of the crops. Figure 5.6 showed that the water footprint of groundnuts, for example, requires much more compared to other crop types. This is not the only factor, however, that can explain the differences. Another important factor is the crop growing region i.e. climate and soil type of the region. Particularly crops grown in the dry regions require more water that has a larger water footprint than the humid region.

The following figure 5.9 presented that the green and blue water footprint of crop production estimated at a 5x5 arc minute resolution that shows, the green, blue water footprint related to agricultural production. The data are shown in mm/y and have been calculated as the aggregated water footprint per grid cell (in m^3/y) divided by the area of the grid cell. A large green water footprint per grid cell is found in the upper catchment (eastern and southern eastern) part of the

Basins while less proportion in northern and some central parts of the Basin. Bluewater footprint per grid cell found in central & northeastern parts was as low in the Southern parts of the Basin.

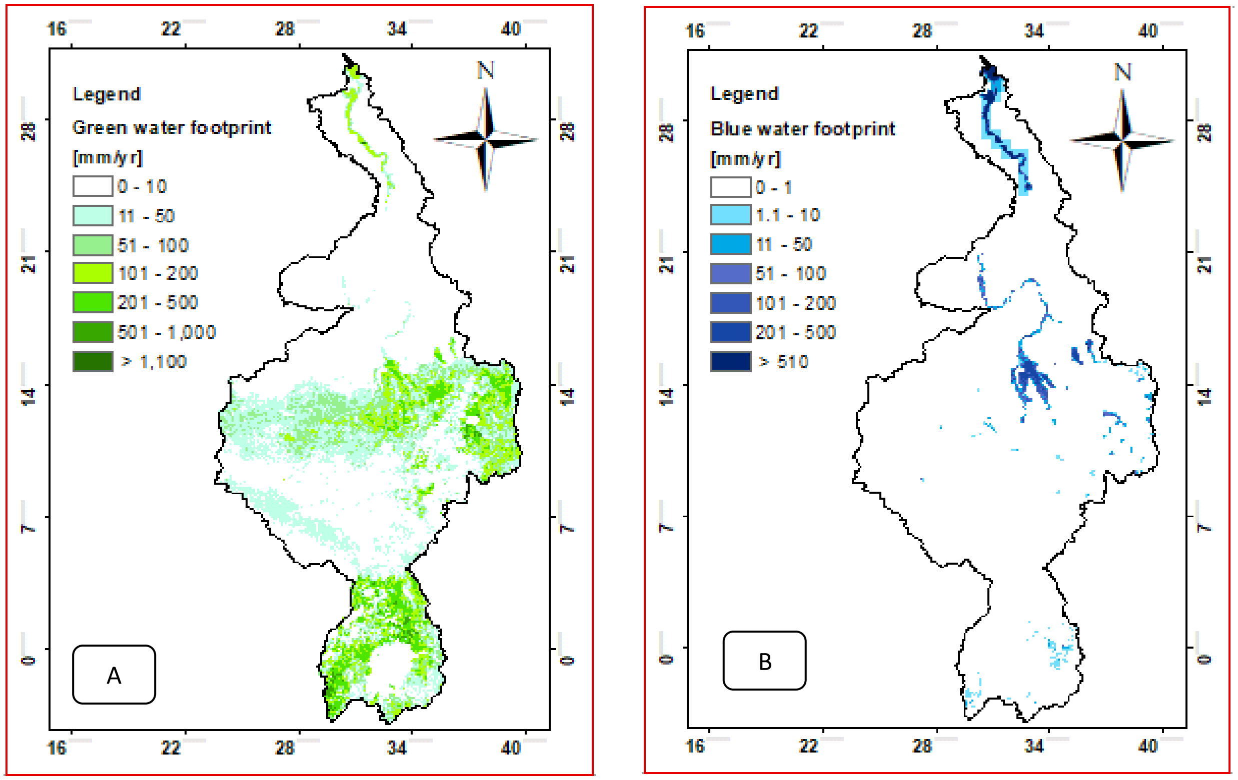
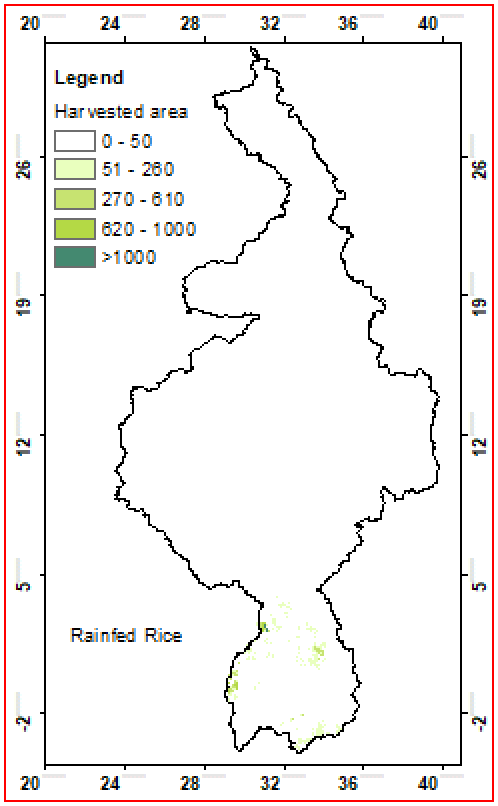
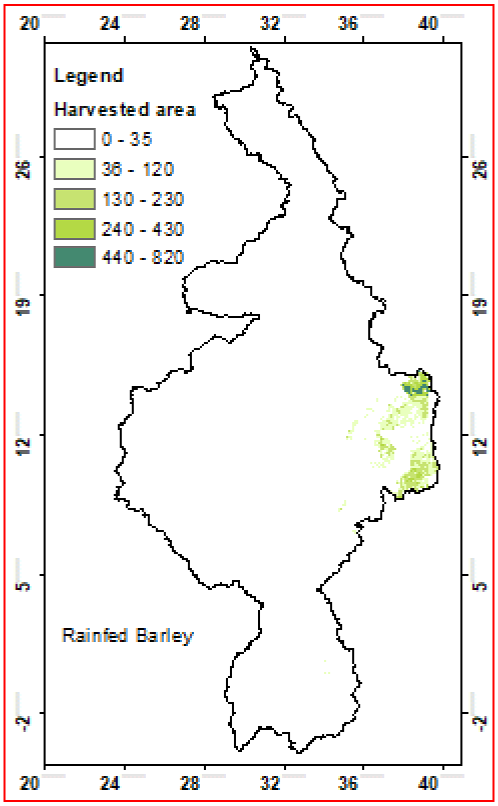


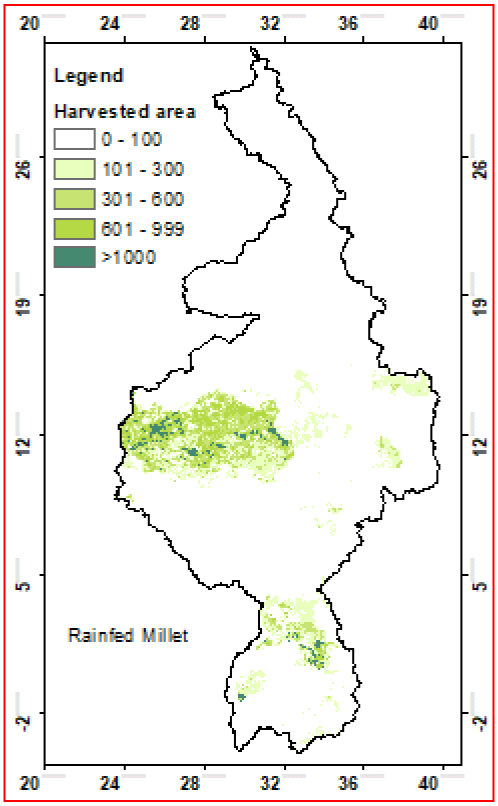
Figure 5. 9 Green [A] & blue [B] water footprint of crop production at 5x5 arc minute resolution

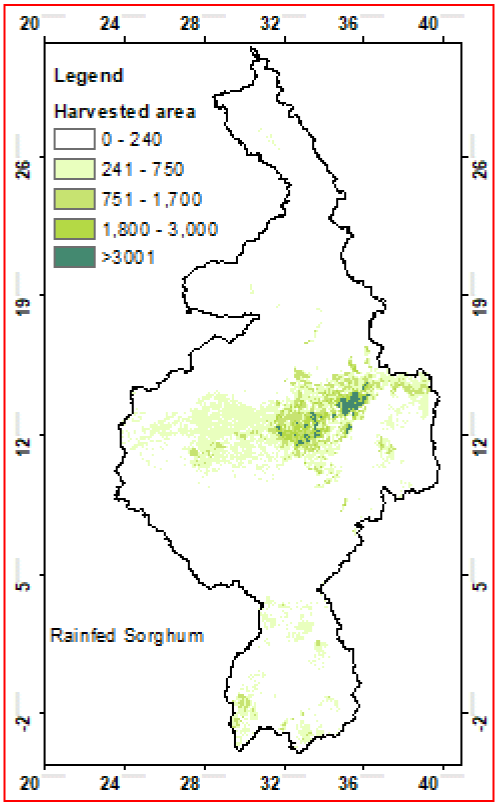
5.3.7 Basin maps of the rainfed and irrigated harvested area for major crops

The harvested area of the selected crop, rainfed and irrigated, differs significantly among crops and across production regions. When considered irrigated harvested areas, crops with the relatively large irrigated areas are sorghum and groundnuts mainly in the lower Nile Basin part; while considering the rainfed harvested area, crops with the relatively large rainfed areas are millet, groundnut, sorghum, and maize mainly in the upper Nile Basin catchment.


Legend
Harvested area
0 - 50
51 - 260
270 - 610
620 - 1000
>1000
Rainfed Rice
20
24
28
32
36
40
26
19
12
5
-2


Legend
Harvested area
0 - 35
36 - 120
130 - 230
240 - 430
440 - 820
Rainfed Barley
20
24
28
32
36
40
26
19
12
5
-2


Legend
Harvested area
0 - 100
101 - 300
301 - 600
601 - 999
>1000
Rainfed Millet
20
24
28
32
36
40
26
19
12
5
-2


Legend
Harvested area
0 - 240
241 - 750
751 - 1,700
1,800 - 3,000
>3001
Rainfed Sorghum
20
24
28
32
36
40
26
19
12
5
-2

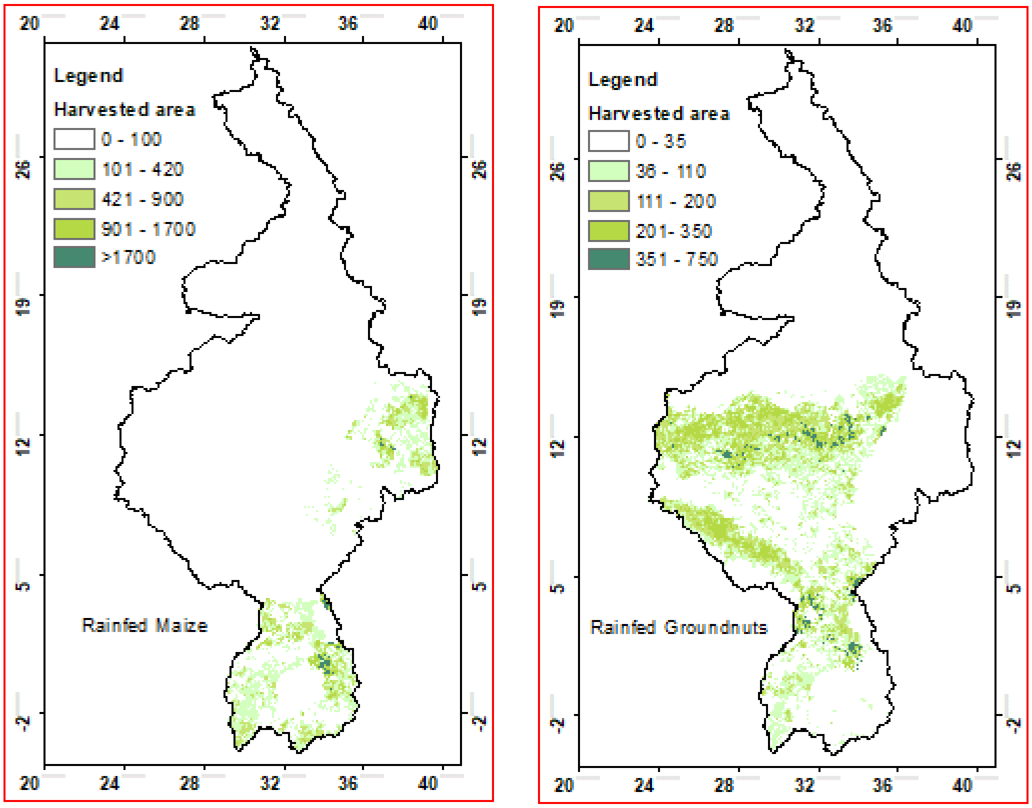


Figure 5. 9 Basin maps of rainfed harvested area (mm/yr) for selected dominant crops.

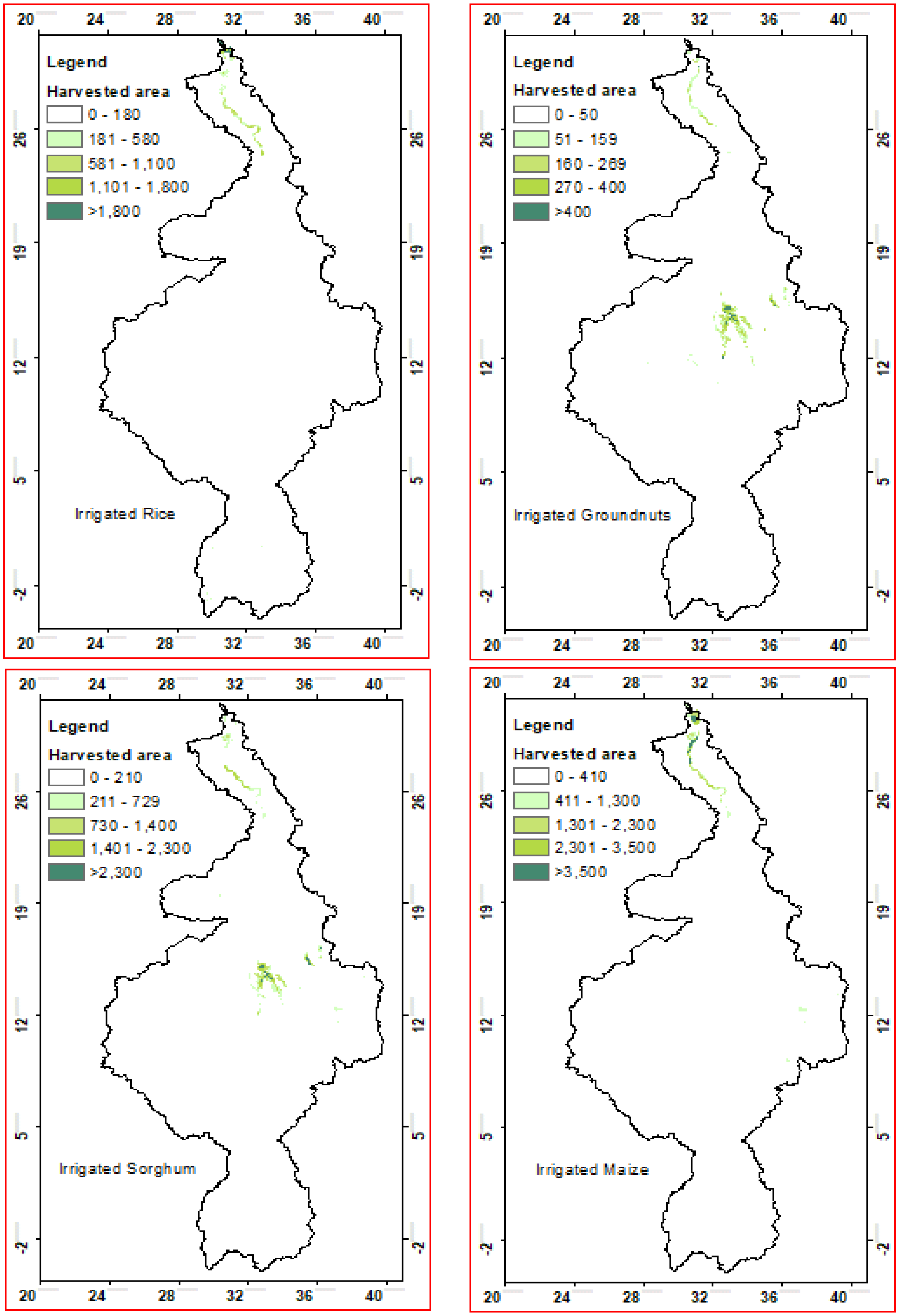


Figure 5. 10 Basin maps of the irrigated harvested area (mm/yr) for selected dominant crops

5.4 Discussion

To compare our estimates with previous studies, selected studies have estimated the water footprint in different regions. The inter-annual variability and spatial distribution of consumptive water footprint (mm/y) of crop production were done in China for different periods (Zhuo *et al*., 2016). Similar variations in water footprints were found in different studies. Similar findings have been done in Mekonnen *et al*. (2015) for the Latin American countries. The water footprint of crops varies significantly among crops and across production regions. The results show that in most countries the annual green and blue water footprint of the crops has dropped (Figure 5.4-5.8). When considered the Nile Basin countries, the average water footprint per tonne of crop products (mm/y) in the overall Basin countries, crops with relatively large water footprint are groundnuts, sorghum, and maize on the other hand crops like millet and rice are relatively small water footprint.

Generally, the green and blue water footprint of the crops can determine by the climate, soil, and irrigation type, and crop variety. Similarly, it has been observed that the region of production influences the water footprint of crop products related to existing regional differences in irrigation development. The blue WF of the crop is larger than green during the dry season, where it is lower during the rainy season. For the upper Nile Basin countries, a relatively greater green water footprint has been measured, while small in the lower Nile Basin. The variations may also explain due to different crop water requirements. Production of groundnut, for example, requires much more compared to other cereals.

In General, the results show that the harvested area of the selected crops, both rainfed and irrigated (mm/yr) area, differs significantly among crops and across regions. The basin maps of the irrigated area (mm/yr) for selected dominant crops shows that produced largely along the Nile basin terrain. While the basin maps of the rainfed harvested area (mm/yr) for selected dominant crops show produced largely in the upper Nile basin and middle Nile basin regions.

5.5 Conclusion

The average national water footprint of selected crops for the two different years 1986 and 2015 is presented in Figure 5.4-5.8 shows, the spatial distribution of the water footprint of all the dominant crops for the years 1986 and 2015 at the spatial resolution of 5 arc-minute. There are temporal and spatial variations in the water footprint in the Nile Basin countries. The water footprint of crops varies across the Basin and its production processes within the various crops. The water footprint of crops varies greatly across the Basin countries due to the number of factors. This could be due to the variation in climate, soil, irrigation type, and agricultural practice of the region. The lower Nile Basin region has the largest water consumptive as compared to the lower Nile Basin for all the crops due to the aridity of the region. On the other hand, due to the large harvested area, the large water footprint has been observed in the upper Nile Basin regions. Generally, the water footprint of crops decreases from the first year to the final year of the study period. The result of this study could be useful in policy design for better water management.

6. Long-term change in the water footprint and virtual water flows in Nile Basin countries

Abstract

In the face of complex climate change and the ensuing reduction in freshwater availability, the world is facing huge prolonged water crises in balancing the demand and supply of water for the growing population. There are lots of hopes and expectations by researching this emerging global water challenges. This study aims to analyze long-term changes in WF and virtual water flows of selected crops in the Nile Basin countries over thirty years. The annual WF for the selected crops was estimated using the AquaCrop model. The findings show that there is a substantial difference in green and blue WF among crops throughout the riparian states. The biggest annual average blue WF in crop production was found in Sudan, South Sudan, and Egypt. In Sudan maize 6046m^3/tonne, rice 5175m^3/tonne, sorghum 2644m^3/tonne, and millet 2160m^3/tonne and in Egypt groundnut 3138m^3/tonne. The largest WF was recorded during the dry year and the minimum WF during the wet year. The WF and imported and exported quantity of traded crops could determine the Net virtual water import of crops. Egypt is the highest exporter of rice with an average Net VWE of 810 Mm^3 per year followed by 19 Mm^3 in Sudan and 16 Mm^3 in Egypt for groundnuts. On the other hand, Egypt is the highest importer of maize with net virtual water import of 4359 Mm^3 followed by Congo, DR (583 Mm^3), and Sudan (539 Mm^3) for rice and sorghum respectively. To reduce the pressure on riparian states' water resources; it is recommended to produce crops in countries with high room for improvement. The water-scarce countries in the Basin would be better off by increasing the import of water-intensive crops from relatively water abundant countries. Hence, by the findings of this study trading, virtual water trade can help to maintain the water use of the regions rationally and sustainably.

Keywords: Green and blue water footprint, AquaCrop, Net virtual water, Nile Basin countries.

6.1 Introduction

Water is a precious and indispensable asset to achieving sustainable growth by its significant contribution in enhancing socio-economic development, hydro-political stability, and environmental sustainability (Sebri, 2016). Without it, no countries thrive and achieve sustainable growth. As well, water productivity needs to be continuously enhanced while it is a crucial input to agricultural production, yet the continued increase in freshwater demand has resulted in lowering these resources (FAO, 2017). Water experts warn that one of the most critical challenges of the 21st century is the efficient use of global water resources (Jury & Vaux, 2005). The continued growth in blue water footprint due to growing populations, increasing demand for food, combined with climate change, are likely to result in water scarcity in many river Basin (Hoekstra & Mekonnen,2011; Hoekstra *et al.*, 2012). Moreover, these environmental challenges are threatening future global food security and impairing ecosystems (FAO, 2015).To address the rising pressure on freshwater resources, using more efficiently is vital (Mekonnen & Hoekstra, 2014), particularly agricultural production which is the largest water-consuming sector (Falkenmark & Karlberg, 2014; Dalin *et al.*, 2015).

There are lots of hopes and expectations by researching on these emerging global water challenges. For these emerging global water challenges, science must play a critical role in formulating a successful solution (Jury & Vaux, 2005). To address water scarcity problems, implementing improvement of water use efficiency policy measures at different levels is also essential (Mekonnen & Hoekstra, 2011). Water management through water footprint and virtual water trade might have a vital role to resolve the emerging global water crisis caused by climate change and population growth (Mekonnen & Hoekstra, 2011; Qasemipour & Abbasi, 2019). Therefore, understanding the water footprint and virtual water trade can play a vital role in sustainable water management. Reducing water footprint in agriculture is expected to provide solutions to the growing pressure on global freshwater supplies (Mekonnen & Hoekstra, 2013). The virtual water could provide a successful platform to identify options that provide an efficient water management strategy (Hoekstra & Hung, 2002; Chapagain & Hoekstra, 2003).

Water availability and distribution vary widely across countries and regions as it is not distributed evenly across the world (Rijsberman, 2006). Thus, it is essential to allocate the world's limited freshwater resources prudently (Hoekstra, 2013). Furthermore, agricultural water use varies depending on the location and climatic region (Neilsen *et al.*, 2018). This redistribution could take place through the trade of goods from regions of relatively endowed with water to highly water-scarce regions (Tian *et al.*, 2018 & Zhang *et al.*, 2018). In general, a water-scarce region could import water-intensive crops produced in relatively water-rich regions rather than growing with scarce local water resources (Ewing, 2011; Huang *et al.*, 2019). Water availability also varies temporally where the Nile is a case in point.

To increase water productivity strategies in severe water scarcity regions three things can emerge: sustainability, efficiency, and equity of water use (Mekonnen *et al*., 2015). The concept of virtual water (VW) has gained an increased interest in policy development (Chai *et al*., 2014). Virtual water flows are directly related concepts that have been introduced by Hoekstra for better water management (Hoekstra & Hung, 2002). In the role of water management in agricultural production, VW has helped to reduce water scarcity (Kuiper *et al*., 2011). The key value of VW and water footprint would have been used to explain the relationship between food and water security (Schyns & Hoekstra, 2014).

The virtual water trade through water-intensive products could alleviate water scarcity (Zimmer & Renault, 2003; Horlemann & Neubert, 2006). Nations who are unable to produce food locally could solve their food demand through the trading of products that have not been well understood or ignored (Hoekstra & Hung, 2002). The export of a product from a water-efficient region to water inefficient region can save water globally (Molden *et al*., 2010; Mekonnen & Hoekstra, 2014). According to Ma *et al* (2006), Inter-Basin water transfer can be realized either by real water or by VW transfers in the form of commodities trade.

According to Horlemann and Neubert (2006), virtual water flow is an economically unseen, ecologically sound, and peaceful way of the use of water. The trade balance estimation at the state level could provide a conceptual image of the conflict between the two alternatives of virtual water trade and physical inter-basin water transfer (Verma *et al.*, 2009). Better water management could be achieved if most of the production has been done in the countries which have better water resource compared to water-scarce area and where the crop water requirement is very high, higher evapotranspiration and larger water footprint (Hoekstra *et al*., 2011). It would be important when there is room to save both the physical and virtual water flow. Analysis of virtual water flow would help to promote an understanding among the Basin countries. The transboundary nature of the Nile water has important implications for water resources development and necessitates close collaboration with all riparian countries in the planning, development, and management of the river Basin (Di Nunzio, 2013; Hammond, 2013; Demin, 2015; Abtew & Dessu, 2019). It has been increasingly recognized cooperation among states on the development and management of Nile water (Mohamed & Loulseged, 2008).

In most water-scarce regions of arid and semiarid countries, the management of water is a controversial issue (Aldaya *et al*., 2010), where the Nile River Basin is one example. The Nile Basin is a region that faces water scarcity due to manmade problems and mismanagement on the water resource. According to Sulser *et al*., (2010), water scarcity is increasingly a critical issue in the Nile Basin due to the pressing need for development, high population growth, and climate change. A virtual water flow study for the Nile Basin is important to address the looming water resource problems. It has opened the door to more productive water use. An initial approximation of the ‘trade’ in virtual water of Nile Basin states in terms of national water security was studied by Zeitoun *et al.*, (2010). For the current study, however, the results were obtained by simulating with high spatial resolution using AquaCrop model. Moreover, the current study also makes use of different tools, methods, and techniques.

This paper investigates the long-term changes in water footprint and virtual water flows using the current water footprint of five selected crops (rice paddy, maize, millet, sorghum, and groundnuts) in the Basin countries from 1986 to 2015. These five crops were selected based on the largest irrigated area coverage and produced in the Nile Basin. The current study could provide up-to-date information on virtual water flow in the Nile Basin countries. The study suggests that Nile Riparian states to consider the opportunity of virtual water trade to alleviate national water scarcity issues.

6.2 Methods

The annual water footprint for the selected five crops was estimated in all the eleven Nile Basin countries for the years 1986-2015 following the green-blue water accounting standard (Hoekstra *et al*., 2019). The selection of crops is based on FAO (2019), a database that considers the largest in production and area harvested in the Basin. The AquaCrop model was applied to calculate the water footprint of crops in the Nile Basin countries and simulate current agricultural practices. The model was implemented at 5x5-arc minute grids spatial resolution for all grid cells for all selected dominant crops. During the study period, ET and crop yield simulated the dynamic soil water balance. The green and blue crop water use of the crops and yield are the outputs. The model outputs had been processed to separate the number of ingoing and outgoing water into green and blue components. For these specific objective,s the methods have been used which is stated in the general methodology section.

6.2.1 The water footprint calculation

This study follows the methodology based on the standard on the water footprint of water accounting developed by Hoekstra, (2019). Based on the study, daily soil moisture has been separated into green and blue components. Green and Bluewater accounting in a soil water balance was calculated following Hoekstra, (2019). The definition of green and blue water footprint has been defined as a green water footprint is the ratio of ET from the green water and yield while the blue water footprint is the ratio of ET from the blue water to the yield. While the effective rainfall is the amount of rain that is added and stored in the soil.

6.2.2 Virtual water trade estimation

Gross virtual water import and virtual water export define as the volume of water virtually imported or exported through trade. Virtual water trade is calculated by multiplying the volume of trade by its water footprint (m^3/tonne) for each crop in tonnes. Virtual water trade between nations is estimated by multiplying crop trade, import, and export quantity (tonne) of products by their associated water footprint of the crop in the nation. VW trade is thus calculated as following (Chapagain &Hoekstra, 2011; Mekonnen& Hoekstra, 2011):

$$VWT[n_{e,}n_{i,}c,t] = CT[n_{e,}n_{i,}c,t]\ x\ SWD[n_{e,}c] \tag{7.1}$$

Where VWT is the virtual water trade in m^3/yr. CT is the crop trade (tonne/yr). In the exporting nation, SWD reflects the basic water demand (m^3/tonne) of crop c. FAOSTAT (2019) provided the volume of crop trade (CT, tonne/y). The import of gross virtual water to a nation ni is the amount of all imports:

$$GVWI[n_{i,}t] = \sum_{n_e,c} VWT[n_{e,}n_{i,}c,t] \tag{7.2}$$

The sum of all exports is the gross virtual water export from a country ne:

$$GVWE[n_{e,}t] = \sum_{n_i,c} VWT[n_{ei,}n_{i,}c,t] \tag{7.3}$$

A country's net virtual water import is equal to the difference between the gross virtual water import and gross virtual water export. Therefore, country x's virtual water trade balance for year t may write as:

$$NVWI[x,t] = GVWI[n_{ei},t] - GVWE[n_{ei},t] \tag{7.4}$$

Where $NVWI$ is the net virtual water import (m^3/yr) to the country. Net virtual water import to a country has either a positive or a negative sign. To assess import from outside of the country which is the virtual water import, the global averages water footprint of traded crops was obtained from (Mekonnen & Hoekstra, 2011).

While the water footprint (m^3/tonne) of rice was estimated for paddy rice, the rice trade was in total milled-rice equivalent. Therefore, the milled equivalent rice was converted to rice paddy equivalent by using the product fraction of 0.64 obtained from Mekonnen and Hoekstra, (2010).

6.3 Data

Different global data sources were used to estimate crop WF. These five crops (rice, maize, millet, sorghum, and groundnuts) were selected based on the FAO (2019) database on both the largest in production and area harvested. The climate data were obtained from CRU TS-3.20 with a 30 x 30 arc-minute grid spatial resolution (Harris *et al*., 2014). Soil data with 5x5 arc minute resolution were obtained from the ISRIC-WISE dataset (Batjes, 2014). The MIRCA 2000 dataset was used with a resolution of 5x5 arc minutes for the irrigated and rainfed harvested area for each crop (Portmann *et al*., 2010) which made to fit FAO's national level total harvested area. The yearly harvested area at 5x5 arc minute was derived by multiplying the reference MIRCA2000 map by the scaling coefficients. The AquaCrop model was used to assess the annual water footprint of the selected crops during the period 1986–2015. The global averages of the WF of traded crops were obtained from (Mekonnen & Hoekstra, 2011).

6.4 Results

6.6.1 Long term change in the green and blue water footprint of selected crops

The total green and blue water footprint changed over the study period from 1986 to 2015. The water footprint of crops can increase over the year due to an increase in the cultivated area, which contributes to an increase in crop production. Figure 6.1 below shows the change in national average green, blue and total WF of crop consumption in Nile Basin countries. The largest total water footprint of crops is observed in Egypt. Among all the crops, groundnuts have the largest national average total crop consumption WF on average 5,500 m^3/tonne in the Nile Basin countries. The results indicated that there is a difference in the average water footprint of crops in (m^3/tonne) among countries in terms of water footprint, which ranges from 500 m^3/tonne in Uganda to 14,000 m^3/tonne in Sudan. The consumptive water footprint of crop includes a green (rainfall) and blue (irrigation) component. When we compare the green and blue consumptive water footprints, the green water footprint is a higher proportion than the blue. Similar findings were done in (Zhuo *et al*., 2016 & Mekonnen *et al*., 2015) which have done for the Latin American countries.

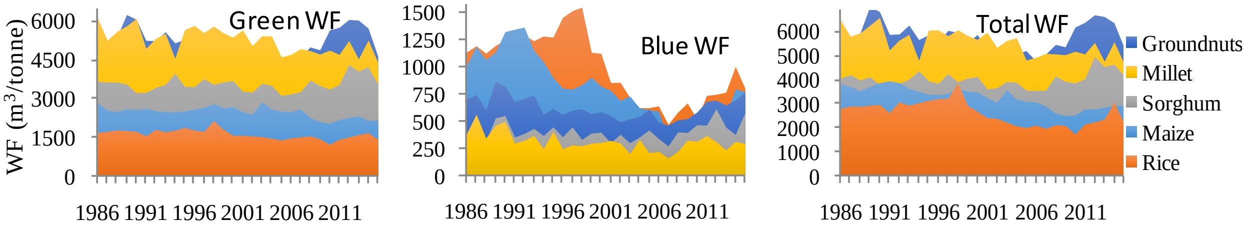


Figure 6. 1 Average national green, blue and total WF of crops in the Nile Basin countries

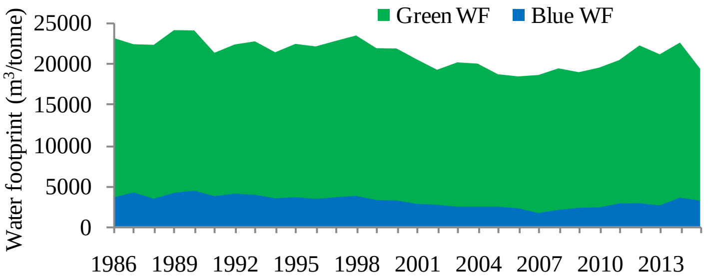


Figure 6. 2 The total green and blue WF of crop production in the Nile Basin countries

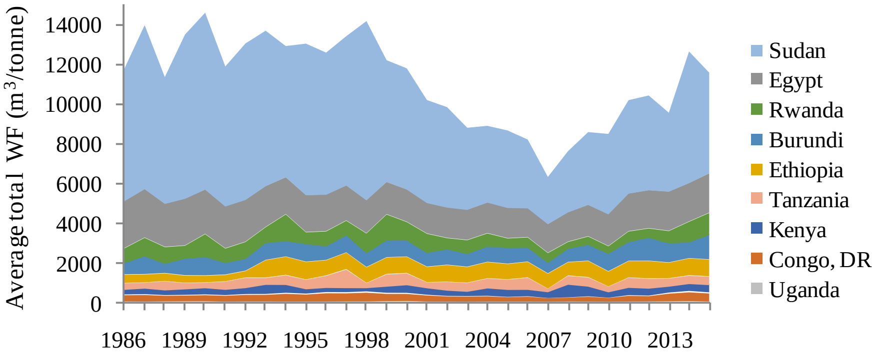


Figure 6. 3 Average total WF of selected crops (m^3/tonne)

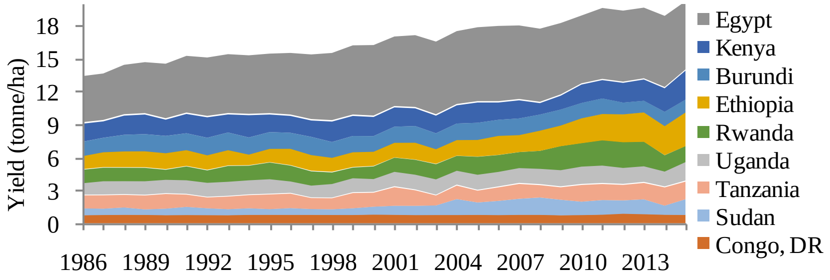


Figure 6. 4 Crop yield (tonne/ha) in the Nile Basin countries

The results indicated that Sudan and Egypt have the largest average total water footprint of crop consumption and the lowest WF is recorded in Uganda and Congo. Figure 6.3 showing the total green and blue WF of the 5 crops in Nile Basin countries over the study period. The average total WF of selected crops (m^3/tonne) is high in Sudan due to the higher production of crops in the region.

The average annual aggregated green and blue water footprint for the selected crops over the study period 1986–2015 for all the Basin countries was estimated. Upstream countries like Burundi, Democratic Republic of Congo, Ethiopia, Kenya, Rwanda were dominated by the green components of the water footprint whereas the downstream countries Egypt and Sudan dominated by the blue component. As indicated in the figures 6.5-6.9, some of the crops had the largest WF per unit of weight (m^3/tonne), while some had the smallest WF with in the same country. Some had the largest blue water footprint, while others had the smallest value. Regarding the green water footprint, certain crops had the largest values in almost all countries.

