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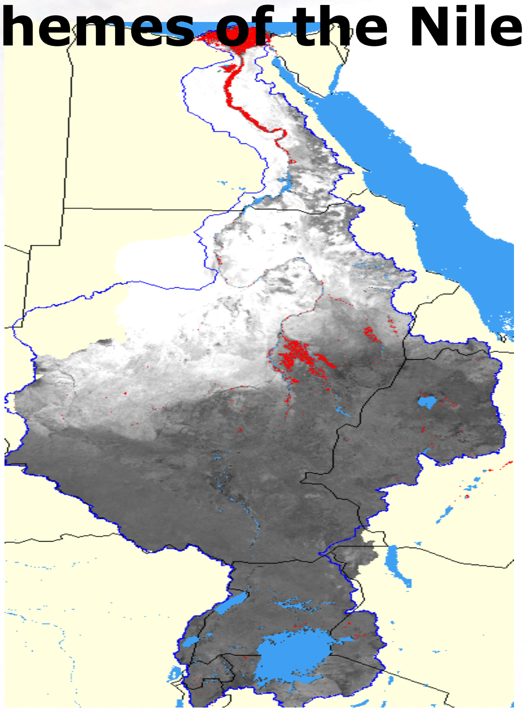
Chris Perry, London, UK

May 2009

Efficient Water Use for Agricultural
duction (EWUAP) Project

ultural Water Use and Water Productivity in the Large Scale Irrigation (LSI) Schemes of the Nile Basin



Final Report
By

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May 2009

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Executive Summary

Irrigation is a complex process and the conditions are widely varying across the Nile Basin. Various professional opinions exist on good irrigation management practices, and this makes the assessment of the current Large Scale Irrigation (LSI) systems not easier. The variations are induced by the physical soil-crop-atmosphere processes, the water governance and the economical situation. Water governance is related to the institutions, acts, rights, responsibilities and the objectives of the LSI systems.

Benchmarking of all the irrigation systems in the Nile Basin can only be accomplished by the inclusion of standardized data. Considering that national scale irrigation information databases do not exist, very scant information has been provided by the National Project Coordinators that is insufficient to form a basis for a solid analysis. For instance the objectives of irrigation could not be provided. Without proper information on the specific goals of certain LSIs, it is difficult to assess whether the irrigation objectives are met, and more generic productivity criteria needs to be developed.

This study utilizes satellite data on irrigated areas, biomass production and consumptive use to derive a minimum set of indicators. The performance was separated into results, processes and sustainability. Areas with excellent productivities of land (kg/ha) and water (kg/m^3) resources have been identified. The major physical processes leading to satisfactory productivity have been described for each climatic zone.

The good and poor irrigation practices have been presented for each country, and this facilitates the national scale benchmarking process. Sudan, Rwanda and Burundi should focus on crop production. Kenya and Uganda should conserve irrigation water use. Ethiopia should increase their water supply to irrigated areas and Egypt has a significant non-uniformity between Upper Egypt, Nile Delta and the Western Desert. When combining all 10 indicators with equal weight, Kenya turned out to have the best irrigation practices.

LSIs with good practices have been identified for each country and for each climatic zone. The reasons for good performance have been estimated from the Process Indicators. Visits to these spots are recommended to get feedback from the local irrigation managers.

The overall conclusion is that the Nile Basin has excellent irrigation systems. The yields are in pace with the world wide values, and so is the water productivity. There are also areas with very weak irrigation performance. It is recommended that NBI develops guidelines for these systems, and this study is a first step in that direction.

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PART 1 Inventory of LSI schemes, Best Practices and Best Practice Sites

1 Introduction

1.1 General background

The Efficient Water Use for Agricultural Production (EWUAP) project is one of eight projects of the Nile Basin Initiative's (NBI) Shared Vision Program (SVP). The SVP was initiated because of the expressed need to develop a common shared vision to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the common Nile Basin water resources. The EWUAP project is designed to be a first step in bringing together regional and national stakeholders to develop a common shared vision on increased availability and efficient use of water for agricultural production. The EWUAP project intends to achieve its objectives by:

- establishing forums to discuss developments for the Nile Basin with a broad range of stakeholders at regional, national, and community levels;
- improving understanding of the relationship between water resources and agricultural development;
- enhancing basin wide agricultural management capacities;
- bringing together regional and national stakeholders to have a common view and understanding on ways and means of improving water use in the sector and develop a shared vision on common issues;
- developing a sound conceptual and practical basis (best practices and guidelines) for the Nile riparian countries to increase availability and efficient use of water for agriculture; and
- creating a framework to promote basin-wide cooperation and awareness, and build capacity by focusing on the common and basic issues related to water harvesting and irrigation.

In view of the above, the existing Large Scale Irrigation schemes in the basin were inventoried. This report describes the findings of the LSI study. The main problems and issues (best practices, misconceptions, opportunities, weaknesses and needs) are described. The status of LSI activities in the basin are described. The irrigation conditions are compared to global and/or regional best practices.

The project is executed by a team of two individual consultants: Dr. Wim Bastiaanssen from Wageningen in The Netherlands and Dr. Chris Perry from London in the UK. Perry is an agricultural water economist, and Bastiaanssen is an irrigation hydrologist and water resources engineer. EWUAP entered into contract with Bastiaanssen and Perry was subcontracted to cover the economical and institutional components.

1.2 Relevance of irrigation in the Nile Basin

Agriculture plays a major role in the lives and livelihoods of most households in the Nile Basin countries and contributes significantly to overall economic growth and Gross Domestic Product (GDP). Irrigation is considered an effective vehicle to boost rural development and provide jobs to disadvantaged people. There are now approximately 180 million people living in the Nile Basin, and food security is an issue of growing concern. Rwanda is anticipating a total area of 66.000 ha devoted to rice cultivation with an associated target yield of 7 tons / ha in the long term. The United Nations has estimated that Africa needs extensive water resources development over the next 20 years if food production is to keep pace with the rapid expansion of its population. FAO is working on a "Blue Revolution" programme for putting water for agriculture and energy in Africa in the spotlight. The blue revolution program aims to ensure water supplies to villages and for irrigated land.

Irrigated land constitutes on average 20 % of arable land worldwide, including 38 % in Asia, but only 7% in Africa. Only 4% of water reserves are exploited in Africa compared with 20% in Asia. Many Governments of Nile Basin countries therefore have plans to expand irrigation systems. The expansion of irrigated land is mainly constrained by the available water resources, and a good inventory of diversions and consumption of water in agriculture is required. Instead of growth of land equipped with irrigation infrastructure, it is feasible also to critically evaluate whether the current management can be improved. This study is therefore relevant to the larger scale irrigation planning of the Nile basin.

With its population set to double by 2050, Africa needs to triple its food production in the next four decades (FAO, 2008). Agriculture is also the dominant user of water resources in the Nile Basin, and this issue will be highlighted because many water professionals in the basin - and even NBI staff - underestimates the role of irrigation in the Nile water allocation process.

The British imperial interests focused on increasing agricultural productivity a century ago and it was recognized early, that prosperity in the Nile Basin will require controlled supplies of water. Dams and water schemes were designed and constructed towards the end of the 19th century. The control and regulation of the Nile River was considered the most effective way to provide reliable supplies and to prevent excessive floods. Perennial irrigation was introduced in Egypt and this created a large surplus of food and cash crops - particularly cotton. The sloping terrain between the Blue and White Niles south of their confluence was, during the 19th century, regarded as being suitable for irrigation and the giant Gezira irrigation scheme then came into being. The lack of continuous water resources availability motivated the construction of larger dams. Besides Aswan dam, a dam at Sennar on the Blue Nile was constructed and another one at Jabal Auliya on the White Nile. These large infrastructure investments created the basis for a large proportion of current irrigation activities in the Nile Basin.

Whereas historically there was sufficient water for irrigation, and water resources could be utilized for agriculture, pressure is now mounting to reduce the amount of water allocated to agriculture. This pressure on water resources is brought about by expanding urban centres, industry, mining, recreation and tourism. Water conservation in irrigation is in conflict with the political desire to expand irrigation and secure food production. Within this potentially contradictory situation, solutions have to be found. Key challenges for irrigation managers are therefore: (i) to sustain the current irrigation activities with less water resources (more *crop per drop*) by intensifying irrigation management on existing areas: called "vertical expansion", and (ii) to increase the areas under conventional and intensified irrigation management (horizontal expansion). The irrigation sector has *to produce more from less* (Guerra et al., 1998) and become very rational with water resources to make horizontal and vertical expansion possible.

Rainfed agriculture (supported to an extent by Small-Scale Irrigation (SSI) and water harvesting systems) is the dominant form of agriculture in the upstream countries, whereas the downstream countries (Sudan and Egypt) are dominated by irrigated agriculture in Large Scale Irrigation (LSI) schemes. Despite large capital and infrastructure investments, little is still known about the actual water requirements, water application, water consumption, production, and the management of these LSI systems. The difference between SSI and LSI is often weak, and depend mainly with the level of contiguity.

Considering that there is approximately 5 million ha of irrigated land in the Nile basin, it is useful to get a rough estimate of the total amount of water used by LSI systems in order to determine their impact on the water resources for other water use sectors. If we assume that the average annual cropping intensity is 1.5 (i.e. three crop seasons in two calendar years) and an annual crop consumptive water use (i.e. crop evapotranspiration) of 1000 mm/yr, the total consumed water will be 50 BCM/yr (Billion Cubic Meter or 10^9 m^3 per year). If we further assume that 20% of the crop consumptive use (10 BCM) originates from rainfall and neglect groundwater as a source of irrigation water for the sake of simplicity, then the remaining 40 BCM must be the net withdrawal from Nile Basin surface water resources. Due to distribution and percolation losses, probably double the amount of water needs to be diverted from the river (80 BCM) to achieve 40 BCM of consumptive use (i.e. an irrigation efficiency of 50%). Water that is not consumed by the crops mostly returns to the river system and can be re-used for downstream irrigation systems. Considering a total area in the Nile basin of 3.3 million km^2, a net withdrawal from surface water of 40 BCM is equivalent to a water layer of 12 mm/yr. This means that about 12mm of rain across the whole basin is skimmed of for irrigated crop production.

The inflow of water from the many tributaries and main rivers of the Nile system (Kagera, White Nile, Sobat, Blue Nile, Atbara) is highly variable. Streamflow by default increases from the upperstream catchments to the central part of the basin. The longer term average discharge at the confluence of Khartoum is approximately 100 BCM/yr. Due to river abstractions, riparian vegetation water use, seepage losses and evaporation losses, the river looses water on its downstream course. The mean annual discharge of the main Nile measured at Dongola in Northern Sudan is 87 BCM (Conway, 2005). The longer term inflow into Lake Nasser is estimated to be 84 BCM/yr. An amount of 10 BCM/yr is evaporated from Lake Nasser and the remaining 74 BCM is shared among Egypt (55.5 BCM) and Sudan (18.5 BCM).

The primary water source for large-scale irrigation projects in all Nile countries is surface water. The gross withdrawal of 80 BCM constitutes 80% of the Nile Basin water discharge as measured at Khartoum. In reality the 40 BCM net withdrawal is substantially lower, but it is still approximately 50% of the inflow into Lake Nasser. It is necessary to determine the food production in terms of the 40 BCM water used in order to justify current irrigation systems, and to help plan future systems and water management. If a more efficient irrigation system is in place, it would be interesting to estimate the possible growth of irrigated areas into the future. While everybody wishes to have efficient irrigation, the physical meaning of this public desire is usually not described, and by the lack of indicators and target values, it is not straightforward to benchmark irrigation systems.

Certain datasets on irrigation systems were developed during the British Imperial era which ensured a certain degree of standardization. The 10 Nile Basin countries now have diverse databases of varying quality standards. There is no general, overall database, and no consistency of reporting of the collected data. This appeared to be a major problem for the execution of this study. The NBI and the EWUAP programme in particular provide the opportunities for a commonly shared database for this most important user of Nile water resources. It is not wise to continue with irrigation planning by tapping internationally waters without any proper foundation.

Considering the importance of agriculture, the vast amounts of water involved and the absence of an international database, EWUAP and the LSI study are highly relevant for the overall basin planning.

1.3 Climate and physical properties

The Nile Basin contains the world's longest river (6,700 km). The catchment area of the Basin is about 3.3 million km^2 and it comprises 10 different political boundaries. It stretches over different topographical and climatic regions. The distribution of the topographic elevation of the Nile Basin is displayed in Figure 1. Basically, the western side of the Central Rift Valley in eastern Africa drains into the Nile Basin. The ridges of the Central Rift Valley form the eastern edge of the Nile Basin in Ethiopia and Kenya. The array of equatorial lakes between Lake Tanganyika via Lake Kivu, and Lake Edward to Lake Albert, form the natural water divide between the Nile Basin and the Congo Basin.

High mountains (>4000 m amsl) can be found in the Nile Basin. Mount Elgon (4321 m) is located on the border between Kenya and Uganda. Mount Karisimbi (4510 m) forms the natural border between Rwanda and Congo. The Ruwenzo Mountains separate Uganda from Congo, and the Margherita peak in this mountain range is 5110 m. In Ethiopia, the Blue Nile makes a giant bend of hundreds of kilometers around the Choke Mountains on its course from Lake Tana to Roseirres reservoir in Sudan. The peak of the Chokes is 3,296 m high. As is apparent from Figure 1, the majority of the Nile basin is located only a few hundred meters above sea level, and the slope is very gentle towards the Mediterranean Sea.

Rainfall decreases from 2,000 mm/yr in the upstream Equatorial Lake region to virtually zero in the Sahara Desert. The Ethiopian Highlands have an annual precipitation of 1,200 to 1,600 mm/yr, a little lower than the Lake Victoria region. The Atlantic and the Indian Oceans supply atmospheric moisture during certain periods of the year. This atmospheric movement leads to the seasonal discharge patterns of the Blue Nile and other rivers emerging from Ethiopia. Whereas the Ethiopian Plateau has a single rainy season, the Equatorial Lakes Plateau has two wet seasons.

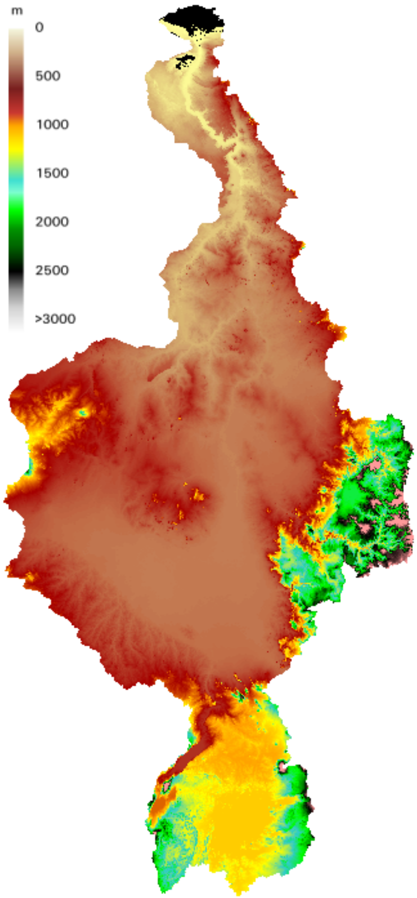

Figure 1 The distribution of terrain elevation in the Nile Basin (source: SRTM – Digital Elevation Model)

A total of 85% of the water resources in the main Nile originates from the Ethiopian highlands. The main rivers originating in these highlands are the Sobat, Blue Nile (Abbay) and the Atbara. These rivers discharge water from the single rainy season between May to October. The mean annual flow of the Blue Nile is 46 BCM, measured at Roseirres/El Deim over the period 1961 to 1990. The variation in the flow is very large – from 21 to 79 BCM (Conway, 2005). Sutcliffe and Parks (1999) reported a longer term average of 49 BCM/yr.

Considerable runoff is also produced from the Equatorial lake region, the source of the White Nile. The mean annual outflow from Lake Victoria, measured at Owen Falls from 1961 to 1997, is 37 BCM (Conway, 2002). Near Mongalla, where the Nile is called the Albert Nile, the flow rate of 33 BCM/yr is approximately constant throughout the year. A substantial part of this water is evaporated in the vast swamps of southern Sudan. Due to the warm climate, significant amounts of water evaporate from reservoirs, swamps and tropical forest. Mohamed et al. (2004) showed that the evaporation from the Sudd (38,600 km^2), Bahr el Ghazal (59,400 km^2) and Sobat marshlands (42,900 km^2) are 63 BCM, 89 BCM, and 55 BCM respectively. Not all of the evaporation is from flooded Nile water. The majority of the evaporation is from rain water. The flat plain areas in Central Sudan are regularly exposed to floods, and here also large amounts of water evaporate into the atmosphere (Bastiaanssen, 2009).

Since the Nile Basin stretches over a vast area, the climatic conditions range from humid tropics with tropical rainforests in the vicinity of the equator to an arid and very hot climate in the downstream part of the basin. The average summer temperature in the downstream part of the Nile Basin varies between 27° C and 32° C. The average winter temperature varies between 13°C and 21 °C. While this land at 30°N has distinct winter and summer temperatures, the upstream end of the basin at the equator has more stable temperatures between 23 and 26°C during the whole year. Figure 2 shows the mean annual temperature for the Nile Basin. There is – not surprisingly – a negative relationship between air temperature and terrain elevation: the higher elevated regions are much colder. The desert in the region between Atbara and Dongola appears to be the warmest areas of the Nile Basin.

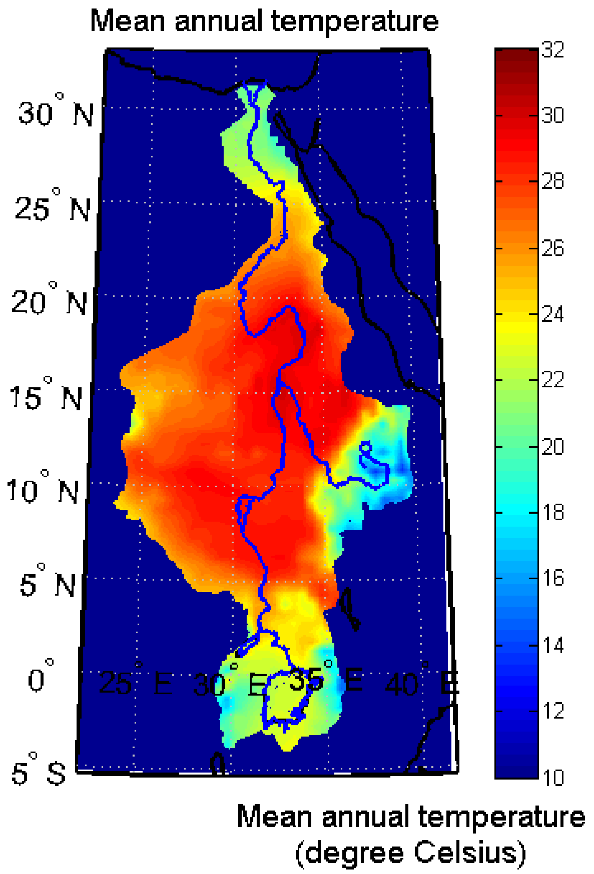

Figure 2 Mean annual air temperature reconstructed from the Climate Research Unit of the University of East Anglia data set TS 2.1 (source: van der Kruijs, 2008)

The vegetation of the Nile Basin is a result of a combination of factors such as elevation, rainfall and temperature regimes. Figure 3 shows the Nile Basin land cover map. The majority of the land is desert ("barren or sparsely vegetated"). Croplands are found mainly on alluvial soils and in regions with a flat topography and significant rainfall (> 500 mm/yr). The areas around Lake Tana are farmed, as well as the plain area in eastern Sudan. The Darfur area in western Sudan has only scanty agriculture. The region in Uganda bordering Lake Victoria supports many farming practices. Cropland is thus a common cover type in the landscape of the Nile Basin.