This study documents the net virtual water trade related to national trade among the Nile Basin countries under current conditions. The net virtual water imported per country in the years 1986-2015 (million m^3/y) has been shown in figure 6.6-6.9. The spatial and seasonal variability of WFs related to the production of all crops in all the Basin countries was presented. The largest contribution to the total water footprint comes from the green water footprint. Substantial inter-annual variability was observed among countries and crops. The variation in the water footprint appears to be driven by inter-annual climatic variability, season, soil, and management practices. The yearly green, blue and total WF per unit for all selected crops has shown in figure 6.5-6.9. The water footprint of crops in almost all dominated by the green WF. The annual net virtual water trade related to trade in selected crops over time presented in figure 6.5-6.9. The net virtual water imports related to all the crops are increasing; so do the net virtual water exports related to the crops for most of the countries. Some of the crops show a modest change over the study period. The virtual water trade related to all selected crops has high inter-annual variability

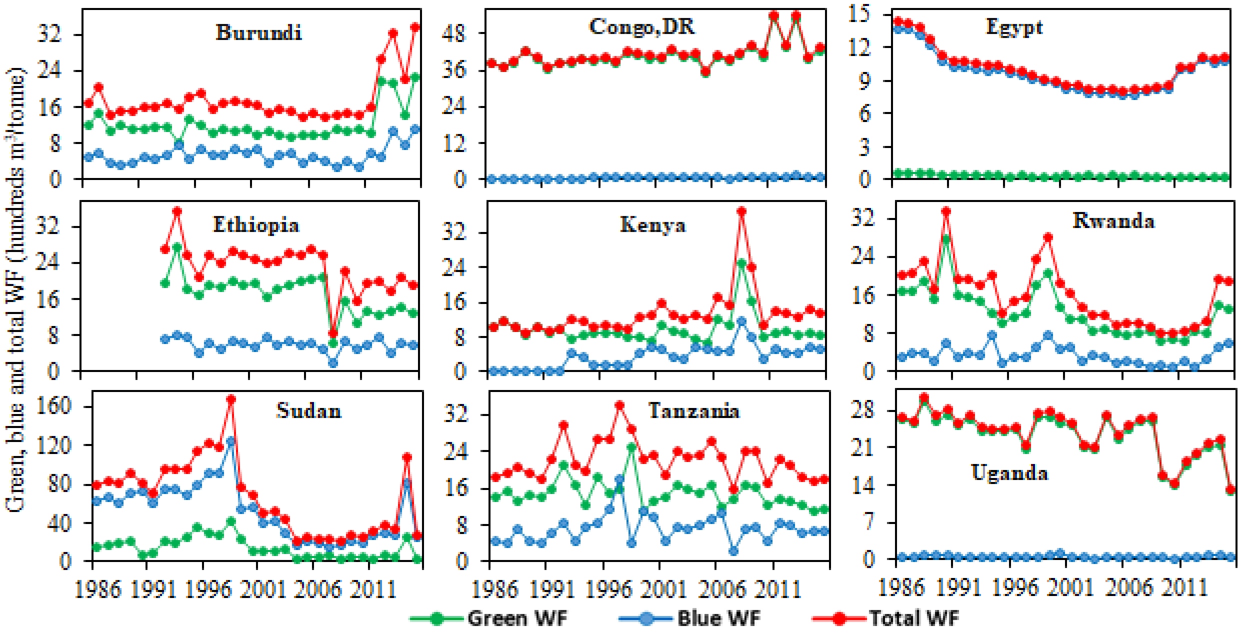


Figure 6. 5 Green, blue and total WF of rice in Nile Basin countries in the period 1986–2015

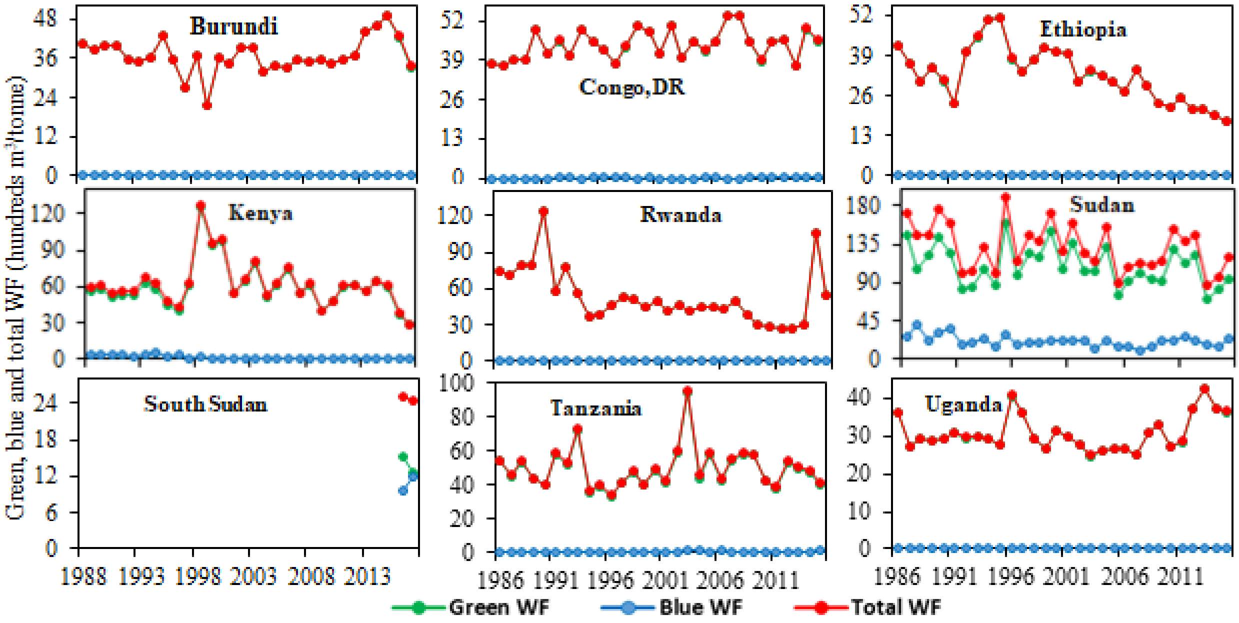


Figure 6. 6 Green, blue and total WF of maize in Nile Basin countries period 1986–2015

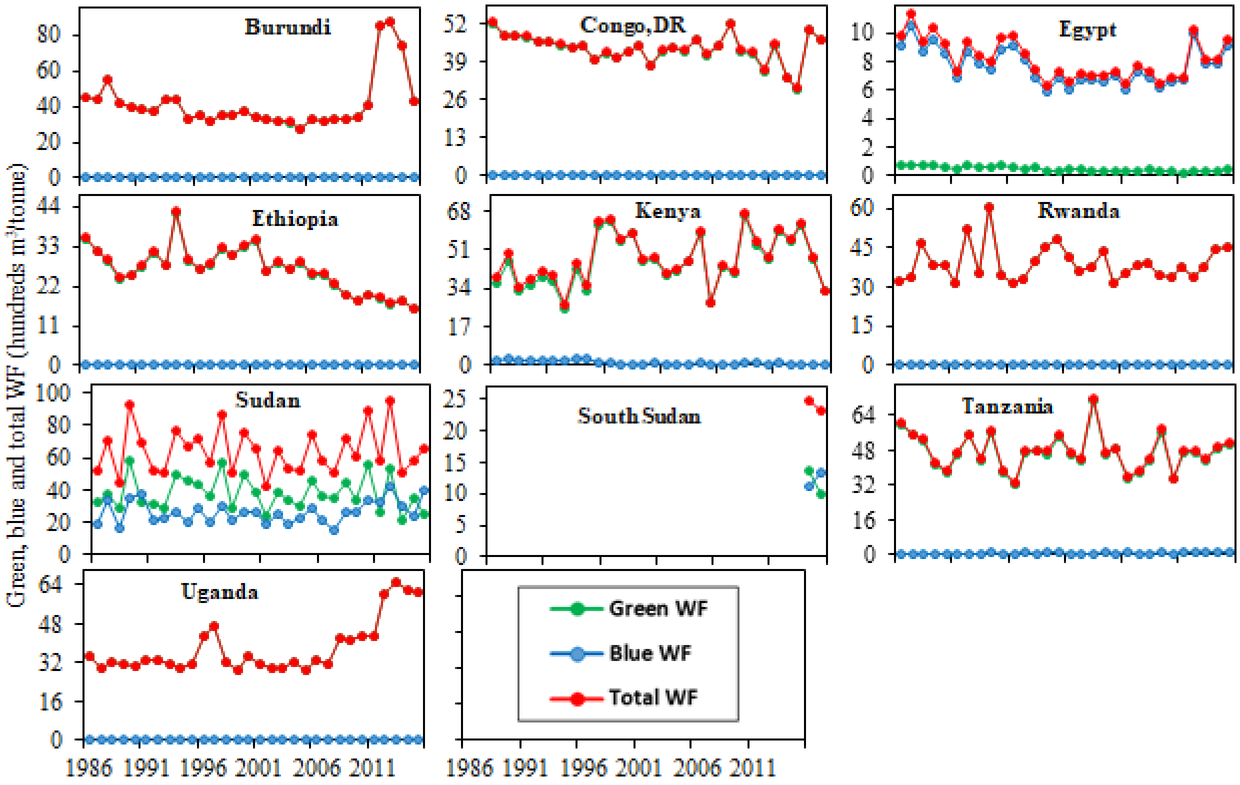


Figure 6. 7 Green, blue and total WF of millet in Nile Basin countries period 1986–2015

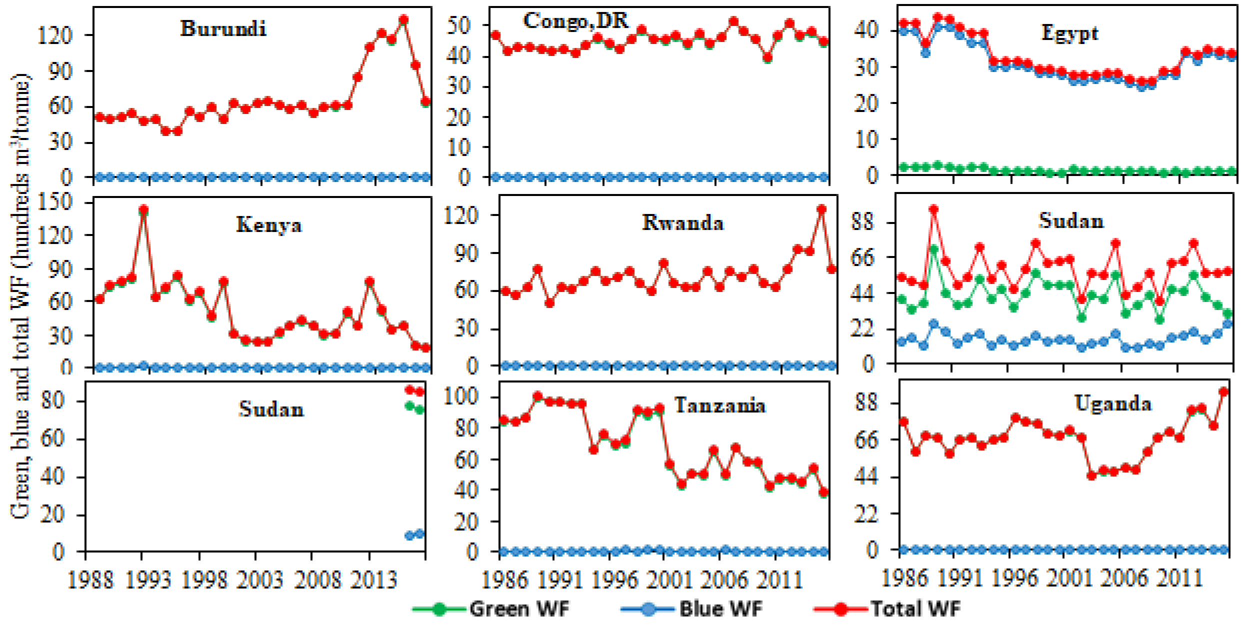


Figure 6. 8 Green, blue & total WF of groundnut in Nile Basin countries in period 1986–2015

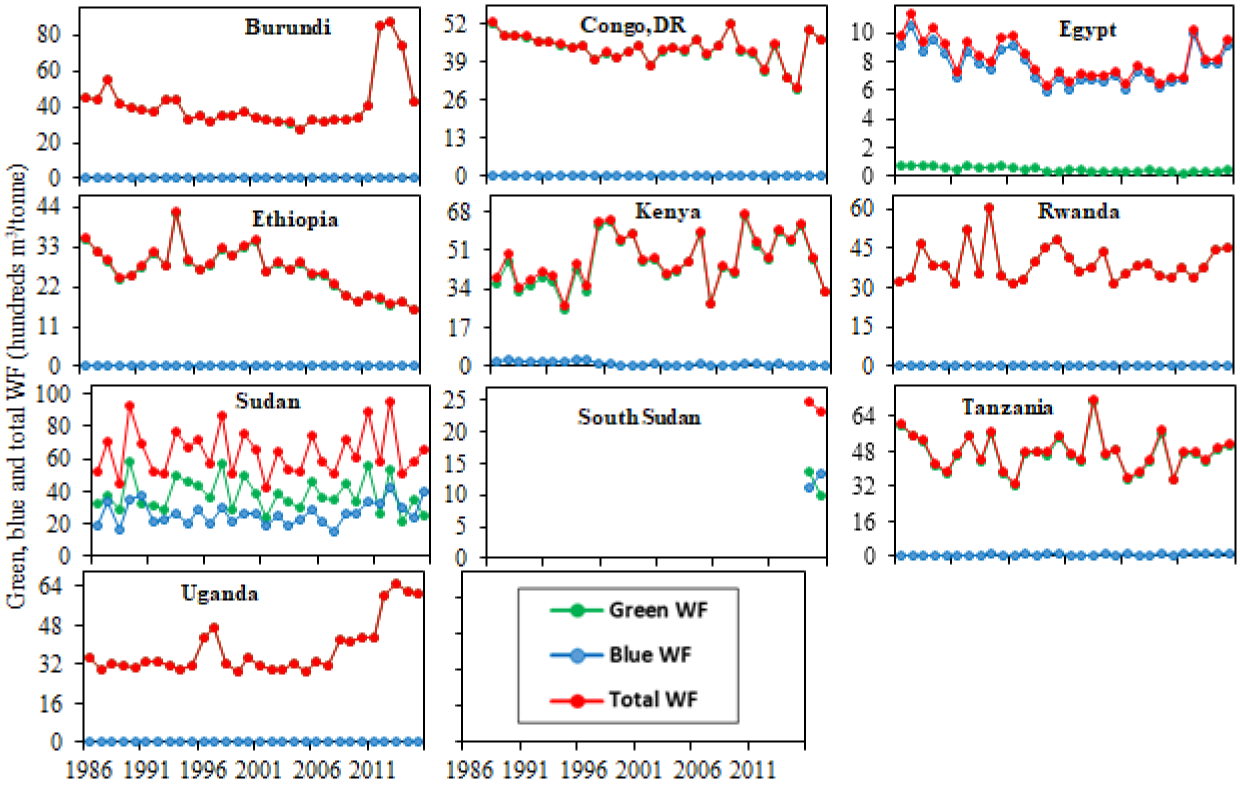


Figure 6. 9 Green, blue & total WF of sorghum in Nile Basin countries period 1986–2015

A comparison of the annual average green, blue, and total WF of the five crops in the Nile Basin countries in the period 1986 in the current study has been done. In the production of rice, the largest annual average blue water footprint obtained in Sudan that is about 5175 m^3/tonne and Egypt 977 m^3/tonne. Countries like Congo DR, Uganda, Tanzania, Ethiopia, and Burundi have a higher green water footprint than blue water footprint in rice production (Figure 6.5). As indicated in figure 6.5 the largest WF has recorded during the dry year and the minimum water footprint recorded during the wet year. The reason for the variation in water footprint over years could be due to the water-saving technology.

For maize production, the largest annual average blue water footprint obtained in Sudan that is about 6046 m^3/tonne and followed by South Sudan 1566 m^3/tonne and Egypt 1111 m^3/tonne. Rwanda, Burundi, and Uganda are the lowest blue WF value. Only three countries Sudan, South Sudan, and Egypt are higher blue WF whereas the rest countries are the higher green WF than blue WF for maize production (Figure 6.6).

For millet production, the largest annual average blue water footprint obtained in Sudan that is about 2160m^3/tonne and followed by South Sudan 1080 m^3/tonne. Sudan and South Sudan are higher green and blue WF in millet production whereas the rest of the countries are higher in green WF than blue WF (Figure 6.7).

For groundnuts production, the largest annual average blue water footprint obtained in Egypt that is about 3138 m^3/tonne and followed by Sudan 1582 m^3/tonne and Sudan 924 m^3/tonne. Sudan and South Sudan use both green and blue WF whereas the other countries use only blue WF (Figure 6.8).

For sorghum production, the largest annual average blue water footprint obtained in Sudan that is about 2644 m^3/tonne and followed by South Sudan 1243 m^3/tonne and Egypt 770 m^3/tonne. For sorghum production, Sudan and South Sudan are higher in green and blue WF whereas the rest of the countries use only the green WF (Figure 6.9).

6.6.2 Virtual water flows of the Nile Basin countries in the period 1986–2015

The gross virtual water import and export of the Nile Basin countries were done for both the international and inter-regional virtual water flows. The result shows that the inter-annual variability of water footprint that leads to the variation of virtual water flows. The annual variation for the virtual water flows has seen across every Basin country. The international flow indicates the flow is within the world countries and the inter-regional flow indicated the flow within the Basin countries. The virtual water import indicates the flow from abroad whereas the virtual water export the flow is abroad. According to the result, the international flows have larger virtual water flows than inter-regional virtual water flows.

Gross inter-regional virtual water import is higher than gross inter-regional VWE since the import of crop commodities has been greater than exported values. Regarding the international VW flows in Nile Basin countries, the gross international VWE ranges from 0.4 to 1.25 billion m^3/y and gross international virtual water import ranges from 5.5 to16.2 billion m^3/y. The gross inter-regional virtual water export value has been increased from 0.001 to 0.5 billion m^3/y whereas the gross inter-regional virtual water import from 0.4 to 1.2 billion m^3/y. Figure 6.10 shows that the international and inter-regional virtual water flows within the Nile Basin countries which include from/to other countries. Inter-regional VWI and VWE are different within basin countries.

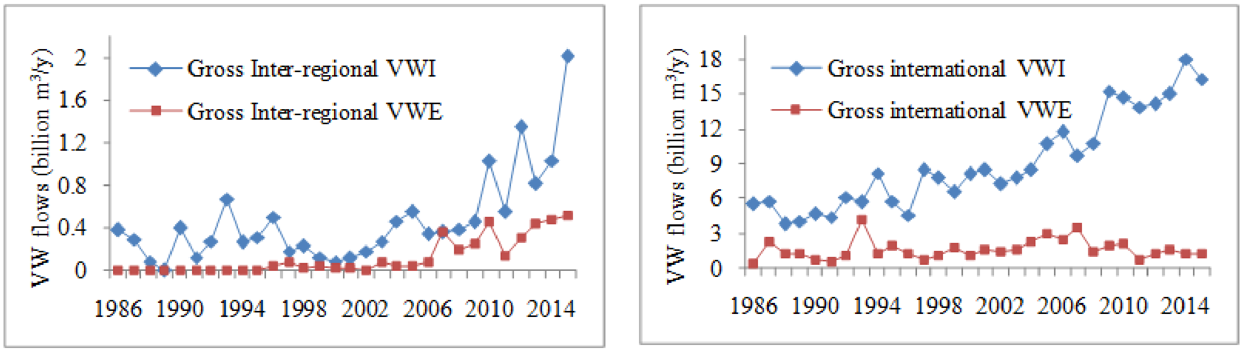


Figure 6. 10 Inter-regional and international virtual water flows in Nile Basin countries.

The international net virtual water import ranges from 5.5 billion m^3/y to 16.2 billion m^3/y whereas the inter-regional net virtual water import ranges from 0.51 billion m^3/y to 1.5 billion m^3/y from the initial year to the final year respectively. The international and inter-regional net virtual water import of crops has increased from the initial study period to the final study period. The virtual water import and virtual water export of crops per country have shown the incremental changes.

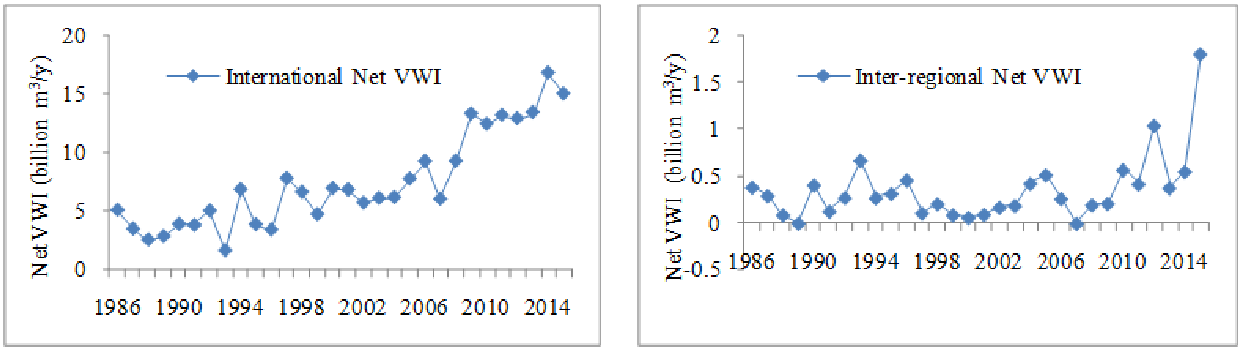


Figure 6. 11 Net virtual water import result from international and inter-regional trade in Nile Basin countries

The highest international NVW has shown for maize crops that estimate about 3507 Mm^3 in the year 1986 and increased by 10890 Mm^3 in the year 2015 followed by rice from 1485 Mm^3 to 2502 Mm^3 in 1986 and 2015 respectively. Regarding the inter-regional NVW of crop trade, the highest value has been estimated for maize for 381 Mm^3 to 240 Mm^3.by the year 1986 and 2015. The following Table 7.1 shows the international and inter-regional NVW (Mm^3) of crop trade in Nile Basin countries.

Table 7. 1 International and inter-regional NVW (Mm^3) of crop trade in Nile Basin countries

Crops	International NVW (Mm^3)		Inter-Regional NVW (Mm^3)	
	1986	2015	1986	2015
Groundnuts	-4	28	0	-4
Maize	3507	10890	381	240
Millet	-5	-26	0	-18
Rice	1485	2502	0	1581
Sorghum	112	1626	0	0
Total	5095	15021	382	1799

6.6.3 Net virtual water import and regional trade in Nile Basin countries

The current study assessed the net virtual water import of the selected crops for the current conditions in the Basin countries as a whole. To show virtual water trade in the Basin countries with the whole basin regions, a list of countries for import and export of those selected crop products were selected from FAOSTAT along with the world region that presented in the figures. The gross virtual water trade between and within regions of the country have been analyzed. Figure 6.12-6.14 shows the trends of net virtual water import for all selected crops in the Nile Basin countries for the period 1986–2015. In the analysis, Eritrea has excluded from the study because the selected crops are not produced in that region.

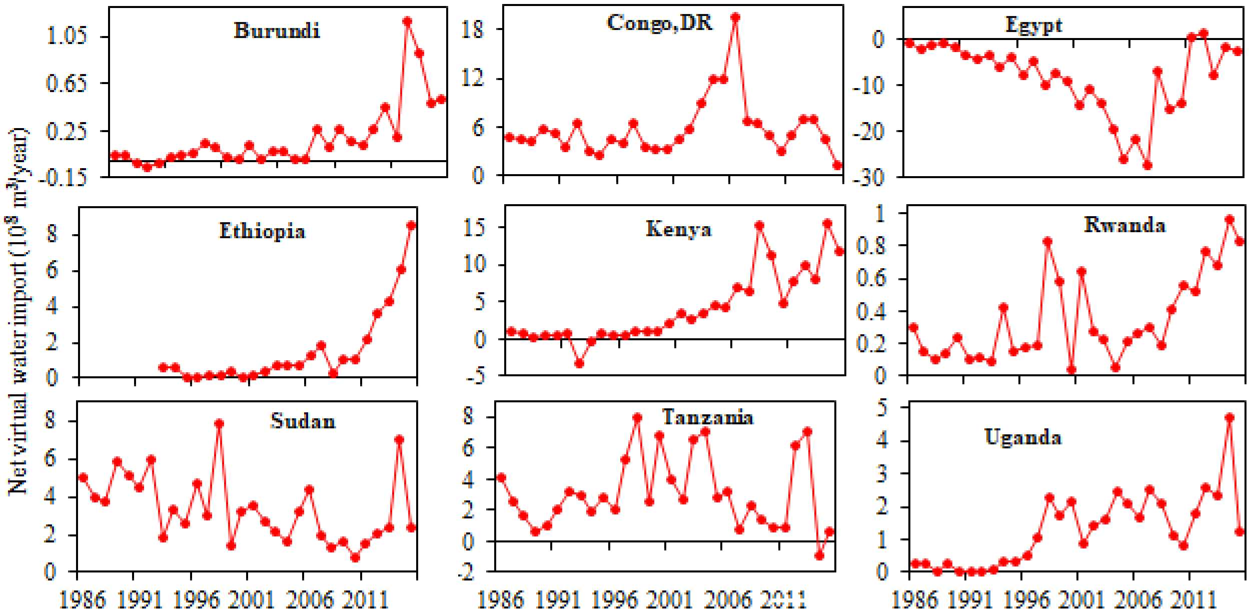


Figure 6. 12 Net virtual water import for rice in Nile Basin countries the period 1986–2015

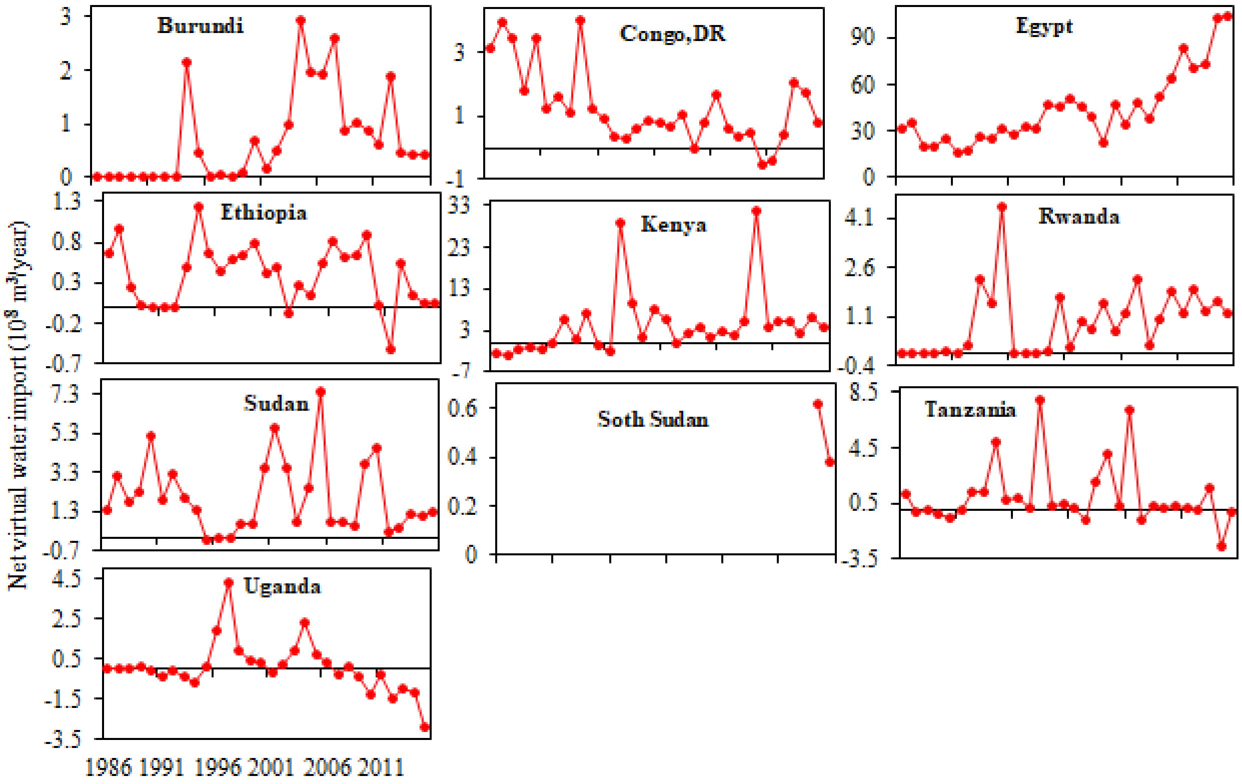


Figure 6. 13 Net virtual water import for maize in Nile Basin countries the period 1986–2015

s

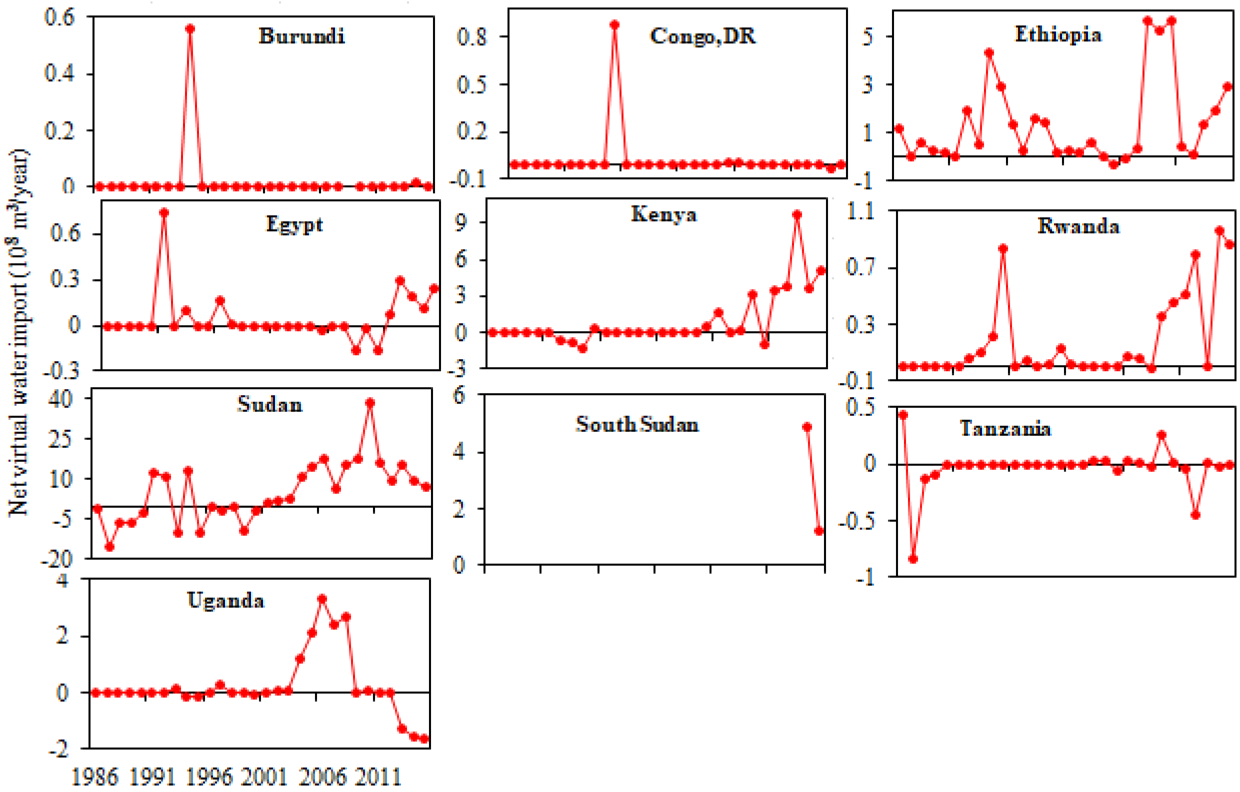


Figure 6. 14 Net virtual water import for sorghum in Nile basin countries the period 1986–2015

6.6.4 Average yield and production difference in harvested area

The country-level yield has been simulated and the estimated average yield (tonne/ha) and production (tonne) in all crops along with all Nile Basin countries with the harvested area (ha) from the period of 1986-2015 have been shown in Table 7.2. Crop production depends on the availability of arable land and is affected by crop yield. The importance of crop production related to harvested areas and yields. Crop yields are the production per unit of harvested area for crop products. Hence, the yield obtained by dividing the production by the area harvested. The results reveal that the maximum yield is obtained from Egypt for rice production (about 8.6 tonnes) followed by maize and sorghum (Table 7.2). According to FAO (2006), the world's largest national average rice yield in 2005 was 9.5 tonne per hectare from Egypt. Although the largest production in Egypt has been due to the newly developed technology, it has reached its maximum production level. The other countries have room to maximize their production level.

Table 7.2 Estimated total average yield (tonne/ha) and production (tonne) with the harvested area (ha) for all crops along with all Nile Basin countries (1986-2015).

Crop	Country	Harvested area (ha)	Yield (tonne/ha)	Production (tonne)
Rice	Burundi	9073	3.01	26566
	Congo, DR	292907	0.63	182736
	Egypt	565740	8.60	4964810
	Ethiopia	18147	2.18	48703
	Kenya	16435	3.71	60848
	Rwanda	4981	3.36	19145
	Sudan	4901	2.09	12522
	Tanzania	445444	2.36	1088818
	Uganda	38804	1.57	63288
Maize	Burundi	118272	1.20	141725
	Congo, DR	1450654	0.81	1165067
	Egypt	852933	6.97	5972375
	Ethiopia	1549331	2.05	3362690
	Kenya	1374181	2.03	2757916
	Rwanda	119539	1.34	184352
	Sudan	59951	0.92	47001
	South Sudan	205558	1.01	204000
	Tanzania	2320590	1.58	3457665
	Uganda	689438	1.78	1335829
Millet	Burundi	10419	1.12	11631
	Congo, DR	59551	0.67	39738
	Ethiopia	298158	1.22	389322
	Kenya	96899	0.70	67571
	Rwanda	4118	0.84	3580
	Sudan	2436714	0.31	764051
	South Sudan	9189	1.18	10739
	Tanzania	282572	0.92	259036
	Uganda	334678	1.49	502169
Sorghum	Burundi	55824	1.14	64226
	Congo, DR	18730	0.71	12279
	Egypt	142277	5.25	750116

Crop	Country	Harvested area (ha)	Yield (tonne/ha)	Production (tonne)
	Ethiopia	1240720	1.60	2147135
	Kenya	149647	0.93	137541
	Rwanda	138375	1.09	149266
	Sudan	6310621	0.68	4344632
	South Sudan	735425	1.45	1050562
	Tanzania	672169	0.99	668859
	Uganda	289509	1.32	373985
Groundnuts	Burundi	14587	0.77	10892
	Congo, DR	518332	0.81	420143
	Egypt	46523	2.90	143004
	Kenya	17014	1.18	19712
	Rwanda	16960	0.64	10603
	Sudan	1187416	0.81	961853
	South Sudan	200163	0.59	116938
	Tanzania	358809	0.77	343010
	Uganda	248142	0.78	191368

6.5 Discussion

A comparison of the average values for the period 1986-2015 with the current study and reported values in Mekonnen and Hoekstra, (2011) have provided useful insights on virtual water import and export crop products in the Nile riparian states. Rice and maize are the most traded products in the region among the selected crops in all the Basin countries. The highest Net VWE in Mm^3 is in Egypt and Sudan for rice and sorghum respectively. In terms of net virtual water import and export of crop products, there is a difference between the Nile Basin countries. The majority of the Basin countries are importer for the selected crops. Generally, the highest Net virtual water import in Mm3 was in Egypt and Sudan for maize and sorghum respectively. Egypt, Congo, Sudan, and Kenya were the highest importer of maize ($4359Mm^3$), rice ($583Mm^3$), sorghum ($539Mm^3$), and maize ($437Mm^3$) respectively with the annual average value for the study period. Some of the Basin countries such as Egypt, Sudan, Uganda and Tanzania export some commodities items like rice, groundnuts millet, and sorghum respectively. Figure 6.12-6.14 presents the results of the net virtual water import long-term patterns of the Nile Basin countries from the period of 1986 to 2015.

Virtual water trade can play a significant role in addressing regional water shortage. For instance, Egypt and Sudan are net virtual water exporters for rice and sorghum in the Nile Basin countries. As a severe water-scarce region, these countries export more water in the form of crops to other areas through trade. Meanwhile, these countries could greatly benefit from importing water-intensive crops from the relatively water abundant countries and exports less water to consume crops. At the same time, it is more economical to produce such water-intensive goods in the region from areas that are a relatively water-abundant region and export large quantities of virtual water to other regions by transferring agricultural products. According to Feng *et al.*, (2011), studies in China suggest that in most water-scarce regions it should increase the import of water-intensive goods from other more water abundant regions.

Water is an important resource urgently needed for regional development and supposed to use in a manner that promotes its productivity and thus sustainability. WF of crop products can be useful for sustainable use, by creating awareness of producers who provide sustainable products. Since WF is a measure of water consumption, the management of water consumption has policy implications.

This finding revealed that the majority of the Nile Basin countries are mainly net virtual water importer through agricultural trade. It is difficult to compare previous findings with this particular study due to variations in methodologies employed by the researchers in the different studies. Consequently, the green water footprint of the current study for the Basin countries is in agreement with the results of Mekonnen & Hoekstra 2011. However, the results were different from other studies like Zeitoun *et al.*, (2010) due to many reasons mentioned previously: variation in the methods applied, the type of crops variety, the study period, the models and data used. The current study benefited from the latest available national data and improved methodologies compared with previous studies.

6.6 Conclusions

In this paper, the long-term change in water footprint and virtual water trade in the Nile Basin countries were estimated concerning the current water footprint. The analysis shows that there are large differences in water footprint within the nation and the net virtual water import variation. There is a significant variation among WF and virtual water trade among the upstream and downstream countries. Countries like; Egypt and Sudan have higher water consumption for crop production. The net virtual water trade balance of Egypt drawn in the current study suggests that this country has a high net import of virtual water, due to the large import of crops. This study was limited to only a few selected crops of the Basin countries to virtual water trade between nations. To develop a comprehensive picture of the total virtual water trade, a comprehensive study that could involve many crop products is required. Domestic virtual water trade is important in countries like the Nile Basin, which is relatively dry in the lower part and wet in the upper part. This study indicates that Nile riparian states should seriously consider the potential of virtual water trade in alleviating nagging water scarcity concerns locally. Policymakers of the Basin countries can use the current national virtual water trade within the country to develop a sound national policy by a trade agreement to achieve higher regional water use efficiency. Hence, this finding is a very important addition in our understanding of water resource management, highlighted the role of virtual water trade in water policy development, and provides policy-relevant information.

7. Conclusion and recommendations

7.1 Summary of the main findings

The use of different irrigation systems for crop production could enhance water productivity by saving water while maintaining the yield. In this research, the field level experiment was conducted to see the effects of irrigation management on barley yield and water productivity in the upper Blue Nile Basin. The study presented that barley can withstand a maximum level of irrigation water up to 80% FIT application level. Deficit irrigation techniques in water scarce-regions could be a sustainable strategy for crop production. For example, the use of deficit irrigation in barley production offers great potential to improve water use.

This research introduces the importance of the water footprint and virtual water of crop production in contributing to sustainable development, management, and building trust among the Nile Basin countries. Water footprint reduction in irrigated crop production is the way forward for efficient and sustainable water resource use. The research measures and provides the first study regarding the potential blue water saving that reduces the WF of crops at the national level using the two different scenarios of deficit irrigation strategy and organic mulching. The analysis of the main crops' blue water footprint could decrease the current blue WF by 42%. The study revealed that in a more water-scarce country like Egypt and Sudan, the biggest share of the country’s blue WF is allocated to sorghum (50%) followed by maize (20%) and rice (16%).

In this study, the long-term change in WF and virtual water trade in the Nile Basin countries estimated to the current WF. The analysis shows that there are significant gaps in water footprint within the nation and the net virtual water import variation. Downstream countries like; Egypt and Sudan have higher water consumption for crop production as compared to upstream countries like Ethiopia. There are temporal and spatial variations in water footprint and virtual water import in the Nile Basin countries. The highest net virtual water import was in Egypt and Sudan for maize and sorghum respectively. Egypt, Congo, Sudan, and Kenya were the highest importer of maize (4359Mm^3), rice (583Mm^3), sorghum (539Mm^3), and maize (437Mm^3) respectively with the annual average value for the study period.

The net virtual water trade balance of Egypt drawn in the current study suggests that the country has a high net import of virtual water, due to the large import of crops. To develop a comprehensive picture of the total virtual water trade, there has to take alternative crop products such as maize, sorghum, rice, and millet. Domestic virtual water trade is important in the Nile Basin countries, which is relatively dry in the lower part, very wet in the middle part, and wets in the upper part.

In dry regions such as Egypt, the type of crop selection should be in a way that has less consuming water use. Egypt and Sudan cover the largest consumptive water footprint of crops compared to the other countries. As it has indicated in the result section, it indicated that Sudan and Egypt have the largest average total water footprint of water consumption. Both countries produce a large amount of crops with a larger water footprint and where the crop water requirement is very high and more evapotranspiration. In terms of yield, Egypt has a relatively large yield compared to the rest of the Nile basin countries. However, with little room for improvement, Egypt has already reached the maximum efficiency level. Therefore, it has recommended that crops should produce in the regions where there is a high room for improvement.

The study suggests that importing water-intensive crops from relatively water abundant regions can benefit a water-scarce country instead of producing at home. In general, to address the water scarcity, the study suggests that better to import water-intensive crops from relatively water abundant countries than producing locally. Moreover, virtual water trade could improve the use of water resources to alleviate the presser on water use. Having a strong virtual water trade policy significantly contributes to building trust and collaboration among transboundary Basin countries. The governments of the Basin countries can use the current national virtual water trade within the country to develop a sound national policy by a trade agreement to achieve higher regional water use efficiency. Hence, the findings can strengthen the significance of considering virtual water trade in water policy development.

For the upper Nile Basin countries like Ethiopia, Burundi, Congo DR, it is especially attractive to grow crops and export to downstream countries because the climate and growing conditions are very suitable for this crop. On the other hand, a downstream country like Sudan has a wide irrigable potential land suitable for producing crops if water scarcity would not be a problem.

Analyzing the water footprint of crops can provide a clear framework for finding potentially suitable strategies at the national level for effective use of water. This can be very useful in achieving an effective water allocation for the development of the region's crop production.

7.2 Contribution of the study, policy implications, and future research area

7.2.1 Contribution of the study

This Ph.D. dissertation contributes in many ways to the research field of water footprint and virtual water trade studies in using shared water resources. First, the work contributes to the baseline for the blue water-saving potential through deficit irrigation and mulching at the regional level. Since it is the first study on the blue WF reduction through DI and OM at the regional level using the AquaCrop model, the previous study focused on field level. Second, it presents an analysis of long-term change in the WF of selected crops and virtual water flows in Nile Basin countries that could use as input for policymakers. Thirdly, it can contribute to the improved irrigation management of crop production. Although the Nile Basin countries may implement different water policies for its water management, effective riparian cooperation, and careful consideration of water footprint and virtual water trade needed to develop policies. Virtual water trade could be a very effective alternative to physical water transfers in alleviating water scarcity. Since water is an important component of sustainable regional development and thus it is very important to use water efficiently.

From the results presented, the following recommendations are drawn:

- **Adaptive technology**: To alleviate the problem of water scarcity caused due to the rapid increase of population, industrialization, and climate variability, implementing deficit irrigation and mulching is vital.
- **Additive IWRM**: Appropriate integrated water resource management approach can implement to alleviate the water scarcity problems. Since IWRM is a tool for sustainable

use of water to meet different needs. Since the water footprint assessment is an analytical tool that can help to widen the knowledge base for IWRM. It broadens the scope of the study of water scarcity by incorporating the concept of virtual water flow and including the dimension relevant to international and interregional trade. This way, it can contribute to better-informed water management decisions and policy is made.

- **Sustainable Development**: Sustainable and effective adaptive measures for future water resource management are required to alleviate the water scarcity problems.
- SMART water policy on shared water resources should implement.

7.2.2 Policy implications

This study provides the following important start-up suggestions for water management policy implication on shared water resource:

1. **Joint strategic planning**: This work has provided empirical data of long-term changes over the Nile Basin countries on the green and blue WF for specific crops over the last three decades. Moreover, the blue water-saving potential through deficit irrigation and mulching in Nile Basin countries. Thus, it recommended that evidence be used in the design, preparation, and execution of the management of water resources.
2. **Linking country's potential resources with water efficiency**: The results of this study indicate that implementing improved water management for crop production by using deficit irrigation and mulching could offer great potential for increasing water use, a technique of deficit irrigation that increases crop production in water-scarce regions has suggested using water effectively.
3. **Strategizing optimum water-saving practices in irrigation systems**: The research assessed the blue water-saving potential through deficit irrigation and organic mulching throughout the Nile Basin countries. The findings underline that deficit irrigation combines with organic mulching would minimize the blue water footprint and aid in water-scarce countries to sustainable water use. Hence, both the irrigation strategy for all the deficit irrigation and organic mulching can be used by the nations in developing the water policies of the countries to use water sustainably.

4. **SMART transboundary water policy:** In developing the national water policy the considering the virtual water is better to take comparative advantages. It can be very useful in water management to produce crops in a country with a comparative advantage in irrigation water for crop production and improve irrigation systems. National efforts have to consider virtual water values in developing national water policies. Therefore, it can generate significant benefits to the countries.
5. **Water-saving technologies:** Countries must adopt successful policy interventions to resolve the water scarcity crisis at different scales. Such policy interventions include increasing productivity of water use; implementing water-saving technology; growing crops of countries with high scope for improvement.
6. **Water valuation research, development, monitoring, evaluation & learning practices**: Water is an essential component of sustainable regional growth, and is critical for efficient use of water. The water-scarce countries in the Basin can increase imports of water-intensive crops from water sufficient regions with better water availability. Consequently, policymakers take effective policy actions properly to manage the water resource and to avoid future challenges with the available water.
7. **Shared water footprint information & management systems:** Most nations do not pay much attention to their internal crop water footprints and virtual water exchanges while designing water initiatives. Knowing and considering the internal and external virtual water and crop WF of the nation is critical throughout the development of a good regional and national water policy for water-efficient usage.

7.2.3 Future research area

This research is limited in scope and evaluated only five dominant crops in Nile Basin countries with water footprint and virtual water flows. Therefore, it would be nice if more work would need to carry out into more crops that are the largest in production and area harvested in the Basin countries. Setting a benchmark so that countries like Ethiopia reached the level of productivity similar to Egypt. Another specific area, however, would be the once the optimal level of deficit irrigation is known, addressing the issue of yield and production in best management practices of deficit irrigation and organic mulching is vital. This work mainly focused on the theoretical dimensions of complementary methods, thus, assess the methods for implementation of deficit irrigation and organic mulching on the cost and benefit analysis of it is needed. Implementation of deficit irrigation and organic mulching, for example, maybe expensive.

Reference

Ababaei, B., Ramezani, H., 2016. Water footprint assessment of main cereals in Agric. Water Manag. 179, 401–411.

Abawari, Y.M., Security, H., 2011. Conflict and cooperation among the Nile basin countries with special emphasis on the Nile Basin Initiative (NBI). Int. Inst. Soc. Stud.

Abtew, W., Dessu, S.B., 2019. The Nile River and transboundary water rights. In the grand Ethiopian renaissance dam on the Blue Nile. In: Springer Geography. pp. 13–27.

Aldaya, M.M., Martínez-Santos, P., Llamas, M.R., 2010. Incorporating the water footprint and virtual water into policy: Reflections from the Mancha Occidental region, Spain. Water Resour. Manag. 24, 941–958.

Ali, S., Xu, Y., Ma, X., Ahmad, I., 2017. Planting patterns and deficit irrigation strategies to improve wheat production and water use efficiency under simulated rainfall conditions. Front. Plant Sci. 8, 1408.

Ali Y.S., Crsato A., Mohamed Y. A., Wright N.G., and Roelvink J.A., 2014. water resource assessment along with the Blue Nile River, north Africa with one dimensional model. In proceeding of the institute of Civil Engineers- water management. vol. 167, no. 7, pp 394-413

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Irrig. Drain. 300, 300.

Allan, J.A. (2003) Virtual water — the water, food, and trade nexus: Useful concept or misleading metaphor? Water International 28 (1): 106–113.

Allen, R.G., Tasumi, M., Trezza, R., 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC) – Model. ASCE J. Irrigation and Drainage Engineering 133, 380-394.

Amador DS, Jose AC, and M.C., 2018. Sustainable water resources management: a bibliometric overview. MDPI Water 10, 1191.

Ambachew, S., Alamirew, T., and Melese, A., 2014. Performance of mungbean under deficit irrigation application in the semi-arid highlands of Ethiopia. Agric. Water Manag., 136, pp.68-74.

Ararssa, A.A., Gebremariam, A.G., Legesse, W.M., Mekonnen, M.M., 2019. Effects of irrigation management on yield and water productivity of barley *Hordeum vulgare* in the upper Blue

Nile basin: a case study in northern Gondar. Water Conserv. Sci. Eng. 4(2), 113–121.

Araya, A., Habtu, S., Meles, K., Kebede, A., Dejene, T., 2010. Test of AquaCrop model in simulating biomass and yield of water-deficient and irrigated barley (*Hordeum vulgare*). Agric. Water Manag. 97, 1838–1846.

Araya, A., Stroosnijder, L., 2010. Effects of tied ridges and mulch on barley (Hordeum vulgare) rainwater use efficiency and production in Northern Ethiopia. Agric. Water Manag. 97, 841–847.

Arjoon, D., Tilmant, A., Herrmann, M., 2016. Sharing water and benefits in transboundary river basins. Hydrol. Earth Syst. Sci. 20 (6), 2135–2150.

Awel, S., Tena Alamrew, Michael AW, 2018. Performance assessment of community-managed irrigation practices in the Wesha small-scale irrigation project, Southern Ethiopia. Irrig. Drain. Syst. Eng. 7.

Bahri, A., 2012. Integrated urban water management. TEC background papers, (16), pp.1-89.

Bastiaanssen, W.G.M., Steduto, P., 2017. The water productivity score (WPS) at the global and regional level: Methodology and first results from remote sensing measurements of wheat, rice, and maize. Sci. Total Environ. 575, 595–611.

Baten, M.A., Titumir, R.A.M., 2016. Environmental challenges of trans-boundary water resources management: the case of Bangladesh. Sustain. Water Resour. Manag. 2, 13–27.

Batjes, N.H., 2014. ISRIC-WISE derived soil properties on a 5 by 5 arc-minutes global grid (ver. 1.2) (No. 2012/01).

Bayeh, M., Berhane, L., 2011. Barley research and development in Ethiopia: An overview. Proceedings of the 2nd national barley research and development review workshop, Barley Research and Development in Ethiopia. Proceedings of the 2nd National Barley Research and Development Review Workshop.

Bekele, S., Smakhtin, V., Molden, D., and Peden, D., 2012. The Nile River Basin: water, agriculture, governance, and livelihoods. Routledge.

Bryson, J.M., 2018. Strategic planning for public and nonprofit organizations: A guide to strengthening and sustaining organizational achievement. John Wiley & Sons.

Cai, X., Rosegrant, M.W., 2003. The concept of efficiency in w 163–178.

Carter, K. E., & Stoker, R., 1985. Effects of irrigation and sowing date on yield and quality of barley and wheat. New Zeal. J. Exp. Agric. 13, 77–83.

Carvalho, D F. D., Oliveira Neto, D. H. D., Felix, L. F., Guerra, J. G. M., & Salvador, C., 2016.

Yield, water use efficiency, and yield response factor in carrot crop under different irrigation depths. Cienc. Rural. St. Maria 46, 1145–1150.

Cavazza, F, Galioto F, Raggi, M, V.D., 2018. The role of ITC in improving sequential decisions for water management in agriculture. Water 10, 1141.

Central Intelligence Agency, 2013. The world factbook 2012-13. central intelligence agency.

UNEP, 2011. Water footprint and corporate water accounting for resource efficiency United Nations global compact, pacific institute.

Chai, Q., Gan, Y., Turner, N.C., Zhang, R.Z., Yang, C., Niu, Y., Siddique, K.H.M., 2014. Water-saving innovations in Chinese agriculture, Advances in Agronomy. Elsevier.

Chapagain, a. K., Hoekstra, A.Y., 2003. The water needed to have Dutch drink coffee. UNESCO-IHE Institute for Water Education, Water Research Series 14, 8.

Chapagain, a K., Hoekstra, a Y., 2004. The water footprint of nations. Volume 1 : Main report. Value Water Res. Rep. Ser. 1, 1–80.

Chapagain, A.K., Hoekstra, A.Y., 2003. Virtual water flows between nations in relation to trade in livestock and livestock products.

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., 2011. The blue, green, and grey water footprint of rice from production and consumption perspectives. Ecol. Econ. 70, 749–758.

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., 2006. Water-saving through international trade of agricultural products 455–468.

Chapagain, A.K., Hoekstra, A.Y., States, U., 2008. The global component of freshwater demand and supply : an assessment of virtual water flows between nations as a result 33, 19–32.

Cho, M., Karaaslan, M., Chowdhury, S., Ko, F., Renneckar, S., 2018. Skipping Oxidative Thermal Stabilization for Lignin-Based Carbon Nanofibers, ACS Sustainable Chemistry and Engineering.

Chukalla, A.D., Krol, M.S., Hoekstra, A.Y., 2015. Green and blue water footprint reduction in irrigated agriculture: The effects of irrigation techniques, irrigation strategies, and mulching. Hydrol. Earth Syst. Sci. 19 (12), 4877–4891.

Costa, J.M., Ortuño, M.F., Chaves, M.M., 2007. Deficit irrigation as a strategy to save water: physiology and potential application to horticulture. J. Integr. Plant Biol. 49 (10), 1421–

1434.

Dalin, C., Qiu, H., Hanasaki, N., Mauzerall, D.L., Rodriguez-Iturbe, I., 2015. Balancing water resource conservation and food security in China. Proc. Natl. Acad. Sci. U. S. A. 112, 4588–4593.

Demin, A.P., 2015. Distribution of water resources: A case study of the transboundary Nile river. Geogr. Nat. Resour. 36, 198–205.

Deng, X.P., Shan, L., Zhang, H., Turner, N.C., 2006. Improving agricultural water use efficiency in arid and semiarid areas of China. Agric. Water Manag. 80, 23–40.

Di Nunzio, J., 2013. Conflict on the Nile: The future of transboundary water disputes over the world's longest river. Future directions international strategic analysis paper, Dalkeith.

Du, T., Kang, S., Zhang, J., Davies, W.J., 2015. Deficit irrigation and sustainable water-resource strategies in agriculture for China's food security. J. Exp. Bot. 66 (8), 2253–2269.

Earle, A., 2013. Transboundary water management: Principles and practice. Earthscan.

El-Wahed, M.A., Sabagh, A. El, Saneoka, H., Abdelkhalek, A.A., Barutçular, C., 2015. Sprinkler irrigation uniformity and crop water productivity of barley in the arid region. Emirates J. Food Agric. 27, 770–775.

Evans, R.G., Sadler, E.J., 2008. Methods and technologies to improve the efficiency of water use. Water Resour. Res. 44, 1–15.

Falkenmark, M., Karlberg, L., 2014. Present and future water requirements for feeding humanity.

FAO, 2006. Record rice yields for Egypt http://www.fao.org/newsroom/en/news/2006/1000387/index.html 2–3.

FAO, 2015. Towards a water and food secure future: Critical perspectives for policy-makers 1–76.

FAO, 2017. The future of food and agriculture: trends and challenges. annual report, food and agriculture organization of the United Nations.

FAOSTAT, 2019. FAOSTAT on-line database, food and agriculture organization, Rome.

Feng, K., Ling, Y., Guan, D., Hubacek, K., 2011. Assessing regional virtual water flows and water footprints in the Yellow River Basin, China: A consumption-based approach. Appl. Geogr. 32 (2), 691–701.

Fereres, E., Goldhamer, D.A., Parsons, L.R., 2003. Irrigation water management of horticultural crops. Hort Sci. 38 (5), 1036–1042.

Fereres, E., Rabanales, C.U. De, 2007. Deficit irrigation for reducing agricultural water use 58, 147–159.

Feyisa, 2016. Proceedings of the 7th and 8th annual regional conference on completed research of soil and water management research, 25–31, January 2013 and 13–20, 2014, Bahir Dar, Ethiopia. Awash 1–188.

Gebrehiwot, K.A., Gebrewahid, M.G., 2016. The need for agricultural water management in sub-Saharan Africa. J. Water Resour. Prot. 08, 835–843.

Georgakakos, A.P., 2010. A decision support system for integrated water resources planning and management in the Nile Basin.

Gerbens-Leenes, P.W., Hoekstra, A.Y., Meer, T.H. Van Der, 2008. The water footprint of bio-energy: Global Water Use for Bio-Ethanol, Bio-Diesel, Heat, and Electricity. Value Water Res. Rep. Ser. 34, 108.

Ghufran, M.A., Batool, A., Irfan, M.F., Butt, M.A., 2015. The water footprint of major cereals and some selected minor crops of Pakistan. J. Water Resour. Hydraul. Eng. 4 (4), 358–366.

Gil, P.M., Lobos, P., Durán, K., Olguín, J., Cea, D., Scha, B., 2018. Scientia horticultural partial root-zone drying irrigation, shading, or mulching effects on water savings, productivity, and quality of ‘Syrah’ grapevines. Sci. Hortic. (Amsterdam). 240, 478–483.

Grafton RQ, Williams J, Perry CJ, Molle F, Ringler C, Steduto P, A.R., 2018. The paradox of irrigation efficiency. Science (80). 361, 748–750.

Haile Selassie, A., Hagos, F., Awulachew, S., 2008. Production systems in the Blue Nile Basin: implications for environmental degradation and upstream and downstream linkages.

Hammond, M., 2013. The Grand Ethiopian renaissance dam and the Blue Nile: Implications for transboundary water governance’ GWF discussion Paper 1306, global water forum, Canberra, Australia. Water Int. 44, 77–80.

Harris, I., Jones, P.D., Osborn, T.J., Lister, D.H., 2014. Updated high-resolution grids of monthly climatic observations–the CRU TS3 10 Dataset. Int. J. Climatol. 34, 623-642.

Hatem, C., Krol M. S., Hoekstra A Y. 2018. Virtual water trade patterns in relation to environmental and socioeconomic factors: A case study for Tunisia. Sci. Total Environ 613–614 (287–297)

Helmut Kloos and Worku Legesse, 2010. Environmental studies and water resources management in Ethiopia. African studies.

Hoekstra, A.Y., Hung, P.Q., 2002. A quantification of virtual water flows between nations in relation to international crop trade. Water Res. 49, 203–9.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., 2009. Water Footprint Manual State of the Art 2009. Water Footprint. Netw. 131.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., 2011. The water footprint assessment manual: Setting the global standard. Routledge. Earthscan, London, UK.

Hoekstra, A.Y., Mekonnen, M.M., 2011. Global water scarcity: the monthly blue water footprint compared to blue water availability for the world's major river basins. Water 78.

Hoekstra, A.Y., Mekonnen, M.M., 2012. The water footprint of humanity." Proceedings of the national academy of sciences 109 (9), 3232–3237.

Hoekstra, Arjen Y, Mekonnen, M.M., Chapagain, A.K., Mathews, R.E., Richter, B.D., 2012. Global monthly water scarcity: Bluewater footprint versus blue water availability. PLoS One 7 (2), e32688.

Hoekstra, Arjen Y., Mekonnen, M.M., Chapagain, A.K., Mathews, R.E., Richter, B.D., 2012. Global monthly water scarcity: Bluewater footprints versus blue water availability. PLoS One 7.

Hoekstra, A.Y., 2013. The water footprint of modern consumer society. Routledge, New York. Routledge, London.

Hoekstra, A.Y., 2014. Sustainable, efficient, and equitable water use: the three pillars under wise freshwater allocation. Wiley Interdiscip. Rev. Water, 1, 31–40.

Hoekstra, A.Y., 2017. Water Footprint Assessment : Evolvement of a new approach.

Hoekstra, A.Y., 2019. Green-blue water accounting in a soil water balance. Adv. Water Resour. 129, 112–117.

Hogeboom RJ, Schyns JF, Krol MS, & H.A., 2019. Global water saving and water scarcity alleviation potential by reducing water footprints of crops to benchmark levels (submitted).

Horlemann, L., Neubert, S., 2006. Virtual water trade: a realistic concept for resolving the water crisis?

Horst, M.G., Shamutalov, S.S., Pereira, L.S., 2005. Field assessment of the water-saving potential with furrow irrigation in Fergana, Aral Sea basin. Agric. water Manag. 77(1–3), 210–231.

Hsiao, T.C., Heng, L., Steduto, P., Rojas-lara, B., Raes, D., Fereres, E., 2009. AquaCrop—The FAO crop model to simulate yield response to water: III. parameterization and testing for maize. Agron. J. 101(3), 448-459.

Huang, Jing, Ridoutt, B.G., Thorp, K.R., Wang, X., Lan, K., Liao, J., Tao, X., Wu, C., Huang, Jianliang, Chen, F., Scherer, L., 2019. Water-scarcity footprints and water productivities indicate unsustainable wheat production in China. Agric. Water Manag. 224, 105744.

Humphreys, E., Eberbach, P.L., Katupitiya, A., Kukal, S.S., 2011. Field Crops Research Growth, yield and water productivity of zero-till wheat as affected by rice straw mulch and irrigation schedule. F. Crop. Res. 121, 209–225.

Hussain, I., Hussain, Z., Sial, M. H., Akram, W., & Hussain, M.F., 2007. Optimal Cropping Pattern and Water Productivity: A case of Punjab Canal. J. Agron. 6, 526–533.

Hussain, G., Al-Jaloud, A.A., 1998. Effect of irrigation and nitrogen on yield, yield components, and water use efficiency of barley in Saudi Arabia. Agric. Water Manag. 36, 55–70.

Igbadun, H.E., Ramalan, A.A., Oiganji, E., 2012. Effects of regulated deficit irrigation and mulch on yield, water use, and crop water productivity of onion in Samaru, Nigeria. Agric. Water Manag. 109, 162–169.

Irmak, S., 2015. Interannual variation in long-term center-pivot irrigated maize evapotranspiration and various water productivity response indices I: grain yield, actual and basal evapotranspiration, irrigation yield production functions, evapotranspiration yield. J. Irrig. Drain Eng., ASCE 141, 1–17.

Jabran, K., Ullah, E., Hussain, M., Farooq, M., Zaman, U., Yaseen, M., Chauhan, B.S., 2015. Mulching Improves Water Productivity, Yield, and Quality of Fine Rice under Water-saving Rice Production Systems 201, 389–400.

Jayakumar, M., Janapriya, S., Surendran, U., 2017. Effect of drip fertigation and polythene mulching on growth and productivity of coconut (Cocos nucifera L .), water, nutrient use efficiency, and economic benefits. Agric. Water Manag. 182, 87–93.

Jefferies, D., Muñoz, I., Hodges, J., King, V.J., Aldaya, M., Ercin, A.E., Milà I Canals, L., Hoekstra, A.Y., 2012. Water footprint and life cycle assessment as approaches to assess potential impacts of products on water consumption. Key learning points from pilot studies on tea and margarine. J. Clean. Prod. 33, 155–166.

Johnston, R., 2012. Availability of water for agriculture in the Nile Basin (pp. 61-83). Routledge-Earthscan: Abingdon, UK.

Jury, W.A., Vaux., H., 2005. The role of science in solving the world's emerging water problems. Proc. Natl. Acad. Sci. 102(44), 15715-15720.

Kang, Y., Khan, S., Ma, X., 2009. Climate change impacts on crop yield, crop water productivity, and food security - A review. Prog. Nat. Sci. 19, 1665–1674.

Karasu, A., Kuşcu, H., Öz, M., Bayram, G., 2015. The effect of different irrigation water levels on grain yield, yield components, and some quality parameters of silage maize (Zea mays indentata Sturt.) in Marmara region of Turkey. Not. Bot. Horti Agrobot. Cluj-Napoca 43, 138–145.

Karimi, P., David, S., and Bastiaanssen, W.G., 2011. Mapping crop water productivity in the Nile basin through the combined use of remote sensing and census data.

Karimi, P., Molden, D., Notenbaert, A., Peden, D., 2013. Nile basin farming systems and productivity. Nile River Basin Water, Agric. Gov. Livelihoods 9780203128, 133–153.

Kliota N., Shmuelia, D., Shamirb U., 2001. Institutions for management of transboundary water resources: their nature, characteristics, and shortcomings. Water Policy 3 (229–255).

Kruashvili, I., Bziava, K., Inashvili, I., Lomishvili, M., 2016. Determination of optimal irrigation rates of crops under consideration of soil properties and climatic conditions. Ann. Agrar. Sci. 14, 217–221.

Kuiper, D., Zarate, E., and, Aldaya, M., 2011. Water footprint and corporate water accounting for resource efficiency. United Nations Environ. Program. Nairobi 184.

Levy, B.S., Sidel, V.W., 2011. Water rights and water fights: preventing and resolving conflicts before they boil over. 101, 778–780.

Liu, J., Yang, H., 2010. Spatially explicit assessment of global consumptive water uses in cropland: Green and blue water. J. Hydrol. 384, 187–197.

Ma, J., Hoekstra, A.Y., Wang, H., Chapagain, A.K., Wang, D., 2006. Virtual versus real water transfers within China 835–842.

Mekonen A. 2011. Deficit irrigation practice as an alternative means of improving water use efficiencies in irrigated agriculture. Case study of maize crop at Arba Minch, Ethiopia. African journal of agricultural research. 6 (2) 226-235.

Mekonnen, M. M., Hoekstra, A.Y., 2010. A global and high-resolution assessment of the green, blue, and grey water footprint of wheat. Hydrol. Earth Syst. Sci. 14 (7), 1259–1276.

Mekonnen, M.M., 2011. Spatially and temporally explicit water footprint accounting.

Mekonnen, M. M., Hoekstra, A.Y., 2011a. National water footprint accounts: the green, blue, and grey water footprint of production and consumption. Value of water research, Research Report Series No. 50. UNESCO-IHE Inst. Water Educ. 1 (a).

Mekonnen, M. M., Hoekstra, A.Y., 2011b. The green, blue, and grey water footprint of crops and derived crop products. Hydrol. Earth Syst. Sci. 15, 1577–1600.

Mekonnen, M M, Hoekstra, A.Y., 2011. National water footprint accounts: the green, blue, and grey water footprint of production and consumption.

Mekonnen, M.M., Hoekstra, A.Y., 2013. Water footprint benchmarks for crop production, Value of water research report series No. 64, UNESCO-IHE, Delft, the Netherlands 60.

Mekonnen, M. M., Hoekstra, a Y., 2014. Water footprint benchmarks for crop production : A fi rst global assessment. Ecol. Indic. 46, 214–223.

Mekonnen, Mesfin M, Hoekstra, A.Y., 2014. Water conservation through trade : the case of Kenya. Water Int. 39, 451–468.

Mekonnen, M.M., Hoekstra, A.Y., 2016. Four billion people facing severe water scarcity. Sustainability 1–7.

Mekonnen, Mesfin M, Pahlow, M., Aldaya, M.M., Zarate, E., Hoekstra, A.Y., 2015. sustainability, efficiency, and equitability of water consumption and pollution in Latin America and the Caribbean. Sustainability 7, 2086–2112.

Melesse, A., Abtew, W., Setegn, S., 2014. Nile River Basin: Ecohydrological challenges, climate change, and hydro-politics. springer 1–718.

Mila, A.J., Ali, M.H., Akanda, A.R., Rashid, M.H.O., Rahman, M.A., 2017. Effects of deficit irrigation on yield, water productivity, and economic return of sunflower. Cogent Food Agric. 3, 1–14.

Mohamed, Y., Loulseged, M., 2008. The Nile Basin water resources: Overview of key research questions pertinent to the Nile Basin initiative, IWMI.

Mohlotsane, P.M., Owusu-Sekyere, E., Jordaan, H., Barnard, J.H., van Rensburg, L.D., 2018. Water footprint accounting along the wheat-bread value chain: Implications for sustainable and productive water use benchmarks. Water (Switzerland) 10, 1–16.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., & Kijne, J., 2010. Improving agricultural water productivity: between optimism and caution. Agric. Water Manag. 97, 528–535.

Multsch, S., Elshamy, M.E., Batarseh, S., Seid, A.H., Frede, H.G., and Breuer, L., 2017. Improving irrigation efficiency will be insufficient to meet future water demand in the Nile Basin. Journal of Hydrology: Regional Studies, 12, pp.315-330.

NBI, 2004. Efficient water use for agricultural production. Nile Basin Initiative, Report.

Neilsen, D., Bakker, M., Van der Gulik, T., Smith, S., Cannon, A., Losso, I., Sears, A.W., 2018. Landscape based agricultural water demand modeling-A tool for water management decision making in British Columbia, Canada. Front. Environ. Sci. 6, 1–18.

Nill, J., and Kemp, R., 2009. Evolutionary approaches for sustainable innovation policies: From niche to paradigm?. Research Policy, 38(4), pp.668-680.

Nouri, H., Stokvis, B., Galindo, A., Blatchford, M., Hoekstra, A.Y., 2019. Water scarcity alleviation through water footprint reduction in agriculture : The effect of soil mulching and drip irrigation. Sci. Total Environ. 653, 241–252.

Pan, S. Y., Lin, Y. J., Snyder, S. W., Ma, H. W., & Chiang, P.C., 2016. Assessing the environmental impacts and water consumption of pretreatment and conditioning processes of corn stover hydrolysate liquor in Biore fiseries. Energy 116, 436–444.

Pan, S. Y., Snyder, S. W., Ma, H. W., Lin, Y. J., & Chiang, P.C., 2017. Development of a resin water electro-deionization process for impaired water desalination with high energy efficiency and productivity. Acs Sustain. Chem. Eng. 5, 2942–2948.

Paul, J.A., Wahlberg, K., 2008. A new era of world hunger?: The global food crisis analyzed. friedrich-ebert-stiftung, department for development policy.

Perea, R.G., Daccache, A., Díaz, J.R., Poyato, E.C., Knox, J.W., 2018. Modeling impacts of precision irrigation on crop yield and in-field water management. Precis. Agric. 19, 497–512.

Pereira, L.S., 2005. Relating water productivity and crop evapotranspiration. Agric. Eng. 31–49.

Perry C, Steduto P, K.F., 2017. Does improved irrigation technology save water? A review of the evidence. Food and agriculture organization of the united nations, Cairo, 42.

Pioufle, O. Le, Declerck, S., 2018. Reducing water availability impacts the development of the arbuscular mycorrhizal fungus Rhizophagus irregularis MUCL 41833 and its ability to take up and transport phosphorus under in vitro conditions. Front. Microbiol. 9, 1–13.

Portmann, F.T., Siebert, S., Döll, P., 2010. MIRCA2000—Global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling. Global Biogeochem. Cycles 24, 1–24.

Qasemipour, E., Abbasi, A., 2019. Virtual water flow and water footprint assessment of an arid region: A case study of South Khorasan province, Iran. Water 11 (9), 1755.

Raes, D., Steduto, P., Hsiao, T.C., Fereres, E., 2009. AquaCrop-The FAO crop model to simulate yield response to water: II. Main algorithms and software description. Agron. J. 101(3), 438-447.

Rahaman, M.M., and Varis, O., 2005. Integrated water resources management: evolution, prospects, and future challenges. Sustainability: science, practice, and policy, 1(1), pp.15-21.

Raskin, P., Gleick, P.H., Kirshen, P., Pontius Jr, R.G., Strzepek, K., 2017. Comprehensive assessment of the freshwater resources of the world. Stock. Environ. Inst.

Razaq, A., Khan, Muhammad Jamal, Sarwar, T., Khan, Mohammad Jamal, 2019. Influence of deficit irrigation, sowing methods, and mulching on yield components and yield of wheat in a semiarid environment. Pakistan J. Bot. 51(2), 553–560.

Rijsberman, F.R., 2006. Water scarcity: Fact or fiction? Agric. Water Manag. 80 (1–3), 5–22.

Rockstro, J., Falkenmark, M., Karlberg, L., Hoff, H., Rost, S., Gerten, D., 2009. Future water availability for global food production: The potential of green water for increasing resilience to global change. Water Resour. Res. 45, 1–16.

Roth, V., Lemann, T., Zeleke, G., Teklay, A., 2018. Effects of climate change on water resources in the upper Blue Nile Basin of Ethiopia. Heliyon.

Saravanan, V.S., McDonald, G.T., and Mollinga, P.P., 2009, February. A critical review of integrated water resources management: moving beyond polarised discourse. In Natural Resources Forum (Vol. 33, No. 1, pp. 76-86). Oxford, UK: Blackwell Publishing Ltd.

Salman, S.M., 2015. United Nations general assembly resolution: International decade for action, water for life, 2005–2015: a water forum contribution. Water Int. 30(3), 415-418.

Samuel, W.K., 2016. Review of barley production and marketing in Ethiopia 7, 91–100.

Santos, L., Oweis, T., Zairi, A., 2002. Irrigation management under water scarcity. Agric. Water Manag. 57, 175–206.

Sarwar, A., Perry, C., 2002. Increasing water productivity through deficit irrigation: Evidence from the Indus plains of Pakistan. Irrig. Drain. 51, 87–92.

Schyns, J.F., Hoekstra, A.Y., 2014. The added value of water footprint assessment for national water policy: a case study for Morocco. PLoS One 9 (6), e99705.

Schyns, J.F., Hoekstra, A.Y., Booij, M.J., Hogeboom, R.J., Mekonnen, M.M., 2019. Limits to the world's green water resources for food, feed, fiber, timber, and bioenergy. Proc. Natl. Acad. Sci. 116 (11), 4893–4898.

Sebri, M., 2016. Testing the environmental Kuznets curve hypothesis for water footprint indicator: a cross-sectional study. J. Environ. Plan. Manag. 59, 1933–1956.

Seckler, D., Molden, D., Sakthivadivel, R., 2003. The concept of efficiency in water resources management and policy. water productivity in agriculture: limits and opportunities for improvement 1, 37–51.

Shafi, M., Falal, F., Pak, J.B., 2011. Effect of nitrogen application on yield and yield components of barley (Hordeum Vulgare L .). Pakistani J. Bot. 43, 1471–1475.

Siebert, S., Döll, P., 2010. Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. J. Hydrol. 384, 198–217.

Steduto, P., Hsiao, T.C., Raes, D., Fereres, E., 2009. AquaCrop—The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agron. J. 101(3), 426-437.

Stephens, T., Couzens, E., 2016. The 2030 Agenda for Sustainable Development 19, 1–3.

Sulser, T.B., Ringler, C., Zhu, T., Msangi, S., Bryan, E., Rosegrant, M.W., 2010. Green and blue water accounting in the Ganges and Nile basins: Implications for food and agricultural policy. J. Hydrol. 384, 276–291.

Tadesse, D., Mekuria, W., Derso, B., Asres, T., 2018. On-farm characterization of barley (Hordeum vulgare L .) landraces in the highlands of North Gondar, Ethiopia. Int. J. Sci. Res. Manag. 06, 149–157.

Temesgen T, Ayana M, Bedadi B. 2018. Evaluating the Effects of Deficit Irrigation on Yield and Water Productivity of Furrow Irrigated Onion (Allium cepa L.) in Ambo, Western Ethiopia. Irrigat Drainage Sys Eng 7: 203.