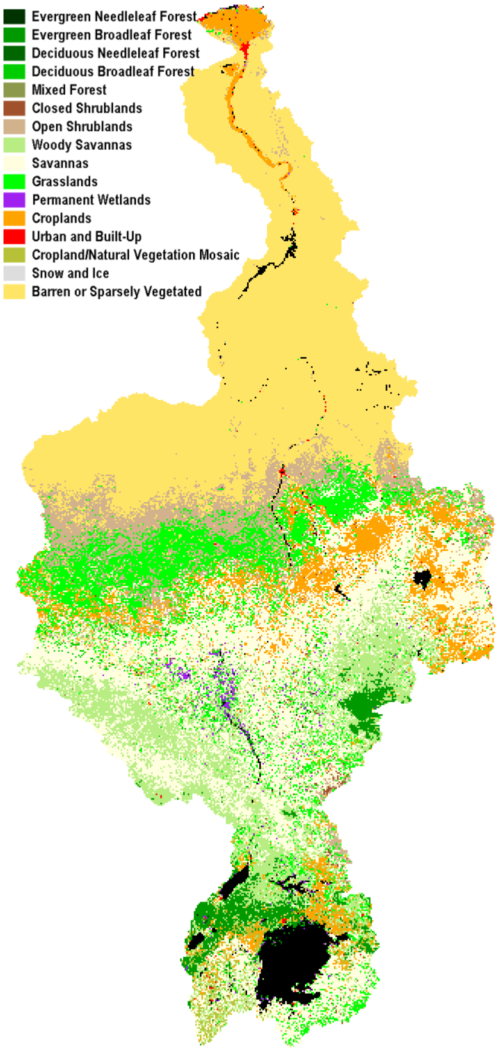

Figure 3 Land cover map of the Nile Basin in the year 2000 (source: International Geosphere Biosphere Project IGBP global land cover map)

1.4 Irrigation performance frameworks

By irrigating their land, farmers become less dependent on erratic rainfall and therefore can invest more in improved agronomical practices such as land preparation, soil tillage, crop protection, weeding, and adequate fertilizer applications. The overall purpose of irrigation is to optimize the socio-economic benefit per unit of land or per unit of water. Generally, crop yield will increase by adding irrigation water to the soil. An irrigation system needs to be (in the most simple form) evaluated in terms of land productivity (kg/ha) and water productivity (kg/m^3). In case of deviations from optimal values, a package of interventions need to be prepared. These interventions should focus on the weak elements, and it is desirable to have more information on how LSIs function.

The main objective of irrigated agriculture is to enhance crop production by keeping soil moisture in a certain desirable range. Unfortunately, wet to very wet soils are often regarded by farmers as being desirable. They believe that wet soils are good for crop growth which is only partially true. The international research arena produced an analytical framework to describe the functioning of irrigation systems in a standard manner: the irrigation performance indicators (ICID; FAO; IWMI). Understanding the rate of change of performance of a given irrigation system, caused by the level of inputs and other services to achieve the desired outputs, is essential for proper irrigation management.

Performance assessments are meant to provide crucial information on (i) the ideal and (ii) actual irrigation conditions in a given system. A performance indicator is set to a target level with an allowable range of deviation (tolerance margin) depending on the local boundary conditions. Continuous observations of the indicator value at close intervals indicate the output level variation against the target value. The indicator can fluctuate within the allowable range, without triggering a management action. However, if the indicator moves out of this range, diagnosis of the problem should lead to corrective action.

Strategic performance assessment spans long intervals (seasons, years) and considers criteria of productivity, profitability, sustainability and environment impacts (Bos et al., 2005). *Operational performance assessment* assists with accomplishing targets of irrigation and cultivation processes. Operational performance evaluates routine implementation of operational procedures based on specific functions. It specifically measures the extent to which target levels, to be achieved by operational irrigation system processes, are being met.

To assess the operational performance, it is required to measure the actual inputs of resources and the related outputs. A general approach to irrigation performance was published by Bos et al. (1994). Performance information on related activities (e.g. water delivery, drainage control, water shortage) is required by the operational managers in time to make relevant decisions. Water managers of an irrigation scheme should monitor the performance of key operations closely to identify shortcomings and take corrective measures at the right time. Unfortunately, non of the countries seems to have a systematic irrigation performance framework, although there exist a desire for it. An appraisal of irrigation systems – such as the current diagnosis - should address these issues wherever possible.

The NBI is developing, as part of EWUAP, a common view on satisfactory irrigation practices in the Nile Basin, and our report is contributing to this process. In general terms, good irrigation practices could be defined and evaluated for different disciplines. The inset shows that different disciplines have different criteria for evaluating good irrigation management. Except for land and water productivity, there is not one single criterion that can be used as an overall indicator. As a first step, one could check whether the project design and goals are met. Because some systems were constructed 100 years ago in a period with deviating perceptions targets, this is not self-evident.

Perceptions of good and efficient irrigation management:		
Civil engineer	:	Sufficient storage for ensuring annual water yield security
Irrigation engineer	:	High irrigation efficiency
Agricultural engineer	:	Crop water requirements are met
Agronomist	:	High land productivity (crop yield)
Water resources engineer	:	High water productivity
Basin planner	:	Low net surface water withdrawals and high recoverable fraction
Environmentalist	:	Sustainable agro-ecosystems and bio-diversity
Economist	:	High cost recovery
Social scientist	:	Fair water governance
Policy maker	:	Alleviation of poverty

While irrigation engineers promoted irrigation efficiency as a key indicator for good irrigation management, this criterion has recently been revisited (Seckler 1996; Molden et al., 2007). The key problem is that a low irrigation efficiency is not necessarily bad as long as water can be recovered into the irrigation cycle. Conversely, an irrigation system with an improved efficiency implies that a larger fraction of water supplied has turned into consumptive use. The latter could be highly undesirable from the perspective of a downstream user because a higher consumptive use implies that more water is evaporated into the atmosphere and no longer present in the basin. Runoff, drainage and percolation losses are often recoverable, but evaporated water not. It is therefore wiser to focus on consumed vs. non-consumed water and recoverable vs. non-recoverable water. This implies that irrigation efficiency improvement is not necessarily a saving of water, and that there is a risk that water consumption increases instead of the foreseen decrease.

To avoid the use of ill-defined criteria of efficiency that could be confused with physical processes of the irrigation cycle, Perry (2007) proposed a different set of irrigation indicators that are now accepted as the new ICID indicators for irrigation management in the basin context. This new ICID terminology avoids the word efficiency and relies instead on the hydrological framework that defines component water flows. First a distinction between consumed and non-consumed water use is made. Consumptive use is water evaporated, comprising (i) a beneficial consumed fraction (water consumed for the desired purpose) and (ii) a non-beneficial consumed fraction (water evaporated or transpired without producing an utilizable product).

Non-consumed use is water that remains in the current hydrological cycle. It is water not lost to the atmosphere, to saline sinks, or to contaminated streams or aquifers. It is: (i) the recoverable fraction of surface water (water that can be recovered and re-used) and (ii) non-recoverable fraction (water that cannot be economically recovered, such as outflows to the sea).

Although reductions in the volume of water withdrawn from a source (river or aquifer) are widely used as the basis for water saving, it could be misleading if used on a basin scale, since recoverable flows can be re-used elsewhere or at another time. On a basin scale, the actual consumed water should rather be used as the basis for management (Hellegers et al., 2008).

The concept of water productivity has rapidly gained international attention and recognition over the last 10 years because it directly links outputs from irrigation (yield, food, jobs, income) to the inputs, i.e. water consumed (water supply minus return flow). While EWUAP refers to "efficient water use" in irrigation, for reasons of compliance to a modern terminology we will use "productive water use" in irrigation throughout this report. Hence, we will be very explicit on the interpretation of efficient water use, and associate that consistently with water productivity to avoid confusions on the management implications.

Productive water use is suggested by socio-economical water professionals to be associated with strong economies and with good institutional infrastructure for maintenance as well as scheme financing. These factors need to be taken into account when assessing the current quality of irrigation practices in the Nile Basin.

Any improvement of irrigation management and growth of the irrigation sector requires a quantitative description of the inputs (water) and outputs (crop yield). At the start of this study, it has been anticipated that good flow measurements will not become available. Complete absence of quantitative flow information is a serious limitation for water productivity and providing recommendations for future water management in existing systems and planning of new systems. The use of remote sensing techniques to measure consumptive use, i.e. actual crop evapotranspiration in a spatially distributed manner is under these circumstances a desirable alternative solution. Satellite remote sensing can furnish near-real time data in an objective and unbiased manner (Bastiaanssen and Bos, 1999; Bastiaanssen et al., 2000). Remote sensing data can also be used to estimate water productivity. This study will therefore embark on remote sensing techniques because it is the only source to quantitatively describe the LSI conditions of the vast Nile Basin in a standardized manner.

1.5 Study objectives

The objective of the study described in this report is to provide an overview of the performance of LSI systems in the Nile Basin against internationally accepted standards and benchmarks and recommendations on how to improve the management of the LSIs. Good irrigation practices in the Nile Basin and areas that need to undergo improvement programs will be identified. A minimum data set will be acquired from remote sensing measurements, such as the inventory of LSI systems.

The tasks of this study can be summarized as follows:

- Identify and document LSI schemes in the basin along with the relevant issues/problems in terms of weaknesses, opportunities, potential and needs of the sub-sector using a combination of desk review, consultation with the NPCs and other parties, and research.

- Search, diagnose, identify, and document relevant global and/or regional best practices related to the development and management of large scale irrigated farms.
- Develop appropriate guidelines for the implementation of some of the identified global and/or regional best practices.
- Explore appropriate strategies and options for improving public and private-managed irrigation systems with participation from regional, national, and local stakeholders.
- Identify, select and describe sites or centers of excellence for a few selected best practices.
- Prepare action plans and/or technical notes for use by the Subsidiary Action Programs and provide information on future perspectives of the sub-sector in terms of investment and development.
- Organize and facilitate regional workshops to share/disseminate the best practices and action plans and also organize and facilitate study tour(s) to areas of best practices within or outside of the Basin.
- Offer capacity building opportunities, and promote exchange of best practices and sharing information on learned lessons.

The outputs/outcomes of the consultancy work will be used to inform partners and stakeholders from the Ministries of Agriculture, Water and Irrigation, Land and Environment, the Nile Technical Advisory Committee (TAC), and representatives of NGOs, the World Bank, donors, and the Nile Secretariat on issues related to Large Scale (Public and Private-Managed) Irrigation.

1.6 Data organization

The vast basin, its complex political boundaries, and the diversity of irrigation history and experience across the study area, together with the absence of data and information systems at EWUAP, made the data collection of this study a real challenge. Anticipating such a situation, maximum use of satellite data had been proposed from the beginning of the study. Standardization of data collection is very important for conducting a consistent analysis. Satellite data meets the requirement of standardized and consistent data sets. Good quality irrigation performance evaluations and comparisons can only be achieved if the same data is collected for *all* systems (e.g. Wolters, 1990; Molden et al., 1998). Missing data on crop types, yield, or delivered volumes, hamper computation of certain irrigation performance indicators.

Dialogue between local experts and the international consultants has been set up to foster the data exchange, especially on strategic data (goals, objectives) and location of the LSIs. The consultancy team (Drs. Wim Bastiaanssen and Chris Perry) therefore assisted EWUAP to organize two regional irrigation workshops and two irrigation study tours. The location and time of these joint activities are summarized in Table 1. Due to the growing interest in remote sensing techniques, an international training course was held in December 2008 to acquaint irrigation professionals with GIS / Remote Sensing technologies. This training was no official part of the LSI study (and will therefore not be mentioned further in this report).

Table 1 Workshops organized to facilitate the execution of the LSI study

Workshop	Location	Time frame
Inception Phase	Addis Ababa	13 and 14 March, 2008
Validation Phase	Arusha	28 and 29 July, 2008
Dissemination Phase	Khartoum	28 January, 2009
Recommendation Phase	Nairobi	27 May, 2009
Technical workshop	Nairobi	25 and 26 May 2009
Study tour	Cairo – Kafr El Sheik	15 and 16 September, 2008
Study tour	Khartoum – Kenana	25 to 27 January, 2009

At the Inception Phase workshop, a detailed questionnaire was handed to participants from each of the basin countries to collect background information on the local irrigation schemes. This background information is required for the characterization of irrigation schemes, their objectives, water demand and supply, technology, institutions and management. The questionnaire is enclosed as Appendix 1. By the time of the Validation Workshop, only Egypt and Kenya had provided a substantive response. Accordingly, a simpler data set was proposed at the Arusha meeting (July 2008), with an agreed deadline of August 15[1] for submission of information. It was also suggested that a dataset of minimally three irrigation schemes for each country was provided. The aim was to have at least a few complete datasets, rather than trying to be comprehensive. The response was again insufficient for making a standardized analysis among countries and irrigation schemes. The countries have not been able to provide the data for 3 irrigation schemes. The countries also failed to hand over maps with location of irrigated areas and the names of the schemes. An exception is Egypt and Burundi that provided data for certain irrigation schemes, although not the type of data being asked for.

In the absence of this information, "best practices" in terms of infrastructure, institutional arrangements, water allocation procedures, rules for allocation and responsibilities for management cannot be specified. The factors that might be expected to influence the performance of irrigation systems include, for example, whether the system is agency-managed or farmer-managed; the nature of the infrastructure and its condition; land tenure arrangements and farm sizes; the reliability and adequacy of irrigation supplies; the types of crops grown, prices, and access to markets.

For the purposes of this study – which did not provide for field visits to irrigation systems or agencies managing irrigation systems - the limited set of information actually available poses significant difficulties. It was therefore decided to conduct the current study essentially on the basis of public domain data. This lack of information has effects on the capability to describe guidelines of implementation and the action plans for future investments. It is not straightforward to report on action plans if the local context of irrigation is hardly understood.

The main report has four different components:

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[1] August 25 for Burundi

Part 1: Inventory of LSI schemes, Best Practices and Best Practice Sites:
Part 2: Guidelines on Best Practices and Sites
Part 3: Action Plans for Up scaling and/or Investment by SAPs
Part 4: Summary and Way Forward

The subsequent chapters in part 1 of the main report will address the follow questions:

- Chapter 2: Where are the LSI schemes located and what are the major agricultural activities ?
- Chapter 3: How can good practices be determined?
- Chapter 4: What are the key physical processes in the LSI schemes?
- Chapter 5: What are the key socio-economic factors in the LSI?
- Chapter 6: Which country level institutions exist and what are the centres of excellence?
- Chapter 7: Where is irrigation management good, and what are the success factors?

The appendices of this main report contain irrigation reports for each country. They are essentially based on new data that we have derived from satellites. Also existing data and public domain data has been consulted to check consistencies.

Another appendix contains the reports of the study tours to Egypt and Sudan.

2 Inventory of large scale irrigation schemes in the Nile Basin

2.1 General

The Large Scale Irrigated (LSI) areas of eight Nile Basin countries are identified in this study. The various Nile Basin countries use different definitions for LSIs. We have in this study used a minimum irrigated area of 200 ha to comply with the minimum size of the Nile country definitions. This means that all areas smaller than 200 ha are disregarded. In fact, a parallel study conducted for EWUAP is dealing with the small holder irrigation practices (McAllistor-Anderson, 2008). The DRC covers a very small area of the Nile Basin, and due to its two rainy seasons, irrigation is not a common phenomenon in the DRC. Since the DRC has no LSI, this country has been excluded from this LSI study. Eritrea is not an active member of the NBI, and its irrigated area is therefore also not included. For these reasons, eight countries were investigated.

LSI schemes are usually managed centrally by Governments down to a certain level from where the responsibility for water distribution is transferred to the users of irrigation water. Irrigation schemes are usually subdivided into units which service a specific "service area" or "canal command area" through a system of canals and pipelines. Irrigation managers use "canal command areas" as the management unit for decisions regarding flow regulation and water allocations.

Quality assessment of an irrigation management system requires the boundaries of the canal command areas to be known. A digital database with the physical boundaries of schemes and command areas for the Nile Basin would have been very valuable, but it was not obtainable through EWUAP nor did it become available after the various workshops where this lack of information has been discussed. It will have a great recurrent value for the entire irrigation sector in the Nile Basin. This study has prepared a first version of such map.

In the absence of the physical boundaries of the irrigation system, the management and operation of LSI schemes cannot be discussed. This poses a limitation for water balance determinations. It also hampers the presentation of aggregated data; it is not possible to present and discuss the irrigation situation in a certain command area or total irrigation scheme if the boundaries are unknown. For the presentation of spatially aggregated data, we used the administrative boundaries instead. A shape file of all administrative boundaries has kindly been provided by the FAO Nile Basin office (see Figure 4). The shape file of Figure 4 will be used for the presentation of pixel based results in chapter 4 and the country reports in the Appendices.

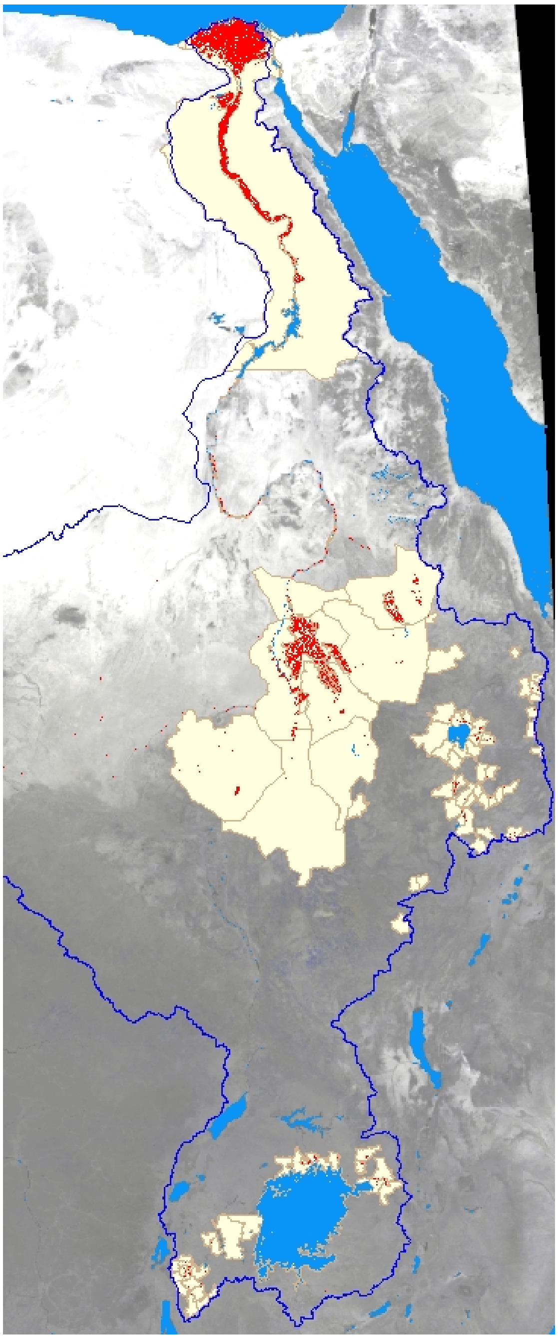

Figure 4 Distribution of administrative boundaries of areas across the Nile Basin which contain LSI systems. These boundaries were used for the presentation of aggregated irrigation data results. The red dots and clumps of dots refer to LSI schemes

2.2 Public domain irrigated area statistics

There are two public domain databases available that can be used to develop a spatial inventory of the location and size of LSI systems in the Nile Basin:

- FAO - Global Map Irrigated Areas (GMIA)
- IWMI – Global Irrigated Area Map (GIAM)
    -

The first global map of irrigated areas was developed at the Center for Environmental Systems Research, University of Kassel in 1999; it described the fraction of each 0.5 degree cell area that was equipped for irrigation around 1995. The most up-to-date available global map of irrigated areas (version 4.0.1, February 2007) is an improved version of the GMIA map which has been prepared jointly with the Land and Water Development Division of FAO in Rome. The GMIA map shows the area within each 5 minute cell (area 9.25 km by 9.25 km at the equator) that was equipped for irrigation around year 2000. It was updated through the use of a Global Irrigation Map Generator which combines a data base containing geographic information on irrigated areas (e.g. point or polygon information on the location, size of irrigation projects, raster data) and statistical information on the total irrigated area in administrative units like countries, districts, or counties (scheme of mapping methodology).

The FAO Nile Basin office in Entebbe is working on a refinement of the GMIA map for the Nile Basin countries only. During the reporting period, this product was not available for inclusion in the current study.

IWMI produced their GIAM map for 1999 using multiple satellite sensor and secondary data. The study first segmented the world into climate and elevation zones and analyzed satellite images separately for these zones. The class identification and labelling process is based on a spectral matching technique. The time-series spectra of classes were compared with the target ones obtained from ground truthed locations. The irrigated areas in these maps were calculated based on sub-pixel areas. The sub-pixel areas were established by multiplying the full pixel areas of the classes with the irrigated area fractions established and based on: (i) Google Earth, (ii) high resolution imagery, and (iii) a sub-pixel decomposition technique.

Both FAO and IWMI products have a global orientation, and they should therefore be considered as first approximations. It is unfair to expect them to be perfect, but by absence of better materials, this is the best point of departure. While these FAO and IWMI datasets are a good start for the inventory of LSI schemes in the Nile Basin, their results are not mutually consistent (Table 2). If we look at the total irrigated areas of the eight Nile Basin countries, FAO estimates 5.6 million ha under irrigation, and IWMI only 4.3 million ha. Except for Rwanda, Kenya and Uganda, the FAO estimates exceed the areas estimated by IWMI. This difference of 25 % is undesirable, and shows the need to establish an accurate LSI map under the umbrella of NBI. The data from Aquastat has been added for the sake of completeness. It reveals that FAO has internally inconsistent statistics.