Tian, X., Sarkis, J., Geng, Y., Qian, Y., Gao, C., Bleischwitz, R., Xu, Y., 2018. Evolution of China’s water footprint and virtual water trade: A global trade assessment. Environ. Int. 121, 178–188.

Tsakmakis, I.D., Zoidou, M., Gikas, G.D., Sylaios, G.K., 2018. Impact of irrigation technologies and strategies on cotton water footprint using AquaCrop and CROPWAT models. Environ. Process. 5 (1), 181–199.

UNESCO, 2012. Global water resources under increasing pressure from rapidly growing demands and climate change, according to the new UN World Water Development Report.

United Nations Water, 2006. Coping with water scarcity–A strategic issue and priority for system-wide action. UN-Water: Geneva, Switzerland.

Usman, S., Kundiri, A.M., 2016. Role of soil science: an answer to sustainable crop production for economic development in sub-Saharan Africa. Int. J. Soil Sci. 11, 61–70.

Van Hofwegen, P., 2004. E-Conference synthesis: virtual water trade-conscious choices.

Verkerk, M.P., 2007. Global Water Governance. Conceptual Design of Global Institutional Arrangements. scriptie_Verkerk.pdf.

Verma, S., Kampman, D.A., Zaag, P. Van Der, Hoekstra, A.Y., 2009. Going against the flow : A critical analysis of inter-state virtual water trade in the context of India’s National River Linking Program. Phys. Chem. Earth 34, 261–269.

Whittington, D., Wu, X., Sadoff, C., 2005. Water resources management in the Nile basin: The economic value of cooperation. Water Policy 7 (3), 227–252.

Williams, D., 2003. Managing sovereignty: the World Bank and development in sub-Saharan Africa. Mondes Dev. 3, 5–21.

Yenesew M. and Tilahun K., 2009. Yield and water use efficiency of deficit irrigated maize in a semi-arid region of Ethiopia. Policy Anal. 9, 1–8.

Yenesew, M.Y., 2015. Agricultural water productivity optimization for irrigated Teff (Eragrostic Tef) in water-scarce semi-arid region of Ethiopia.

Zeitoun, M., Allan, J.A.T., Mohieldeen, Y., 2010. Virtual water ‘flows’ of the Nile Basin, 1998–2004: A first approximation and implications for water security. Glob. Environ. Chang. 20, 229–242.

Zhang, G.P., Hoekstra, A.Y., Mathews, R.E., 2013. Water footprint assessment (WFA) for better water governance and sustainable development. 2, 1–6.

Zhang, Y., Zhang, J.H., Tian, Q., Liu, Z.H., Zhang, H.L., 2018.Virtual water trade of agricultural products: A new perspective to explore the Belt and Road. Sci. Total Environ. 622–623, 988–996.

Zhuo, L., Mekonnen, M., Hoekstra, A., Wada, Y., 2015. Inter- and intra-annual variation of the water footprint of crops and blue water scarcity in the Yellow River Basin (1961-2009). Adv. Water Resour.

Zhuo, L., Mekonnen, M., Hoekstra, A.Y., 2016. The effect of inter-annual variability of consumption, production, trade, and climate on crop-related green and blue water footprints and inter-regional virtual water trade : A study for China (1978 e 2008). Water Res. 94, 73–85.

Zimmer, D., Renault, D., 2003. Virtual water in food production and global trade: Review of methodological issues and preliminary results, In Hoekstra, virtual water trade: proceedings of the international expert meeting on virtual water trade. value of water research report series No 93–109.

Appendix I. AquaCrop simulation results at reference condition

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Burundi	1986	3405	1193	9	493	3653	27	1510	2172	3.1	10431
Rice	Burundi	1987	6000	1453	11	568	3432	26	1342	1884	2.4	14174
Rice	Burundi	1988	5000	1065	8	372	3663	26	1280	2031	3.4	17189
Rice	Burundi	1989	6000	1198	6	313	3934	20	1028	1619	3.3	19699
Rice	Burundi	1990	6000	1134	6	384	3799	21	1286	1940	3.4	20105
Rice	Burundi	1991	6500	1132	10	478	3511	31	1483	2043	3.1	20160
Rice	Burundi	1992	6500	1143	8	451	3582	25	1413	2147	3.1	20366
Rice	Burundi	1993	6383	1159	8	528	3590	24	1635	2468	3.1	19770
Rice	Burundi	1994	5180	811	9	759	2928	34	2738	3510	3.6	18697
Rice	Burundi	1995	5000	1336	8	468	3568	20	1249	1779	2.7	13354
Rice	Burundi	1996	7500	1210	11	680	3227	28	1813	2548	2.7	20009
Rice	Burundi	1997	10000	1048	10	524	3389	31	1695	2451	3.2	32352
Rice	Burundi	1998	6850	1107	8	562	3232	23	1639	2418	2.9	19994
Rice	Burundi	1999	9000	1063	10	664	3380	31	2110	3098	3.2	28613
Rice	Burundi	2000	8500	1125	10	569	3461	30	1751	2515	3.1	26137
Rice	Burundi	2001	9500	996	8	659	3259	27	2156	3298	3.3	31081
Rice	Burundi	2002	9600	1092	6	380	3628	21	1261	2018	3.3	31896
Rice	Burundi	2003	9750	1005	7	546	3156	23	1713	2357	3.1	30622
Rice	Burundi	2004	9800	930	8	598	2957	24	1901	2564	3.2	31164
Rice	Burundi	2005	9950	997	8	363	3506	28	1277	1777	3.5	34997
Rice	Burundi	2006	10250	988	8	483	3177	25	1552	2295	3.2	32955
Rice	Burundi	2007	10500	982	8	388	3315	26	1311	1963	3.4	35447
Rice	Burundi	2008	11000	1115	6	290	3587	20	933	1341	3.2	35402
Rice	Burundi	2009	12000	1078	7	388	3606	24	1299	1906	3.3	40129
Rice	Burundi	2010	12750	1140	5	286	3650	15	917	1505	3.2	40833

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Burundi	2011	14100	1018	10	568	3339	34	1864	2489	3.3	46262
Rice	Burundi	2012	15355	2158	9	479	4604	19	1021	1636	2.1	32756
Rice	Burundi	2013	10835	2142	11	1081	3936	21	1987	2566	1.8	19909
Rice	Burundi	2014	11865	1448	10	773	4086	30	2181	3103	2.8	33474
Rice	Burundi	2015	17123	3657	33	2073	4058	37	2301	2962	1.1	18999
Rice	Congo_DR	1986	246252	3824	38	6	2250	22	3	8	0.6	144933
Rice	Congo_DR	1987	258378	3679	29	4	2205	18	2	7	0.6	154838
Rice	Congo_DR	1988	275237	3847	25	5	2472	16	3	8	0.6	176869
Rice	Congo_DR	1989	290175	4203	42	8	2447	25	5	10	0.6	168962
Rice	Congo_DR	1990	307388	3968	40	5	2274	23	3	8	0.6	176110
Rice	Congo_DR	1991	306857	3648	24	3	2448	16	2	5	0.7	205916
Rice	Congo_DR	1992	340795	3831	31	4	2369	19	2	7	0.6	210711
Rice	Congo_DR	1993	370891	3865	35	5	2221	20	3	8	0.6	213145
Rice	Congo_DR	1994	370860	3961	25	5	2515	16	3	8	0.6	235484
Rice	Congo_DR	1995	274304	3912	83	6	2584	55	4	13	0.7	181191
Rice	Congo_DR	1996	272442	3980	68	9	2605	45	6	14	0.7	178358
Rice	Congo_DR	1997	253373	3831	73	5	2443	46	3	11	0.6	161565
Rice	Congo_DR	1998	285277	4146	76	8	2484	45	5	13	0.6	170884
Rice	Congo_DR	1999	275321	4099	86	13	2526	53	8	18	0.6	169681
Rice	Congo_DR	2000	263389	3981	85	15	2556	55	9	21	0.6	169095
Rice	Congo_DR	2001	255998	3949	61	9	2679	41	6	14	0.7	173675
Rice	Congo_DR	2002	247341	4238	71	8	2518	42	5	14	0.6	146960
Rice	Congo_DR	2003	243752	4019	62	6	2603	40	4	11	0.6	157845
Rice	Congo_DR	2004	247873	4064	64	9	2578	41	6	14	0.6	157258
Rice	Congo_DR	2005	248098	3530	65	6	2441	45	4	13	0.7	171510
Rice	Congo_DR	2006	248265	4013	63	6	2568	40	4	12	0.6	158874
Rice	Congo_DR	2007	248560	3924	33	4	2968	25	3	9	0.8	188014

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Congo_DR	2008	236651	4086	60	7	2748	40	4	12	0.7	159173
Rice	Congo_DR	2009	246986	4336	102	8	2324	54	4	12	0.5	132389
Rice	Congo_DR	2010	248996	4063	101	13	2207	55	7	17	0.5	135218
Rice	Congo_DR	2011	296520	5315	85	13	3077	49	8	18	0.6	171658
Rice	Congo_DR	2012	296932	4356	71	10	2980	49	7	17	0.7	203147
Rice	Congo_DR	2013	301843	5281	119	19	2653	60	10	22	0.5	151667
Rice	Congo_DR	2014	240529	3937	99	16	2707	68	11	22	0.7	165372
Rice	Congo_DR	2015	787937	4243	113	11	2647	71	7	17	0.6	491567
Rice	Egypt	1986	422334	59	277	1098	342	1601	6342	6935	5.8	2438875
Rice	Egypt	1987	411901	62	285	1081	362	1662	6296	6881	5.8	2400072
Rice	Egypt	1988	350715	65	272	1048	392	1647	6358	7005	6.1	2126675
Rice	Egypt	1989	412226	59	256	965	385	1659	6255	6857	6.5	2672338
Rice	Egypt	1990	434811	52	220	862	376	1601	6267	6901	7.3	3159483
Rice	Egypt	1991	461294	51	201	833	378	1501	6209	6777	7.5	3439160
Rice	Egypt	1992	509714	54	200	822	410	1529	6286	6882	7.7	3899901
Rice	Egypt	1993	537714	53	206	809	408	1589	6245	6905	7.7	4150357
Rice	Egypt	1994	577719	39	198	800	308	1570	6328	6844	7.9	4571556
Rice	Egypt	1995	587052	40	195	809	329	1585	6582	7152	8.1	4776125
Rice	Egypt	1996	588958	36	186	779	300	1546	6461	6949	8.3	4883084
Rice	Egypt	1997	649563	46	186	765	383	1565	6436	6959	8.4	5466360
Rice	Egypt	1998	517380	31	181	744	269	1565	6431	6977	8.6	4470227
Rice	Egypt	1999	654638	27	183	714	243	1626	6343	6881	8.9	5811903
Rice	Egypt	2000	658642	21	172	702	194	1562	6389	6789	9.1	5995275
Rice	Egypt	2001	562530	45	176	647	420	1630	6004	6684	9.3	5222164
Rice	Egypt	2002	649718	35	168	665	325	1576	6247	6835	9.4	6100156
Rice	Egypt	2003	633571	42	152	635	409	1482	6194	6765	9.7	6176267
Rice	Egypt	2004	645671	36	156	630	352	1531	6196	6762	9.8	6352372

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Egypt	2005	613301	41	153	629	409	1533	6277	6874	10.0	6125302
Rice	Egypt	2006	670471	32	161	613	324	1617	6180	6773	10.1	6755001
Rice	Egypt	2007	704055	49	151	622	476	1471	6078	6676	9.8	6876830
Rice	Egypt	2008	745093	28	168	635	272	1639	6179	6761	9.7	7253375
Rice	Egypt	2009	575467	19	163	661	185	1562	6340	6852	9.6	5520480
Rice	Egypt	2010	459525	31	163	664	289	1533	6252	6851	9.4	4329503
Rice	Egypt	2011	593185	18	169	846	175	1620	8095	8714	9.6	5675023
Rice	Egypt	2012	620286	31	157	844	293	1500	8047	8704	9.5	5911085
Rice	Egypt	2013	640101	22	168	923	211	1601	8798	9386	9.5	6099998
Rice	Egypt	2014	573704	32	171	899	303	1628	8567	9241	9.5	5467384
Rice	Egypt	2015	510853	35	168	915	329	1582	8633	9325	9.4	4817963
Rice	Ethiopia	1993	5400	1969	3	721	3645	6	1335	1967	1.9	10000
Rice	Ethiopia	1994	7210	2728	4	794	3748	5	1091	2032	1.4	9906
Rice	Ethiopia	1995	5900	1812	4	753	3378	7	1404	2319	1.9	11000
Rice	Ethiopia	1996	6989	1680	2	426	3680	4	932	1667	2.2	15307
Rice	Ethiopia	1997	6500	1923	3	624	3549	6	1152	1775	1.8	12000
Rice	Ethiopia	1998	7000	1887	3	510	3504	5	947	1446	1.9	13000
Rice	Ethiopia	1999	7500	1999	5	667	3732	9	1244	1937	1.9	14000
Rice	Ethiopia	2000	8200	1914	4	635	3502	8	1161	1848	1.8	15000
Rice	Ethiopia	2001	8364	1954	5	533	3601	8	982	1638	1.8	15412
Rice	Ethiopia	2002	7700	1639	5	753	3281	10	1508	2280	2.0	15412
Rice	Ethiopia	2003	7200	1842	5	609	3326	9	1099	1760	1.8	13000
Rice	Ethiopia	2004	6500	1925	5	670	3554	10	1236	1915	1.8	12000
Rice	Ethiopia	2005	6241	1989	2	576	3583	3	1038	1760	1.8	11244
Rice	Ethiopia	2006	6421	2057	4	623	3601	7	1090	1687	1.8	11244
Rice	Ethiopia	2007	6100	2070	3	515	3816	6	950	1668	1.8	11244
Rice	Ethiopia	2008	13000	641	1	218	3523	7	1197	1844	5.5	71394

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Ethiopia	2009	47739	1567	4	669	3385	8	1446	2205	2.2	103128
Rice	Ethiopia	2010	29866	1075	2	497	3254	7	1505	2249	3.0	90412
Rice	Ethiopia	2011	30649	1344	3	587	3887	10	1698	2373	2.9	88619
Rice	Ethiopia	2012	41811	1230	6	760	3561	18	2200	2996	2.9	121042
Rice	Ethiopia	2013	58806	1355	2	408	4245	7	1278	1819	3.1	184210
Rice	Ethiopia	2014	46832	1431	4	640	4028	11	1801	2410	2.8	131821
Rice	Ethiopia	2015	45454	1318	5	596	4053	14	1834	2555	3.1	139780
Rice	Kenya	1986	13783	1034	0	0	3520	0	0	1	3.4	46930
Rice	Kenya	1987	13960	1152	0	0	3826	0	0	0	3.3	46353
Rice	Kenya	1988	13307	1032	0	11	3862	0	42	49	3.7	49793
Rice	Kenya	1989	13516	872	0	9	3654	0	36	42	4.2	56662
Rice	Kenya	1990	12123	1014	0	12	3428	0	39	46	3.4	40999
Rice	Kenya	1991	12516	915	0	8	3705	0	34	41	4.0	50652
Rice	Kenya	1992	11509	972	0	12	3768	0	45	50	3.9	44602
Rice	Kenya	1993	11330	780	0	431	3238	0	1787	2920	4.1	47000
Rice	Kenya	1994	10790	834	0	343	3652	0	1499	2272	4.4	47232
Rice	Kenya	1995	10842	904	0	149	3616	0	597	1340	4.0	43369
Rice	Kenya	1996	12474	904	0	172	3665	0	699	1433	4.1	50562
Rice	Kenya	1997	10340	913	0	139	3625	0	553	1206	4.0	41075
Rice	Kenya	1998	8639	794	0	172	3844	0	835	2282	4.8	41829
Rice	Kenya	1999	13229	803	0	451	3199	0	1798	3264	4.0	52711
Rice	Kenya	2000	13882	723	0	594	2726	0	2242	3807	3.8	52349
Rice	Kenya	2001	13200	1059	0	515	3609	0	1756	3407	3.4	45000
Rice	Kenya	2002	13000	950	0	339	3288	0	1173	2600	3.5	45000
Rice	Kenya	2003	10781	897	0	300	3370	0	1127	2622	3.8	40502
Rice	Kenya	2004	13223	743	0	569	2770	0	2119	3850	3.7	49295
Rice	Kenya	2005	15940	676	0	535	2658	0	2106	3559	3.9	62677

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Kenya	2006	23106	1221	0	495	3428	0	1389	2878	2.8	64840
Rice	Kenya	2007	16457	1056	0	502	3033	0	1441	2527	2.9	47256
Rice	Kenya	2008	16734	2525	0	1154	3301	0	1509	2941	1.3	21881
Rice	Kenya	2009	21829	1629	0	783	3149	0	1513	2993	1.9	42202
Rice	Kenya	2010	20181	791	0	287	3354	0	1216	2626	4.2	85536
Rice	Kenya	2011	28031	904	0	510	3587	0	2024	3573	4.0	111229
Rice	Kenya	2012	30095	928	0	433	3775	0	1760	3499	4.1	122465
Rice	Kenya	2013	30392	838	0	414	4047	0	1998	3652	4.8	146696
Rice	Kenya	2014	28390	889	0	576	3517	0	2277	4053	4.0	112263
Rice	Kenya	2015	29438	835	0	536	3305	0	2121	3662	4.0	116473
Rice	Rwanda	1986	1921	1696	0	306	3950	0	714	1133	2.3	4475
Rice	Rwanda	1987	1583	1666	0	405	3477	0	846	1213	2.1	3304
Rice	Rwanda	1988	1707	1911	0	389	3905	0	795	1558	2.0	3489
Rice	Rwanda	1989	1648	1526	0	220	3982	0	574	1032	2.6	4300
Rice	Rwanda	1990	3720	2766	0	589	3747	0	798	1310	1.4	5039
Rice	Rwanda	1991	3629	1611	0	322	3888	0	777	1260	2.4	8761
Rice	Rwanda	1992	3494	1549	0	378	3690	0	901	1577	2.4	8322
Rice	Rwanda	1993	2729	1471	0	357	3818	0	927	1543	2.6	7083
Rice	Rwanda	1994	907	1240	0	770	3141	0	1951	2692	2.5	2299
Rice	Rwanda	1995	336	1039	0	199	3771	0	720	1167	3.6	1220
Rice	Rwanda	1996	1067	1143	0	320	3590	0	1006	1604	3.1	3352
Rice	Rwanda	1997	1725	1246	0	316	3720	0	944	1637	3.0	5150
Rice	Rwanda	1998	2211	1828	0	517	3380	0	957	1478	1.8	4089
Rice	Rwanda	1999	2565	2050	0	767	3609	0	1351	2328	1.8	4516
Rice	Rwanda	2000	2328	1355	0	484	3724	0	1329	2066	2.7	6400
Rice	Rwanda	2001	2716	1091	0	534	3398	0	1662	2643	3.1	8458
Rice	Rwanda	2002	3428	1115	0	236	3702	0	783	1392	3.3	11378

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Rwanda	2003	4060	863	0	339	3140	0	1236	1775	3.6	14774
Rice	Rwanda	2004	6493	876	0	321	3172	0	1162	1724	3.6	23513
Rice	Rwanda	2005	7430	790	0	178	3611	0	812	1149	4.6	33940
Rice	Rwanda	2006	7489	790	0	226	3347	0	959	1822	4.2	31737
Rice	Rwanda	2007	8008	818	0	208	3365	0	855	1297	4.1	32954
Rice	Rwanda	2008	9624	851	0	97	3755	0	430	828	4.4	42487
Rice	Rwanda	2009	7878	650	0	155	3731	0	889	1591	5.7	45182
Rice	Rwanda	2010	6924	700	0	114	3536	0	573	1009	5.0	34957
Rice	Rwanda	2011	7787	641	0	212	3553	0	1178	1748	5.5	43184
Rice	Rwanda	2012	7845	838	0	118	4765	0	674	1339	5.7	44621
Rice	Rwanda	2013	9375	801	0	263	4078	0	1340	1799	5.1	47705
Rice	Rwanda	2014	12685	1397	0	540	4175	0	1614	2634	3.0	37898
Rice	Rwanda	2015	16119	1329	0	583	4102	0	1799	2604	3.1	49762
Rice	Sudan (current)	2014	15618	2620	3906	4231	2836	4227	4578	5029	1.1	16900
Rice	Sudan (current)	2015	7560	325	1209	1285	1376	5116	5439	5876	4.2	32000
Rice	Sudan (former)	1986	1500	1609	3446	2873	1716	3675	3065	3406	1.1	1600
Rice	Sudan (former)	1987	1200	1698	3584	3086	1698	3584	3086	3400	1.0	1200
Rice	Sudan (former)	1988	1200	2004	3291	2753	2004	3291	2753	3167	1.0	1200
Rice	Sudan (former)	1989	500	2074	3782	3399	2074	3782	3399	3863	1.0	500
Rice	Sudan (former)	1990	800	717	3661	3687	896	4577	4609	5006	1.3	1000
Rice	Sudan (former)	1991	800	952	3108	3020	1309	4273	4153	4516	1.4	1100
Rice	Sudan (former)	1992	1300	2080	3971	3511	1920	3665	3240	3462	0.9	1200
Rice	Sudan (former)	1993	1600	1978	3984	3540	1854	3735	3319	3665	0.9	1500
Rice	Sudan (former)	1994	2000	2662	3819	3184	2196	3151	2627	2913	0.8	1650
Rice	Sudan (former)	1995	1630	3590	4272	3585	2643	3145	2639	3064	0.7	1200
Rice	Sudan (former)	1996	2940	3032	4936	4252	2062	3358	2893	3224	0.7	2000
Rice	Sudan (former)	1997	2940	2849	4951	4126	1938	3368	2807	3144	0.7	2000

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne) Green	Sb_cr	Sb_i	CWU (m^3/ha) Green	Sb_cr	Sb_i	Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Rice	Sudan (former)	1998	3780	4282	6277	6173	2265	3321	3266	3619	0.5	2000
Rice	Sudan (former)	1999	9240	2365	2778	2627	2815	3308	3127	3447	1.2	11000
Rice	Sudan (former)	2000	5460	1122	2910	2799	1644	4263	4101	4502	1.5	8000
Rice	Sudan (former)	2001	6160	1128	2070	1934	2015	3697	3453	3770	1.8	11000
Rice	Sudan (former)	2002	4762	1049	2186	2082	1763	3673	3498	4003	1.7	8000
Rice	Sudan (former)	2003	8000	1353	1572	1496	2664	3095	2945	3466	2.0	15748
Rice	Sudan (former)	2004	7560	367	876	841	1748	4171	4006	4397	4.8	36000
Rice	Sudan (former)	2005	5880	555	1117	1004	1888	3801	3416	3778	3.4	20000
Rice	Sudan (former)	2006	7083	509	1024	941	1867	3759	3453	3731	3.7	26000
Rice	Sudan (former)	2007	6250	726	822	719	2673	3025	2647	3095	3.7	23000
Rice	Sudan (former)	2008	6722	410	926	886	1829	4131	3956	4369	4.5	30000
Rice	Sudan (former)	2009	6303	492	1129	1122	1758	4029	4005	4493	3.6	22500
Rice	Sudan (former)	2010	6400	558	1020	1023	2036	3722	3732	4162	3.6	23350
Rice	Sudan (former)	2011	6720	405	1295	1422	1508	4818	5289	5771	3.7	25000
Rice	Sudan (former)	2012	7560	745	1412	1557	2366	4483	4942	5324	3.2	24000
Rice	Sudan (former)	2013	7562	603	1309	1451	1992	4326	4798	5201	3.3	25000
Rice	Tanzania	1986	185978	1401	110	341	3750	293	913	1304	2.7	497882
Rice	Tanzania	1987	238580	1521	102	311	3783	253	774	1162	2.5	593401
Rice	Tanzania	1988	234375	1321	164	564	3180	395	1358	1805	2.4	564231
Rice	Tanzania	1989	261760	1473	128	324	3534	307	777	1093	2.4	627917
Rice	Tanzania	1990	261210	1420	109	285	3665	282	736	1055	2.6	674120
Rice	Tanzania	1991	250476	1584	157	474	3497	346	1047	1565	2.2	552847
Rice	Tanzania	1992	208268	2101	210	643	3514	352	1075	1552	1.7	348276
Rice	Tanzania	1993	240286	1660	126	313	3973	302	750	1172	2.4	575063
Rice	Tanzania	1994	238771	1229	185	571	2924	441	1359	1706	2.4	567796
Rice	Tanzania	1995	302004	1844	229	610	3498	434	1157	1604	1.9	572962
Rice	Tanzania	1996	393525	1509	275	875	2817	513	1633	2099	1.9	734386

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Tanzania	1997	330316	1600	386	1427	2468	596	2200	2782	1.5	509446
Rice	Tanzania	1998	501680	2504	148	246	3976	235	390	685	1.6	796547
Rice	Tanzania	1999	290559	1125	266	839	2575	608	1922	2504	2.3	665068
Rice	Tanzania	2000	318351	1320	238	745	3019	545	1705	2256	2.3	728309
Rice	Tanzania	2001	311095	1419	115	362	3699	299	942	1392	2.6	810892
Rice	Tanzania	2002	433537	1658	194	558	3496	410	1177	1669	2.1	913895
Rice	Tanzania	2003	475848	1594	177	522	3431	380	1124	1659	2.2	1024190
Rice	Tanzania	2004	469969	1511	202	613	3255	435	1321	1727	2.2	1012320
Rice	Tanzania	2005	538081	1685	206	715	3403	416	1444	1989	2.0	1086680
Rice	Tanzania	2006	485790	1210	258	799	2700	575	1784	2245	2.2	1084518
Rice	Tanzania	2007	427697	1361	76	157	3936	219	453	746	2.9	1237186
Rice	Tanzania	2008	680399	1665	191	545	3305	379	1082	1456	2.0	1350889
Rice	Tanzania	2009	617522	1634	185	577	3426	387	1210	1583	2.1	1294612
Rice	Tanzania	2010	866868	1251	120	331	3547	341	939	1339	2.8	2457687
Rice	Tanzania	2011	857971	1366	202	643	3351	496	1577	2114	2.5	2104018
Rice	Tanzania	2012	612247	1311	162	641	3742	463	1830	2371	2.9	1748130
Rice	Tanzania	2013	711529	1225	158	480	3708	477	1453	1963	3.0	2153138
Rice	Tanzania	2014	733715	1112	155	498	3827	534	1715	2201	3.4	2525766
Rice	Tanzania	2015	884908	1154	155	498	3721	498	1604	2103	3.2	2852355
Rice	Uganda	1986	10105	2632	39	28	3590	53	38	73	1.4	13783
Rice	Uganda	1987	8510	2557	31	24	3504	43	33	66	1.4	11664
Rice	Uganda	1988	9042	2967	43	34	3634	53	41	70	1.2	11076
Rice	Uganda	1989	17019	2612	47	41	3327	60	52	92	1.3	21675
Rice	Uganda	1990	20730	2731	51	44	3130	59	50	88	1.1	23754
Rice	Uganda	1991	23934	2531	33	15	3787	49	22	43	1.5	35800
Rice	Uganda	1992	26593	2655	40	21	3831	58	31	60	1.4	38372
Rice	Uganda	1993	28188	2436	39	24	3533	57	35	71	1.4	40873

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Rice	Uganda	1994	29252	2408	32	17	3656	49	27	50	1.5	44423
Rice	Uganda	1995	30073	2413	34	18	3727	52	28	55	1.5	46451
Rice	Uganda	1996	31714	2443	34	22	3691	51	33	65	1.5	47925
Rice	Uganda	1997	32807	2088	37	25	3389	61	41	76	1.6	53250
Rice	Uganda	1998	34994	2675	37	31	3678	51	43	84	1.4	48107
Rice	Uganda	1999	37033	2678	61	45	3180	72	53	91	1.2	43969
Rice	Uganda	2000	39344	2571	76	50	2904	86	57	106	1.1	44438
Rice	Uganda	2001	41556	2514	37	20	3487	51	27	56	1.4	57651
Rice	Uganda	2002	43743	2124	28	20	3322	44	31	65	1.6	68419
Rice	Uganda	2003	47024	2068	22	15	3205	33	23	51	1.5	72886
Rice	Uganda	2004	50851	2671	35	25	3157	42	30	52	1.2	60098
Rice	Uganda	2005	55772	2283	34	20	3474	52	31	63	1.5	84871
Rice	Uganda	2006	61787	2458	34	21	3377	46	28	57	1.4	84901
Rice	Uganda	2007	65068	2598	31	9	3669	44	13	26	1.4	91910
Rice	Uganda	2008	69989	2624	41	20	3460	54	27	47	1.3	92280
Rice	Uganda	2009	47024	1540	31	18	3187	65	37	70	2.1	97343
Rice	Uganda	2010	47571	1422	23	13	3448	55	30	65	2.4	115332
Rice	Uganda	2011	49211	1798	36	18	3757	75	37	65	2.1	102813
Rice	Uganda	2012	50304	1958	37	19	4013	75	39	69	2.0	103110
Rice	Uganda	2013	50851	2122	40	39	3801	72	70	106	1.8	91080
Rice	Uganda	2014	51945	2161	58	36	3569	96	59	87	1.7	85784
Rice	Uganda	2015	52096	1286	22	16	4063	71	49	85	3.2	164589
Maize	Burundi	1986	131999	3266	3	0	4057	3	0	0	1.2	164000
Maize	Burundi	1987	132999	3164	3	0	4004	4	0	0	1.3	168300
Maize	Burundi	1988	133999	3235	3	0	4152	4	0	0	1.3	172000
Maize	Burundi	1989	123999	3112	3	0	4247	4	0	0	1.4	169200
Maize	Burundi	1990	123999	2904	2	0	3932	3	0	0	1.4	167900

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Burundi	1991	123999	2862	3	0	3974	4	0	0	1.4	172200
Maize	Burundi	1992	123999	2808	2	0	3993	4	0	0	1.4	176300
Maize	Burundi	1993	120000	3133	3	0	4493	4	0	0	1.4	172100
Maize	Burundi	1994	100000	3266	4	0	4010	5	0	0	1.2	122758
Maize	Burundi	1995	120000	3119	3	0	3977	4	0	0	1.3	153021
Maize	Burundi	1996	110000	3199	3	0	4201	4	0	0	1.3	144462
Maize	Burundi	1997	115000	2815	3	0	3549	4	0	0	1.3	144991
Maize	Burundi	1998	115000	3530	3	0	4047	3	0	0	1.1	131830
Maize	Burundi	1999	115000	3351	4	0	3750	5	0	0	1.1	128706
Maize	Burundi	2000	112000	3837	4	0	4037	5	0	0	1.1	117840
Maize	Burundi	2001	115000	3652	4	0	3950	4	0	0	1.1	124395
Maize	Burundi	2002	116000	3428	3	0	3747	3	0	0	1.1	126799
Maize	Burundi	2003	113000	3362	4	0	3587	4	0	0	1.1	120575
Maize	Burundi	2004	114000	3544	4	0	3830	5	0	0	1.1	123208
Maize	Burundi	2005	116000	3348	4	0	3627	4	0	0	1.1	125666
Maize	Burundi	2006	115000	3730	4	0	3789	4	0	0	1.0	116825
Maize	Burundi	2007	105619	3577	2	0	3912	3	0	0	1.1	115507
Maize	Burundi	2008	117200	3843	3	0	3859	3	0	0	1.0	117681
Maize	Burundi	2009	120000	3939	3	0	3951	3	0	0	1.0	120379
Maize	Burundi	2010	125599	3956	3	0	3982	3	0	0	1.0	126412
Maize	Burundi	2011	127999	4762	5	0	4780	5	0	0	1.0	128483
Maize	Burundi	2012	119478	3865	4	0	4546	5	0	0	1.2	140536
Maize	Burundi	2013	122870	3913	5	0	5173	6	0	0	1.3	162417
Maize	Burundi	2014	97242	3652	5	0	4801	6	0	0	1.3	127829
Maize	Burundi	2015	121179	3239	5	0	4528	8	0	0	1.4	169417
Maize	Congo_DR	1986	1027808	4179	7	0	3367	5	0	0	0.8	828178
Maize	Congo_DR	1987	1027864	3966	7	0	3378	6	0	0	0.9	875459

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Congo_DR	1988	1141638	4337	6	0	3517	5	0	0	0.8	925813
Maize	Congo_DR	1989	1211439	4308	8	0	3509	6	0	0	0.8	986734
Maize	Congo_DR	1990	1268777	4311	8	0	3534	7	0	0	0.8	1040013
Maize	Congo_DR	1991	1283455	4229	8	0	3490	6	0	0	0.8	1059209
Maize	Congo_DR	1992	1333119	4294	8	0	3545	7	0	0	0.8	1100571
Maize	Congo_DR	1993	1406854	4248	9	0	3523	7	0	0	0.8	1166525
Maize	Congo_DR	1994	1472667	4007	8	0	3312	7	0	0	0.8	1217372
Maize	Congo_DR	1995	1269417	4295	20	0	3452	16	0	0	0.8	1020346
Maize	Congo_DR	1996	1376515	4182	26	0	3405	21	0	0	0.8	1120701
Maize	Congo_DR	1997	1357529	3944	24	0	3476	21	0	0	0.9	1196354
Maize	Congo_DR	1998	1460956	3809	18	0	3206	15	0	0	0.8	1229901
Maize	Congo_DR	1999	1499871	4423	17	0	3543	13	0	0	0.8	1201473
Maize	Congo_DR	2000	1481848	4282	16	0	3466	13	0	0	0.8	1199225
Maize	Congo_DR	2001	1463310	4353	21	0	3501	17	0	0	0.8	1176887
Maize	Congo_DR	2002	1481849	4502	22	0	3513	17	0	0	0.8	1156529
Maize	Congo_DR	2003	1482410	4314	19	0	3364	15	0	0	0.8	1156125
Maize	Congo_DR	2004	1474343	4184	20	0	3357	16	0	0	0.8	1182673
Maize	Congo_DR	2005	1481664	4446	24	0	3482	19	0	0	0.8	1160291
Maize	Congo_DR	2006	1482075	4449	23	0	3473	18	0	0	0.8	1157192
Maize	Congo_DR	2007	1483591	4307	22	0	3362	17	0	0	0.8	1158096
Maize	Congo_DR	2008	1482730	4484	17	0	3495	13	0	0	0.8	1155793
Maize	Congo_DR	2009	1483025	4521	23	0	3537	18	0	0	0.8	1160347
Maize	Congo_DR	2010	1484772	4357	22	0	3393	17	0	0	0.8	1156423
Maize	Congo_DR	2011	1478843	4507	20	0	3569	16	0	0	0.8	1171014
Maize	Congo_DR	2012	1744996	5430	27	0	4299	21	0	0	0.8	1381427
Maize	Congo_DR	2013	1748633	5330	26	0	4207	21	0	0	0.8	1380153
Maize	Congo_DR	2014	1506881	5413	24	0	4263	19	0	0	0.8	1186887

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Congo_DR	2015	2620750	5653	31	0	4409	24	0	0	0.8	2044292
Maize	Egypt	1986	722684	68	169	1293	340	845	6456	6792	5.0	3607441
Maize	Egypt	1987	760433	76	178	1370	362	847	6517	6868	4.8	3618418
Maize	Egypt	1988	822981	90	167	1299	447	828	6453	6885	5.0	4087465
Maize	Egypt	1989	841472	77	156	1208	416	837	6499	6989	5.4	4528850
Maize	Egypt	1990	829795	69	142	1099	402	819	6353	6833	5.8	4797885
Maize	Egypt	1991	868397	61	138	1066	361	813	6287	6676	5.9	5120718
Maize	Egypt	1992	825936	64	132	1045	391	810	6413	6846	6.1	5068137
Maize	Egypt	1993	828703	69	133	1046	421	809	6361	6771	6.1	5038544
Maize	Egypt	1994	865104	53	141	1080	312	833	6383	6759	5.9	5111377
Maize	Egypt	1995	735297	53	140	1085	327	861	6688	7153	6.2	4532817
Maize	Egypt	1996	742384	39	125	952	268	866	6623	6966	7.0	5162589
Maize	Egypt	1997	813698	44	121	908	311	864	6475	6805	7.1	5802891
Maize	Egypt	1998	876650	36	116	901	264	837	6509	6921	7.2	6335236
Maize	Egypt	1999	816910	29	114	854	221	858	6417	6746	7.5	6141797
Maize	Egypt	2000	842705	25	113	841	192	868	6461	6745	7.7	6472774
Maize	Egypt	2001	872700	57	113	894	395	788	6240	6640	7.0	6092089
Maize	Egypt	2002	827814	42	102	817	326	793	6347	6712	7.8	6429383
Maize	Egypt	2003	833980	41	101	813	317	790	6365	6793	7.8	6529787
Maize	Egypt	2004	788404	40	100	801	313	788	6338	6742	7.9	6235521
Maize	Egypt	2005	868082	42	98	787	342	799	6421	6776	8.2	7084489
Maize	Egypt	2006	761412	38	97	765	320	810	6404	6850	8.4	6373684
Maize	Egypt	2007	775796	48	97	772	386	777	6211	6583	8.0	6242614
Maize	Egypt	2008	936116	39	102	811	308	809	6414	6815	7.9	7400704
Maize	Egypt	2009	982937	26	104	832	207	814	6509	6803	7.8	7685359
Maize	Egypt	2010	968377	32	109	890	230	795	6473	6810	7.3	7040450
Maize	Egypt	2011	888198	22	116	1041	171	898	8062	8378	7.7	6875887