Table 2 Actually irrigated areas in the Nile Basin according to different sources

Country	**FAO – GMIA (irrigated areas in the entire country)**	**IWMI – GIAM (irrigated areas in the entire country)**	**Current study (only irrigated areas in the Nile Basin component of the Nile Basin)**	**FAO Aquastat (the entire country)**
	Irrigated area (ha)			
Burundi	14,400	11,793	14,625	90,000
Egypt	3,245,650	2,144,099	2,963,581	5,419,000
Ethiopia	184,239	160,785	90,769	187,000
Kenya	66,610	85,401	34,156	77,000
Rwanda	4,000	80,067	17,638	1,697,000
Sudan	1,946,200	1,737,188	1,749,300	4,000
Tanzania	184,330	46,022	475	108,000
Uganda	9,120	30,017	25,131	9,000
Total	**5,654,549**	**4,295,372**	**4,895,675**	**7,591,000**

After a comparison of the FAO and IWMI products against independently acquired MODIS and Landsat images it was concluded that the FAO product is currently more accurate for eastern Africa. A first round of irrigation performance analysis was therefore executed and presented at the LSI Validation Workshop in Arusha based on the selected FAO map of irrigated areas. The feedback received from the participants was that (i) many of the irrigated land identified in the equatorial region are marshlands and swamps and (ii) certain LSI systems are missing. A miss-classification of the irrigated land resulted in an erroneous irrigation analysis. The consultants have therefore requested the National Project Coordinators (NPC) and representatives to assist them with locally available maps of irrigated land and to get access to detailed land cover maps and GIS systems. This exercise was only partially successful (as indicated in chapter 1 the response was below expectations and not very encouraging).

2.3 Multiple-source identification of LSI schemes present in the Nile Basin

Multiple sources of information were integrated to improve the FAO – GMIA map for the Nile Basin. Burundi and Rwanda have sent shape files that were generated from existing maps and GPS field surveys. Following the recommendations of the Arusha Validation workshop, Google Earth images were used to manually detect irrigated areas. Historic Landsat images were also collected and manually inspected to identify additional irrigated areas. It should be recognized that an area of 200 ha is a block of land of 1.4 km x 1.4 km only, and that it is not easy to detect these small spatial features in a 3,300 million ha large basin (3.3 million km^2).

The success of this additional inventory from Google Earth and Landsat images depends on the time of the image acquisition (bare or cropped land) and the nature of the irrigation system. Some irrigation systems can easily be detected at certain times and at other times not. Larger rectangular systems can be recognized more easily than irregularly shaped irrigation systems. So the shape and size of the irrigation schemes had an effect on the recognition of the LSIs. Table 3 indicates which methodologies were used for different countries.

Table 3 Sources of information used to identify the irrigated areas per country. The data covers the period 2000 to 2008

Country	**FAO - GMIA**	**Reports and other studies**	**Shape files from the country representative**	**Manual digitizing**
Uganda		x		x
Tanzania		x		x
Sudan	x	x		x
Rwanda		x	x	
Kenya		x		x
Ethiopia	x	x		x
Egypt	x	x		x
Burundi		x	x	

An additional check was made to verify whether the land was cropped. MODIS-based Leaf Area Index and Vegetation Index maps from 2007 were used to check whether the land was irrigated during 2007. Minimum biomass production and crop evapotranspiration thresholds were applied to filter irrigated from irrigable land and fallow land. The inclusion of the MODIS data resulted in the final Nile Basin irrigation mask to be 250 m (see Figure 5).

The next step of the improvement of the irrigated area map would be to organize a field survey to the areas with the largest uncertainties. The largest uncertainties are found in Kenya, Uganda and Ethiopia. Such field survey has to be organized throught EWUAP because these countries on their own have not been able to provide these maps.

We found that a total surface of 4,895,675 ha is irrigated at least during one growing season (see Table 2). Our results are within the range of the FAO and IWMI estimates. A total of 61% of the irrigated land is located in Egypt and 36% in Sudan. The vast majority (97%) of the LSI systems are thus located in these two arid countries. Ethiopia has the third largest area (90,000 ha) of irrigated land in the Nile Basin. The remaining area is divided in small pieces among the remaining six Nile Basin countries. These percentages are likely to change in the future when investments in land reclamation activities and the development of irrigation systems continue, especially when donor funding become available after the FAO's declaration to promote irrigated agriculture in Africa.

The map with irrigated areas is displayed in Figure 5. Most LSI systems are in the vicinity of streams and rivers from where water can be withdrawn without restriction. Irrigation water is also withdrawn from reservoirs and natural lakes (Lake Victoria and Lake Tana). Some of these systems will be discussed in more detail in section 2.3.

Figure 5 can be considered as a reasonable baseline map for irrigation planning in the Nile Basin. In recent consultation with national irrigation experts from the NBI countries (Addis Ababa; December 2008) the general impression was that this map is acceptable, though not perfect. Refinements of the map can be made, and this is a recommendation for a next study under the umbrella of NBI.

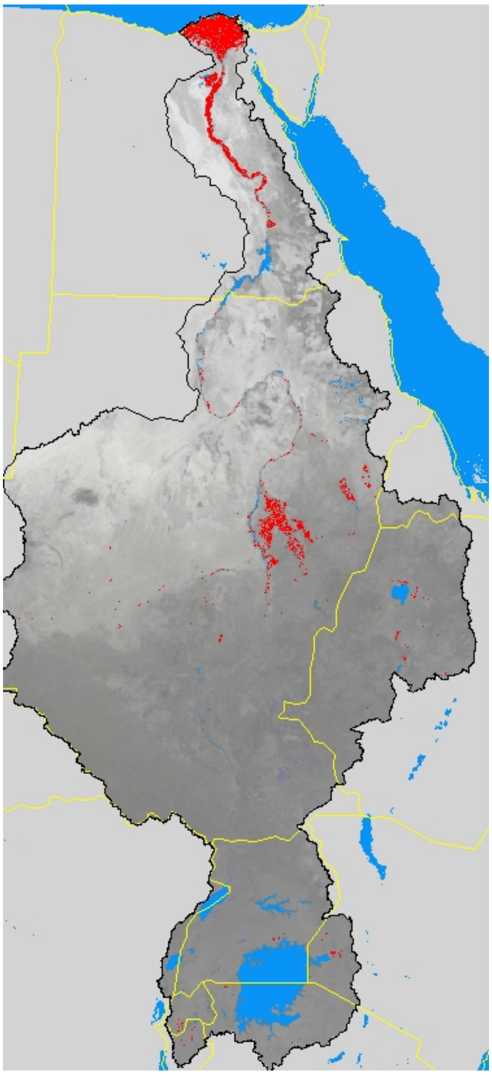

Figure 5 Distribution of irrigated areas across the Nile Basin, indicated by red dots (source: this study). The spatial resolution is 250 m. The country boundaries are superimposed

The irrigated area for each administrative district is presented in Table 4. A minimum size of 200 ha has been used as a criterion to include a certain district. Whereas the districts in the equatorial region cover only a few hundred hectares, the districts in Egypt cover thousands of hectares.

Table 4 Irrigated area for each administrative district in the Nile Basin[2]

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[2] A minor difference in irrigated area statistics presented in this table per district and the total irrigated area per country exists. This difference can be explained by the removal of certain districts with scattered irrigation systems smaller than 200 ha

Country	Administrative district	Area irrigated (ha)		Country	Administrative district	Area irrigated (ha)
Burundi	Bugabira	2413		Kenya	Bungoma	4319
Burundi	Bugendana	1944		Kenya	Butere Mumais	3413
Burundi	Bugenyuzi	3200		Kenya	Kericho	1531
Burundi	Busiga	2063		Kenya	Kisumu	22350
Burundi	Butaganzwa	713		Kenya	Nandi	2544
Burundi	Butaganzwal	3025		Rwanda	Butare	4025
Burundi	Cankuzo	1113		Rwanda	Gatagara	1038
Egypt	Al Buhayrah	465644		Rwanda	Gatsibo	281
Egypt	Al Daqahliyah	305981		Rwanda	Gikongoro	300
Egypt	Al Fayyum	141263		Rwanda	Gisagara	7594
Egypt	Al Gharbiyah	176881		Rwanda	Kayonza	813
Egypt	Al Iskandariyah	89200		Rwanda	Nyanza	3275
Egypt	Al Jizah	55594		Rwanda	Nyaruguru	313
Egypt	Al Minufiyah	127956		Sudan	Al Jazeera	31681
Egypt	Al Minya	200238		Sudan	Aliab & Food Security	1800
Egypt	Al Qalyubiyah	64019		Sudan	Asalaia	8388
Egypt	Al Wadi/Al Jadid	1081		Sudan	Bawga	806
Egypt	As Ismailiyah	34544		Sudan	Blue Nile	7819
Egypt	Ash Sharqiyah	346875		Sudan	Blue Nile schemes	47731
Egypt	Aswan	44288		Sudan	El afad scheme	1031
Egypt	Asyiut	142438		Sudan	El bakri scheme	238
Egypt	Beni Suwayf	121744		Sudan	El gamoaia	2550
Egypt	Bur Said	9344		Sudan	El gazera & Managil scheme	743694
Egypt	Dumyat	53650		Sudan	El golid scheme	2375
Egypt	Kafr-El-Sheikh	300100		Sudan	El goshap scheme	400
Egypt	Matruh	12875		Sudan	El guriar scheme	469
Egypt	not specified	247169		Sudan	El jiniad	26244
Egypt	Qina	140400		Sudan	Fadlab	675
Egypt	Suhaj	137381		Sudan	Gabria, Karad ps	406
Ethiopia	Abay Chomen	11081		Sudan	Ganadutu	800
Ethiopia	Achefer	625		Sudan	Gedaref	11906
Ethiopia	Adwa	656		Sudan	Ghabah scheme	288
Ethiopia	Alaje	194		Sudan	Ghadar scheme	63
Ethiopia	Alefa	231		Sudan	Ghanati scheme	194
Ethiopia	Ambasel	325		Sudan	Halfa sugar	112350
Ethiopia	Ambo	488		Sudan	Kaboshia	194
Ethiopia	Amuru Jarti	475		Sudan	Karmakol scheme	550
Ethiopia	Asosa	488		Sudan	Kassala	49275
Ethiopia	Awabel	413		Sudan	Kelli	413
Ethiopia	Bahir Dar Zuria	2413		Sudan	Kenana	39000
Ethiopia	Bench	338		Sudan	Kenana new extention	231
Ethiopia	Berehna Aleltu	925		Sudan	Khartoum	23975
Ethiopia	Bure Wemberma	431		Sudan	Kitiab	1281
Ethiopia	Chilga	3256		Sudan	Kulud scheme	581

Ethiopia	Dejen	2550		Sudan	Lati basin scheme	3613
Ethiopia	Dembia	10956		Sudan	Northern	350
Ethiopia	Dera	575		Sudan	Nuri scheme	525
Ethiopia	Enderta	700		Sudan	Rahad	122225
Ethiopia	Farta	4194		Sudan	Seleim, Borgiag ps	14394
Ethiopia	Fogera	6263		Sudan	Seliet	2938
Ethiopia	Gidan	1300		Sudan	Sennar	69331
Ethiopia	Goncha Siso Enese	200		Sudan	South Kordofan	26150
Ethiopia	Gonder Zuria	4400		Sudan	Suki	28931
Ethiopia	Guduru	1050		Sudan	Tungasi scheme	1138
Ethiopia	Guzamn	556		Sudan	Umm dom ps	1375
Ethiopia	Hintalo Wajirat	2725		Sudan	Upper Nile	22956
Ethiopia	Hulet Ej Enese	331		Sudan	Wad Aunsa	16525
Ethiopia	Jabi Tehnan	14075		Sudan	West Sennar sugar scheme	12494
Ethiopia	Jeldu	238		Sudan	White Nile	156744
Ethiopia	Kafta Humera	369		Sudan	Ziadab	3606
Ethiopia	Kemekem	3394		Tanzania	Bukoba	4831
Ethiopia	Machakel	3031		Tanzania	Karagwe	1650
Ethiopia	Merawi	400		Uganda	Bugiri	1319
Ethiopia	Mulona Sululta	3031		Uganda	Jinja	9988
Ethiopia	Ofla	325		Uganda	Mabira Forest	1325
Ethiopia	Samre	506		Uganda	Mayuge	556
Ethiopia	Setema	856		Uganda	Mukono	11450
Ethiopia	Shebel Berenta	1481		Uganda	Wakiso	256
Ethiopia	Sigmo	575				
Ethiopia	Walmara	1294				
Ethiopia	Wegde	281				

2.4 Selected LSI schemes for detailed irrigation performance analysis

General

In addition to remote sensing data for the entire Nile Basin, more information was acquired from a few selected schemes to get a comprehensive picture of the irrigation and drainage mechanisms, including its socio-economic dimension. Burundi, Egypt and Kenya have provided useful additional irrigation data, which are difficult to get access to via public domain websites. Rwanda and Sudan have provided data related to certain irrigation schemes and their acreages. Rwanda has also provided strategic rice production information. Ethiopia, Tanzania and Uganda did not provide their data.

The authors of this report had access to some additional data for the LSI schemes in Sudan from a previous study. Considering the importance of Sudan as an irrigation country, it was decided to include this data in the analysis. Overall, it can be concluded that there is very little information available on the water balance of the LSI systems. Because water resources information for future planning of irrigation development is indispensable, a simple water budget was computed for all irrigated land in each country. The resulting water budgets are presented in the parallel report. The countries with extra irrigation data will be discussed in alphabetic order hereafter.

Burundi

Burundi provided shape files with the locations of their LSIs. Irrigation takes place in the following river basins: Ruvubu, Malagarazi, Rukoziri, Lake Tanganyika, Rumpungwe, and Kanyaru. The major irrigated crop is rice, followed by babana, sugarcane, maize and coffee. Sosumu is one of the important sugarcane schemes in Burundi. The Burundi delegation has provided important background data on four irrigation schemes: Nyamugari (150 ha), Kagoma (178 ha), Nyakagezi (200 ha) and Nyarubanda (235 ha). The main purpose of irrigation in Burundi is rural development. The irrigation systems consist of surface irrigation. The results of the data analysis will be provided in Chapter 3.

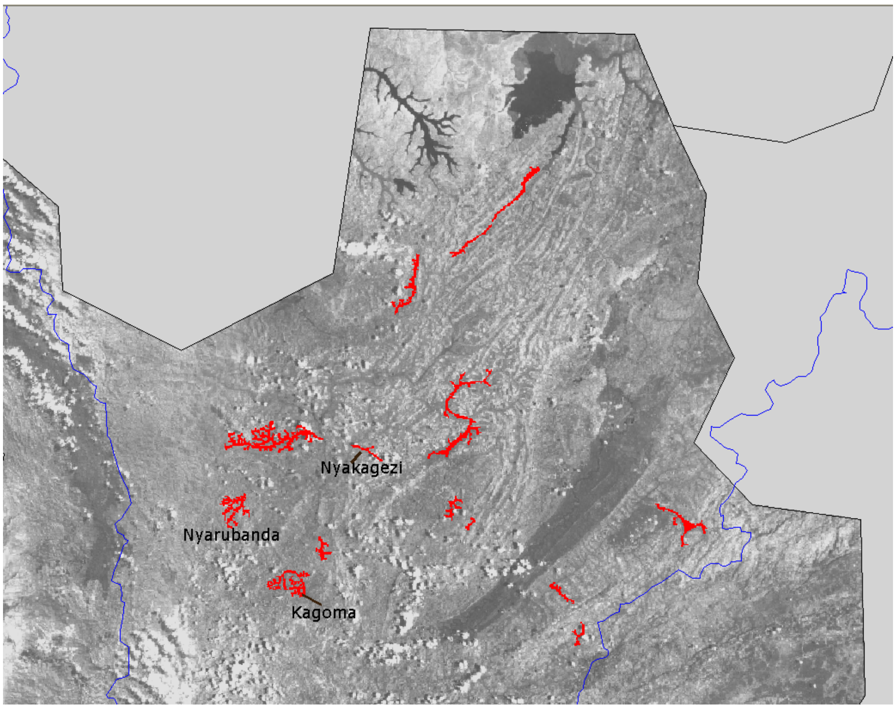

Figure 6 Location of selected irrigation schemes in Burundi for in-depth study. The background is from a Landsat image.

Egypt

Egypt has collected irrigation data for the Bahr El Nour canal in the central-north Nile Delta. The water for this irrigation system is supplied from the Zifta barrage, located North of Tanta city. The canal command area supplies water to 1,500 ha of land. The second pilot area selected for a more detailed study is W10, located West of Kafr El Sheikh and supplied with water by the Mit Yazid canal. W10 is part of the Integrated Irrigation Improvement and Management Project (IIIMP) and was visited during the study tour of September 2008. The irrigated area selected in W10 is referred to as El-Sefsafa, and comprises an area of 650 ha. The third area selected for detailed studies in Egypt is the Sila district located in the Fayoum Depression. The area comprises 10,000 ha and is thus significantly larger than the other two focus areas in Egypt.

A dual cropping system is practiced in the Nile Delta. The farmers follow a certain crop rotation system. The summer crops consist mainly of rice, cotton and maize. The typical winter crops are wheat and berseem (fodder). The cropping seasons for the different varieties of berseem and their number of cuts are quite diverse, making it impossible to choose a single fixed cropping season for berseem. Other winter crops include faba beans and (in Kafr El Sheikh) sugar beets. Orchards with fruit trees are perennial and they occur everywhere. Vegetables are cultivated in both the winter and summer season. Detailed cropping calendars are presented in the country reports.

The summer crops consist mainly of rice, cotton and maize. The length of the cropping season has shifted over the last couple of years. The rice growing season has been shortened by a few weeks after the introduction of shorter duration and new high yielding varieties.

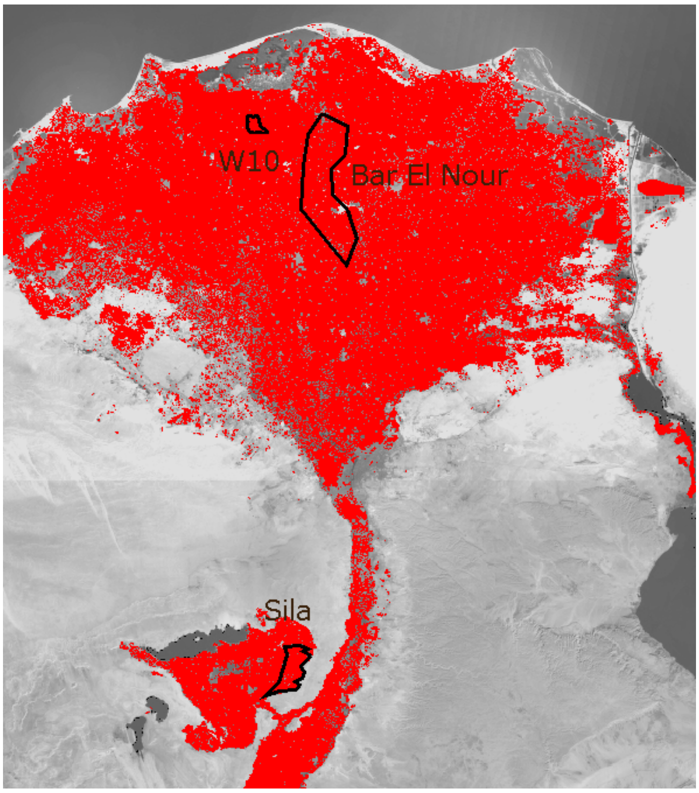

Figure 7 Location of selected irrigation schemes in Egypt for in-depth study. The background is from a Landsat image.

Kenya

The National Irrigation Board of Kenya has provided some information on selected LSIs. Most of the schemes are unfortunately not located inside the Nile Basin. The schemes in the lowlands of Lake Victoria for which key data are provided are (i) Ahero (scheme) and Nyando (district) with 960 ha, (ii) Bunyala (scheme) and Busia (district) with 313 ha and (iii) West Kano (scheme) near Kabonyo town and Kisumu (district) with 900 ha. While these schemes are very small compared to the LSIs in Egypt and Sudan, they contribute significantly to the irrigation activities in Kenya.