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Egypt	2012	1041192	32	110	1018	248	852	7914	8261	7.8	8092981
Maize	Egypt	2013	749890	30	121	1115	231	936	8620	8967	7.7	5799526
Maize	Egypt	2014	1039088	43	118	1078	337	915	8363	8876	7.8	8059269
Maize	Egypt	2015	1060840	39	122	1149	290	895	8449	8897	7.4	7802555
Maize	Eritrea	1993	8964	7979	0	0	2916	0	0	0	0.4	3276
Maize	Eritrea	1994	15458	2926	0	0	3784	0	0	0	1.3	19990
Maize	Eritrea	1995	10547	7544	0	0	3456	0	0	0	0.5	4832
Maize	Eritrea	1996	6100	7095	0	0	4586	0	0	0	0.6	3943
Maize	Eritrea	1997	16905	10139	0	0	3396	0	0	0	0.3	5663
Maize	Eritrea	1998	28302	4018	0	0	3954	0	0	0	1.0	27855
Maize	Eritrea	1999	13309	4344	0	0	3997	0	0	0	0.9	12247
Maize	Eritrea	2000	16506	12925	0	0	4489	0	0	0	0.3	5733
Maize	Eritrea	2001	7557	3537	0	0	3962	0	0	0	1.1	8465
Maize	Eritrea	2002	9541	13183	0	0	3649	0	0	0	0.3	2641
Maize	Eritrea	2003	9887	10027	0	0	3766	0	0	0	0.4	3713
Maize	Eritrea	2004	5881	6650	0	0	3386	0	0	0	0.5	2994
Maize	Eritrea	2005	20485	9197	0	0	4869	0	0	0	0.5	10844
Maize	Eritrea	2006	21375	2457	0	0	3749	0	0	0	1.5	32612
Maize	Eritrea	2007	12170	5277	0	0	4508	0	0	0	0.9	10397
Maize	Eritrea	2008	10558	8257	0	0	3381	0	0	0	0.4	4323
Maize	Eritrea	2009	11825	1716	0	0	3315	0	0	0	1.9	22841
Maize	Eritrea	2010	12864	1693	0	0	3161	0	0	0	1.9	24017
Maize	Eritrea	2011	10131	1123	0	0	2790	0	0	0	2.5	25160
Maize	Eritrea	2012	6206	1285	0	0	2319	0	0	0	1.8	11199
Maize	Eritrea	2013	13260	1502	0	0	3119	0	0	0	2.1	27530
Maize	Eritrea	2014	11125	820	0	0	3502	0	0	0	4.3	47524
Maize	Eritrea	2015	4295	3323	0	0	3679	0	0	0	1.1	4756

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Ethiopia	1993	827472	2223	7	61	3930	13	108	156	1.8	1462680
Maize	Ethiopia	1994	1203636	3318	11	97	3898	13	114	153	1.2	1414253
Maize	Ethiopia	1995	1442423	2630	7	65	3643	9	91	146	1.4	1997624
Maize	Ethiopia	1996	1850891	2118	5	54	3718	8	95	128	1.8	3248735
Maize	Ethiopia	1997	1694687	2164	5	55	3807	9	97	145	1.8	2981550
Maize	Ethiopia	1998	1439322	2112	5	51	3438	8	82	100	1.6	2343011
Maize	Ethiopia	1999	1621709	2209	6	53	3850	10	92	127	1.7	2826020
Maize	Ethiopia	2000	1639412	2262	5	48	3707	8	79	103	1.6	2686247
Maize	Ethiopia	2001	1872747	2109	5	43	3728	8	76	118	1.8	3309915
Maize	Ethiopia	2002	1471215	1866	5	50	3580	9	96	150	1.9	2823074
Maize	Ethiopia	2003	1781581	2350	5	59	3614	8	91	127	1.5	2740021
Maize	Ethiopia	2004	1760511	2296	6	64	3800	9	106	143	1.7	2914168
Maize	Ethiopia	2005	1939747	1815	4	46	3675	8	93	131	2.0	3927579
Maize	Ethiopia	2006	1483720	1340	3	35	3608	9	94	134	2.7	3994869
Maize	Ethiopia	2007	1687340	1883	4	44	3737	8	87	115	2.0	3348637
Maize	Ethiopia	2008	1753081	1726	4	44	3725	8	94	136	2.2	3784700
Maize	Ethiopia	2009	1727404	1594	5	49	3596	11	111	158	2.3	3898392
Maize	Ethiopia	2010	1929387	1341	4	36	3476	10	93	130	2.6	5001117
Maize	Ethiopia	2011	2014886	1335	4	40	4095	11	122	158	3.1	6181854
Maize	Ethiopia	2012	1977749	1338	3	37	4230	11	116	171	3.2	6251502
Maize	Ethiopia	2013	2061785	1299	3	36	4206	11	115	150	3.2	6674186
Maize	Ethiopia	2014	2084276	1221	3	36	4250	10	124	164	3.5	7257949
Maize	Ethiopia	2015	2059996	1064	3	36	4289	12	144	195	4.0	8307928
Maize	Ethiopia PDR	1986	838307	3059	10	88	3841	12	110	159	1.3	1052774
Maize	Ethiopia PDR	1987	991706	2089	7	60	3711	12	107	149	1.8	1761841
Maize	Ethiopia PDR	1988	1047187	1942	6	56	3638	12	105	136	1.9	1962094
Maize	Ethiopia PDR	1989	993733	2185	7	61	3788	12	105	160	1.7	1722589

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Ethiopia PDR	1990	1228886	2178	7	68	3633	12	113	175	1.7	2049854
Maize	Ethiopia PDR	1991	1099590	2887	9	91	3761	11	118	167	1.3	1432474
Maize	Ethiopia PDR	1992	955556	2287	8	77	3645	13	122	151	1.6	1523071
Maize	Kenya	1986	1189494	1521	87	1	3595	205	2	3	2.4	2811149
Maize	Kenya	1987	1203719	1964	100	1	3799	194	2	3	1.9	2328396
Maize	Kenya	1988	1181373	1537	99	1	3616	233	2	3	2.4	2778501
Maize	Kenya	1989	1166916	1684	104	1	3756	231	2	4	2.2	2602879
Maize	Kenya	1990	1130683	1877	102	1	3686	201	2	4	2.0	2219936
Maize	Kenya	1991	1079216	1683	102	1	3778	230	2	3	2.2	2422251
Maize	Kenya	1992	1024020	1364	122	1	3555	318	3	5	2.6	2669375
Maize	Kenya	1993	1134469	1836	115	1	3443	216	2	5	1.9	2126703
Maize	Kenya	1994	1070445	1159	95	1	3444	284	3	4	3.0	3181621
Maize	Kenya	1995	1273149	1905	29	1	3905	59	2	4	2.1	2610120
Maize	Kenya	1996	1281897	2316	31	1	3815	52	2	4	1.6	2111788
Maize	Kenya	1997	1343525	2561	35	1	4100	56	2	4	1.6	2150565
Maize	Kenya	1998	1316631	2587	22	1	4330	36	1	2	1.7	2203378
Maize	Kenya	1999	1334585	2259	35	1	3950	61	2	5	1.7	2333106
Maize	Kenya	2000	1228716	1944	36	2	3355	61	3	6	1.7	2120712
Maize	Kenya	2001	1382088	1849	28	1	3678	55	2	4	2.0	2749275
Maize	Kenya	2002	1396942	2105	33	1	3638	58	2	4	1.7	2414561
Maize	Kenya	2003	1490980	2276	26	1	3795	43	1	3	1.7	2485257
Maize	Kenya	2004	1139420	1530	25	1	3565	58	2	6	2.3	2654488
Maize	Kenya	2005	1454336	1706	28	1	3553	58	3	5	2.1	3028870
Maize	Kenya	2006	1600574	1914	30	1	3827	59	2	4	2.0	3201078
Maize	Kenya	2007	1424991	1941	22	1	3670	42	2	3	1.9	2694364
Maize	Kenya	2008	1481885	2242	34	1	3651	55	2	5	1.6	2413050
Maize	Kenya	2009	1429391	2072	41	2	3825	75	3	6	1.8	2638084

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Kenya	2010	1720538	1751	26	1	3650	54	2	3	2.1	3585934
Maize	Kenya	2011	1741665	2072	33	2	4037	64	3	7	1.9	3393095
Maize	Kenya	2012	1904490	2273	30	1	4111	55	2	4	1.8	3445115
Maize	Kenya	2013	1793331	2580	29	1	4560	51	2	5	1.8	3169845
Maize	Kenya	2014	1757916	2062	33	2	4227	67	4	7	2.0	3603674
Maize	Kenya	2015	1548047	1518	29	2	4503	87	4	8	3.0	4590295
Maize	Rwanda	1986	79250	3370	0	0	3809	0	0	0	1.1	89590
Maize	Rwanda	1987	61100	2508	0	0	3722	0	0	0	1.5	90665
Maize	Rwanda	1988	75000	2190	0	0	3942	0	0	0	1.8	135000
Maize	Rwanda	1989	80000	3193	0	0	3791	0	0	0	1.2	95000
Maize	Rwanda	1990	98522	3620	0	0	3712	0	0	0	1.0	101000
Maize	Rwanda	1991	90000	3321	0	0	3838	0	0	0	1.2	104000
Maize	Rwanda	1992	80000	3060	0	0	3749	0	0	0	1.2	98000
Maize	Rwanda	1993	50000	2399	0	0	4175	0	0	0	1.7	87000
Maize	Rwanda	1994	40000	2275	0	0	3811	0	0	0	1.7	67000
Maize	Rwanda	1995	50000	3326	0	0	3725	0	0	0	1.1	56000
Maize	Rwanda	1996	60000	3565	0	0	3957	0	0	0	1.1	66595
Maize	Rwanda	1997	76481	3189	0	0	3479	0	0	0	1.1	83427
Maize	Rwanda	1998	71212	4744	0	0	3905	0	0	0	0.8	58618
Maize	Rwanda	1999	72673	4563	0	0	3448	0	0	0	0.8	54912
Maize	Rwanda	2000	89053	5590	0	0	3924	0	0	0	0.7	62501
Maize	Rwanda	2001	105560	4755	0	0	3648	0	0	0	0.8	80979
Maize	Rwanda	2002	104628	3972	0	0	3480	0	0	0	0.9	91686
Maize	Rwanda	2003	102820	4298	0	0	3298	0	0	0	0.8	78886
Maize	Rwanda	2004	115000	4695	0	0	3602	0	0	0	0.8	88209
Maize	Rwanda	2005	109400	3933	0	0	3496	0	0	0	0.9	97251
Maize	Rwanda	2006	113312	4126	0	0	3519	0	0	0	0.9	96662

			Harvested	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	area (ha)	Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i	(m^3/ha)	(tonne/ha)	(tonne)
Maize	Rwanda	2007	141168	5068	0	0	3650	0	0	0	0.7	101659
Maize	Rwanda	2008	144896	3178	0	0	3660	0	0	0	1.2	166853
Maize	Rwanda	2009	147129	1959	0	0	3820	0	0	0	2.0	286946
Maize	Rwanda	2010	184658	1622	0	0	3798	0	0	0	2.3	432404
Maize	Rwanda	2011	223414	1864	0	0	4385	0	0	0	2.4	525679
Maize	Rwanda	2012	253698	1978	0	0	4468	0	0	0	2.3	573038
Maize	Rwanda	2013	292326	2124	0	0	4851	0	0	0	2.3	667833
Maize	Rwanda	2014	233150	1786	0	0	4467	0	0	0	2.5	583096
Maize	Rwanda	2015	241713	2441	0	0	4141	0	0	0	1.7	410082
Maize	South Sudan	2014	278000	962	1530	5	928	1475	4	11	1.0	268000
Maize	South Sudan	2015	133116	780	1596	1	820	1679	1	0	1.1	140000
Maize	Sudan (current)	2014	45200	1513	1210	3886	1607	1285	4127	4229	1.1	48000
Maize	Sudan (current)	2015	38640	1213	1200	3472	1507	1491	4313	4762	1.2	48000
Maize	Sudan (former)	1986	63000	2091	2090	5350	1195	1194	3057	3242	0.6	36000
Maize	Sudan (former)	1987	53000	2501	2500	6444	1180	1179	3040	3284	0.5	25000
Maize	Sudan (former)	1988	60000	2493	2294	5645	1247	1147	2823	2827	0.5	30000
Maize	Sudan (former)	1989	60000	3033	2425	6231	1517	1213	3116	3589	0.5	30000
Maize	Sudan (former)	1990	55000	2437	2865	7609	1196	1406	3735	4407	0.5	27000
Maize	Sudan (former)	1991	125000	1950	2918	7753	952	1424	3783	4080	0.5	61000
Maize	Sudan (former)	1992	120000	2495	3072	7792	1060	1306	3312	3196	0.4	51000
Maize	Sudan (former)	1993	81000	2592	2516	6435	1280	1242	3178	3335	0.5	40000
Maize	Sudan (former)	1994	100000	2693	2241	5711	1293	1076	2741	2797	0.5	48000
Maize	Sudan (former)	1995	36540	2654	1935	4814	1525	1112	2767	2955	0.6	21000
Maize	Sudan (former)	1996	83160	2253	1715	4296	1463	1113	2790	3085	0.6	54000
Maize	Sudan (former)	1997	80000	2166	1676	4258	1408	1089	2767	3015	0.7	52000
Maize	Sudan (former)	1998	63840	2123	1755	4625	1397	1154	3043	3213	0.7	42000
Maize	Sudan (former)	1999	63420	2821	1968	5076	1646	1148	2962	3055	0.6	37000

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Sudan (former)	2000	71820	2272	1769	4525	1677	1306	3339	3902	0.7	53000
Maize	Sudan (former)	2001	71820	1872	1600	4343	1382	1181	3205	3391	0.7	53000
Maize	Sudan (former)	2002	63420	1561	1387	3778	1305	1159	3157	3465	0.8	53000
Maize	Sudan (former)	2003	71820	1989	1529	3924	1468	1128	2895	2945	0.7	53000
Maize	Sudan (former)	2004	58380	1488	1231	3309	1530	1265	3401	3979	1.0	60000
Maize	Sudan (former)	2005	9800	1318	1221	3159	1345	1246	3224	3464	1.0	10000
Maize	Sudan (former)	2006	104167	1248	1200	3120	1306	1256	3265	3337	1.0	109000
Maize	Sudan (former)	2007	36667	789	547	1450	1507	1045	2769	2869	1.9	70000
Maize	Sudan (former)	2008	30672	781	629	1640	1578	1271	3314	3803	2.0	62000
Maize	Sudan (former)	2009	37083	757	705	1965	1348	1255	3497	3959	1.8	66000
Maize	Sudan (former)	2010	26460	968	891	2570	1280	1178	3399	3557	1.3	35000
Maize	Sudan (former)	2011	31080	996	1039	3157	1346	1404	4267	4816	1.4	42000
Maize	Sudan (former)	2012	30660	827	868	2616	1376	1444	4351	4536	1.7	51000
Maize	Sudan (former)	2013	26880	788	857	2571	1262	1372	4116	4355	1.6	43041
Maize	Tanzania	1986	1903160	3140	37	29	3655	43	34	84	1.2	2215508
Maize	Tanzania	1987	1726000	2574	26	22	3547	36	31	71	1.4	2377885
Maize	Tanzania	1988	1852146	2654	32	27	3407	42	35	85	1.3	2376971
Maize	Tanzania	1989	1982297	2296	25	20	3648	40	31	75	1.6	3149510
Maize	Tanzania	1990	1633153	2352	24	20	3531	36	30	84	1.5	2451449
Maize	Tanzania	1991	1848770	2816	33	25	3564	42	32	71	1.3	2339277
Maize	Tanzania	1992	1906998	2895	38	26	3398	44	30	73	1.2	2238057
Maize	Tanzania	1993	1821428	2820	37	29	3543	46	36	92	1.3	2288082
Maize	Tanzania	1994	1203035	2468	39	32	3073	49	40	86	1.2	1497852
Maize	Tanzania	1995	1361567	1646	28	23	3458	59	48	111	2.1	2861293
Maize	Tanzania	1996	1572570	1793	33	27	3269	60	49	117	1.8	2866463
Maize	Tanzania	1997	1556645	2854	51	41	3342	59	48	103	1.2	1822594
Maize	Tanzania	1998	2078181	2900	33	26	3729	43	34	92	1.3	2671968

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Tanzania	1999	952751	1210	24	17	3094	62	43	103	2.6	2436589
Maize	Tanzania	2000	951383	1133	37	28	2434	80	61	137	2.1	2044387
Maize	Tanzania	2001	805705	986	22	19	3247	71	61	156	3.3	2654140
Maize	Tanzania	2002	1710120	1357	21	19	3484	53	50	114	2.6	4389235
Maize	Tanzania	2003	3438783	4504	78	58	3428	59	44	104	0.8	2616968
Maize	Tanzania	2004	3158149	2119	43	35	3109	62	52	133	1.5	4633476
Maize	Tanzania	2005	3063876	2964	61	51	3152	65	54	123	1.1	3257306
Maize	Tanzania	2006	2552036	2440	46	34	3274	61	46	98	1.3	3424425
Maize	Tanzania	2007	2564526	2492	35	29	3547	50	42	108	1.4	3650404
Maize	Tanzania	2008	3962250	2166	41	31	2983	56	43	117	1.4	5455999
Maize	Tanzania	2009	2682528	2092	51	48	2834	69	65	160	1.4	3634474
Maize	Tanzania	2010	2928209	2090	36	32	3414	59	52	122	1.6	4782698
Maize	Tanzania	2011	2849296	1779	55	55	3206	98	100	232	1.8	5135449
Maize	Tanzania	2012	3999959	2248	63	74	3104	87	102	214	1.4	5523955
Maize	Tanzania	2013	4081799	2554	56	62	3344	73	81	173	1.3	5344039
Maize	Tanzania	2014	3714174	1398	42	42	2828	85	84	168	2.0	7511781
Maize	Tanzania	2015	3756208	2009	46	45	3250	75	73	163	1.6	6077726
Maize	Uganda	1986	317882	4432	8	0	4503	8	0	0	1.0	322978
Maize	Uganda	1987	306233	3757	7	0	4399	8	0	0	1.2	358530
Maize	Uganda	1988	324896	3591	7	0	4742	9	0	0	1.3	429059
Maize	Uganda	1989	430072	3207	5	0	4650	8	0	0	1.5	623644
Maize	Uganda	1990	363687	3009	5	0	4603	8	0	0	1.5	556374
Maize	Uganda	1991	417589	3443	6	0	4652	8	0	0	1.4	564181
Maize	Uganda	1992	435784	3135	6	0	4710	10	0	0	1.5	654650
Maize	Uganda	1993	503010	2758	5	0	4425	8	0	0	1.6	806965
Maize	Uganda	1994	552321	2789	7	0	4393	10	0	0	1.6	870199
Maize	Uganda	1995	570850	2699	6	0	4368	9	0	0	1.6	923819

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Maize	Uganda	1996	584001	3498	6	0	4547	7	0	0	1.3	759115
Maize	Uganda	1997	598001	3857	7	0	4775	9	0	0	1.2	740249
Maize	Uganda	1998	616001	3067	5	0	4601	7	0	0	1.5	923999
Maize	Uganda	1999	607355	2531	5	0	4402	9	0	0	1.7	1056340
Maize	Uganda	2000	625632	2504	5	0	4393	9	0	0	1.8	1097592
Maize	Uganda	2001	652001	2419	4	0	4361	8	0	0	1.8	1175319
Maize	Uganda	2002	674207	2357	4	0	4307	7	0	0	1.8	1232300
Maize	Uganda	2003	710001	2282	3	0	4179	5	0	0	1.8	1299998
Maize	Uganda	2004	750001	3064	5	0	4414	7	0	0	1.4	1080376
Maize	Uganda	2005	780001	2688	5	0	4262	8	0	0	1.6	1236997
Maize	Uganda	2006	814615	2868	6	0	4437	9	0	0	1.5	1260419
Maize	Uganda	2007	844001	2920	5	0	4365	7	0	0	1.5	1261803
Maize	Uganda	2008	862001	1565	3	0	4202	8	0	0	2.7	2314911
Maize	Uganda	2009	936957	1735	4	0	4356	9	0	0	2.5	2352066
Maize	Uganda	2010	1029214	1966	3	0	4599	7	0	0	2.3	2407989
Maize	Uganda	2011	1063001	2023	4	0	4874	11	0	0	2.4	2560787
Maize	Uganda	2012	1094001	2099	5	0	5274	12	0	0	2.5	2748419
Maize	Uganda	2013	998848	1999	4	0	5495	10	0	0	2.7	2746296
Maize	Uganda	2014	1103920	1988	5	0	5024	13	0	0	2.5	2789304
Maize	Uganda	2015	1117044	2062	5	0	5390	14	0	0	2.6	2920195
Millet	Burundi	1986	12000	4048	4	0	4048	4	0	0	1.0	12000
Millet	Burundi	1987	12000	3870	4	0	3967	5	0	0	1.0	12300
Millet	Burundi	1988	12000	3968	4	0	4166	5	0	0	1.1	12600
Millet	Burundi	1989	12000	3987	4	0	4286	5	0	0	1.1	12900
Millet	Burundi	1990	12000	3552	4	0	3877	4	0	0	1.1	13100
Millet	Burundi	1991	12000	3486	5	0	3893	5	0	0	1.1	13400
Millet	Burundi	1992	12500	3609	5	0	3955	5	0	0	1.1	13700

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Millet	Burundi	1993	13000	4306	5	0	4438	5	0	0	1.0	13400
Millet	Burundi	1994	10000	3585	7	0	3970	7	0	0	1.1	11075
Millet	Burundi	1995	10000	2721	3	0	3927	4	0	0	1.4	14429
Millet	Burundi	1996	10000	3690	5	0	4167	6	0	0	1.1	11292
Millet	Burundi	1997	10000	2151	3	0	3595	5	0	0	1.7	16717
Millet	Burundi	1998	9500	3613	3	0	3993	4	0	0	1.1	10500
Millet	Burundi	1999	9000	3458	6	0	3882	6	0	0	1.1	10105
Millet	Burundi	2000	8300	3930	6	0	4107	6	0	0	1.0	8675
Millet	Burundi	2001	10000	3922	5	0	3922	5	0	0	1.0	10000
Millet	Burundi	2002	9200	3207	3	0	3732	4	0	0	1.2	10706
Millet	Burundi	2003	10000	3389	4	0	3591	4	0	0	1.1	10597
Millet	Burundi	2004	9187	3326	5	0	3849	5	0	0	1.2	10631
Millet	Burundi	2005	7500	3584	5	0	3706	5	0	0	1.0	7754
Millet	Burundi	2006	10000	3482	5	0	3746	6	0	0	1.1	10757
Millet	Burundi	2007	10500	3549	3	0	3887	3	0	0	1.1	11500
Millet	Burundi	2008	10000	3444	3	0	3789	4	0	0	1.1	11000
Millet	Burundi	2009	10200	3546	4	0	3893	5	0	0	1.1	11200
Millet	Burundi	2010	11000	3692	3	0	3927	3	0	0	1.1	11700
Millet	Burundi	2011	11200	4406	6	0	4721	7	0	0	1.1	12000
Millet	Burundi	2012	11000	4591	8	0	4591	8	0	0	1.0	11000
Millet	Burundi	2013	10500	4912	6	0	5240	7	0	0	1.1	11200
Millet	Burundi	2014	9684	4261	8	0	4715	9	0	0	1.1	10717
Millet	Burundi	2015	8288	3350	13	0	4840	19	0	0	1.4	11973
Millet	Congo_DR	1986	48415	3774	8	0	2726	5	0	0	0.7	34967
Millet	Congo_DR	1987	46699	3707	8	0	2667	6	0	0	0.7	33605
Millet	Congo_DR	1988	47519	3944	4	0	2828	3	0	0	0.7	34070
Millet	Congo_DR	1989	48066	3928	7	0	2829	5	0	0	0.7	34626

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Millet	Congo_DR	1990	62906	4937	7	0	3012	4	0	0	0.6	38372
Millet	Congo_DR	1991	55076	4141	10	0	2527	6	0	0	0.6	33608
Millet	Congo_DR	1992	56733	4557	10	0	2784	6	0	0	0.6	34664
Millet	Congo_DR	1993	58417	4059	10	0	2484	6	0	0	0.6	35751
Millet	Congo_DR	1994	60195	4892	8	0	3010	5	0	0	0.6	37036
Millet	Congo_DR	1995	122610	4505	14	0	2947	9	0	0	0.7	80207
Millet	Congo_DR	1996	124766	4243	19	0	2805	13	0	0	0.7	82496
Millet	Congo_DR	1997	40726	3789	14	0	2504	9	0	0	0.7	26920
Millet	Congo_DR	1998	41777	4351	11	0	2877	7	0	0	0.7	27625
Millet	Congo_DR	1999	42950	5021	8	0	3320	5	0	0	0.7	28393
Millet	Congo_DR	2000	51906	4876	10	0	3237	7	0	0	0.7	34459
Millet	Congo_DR	2001	53300	4132	9	0	2731	6	0	0	0.7	35231
Millet	Congo_DR	2002	54090	5043	8	0	3370	6	0	0	0.7	36150
Millet	Congo_DR	2003	55098	3983	8	0	2633	5	0	0	0.7	36420
Millet	Congo_DR	2004	55507	4545	8	0	3004	5	0	0	0.7	36690
Millet	Congo_DR	2005	55930	4219	14	0	2789	9	0	0	0.7	36970
Millet	Congo_DR	2006	56354	4528	11	0	2993	7	0	0	0.7	37250
Millet	Congo_DR	2007	56778	5390	6	0	3562	4	0	0	0.7	37530
Millet	Congo_DR	2008	57149	5350	8	0	3538	5	0	0	0.7	37787
Millet	Congo_DR	2009	57625	4498	10	0	2973	7	0	0	0.7	38092
Millet	Congo_DR	2010	58052	3891	13	0	2573	8	0	0	0.7	38385
Millet	Congo_DR	2011	58500	4503	20	0	2972	13	0	0	0.7	38606
Millet	Congo_DR	2012	61943	4604	10	0	3566	8	0	0	0.8	47975
Millet	Congo_DR	2013	61943	3727	17	0	2887	13	0	0	0.8	47979
Millet	Congo_DR	2014	69230	4949	18	0	3293	12	0	0	0.7	46057
Millet	Congo_DR	2015	66264	4549	22	0	3034	14	0	0	0.7	44206
Millet	Eritrea	1993	32685	8817	0	0	2203	0	0	0	0.2	8165

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Millet	Eritrea	1994	72774	3911	0	0	3246	0	0	0	0.8	60391
Millet	Eritrea	1995	50954	13124	0	0	3291	0	0	0	0.3	12776
Millet	Eritrea	1996	10138	5367	0	0	3884	0	0	0	0.7	7336
Millet	Eritrea	1997	42905	10103	0	0	2779	0	0	0	0.3	11802
Millet	Eritrea	1998	72961	4023	0	0	2768	0	0	0	0.7	50197
Millet	Eritrea	1999	50753	7162	0	0	3176	0	0	0	0.4	22507
Millet	Eritrea	2000	54521	26384	0	0	3716	0	0	0	0.1	7679
Millet	Eritrea	2001	46959	4806	0	0	3504	0	0	0	0.7	34237
Millet	Eritrea	2002	36806	18688	0	0	3049	0	0	0	0.2	6004
Millet	Eritrea	2003	90984	11978	0	0	2862	0	0	0	0.2	21739
Millet	Eritrea	2004	42440	14710	0	0	3254	0	0	0	0.2	9389
Millet	Eritrea	2005	80670	7292	0	0	4109	0	0	0	0.6	45450
Millet	Eritrea	2006	51046	2313	0	0	2561	0	0	0	1.1	56532
Millet	Eritrea	2007	91841	5207	0	0	3729	0	0	0	0.7	65769
Millet	Eritrea	2008	23978	21283	0	0	3487	0	0	0	0.2	3929
Millet	Eritrea	2009	50724	9009	0	0	2904	0	0	0	0.3	16349
Millet	Eritrea	2010	32386	5046	0	0	3292	0	0	0	0.7	21128
Millet	Eritrea	2011	26129	5512	0	0	2920	0	0	0	0.5	13842
Millet	Eritrea	2012	8738									
Millet	Eritrea	2013	45242	2039	0	0	2631	0	0	0	1.3	58387
Millet	Eritrea	2014	46746	7699	0	0	3002	0	0	0	0.4	18229
Millet	Eritrea	2015	4174	9717	0	0	3413	0	0	0	0.4	1466
Millet	Ethiopia	1993	161219	4506	31	0	3871	27	0	0	0.9	138503
Millet	Ethiopia	1994	237176	5035	32	0	3764	24	0	0	0.7	177307
Millet	Ethiopia	1995	235644	5119	25	0	3497	17	0	0	0.7	160980
Millet	Ethiopia	1996	240523	3794	12	0	3655	12	0	0	1.0	231727
Millet	Ethiopia	1997	276312	3354	17	0	3639	19	0	0	1.1	299786

			Harvested	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	area (ha)	Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i	(m^3/ha)	(tonne/ha)	(tonne)
Millet	Ethiopia	1998	292832	3742	16	0	3378	15	0	0	0.9	264326
Millet	Ethiopia	1999	432803	4135	20	0	3669	17	0	0	0.9	384084
Millet	Ethiopia	2000	366786	4008	15	0	3604	13	0	0	0.9	329789
Millet	Ethiopia	2001	348241	3981	14	0	3671	13	0	0	0.9	321131
Millet	Ethiopia	2002	265452	3071	16	0	3428	17	0	0	1.1	296345
Millet	Ethiopia	2003	312282	3412	12	0	3461	12	0	0	1.0	316772
Millet	Ethiopia	2004	310011	3256	16	0	3578	18	0	0	1.1	340657
Millet	Ethiopia	2005	341262	3029	11	0	3607	14	0	0	1.2	406323
Millet	Ethiopia	2006	393210	2738	12	0	3564	16	0	0	1.3	511756
Millet	Ethiopia	2007	387154	3439	11	0	3661	11	0	0	1.1	412180
Millet	Ethiopia	2008	392926	2917	12	0	3645	14	0	0	1.2	491082
Millet	Ethiopia	2009	369933	2360	14	0	3457	20	0	0	1.5	541841
Millet	Ethiopia	2010	413103	2205	10	0	3508	16	0	0	1.6	657207
Millet	Ethiopia	2011	423756	2514	13	0	4132	21	0	0	1.6	696462
Millet	Ethiopia	2012	408151	2156	12	0	4094	22	0	0	1.9	775049
Millet	Ethiopia	2013	435076	2160	11	0	4127	22	0	0	1.9	831427
Millet	Ethiopia	2014	468736	1959	9	0	4210	19	0	0	2.1	1007483
Millet	Ethiopia	2015	391177	1776	10	0	4343	25	0	0	2.4	956530
Millet	Ethiopia PDR	1986	218774	4222	22	0	3760	20	0	0	0.9	194858
Millet	Ethiopia PDR	1987	128626	3609	24	0	3475	23	0	0	1.0	123852
Millet	Ethiopia PDR	1988	142598	3070	16	0	3507	19	0	0	1.1	162893
Millet	Ethiopia PDR	1989	121584	3518	21	0	3611	22	0	0	1.0	124812
Millet	Ethiopia PDR	1990	126501	3087	20	0	3602	24	0	0	1.2	147610
Millet	Ethiopia PDR	1991	159157	2370	11	0	3632	17	0	0	1.5	243934
Millet	Ethiopia PDR	1992	143724	4027	25	0	3725	23	0	0	0.9	132947
Millet	Kenya	1986	69399	5652	357	0	3668	232	0	0	0.6	45040
Millet	Kenya	1987	106152	5864	345	0	3931	231	0	0	0.7	71154

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne) Green	WF (m^3/tonne) Sb_cr	WF (m^3/tonne) Sb_i	CWU (m^3/ha) Green	CWU (m^3/ha) Sb_cr	CWU (m^3/ha) Sb_i	Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Millet	Kenya	1988	107494	5095	359	0	3761	265	0	0	0.7	79341
Millet	Kenya	1989	110172	5316	358	0	3923	265	0	0	0.7	81309
Millet	Kenya	1990	100786	5320	311	0	3688	216	0	0	0.7	69884
Millet	Kenya	1991	91380	6319	454	0	3874	279	0	0	0.6	56028
Millet	Kenya	1992	81249	5847	505	0	3780	327	0	0	0.6	52527
Millet	Kenya	1993	86487	4584	312	0	3541	241	0	0	0.8	66807
Millet	Kenya	1994	81137	4071	349	0	3610	309	0	0	0.9	71939
Millet	Kenya	1995	94277	6216	110	0	3838	68	0	0	0.6	58213
Millet	Kenya	1996	84750	13546	206	0	3910	59	0	0	0.3	24466
Millet	Kenya	1997	96603	9415	136	0	4038	58	0	0	0.4	41429
Millet	Kenya	1998	84117	9783	99	0	4222	43	0	0	0.4	36301
Millet	Kenya	1999	88937	5433	100	0	3845	70	0	0	0.7	62937
Millet	Kenya	2000	86764	6476	136	0	3541	75	0	0	0.5	47440
Millet	Kenya	2001	103650	7980	140	0	3785	66	0	0	0.5	49162
Millet	Kenya	2002	110451	5244	98	0	3558	66	0	0	0.7	74948
Millet	Kenya	2003	114870	6222	78	0	3749	47	0	0	0.6	69207
Millet	Kenya	2004	109643	7500	133	0	3670	65	0	0	0.5	53655
Millet	Kenya	2005	84389	5474	98	0	3749	67	0	0	0.7	57795
Millet	Kenya	2006	138592	6135	105	0	3868	66	0	0	0.6	87376
Millet	Kenya	2007	130792	3970	51	0	3875	49	0	0	1.0	127632
Millet	Kenya	2008	52928	4786	85	0	3767	67	0	0	0.8	41661
Millet	Kenya	2009	90310	6031	133	0	3785	84	0	0	0.6	56673
Millet	Kenya	2010	93332	6104	98	0	3755	60	0	0	0.6	57413
Millet	Kenya	2011	101348	5581	107	0	4201	80	0	0	0.8	76283
Millet	Kenya	2012	121888	6413	102	0	4320	68	0	0	0.7	82113
Millet	Kenya	2013	92564	6055	80	0	4608	61	0	0	0.8	70446
Millet	Kenya	2014	126211	3745	68	0	4388	79	0	0	1.2	147892

			Harvested	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	area (ha)	Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i	(m^3/ha)	(tonne/ha)	(tonne)
Millet	Kenya	2015	66312	2815	56	0	4671	92	0	0	1.7	110056
Millet	Rwanda	1986	1160	7449	0	0	3853	0	0	0	0.5	600
Millet	Rwanda	1987	940	7061	0	0	3711	0	0	0	0.5	494
Millet	Rwanda	1988	2000	8033	0	0	4016	0	0	0	0.5	1000
Millet	Rwanda	1989	2000	7938	0	0	3969	0	0	0	0.5	1000
Millet	Rwanda	1990	6000	22406	0	0	3734	0	0	0	0.2	1000
Millet	Rwanda	1991	2000	5853	0	0	3772	0	0	0	0.6	1289
Millet	Rwanda	1992	1840	7732	0	0	3812	0	0	0	0.5	907
Millet	Rwanda	1993	1200	5736	0	0	4226	0	0	0	0.7	884
Millet	Rwanda	1994	960	3614	0	0	3829	0	0	0	1.1	1017
Millet	Rwanda	1995	937	3930	0	0	3699	0	0	0	0.9	882
Millet	Rwanda	1996	1080	4752	0	0	3951	0	0	0	0.8	898
Millet	Rwanda	1997	3000	5314	0	0	3542	0	0	0	0.7	2000
Millet	Rwanda	1998	4000	5159	0	0	3870	0	0	0	0.7	3000
Millet	Rwanda	1999	5000	4542	0	0	3634	0	0	0	0.8	4000
Millet	Rwanda	2000	5000	5021	0	0	4017	0	0	0	0.8	4000
Millet	Rwanda	2001	5528	4254	0	0	3666	0	0	0	0.9	4765
Millet	Rwanda	2002	5313	4613	0	0	3473	0	0	0	0.8	4000
Millet	Rwanda	2003	5000	4131	0	0	3305	0	0	0	0.8	4000
Millet	Rwanda	2004	5000	4487	0	0	3589	0	0	0	0.8	4000
Millet	Rwanda	2005	5000	4462	0	0	3569	0	0	0	0.8	4000
Millet	Rwanda	2006	5000	4425	0	0	3540	0	0	0	0.8	4000
Millet	Rwanda	2007	5371	4944	0	0	3590	0	0	0	0.7	3900
Millet	Rwanda	2008	5571	3895	0	0	3564	0	0	0	0.9	5097
Millet	Rwanda	2009	5438	3010	0	0	3766	0	0	0	1.3	6802
Millet	Rwanda	2010	5905	2942	0	0	3737	0	0	0	1.3	7500
Millet	Rwanda	2011	5377	2719	0	0	4361	0	0	0	1.6	8624