The Nyanza scheme is located in the Nzoia Basin. The water sources include abstraction from Lake Victoria, groundwater, diversions from rivers and from wetlands. The use of lake water requires lifting. The Lake shore area has a mild climate: the wet season elapses from March to May and the dry season from December to February. The average annual rainfall varies from 800 to 1,000 mm and increases towards the Highlands to 2,000 mm per year. Evaporation exceeds rainfall in those months except for April and May. Supplementary irrigation is thus essential. The irrigated crops are mainly rice, pineapple and sugarcane.

Bunyala is the major existing irrigation scheme in the area under the management of the National Irrigation Board and covers 280 ha. Lessons learned here are: the need for comprehensive and sound operation and maintenance arrangements; the need to produce crops that can pay for the pumping costs.

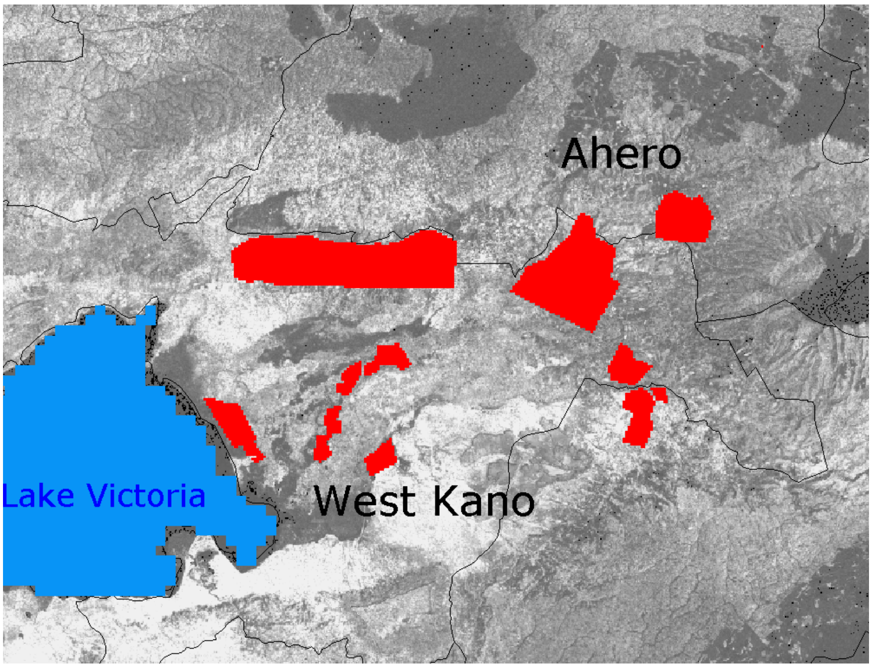

Figure 8 Location of selected irrigation schemes in Kenya for in-depth study. The background is from a Landsat image

Rwanda

The irrigation systems of Rwanda are used mainly to produce rice. There is approximately 15,000 ha rice in Rwanda. There are about 2,000 ha of sugarcane plantation near Kigali City on the banks of the Nyabugogo and Nyabarongo Rivers. Maize and sorghum can also be irrigated under the agricultural conditions of Rwanda.

The seven most important LSIs of Rwanda are build behind small dams. As demonstrated in Figure 9 most of the systems are located in narrow river valleys. The LSIs are Kanyonyomba, d'Agasasa, Migina, Bugarama, Kibaya, Base and Murago.

The largest irrigated rice system in Rwanda is Bugarama (1,236 ha) located in the Rusizi district, western Province. The second largest LSI system with rice in Rwanda – for which data is made available - is Kabogobogo (598 ha), located in the Gisagara district, southern Province. The third largest rice irrigation system is

Miravi (408 ha) that is situated in the same Gisagara district. The source of this information is RADA – rice development unit.

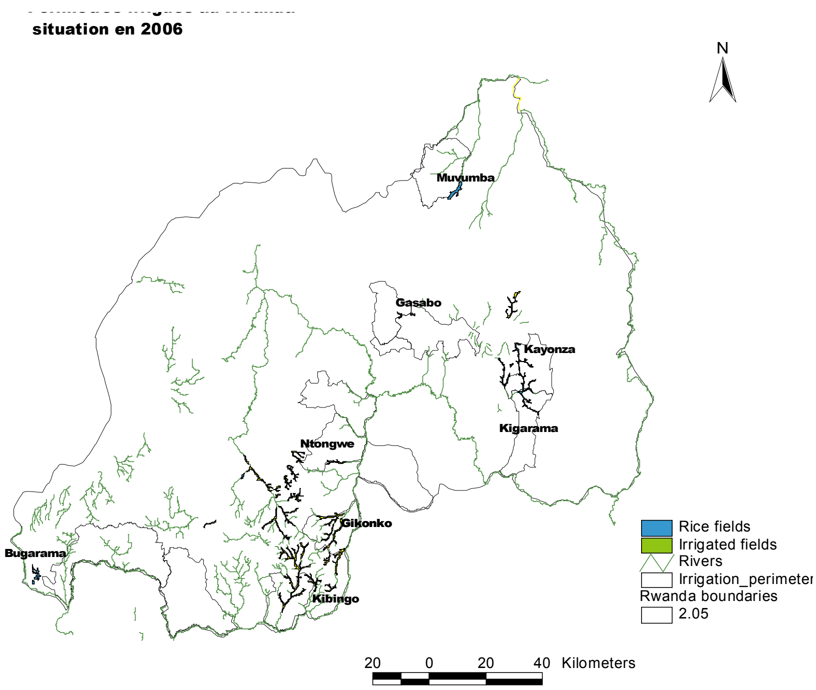

Figure 9 Location of the detailed study areas in Rwanda

Sudan

Sudan hosts the second largest area of national irrigated land in the Nile Basin countries. The majority of the schemes are found between 12° and 16° North where rainfall is insufficient for an assured crop production (200 to 500 mm/yr). The Gezira/Managil Scheme is the largest in size (982,063 ha), followed by the Rahad Scheme (153,756 ha) and the New Halfa Scheme (146,138 ha). The Gezira scheme is Africa's largest irrigation system. Water is withdrawn from the White Nile (Kenana Sugar Scheme and Assalya Sugar Scheme), Blue Nile (Gezira, El Suki Scheme, Sennar Sugar Scheme, Guneid Sugar Scheme and Guneid Extension), the Dinder River (El Suki Scheme), the Rahad River (Rahad Scheme), and the Atbara River (New Halfa scheme and New Halfa Sugar Scheme). All these rivers run from the Ethiopian Plateau to the arid landscape of Sudan. Figure 11 summarizes the location and the names of the major LSI schemes of Sudan.

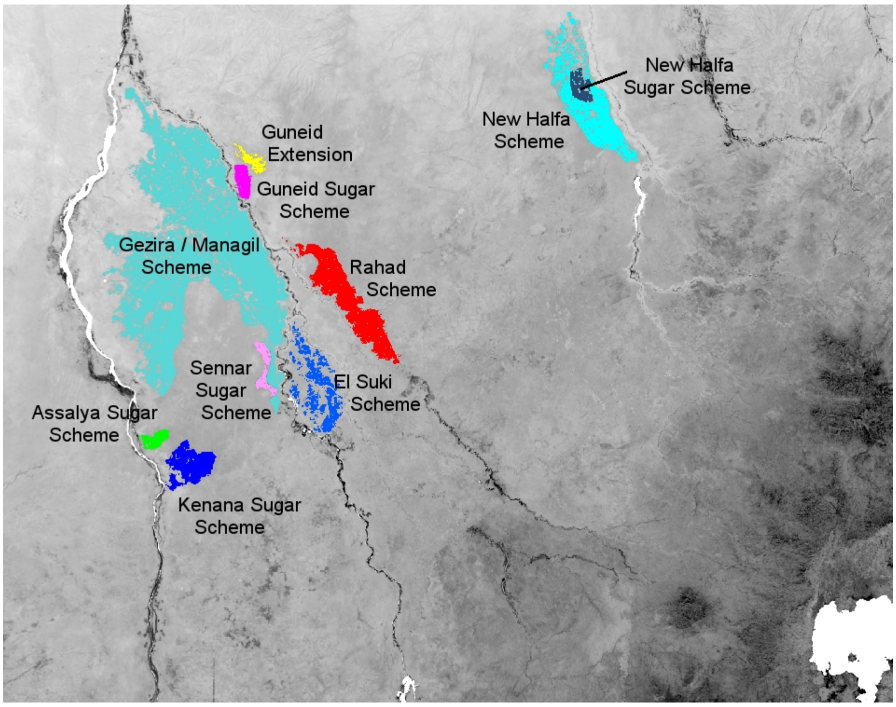

Figure 10 Location of the detailed study areas in Sudan (source: WaterWatch, 2006)

Five irrigation systems are for large scale sugar plantations of which four are owned by the Sudanese government and one (Kenana Sugar Co.) by a group of investors that have 63,531 ha of irrigated land. The major crops in the other five schemes (of which the Gezira/Managil Scheme occupies 982,063 ha) consist of cotton, sorghum, wheat and groundnuts. Approximately 60% of the total area in the Gezira/Managil system is sorghum. Other crops are cotton (17%), wheat (6%), groundnut (4%) and other crops (13%). From sowing to harvesting, sorghum requires approximately 120 days (4 months). Sorghum grows between June and December, depending on sowing date. The winter crops are wheat and cotton, which are both harvested in February and March. The Rahad Scheme contains groundnuts and sorghum.

2.5 Distribution of irrigated crop types

Considering the vast size of the irrigated areas, the volumes of water being diverted and the economic returns from irrigation, it is of essence to understand the major irrigated crops more systematically. The major irrigated crops in the Nile Basin are wheat, fodder, maize, cotto, rice, vegetables, sorghum and groundnuts. The location of all these crops is only marginally understood, and they may change from year to year due to crop rotation. Irrigated fodder typically occurs in Egypt. According to the statistics of Table 5, Sudan has not much irrigated fodder. Sudan hosts the majority of sorghum and groundnuts. Vegetables are the main irrigated crops in Ethiopia. Rice and vegetables are the dominant irrigated crops of Uganda, Tanzania, Rwanda, Kenya and Burundi. Vegetables can be regarded as high value crops. Rice is staple food in the equatorial region. Sugarcane is most common in Sudan and Ethiopia.

Table 5 suggests that there is a total irrigated area of 7,591,000 ha in the Nile Basin. The source is Aquastat. This source was added in the last column of Table 2.

There is a considerable difference in annual cropping intensity. According to Aquastat, Egypt and Burundi have multiple crops and cropping intensities of 167 and 180% respectively. The average value for the entire Nile Basin is 135%. This implies that several countries have only one irrigation season. This is true for single modal rainfall climates, where irrigation takes place in the dry period. While it is good to have these statistics, there are no maps available that show where these types of crops are grown. The implication is that we cannot assess the crop specific values for biomass production and crop water use. That is feasible only if for every pixel the type of crop is known. Instead, the subsequent chapters deal with average values for administrative boundaries (districts, countries), rather than for crops. Although it will be a considerable effort, it is worth making a geographical crop inventory. This is one of the activities of the FAO-Nile program.

Table 5 Irrigated crop types in the Nile Basin (expressed in 1000 ha). The sources is Aquastat

	Burundi	**Egypt**	**Ethiopia**	**Kenya**	**Rwanda**	**Sudan**	**Tanzania**	**Uganda**	**Total**
wheat	0	1021	0	0	0	249	0	0	1270
fodder	0	1098	0	0	0	0	0	0	1098
maize	43	795	23	4	0	33	16	0	914
cotton	0	321	43	3	0	332	0	0	699
rice	17	607	0	18	2	0	34	5	683
vegetables	9	421	70	26	2	80	38	0	646
sorghum	18	158	20	0	0	394	0	0	590
groundnuts	0	49	0	0	0	384	0	0	433
fruit	0	311	0	0	0	95	0	0	406
pulses	0	178	2	0	0	46	0	0	226
citrus	0	131	3	5	0	12	7	0	158
sugar cane	3	0	17	2	0	72	13	4	111
patatoes	0	85	0	0	0	0	0	0	85
barley	0	58	0	0	0	0	0	0	58
sugar beets	0	41	0	0	0	0	0	0	41
Oil crop	0	20	0	0	0	0	0	0	20
coffee	0	0	0	18	0	0	0	0	18
soyabeans	0	0	4	0	0	0	0	0	4
tabacco	0	0	4	0	0	0	0	0	4
bananas	0	0	1	1	0	0	0	0	2
All irrigated crop	**90**	**5419**	**187**	**77**	**1697**	**4**	**108**	**9**	**7591**
Equipped for irrigation	**50**	**3246**	**161**	**68**	**1946**	**4**	**150**	**9**	**5634**
Annual cropping intensity	180	167	116	113	87	100	72	100	

Rwanda and Tanzania have an annual cropping intensity being less than 100%. This is related to the fact that not all irrigable land is irrigated. The lack of economic incentives and ensured water resources are typical reasons for this behaviour.

3 Spatial irrigation diagnosis: methodology

3.1 Selection of irrigation performance indicators

To get water from the river to the irrigation plot requires management by several stakeholders at different levels. The national Governments are responsible for water resources planning at the river basin scale and the NBI advises on international water allocation and river basin hydrology issues. The Line Agencies are responsible for the construction of dams and the allocation and distribution of irrigation water through the main network of canals. At certain points in the delivery system, the responsibility for managing the irrigation water is transferred to the water user associations or equivalent water user cooperatives. The individual farmer is the end-user of water.

All the stakeholders together will determine the attainable and achievable land and water productivities.

It is generally accepted that the management of irrigation systems by the governing water institutes, water user associations, and the farmers has impact on the attainable productivity levels and water consumption. The challenge of this study is to find the datasets that could underpin this socio-technical irrigation systems analysis, and to highlight weaknesses and strengths of the systems.

The general framework of irrigation performance introduced in Chapter 1 is meant to quantify irrigation and irrigation related processes between allocation – diversion – distribution – consumption – production – gross return – income – welfare – social stability. The joint ICID – IWMI publication (Bos et al., 2005) describes the data set required for the calculation of a comprehensive set of irrigation performance indicators:

- actual cropped area
- irrigable area
- crop yield
- crop water demand
- crop water consumption (ET)
- effective precipitation
- irrigation water supply
- irrigation interval
- irrigation water fee
- operation and maintenance costs
- market prices
- production costs

- actual canal water level
- groundwater depth
- salinity of irrigation water
- functioning of infrastructure

Considering that requests for key data were not met (not even for the detailed analysis of selected LSI schemes) indicators to describe LSI operations had to be simplified. Consequently, a minimum list of indicators should be compiled that can be derived from other sources.

If water is the limiting resource for crop yield, then the productivity should be expressed as yield per unit of water (and not per unit of land, as is done traditionally). While farmers and agronomists focus on benefit per unit of land, water resources engineers are more interested to evaluate benefits per unit of water. The overall water scarcity prompts water resources planners and irrigators to allocate water in accordance with social and political priorities: first to domestic use, then to industry (which usually adds more value than irrigation) and finally to irrigation (having ensured that environmental needs are met). This is not necessarily the attitude of the farmer who's legitimate interest is to maximize his farming income. Which in turn means having "enough" water to ensure good yields. In the longer term, especially where water is scarce or where a non-renewable resource is utilized, it is to the advantage of the farmer to be conservative with irrigation water and increase the sustainability of irrigation systems.

For the purpose of this study, we regard an irrigation system to be performing well if (later on we will see that some modification is required):

- Crop production is at a level that secures food production and provides a steady and sufficient income for farmers to be able to continue their farming practices and by doing so provide employment and utilize the agribusiness industry of the region (kg/ha).
- High crop production is achieved with a minimum amount of total water consumption so that more water remains in the basin for downstream irrigators and other water user sectors (kg/m3).

Since the location of the crop types are not known, biomass productivity can be used as a surrogate for crop yield. Crop yield is the result of biomass production, harvest index and the moisture content of the harvested product. Biomass production is the total dry matter production inside and above the ground (roots, stems, leaves, grains, flowers etc). There are remote sensing techniques available to estimate biomass production without knowing the crop type. This is an advantage for the type of studies portrayed in this report. Biomass production can in general terms be considered as the indicator for land productivity. This solves also the problem of having to compare many different vegetative products; the total biomass production for a given area is easy to synthesize. It is especially useful for this LSI study with 5 million ha of irrigated land without accurate description of the crop types. It should be noted at the same time, that the absence of reliable crop information prevents an adequate agro-economic assessment. Nevertheless, the advantage of biomass production is that the physical production levels can be assessed and used to qualitatively express land production of irrigated parcels, LSIs, and countries in the Nile Basin. A consequence of the absence of crop statistics and crop yield data throughout the Nile Basin requires water productivity to be expressed in terms of biomass water productivity. This is not a problem provided the resulting values are recognized to be higher than published values.

The land and water productivity indicators are the outcome of the combined impact of soils, climate, institutions, education, market prices, irrigation management transfer, available water resources, laws, regulations, irrigation modernization, irrigation systems, the irrigation water distribution system and much more. Where we have detailed data provided by the national irrigation coordinators for selected LSI schemes (see Figure 11), we have utilized the yield and flow data wherever applicable. In all other cases, we have used remote sensing data to estimate the productivity of LSI schemes.

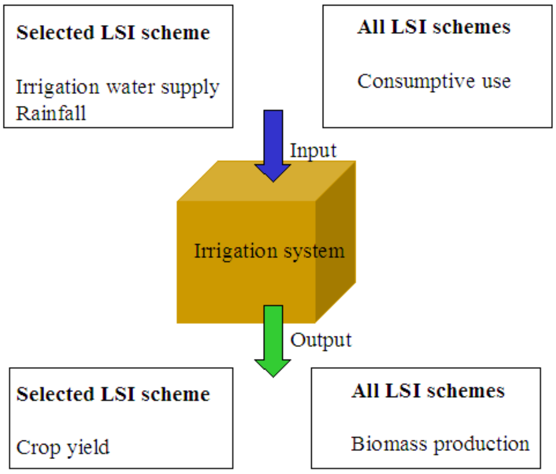

Figure 11 Schematic diagram showing the different expressions for land and water productivity

3.2 Irrigation efficiency or water productivity?

The international irrigation community is under pressure to produce more food from less available water resources. This is not a special feature of the Nile Basin, but holds true for most irrigated river basins located in semi-arid and arid climate systems. Improved irrigation efficiency was traditionally seen as the answer to overcome the water crisis in the irrigation sector. Several results at various places have indicated that the problem is hydrologically more complex.

Improving irrigation efficiency will reduce losses from irrigated plots and the conveyance system, but "losses" may also be recovered in streams and underlying aquifers, which is beneficial for irrigation systems dependent on groundwater. When irrigation canals in Haryana (India) were lined to increase the conveyance efficiency, the recharge to the aquifers reduced. Due to a lower supply – and continuation of the abstractions - the groundwater table declination accelerated; exactly the opposite to what the agencies wanted to achieve!

At certain places in USA, China, Morocco and Tunisia, the total volumetric crop water consumption has increased due to the introduction of water saving technologies. Modern irrigation systems such as micro-sprinklers and drip systems have a high consumption/supply fraction. These efficient systems impose very low losses from irrigated plots and as a consequence almost all irrigation water diverted from the river is evaporated via the crops into the atmosphere. Studies conducted by for instance Fereres and Soriano (2007) in Spain and Ward and Pulido-Velazquez (2008) in the Upper Rio Grande Basin of USA confirm that the volumetric ET increased after the introduction of irrigation systems with a high consumption/supply fraction. This is related to the spreading of water across a larger area of cropped land. Farmers with water rights noted that their consumption/supply fraction increased and that not all their entitled water was used. Consequently they decided to expand their farm sizes and irrigated more land with the same total amount of water for which they hold a water right. While this is a desirable short term solution for the farm (more land under irrigation for the same license and higher profits), the net effect is that the total volumetric water consumption increases and more water evaporate into the atmosphere. This water is not longer physically present in the basin, and sooner or later it will result into a undesirable environmental situation with diminishing water resources.

By reducing transpiration from crops and evaporation from soil considerable "real" water savings can be achieved. Research centres involved in scientific irrigation technology to control ET, opposed to control diversion, can be found in Spain, Syria, China, Australia and California, amongst others. Techniques were developed to regulate crop transpiration to specific requirements (e.g. Goldhammer et al., 2002). Crops are for example provided with insufficient moisture in order to intendently create water stress.

The reduction of non-beneficial evaporation (E) can be achieved by mulching, localized irrigation, narrow crop spacing, dense planting, changing cropping patterns, zero tillage, etc. The WorldBank supports this new direction in irrigation management where the aim is to reduce total ET and maintain crop yield (e.g. Olson, 2005).

The international research community (FAO, IWMI, ICBA[3], CIHEAM[4]) and several agricultural universities have done excellent research work to demonstrate that crop ET can be reduced, while yield is maintained. This is an exciting breakthrough because it shows that production – thus farming – can be maintained even at reduced water availability for the irrigation sector. In China they reduced ET by 40% while maintaining wheat yield (Zhang et al., 2007). In Syria they realised 40% deficit in ET without yield reduction (Zhang and Oweis (1999) and McCann et al. (2007)). In Colorado, Al-Kaisi et al. (1997) demonstrated that the actual ET of irrigated crops can be reduced by 15 to 25% before a noticeable reduction of wheat yield occurred. All these examples articulate that it is technically feasible to considerably increase water productivity by introducing mild stress levels and partition a large as possible fraction of ET into T (i.e. beneficial fraction greater than 0.9).

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[3] ICBA = International Center for Biosaline Agriculture

[4] CIHEAM = International Center for Advanced Mediterranean Agronomic Studies

Hence, irrigation efficiency improvement is not a legitimate reason for expanding irrigated areas. An efficiency improvement will reduce the losses, but the losses are often not real losses. The consequence of having reduced irrigation water losses on the hydrological cycle and water availability to downstream users should be assessed prior to the onset of the irrigation efficiency improvement program. Instead, the challenge is to minimize crop ET because that is a real water saving.

3.3 Raster and vector based irrigation performance analysis

Data on: water volumes applied to crops; crop types; and crop yields, were only partially available and not systematically for the entire Nile Basin. This strongly limited the application of the standard set of ICID-IWMI indicators. In this study we took a pragmatic approach and focused essentially on a number of indicators that can be derived from satellite data. This was the only option for performing a consistent and comparative data analysis. The list of irrigation performance indicators that can be derived for any 250 m x 250 m pixel is as follows:

- Crop consumptive use: it indicates the actual ET consumed by the crop and evaporated into the atmosphere;
- Crop water deficit: it reflects the amount of water that is missing to obtain potential ET under optimally watered condition;
- Adequacy: it reflects the reduction of water uptake by roots and crop transpiration (T) and is thus an indirect measure of irrigation water supply;
- Beneficial fraction: it shows the partitioning of consumptive use into beneficial crop transpiration T and non-beneficial evaporation E
- Uniformity: it describes the spatial variation of adequacy as a surrogate for spatial variation of irrigation water distribution within an irrigated system;
- Reliability: it expresses the temporal variation of adequacy, which in turn is an expression of regular irrigation water delivery and an indication of the irrigation service.

These six indicators will be referred to as Process Orientated indicators (PO indicators). The importance of these PO indicators is summarized in Table 6. They give more insight into irrigation mechanisms without having to measure them in the field.

Table 6 Definitions of the irrigation performance indicators used in this study to determine good and poor practices from satellite data

Type	**Indicator**	**Acronym**	**Unit**	**Formula**	**Why important ?**
RO	Biomass productivity	bio	kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	kg/m^3	Bio/ET$_{act}$	Food benefits from scarce water resources; irrigation planning
PO	Crop water consumption	cwc	m^3/ha/year	ET$_{act}$	Water depletion from river basins; real water saving programs
	Crop water deficit	cwd	m^3/ha/year	ET$_{pot}$-ET$_{act}$	Indication of sufficiency of irrigation water supply
	Adequacy	ad	-	T$_{act}$/T$_{pot}$	Crop water stress, sufficiency in water supply, accessibility to water, and regulated deficit irrigation
	Beneficial fraction	bf	-	T$_{act}$/ET$_{act}$	Degree of non-beneficial consumptive use
	Uniformity	un	-	1-CV(T$_{act}$/T$_{pot}$) (x,y)	Spatial variation of irrigation water distribution, accessbility to water
	Reliability	rel	-	1-CV(T$_{act}$/T$_{pot}$) (t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope vegetation index time profile	Farm outputs and land quality deterioration
	Water sustainability	amsre	1/year	Slope soil moisture time profile	Irrigation systems functioning and water resources availability

The longer term success of irrigation can be derived from the sustainability of a given irrigation system.. The sustainability can change due to lack of maintenance, a poor financial situation (resulting in structural repairs to be postponed), low market prices that prevent agriculture from becoming viable, etc. The processes and elements leading to an unsustainable situation are difficult to determine, but the net effect is an irrigation system with a diminishing crop canopy. Trends in vegetation cover (i.e. crop canopy) were determined by analyzing a 23 year record of vegetation index. The impact of under-irrigation and over-irrigation were determined by studying a 6 year time series of soil moisture. The indicators analyzed are:

- *Land Sustainability*: a diminishing vegetation cover (i.e. crop canopy) development.

- *Water Sustainability*: a drier (under-irrigation) or wetter (over-irrigation) soil or even water logging if drainage systems are inadequate.

These indicators will be referred to as the Sustainability indicators. Figure 12 shows the link between the three categories of indicators.

Figure 12 Schematic representation of the link between the selected physical indicators (PO), productivity (RO) and sustainability (SO)

3.4 Linking irrigation practices and irrigation indicators

Different objectives and strategies exist within irrigation systems. These practices have a certain impact on the physical processes, such as irrigation scheduling. The link between actions and indicators is paramount to understand the functioning of a particular irrigation system. While these links are hypothetical, a framework is necessary to determine the operating processes from a set of indicators. Although qualitative, it can significantly support the diagnoses of irrigation systems. Specific perceptions of individuals or donors sometimes have far reaching consequences on how a certain irrigation system functions. On the basis of indicators and a link to the processes, biased and subjective views can be omitted.

Several typical management options, strategies and actions are described below, and their impacts on the indicators are described. This link will be used in subsequent chapters to use the indicators in an inverse manner, to arrive at the processes that are likely occuring in the field.

Full supply vs. deficit supply (stress management)
A full irrigation supply due to presence of abundant water resources will create wet soils, high crop water consumption, a high adequacy, little crop water deficit and high uniformity because water is present everywhere and it will reach the tail end. A deficit supply will cause lower crop water consumption, lower adequacy, lower crop water deficit and probably a higher non-uniformity. The combination of these 4 indicators is thus relevant.

Frequent vs. infrequent water supply (irrigation interval)
Regular irrigation with for instance micro-irrigation or an on-demand irrigation system will results in regular water supply and a constant adequacy level against time. Since adequacy is related to water supply, a high reliability reflects regular irrigation water supply. A low reliability suggests that irrigation water was not applied in time.

Micro vs. surface irrigation (irrigation system)
A micro-irrigation system is designed to bring the water to the crop or tree in a site-specific way. This will increase the uniformity and increase the beneficial fraction. For cases where rainfall is not a disrupting factor, the combination of uniformity and beneficial fraction reveals the type of irrigation system

Sprinkler vs. drip systems (overhead system)

An overhead sprinkler system or a center pivot system will wet the entire field, and evaporation from wet canopies and wet soil occurs. This causes a low beneficial fraction. Overhead irrigation systems have a high uniformity as opposed to surface irrigation systems which usually have a low uniformity.

Irrigation management transfer (IMT) vs. Governmental responsibilities
Transfer of responsibilities to Water User Associations will increase the uniformity of water distribution, increase the reliability of the supplies (because there are better operational plans in place) and have a positive impact on crop yield. The biomass production, uniformity and reliability indicators should thus be high when transferability is high.

Strong vs. weak institutes (water governance)
The impact of education, research and rules of national government will result in a certain centralized and uniform action plan. This can be expressed by the uniformity of certain indicators across an administrative water governance boundary. If the resulting uniformities are different from the climatic zone values, it could be ascribed to a well functioning water governance. It is also expected that the overall reliability and sustainability increases with good governance.

Agricultural research and education
Efforts in crop research and development of new varieties will together with a smooth extension service result into higher crop yields and a good uniformity of that production. This can be evaluated from the biomass production and its spatial variation.

Climate change vs. Siltation of reservoirs
A systematic decline in irrigation activities due to overall water shortage should be apparent from time series of soil moisture and vegetation cover. If moisture values decrease, followed by a drop in canopy cover over a long time period (>30 years), then climate change could be the reason. If these trends are evident for irrigated land with unchanged rainfall trends then climate change is unlikely.

Hence, the combination of 10 indices can be used to draw some first conclusions on the irrigation conditions, best practices and some weaknesses. This will be done in chapters 4 and 6.

3.5 Irrigation management reporting

Section 3.3 described three different types of indicators which can be derived from the satellite data: Results Oriented (RO), Process Oriented (PO), and Sustainability Oriented (SO) indicators. The minimum number of 10 indicators are included in the above three categories of indicators. (RO: n=2; PO: n=6; SO: n=2). Because the units of the 10 minimum indicators differ, a normalization procedure was applied to make the indicators mutually compatible. This normalization was accomplished by using the frequency distribution of each indicator and thus ensuring that the study area included the full range of performance values for all indicators. It also prevented unobtainable target levels to be set within the socio-economic and climate context of east Africa. The basic hypothesis is that the class of maximum values of the frequency distribution represents the best irrigation practices. This is the class at the right hand tail of the frequency distribution for most parameters. In some cases it is the left hand tail of the distribution. A lower consumptive use is for instance regarded as being better.

The frequency distribution of individual irrigation performance indicators will be used to assign a score between 1 and 5 to each individual pixel. The category with the best irrigation performance is represented by 5 (see Figure 13). The category with the lowest performance will be assigned a score of 1. Score 3 coincides with the average value of the frequency distribution. The scores of 2 and 4 are intermediate classes. An irrigation report is being prepared where the indicators of Table 6 in each pixel of 250 m x 250 m (6.25 ha) are given performance values. The pixel values are then compared and averaged over districts and countries.

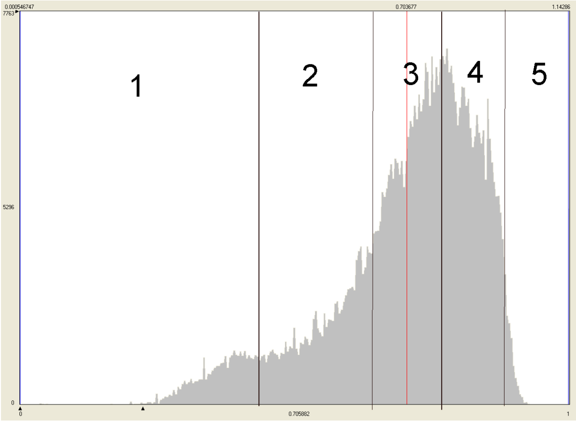

Figure 13 Frequency distribution of the values of one specific irrigation performance indicator. The values can be grouped into 5 classes

There is one additional complexity in this benchmarking of the scores: the target values of the scores of 1 to 5 differ in the various countries and climatic systems. The consumptive water use of crops (and the scores for the related indicators) will for instance be different due to variations in rainfall and the reference ET.

Figure 14 shows the spatial variation of the aridity factor expressed as rainfall/reference ET. Irrigation intensifies with aridity to meet the shortages of water from rain, and one can see from Figure 14 that the amount of irrigation water has to vary considerably to adjust to the varying climatic conditions.

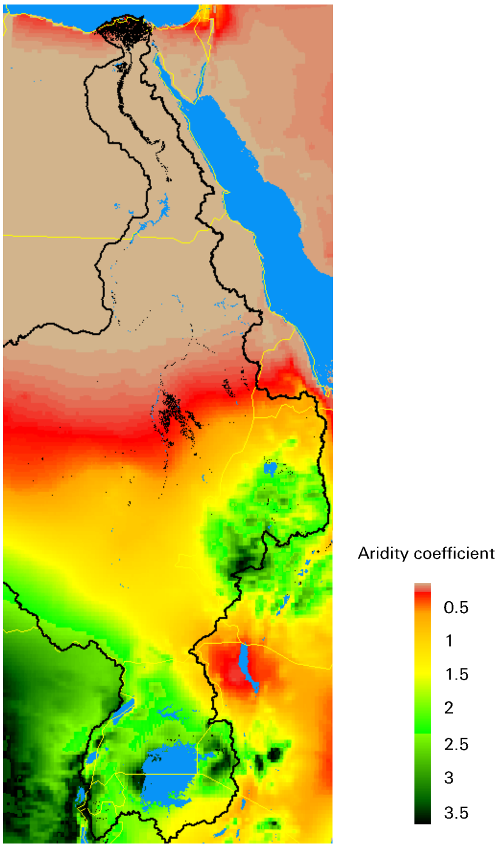

Figure 14 Spatial patterns of rainfall/reference ET across the entire Nile basin to emphasize climatic differences. The irrigation mask is superimposed

To solve the problem of climate diversification across the Nile Basin, discrete climate zones have been identified. For each zone specific benchmark values of irrigation management were defined. The climatic zones are based on monthly rainfall and monthly reference evapotranspiration values. Differential classes were firstly generated from the monthly aridity maps, and then merged for the sake of contiguity. Figure 15 shows the four climatic zones that were finally defined for the benchmarking of the 10 minimum irrigation indicators. The tables with the benchmark values are provided in each of the country reports. The country reports contain the highest level of detail and form the basis for the synopsis of the results described in this report.

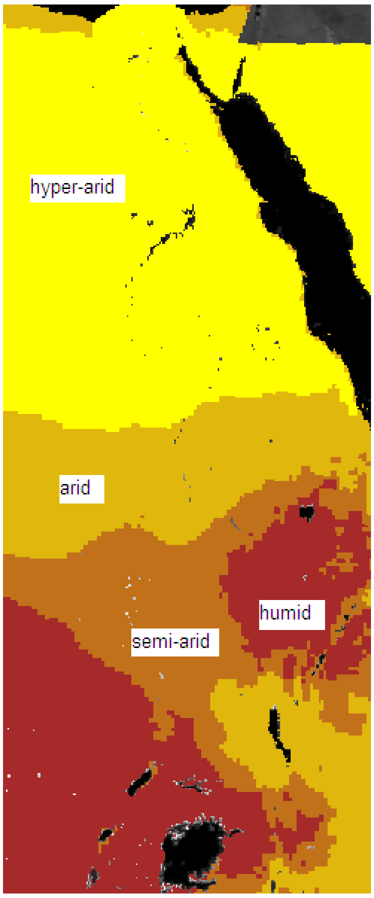

Figure 15 Different climatic zones in the Nile Basin

The set of satellite images consist of the MODerate Resolution Imaging Spectro radiometer (MODIS), Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E), National Oceanic and Atmospheric Administration – Global Inventory Modeling and Mapping Studies (NOAA-GIMMS) and Meteosat Second Generation (MSG) data. This primary remote sensing data consist of green vegetation index (NOAA), green Leaf Area Index (MODIS), surface albedo (MODIS), surface soil moisture (AMSR-E), and solar radiation (MSG). In addition biomass production and crop evapotranspiration (ET_0, ET_{pot}, ET_{act}, E_{act}, T_{act}) were computed with an unpublished new energy balance model that is based on the Surface Energy Balance Algorithm for Land (SEBAL)[5]. For the provision of most up to date information, the satellite images were taken from the year 2007. Hence, all results presented hereafter are based on 2007, except the sustainability time series which were extended to an earlier period.

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[5] SEBAL is a common remote sensing model that is tested widely across a range of irrigation systems. SEBAL requires cloud free conditions, and this was not feasible for the Nile Basin. A microwave version of SEBAL has been used in this study. Microwaves have no hindrance from clouds

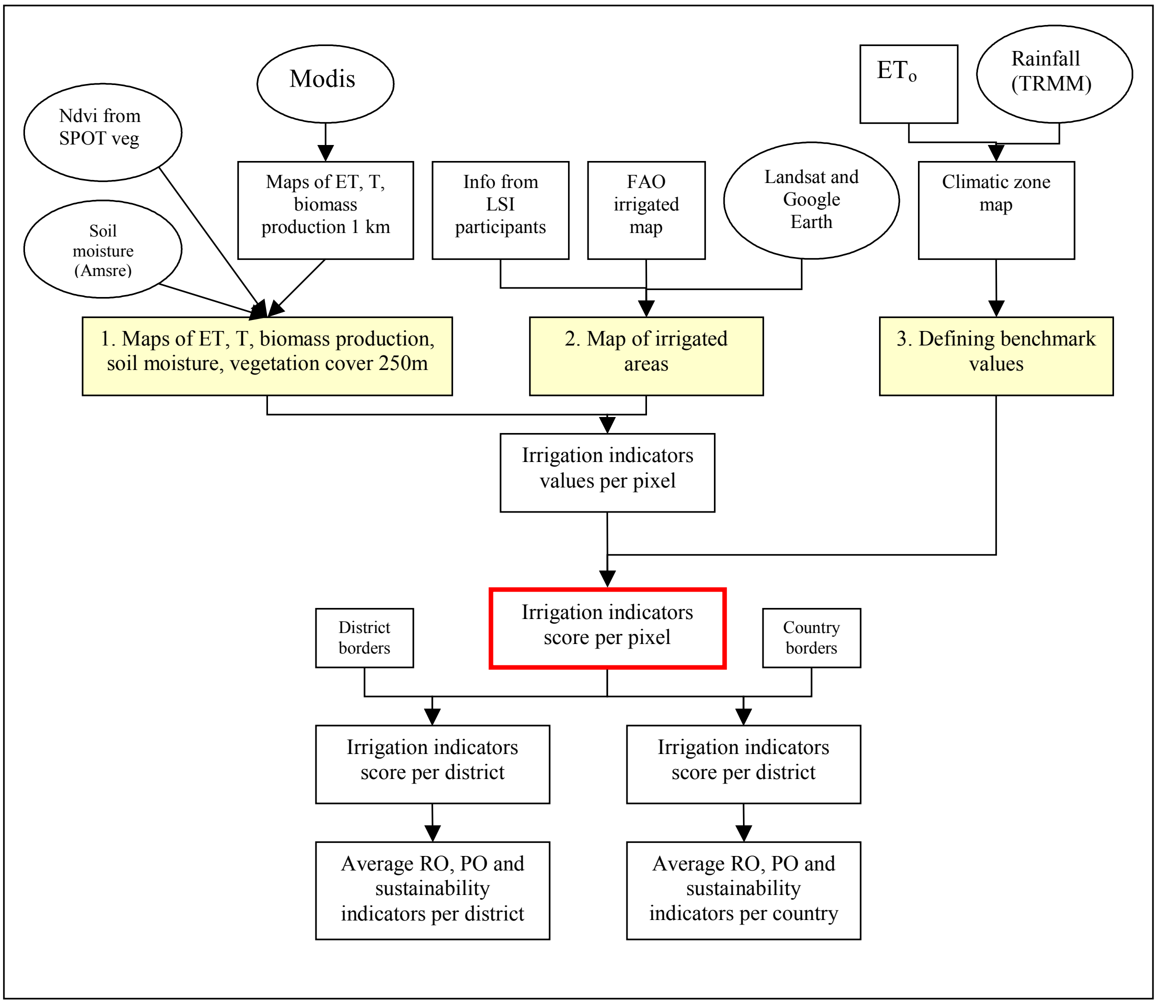


Figure 16 Computational schedule for the irrigation performance indicators

4 Irrigation diagnosis for LSI schemes using Remote Sensing data

4.1 Result Orientated (RO) indicators of LSI schemes

RO indicators measure the productivity of land and water resources. In the absence of boundaries of the canal command areas, we used administrative districts. Average values for districts are presented, and they can be an aggregate of a large number of pixels. The averaging process practically removed all extreme values.

The irrigated areas in southern Sudan seem to have the best land productivity with a score exceeding 4.5. This is related to the presence of the sugarcane estates in this region of the Nile Basin and the direct irrigation from the White Nile. The central-northern part of the Nile Delta exhibits favourable agricultural production also, which is related to the intense cultivation of rice in combination with a high annual cropping intensity. The north and north-eastern part of Lake Victoria also appears to be very suitable for land productivity. The irrigation schemes in Kenya as well as in Uganda attain excellent productivities. Hence, rice on the alluvial soils in the delta and on the flood plains of Lake Victoria seems to grow productively. As noticed earlier, rice is a major irrigated crop in Kenya and Uganda. The LSI schemes on the left Bank of the Blue Nile (Abbay) in Ethiopia appear to be very productive as well. The reason is not totally clear, but the sugarcane growth in Fincha LSI is possibly contributing to that phenomenon.