			Harvested	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	area (ha)	Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i	(m^3/ha)	(tonne/ha)	(tonne)
Millet	Rwanda	2012	5400	2721	0	0	4534	0	0	0	1.7	9000
Millet	Rwanda	2013	5400	3000	0	0	5000	0	0	0	1.7	9000
Millet	Rwanda	2014	10651	10519	0	0	4393	0	0	0	0.4	4448
Millet	Rwanda	2015	6457	5509	0	0	4523	0	0	0	0.8	5301
Millet	South Sudan	2014	11303	1529	977	0	1752	1120	0	0	1.1	12956
Millet	South Sudan	2015	7074	1256	1183	0	1513	1425	0	0	1.2	8522
Millet	Sudan (current)	2014	3834088	8170	1408	0	3830	660	0	0	0.5	1797351
Millet	Sudan (current)	2015	2033227	9451	2513	0	3328	885	0	0	0.4	715958
Millet	Sudan (former)	1986	1820536	14568	2579	0	3089	547	0	0	0.2	386054
Millet	Sudan (former)	1987	883315	10532	4006	0	2486	946	0	0	0.2	208538
Millet	Sudan (former)	1988	2895643	12355	2253	0	3406	621	0	0	0.3	798198
Millet	Sudan (former)	1989	1186794	14422	3186	0	3243	716	0	0	0.2	266853
Millet	Sudan (former)	1990	777762	12449	3526	0	2508	710	0	0	0.2	156669
Millet	Sudan (former)	1991	1156654	8343	1791	0	3188	684	0	0	0.4	441901
Millet	Sudan (former)	1992	1668953	8496	1930	0	3106	706	0	0	0.4	610114
Millet	Sudan (former)	1993	945120	10657	2445	0	3117	715	0	0	0.3	276394
Millet	Sudan (former)	1994	3420972	8702	1475	0	3549	601	0	0	0.4	1395281
Millet	Sudan (former)	1995	3089025	17984	2961	0	3238	533	0	0	0.2	556257
Millet	Sudan (former)	1996	1898973	10000	1642	0	3198	525	0	0	0.3	607334
Millet	Sudan (former)	1997	3496101	12537	1960	0	3243	507	0	0	0.3	904404
Millet	Sudan (former)	1998	3557502	11934	1980	0	3004	499	0	0	0.3	895615
Millet	Sudan (former)	1999	3133569	14987	2124	0	3319	470	0	0	0.2	694074
Millet	Sudan (former)	2000	2412774	10624	2119	0	3036	606	0	0	0.3	689420
Millet	Sudan (former)	2001	3288202	13686	2319	0	3332	565	0	0	0.2	800615
Millet	Sudan (former)	2002	2691421	10392	2127	0	3000	614	0	0	0.3	777066
Millet	Sudan (former)	2003	3227905	10287	1357	0	3493	461	0	0	0.3	1096164
Millet	Sudan (former)	2004	1603130	13076	2323	0	3138	557	0	0	0.2	384679

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Millet	Sudan (former)	2005	2554301	7557	1451	0	3058	587	0	0	0.4	1033745
Millet	Sudan (former)	2006	2774556	9323	1495	0	3256	522	0	0	0.3	969063
Millet	Sudan (former)	2007	2989665	10053	1159	0	3526	406	0	0	0.4	1048682
Millet	Sudan (former)	2008	2840464	9447	1541	0	3435	560	0	0	0.4	1032872
Millet	Sudan (former)	2009	2801022	9157	2310	0	2886	728	0	0	0.3	882802
Millet	Sudan (former)	2010	2599852	13017	2304	0	3273	579	0	0	0.3	653823
Millet	Sudan (former)	2011	2792449	11214	2665	0	3530	839	0	0	0.3	878874
Millet	Sudan (former)	2012	1595145	12287	2208	0	4073	732	0	0	0.3	528733
Millet	Sudan (former)	2013	3132308	7081	1649	0	3242	755	0	0	0.5	1433990
Millet	Tanzania	1986	332264	5390	70	0	4781	62	0	0	0.9	294733
Millet	Tanzania	1987	290754	4551	47	0	4567	47	0	0	1.0	291777
Millet	Tanzania	1988	259749	5316	79	0	4372	65	0	0	0.8	213593
Millet	Tanzania	1989	300780	4360	54	0	4360	54	0	0	1.0	300821
Millet	Tanzania	1990	178463	3992	44	0	4485	50	0	0	1.1	200520
Millet	Tanzania	1991	256666	5835	78	0	4559	61	0	0	0.8	200520
Millet	Tanzania	1992	309012	5261	80	0	4555	70	0	0	0.9	267567
Millet	Tanzania	1993	313124	7187	98	0	4699	64	0	0	0.7	204721
Millet	Tanzania	1994	257467	3558	75	0	4043	85	0	0	1.1	292620
Millet	Tanzania	1995	205535	3934	72	0	4296	78	0	0	1.1	224448
Millet	Tanzania	1996	228196	3385	65	0	4000	77	0	0	1.2	269604
Millet	Tanzania	1997	352639	4106	86	0	4089	86	0	0	1.0	351221
Millet	Tanzania	1998	268099	4801	52	0	4224	46	0	0	0.9	235900
Millet	Tanzania	1999	195804	4004	87	0	3975	87	0	0	1.0	194405
Millet	Tanzania	2000	250716	4815	105	0	4204	92	0	0	0.9	218904
Millet	Tanzania	2001	199719	4194	59	0	4327	61	0	0	1.0	206052
Millet	Tanzania	2002	347619	5941	106	0	4007	71	0	0	0.7	234453
Millet	Tanzania	2003	201849	9409	139	0	4255	63	0	0	0.5	91280

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Millet	Tanzania	2004	294079	4445	125	0	4030	114	0	0	0.9	266637
Millet	Tanzania	2005	283062	5813	83	0	4493	64	0	0	0.8	218778
Millet	Tanzania	2006	283212	4238	124	0	3665	107	0	0	0.9	244904
Millet	Tanzania	2007	399999	5466	56	0	4207	43	0	0	0.8	307906
Millet	Tanzania	2008	212670	5809	95	0	4168	68	0	0	0.7	152564
Millet	Tanzania	2009	398505	5751	81	0	4519	64	0	0	0.8	313173
Millet	Tanzania	2010	338276	4266	58	0	4346	59	0	0	1.0	344648
Millet	Tanzania	2011	345063	3791	85	0	4636	104	0	0	1.2	422024
Millet	Tanzania	2012	248667	5338	111	0	4931	102	0	0	0.9	229734
Millet	Tanzania	2013	327855	5028	93	0	4991	92	0	0	1.0	325405
Millet	Tanzania	2014	261865	4694	116	0	4895	121	0	0	1.0	273068
Millet	Tanzania	2015	335448	4051	125	0	4578	142	0	0	1.1	379088
Millet	Uganda	1986	338145	3594	6	0	4498	8	0	0	1.3	423188
Millet	Uganda	1987	324208	2708	5	0	4332	8	0	0	1.6	518587
Millet	Uganda	1988	365939	2919	5	0	4563	7	0	0	1.6	572108
Millet	Uganda	1989	381485	2880	5	0	4604	7	0	0	1.6	609971
Millet	Uganda	1990	372325	2909	4	0	4375	7	0	0	1.5	560089
Millet	Uganda	1991	380543	3080	5	0	4623	8	0	0	1.5	571215
Millet	Uganda	1992	396189	2951	6	0	4725	10	0	0	1.6	634322
Millet	Uganda	1993	404260	2990	6	0	4517	9	0	0	1.5	610842
Millet	Uganda	1994	407432	2907	6	0	4317	9	0	0	1.5	605005
Millet	Uganda	1995	395273	2751	5	0	4404	9	0	0	1.6	632634
Millet	Uganda	1996	400276	4055	6	0	4461	7	0	0	1.1	440365
Millet	Uganda	1997	395273	3606	8	0	4583	10	0	0	1.3	502346
Millet	Uganda	1998	401277	2903	5	0	4648	8	0	0	1.6	642443
Millet	Uganda	1999	375517	2641	5	0	4260	8	0	0	1.6	605850
Millet	Uganda	2000	384117	3123	7	0	4345	10	0	0	1.4	534352

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Millet	Uganda	2001	389268	2954	5	0	4434	8	0	0	1.5	584415
Millet	Uganda	2002	396121	2775	5	0	4137	7	0	0	1.5	590501
Millet	Uganda	2003	400087	2477	3	0	3964	5	0	0	1.6	640219
Millet	Uganda	2004	412284	2591	5	0	4145	8	0	0	1.6	659454
Millet	Uganda	2005	420290	2640	6	0	4224	9	0	0	1.6	672492
Millet	Uganda	2006	429131	2678	5	0	4289	8	0	0	1.6	687429
Millet	Uganda	2007	437302	2522	4	0	4224	7	0	0	1.7	732505
Millet	Uganda	2008	200138	3069	7	0	4218	9	0	0	1.4	275046
Millet	Uganda	2009	192098	3294	8	0	4281	10	0	0	1.3	249646
Millet	Uganda	2010	165182	2735	4	0	4398	6	0	0	1.6	265579
Millet	Uganda	2011	172119	2843	7	0	4832	11	0	0	1.7	292555
Millet	Uganda	2012	175121	3693	8	0	5150	11	0	0	1.4	244196
Millet	Uganda	2013	180124	4219	8	0	5345	10	0	0	1.3	228198
Millet	Uganda	2014	174900	3719	11	0	5046	14	0	0	1.4	237335
Millet	Uganda	2015	173932	3633	11	0	5058	15	0	0	1.4	242190
Sorghum	Burundi	1986	61000	4488	4	0	4488	4	0	0	1.0	61000
Sorghum	Burundi	1987	63000	4410	5	0	4375	5	0	0	1.0	62500
Sorghum	Burundi	1988	77000	5508	6	0	4564	5	0	0	0.8	63800
Sorghum	Burundi	1989	58000	4165	5	0	4704	5	0	0	1.1	65500
Sorghum	Burundi	1990	58000	3940	4	0	4328	5	0	0	1.1	63700
Sorghum	Burundi	1991	58000	3792	5	0	4263	6	0	0	1.1	65200
Sorghum	Burundi	1992	58000	3729	5	0	4295	6	0	0	1.2	66800
Sorghum	Burundi	1993	58000	4368	5	0	4917	6	0	0	1.1	65300
Sorghum	Burundi	1994	45000	4423	8	0	4396	8	0	0	1.0	44721
Sorghum	Burundi	1995	50000	3274	4	0	4312	5	0	0	1.3	65840
Sorghum	Burundi	1996	50000	3498	5	0	4620	6	0	0	1.3	66031
Sorghum	Burundi	1997	55000	3128	5	0	3879	6	0	0	1.2	68208

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Sorghum	Burundi	1998	54000	3545	3	0	4427	4	0	0	1.2	67431
Sorghum	Burundi	1999	50000	3480	6	0	4175	7	0	0	1.2	59992
Sorghum	Burundi	2000	50965	3747	6	0	4484	7	0	0	1.2	60980
Sorghum	Burundi	2001	55000	3437	5	0	4317	6	0	0	1.3	69074
Sorghum	Burundi	2002	57000	3234	3	0	4155	4	0	0	1.3	73246
Sorghum	Burundi	2003	58046	3177	4	0	3912	5	0	0	1.2	71471
Sorghum	Burundi	2004	55000	3114	4	0	4199	6	0	0	1.3	74162
Sorghum	Burundi	2005	55000	2769	4	0	3889	6	0	0	1.4	77231
Sorghum	Burundi	2006	65000	3289	5	0	4161	7	0	0	1.3	82249
Sorghum	Burundi	2007	66000	3214	3	0	4167	4	0	0	1.3	85565
Sorghum	Burundi	2008	62000	3236	3	0	4166	4	0	0	1.3	79818
Sorghum	Burundi	2009	63000	3329	4	0	4289	5	0	0	1.3	81176
Sorghum	Burundi	2010	64300	3366	3	0	4347	4	0	0	1.3	83023
Sorghum	Burundi	2011	67800	4083	6	0	5230	8	0	0	1.3	86854
Sorghum	Burundi	2012	53523	8465	15	0	4986	9	0	0	0.6	31527
Sorghum	Burundi	2013	48292	8769	12	0	5711	8	0	0	0.7	31453
Sorghum	Burundi	2014	32254	7378	14	0	5113	10	0	0	0.7	22354
Sorghum	Burundi	2015	26528	4237	10	0	4885	11	0	0	1.2	30587
Sorghum	Congo_DR	1986	67190	5227	16	0	2990	9	0	0	0.6	38437
Sorghum	Congo_DR	1987	63802	4772	17	0	2835	10	0	0	0.6	37906
Sorghum	Congo_DR	1988	70005	4779	14	0	3079	9	0	0	0.6	45106
Sorghum	Congo_DR	1989	68298	4739	18	0	3125	12	0	0	0.7	45044
Sorghum	Congo_DR	1990	78345	4587	16	0	2887	10	0	0	0.6	49299
Sorghum	Congo_DR	1991	8221	4597	16	0	2900	10	0	0	0.6	5187
Sorghum	Congo_DR	1992	8657	4483	18	0	2810	11	0	0	0.6	5426
Sorghum	Congo_DR	1993	8554	4379	19	0	2787	12	0	0	0.6	5444
Sorghum	Congo_DR	1994	7069	4437	20	0	3147	15	0	0	0.7	5014

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Sorghum	Congo_DR	1995	16930	3956	44	0	2925	32	0	0	0.7	12518
Sorghum	Congo_DR	1996	20206	4177	37	0	2880	25	0	0	0.7	13932
Sorghum	Congo_DR	1997	7011	4031	34	0	2700	23	0	0	0.7	4697
Sorghum	Congo_DR	1998	6674	4236	32	0	2923	22	0	0	0.7	4605
Sorghum	Congo_DR	1999	6656	4447	33	0	3110	23	0	0	0.7	4655
Sorghum	Congo_DR	2000	6123	3750	45	0	2952	36	0	0	0.8	4820
Sorghum	Congo_DR	2001	8108	4276	33	0	3039	24	0	0	0.7	5764
Sorghum	Congo_DR	2002	8645	4354	32	0	3018	22	0	0	0.7	5992
Sorghum	Congo_DR	2003	8906	4271	30	0	2915	20	0	0	0.7	6078
Sorghum	Congo_DR	2004	9065	4628	32	0	3129	22	0	0	0.7	6129
Sorghum	Congo_DR	2005	8427	4111	35	0	2863	24	0	0	0.7	5867
Sorghum	Congo_DR	2006	9403	4431	28	0	2937	19	0	0	0.7	6231
Sorghum	Congo_DR	2007	9344	5174	25	0	3432	17	0	0	0.7	6198
Sorghum	Congo_DR	2008	7946	4260	31	0	3058	22	0	0	0.7	5704
Sorghum	Congo_DR	2009	9182	4210	31	0	2800	21	0	0	0.7	6108
Sorghum	Congo_DR	2010	7852	3568	35	0	2544	25	0	0	0.7	5599
Sorghum	Congo_DR	2011	7072	4457	42	0	3525	34	0	0	0.8	5594
Sorghum	Congo_DR	2012	5305	3348	35	0	3689	38	0	0	1.1	5845
Sorghum	Congo_DR	2013	6149	2965	32	0	3116	34	0	0	1.1	6462
Sorghum	Congo_DR	2014	6197	4968	43	0	3450	30	0	0	0.7	4303
Sorghum	Congo_DR	2015	6545	4632	43	0	3112	29	0	0	0.7	4398
Sorghum	Egypt	1992	470468	3111	6	28	4054	8	37	45	1.3	613157
Sorghum	Egypt	1986	149040	74	48	861	290	187	3382	3797	3.9	585569
Sorghum	Egypt	1987	127486	81	55	1003	341	233	4226	4631	4.2	537037
Sorghum	Egypt	1988	126279	76	43	825	341	192	3707	4072	4.5	567555
Sorghum	Egypt	1989	123082	83	43	911	386	201	4240	4673	4.7	572764
Sorghum	Egypt	1990	128470	68	39	821	325	184	3903	4259	4.8	610763

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Sorghum	Egypt	1991	130197	46	36	654	239	187	3366	3793	5.1	669698
Sorghum	Egypt	1992	143018	79	42	827	414	218	4317	4750	5.2	746839
Sorghum	Egypt	1993	139826	61	35	748	335	193	4077	4470	5.5	762414
Sorghum	Egypt	1994	151269	58	40	705	270	188	3305	3651	4.7	709658
Sorghum	Egypt	1995	141368	70	50	842	318	228	3813	4220	4.5	640384
Sorghum	Egypt	1996	132743	63	51	865	276	226	3803	4174	4.4	583973
Sorghum	Egypt	1997	149291	53	45	765	276	233	3940	4384	5.2	769135
Sorghum	Egypt	1998	151452	59	41	644	337	232	3646	4111	5.7	857947
Sorghum	Egypt	1999	158353	41	34	565	239	201	3301	3685	5.8	925843
Sorghum	Egypt	2000	155667	42	40	647	245	238	3815	4195	5.9	918089
Sorghum	Egypt	2001	142424	50	26	584	297	155	3459	3852	5.9	844243
Sorghum	Egypt	2002	149559	47	30	644	277	179	3784	4198	5.9	879194
Sorghum	Egypt	2003	160105	37	35	635	214	202	3701	3964	5.8	932675
Sorghum	Egypt	2004	145955	41	32	635	234	182	3646	4027	5.7	838364
Sorghum	Egypt	2005	145570	36	36	662	204	204	3756	4064	5.7	826230
Sorghum	Egypt	2006	149401	38	29	582	221	167	3352	3670	5.8	861257
Sorghum	Egypt	2007	142371	37	34	695	215	198	3998	4351	5.8	819023
Sorghum	Egypt	2008	147584	47	33	657	266	185	3741	4152	5.7	840042
Sorghum	Egypt	2009	135277	32	34	588	176	188	3284	3655	5.6	755566
Sorghum	Egypt	2010	134228	29	37	631	145	189	3198	3525	5.1	680115
Sorghum	Egypt	2011	150345	24	35	637	128	190	3475	3874	5.5	820055
Sorghum	Egypt	2012	136705	37	49	944	200	263	5071	5430	5.4	734790
Sorghum	Egypt	2013	135227	29	40	748	158	213	4018	4362	5.4	726161
Sorghum	Egypt	2014	142184	33	37	751	185	205	4155	4341	5.5	786814
Sorghum	Egypt	2015	143843	51	47	860	249	231	4193	4557	4.9	701288
Sorghum	Eritrea	1993	834724	40192	0	0	2567	0	0	0	0.1	53319
Sorghum	Eritrea	1994	114174	2009	0	0	2897	0	0	0	1.4	164637

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Sorghum	Eritrea	1995	117144	3686	0	0	2791	0	0	0	0.8	88700
Sorghum	Eritrea	1996	89784	1943	0	0	2973	0	0	0	1.5	137388
Sorghum	Eritrea	1997	168418	6966	0	0	3090	0	0	0	0.4	74711
Sorghum	Eritrea	1998	230573	2319	0	0	3530	0	0	0	1.5	351007
Sorghum	Eritrea	1999	190568	2463	0	0	2989	0	0	0	1.2	231254
Sorghum	Eritrea	2000	146805	5657	0	0	3631	0	0	0	0.6	94235
Sorghum	Eritrea	2001	143114	4867	0	0	3243	0	0	0	0.7	95348
Sorghum	Eritrea	2002	153298	9360	0	0	3010	0	0	0	0.3	49292
Sorghum	Eritrea	2003	173614	6222	0	0	3311	0	0	0	0.5	92380
Sorghum	Eritrea	2004	178784	5390	0	0	2839	0	0	0	0.5	94166
Sorghum	Eritrea	2005	227294	4525	0	0	4207	0	0	0	0.9	211328
Sorghum	Eritrea	2006	269250	3127	0	0	3321	0	0	0	1.1	285913
Sorghum	Eritrea	2007	244444	3423	0	0	3785	0	0	0	1.1	270308
Sorghum	Eritrea	2008	196177	5929	0	0	2920	0	0	0	0.5	96610
Sorghum	Eritrea	2009	185876	3159	0	0	2294	0	0	0	0.7	135014
Sorghum	Eritrea	2010	214219	5140	0	0	2650	0	0	0	0.5	110444
Sorghum	Eritrea	2011	134662	1209	0	0	2242	0	0	0	1.9	249670
Sorghum	Eritrea	2012	93658									
Sorghum	Eritrea	2013	94288	1149	0	0	2819	0	0	0	2.5	231311
Sorghum	Eritrea	2014	216515	3263	0	0	3261	0	0	0	1.0	216372
Sorghum	Eritrea	2015	169724	935	0	0	3736	0	0	0	4.0	678307
Sorghum	Ethiopia	1993	462201	2775	6	26	4128	9	38	54	1.5	687401
Sorghum	Ethiopia	1994	773829	4201	8	39	4081	8	38	54	1.0	751755
Sorghum	Ethiopia	1995	929722	2887	5	27	3713	6	35	55	1.3	1195965
Sorghum	Ethiopia	1996	1393739	2659	3	24	3778	5	34	48	1.4	1980404
Sorghum	Ethiopia	1997	1487531	2801	4	23	4018	6	33	47	1.4	2133568
Sorghum	Ethiopia	1998	1023412	3235	4	25	3633	5	28	34	1.1	1149510

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Sorghum	Ethiopia	1999	1104801	3031	5	25	3884	7	32	44	1.3	1415701
Sorghum	Ethiopia	2000	1059693	3293	5	24	3915	5	28	39	1.2	1259884
Sorghum	Ethiopia	2001	1413313	3442	4	23	3934	5	26	40	1.1	1615290
Sorghum	Ethiopia	2002	1149069	2598	4	25	3701	6	36	54	1.4	1636685
Sorghum	Ethiopia	2003	1394063	2846	4	24	3805	5	32	46	1.3	1863585
Sorghum	Ethiopia	2004	1311087	2648	4	27	3763	6	38	51	1.4	1863281
Sorghum	Ethiopia	2005	1315875	2861	4	23	3930	5	31	42	1.4	1807455
Sorghum	Ethiopia	2006	1524390	2515	4	21	3777	5	31	42	1.5	2289371
Sorghum	Ethiopia	2007	1538201	2526	3	18	4001	4	28	41	1.6	2436601
Sorghum	Ethiopia	2008	1610565	2253	3	19	3926	5	33	47	1.7	2806187
Sorghum	Ethiopia	2009	1665780	1934	4	20	3691	7	39	52	1.9	3179751
Sorghum	Ethiopia	2010	1973150	1776	3	15	3730	6	32	48	2.1	4144665
Sorghum	Ethiopia	2011	1957461	1956	3	21	4351	7	46	63	2.2	4353329
Sorghum	Ethiopia	2012	1717846	1848	3	22	4504	8	53	76	2.4	4185538
Sorghum	Ethiopia	2013	1904402	1703	3	19	4503	9	50	61	2.6	5036556
Sorghum	Ethiopia	2014	1913872	1777	3	18	4301	6	44	57	2.4	4631233
Sorghum	Ethiopia	2015	1920293	1554	3	19	4604	9	55	73	3.0	5688008
Sorghum	Ethiopia PDR	1986	859426	3495	7	31	4025	8	35	51	1.2	989691
Sorghum	Ethiopia PDR	1987	831922	3142	6	27	3856	8	33	45	1.2	1021083
Sorghum	Ethiopia PDR	1988	791088	2916	6	26	3727	7	33	42	1.3	1011294
Sorghum	Ethiopia PDR	1989	558539	2407	5	25	3965	9	41	63	1.6	919965
Sorghum	Ethiopia PDR	1990	634404	2495	6	27	3835	9	41	64	1.5	975149
Sorghum	Ethiopia PDR	1991	531449	2752	5	26	3997	7	37	53	1.5	771983
Sorghum	Kenya	1986	139647	3684	245	0	3771	251	0	0	1.0	142926
Sorghum	Kenya	1987	145878	4643	282	0	4001	243	0	0	0.9	125729
Sorghum	Kenya	1988	146720	3264	246	0	3977	300	0	0	1.2	178787
Sorghum	Kenya	1989	110352	3552	255	0	3992	287	0	0	1.1	124047

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Sorghum	Kenya	1990	119490	3895	260	0	3849	257	0	0	1.0	118070
Sorghum	Kenya	1991	118999	3702	260	0	4075	286	0	0	1.1	131003
Sorghum	Kenya	1992	99502	2470	248	0	3762	378	0	0	1.5	151551
Sorghum	Kenya	1993	121773	4234	318	0	3627	272	0	0	0.9	104308
Sorghum	Kenya	1994	107598	3251	292	0	3718	334	0	0	1.1	123030
Sorghum	Kenya	1995	141527	6214	113	0	4007	73	0	0	0.6	91261
Sorghum	Kenya	1996	136005	6368	95	0	4091	61	0	0	0.6	87384
Sorghum	Kenya	1997	143677	5451	85	0	4287	67	0	0	0.8	113016
Sorghum	Kenya	1998	127482	5807	62	0	4487	48	0	0	0.8	98506
Sorghum	Kenya	1999	137960	4633	86	0	4042	75	0	0	0.9	120366
Sorghum	Kenya	2000	119935	4711	97	0	3606	74	0	0	0.8	91802
Sorghum	Kenya	2001	135843	3980	72	0	4066	74	0	0	1.0	138746
Sorghum	Kenya	2002	152832	4151	78	0	3719	70	0	0	0.9	136938
Sorghum	Kenya	2003	159000	4594	59	0	4014	52	0	0	0.9	138926
Sorghum	Kenya	2004	120676	5822	108	0	3833	71	0	0	0.7	79459
Sorghum	Kenya	2005	123788	2730	48	0	3734	65	0	0	1.4	169306
Sorghum	Kenya	2006	166306	4327	78	0	4057	73	0	0	0.9	155929
Sorghum	Kenya	2007	163434	4111	51	0	3978	50	0	0	1.0	158132
Sorghum	Kenya	2008	104731	6621	115	0	3885	67	0	0	0.6	61455
Sorghum	Kenya	2009	157001	5328	123	0	3966	91	0	0	0.7	116877
Sorghum	Kenya	2010	233795	4707	77	0	3959	65	0	0	0.8	196686
Sorghum	Kenya	2011	241401	5916	110	0	4251	79	0	0	0.7	173473
Sorghum	Kenya	2012	235993	5479	87	0	4509	72	0	0	0.8	194233
Sorghum	Kenya	2013	201658	6193	82	0	4897	65	0	0	0.8	159473
Sorghum	Kenya	2014	209269	4731	85	0	4430	79	0	0	0.9	195947
Sorghum	Kenya	2015	167143	3259	67	0	4853	100	0	0	1.5	248856
Sorghum	Rwanda	1986	149717	3264	0	0	4212	0	0	0	1.3	193197

			Harvested	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	area (ha)	Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i	(m^3/ha)	(tonne/ha)	(tonne)
Sorghum	Rwanda	1987	155590	3359	0	0	4064	0	0	0	1.2	188270
Sorghum	Rwanda	1988	151891	4699	0	0	4349	0	0	0	0.9	140600
Sorghum	Rwanda	1989	132400	3821	0	0	4243	0	0	0	1.1	147000
Sorghum	Rwanda	1990	133421	3878	0	0	4145	0	0	0	1.1	142603
Sorghum	Rwanda	1991	160000	3173	0	0	4065	0	0	0	1.3	205000
Sorghum	Rwanda	1992	150000	5227	0	0	3923	0	0	0	0.8	112600
Sorghum	Rwanda	1993	100000	3558	0	0	4558	0	0	0	1.3	128100
Sorghum	Rwanda	1994	80000	6017	0	0	4121	0	0	0	0.7	54800
Sorghum	Rwanda	1995	67093	3477	0	0	4006	0	0	0	1.2	77300
Sorghum	Rwanda	1996	75000	3149	0	0	4286	0	0	0	1.4	102076
Sorghum	Rwanda	1997	108894	3285	0	0	3686	0	0	0	1.1	122204
Sorghum	Rwanda	1998	114639	4034	0	0	4241	0	0	0	1.1	120533
Sorghum	Rwanda	1999	129261	4543	0	0	3780	0	0	0	0.8	107566
Sorghum	Rwanda	2000	174194	4847	0	0	4316	0	0	0	0.9	155106
Sorghum	Rwanda	2001	185443	4186	0	0	3971	0	0	0	0.9	175904
Sorghum	Rwanda	2002	171807	3599	0	0	3862	0	0	0	1.1	184351
Sorghum	Rwanda	2003	179790	3771	0	0	3599	0	0	0	1.0	171587
Sorghum	Rwanda	2004	179306	4376	0	0	3997	0	0	0	0.9	163772
Sorghum	Rwanda	2005	196731	3193	0	0	3700	0	0	0	1.2	227927
Sorghum	Rwanda	2006	170297	3520	0	0	3874	0	0	0	1.1	187380
Sorghum	Rwanda	2007	162322	3817	0	0	3856	0	0	0	1.0	164000
Sorghum	Rwanda	2008	143210	3890	0	0	3912	0	0	0	1.0	144000
Sorghum	Rwanda	2009	146338	3442	0	0	4106	0	0	0	1.2	174553
Sorghum	Rwanda	2010	133375	3399	0	0	4108	0	0	0	1.2	161229
Sorghum	Rwanda	2011	119355	3745	0	0	4761	0	0	0	1.3	151754
Sorghum	Rwanda	2012	97143	3395	0	0	4847	0	0	0	1.4	138695
Sorghum	Rwanda	2013	109121	3745	0	0	5405	0	0	0	1.4	157492

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Sorghum	Rwanda	2014	137227	4473	0	0	4582	0	0	0	1.0	140578
Sorghum	Rwanda	2015	137696	4545	0	0	4548	0	0	0	1.0	137792
Sorghum	South Sudan	2014	922584	1367	1131	0	1871	1548	0	0	1.4	1262890
Sorghum	South Sudan	2015	548266	984	1356	0	1505	2074	0	0	1.5	838233
Sorghum	Sudan (current)	2014	9341441	3488	1541	797	2993	1322	684	702	0.9	8014848
Sorghum	Sudan (current)	2015	4380143	2548	2706	1288	1977	2100	999	1110	0.8	3399138
Sorghum	Sudan (former)	1986	5453388	3277	1444	523	2363	1041	377	396	0.7	3932974
Sorghum	Sudan (former)	1987	3449546	3752	2449	893	1956	1277	466	517	0.5	1798443
Sorghum	Sudan (former)	1988	6203532	2924	1210	406	2534	1049	352	356	0.9	5376219
Sorghum	Sudan (former)	1989	4026498	5793	2529	919	2765	1207	439	507	0.5	1922163
Sorghum	Sudan (former)	1990	2857735	3213	2737	1025	1837	1565	586	676	0.6	1633834
Sorghum	Sudan (former)	1991	5627957	3076	1511	625	2448	1202	498	526	0.8	4478477
Sorghum	Sudan (former)	1992	6485424	2905	1652	578	2265	1288	450	436	0.8	5056754
Sorghum	Sudan (former)	1993	5122166	4950	1963	729	2849	1130	419	453	0.6	2947982
Sorghum	Sudan (former)	1994	7225375	4600	1529	556	2758	917	333	343	0.6	4331703
Sorghum	Sudan (former)	1995	5605272	4342	2146	734	2379	1176	402	424	0.5	3071449
Sorghum	Sudan (former)	1996	7411339	3607	1500	572	2478	1030	393	449	0.7	5091265
Sorghum	Sudan (former)	1997	7475968	5670	2136	822	2649	998	384	420	0.5	3492477
Sorghum	Sudan (former)	1998	7209307	2915	1537	592	2183	1151	444	461	0.7	5399125
Sorghum	Sudan (former)	1999	5277326	4936	1916	732	2692	1045	399	408	0.5	2878039
Sorghum	Sudan (former)	2000	4739497	3925	1850	750	2604	1228	498	579	0.7	3144473
Sorghum	Sudan (former)	2001	6534981	2372	1372	545	2143	1240	493	509	0.9	5902629
Sorghum	Sudan (former)	2002	5701060	3930	1807	721	2400	1103	440	490	0.6	3480884
Sorghum	Sudan (former)	2003	8298813	3437	1358	496	2646	1045	382	402	0.8	6389567
Sorghum	Sudan (former)	2004	4231709	3031	1611	640	2402	1277	507	593	0.8	3354282
Sorghum	Sudan (former)	2005	11226220	4573	2062	831	2511	1132	456	479	0.5	6163720
Sorghum	Sudan (former)	2006	7346038	3618	1586	623	2593	1137	447	461	0.7	5265444

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Sorghum	Sudan (former)	2007	7595018	3516	1145	448	2768	902	353	380	0.8	5978885
Sorghum	Sudan (former)	2008	7473768	4484	1917	766	2847	1217	486	557	0.6	4744124
Sorghum	Sudan (former)	2009	7624605	3389	1932	739	2337	1333	510	567	0.7	5259404
Sorghum	Sudan (former)	2010	6514357	5550	2405	950	2735	1185	468	493	0.5	3210398
Sorghum	Sudan (former)	2011	7326403	2637	2263	958	2182	1873	793	879	0.8	6062215
Sorghum	Sudan (former)	2012	4678959	5322	2946	1322	2733	1512	679	715	0.5	2402258
Sorghum	Sudan (former)	2013	6874776	2172	2083	903	1945	1865	808	844	0.9	6155783
Sorghum	Tanzania	1986	801030	5964	88	0	4884	72	0	0	0.8	656020
Sorghum	Tanzania	1987	759517	5488	66	0	4801	58	0	0	0.9	664481
Sorghum	Tanzania	1988	476615	5272	86	0	4553	74	0	0	0.9	411619
Sorghum	Tanzania	1989	487934	4190	60	0	4624	66	0	0	1.1	538507
Sorghum	Tanzania	1990	380760	3808	49	0	4651	60	0	0	1.2	465032
Sorghum	Tanzania	1991	601201	4653	71	0	4773	73	0	0	1.0	616662
Sorghum	Tanzania	1992	684438	5483	91	0	4761	79	0	0	0.9	594335
Sorghum	Tanzania	1993	642894	4353	67	0	4907	75	0	0	1.1	724718
Sorghum	Tanzania	1994	661085	5625	124	0	4210	93	0	0	0.7	494799
Sorghum	Tanzania	1995	689500	3805	73	0	4631	88	0	0	1.2	839233
Sorghum	Tanzania	1996	662578	3261	70	0	4305	92	0	0	1.3	874537
Sorghum	Tanzania	1997	608990	4715	120	0	4308	110	0	0	0.9	556362
Sorghum	Tanzania	1998	596200	4772	62	0	4510	58	0	0	0.9	563381
Sorghum	Tanzania	1999	659041	4650	125	0	3976	107	0	0	0.9	563521
Sorghum	Tanzania	2000	736083	5399	135	0	4428	111	0	0	0.8	603760
Sorghum	Tanzania	2001	690822	4585	77	0	4587	77	0	0	1.0	691149
Sorghum	Tanzania	2002	655275	4334	83	0	4217	81	0	0	1.0	637578
Sorghum	Tanzania	2003	449590	10121	186	0	4477	82	0	0	0.4	198870
Sorghum	Tanzania	2004	696313	4583	102	0	4313	96	0	0	0.9	655193
Sorghum	Tanzania	2005	736659	4849	81	0	4803	80	0	0	1.0	729675

			Harvested	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	area (ha)	Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i	(m^3/ha)	(tonne/ha)	(tonne)
Sorghum	Tanzania	2006	686781	3515	116	0	3952	130	0	0	1.1	772183
Sorghum	Tanzania	2007	817946	3804	46	0	4517	55	0	0	1.2	971196
Sorghum	Tanzania	2008	561699	4365	84	0	4296	82	0	0	1.0	552771
Sorghum	Tanzania	2009	870738	5660	102	0	4611	83	0	0	0.8	709453
Sorghum	Tanzania	2010	614659	3501	61	0	4577	80	0	0	1.3	803675
Sorghum	Tanzania	2011	808348	4699	110	0	4837	114	0	0	1.0	832031
Sorghum	Tanzania	2012	825808	4729	105	0	4960	110	0	0	1.0	866133
Sorghum	Tanzania	2013	705632	4379	95	0	5201	112	0	0	1.2	838140
Sorghum	Tanzania	2014	851478	4889	118	0	5310	128	0	0	1.1	924769
Sorghum	Tanzania	2015	745446	5040	147	0	4841	141	0	0	1.0	715997
Sorghum	Uganda	1986	207927	3493	7	0	4757	10	0	0	1.4	283191
Sorghum	Uganda	1987	203218	3018	6	0	4689	10	0	0	1.6	315685
Sorghum	Uganda	1988	233355	3237	6	0	4844	9	0	0	1.5	349234
Sorghum	Uganda	1989	231240	3190	6	0	4791	9	0	0	1.5	347331
Sorghum	Uganda	1990	237257	3075	6	0	4641	9	0	0	1.5	358103
Sorghum	Uganda	1991	245323	3307	7	0	4902	10	0	0	1.5	363624
Sorghum	Uganda	1992	248468	3308	8	0	4978	13	0	0	1.5	373892
Sorghum	Uganda	1993	255389	3182	7	0	4779	11	0	0	1.5	383584
Sorghum	Uganda	1994	260280	2998	8	0	4584	12	0	0	1.5	397905
Sorghum	Uganda	1995	266113	3134	8	0	4723	12	0	0	1.5	401066
Sorghum	Uganda	1996	271458	4306	8	0	4735	9	0	0	1.1	298509
Sorghum	Uganda	1997	276466	4701	11	0	5008	11	0	0	1.1	294511
Sorghum	Uganda	1998	280473	3233	7	0	4865	11	0	0	1.5	422147
Sorghum	Uganda	1999	275216	2937	7	0	4598	11	0	0	1.6	430876
Sorghum	Uganda	2000	280473	3456	9	0	4473	12	0	0	1.3	363014
Sorghum	Uganda	2001	282246	3159	7	0	4753	11	0	0	1.5	424695
Sorghum	Uganda	2002	285481	2974	7	0	4461	10	0	0	1.5	428162