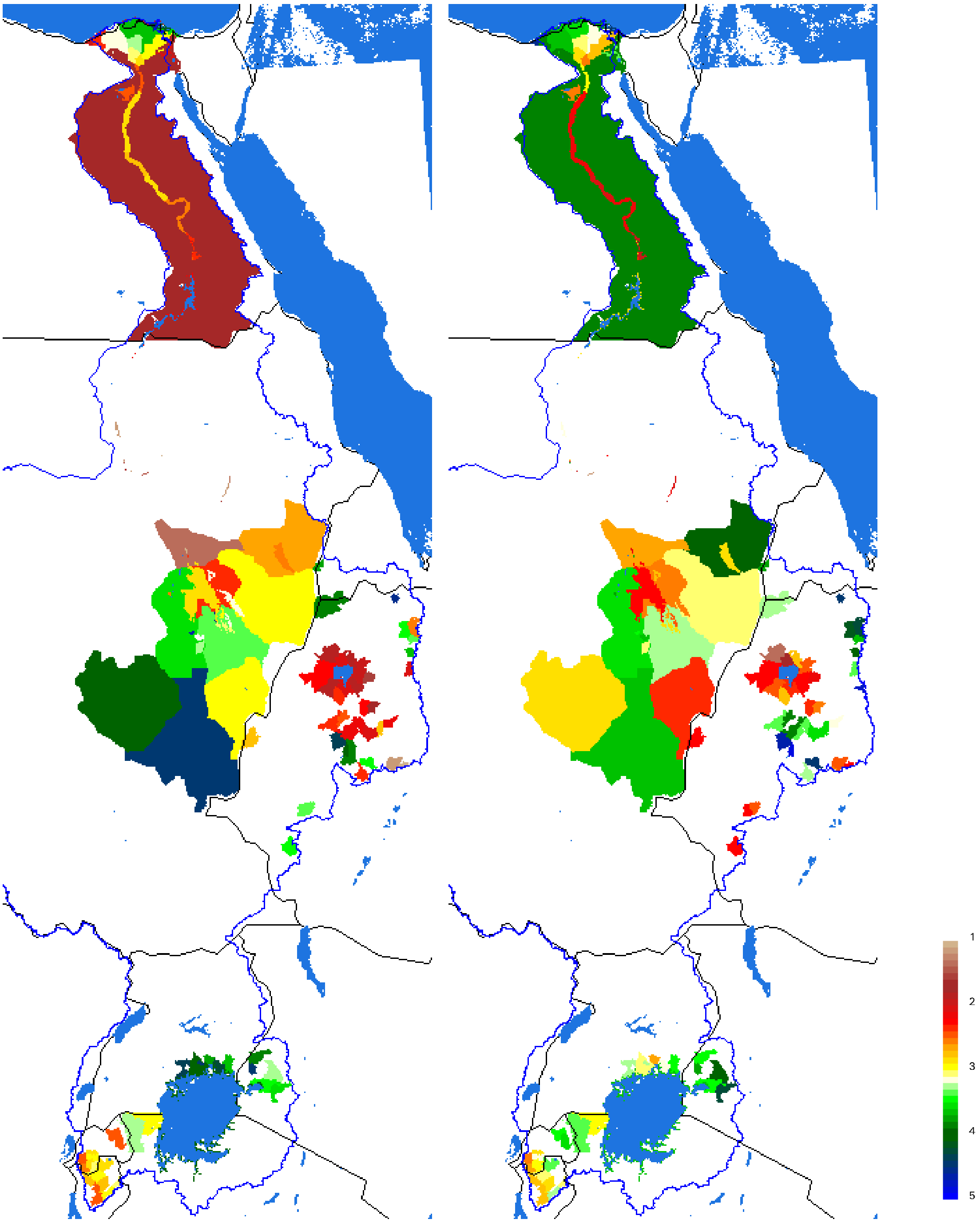
The LSI schemes with a disappointing agricultural performance are found around Lake Tana and around the main Abbay River, all located in Ethiopia. The agricultural production in Burundi and Rwanda also appear to be below average. Fayoum Depression in Egypt and Upper Egypt have lower than average land productivities. Whilst in Fayoum this can be attributed to salinity problems and insufficient drainage capacity to maintain the shallow water table below the root zone, in Upper Egypt it could be related to the hot climates, besides other agronomic aspects that may need more attention from the Egyptian Government.

While favourable land productivity enhances food security and stimulates rural development, it also means that it bears a cost in terms of Nile basin water resources. Water productivity is displayed in Figure 17 as an indication of the efficiency of agricultural water use of irrigation systems. The western Nile Delta and the adjacent western Desert appear to be one of the most efficient water users of the Nile Basin. The Bur Said and Matruh districts in Egypt host the LSIs with best water productivity of Egypt. The Halfa LSI scheme in Sudan, and the LSI schemes in Kenya in the vicinity of Eldoret and Kisumu (see Figure 17) fall in the same class of excellence.

Because water productivity should be regarded as the most crucial for irrigation evaluation and planning in the context of international river basins, values for the 20 best and 20 worst administrative districts are summarized in Table 7. Many of the poor functioning districts are located in Egypt and Sudan. Hence, Egypt hosts very good systems, simultaneously with systems that are poorly managed. It seems that the Egyptian Government provides more irrigation attention to Lower Egypt than to Upper Egypt.

The LSI schemes in Ethiopia show quite interesting results that require special attention. While the agricultural productivity is low, the LSI schemes show an excellent level of water productivity. The water productivity in the schemes around Mekele in Tigray is ranking very high in the Nile Basin. Experience on how to irrigate with minimum water resources could be gained from these regions. The Fincha LSI scheme seems to be the top water producing irrigation system in the entire Nile Basin (at least for 2007, the year of analysis). The LSI schemes located in the bed of the Abbay have – despite their poor productivity - a remarkably good water productivity. This is in agreement with the observations made for Tigray. The rainfall in Tigray is limited, so the stream flows are weak and water is only scarcely present. The crops receive insufficient water resources (as was confirmed during the workshops in Arusha and Khartoum), and this result reveals that deficit irrigation enhances the crop water productivity.

While the water productivity is very favourable, farmers hardly have sufficient production to ensure a normal income. This example shows that both land and water productivity need equal attention. The latter concept is encapsulated into the RO indicators.



Land productivity (-)　Water productivity (-)

Figure 17 Spatial variation of the land and water productivity in the Nile Basin across all administrative districts based on remote sensing data. The value is expressed as a score between 1 (very poor) to 5 (excellent). The Nile Valley has a larger administrative unit with pockets of irrigation at the fringes with the Nile Delta

Table 7 Water productivity values for all irrigated land in the Nile Basin by administrative unit. The ranking is based on normalized biomass water productivity. The value is expressed as a score between 1 (very poor) to 5 (excellent).

20 poorest districts	**country**	**Clim zone**	**bwp**		**20 best districts**	**country**	**Clim zone**	**bwp**
Kulud scheme	Sudan	1	1.1		Butere Mumais	Kenya	4	3.8
Chilga	Ethiopia	3	1.4		Lati basin scheme	Sudan	1	3.8
El guriar scheme	Sudan	1	1.5		Machakel	Ethiopia	4	3.8
Ganadutu	Sudan	1	1.6		Al Iskandariyah	Egypt	1	3.8
Dembia	Ethiopia	4	1.8		Jabi Tehnan	Ethiopia	4	3.9
Kitiab	Sudan	1	1.9		Kassala	Sudan	2	3.9
Aswan	Egypt	1	2.0		Nandi	Kenya	4	4.1
Aliab & Food Security	Sudan	1	2.0		Ofla	Ethiopia	3	4.1
Ghadar scheme	Sudan	1	2.0		Samre	Ethiopia	3	4.1
Ghanati scheme	Sudan	1	2.0		Enderta	Ethiopia	2	4.2
Kaboshia	Sudan	1	2.0		Kericho	Kenya	4	4.2
Gabria, Karad ps	Sudan	1	2.0		Hintalo Wajirat	Ethiopia	3	4.3
Ghabah scheme	Sudan	1	2.1		Jeldu	Ethiopia	4	4.4
Suhaj	Egypt	1	2.1		Adwa	Ethiopia	2	4.5
Ziadab	Sudan	1	2.1		Matruh	Egypt	1	4.6
Asyiut	Egypt	1	2.1		Amuru Jarti	Ethiopia	4	4.7
Seliet	Sudan	1	2.1		Ambasel	Ethiopia	4	4.7
Qina	Egypt	1	2.1		Abay Chomen	Ethiopia	4	4.8
Al Minya	Egypt	1	2.2		Bur Said	Egypt	1	5.0
Farta	Ethiopia	4	2.2		Guduru	Ethiopia	4	5.0

A small test was done by comparing water productivity in sugarcane as a cross cutting theme. Table 8 shows the remote sensing results for various sugar schemes in the Nile basin for which it is certain that only cane is cultivated. The biomass production values need to be multiplied with more or less a factor 3 for acquiring fresh cane yields. The high harvest index can be explained by the high moisture content of cane. The Kagera scheme in Tanzania consumed the lowest amounts of water, being a positive fact. The sugar production was with a biomass production of 33,533 kg/ha the highest in Uganda (Kakira scheme) which is favourable for the local sugar industry, but not necessarily efficient from the viewpoint of productive water use. The highest water productivity of 3.02 kg/m^3 was obtained in Burundi (Sosumo scheme). This analysis shows that the water productivity dimension in irrigation management makes sense, and lead to different views and directions of strategic planning. If we provide equal weight to land and water productivity, then Burundi and Ethiopia are equally good because Ethiopia ranks second in both land and water productivity, but Burundig ranks 3rd in land productivity. This examples also demonstrates that crop yield does not necessarily to be calculated. It is important though, to have geographical maps with the exact location of the major crop types.

Table 8 Land and water productivity analysis of comparable irrigated sugarcane schemes for which the boundaries were known

Country	**Scheme**	**ET**	**Biomass production**	**Cane production**	**Biomass water productivity**	**Water productivity**
		(mm)	**(kg/ha)**	**(kg/ha)**	**(kg/m^3)**	**(kg/m^3)**
Burundi	Sosumo	920	27,782	83,346	3.02	9.06
Ethiopia	Nazareth[6]	964	28,082	84,246	2.91	8.74
Sudan	Kenana	1026	17,165	51,495	1.67	5.02
Sudan	Assalaya	828	14,869	44,607	1.79	5.39
Tanzania	Kagera	738	21,095	63,285	2.86	8.58
Uganda	Kakira	1299	33,533	100,599	2.58	7.74

Interim conclusions:

- The rice systems on alluvial soils in the Nile Delta and flood plain of Lake Victoria demonstrate the highest land productivity. Alluvial soils are thus key for acquiring high productions
- The LSI schemes around Lake Tana and along the course of the Abbay in Ethiopia have a disappointing low agricultural performance.
- The overall land productivity in Rwanda and Burundi is below average.
- The LSI systems in Kenya and western Delta/western Desert in Egypt show the overall highest water productivity.
- The LSI systems in Ethiopia are characterized by conservative water use. Therefore, the LSI systems in the Abbay have the highest water productivity.
- Land and water productivity should be given equal weight for purposes of describing the final result of good irrigation management.
- Burundi and Ethiopia have the best irrigation practices in sugarcane.

4.2 Sustainability Oriented (SO) indicators of LSI schemes

High production on land is unsustainable if the soils degrade due to erosion, poor tillage, loss of nutrients, or salinization due to waterlogging. Soils need to be ploughed regularly and hardpans need to be broken. Diseases are very common in most crops (e.g. rizoctonia and blight in potatoes; mildew and stripe rust in wheat) and pesticides and insecticides need to be applied in mild quantities to protect crops. Productive agriculture will be under threat if the combination of farm and market economics doesn’t improve and gross returns are not increased. In other cases, the limiting element for productive agriculture can be insufficient labour or the absence of infrastructure to transport the fresh products to the nearest market. A general lack of micro-credit funding will hamper financially healthy farming. All these non-water factors could potentially influence the farmer to withdraw from farming and to seek alternative sources of income. The effect of land abandonment is that irrigated land becomes fallow and vegetation cover reduces. The message

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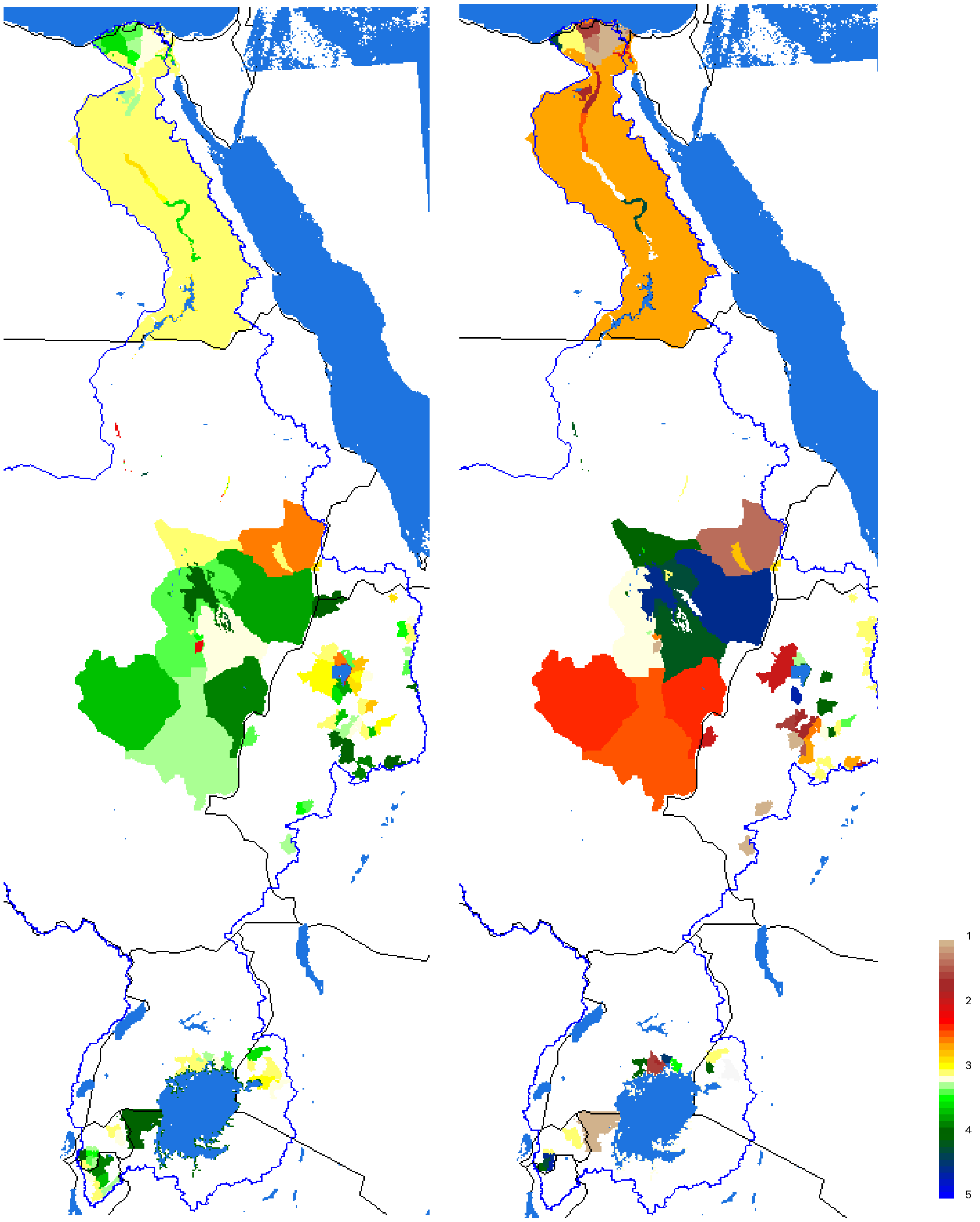
[6] This sugar estate is located just outside the Nile basin near Addis Ababa, but representative for the public sugarcane sector of Ethiopia

here is that non-physical processes can occur and be the reason for a deteriorating LSI system. A decline of canopy dimensions of irrigated crop with time does not prescribe the causing factors, but it will tell us whether something goes in the wrong direction.

Figure 18 shows the temporal trend of the crop canopy development for the period between 1981 and 2003. The score for land and crop sustainability is high if the vegetation index remains similar or increases (score 3 to 5). A reduction of vegetation index suggests that one of the deteriorating processes described above occurs.

The results displayed in Figure 18 suggest that most LSI schemes in Sudan, Burundi and Tanzania are sustainable. The LSI systems in Sudan appear to be more sustainable than in Egypt. While the western Delta and adjacent western Desert are doing well – in fact they have gone through a period of intensification of irrigated agriculture (also the green cover in Upper Egypt near Qena and Luxor increased), the eastern Delta shows zero growth. A score of 3 and higher indicates stable irrigation systems without land degradation. Unsustainable irrigation practices are noticeable in middle Egypt near the town of Asyut, in Ethiopia around Lake Tana, and in Kenya on the irrigation systems that are highly efficient with irrigation water. The Lake Tana region is indeed characterized by soil erosion from land with more than 5% slope (crops are cultivated on slopes up to 10 % and supported by Ethiopian agricultural policy). Sedimentation in streams and reservoirs is a common process in the Tana Basin (SMEC, 2008).

LSI schemes with depleting soil moisture content – hence dwindling water resources - are the Kagera sugarcane scheme (Tanzania), and most LSI schemes in Ethiopia, as well as the irrigated land of the eastern Nile Delta. The reasons for soils under irrigation becoming dryer need further explanation. In the eastern Nile Delta a plausible reason could be the re-allocation of water and more water being diverted to Sinai. In Ethiopia, a drying LSI system could be ascribed to reduced rainfall. The rainfall over the catchment of the Blue Nile diminished over the last 10 years (WaterWatch, 2008), and it is possible that the lower amounts of rainwater was not fully supplemented by irrigation water to maintain soil moisture level in a certain ideal range. The reasons for Kagera to become dryer are not known. The latter poses no concern because the land and crop sustainability is high. It implies that the reduced water availability has no affect on the cropping and irrigation practices.



Land and crop sustainability

Water resources sustainability

Figure 18 Spatial variation of the sustainability of irrigation systems in the Nile Basin across all administrative districts. The value is expressed as a score between 1 (very poor) to 5 (excellent). The Nile Valley has a larger administrative unit with pockets of irrigation at the fringes with the Nile Delta

Interim conclusions:

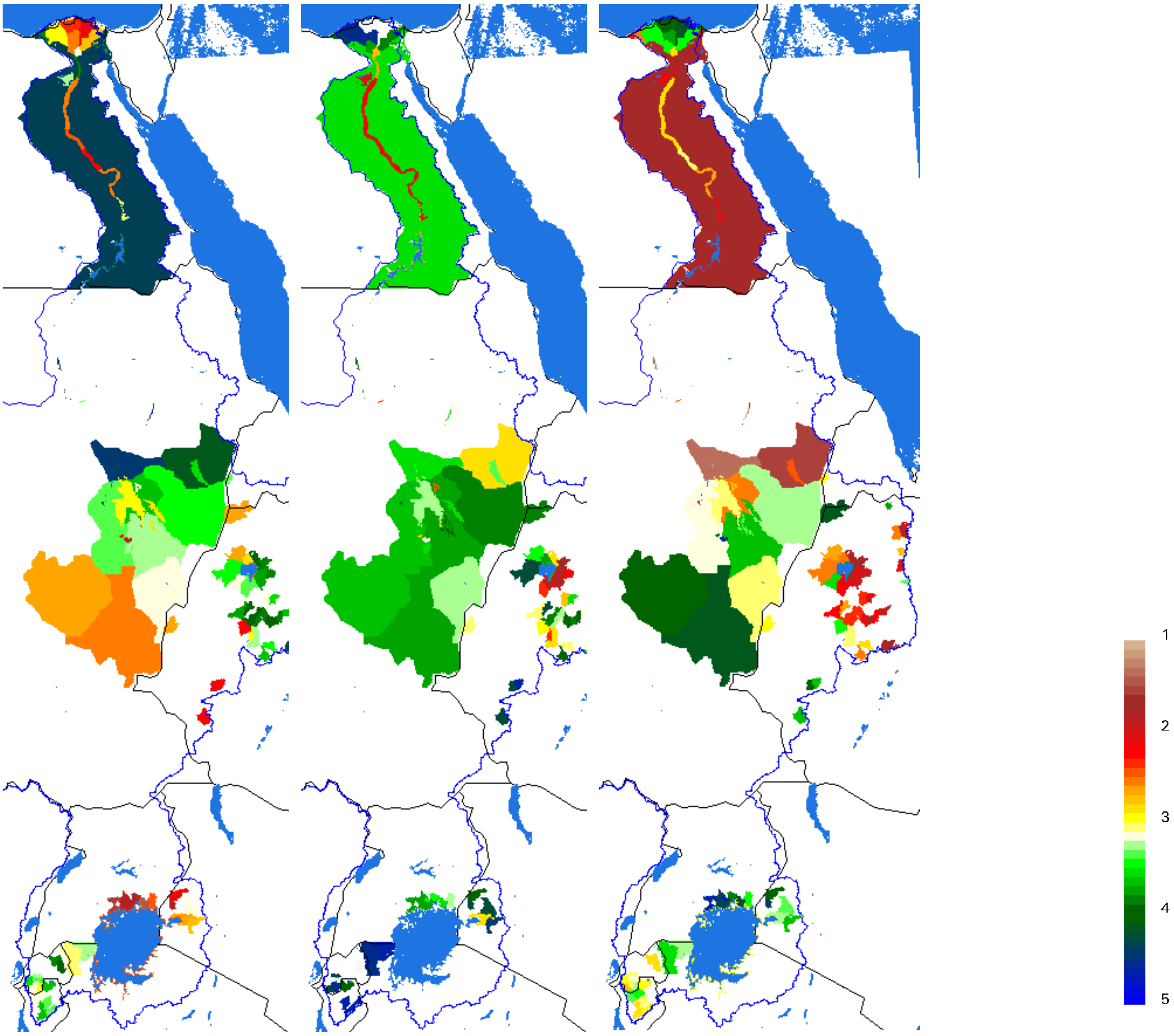
- Most LSI schemes in Sudan, Burundi and Tanzania are sustainable.
- The irrigation systems in Sudan seem to be more sustainable than in Egypt.
- Ethiopia is close to having sound LSI schemes (not good; not bad). Most schemes have either a problem with the sustainability of the land and crops or with the guaranteed water supply from rainfall and irrigation.
- Unsustainable irrigation practices are noticeable in middle Egypt (Asyut), in Ethiopia around Lake Tana, and in Kenya.
- Egypt should give special attention to the impact of exporting irrigation water to Sinai on the Nile delta.