			Harvested	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	area (ha)	Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i	(m^3/ha)	(tonne/ha)	(tonne)
Sorghum	Uganda	2003	290490	2975	5	0	4320	7	0	0	1.5	421711
Sorghum	Uganda	2004	285481	3255	7	0	4557	10	0	0	1.4	399675
Sorghum	Uganda	2005	294497	2899	7	0	4428	10	0	0	1.5	449759
Sorghum	Uganda	2006	308367	3308	7	0	4728	10	0	0	1.4	440708
Sorghum	Uganda	2007	314530	3122	6	0	4550	9	0	0	1.5	458351
Sorghum	Uganda	2008	321542	4210	10	0	4489	11	0	0	1.1	342864
Sorghum	Uganda	2009	340127	4125	11	0	4545	12	0	0	1.1	374711
Sorghum	Uganda	2010	355600	4319	8	0	4771	9	0	0	1.1	392823
Sorghum	Uganda	2011	364615	4293	11	0	5156	13	0	0	1.2	437905
Sorghum	Uganda	2012	373630	6032	15	0	5460	14	0	0	0.9	338209
Sorghum	Uganda	2013	350591	6507	13	0	5561	11	0	0	0.9	299586
Sorghum	Uganda	2014	373630	6179	21	0	5109	17	0	0	0.8	308930
Sorghum	Uganda	2015	371798	6121	19	0	5248	16	0	0	0.9	318774
Groundnuts	Burundi	1986	15000	5159	5	0	4815	5	0	0	0.9	14000
Groundnuts	Burundi	1987	15500	4992	6	0	4637	6	0	0	0.9	14400
Groundnuts	Burundi	1988	15500	5216	6	0	4846	6	0	0	0.9	14400
Groundnuts	Burundi	1989	15000	5447	6	0	5048	6	0	0	0.9	13900
Groundnuts	Burundi	1990	14000	4771	5	0	4635	5	0	0	1.0	13600
Groundnuts	Burundi	1991	15000	4904	7	0	4544	6	0	0	0.9	13900
Groundnuts	Burundi	1992	12302	3978	6	0	4592	7	0	0	1.2	14200
Groundnuts	Burundi	1993	10443	3949	5	0	5257	6	0	0	1.3	13900
Groundnuts	Burundi	1994	12000	5656	11	0	4684	9	0	0	0.8	9938
Groundnuts	Burundi	1995	14000	5099	7	0	4603	6	0	0	0.9	12639
Groundnuts	Burundi	1996	12000	5905	9	0	4921	7	0	0	0.8	10000
Groundnuts	Burundi	1997	13000	4894	8	0	4141	7	0	0	0.8	11000
Groundnuts	Burundi	1998	12000	6309	7	0	4732	5	0	0	0.8	9000
Groundnuts	Burundi	1999	13000	5832	11	0	4434	8	0	0	0.8	9883

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Groundnuts	Burundi	2000	12000	6383	11	0	4662	8	0	0	0.7	8764
Groundnuts	Burundi	2001	12500	6471	11	0	4556	8	0	0	0.7	8800
Groundnuts	Burundi	2002	13000	6186	7	0	4378	5	0	0	0.7	9200
Groundnuts	Burundi	2003	13200	5776	8	0	4113	6	0	0	0.7	9400
Groundnuts	Burundi	2004	12108	6082	9	0	4551	7	0	0	0.7	9060
Groundnuts	Burundi	2005	13000	5475	9	0	4085	7	0	0	0.7	9700
Groundnuts	Burundi	2006	12500	5941	10	0	4377	7	0	0	0.7	9209
Groundnuts	Burundi	2007	13000	6070	6	0	4436	5	0	0	0.7	9500
Groundnuts	Burundi	2008	12900	6213	7	0	4431	5	0	0	0.7	9200
Groundnuts	Burundi	2009	15000	8544	11	0	4557	6	0	0	0.5	8000
Groundnuts	Burundi	2010	18000	11028	12	0	4595	5	0	0	0.4	7500
Groundnuts	Burundi	2011	20000	12204	20	0	5492	9	0	0	0.5	9000
Groundnuts	Burundi	2012	21673	11629	21	0	5346	10	0	0	0.5	9963
Groundnuts	Burundi	2013	23130	13327	21	0	5906	9	0	0	0.4	10250
Groundnuts	Burundi	2014	16708	9492	20	0	5281	11	0	0	0.6	9296
Groundnuts	Burundi	2015	20147	6391	25	0	4811	19	0	0	0.8	15167
Groundnuts	Congo_DR	1986	562449	4660	17	0	3495	13	0	0	0.7	421836
Groundnuts	Congo_DR	1987	537242	4164	15	0	3376	12	0	0	0.8	435545
Groundnuts	Congo_DR	1988	554819	4302	12	0	3548	10	0	0	0.8	457532
Groundnuts	Congo_DR	1989	591817	4306	17	0	3599	14	0	0	0.8	494604
Groundnuts	Congo_DR	1990	658676	4244	16	0	3543	13	0	0	0.8	549929
Groundnuts	Congo_DR	1991	677154	4135	14	0	3350	12	0	0	0.8	548723
Groundnuts	Congo_DR	1992	703080	4234	17	0	3430	14	0	0	0.8	569679
Groundnuts	Congo_DR	1993	762134	4083	18	0	3278	14	0	0	0.8	611752
Groundnuts	Congo_DR	1994	718922	4371	15	0	3674	13	0	0	0.8	604314
Groundnuts	Congo_DR	1995	497369	4582	42	0	3582	33	0	0	0.8	388747
Groundnuts	Congo_DR	1996	474031	4372	39	0	3516	31	0	0	0.8	381169

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Groundnuts	Congo_DR	1997	508252	4214	34	0	3298	27	0	0	0.8	397833
Groundnuts	Congo_DR	1998	510373	4548	31	0	3608	25	0	0	0.8	404966
Groundnuts	Congo_DR	1999	487193	4840	30	0	3865	24	0	0	0.8	389106
Groundnuts	Congo_DR	2000	432887	4535	38	0	3802	32	0	0	0.8	362897
Groundnuts	Congo_DR	2001	449337	4503	32	0	3604	26	0	0	0.8	359651
Groundnuts	Congo_DR	2002	440280	4653	31	0	3685	25	0	0	0.8	348725
Groundnuts	Congo_DR	2003	448459	4384	28	0	3470	22	0	0	0.8	354904
Groundnuts	Congo_DR	2004	461680	4695	32	0	3695	25	0	0	0.8	363328
Groundnuts	Congo_DR	2005	453011	4376	35	0	3482	28	0	0	0.8	360459
Groundnuts	Congo_DR	2006	472517	4620	28	0	3598	22	0	0	0.8	367993
Groundnuts	Congo_DR	2007	472978	5153	23	0	4017	18	0	0	0.8	368696
Groundnuts	Congo_DR	2008	452122	4797	28	0	3854	23	0	0	0.8	363259
Groundnuts	Congo_DR	2009	473304	4536	33	0	3539	25	0	0	0.8	369254
Groundnuts	Congo_DR	2010	450382	3908	34	0	3286	28	0	0	0.8	378721
Groundnuts	Congo_DR	2011	430479	4626	38	0	4116	34	0	0	0.9	383022
Groundnuts	Congo_DR	2012	449922	5067	38	0	4168	31	0	0	0.8	370125
Groundnuts	Congo_DR	2013	430207	4644	43	0	3847	36	0	0	0.8	356359
Groundnuts	Congo_DR	2014	498696	4773	46	0	4007	39	0	0	0.8	418736
Groundnuts	Congo_DR	2015	490202	4421	47	0	3810	40	0	0	0.9	422419
Groundnuts	Egypt	1986	9660	242	412	3553	526	896	7723	8246	2.2	21000
Groundnuts	Egypt	1987	10500	248	396	3577	543	868	7835	8453	2.2	23000
Groundnuts	Egypt	1988	12600	244	334	3066	619	848	7786	8446	2.5	32000
Groundnuts	Egypt	1989	13503	279	391	3719	591	829	7879	8516	2.1	28610
Groundnuts	Egypt	1990	12327	263	401	3675	559	853	7827	8451	2.1	26255
Groundnuts	Egypt	1991	12268	209	384	3483	467	857	7777	8284	2.2	27395
Groundnuts	Egypt	1992	12961	257	355	3313	601	831	7757	8374	2.3	30350
Groundnuts	Egypt	1993	46721	271	363	3327	616	825	7569	8178	2.3	106304

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Groundnuts	Egypt	1994	40721	149	298	2709	429	857	7779	8301	2.9	116946
Groundnuts	Egypt	1995	44579	158	297	2705	464	870	7928	8439	2.9	130642
Groundnuts	Egypt	1996	43589	127	300	2735	363	859	7843	8306	2.9	124981
Groundnuts	Egypt	1997	42951	151	303	2680	442	889	7860	8316	2.9	125988
Groundnuts	Egypt	1998	43609	122	287	2555	371	870	7754	8230	3.0	132351
Groundnuts	Egypt	1999	59205	92	287	2554	280	877	7799	8190	3.1	180771
Groundnuts	Egypt	2000	60329	86	280	2512	267	870	7794	8194	3.1	187169
Groundnuts	Egypt	2001	63347	173	258	2348	561	834	7600	8244	3.2	205066
Groundnuts	Egypt	2002	59288	140	260	2361	451	839	7609	8116	3.2	191037
Groundnuts	Egypt	2003	61868	139	257	2412	439	813	7637	8118	3.2	195869
Groundnuts	Egypt	2004	60725	139	262	2445	440	827	7723	8275	3.2	191846
Groundnuts	Egypt	2005	62260	144	265	2416	462	848	7743	8299	3.2	199560
Groundnuts	Egypt	2006	55550	135	255	2302	447	846	7624	8104	3.3	183970
Groundnuts	Egypt	2007	65250	156	246	2231	521	820	7441	7946	3.3	217580
Groundnuts	Egypt	2008	61401	116	246	2252	395	836	7661	8174	3.4	208835
Groundnuts	Egypt	2009	63780	90	276	2511	279	857	7796	8274	3.1	198012
Groundnuts	Egypt	2010	66764	110	272	2505	335	826	7612	8075	3.0	202906
Groundnuts	Egypt	2011	65050	76	317	3075	241	1005	9764	10209	3.2	206574
Groundnuts	Egypt	2012	62468	126	283	2897	416	931	9527	10089	3.3	205419
Groundnuts	Egypt	2013	65000	119	310	3053	382	996	9818	10380	3.2	209000
Groundnuts	Egypt	2014	57321	139	314	2994	444	1005	9581	10203	3.2	183438
Groundnuts	Egypt	2015	60107	125	308	2953	412	1011	9689	10236	3.3	197246
Groundnuts	Eritrea	1993	5000	3435	0	0	2366	0	0	0	0.7	3444
Groundnuts	Eritrea	1994	290	6537	0	0	4113	0	0	0	0.6	182
Groundnuts	Eritrea	1995	313									
Groundnuts	Eritrea	1996	229	5084	0	0	4549	0	0	0	0.9	205
Groundnuts	Eritrea	1997	258	3273	0	0	3060	0	0	0	0.9	241

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne) Green	Sb_cr	Sb_i	CWU (m^3/ha) Green	Sb_cr	Sb_i	Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Groundnuts	Eritrea	1998	238									
Groundnuts	Eritrea	1999	288	5021	0	0	4667	0	0	0	0.9	267
Groundnuts	Eritrea	2000	358	2227	0	0	2020	0	0	0	0.9	325
Groundnuts	Eritrea	2001	170	4312	0	0	4181	0	0	0	1.0	165
Groundnuts	Eritrea	2002	829	2422	0	0	2535	0	0	0	1.0	868
Groundnuts	Eritrea	2003	181	5122	0	0	4098	0	0	0	0.8	145
Groundnuts	Eritrea	2004	193									
Groundnuts	Eritrea	2005	316	5672	0	0	5378	0	0	0	0.9	300
Groundnuts	Eritrea	2006	287	3709	0	0	3609	0	0	0	1.0	279
Groundnuts	Eritrea	2007	3438	2103	0	0	2657	0	0	0	1.3	4345
Groundnuts	Eritrea	2009	251									
Groundnuts	Eritrea	2010	270	4413	0	0	3223	0	0	0	0.7	197
Groundnuts	Eritrea	2013	266	3961	0	0	3241	0	0	0	0.8	217
Groundnuts	Eritrea	2014	348									
Groundnuts	Ethiopia PDR	1987	4828									
Groundnuts	Ethiopia PDR	1988	10007	2251	0	0	3032	0	0	0	1.3	13482
Groundnuts	Ethiopia PDR	1989	15646	705	0	0	1875	0	0	0	2.7	41638
Groundnuts		1991	5832	2318	0	0	2543	0	0	0	1.1	6398
Groundnuts	Ethiopia PDR	1992	5191	4994	0	0	6272	0	0	0	1.3	6518
Groundnuts	Kenya	1986	11531	6208	102	0	4815	79	0	0	0.8	8944
Groundnuts	Kenya	1987	14127	7345	120	0	4794	78	0	0	0.7	9220
Groundnuts	Kenya	1988	13216	7719	112	0	5121	74	0	0	0.7	8768
Groundnuts	Kenya	1989	18466	8169	102	0	5124	64	0	0	0.6	11583
Groundnuts	Kenya	1990	17264	14155	266	0	4869	92	0	0	0.3	5939
Groundnuts	Kenya	1991	21655	6437	92	0	5009	72	0	0	0.8	16850
Groundnuts	Kenya	1992	16916	7194	147	0	4645	95	0	0	0.6	10921
Groundnuts	Kenya	1993	20110	8320	149	0	4578	82	0	0	0.6	11065

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Groundnuts	Kenya	1994	16796	6141	110	0	4537	81	0	0	0.7	12409
Groundnuts	Kenya	1995	18163	6784	117	0	4499	78	0	0	0.7	12045
Groundnuts	Kenya	1996	16509	4713	50	0	4893	52	0	0	1.0	17139
Groundnuts	Kenya	1997	18015	7724	91	0	4989	59	0	0	0.6	11636
Groundnuts	Kenya	1998	10173	3128	34	0	4927	54	0	0	1.6	16022
Groundnuts	Kenya	1999	17582	2511	40	0	4527	73	0	0	1.8	31699
Groundnuts	Kenya	2000	15351	2413	35	0	4541	65	0	0	1.9	28888
Groundnuts	Kenya	2001	20391	2458	30	0	4630	56	0	0	1.9	38407
Groundnuts	Kenya	2002	15506	3250	53	0	4190	69	0	0	1.3	19991
Groundnuts	Kenya	2003	18773	3932	28	0	4445	31	0	0	1.1	21223
Groundnuts	Kenya	2004	20391	4339	53	0	4607	57	0	0	1.1	21649
Groundnuts	Kenya	2005	18773	3891	44	0	4520	51	0	0	1.2	21804
Groundnuts	Kenya	2006	16481	3061	47	0	4550	69	0	0	1.5	24497
Groundnuts	Kenya	2007	20041	3158	28	0	4803	42	0	0	1.5	30475
Groundnuts	Kenya	2008	19153	5083	69	0	4597	63	0	0	0.9	17321
Groundnuts	Kenya	2009	18638	3843	69	0	4454	80	0	0	1.2	21603
Groundnuts	Kenya	2010	18663	7744	98	0	4732	60	0	0	0.6	11405
Groundnuts	Kenya	2011	13626	5265	69	0	5031	66	0	0	1.0	13021
Groundnuts	Kenya	2012	16536	3590	33	0	5763	53	0	0	1.6	26543
Groundnuts	Kenya	2013	17154	3817	40	0	5835	62	0	0	1.5	26225
Groundnuts	Kenya	2014	21712	2103	28	0	5506	74	0	0	2.6	56835
Groundnuts	Kenya	2015	8696	1846	23	0	5782	72	0	0	3.1	27243
Groundnuts	Rwanda	1986	22400	5942	0	0	4563	0	0	0	0.8	17200
Groundnuts	Rwanda	1987	21800	5726	0	0	4379	0	0	0	0.8	16670
Groundnuts	Rwanda	1988	20000	6248	0	0	4686	0	0	0	0.8	15000
Groundnuts	Rwanda	1989	16400	7759	0	0	4637	0	0	0	0.6	9800
Groundnuts	Rwanda	1990	9311	5064	0	0	4501	0	0	0	0.9	8276

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne) Green	Sb_cr	Sb_i	CWU (m^3/ha) Green	Sb_cr	Sb_i	Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Groundnuts	Rwanda	1991	10000	6274	0	0	4392	0	0	0	0.7	7000
Groundnuts	Rwanda	1992	8500	6072	0	0	4286	0	0	0	0.7	6000
Groundnuts	Rwanda	1993	11000	6755	0	0	4913	0	0	0	0.7	8000
Groundnuts	Rwanda	1994	28000	7549	0	0	4368	0	0	0	0.6	16200
Groundnuts	Rwanda	1995	13000	6805	0	0	4345	0	0	0	0.6	8300
Groundnuts	Rwanda	1996	11000	7101	0	0	4661	0	0	0	0.7	7220
Groundnuts	Rwanda	1997	9916	7628	0	0	3884	0	0	0	0.5	5049
Groundnuts	Rwanda	1998	7045	6638	0	0	4600	0	0	0	0.7	4882
Groundnuts	Rwanda	1999	7397	6038	0	0	3841	0	0	0	0.6	4706
Groundnuts	Rwanda	2000	13463	8249	0	0	4309	0	0	0	0.5	7032
Groundnuts	Rwanda	2001	14767	6546	0	0	4271	0	0	0	0.7	9635
Groundnuts	Rwanda	2002	15900	6319	0	0	4139	0	0	0	0.7	10414
Groundnuts	Rwanda	2003	16803	6339	0	0	3876	0	0	0	0.6	10275
Groundnuts	Rwanda	2004	18883	7567	0	0	4322	0	0	0	0.6	10785
Groundnuts	Rwanda	2005	16011	6276	0	0	3958	0	0	0	0.6	10099
Groundnuts	Rwanda	2006	16196	7579	0	0	4221	0	0	0	0.6	9020
Groundnuts	Rwanda	2007	17000	7150	0	0	4173	0	0	0	0.6	9921
Groundnuts	Rwanda	2008	20898	7725	0	0	4241	0	0	0	0.5	11472
Groundnuts	Rwanda	2009	23048	6641	0	0	4423	0	0	0	0.7	15353
Groundnuts	Rwanda	2010	20558	6326	0	0	4422	0	0	0	0.7	14369
Groundnuts	Rwanda	2011	22846	7755	0	0	5009	0	0	0	0.6	14756
Groundnuts	Rwanda	2012	20638	9382	0	0	5291	0	0	0	0.6	11638
Groundnuts	Rwanda	2013	24160	9128	0	0	5446	0	0	0	0.6	14414
Groundnuts	Rwanda	2014	27513	12550	0	0	4644	0	0	0	0.4	10181
Groundnuts	Rwanda	2015	24353	7743	0	0	4587	0	0	0	0.6	14425
Groundnuts	South Sudan	2014	253988	7715	855	0	4466	495	0	0	0.6	147008
Groundnuts	South Sudan	2015	146338	7521	992	0	4465	589	0	0	0.6	86867

			Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Crops	Countries	Year		Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Groundnuts	Sudan (current)	2014	2469382	3709	1088	869	3486	1023	817	1012	0.9	2320843
Groundnuts	Sudan (current)	2015	1609072	3206	1494	1110	2926	1364	1013	1316	0.9	1468524
Groundnuts	Sudan (former)	1986	592514	4042	911	481	3161	712	376	468	0.8	463444
Groundnuts	Sudan (former)	1987	623697	3442	1089	616	2873	909	514	639	0.8	520481
Groundnuts	Sudan (former)	1988	748216	3742	730	420	3515	686	395	483	0.9	702763
Groundnuts	Sudan (former)	1989	523496	7096	1629	876	3503	804	433	553	0.5	258471
Groundnuts	Sudan (former)	1990	230959	4403	1391	654	2935	927	436	546	0.7	153957
Groundnuts	Sudan (former)	1991	250824	3645	840	464	3316	764	422	496	0.9	228151
Groundnuts	Sudan (former)	1992	546323	3754	1078	586	3191	916	498	588	0.9	464403
Groundnuts	Sudan (former)	1993	792575	5326	1222	674	3432	787	434	536	0.6	510674
Groundnuts	Sudan (former)	1994	930473	4061	770	439	3651	692	395	498	0.9	836584
Groundnuts	Sudan (former)	1995	1225526	4606	983	603	3415	729	447	567	0.7	908583
Groundnuts	Sudan (former)	1996	1036354	3539	703	475	3382	672	454	583	1.0	990313
Groundnuts	Sudan (former)	1997	1670632	4438	880	572	3436	682	443	561	0.8	1293643
Groundnuts	Sudan (former)	1998	1582440	5638	1134	708	3244	653	407	511	0.6	910466
Groundnuts	Sudan (former)	1999	1694451	4863	863	523	3514	624	378	490	0.7	1224517
Groundnuts	Sudan (former)	2000	1632382	4923	956	566	3424	665	394	528	0.7	1135449
Groundnuts	Sudan (former)	2001	1742226	4888	986	609	3365	678	419	531	0.7	1199237
Groundnuts	Sudan (former)	2002	1419209	2960	693	417	3122	731	440	560	1.1	1496771
Groundnuts	Sudan (former)	2003	1190788	4326	792	523	3444	630	416	525	0.8	948107
Groundnuts	Sudan (former)	2004	1176679	4046	897	525	3272	726	425	555	0.8	951655
Groundnuts	Sudan (former)	2005	1080839	5544	1194	760	3286	708	450	557	0.6	640557
Groundnuts	Sudan (former)	2006	659187	3228	692	425	3318	711	437	549	1.0	677587
Groundnuts	Sudan (former)	2007	684017	3705	617	449	3593	599	435	550	1.0	663426
Groundnuts	Sudan (former)	2008	1063241	4250	846	498	3503	698	410	543	0.8	876381
Groundnuts	Sudan (former)	2009	1047364	2803	753	380	3076	827	417	532	1.1	1149231
Groundnuts	Sudan (former)	2010	1309956	4641	1041	581	3315	743	415	518	0.7	935522

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i			
Groundnuts	Sudan (former)	2011	1855093	4585	1162	601	3713	941	487	615	0.8	1502383
Groundnuts	Sudan (former)	2012	1785106	5482	1305	769	3959	942	556	673	0.7	1289057
Groundnuts	Sudan (former)	2013	2449446	4125	1014	543	3594	883	473	584	0.9	2134405
Groundnuts	Tanzania	1986	98516	8490	75	0	5119	46	0	0	0.6	59403
Groundnuts	Tanzania	1987	100322	8377	61	0	5031	37	0	0	0.6	60252
Groundnuts	Tanzania	1988	98909	8659	90	0	4846	50	0	0	0.6	55353
Groundnuts	Tanzania	1989	110492	10018	83	0	5015	42	0	0	0.5	55307
Groundnuts	Tanzania	1990	116073	9688	74	0	5040	38	0	0	0.5	60386
Groundnuts	Tanzania	1991	133822	9701	90	0	5104	47	0	0	0.5	70411
Groundnuts	Tanzania	1992	122598	9565	94	0	5127	50	0	0	0.5	65712
Groundnuts	Tanzania	1993	128007	9542	86	0	5247	47	0	0	0.5	70392
Groundnuts	Tanzania	1994	82049	6586	90	0	4683	64	0	0	0.7	58342
Groundnuts	Tanzania	1995	113000	7487	128	0	4844	83	0	0	0.6	73108
Groundnuts	Tanzania	1996	110547	6835	125	0	4460	82	0	0	0.7	72136
Groundnuts	Tanzania	1997	127147	7084	167	0	4171	99	0	0	0.6	74860
Groundnuts	Tanzania	1998	134829	9114	94	0	4935	51	0	0	0.5	73000
Groundnuts	Tanzania	1999	147946	8858	178	0	4447	89	0	0	0.5	74268
Groundnuts	Tanzania	2000	107943	9149	226	0	4490	111	0	0	0.5	52974
Groundnuts	Tanzania	2001	246564	5638	84	0	4828	72	0	0	0.9	211143
Groundnuts	Tanzania	2002	346341	4350	78	0	4454	79	0	0	1.0	354574
Groundnuts	Tanzania	2003	370612	5071	80	0	4640	73	0	0	0.9	339103
Groundnuts	Tanzania	2004	371934	4992	88	0	4507	80	0	0	0.9	335836
Groundnuts	Tanzania	2005	405784	6526	107	0	4793	79	0	0	0.7	298003
Groundnuts	Tanzania	2006	456306	4956	132	0	4084	109	0	0	0.8	375970
Groundnuts	Tanzania	2007	560000	6751	67	0	4919	49	0	0	0.7	408058
Groundnuts	Tanzania	2008	425023	5808	97	0	4531	75	0	0	0.8	331585
Groundnuts	Tanzania	2009	428550	5748	93	0	4786	77	0	0	0.8	356809

			Harvested	WF (m^3/tonne)			CWU (m^3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	area (ha)	Green	Sb_cr	Sb_i	Green	Sb_cr	Sb_i	(m^3/ha)	(tonne/ha)	(tonne)
Groundnuts	Tanzania	2010	426948	4216	74	0	4640	81	0	0	1.1	469900
Groundnuts	Tanzania	2011	637916	4701	102	0	4997	109	0	0	1.1	678128
Groundnuts	Tanzania	2012	725202	4698	116	0	5206	128	0	0	1.1	803681
Groundnuts	Tanzania	2013	669965	4480	97	0	5469	118	0	0	1.2	817843
Groundnuts	Tanzania	2014	1618332	5401	106	0	5608	110	0	0	1.0	1680345
Groundnuts	Tanzania	2015	1342583	3782	102	0	5222	140	0	0	1.4	1853411
Groundnuts	Uganda	1986	176877	7648	16	0	5137	11	0	0	0.7	118792
Groundnuts	Uganda	1987	148749	5949	12	0	4907	10	0	0	0.8	122693
Groundnuts	Uganda	1988	174342	6819	14	0	5198	10	0	0	0.8	132900
Groundnuts	Uganda	1989	190335	6762	14	0	5207	11	0	0	0.8	146563
Groundnuts	Uganda	1990	186219	5797	13	0	4973	11	0	0	0.9	159758
Groundnuts	Uganda	1991	178778	6575	13	0	5265	11	0	0	0.8	143150
Groundnuts	Uganda	1992	184882	6734	17	0	5380	13	0	0	0.8	147710
Groundnuts	Uganda	1993	187946	6275	14	0	5144	11	0	0	0.8	154068
Groundnuts	Uganda	1994	185148	6573	16	0	4984	12	0	0	0.8	140391
Groundnuts	Uganda	1995	192937	6719	16	0	5044	12	0	0	0.8	144853
Groundnuts	Uganda	1996	195951	7945	17	0	5096	11	0	0	0.6	125695
Groundnuts	Uganda	1997	197961	7704	20	0	5240	13	0	0	0.7	134653
Groundnuts	Uganda	1998	200976	7558	16	0	5291	11	0	0	0.7	140683
Groundnuts	Uganda	1999	196121	7015	17	0	4918	12	0	0	0.7	137507
Groundnuts	Uganda	2000	199899	6836	19	0	4781	14	0	0	0.7	139813
Groundnuts	Uganda	2001	209015	7169	16	0	5032	11	0	0	0.7	146725
Groundnuts	Uganda	2002	211953	6700	14	0	4701	10	0	0	0.7	148711
Groundnuts	Uganda	2003	217054	4505	7	0	4588	7	0	0	1.0	221073
Groundnuts	Uganda	2004	222078	4780	10	0	4780	10	0	0	1.0	222078
Groundnuts	Uganda	2005	226098	4759	12	0	4759	12	0	0	1.0	226118
Groundnuts	Uganda	2006	231039	4994	11	0	4995	11	0	0	1.0	231087

Crops	Countries	Year	Harvested area (ha)	WF (m^3/tonne) Green	WF (m^3/tonne) Sb_cr	WF (m^3/tonne) Sb_i	CWU (m^3/ha) Green	CWU (m^3/ha) Sb_cr	CWU (m^3/ha) Sb_i	Irr_appl (m^3/ha)	Yield (tonne/ha)	Prod (tonne)
Groundnuts	Uganda	2007	236146	4868	9	0	4868	9	0	0	1.0	236146
Groundnuts	Uganda	2008	281366	5862	14	0	4807	11	0	0	0.8	230756
Groundnuts	Uganda	2009	370667	6783	19	0	4742	14	0	0	0.7	259144
Groundnuts	Uganda	2010	386078	7093	14	0	4991	10	0	0	0.7	271631
Groundnuts	Uganda	2011	409978	6693	19	0	5387	15	0	0	0.8	329985
Groundnuts	Uganda	2012	423054	8347	22	0	5850	16	0	0	0.7	296511
Groundnuts	Uganda	2013	422049	8469	20	0	5950	14	0	0	0.7	296498
Groundnuts	Uganda	2014	404464	7481	28	0	5574	21	0	0	0.7	301371
Groundnuts	Uganda	2015	396115	9483	37	0	5602	22	0	0	0.6	233981

Appendix II. AquaCrop simulation results at deficit irrigation & mulching (scenario) condition

			Harvested	WF (m3/tonne)			CWU (m3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	Area_ha	Green	Sb_cr	Sb_i	green	Sb_cr	Sb_i	(m3/ha)	(tonne/ha)	(tonne)
Rice	Burundi	2011	14100	212	400	3069	451	850	6517	6978	2.1	128945
Rice	Burundi	2012	15355	218	397	3035	467	852	6514	7013	2.1	133615
Rice	Burundi	2013	10835	207	384	2884	459	853	6402	6844	2.2	123332
Rice	Burundi	2014	11865	235	370	2832	525	828	6340	6794	2.2	146070
Rice	Burundi	2015	17123	180	372	2829	410	849	6450	6830	2.3	140012
Rice	Congo_DR	2011	296520	143	420	3173	296	874	6598	7013	2.1	132622
Rice	Congo_DR	2012	296932	169	414	3183	345	842	6478	6854	2.0	135884
Rice	Congo_DR	2013	301843	121	497	3881	258	1062	8298	8707	2.1	139109
Rice	Congo_DR	2014	240529	194	448	3638	429	991	8051	8460	2.2	138232
Rice	Congo_DR	2015	787937	186	495	3872	403	1070	8377	8886	2.2	140609
Rice	Egypt	2011	593185	213	512	3788	462	1110	8205	8723	2.2	124147
Rice	Egypt	2012	620286	194	488	3766	429	1079	8319	8779	2.2	132772
Rice	Egypt	2013	640101	5312	0	0	2578	0	0	0	0.5	2427
Rice	Egypt	2014	573704	4036	0	0	4014	0	0	0	1.0	288
Rice	Egypt	2015	510853	33	0	0	3711	0	0	0	112.7	35303
Rice	Ethiopia	2011	30649	4976	0	0	4298	0	0	0	0.9	198
Rice	Ethiopia	2012	41811	717	0	0	3396	0	0	0	4.7	1224
Rice	Ethiopia	2013	58806	25	0	0	2701	0	0	0	109.8	26150
Rice	Ethiopia	2014	46832	5941	0	0	4134	0	0	0	0.7	200
Rice	Ethiopia	2015	45454	4180	0	0	2928	0	0	0	0.7	251
Rice	Kenya	2011	28031	3272	0	0	4114	0	0	0	1.3	214
Rice	Kenya	2012	30095	3306	0	0	2364	0	0	0	0.7	593
Rice	Kenya	2013	30392	4168	0	0	4175	0	0	0	1.0	181
Rice	Kenya	2014	28390	33	0	0	3671	0	0	0	112.1	21648
Rice	Kenya	2015	29438	7091	0	0	4784	0	0	0	0.7	213

			Harvested	WF (m3/tonne)			CWU (m3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	Area_ha	Green	Sb_cr	Sb_i	green	Sb_cr	Sb_i	(m3/ha)	(tonne/ha)	(tonne)
Rice	Rwanda	2011	7787	2931	0	0	3398	0	0	0	1.2	332
Rice	Rwanda	2012	7845	2902	0	0	2574	0	0	0	0.9	3049
Rice	Rwanda	2013	9375	17	0	0	4266	0	0	0	256.1	64200
Rice	Rwanda	2014	12685	2364	0	0	3326	0	0	0	1.4	379
Rice	Rwanda	2015	16119	3026	0	0	3225	0	0	0	1.1	283
Rice	Sudan (current)	2014	15618	56	0	0	3734	0	0	0	66.8	23224
Rice	Sudan (current)	2015	7560	20	0	0	2937	0	0	0	144.9	699584
Rice	Sudan (former)	2011	6720	2488	0	0	2674	0	0	0	1.1	10754
Rice	Sudan (former)	2012	7560	643	0	0	2520	0	0	0	3.9	61363
Rice	Sudan (former)	2013	7562	1182	0	0	2927	0	0	0	2.5	14447
Rice	Tanzania	2011	857971	6467	0	0	5530	0	0	0	0.9	4438
Rice	Tanzania	2012	612247	7990	129	0	4390	71	0	0	0.5	6334
Rice	Tanzania	2013	711529	10161	152	0	4434	67	0	0	0.4	6164
Rice	Tanzania	2014	733715	10258	147	0	4596	66	0	0	0.4	5920
Rice	Tanzania	2015	884908	11195	136	0	4732	58	0	0	0.4	7806
Rice	Uganda	2011	49211	19090	359	0	4241	80	0	0	0.2	3836
Rice	Uganda	2012	50304	8534	112	0	4531	59	0	0	0.5	11498
Rice	Uganda	2013	50851	9393	185	0	4325	85	0	0	0.5	7789
Rice	Uganda	2014	51945	11457	190	0	4216	70	0	0	0.4	7400
Rice	Uganda	2015	52096	7651	136	0	4105	73	0	0	0.5	9011
Maize	Burundi	2011	127999	13198	0	0	5023	0	0	0	0.4	7855
Maize	Burundi	2012	119478	11835	0	0	5272	0	0	0	0.4	10762
Maize	Burundi	2013	122870	15190	0	0	4511	0	0	0	0.3	8170
Maize	Burundi	2014	97242	9271	0	0	3873	0	0	0	0.4	10174
Maize	Burundi	2015	121179	10098	697	0	3904	270	0	0	0.4	98201
Maize	Congo_DR	2011	1478843	10202	863	0	3967	335	0	0	0.4	56900
Maize	Congo_DR	2012	1744996	5099	804	722	3544	559	502	634	0.7	1716290

Crops	Countries	Year	Harvested Area_ha	WF (m3/tonne)			CWU (m3/ha)			Irr_appl (m3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	green	Sb_cr	Sb_i			
Maize	Congo_DR	2013	1748633	5328	1125	909	3187	673	543	730	0.6	962340
Maize	Congo_DR	2014	1506881	5665	843	454	3055	455	245	327	0.5	319605
Maize	Congo_DR	2015	2620750	5100	1061	614	2762	574	333	420	0.5	337708
Maize	Egypt	2011	888198	4842	619	398	3370	431	277	351	0.7	520770
Maize	Egypt	2012	1041192	9892	1433	854	3356	486	290	377	0.3	177585
Maize	Egypt	2013	749890	6733	1275	664	2875	545	284	366	0.4	98638
Maize	Egypt	2014	1039088	5178	710	447	3158	433	273	329	0.6	152967
Maize	Egypt	2015	1060840	5438	952	578	3119	546	331	396	0.6	313298
Maize	Eritrea	2011	10131	7306	1083	682	3204	475	299	378	0.4	347528
Maize	Eritrea	2012	6206	5349	655	428	3443	421	275	353	0.6	598984
Maize	Eritrea	2013	13260	6342	810	588	3212	410	298	383	0.5	620770
Maize	Eritrea	2014	11125	4883	579	463	3191	378	302	400	0.7	677147
Maize	Eritrea	2015	4295	5943	737	576	3213	399	311	403	0.5	903239
Maize	Ethiopia	2011	2014886	7724	981	749	3044	387	295	379	0.4	623570
Maize	Ethiopia	2012	1977749	6695	736	550	3279	360	269	365	0.5	829904
Maize	Ethiopia	2013	2061785	6830	786	565	3248	374	269	374	0.5	776195
Maize	Ethiopia	2014	2084276	6900	847	617	3168	389	283	367	0.5	799951
Maize	Ethiopia	2015	2059996	4247	613	441	2945	425	306	401	0.7	984088
Maize	Kenya	2011	1741665	5820	622	512	3295	352	290	370	0.6	674227
Maize	Kenya	2012	1904490	5713	740	520	3138	406	286	382	0.5	646235
Maize	Kenya	2013	1793331	7723	980	739	3135	398	300	382	0.4	438798
Maize	Kenya	2014	1757916	4396	540	401	3182	391	290	375	0.7	477090
Maize	Kenya	2015	1548047	5174	537	472	3375	350	308	398	0.7	446211
Maize	Rwanda	2011	223414	5959	684	494	3309	380	274	372	0.6	590524
Maize	Rwanda	2012	253698	4136	639	382	3000	464	277	369	0.7	759642
Maize	Rwanda	2013	292326	6526	841	571	3141	405	275	346	0.5	630364
Maize	Rwanda	2014	233150	6932	984	609	3576	508	314	409	0.5	956789

			Harvested	WF (m3/tonne)			CWU (m3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	Area_ha	Green	Sb_cr	Sb_i	green	Sb_cr	Sb_i	(m3/ha)	(tonne/ha)	(tonne)
Maize	Rwanda	2015	241713	7941	1046	731	3924	517	361	447	0.5	882145
Maize	South Sudan	2014	278000	5681	828	525	3484	508	322	410	0.6	1502048
Maize	South Sudan	2015	133116	11343	75	0	4725	31	0	0	0.4	41037
Maize	Sudan (current)	2014	45200	11169	62	0	4547	25	0	0	0.4	40843
Maize	Sudan (current)	2015	38640	11770	92	0	4474	35	0	0	0.4	37595
Maize	Sudan (former)	2011	31080	13379	83	0	4580	28	0	0	0.3	37823
Maize	Sudan (former)	2012	30660	12782	74	0	4580	26	0	0	0.4	41590
Maize	Sudan (former)	2013	26880	13129	90	0	4727	32	0	0	0.4	48177
Maize	Tanzania	2011	2849296	12628	96	0	4673	36	0	0	0.4	45371
Maize	Tanzania	2012	3999959	12858	86	0	4881	33	0	0	0.4	48588
Maize	Tanzania	2013	4081799	8852	90	0	4316	44	0	0	0.5	40001
Maize	Tanzania	2014	3714174	9561	120	0	4537	57	0	0	0.5	53625
Maize	Tanzania	2015	3756208	8789	124	0	4116	58	0	0	0.5	51771
Maize	Uganda	2011	1063001	9368	170	0	3881	70	0	0	0.4	52675
Maize	Uganda	2012	1094001	12158	95	0	4414	34	0	0	0.4	48951
Maize	Uganda	2013	998848	12167	190	0	4241	66	0	0	0.3	51574
Maize	Uganda	2014	1103920	12522	232	0	4119	76	0	0	0.3	35502
Maize	Uganda	2015	1117044	7416	83	0	4367	49	0	0	0.6	145182
Sorghum	Burundi	2011	67800	16409	23	0	5099	7	0	0	0.3	6734
Sorghum	Burundi	2012	53523	17452	21	0	5510	7	0	0	0.3	7303
Sorghum	Burundi	2013	48292	12767	23	0	4916	9	0	0	0.4	6434
Sorghum	Burundi	2014	32254	6920	18	0	4080	11	0	0	0.6	11879
Sorghum	Burundi	2015	26528	6134	20	0	3221	10	0	0	0.5	295398
Sorghum	Congo_DR	2011	7072	5486	17	0	3100	10	0	0	0.6	303559
Sorghum	Congo_DR	2012	5305	5759	14	0	3294	8	0	0	0.6	317401
Sorghum	Congo_DR	2013	6149	5671	19	0	3314	11	0	0	0.6	345797
Sorghum	Congo_DR	2014	6197	5642	18	0	3310	11	0	0	0.6	386475

			Harvested	WF (m3/tonne)			CWU (m3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	Area_ha	Green	Sb_cr	Sb_i	green	Sb_cr	Sb_i	(m3/ha)	(tonne/ha)	(tonne)
Sorghum	Congo_DR	2015	6545	5559	16	0	3124	9	0	0	0.6	380510
Sorghum	Egypt	2011	150345	5628	20	0	3162	11	0	0	0.6	395002
Sorghum	Egypt	2012	136705	5433	20	0	3033	11	0	0	0.6	425482
Sorghum	Egypt	2013	135227	5761	17	0	3372	10	0	0	0.6	420832
Sorghum	Egypt	2014	142184	6064	50	0	3330	27	0	0	0.5	273069
Sorghum	Egypt	2015	143843	5793	45	0	3276	26	0	0	0.6	268045
Sorghum	Eritrea	2011	134662	5649	40	0	3121	22	0	0	0.6	280834
Sorghum	Eritrea	2012	93658	6027	36	0	3347	20	0	0	0.6	283481
Sorghum	Eritrea	2013	94288	6398	36	0	3615	20	0	0	0.6	275228
Sorghum	Eritrea	2014	216515	6001	44	0	3536	26	0	0	0.6	255097
Sorghum	Eritrea	2015	169724	6011	37	0	3366	21	0	0	0.6	251635
Sorghum	Ethiopia	2011	1957461	6165	36	0	3434	20	0	0	0.6	245233
Sorghum	Ethiopia	2012	1717846	5841	32	0	3261	18	0	0	0.6	250351
Sorghum	Ethiopia	2013	1904402	6210	37	0	3400	20	0	0	0.5	252788
Sorghum	Ethiopia	2014	1913872	5834	41	0	3239	23	0	0	0.6	251492
Sorghum	Ethiopia	2015	1920293	6123	33	0	3371	18	0	0	0.6	260110
Sorghum	Kenya	2011	241401	6775	27	0	3702	15	0	0	0.5	258441
Sorghum	Kenya	2012	235993	6364	32	0	3583	18	0	0	0.6	254548
Sorghum	Kenya	2013	201658	6038	38	0	3325	21	0	0	0.6	260616
Sorghum	Kenya	2014	209269	5214	40	0	3076	24	0	0	0.6	265716
Sorghum	Kenya	2015	167143	6072	43	0	3776	27	0	0	0.6	267651
Sorghum	Rwanda	2011	119355	6675	42	0	3842	24	0	0	0.6	258955
Sorghum	Rwanda	2012	97143	6138	50	0	3570	29	0	0	0.6	250190
Sorghum	Rwanda	2013	109121	6161	52	0	3636	31	0	0	0.6	294310
Sorghum	Rwanda	2014	137227	5704	53	0	3545	33	0	0	0.6	304631
Sorghum	Rwanda	2015	137696	367	670	4364	543	992	6460	6845	1.5	14299
Sorghum	South Sudan	2014	922584	374	652	4435	557	972	6610	7133	1.5	15650

Crops	Countries	Year	Harvested Area_ha	WF (m3/tonne) Green	Sb_cr	Sb_i	CWU (m3/ha) green	Sb_cr	Sb_i	Irr_appl (m3/ha)	Yield (tonne/ha)	Prod (tonne)
Sorghum	South Sudan	2015	548266	365	546	3787	629	941	6525	7100	1.7	21710
Sorghum	Sudan (current)	2014	9341441	421	630	4570	605	905	6563	7100	1.4	19394
Sorghum	Sudan (current)	2015	4380143	395	637	4538	570	919	6550	7108	1.4	17792
Sorghum	Sudan (former)	2011	7326403	317	617	4320	479	932	6533	6933	1.5	18552
Sorghum	Sudan (former)	2012	4678959	385	561	4112	610	889	6515	7066	1.6	20535
Sorghum	Sudan (former)	2013	6874776	408	556	4161	623	849	6351	6805	1.5	71320
Sorghum	Tanzania	2011	808348	228	456	3408	440	880	6573	7059	1.9	78537
Sorghum	Tanzania	2012	825808	238	457	3406	469	901	6710	7192	2.0	87830
Sorghum	Tanzania	2013	705632	191	471	3425	369	907	6603	6988	1.9	84038
Sorghum	Tanzania	2014	851478	225	476	3365	445	940	6644	7060	2.0	84796
Sorghum	Tanzania	2015	745446	185	444	3224	377	906	6582	6963	2.0	89030
Sorghum	Uganda	2011	364615	140	447	3197	289	920	6579	6915	2.1	121844
Sorghum	Uganda	2012	373630	131	441	3167	274	922	6620	6994	2.1	126127
Sorghum	Uganda	2013	350591	260	388	2916	564	843	6330	6820	2.2	137501
Sorghum	Uganda	2014	373630	215	390	2973	465	843	6421	6873	2.2	128038
Sorghum	Uganda	2015	371798	212	392	3047	448	832	6459	6884	2.1	131150
Millet	Burundi	2011	11200	9435	147	0	4043	63	0	0	0.4	7783
Millet	Burundi	2012	11000	6260	65	0	4450	46	0	0	0.7	11736
Millet	Burundi	2013	10500	10306	116	0	4588	51	0	0	0.4	8020
Millet	Burundi	2014	9684	4112	42	0	4534	47	0	0	1.1	11217
Millet	Burundi	2015	8288	3409	52	0	4220	64	0	0	1.2	21763
Millet	Congo_DR	2011	58500	3202	43	0	4240	57	0	0	1.3	20328
Millet	Congo_DR	2012	61943	3319	34	0	4228	44	0	0	1.3	25979
Millet	Congo_DR	2013	61943	4265	66	0	3839	60	0	0	0.9	13957
Millet	Congo_DR	2014	69230	5000	34	0	4038	28	0	0	0.8	15160
Millet	Congo_DR	2015	66264	5775	65	0	4208	47	0	0	0.7	14859
Millet	Eritrea	2011	26129	5270	53	0	4214	42	0	0	0.8	15011

Crops	Countries	Year	Harvested Area_ha	WF (m3/tonne) Green	Sb_cr	Sb_i	CWU (m3/ha) green	Sb_cr	Sb_i	Irr_appl (m3/ha)	Yield (tonne/ha)	Prod (tonne)
Millet	Eritrea	2012	8738	4151	60	0	4038	58	0	0	1.0	16034
Millet	Eritrea	2013	45242	4212	34	0	4472	36	0	0	1.1	21277
Millet	Eritrea	2014	46746	6919	88	0	4307	55	0	0	0.6	11922
Millet	Eritrea	2015	4174	5159	89	0	4075	70	0	0	0.8	14721
Millet	Ethiopia	2011	423756	10609	122	0	4133	48	0	0	0.4	7271
Millet	Ethiopia	2012	408151	7089	88	0	4712	58	0	0	0.7	9057
Millet	Ethiopia	2013	435076	4755	38	0	5036	40	0	0	1.1	17513
Millet	Ethiopia	2014	468736	4918	46	0	5094	48	0	0	1.0	17768
Millet	Ethiopia	2015	391177	2801	35	0	5170	64	0	0	1.8	40075
Millet	Kenya	2011	101348	2262	26	0	5266	61	0	0	2.3	20245
Millet	Kenya	2012	121888	8141	0	0	4209	0	0	0	0.5	11580
Millet	Kenya	2013	92564	7742	0	0	3973	0	0	0	0.5	11187
Millet	Kenya	2014	126211	8685	0	0	4370	0	0	0	0.5	10062
Millet	Kenya	2015	66312	10928	0	0	4413	0	0	0	0.4	6623
Millet	Rwanda	2011	5377	6683	0	0	4112	0	0	0	0.6	5729
Millet	Rwanda	2012	5400	8528	0	0	4003	0	0	0	0.5	4694
Millet	Rwanda	2013	5400	8486	0	0	4116	0	0	0	0.5	4122
Millet	Rwanda	2014	10651	8928	0	0	4525	0	0	0	0.5	5576
Millet	Rwanda	2015	6457	8954	0	0	3892	0	0	0	0.4	12172
Millet	South Sudan	2014	11303	9288	0	0	3978	0	0	0	0.4	5568
Millet	South Sudan	2015	7074	9349	0	0	4243	0	0	0	0.5	4992
Millet	Sudan (current)	2014	3834088	10143	0	0	3673	0	0	0	0.4	3591
Millet	Sudan (current)	2015	2033227	8983	0	0	4176	0	0	0	0.5	3275
Millet	Sudan (former)	2011	2792449	8306	0	0	3733	0	0	0	0.4	3324
Millet	Sudan (former)	2012	1595145	10394	0	0	4126	0	0	0	0.4	5344
Millet	Sudan (former)	2013	3132308	9070	0	0	3974	0	0	0	0.4	6470
Millet	Tanzania	2011	345063	8507	0	0	3736	0	0	0	0.4	6983

			Harvested	WF (m3/tonne)			CWU (m3/ha)			Irr_appl	Yield	Prod
Crops	Countries	Year	Area_ha	Green	Sb_cr	Sb_i	green	Sb_cr	Sb_i	(m3/ha)	(tonne/ha)	(tonne)
Millet	Tanzania	2012	248667	8683	0	0	3562	0	0	0	0.4	6894
Millet	Tanzania	2013	327855	10210	0	0	3909	0	0	0	0.4	7229
Millet	Tanzania	2014	261865	8677	0	0	3720	0	0	0	0.4	6864
Millet	Tanzania	2015	335448	10538	0	0	3929	0	0	0	0.4	6038
Millet	Uganda	2011	172119	9612	0	0	3765	0	0	0	0.4	6659
Millet	Uganda	2012	175121	10370	0	0	3818	0	0	0	0.4	7694
Millet	Uganda	2013	180124	8889	0	0	3972	0	0	0	0.4	10300
Millet	Uganda	2014	174900	8440	0	0	3957	0	0	0	0.5	9639
Millet	Uganda	2015	173932	10609	0	0	4689	0	0	0	0.4	10097
Groundnuts	Burundi	2011	20000	5588	73	0	4037	53	0	0	0.7	250256
Groundnuts	Burundi	2012	21673	6741	84	0	4278	53	0	0	0.6	235191
Groundnuts	Burundi	2013	23130	6547	88	0	4152	56	0	0	0.6	235872
Groundnuts	Burundi	2014	16708	8632	110	0	4349	55	0	0	0.5	204435
Groundnuts	Burundi	2015	20147	6257	120	0	3692	71	0	0	0.6	269236
Groundnuts	Congo_DR	2011	430479	8954	67	0	4431	33	0	0	0.5	277121
Groundnuts	Congo_DR	2012	449922	7626	94	0	4171	51	0	0	0.5	232448
Groundnuts	Congo_DR	2013	430207	7642	89	0	4442	52	0	0	0.6	249067
Groundnuts	Congo_DR	2014	498696	5631	71	0	4181	52	0	0	0.7	317057
Groundnuts	Congo_DR	2015	490202	6281	102	0	4624	75	0	0	0.7	469625
Groundnuts	Egypt	2011	65050	6068	119	0	4702	92	0	0	0.8	562003
Groundnuts	Egypt	2012	62468	5431	86	0	5068	80	0	0	0.9	625262
Groundnuts	Egypt	2013	65000	6937	100	0	5109	74	0	0	0.7	1191856
Groundnuts	Egypt	2014	57321	4625	89	0	4889	94	0	0	1.1	1419191
Groundnuts	Egypt	2015	60107	10194	15	0	4679	7	0	0	0.5	81196
Groundnuts	Eritrea	2013	266	7750	10	0	4502	6	0	0	0.6	86414
Groundnuts	Eritrea	2014	348	8835	11	0	4635	6	0	0	0.5	91460
Groundnuts	Kenya	2011	13626	9194	13	0	4756	7	0	0	0.5	98463

Crops	Countries	Year	Harvested Area_ha	WF (m3/tonne)			CWU (m3/ha)			Irr_appl (m3/ha)	Yield (tonne/ha)	Prod (tonne)
				Green	Sb_cr	Sb_i	green	Sb_cr	Sb_i			
Groundnuts	Kenya	2012	16536	7864	12	0	4500	7	0	0	0.6	106560
Groundnuts	Kenya	2013	17154	8715	12	0	4699	6	0	0	0.5	96402
Groundnuts	Kenya	2014	21712	9088	14	0	4944	8	0	0	0.5	100585
Groundnuts	Kenya	2015	8696	8467	13	0	4670	7	0	0	0.6	103665
Groundnuts	Rwanda	2011	22846	8515	14	0	4441	7	0	0	0.5	96571
Groundnuts	Rwanda	2012	20638	9032	14	0	4613	7	0	0	0.5	98539
Groundnuts	Rwanda	2013	24160	10564	15	0	4593	7	0	0	0.4	85194
Groundnuts	Rwanda	2014	27513	10249	19	0	4705	9	0	0	0.5	90873
Groundnuts	Rwanda	2015	24353	10084	14	0	4754	7	0	0	0.5	94742
Groundnuts	South Sudan	2014	253988	9483	16	0	4516	7	0	0	0.5	93388
Groundnuts	South Sudan	2015	146338	8685	16	0	4575	8	0	0	0.5	105294
Groundnuts	Sudan (current)	2014	2469382	9544	14	0	4569	7	0	0	0.5	100059
Groundnuts	Sudan (current)	2015	1609072	9037	13	0	4255	6	0	0	0.5	99794
Groundnuts	Sudan (former)	2011	1855093	6026	7	0	4148	4	0	0	0.7	149403
Groundnuts	Sudan (former)	2012	1785106	6321	10	0	4248	7	0	0	0.7	149250
Groundnuts	Tanzania	2011	637916	6675	10	0	4471	7	0	0	0.7	154751
Groundnuts	Tanzania	2012	725202	6546	8	0	4378	6	0	0	0.7	157956
Groundnuts	Tanzania	2013	669965	7992	13	0	4394	7	0	0	0.5	154690
Groundnuts	Tanzania	2014	1618332	9020	18	0	4399	9	0	0	0.5	180792
Groundnuts	Tanzania	2015	1342583	9499	12	0	4504	6	0	0	0.5	183076
Groundnuts	Uganda	2011	409978	8773	17	0	5003	10	0	0	0.6	233819
Groundnuts	Uganda	2012	423054	10940	20	0	5257	9	0	0	0.5	203271
Groundnuts	Uganda	2013	422049	10757	17	0	5374	9	0	0	0.5	210862
Groundnuts	Uganda	2014	404464	9636	24	0	5169	13	0	0	0.5	216977
Groundnuts	Uganda	2015	396115	11568	27	0	5100	12	0	0	0.4	174637

Appendix III. Export quantity and import quantity (tonne) of selected crops in Nile Basin countries taken from FAOSTAT

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
Burundi	1986	0	1561	0	0	0	0	0	0	0	0
	1987	0	1659	0	0	0	0	0	0	0	0
	1988	855	4	0	0	0	0	0	0	0	0
	1989	2710	27	0	0	0	0	0	0	0	0
	1990	663	8	0	0	0	0	0	0	0	0
	1991	40	1142	0	0	0	0	0	0	0	0
	1992	25	1673	0	0	0	0	0	0	0	0
	1993	0	2434	0	0	0	0	0	0	0	0
	1994	3	5637	0	66200	0	0	0	12600	0	0
	1995	2	3962	0	14600	0	0	0	0	0	0
	1996	15	1029	0	0	0	0	0	0	0	0
	1997	10	643	0	1439	0	0	0	0	0	0
	1998	0	4712	0	793	0	0	0	0	0	70
	1999	1	461	0	3252	0	0	0	0	0	0
	2000	0	2909	0	18000	0	0	0	0	5	9
	2001	0	3125	0	4102	0	0	0	0	5	15
	2002	0	820	0	15000	0	0	0	0	0	4
	2003	0	261	0	29755	0	0	0	0	1	40
	2004	0	10856	0	82821	0	0	0	0	1	8
	2005	0	5116	0	59000	0	0	0	0	0	3
	2006	0	11137	0	51350	0	0	0	0	0	6
	2007	0	7328	0	72500	0	0	0	0	0	54
	2008	0	5499	196	22491	0	0	7	0	0	20
	2009	290	11477	0	26451	0	0	0	0	0	0
	2010	576	20455	0	22370	0	26	223	249	0	712
	2011	61	8193	1120	13410	0	13	202	300	0	205
	2012	2	28549	0	48467	0	43	4	65	0	793
	2013	0	18061	3	12067	0	56	0	25	0	1981
	2014		13683	1	11772	0	19	24	273	0	3102

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
	2015	153	9892	0	13054	0	41	32	40	0	1389
Congo_DR	1986	0	80000	0	75000	0	0	0	0	0	0
	1987	0	80000	0	100000	0	0	0	0	0	0
	1988	0	70000	0	80000	0	0	0	0	0	0
	1989	0	86593	0	42707	0	0	0	0	0	0
	1990	0	85000	0	80000	0	0	0	0	0	0
	1991	0	60825	0	30000	0	0	0	0	0	0
	1992	0	105500	0	38000	0	0	0	0	0	0
	1993	0	50160	0	26700	0	0	0	0	0	0
	1994	0	42709	0	100000	0	0	0	0	0	0
	1995	0	70766	30	29000	0	0	0	22000	0	0
	1996	0	62416	33	22001	0	0	0	0	0	0
	1997	0	104494	36	9300	0	0	0	0	0	0
	1998	0	53589	39	8000	0	0	0	0	0	0
	1999	0	51130	41	14000	0	0	0	0	0	0
	2000	0	51337	95	20000	0	0	0	0	0	0
	2001	0	71648	0	18000	0	0	0	0	0	0
	2002	301	85215	0	14885	0	0	0	0	0	0
	2003	0	141718	131	25000	0	0	0	0	0	0
	2004	0	185257	17510	3250	0	6	0	0	0	0
	2005	0	208952	121	17616	0	52	0	90	0	0
	2006	0	306088	71	37702	0	0	16	175	0	0
	2007	0	110206	0	14718	0	0	0	0	0	24
	2008	0	98237	0	7624	0	0	0	0	0	3
	2009	0	72978	91158	31849	0	17	0	0	0	3
	2010	0	47480	93411	10183	0	0	0	0	0	97
	2011	0	59759	46351	1829	0	4	0	0	0	75

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
	2012	0	99589	1291	7907	0	0	0	0	0	79
	2013	170	81667	224	39138	0	0	0	0	0	68
	2014	3	71141	54	31819	0	0	2138	760	131	137
	2015	0	32302	5	14026	0	0	0	2	712	0
Egypt	1986	36043	7000	0	2028000	0	0	0	41	331	0
	1987	99967	22321	0	2200000	0	0	10	109	36	46
	1988	71353	22100	0	1300000	0	0	140	0	199	8
	1989	32805	3386	5471	1433180	0	0	36	0	1069	0
	1990	75340	2443	63	1900000	0	0	0	0	1567	0
	1991	150952	3800	0	1300000	0	0	0	100000	699	18
	1992	187471	180	3579	1443817	0	0	0	0	2303	0
	1993	144123	1330	11434	2148000	0	0	0	11100	7044	21
	1994	245878	982	2518	2021007	0	0	0	0	4229	0
	1995	156784	4730	516	2425162	0	0	0	0	6278	0
	1996	327834	360	1131	2471502	0	0	0	17197	3088	390
	1997	202592	694	2612	3059000	1169	0	0	220	7149	385
	1998	428925	697	460	2969000	68	0	0	204	9196	1948
	1999	306971	6045	350	4712000	0	6130	0	74	2917	0
	2000	392987	1210	1493	4710000	22	0	0	0	1076	0
	2001	656191	98525	1346	4797234	87	0	0	0	1301	84
	2002	464385	1343	612	4720569	106	0	0	0	6230	19
	2003	585740	1924	988	4052619	110	15	0	0	4352	33
	2004	836481	2927	1554	2429278	422	24	0	0	5713	15
	2005	1111502	4417	4446	5094985	1257	0	892	0	8404	32
	2006	982760	105674	4828	3769368	1010	1072	17	0	5249	87
	2007	1223318	117863	5322	5263135	1766	0	65	0	5045	43
	2008	306835	42666	1600	3979948	94	222	5318	0	8030	40

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
	2009	648702	15649	20468	5416326	412	240	3633	13767	21606	2953
	2010	599738	17552	9100	6170460	310	382	8435	12324	3804	4913
	2011	39972	93721	2255	7047864	218	226	3466	25699	17687	3661
	2012	146869	291253	4396	6061595	184	343	2351	35229	9089	6147
	2013	335774	20360	2463	5771770	106	48	203	25000	13482	4854
	2014	88304	31331	784	8230783	576	2296	426	15900	20252	5305
	2015	136195	30196	30008	7951374	20	2134	390	26100	7400	4317
Eritrea	1993	0	19	0	0	0	0	0	14568	0	0
	1994	0	2800	0	0	0	0	0	31330	0	0
	1995	0	3000	0	0	0	0	0	16500	70	0
	1996	0	18210	14	13227	8	4698	174	20979	0	0
	1997	0	2003	0	12443	0	3604	100	42829	80	0
	1998	0	7200	0	0	0	0	0	37700	69	0
	1999	0	0	0	0	0	0	0	6008	4	0
	2000	0	59	0	122	0	0	0	21900	30	0
	2001	0	2070	0	11036	0	0	0	25323	35	0
	2002	0	66	0	11000	0	0	0	33000	110	0
	2003	0	130	41	5264	0	190	0	29000	109	0
	2004	0	94	41	5264	0	0	0	90000	109	0
	2005	0	889	500	20500	0	190	0	128000	191	2
	2006	0	76	2829	3743	500	190	0	35715	132	0
	2007	0	210	0	1860	0	190	0	32000	133	2
	2008	0	544	0	1800	0	23	0	27600	91	394
	2009	0	659	0	1800	0	0	0	63770	107	1
	2010	0	600	0	2000	0	120	0	54350	141	3
	2011	0	1238	0	2000	0	0	0	30000	192	900
	2012	0	0	0	10486	0	0	0	24000	483	99

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
	2013	0	434	0	792	0	0	0	25000	281	91
	2014	0	357	0	900	0	0	0	30000	9	96
	2015	0	284	0	84	0	0	0	0	0	0
Ethiopia	1993	0	13165	0	21000	0	1	0	19900	0	0
	1994	0	10241	0	36300	0	0	49	102875	0	0
	1995	0	1295	0	24500	0	0	63	100354	0	0
	1996	0	2100	0	20500	0	0	63	50000	0	0
	1997	0	3600	0	26800	0	0	63	10000	0	0
	1998	0	5405	1701	30000	76	0	239	50000	0	0
	1999	0	8756	979	35000	80	0	408	49000	0	0
	2000	0	2681	385	18300	156	0	1051	7400	0	0
	2001	0	4505	1327	23500	50	0	118	8500	0	0
	2002	0	10415	12848	3189	8904	0	1198	10000	0	0
	2003	0	20163	746	11582	625	0	1412	24416	0	0
	2004	0	17334	11086	11347	28	1	1760	4606	0	0
	2005	0	17388	2606	30436	5	0	13420	2861	0	0
	2006	0	29996	672	60271	139	0	1371	1088	0	0
	2007	0	44326	17	31912	93	1	2402	16468	0	0
	2008	0	22287	0	36050	41	5	2224	252697	0	0
	2009	20	30239	0	54466	16	1	0	268640	0	0
	2010	15	44780	35994	29222	12	3	21786	351734	0	0
	2011	8	71405	60148	7625	34	1	21714	53439	0	0
	2012	8	114862	3400	42067	15	0	10972	25846	0	0
	2013	30	154841	8786	18424	57	1	4797	88492	0	0
	2014	279	184989	1	4313	844	2	17131	137268	0	0
	2015	46	283010	434	4274	359	3	7005	200745	0	0

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
Ethiopia PDR	1986	0	11073	500	21000	0	2102	0	34400	0	0
	1987	0	13297	0	45000	0	0	26	70	0	0
	1988	0	10155	0	11800	0	2060	0	20160	0	0
	1989	0	40181	0	740	0	40	0	11840	0	0
	1990	0	10175	0	39	0	0	0	8500	0	0
	1991	0	11061	0	78	0	0	0	100	0	0
	1992	0	13334	0	166	0	2	0	63200	0	0
Kenya	1986	26	59746	228458	700	1	0	52	0	0	0
	1987	1032	38570	280039	0	180	0	504	0	0	0
	1988	17	10000	167037	0	12	0	22	0	0	0
	1989	31	30008	110431	2	0	0	150	0	3	0
	1990	25	27989	159883	0	423	0	223	14	0	0
	1991	88	61165	18719	0	25098	0	5569	3000	34	0
	1992	175541	59597	34465	415320	3642	0	34057	15000	116	0
	1993	42971	37309	46132	80051	20	0	81225	35253	232	0
	1994	33659	83659	90485	650224	127	100	41901	10	246	12
	1995	583	27093	139658	40000	70	85	308	5000	101	19
	1996	75	28807	199974	6759	61	7	60	0	68	228
	1997	2527	62435	2636	1101105	10	348	243	566	26	90
	1998	203	62665	9124	368761	20	104	997	225	250	123
	1999	115	52054	30489	73520	120	986	853	48	444	340
	2000	126	105714	1867	409416	0	1092	1190	1518	157	597
	2001	147	137496	421	314381	0	776	680	420	3	194
	2002	157	137843	30059	16348	0	122	194	0	181	21
	2003	424	191653	8165	100132	849	2564	350	48	218	49
	2004	77	223187	14538	241757	48	2113	286	166	41	851

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
	2005	764	228041	10405	94000	65	3643	75	17150	4	132
	2006	776	259137	16578	147000	0	645	97	37700	5	171
	2007	595	259035	48328	113768	112	38558	919	605	3	1733
	2008	1170	264772	20947	243656	0	11293	893	3301	7	4151
	2009	2273	296204	5891	1508414	81	12037	1503	58822	36	5867
	2010	1612	282314	10850	229596	16	16979	49709	10035	102	10682
	2011	7342	358031	10850	258525	17	2440	800	58223	111	9331
	2012	13917	483498	1479	236000	114	1583	0	69500	72	8500
	2013	1745	412411	4972	93473	7	7968	6127	157000	223	7603
	2014	271	674300	2210	293073	110	973	3257	76179	1	13008
	2015	120	544569	5843	250351	203	13836	2813	153942	74	5885
Rwanda	1986	0	9671	0	714	0	0	0	280	0	0
	1987	0	4680	0	3	0	0	0	5	0	0
	1988	0	2734	0	0	0	0	0	0	0	0
	1989	0	5205	0	0	0	0	0	10	0	0
	1990	0	4497	0	939	0	0	0	0	0	0
	1991	0	3344	0	0	0	0	0	0	0	0
	1992	0	3831	0	7190	0	0	0	1120	0	0
	1993	0	3362	0	94000	0	0	0	3078	0	0
	1994	0	13527	0	67000	0	0	0	3650	0	0
	1995	0	7784	0	134000	0	0	0	24043	0	0
	1996	3	7740	393	207	0	0	0	35	0	90
	1997	0	7546	407	0	0	0	0	1508	0	2
	1998	0	22421	0	219	0	458	0	186	0	3
	1999	0	13270	0	1263	0	0	0	533	0	0
	2000	0	1700	0	30000	0	0	0	2795	0	0

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
	2001	0	25238	0	4002	0	0	0	442	0	0
	2002	0	13062	0	25170	0	0	0	26	0	48
	2003	0	12119	1510	16957	0	0	0	0	0	130
	2004	0	3011	0	32362	0	0	0	0	0	748
	2005	143	14507	5	16385	0	0	5	0	0	11
	2006	103	16673	552	29076	0	0	0	2052	0	617
	2007	50	18715	1465	45207	0	0	50	1697	0	1927
	2008	75	12714	138	7791	0	0	100	19	0	7772
	2009	31	32274	175	52957	0	85	5	10299	8	11331
	2010	232	44619	1633	118064	0	9	9	13487	0	5131
	2011	315	39522	1691	66559	6	67	0	13554	12	3137
	2012	4022	57204	7245	101154	10	284	83	23454	53	3903
	2013	16330	63349	7488	62940	0	0	0	0	0	0
	2014	21868	48693	1802	89603	0	102	185	21514	131	1
	2015	26000	48003	3986	51772	0	18	0	18901	103	472
South Sudan	2014	1	25618	0	24685	0	192		194658	0	18
	2015	24	31998	0	16084	0	500		52269	0	6
Sudan	2012	0	34763	61789	26705	0	0	244	99070	109	0
	2013	0	44115	4819	28167	221	44	19333	310159	5251	362
	2014	0	41560	556	16111	1	1011	1459	167443	1142	0
	2015	0	53852	2604	23121	168	0	5875	118133	697	34
Sudan (former)	1986	0	40000	0	15000	1099	0	30490	6950	1090	0
	1987	0	30000	0	27600	3463	0	534249	8500	7283	0
	1988	0	30000	0	17600	281	0	237137	25250	69080	0
	1989	0	40000	0	19400	3952	0	308047	29970	27000	0

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
	1990	0	40000	0	40000	0	0	100000	7000	9600	0
	1991	0	40000	0	15000	0	0	0	240000	6500	0
	1992	0	40000	25000	26000	0	0	0	215000	2650	0
	1993	0	12378	27000	20000	301000	0	613296	112000	14432	0
	1994	0	21921	5300	13400	0	0	116055	248300	6213	0
	1995	0	14588	12500	0	20000	0	406911	25400	4642	0
	1996	0	24166	0	0	20000	0	17250	2000	2176	0
	1997	0	15765	0	142	0	0	50000	44	5301	0
	1998	0	30039	23785	10845	0	50	722	18	15448	0
	1999	0	11873	0	7015	1179	0	321121	36	269	0
	2000	18	30253	0	41118	410	0	52209	493	8481	0
	2001	0	43204	0	71113	330	0	1651	27368	15021	0
	2002	0	31788	27673	57168	0	0	18501	36561	8258	0
	2003	0	31709	2350	10221	0	0	12369	60280	252	0
	2004	0	49467	140	42214	0	0	13854	223690	1560	0
	2005	0	76252	0	130278	0	0	3053	203514	2637	0
	2006	0	113918	0	13354	1549	28050	2601	312419	198	0
	2007	0	56212	0	27430	5581	0	113396	199214	965	0
	2008	0	36620	2014	18780	90	5	161067	284305	2705	7
	2009	0	38466	0	108728	0	53540	741	300809	345	54
	2010	0	19084	204	103921	0	33632	5001	437117	120	3102
	2011	0	30788	5280	6926	0	17	27241	290269	398	32
Uganda	1986	0	6000	0	0	0	0	0	0	0	0
	1987	0	6000	0	700	0	0	0	0	0	0
	1988	0	0	0	0	0	0	0	0	0	0
	1989	0	6100	0	5200	0	0	0	0	0	0

	Rice		Maize		Millet		Sorghum		Groundnuts	
	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
1990	0	0	26733	7100	0	0	0	0	0	0
1991	0	409	33070	0	1285	0	0	0	0	0
1992	0	827	29623	8696	0	0	0	0	0	0
1993	0	2084	160438	46000	0	0	0	4100	0	0
1994	87	8061	100621	13733	301	0	3981	0	224	0
1995	539	8834	69320	33060	1582	0	8684	3926	252	73
1996	120	12525	81204	78342	491	8	277	90	5	0
1997	1694	32503	29370	118431	217	3	1763	6748	11	0
1998	1374	53683	33164	41074	477	20	1464	1609	47	
1999	227	39741	23163	26754	2	0	1018	300	150	17
2000	1567	51256	4156	16691	32	0	1120	0	10	0
2001	894	22225	23769	3454	148	0	188	0	0	357
2002	765	42989	41594	29052	710	0	81	2714	45	74
2003	927	48924	31431	53209	1272	0	420	2368	0	192
2004	7045	62005	63029	97400	2067	0	499	37900	0	300
2005	13264	66475	59814	48200	198	0	442	72700	22	214
2006	14989	50858	80990	40300	2043	0	349	100500	54	30
2007	24591	74717	56254	9410	1028	0	141	77590	119	439
2008	25336	63363	24489	22715	1735	128	15509	74368	16	2667
2009	38107	80117	50630	6559	340	153	11029	7561	54	10129
2010	39919	77202	127314	1457	1587	29	6826	5786	50	4812
2011	38087	91972	54978	17243	1684	18	1016	1570	150	1469
2012	71203	134004	177952	16100	1349	1265	13693	6300	291	457
2013	70659	115615	103950	5033	455	302	53239	4341	220	5368
2014	57773	171919	112927	790	226	25	61742	4709	28	4192
2015	53472	120469	281086	2447	13518	5	65002	5211	1850	1137

		Rice		Maize		Millet		Sorghum		Groundnuts	
		Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
Tanzania	1986	0	141665	0	34731	0	0	0	7140	0	0
	1987	0	83500	90000	31000	0	0	28379	0	0	0
	1988	7	50400	18711	9000	0	0	4500	0	0	0
	1989	0	21025	30347	80	0	0	3000	0	0	0
	1990	0	34000	57039	2208	0	0	0	0	0	0
	1991	0	60000	7000	1651	0	0	0	0	15000	0
	1992	0	70000	4141	44000	0	0	0	0	6000	0
	1993	0	91000	9637	49000	0	0	0	0	0	0
	1994	0	60000	0	193000	0	0	0	0	0	0
	1995	0	67719	0	43917	0	0	0	0	170	0
	1996	0	48047	0	50575	0	0	0	0	510	0
	1997	1151	98975	16185	12989	578	0	400	0	695	61
	1998	11922	181412	20	269615	112	20	126	1	231	1252
	1999	15931	85593	15808	35585	365	7	230	7	848	521
	2000	5686	191648	16871	49453	381	0	776	173	367	4
	2001	6432	139028	26386	45878	839	4	301	20	973	350
	2002	9047	76500	152310	63373	38	0	181	94	3626	774
	2003	10906	189201	156192	77991	232	32	299	296	13151	10
	2004	2434	194280	53747	211300	2007	5	272	619	3975	19
	2005	9286	75021	98985	44500	1758	4	1814	20	3776	109
	2006	4390	94200	23507	295700	235	0	273	1226	481	267
	2007	20156	48446	87076	6609	1000	1	427	390	11310	5858
	2008	5589	64188	12096	20468	1504	2124	4089	2100	14817	5425
	2009	808	39603	5828	9108	12231	4	420	4643	5886	9786
	2010	48275	74876	4385	18588	985	3	663	1060	3899	12278
	2011	35176	50851	7442	11931	836	4	2323	652	2006	10858
	2012	17494	197522	175302	74532	1021	1	15878	433	17209	9995

	Rice		Maize		Millet		Sorghum		Groundnuts	
	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
2013	51433	284787	40449	75981	307	19464	1356	1117	4081	8919
2014	47862	9018	274428	14987	620	2787	655	4	844	16863
2015	7902	28849	57764	22209	1292	121	79	12	117	1986