4.3 Process Oriented (PO) indicators of LSI schemes

Information on the physical irrigation processes (PO) can be used to interpret the results (R O) and sustainability (SO) of the LSI schemes. The LSI schemes with a relatively high consumptive use are found in the central Delta, eastern Delta and entire Nile Valley (see Figure 19). This is the score after correcting the crop ET for climatic variations. The irrigation schemes in southern Sudan and in Uganda can also be classed as high water consuming systems. It should be noted that the rainfall in the upstream part of the Nile Basin is very high, and that abundant water in combination with a hot climate certainly contributes to the high annual consumptive use values for Uganda. This can also be the reason for the higher than average consumptive use in southern Sudan and southern Ethiopia. It seems that the cultivation of certain crop types in certain climates generate the highest class of crop ET for that particular climate zone.

The LSI schemes that are conservative with water use are in Ethiopia, Rwanda and Burundi. These irrigation schemes are using their precious water resources with discretion. The challenge for irrigation managers is (i) to provide sufficient water for an acceptable crop yield, and (ii) being conservative with water at the same time. Conservative use of water is needed to keep operational pumping costs low, and to reduce contamination of groundwater and surface water resources through reduced percolation. The ideal is to have a mild water stress. A mild water stress generally moves the water productivity upwards. The crop water deficit indicator shows areas where stress is mild (score 5) or is intolerably high (score <3).

The analysis shows that crop water deficit is high in the Fayoum Depression and the Nile Valley. The LSI systems present in the Tana catchment area that drains into Lake Tana are also water short, especially at the south-eastern side of the Lake area. Small holders irrigate their lands without significant infrastructures. Reservoirs are currently planned and under construction in this region of Ethiopia to enhance the water availability during dry seasons. Hence, it is confirmed that this region is water short.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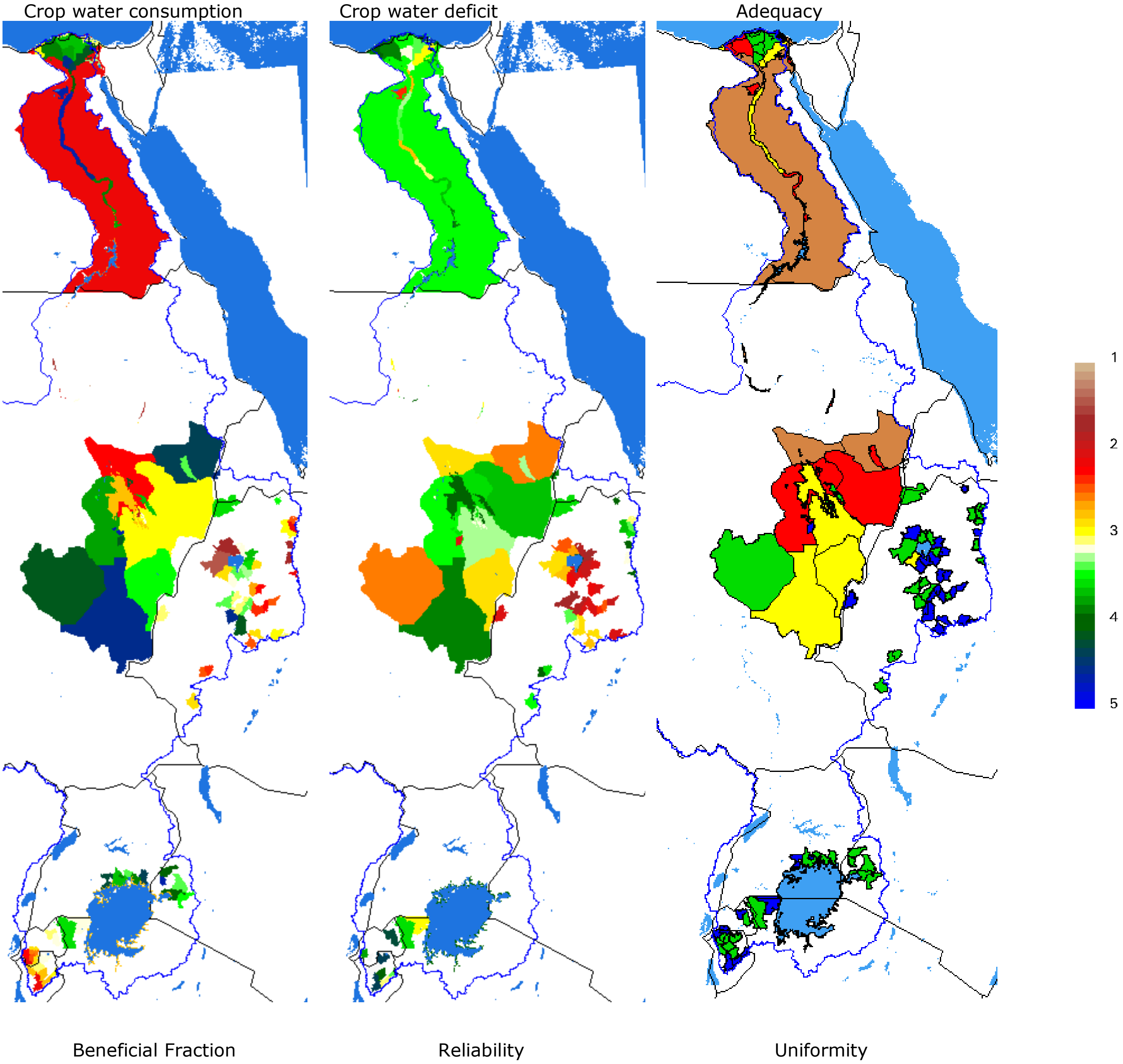


Figure 19 Spatial variation of the physical processes that occur in LSI schemes in the Nile Basin across all administrative districts. The value is expressed as a score between 1 (very poor) to 5 (excellent). The Nile Valley has a larger administrative unit with pockets of irrigation at the fringes with the Nile Delta

Adequacy of water supply is related to transpiration reduction and crop water deficit provides direct information on the lack of irrigation water supply. Most of the areas that experience crop water deficit, also exhibit a lack of adequacy. Crops are not adequately supplied by water in northern Sudan (e.g. Halfa schemes) and throughout Ethiopia. The latter emphasizes that certain LSI systems are significantly under-irrigated. There is a need to optimize irrigation management and for comprehensive methods to define the best practices: not too much and also not too little. Whereas Ethiopia has excellent water conservation practices, it is inadequate in irrigation water supplies and this goes at the costs of food production. The optimum level of transpiration stress could be empirically determined by plotting water productivity vs. adequacy. Figure 20 shows that the best water productivity (score >4) can be acquired for adequacy levels between 2 and 4, with a slight preference for 4. Most of Ethiopian irrigation systems have and adequacy between 3 and 4. This confirms that mild stress levels yield into the highest water productivity values.

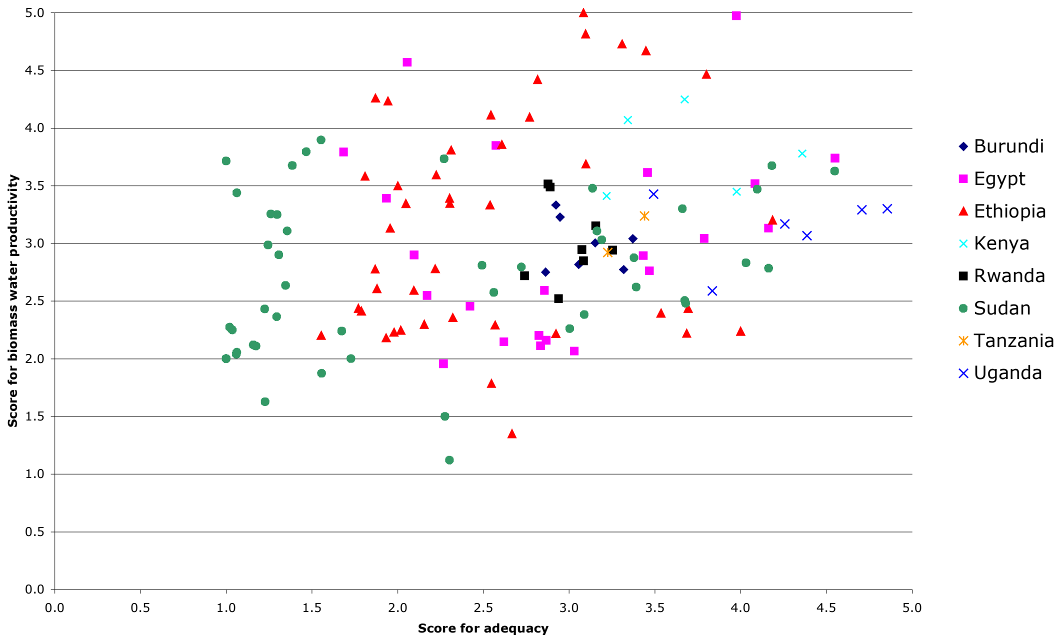


Figure 20 Relationship between biomass water productivity and adequacy for all districts with LSI schemes in the Nile Basin. The optimum level of water productivity is achieve at mild transpiration stress

The beneficial fraction is not the same throughout the Nile basin. Whereas it is generally good in the Nile Delta, Upper Egypt, Tanzania and Kenya, it is beyond expectations in Ethiopia, Rwanda and Burundi. The beneficial fraction can be managed by means of on-farm irrigation practices, especially in the more arid climatic zones. Soil evaporation does not contribute to production, and the so called vapor shift from evaporation to transpiration (Rockstrom, 2004) will considerably enhance the men’s ability to increase food production.

Reliability of irrigation water supply is generally considered important for improving productive water use in irrigation systems (Perry, 2005). The reliability in water supply in Egypt is very high, even at the downstream end of the Nile Basin. This shows that there are sufficient water resources available at the end of the Nile basin, and not all water is consumed. The water supply to Fayoum is irregular, and this suggests a mismatch between supply and demand for Fayoum. This is consistent with the low score for adequacy and crop water deficit in Fayoum. Recently, irrigation management in Fayoum has been transferred to Water Boards, and this analysis show that – despite the good intentions – that irrigation management transfer does not seem to function very well. Sudan and Ethiopia also shows low reliabilities.

Without exception, the uniformity in the equatorial region is excellent. All irrigation water is fairly distributed. Also, Ethiopia has a very good rating, so in terms of equity, all countries with a young irrigation history perform very well. The problems of uniformity appear to occur in Sudan and Egypt. It is remarkable that the central Delta between the Roseitta and Damietta branches of the Nile is more uniform, and that the edges of the Delta bordering the Western and Eastern Desert are less uniform. This suggest that geographical features (thus also soils) are very important.

Interim conclusions:

- Sudan, Ethiopia, Tanzania, Rwanda and Burundi have LSI schemes with conservative water use.
- Uganda, Kenya and Egypt are the large water consumers.
- There is an insufficient irrigation water supply to Fayoum Depression and to most of the LSI's in Ethiopia.
- There is sufficient irrigation water supply to the LSI's in the Nile Delta (downstream end) and the Equatorial Lake region (upstream end). This implies that surface water resources for irrigation are available throughout the basin.
- The uniformity in soil moisture is the highest in areas with substantial rainfall. The Central Nile Delta and Darfur are the only exceptions to that.
- The reliability in Egypt, Sudan and Ethiopia is highly variable. This implies that the central Government has not been able to introduce uniformity in the irrigation water supplies.
- The LSI systems in Ethiopia, Burundi and Rwanda should focus on the reduction of non-beneficial evaporation losses.
- The highest water productivity is obtained at mild levels of adequacy; optimization of irrigation is not straightforward without measurement systems in place; a little stress is preferred, but it can turn easily into a loss of crop production.

4.4 Overall country scale irrigation performance

The political boundaries across irrigation systems may have impact on the level of education, institutional settings, operational irrigation rules, capital investment, operation and maintenance costs, irrigation management transfer etc. The presentation of the country average LSI performance results thus provide and interesting picture to evaluate the role of water governance.

Averaging the 10 minimum indicators with equal weight, an average score is obtained that provides the simplest expression of good irrigation practices. Figure 21 displays the average score per country, and it should be pointed out that climatic normalization was performed to achieve this result. In terms of a total average score, Kenya seems to do best, with an average score of 3.64. Burundi, Rwanda and Uganda are next in line. This result suggests that the countries with the lower irrigated acreages and the youngest irrigation history have the best overall LSI scores.

Countries with irrigated areas of 10,000 to 20,000 ha will by default have a better uniformity than Sudan and Egypt with millions of hectares. It is a fact that the latter two countries host a wide range of cropping systems, crop varieties, irrigation systems, institutions, soils etc. Under these circumstances, it is unavoidable to have certain LSI schemes that are performing lower, and which will reduce the average national score. These vast irrigation schemes have on the contrary also patches of fertile soil with shallow water tables, guaranteed water supply and with excellent drainage conditions that achieve an above average productivity level. This typically occurs in Egypt with areas that are very productive (western Desert) and areas that have a poor production (Qena Nile Valley). The direct effect of the country total LSI size on the average performance is thus not so great. Larger sized irrigation schemes will likely host more compositions of crops and irrigation systems, and these compositions create unavoidably more variation. The latter will induce an indirect effect on the average performance value. Hence there is a likely bias on the country level results that is caused by the total LSI size. A second explanation for variability and thus less performance is the large distance from the capital town. The efficiency of communications and exchanges within Irrigation Departments could be lower if the decision makers are located far away from the LSIs. This is an interesting thought that could be investigated in more depth during this study.

Ethiopia and Burundi (to a lesser extent Sudan) are countries at the lower side of the RO spectrum. Ethiopia is the country with overall the poorest irrigation practices in the Nile Basin (score is 2.9) after averaging RO, PO and sustainability. These countries have a low productivity and they should provide special attention to improve their agricultural and irrigation practices. This is a very general observation at country level, and it does not apply to all LSI schemes in these countries.

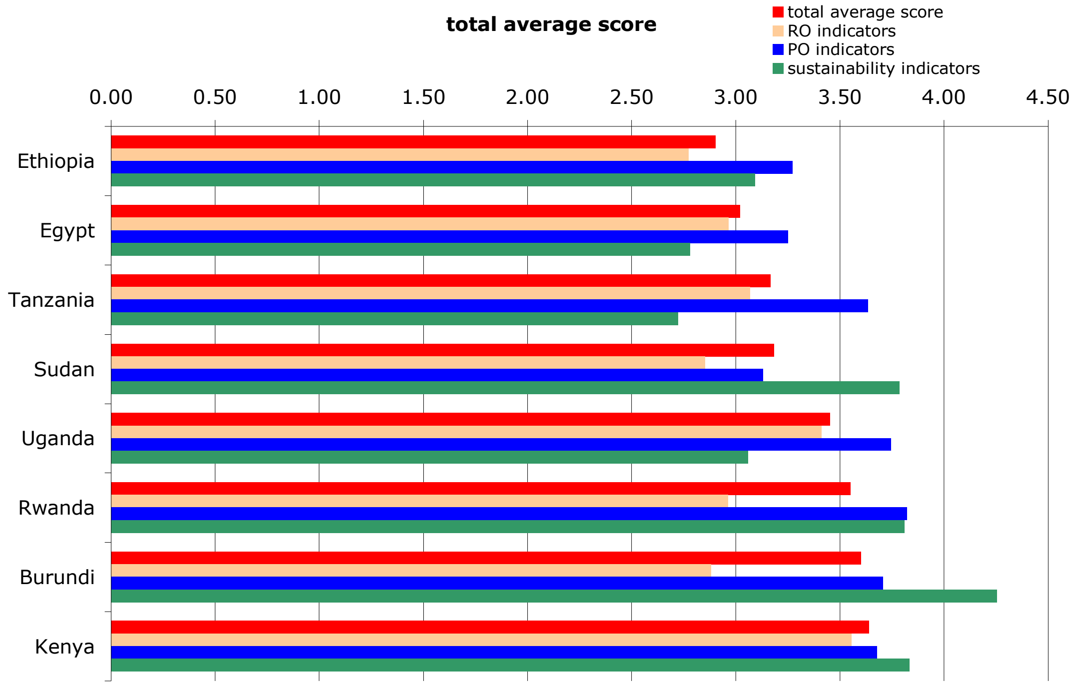


Figure 21 Breakdown of the average irrigation performance scores (RO, PO, and SO and their average values) by country in the Nile Basin

By breaking down the total score into 3 categories of indicators (RO, PO, and sustainability), it is easier to understand the irrigation mechanisms for each country. Having a good average score does not imply that the LSI schemes in a given country have a satisfactory overall land and water productivity. Indeed, if we look at the RO indicators, the ranking is different. Kenya and Uganda are the countries that show the best agricultural production per unit of land and per unit of water. This productive use of irrigation water can be related to the dominance of rice and other vigorous crops such as sugarcane, bananas and pineapple. The RO achievements in Kenya and Uganda are significantly better than for Rwanda and Burundi. The production in Rwanda and Burundi is the main cause for that. Whereas in principle it could be related to physiography of this part of the Nile Basin, it is more logical that the progress in agricultural research and extension in these countries is lagging behind. Not a strange observation when looking at the recent history of these countries.

Good overall results do not mean that the irrigation systems are sustainable. Countries such as Rwanda or Burundi are high in the final ranking because the sustainability of their irrigation system is very favourable (score of 3.7 and 4.4 respectively), whilst they are not performing satisfactory in terms of productivity results (RO). On the contrary, Tanzania and Uganda demonstrate a good set of irrigation practices, but their systems do not seem to be sustainable. A summary of the various elements of irrigation management for each country is provided in Figure 22.

The RO results seem to be more related to PO than to SO. Apparently sustainability has determining features that are independent of the results, but play a role in the continuation of the RO. Figure 22 shows the relative position of the various districts. It is obvious that Egypt and Sudan have dots everywhere due to their 97% coverage of all irrigated land. Ethiopia has LSI schemes at various combinations of PO and RO indicators.

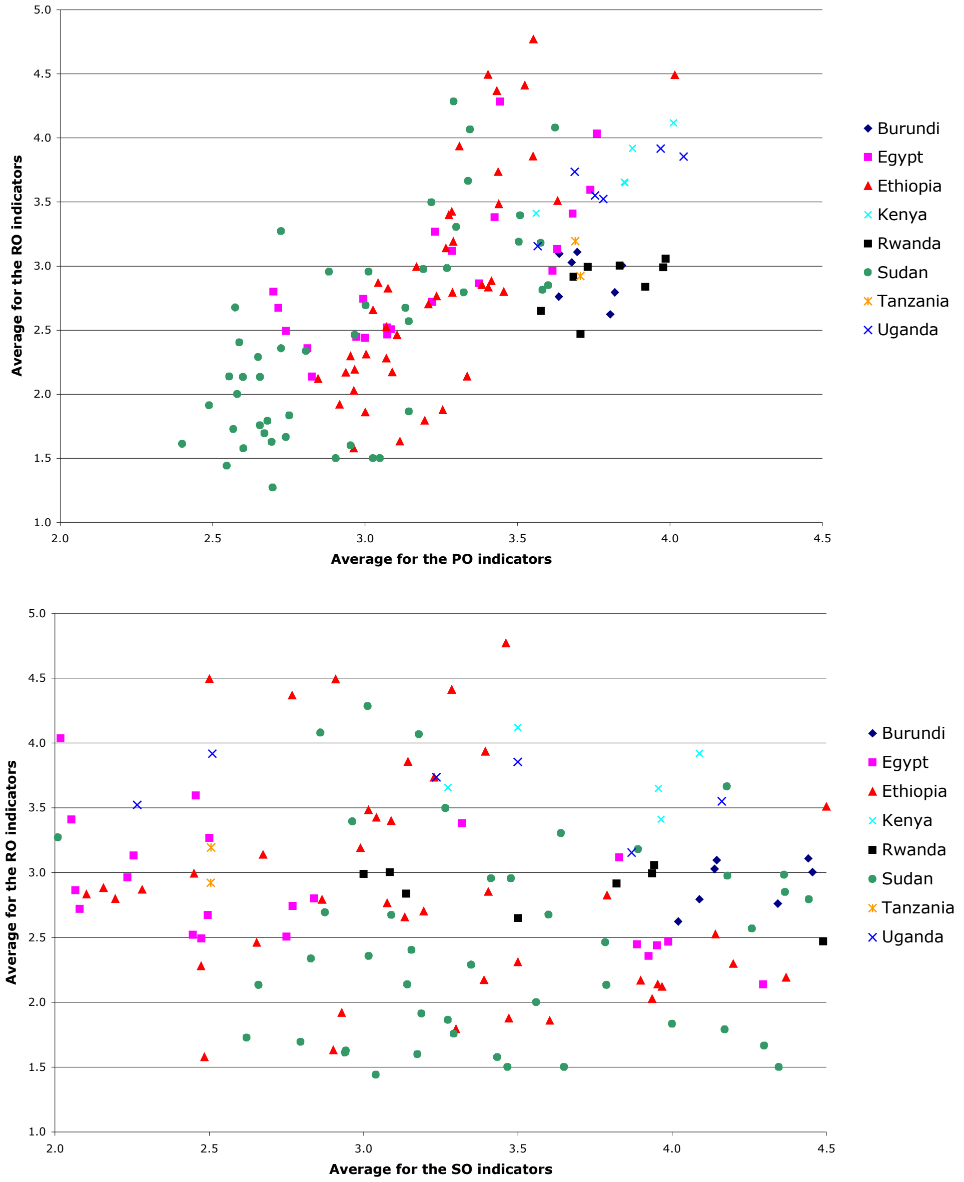


Figure 22 Major differences in management characteristics between all LSI schemes

Table 9 summarizes all the 10 indicators by country. The results show that the LSI schemes in Burundi have highly sustainable irrigation practices and are extremely uniform. The latter is not surprising, considering that there are only 14,625 ha of irrigated land. Burundi should work more on improving crop yield and reducing soil evaporation.

Egypt has a reasonable productivity, but a significant non-uniformity due to the differences between the Nile Valley, Fayoum Depression, the Nile Delta and the Western Desert. The cropping system is sustainable, albeit a trend is present that suggests that the soil moisture levels are declining. This trend needs to be watched. Programmes on real water savings should be introduced and the results of ongoing improvement projects need to be evaluated in terms of impact on consumptive use. There is a potential risk that continuous supply of irrigation water will lead to a higher annual cropping intensity and further increase of crop ET. The extra-ordinary high rice yields in the Delta suggest that ET has increased already, and this could lead to a situation where the overall sustainability becomes at threat. Due to the dense foliage for most of the year, almost all consumed water in Egypt is used beneficially. This places the country in a good position for utilizing Nile water resources productively.

Ethiopia has overall the poorest irrigation management practices. The land productivity is the lowest of all eight Nile Basin countries investigated. This is mainly caused by a systematic shortage of water due to unreliable supplies in combination with a beneficial fraction that is below average. The uniformity is good, which implies that the all fields are about equally stressed. Ethiopia should ensure the water supply to irrigated crops and launch an agricultural productivity program. There are important lessons to draw from Ethiopia when it comes to water saving and increasing water productivity. Other Nile Basin countries could learn from their on-farm irrigation practices.

Kenya is exploring the land and water resources quite productively, and has satisfactory operations at most fronts. The only drawback is their relatively high crop consumptive use. Kenya should encourage farmers to irrigate with less water, and watch that the sustainability remains under control.

Rwanda has an average productivity, but large volumes of water are not consumed beneficially. Soil evaporation should be reduced in Rwanda, although it could to a large extent be a consequence of the high rainfall and wet surfaces with signification interception evaporation. Improving these two parameters could lead to an increase in agricultural production. Neighbouring Tanzania and Uganda with similar climatic characteristics show a higher beneficial consumptive use fraction; apparently lessons can be drawn from them.

Sudan is plagued by significant non-uniformities that reduce the average water productivities. Tanzania has an average irrigation performance at almost all levels. Uganda is characterized by a uniform and high agricultural production. This goes however at the cost of significant amounts of irrigation water (score 1.8). The sustainability is only marginally good. It would be advisable for the Uganda institutions to invest where water could be saved, and by doing that increase the sustainability.

Table 9 Results of all irrigation performance indicators at national scale. The values represent a score between 1 (very poor) and 5 (excellent)

country	**Burundi**	**Egypt**	**Ethiopia**	**Kenya**	**Rwanda**	**Sudan**	**Tanzania**	**Uganda**
average score	3.60	3.02	2.91	3.64	3.55	3.18	3.17	3.45
wp	3.0	2.9	3.1	3.5	3.0	2.7	3.1	2.9
bio	2.8	3.0	2.4	3.6	2.9	3.0	3.1	3.9
cwc	3.4	2.8	3.6	2.5	3.2	3.2	3.2	1.8
cwd	4.6	3.6	3.2	3.3	4.6	3.4	4.5	3.6
bf	2.8	4.0	2.9	3.9	2.7	3.1	3.2	3.6
ad	3.1	3.2	2.4	3.5	3.1	3.0	3.3	4.1
un	4.4	2.6	4.5	4.0	4.5	2.5	4.5	4.3
rel	3.9	3.3	3.0	4.9	4.8	3.6	3.1	5.0
spot	3.5	3.3	3.4	3.0	3.3	3.6	3.9	3.1
amsre	5.0	2.3	2.8	4.6	4.3	4.0	1.5	3.0

There is a significant variability in the irrigation practices in the Nile Basin, especially between countries and for Egypt, Sudan and Ethiopia also within the countries. While certain aspects are very good in one LSI system, other aspects appear to be excellent somewhere else. A country ranking by indicator is presented in Table 10. Kenya is excellent in water productivity, Uganda is excellent in agricultural production and controlling crop water stress. Ethiopia is excellent in uniform water conservation practices throughout all districts. Egypt is excellent in ensuring all consumptive use is beneficial. Tanzania and Sudan are excellent in keeping their LSI's sustainable.

Table 10 Country ranking by the different irrigation indicators. One(1) relates to the highest score and 8 to the lowest score

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Agricultural productivity	bio	Uganda	Kenya	Tanzania	Sudan	Egypt	Rwanda	Burundi	Ethiopia
Water productivity	wp	Kenya	Tanzania	Ethiopia	Burundi	Rwanda	Egypt	Uganda	Sudan
Crop consumptive use	cwc	Ethiopia	Burundi	Sudan	Tanzania	Rwanda	Egypt	Kenya	Uganda
Adequacy	ad	Uganda	Kenya	Tanzania	Egypt	Burundi	Rwanda	Sudan	Ethiopia
Beneficial water use	bf	Egypt	Kenya	Uganda	Tanzania	Sudan	Ethiopia	Burundi	Rwanda
Uniformity	un	Ethiopia	Tanzania	Rwanda	Burundi	Uganda	Kenya	Egypt	Sudan
Reliability	rel	Uganda	Kenya	Rwanda	Burunid	Sudan	Egypt	Tanzania	Ethiopia
Sustainability	spot	Tanzania	Sudan	Burundi	Ethiopia	Egypt	Rwanda	Uganda	Kenya

Interim conclusions:

- Countries with a low irrigation acreage have a positive bias in the overall ranking due to more homogenous cropping and irrigation systems.
- Ethiopia shoud increase crop yield by alleviating crop water stress and provide irrigation water in a more reliable manner.
- Sudan should increase water productivity and take lessons from Kenya, Tanzania and Ethiopia
- Uganda should introduce real water savings, i.e. ET reduction and take lessons from Ethiopia.
- Rwanda should decrease non-beneficial consumptive use and take lessons from Kenya and Egypt.
- Kenya should pay attention to their irrigation sustainability and take lessons from Tanzania and Sudan.
- Burundi should increase crop yields and beneficial fraction.
- Tanzania should supply irrigation water more regularly.
- Egypt should reduce the significant variation between Upper Egypt, Fayoum Depression and the Nile Delta.
- Sudan should also aim at reducing the widely varying differences in irrigation performance between their LSIs.

4.5 Comparing productivity against other river basins

Land productivity

The comparison of productivities between river basins is only useful if the data at larger scale are available and reliable. The up-scaling of crop yield data is not straightforward. Whereas the yield can be acquired accurately from a particular single field through weight and volume measurements, it will represent a local value only. Although this is strategic information to the local grower, it does not necessarily represent the average value for a scheme, district or country. Very often the crop yield data at larger scale is obtained from surveys and interviews, rather than from direct measurements. This undoubtedly goes at the cost of accuracy. The National statistics are often based on data from these interviews, and the National statistics are used by national and international NGO's to portray a country's agricultural productivity and food security. Hence, most land productivity information available is secondary information with moderate reliability, and should be interpreted with caution.

In this section, it is attempted to get a first order estimation of the land productivities in the LSI schemes, and relate them to other river basins in the world. Data provided by the National Project Coordinators (see Table 11) will be contrasted against public domain data sources (Table 12). Table 11 provides a summary of rice and maize data. The average rice yield for the LSI schemes in

Burundi is 3,625 kg/ha. While the figure of 3,250 kg/ha for Rwanda is a little lower, Kenya's harvest of 3,833 kg/ha reflects a higher rice yield per unit land than Burundi. The big outlier in a positive sense is Egypt, with an average rice yield of 8,929 kg/ha. This number was confirmed during the field visit of September 2008 in the rice belt of Kafr-el-Sheikh. Burundi has also made their yield information on maize available: the average value is 1,000 kg/ha. The apparent variations are very large.

Table 11 Reported crop yields by the National Project Coordinators of LSI's present in the Nile Basin

Country	**Scheme**	**Rice (kg/ha)**	**Maize (kg/ha)**
Burundi	Nyamugari	4,750	1,200
Burundi	Kagoma	3,250	900
Burundi	Nyakagezi	3,250	900
Burundi	Nyarubanda	3,250	1,000
Rwanda	Gitega	3,250	x
Egypt	Bahr El Nour	7,858	x
Egypt	Kafr El Sheikh	10,000	x
Kenya	Ahero/Nyando	3,500	x
Kenya	Bunyala/Busia	4,500	x
Kenya	Kabonyo/Kisumu	3,500	x

A brief literature survey of the production of rice, maize, sugarcane and cotton in the Nile Basin LSI schemes has yielded the data presented in Table 12. Most international data bases on crop yields provide the national average yield, without explicitly describing the yield of rainfed and irrigated crops in certain sub-basins. That will hamper the comparison against crop yields in other basins. A limited number of publications have therefore been consulted for the international benchmarking of land productivity (see Table 12) and water productivity (see Table 13).

The reported rice yields for Egypt by the National coordinators of approximately 9.0 ton/ha are supported by other published sources (8.0 to 8.8 ton/ha). For Uganda it can be concluded that the values provided by the International Rice Research Institute (IRRI) with 1360 kg/ha are a serious underestimation as compared to the rice yields from Kenya (~4000 kg/ha). We have seen that the northern lake Victoria floodplains are very productive due to a perfect combination of alluvial soils and limited climatic fluctuations and the values reported by the NPC seems very reasonable.

Table 12 Published crop yields in the international literature concerning the LSI's present in the Nile Basin

Country	Scheme	Source	Rice	Maize	Wheat	Cotton
			(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
Egypt	Nile Delta	Kotb et al (2000)	8,000			
Egypt	Nile Delta	Ahmed (1998)	8,800			
Egypt	Nile Delta	WaterWatch (2003)	8,544		6,060	2,895
Egypt	Nile Delta	FAO	9,100		6,900	1,900
Egypt	Nile Delta	IRRI	9,970			
Egypt	Country	FAO	9,400	8,100	6,400	2,600
Uganda		IRRI	1,360			

When comparing the Nile basin data with the international world (Table 13), it becomes apparent that the yields of rice and wheat in Egypt are extremely high (8.9 and 6.3 ton/ha for rice and wheat respectively) as compared to the global values of 3.8 ton/ha for rice and 3.5 ton/ha for wheat. The rice production of Burundi, Rwanda and Kenya are comparable with the world wide average values for rice production. Hence, in general terms, it can be remarked that the agricultural production in the equatorial region is in pace with the world wide values. The values in Egypt are substantially higher, and Egypt could help with their excellent agronomic expertise to improve the cereal yields in the upstream areas of the Nile basin.

Table 13 International benchmarking of crop yields attainable in irrigated agriculture

	Average	**Rosegrant et al. (2002) Data from 1995**	**Molden et al. (2007) Data from 2000**	**IRRI**	**Lui (2007) (irr and rainfed)**	**Zwart and Bastiaanssen (2004)**	**Zwart and Bastiaanssen (2006)**
	(Ton/ha)	**(Ton/ha)**	**(Ton/ha)**	**(Ton/ha)**	**(Ton/ha)**	**(Ton/ha)**	**(Ton/ha)**
Rice	**3.8**	1.4	3.4	4.15 (0.75-9.97)		6.2 (2.8 to 11.5)	
Maize	**7.7**		6.1			9,3 (1.5 to 14.0)	
Wheat	**3.5**	2.4	3.4		2.7	3.9 (1.0 to 8.5)	4.4 (2.5 to 5.7)
Cotton lints	**1.4**					1.4 (0.4 to 2.2)	

Water productivity

Several international research groups have published water productivity values to help define suitable target values. A summary of the most common papers that deal with multiple irrigation systems from various countries and river basins is provided in Table 14. Water productivity is expressed per unit ET to avoid complex issues on rainfall and seepage interference with irrigation water supply; ET is the total integrator of various sources of water. While the latter is a logical choice, it is not straightforward to acquire the values of actual crop ET when remote sensing techniques are not available. For this reason, the literature often expressed crop yield per unit of water supply. This is also the case with the data of Rosegrant and Molden presented in Table 14. For the averaging, we have therefore considered an "irrigation efficiency" to simply covert water supply into ET. The column "average" has incorporated this efficiency correction, and is thus not a linear average of the other columns.

The results show that maize has a significantly higher crop water productivity than the other major crops cultivated in the Nile basin. The reason is that maize is a C4 crop with a low carbon dioxide concentration inside the crop that enhances carbon fluxes from the atmosphere into the stomatal cavities. A value of 1.77 kg of maize per m^3 water evaporated is indeed quite good. The water productivity for cereals (rice and wheat) is more or less similar: 0.92 and 0.90 kg/m^3 respectively.

In the absence of crop information and harvest indices, our diagnostic results based on 250 m x 250 m pixels have been expressed in a biomass water productivity value (kg/m^3). If we assume for simplicity that the majority of the crops are cereals (being true as appears from the crop statistics), a water productivity of 0.90 kg/m^3 at a harvest index of 0.35 (being true for cereals) is a biomass water productivity of 2.6 kg/m^3. Yet, values of 2.6 kg/m^3 or higher should be achieved from the pixels values that we have calculated. The average data per country shows the following picture:

- Burundi : 3.94 kg/m^3
- Egypt : 2.82 kg/m^3
- Ethiopia : 3.59 kg/m^3
- Kenya : 3.58 kg/m^3
- Rwanda : 4.10 kg/m^3
- Sudan : 1.59 kg/m^3
- Tanzania : 3.75 kg/m^3
- Uganda : 3.30 kg/m^3

The conclusion to be drawn is that all countries meet the international benchmark value of water productivity (i.e. biomass water productivity of 2.6 kg/m^3) except Sudan. This finding is not unexpected, considering the analysis being discussed before. Without going into details, it must be mentioned that water productivity is strongly coupled to climatic conditions: a higher aridity will always reduce the attainable crop water productivities. The fact that Egypt is above the world average line, can only be explained by the extra-ordinary high yields. This demonstrates once more that a benchmarking procedure per climatic zone should be done. And this is how we have done it.

Table 14 International benchmarking of water productivity (crop yield/ET) attainable in irrigated agriculture. The range is added in brackets

	Average (kg/m^3)	**Rosegrant et al. (2002) (kg/m^3)**	**Molden et al. (2007) Data from 2000 (kg/m^3)**	**Zwart and Bastiaanssen (2004) (kg/m^3)**	**Zwart and Bastiaanssen (2007) (kg/m^3)**	**Lui (2007) (irr and rainfed) (kg/m^3)**
Rice	0.92	0.15 to 0.60	0.46 (0.18-0.54)	1.09 (0.6 to 1.6)		
Maize	1.77		0.87 (0.3-1.33)	1.80 (1.1 to 2.7)		
Wheat	0.90	0.2 to 2.4	0.54 (0.37-0.70)	1.09 (0.6 to 1.7)	1.11 (0.54 to 1.52)	0.8
Cotton - lint	0.23			0.23 (0.14 to 0.33)		

Interim conclusions:

The average rice production levels in the Nile Basin LSI schemes are comparable with the world average values.

Egypt has the highest rice yields of the world, and their agronomists could help the agricultural practioners in other Nile basin countries.

The average maize production levels in the LSI schemes are below world average values; there is scope for improvement to increase maize production levels in the Nile Basin.

Except for Sudan, the water productivity values are very acceptable and in line with the world average values.

A thorough analysis could be achieved if the spatially distributed biomass production can be converted into crop yield; this requires a crop map to be prepared for all irrigation schemes.

5 Social, economic and institutional context

5.1 Introduction

The basic purpose of irrigation is to supplement natural water availability, enhancing the productivity of agriculture. Beyond this fundamental objective, irrigation may be designed to distribute limited supplies of water to many users, or to provide for the full potential demand of a more limited group; the service may be designed to support intensive, high-value cropping or extensive production of food grain. Depending on climate and the availability of irrigation water, the technology of irrigation may be designed to deliver precisely timed, limited quantities of water to individual plants, or large, regular deliveries to flooded fields; irrigation may be the only source of water, or may supplement rainfall. The farmer may be allowed to take water "on-demand", or have to accept a specified schedule. Management of the system may be by government, private agencies, or farmers.

None of these options is "right" – all have their place depending on the objectives that a government sets for its systems, which in turn will reflect climatic conditions, market opportunities, social objectives and economic priorities. This greatly complicates the evaluation of performance. In the preceding analysis, important *physical* aspects of irrigation performance have been identified and described. However, a complete evaluation of whether a system is performing well, and what lessons can be learned from its physical performance characteristics, would require an understanding of these broader objectives.

An example may help to clarify this issue.

Irrigation in Egypt generally aims to provide adequate water to fully irrigate the farmer's chosen cropping pattern. That this objective is achieved is shown by the very high yields reported for Egyptian agriculture. However, the Fayoum area is different. Because of the threat of a rising and saline water table, the irrigation system in Fayoum is designed and operated according to entirely different principles from the rest of Egypt: irrigation channels are sized in proportion to the area served, and deliveries follow a defined rotational program designed to deliver limited, regular supplies equitably to all users; each farmer receives enough water to irrigate part of his land. In the rest of Egypt, supplies are adequate (at least in one, and often two seasons) to irrigate the entire holding.

An important consequence of this is that the *physical* indicators of performance in Fayoum will, if the system is working properly, be quite different from the indicators elsewhere in Egypt. In Fayoum, we can expect to see water stress because the design objective is to limit water supplies. Elsewhere in Egypt, stress should be minimal because that is the design and operational objective. Similarly, if the Fayoum system is working according to its design principles, the stress should be uniform (that is, all farmers should be receiving less than full irrigation requirements, not just those at the tail).

In fact the calculated physical indicators confirm that water stress in Fayoum is indeed much more significant than in other areas of Egypt. Knowing that this was part of the design and operational plan – with the desirable objective of avoiding salinization of the area – we can see that this indicator is a positive reflection of performance. If we did not know this background, the first impression would be that performance in Fayoum is worse than elsewhere.

This example highlights the need to understand more than just the physical indicators of performance if lessons about good practice are to be drawn. For this reason, repeated efforts were made to collect information about the objectives, design standards, planned and actual cropping patterns, water availability and management structures. The results of these efforts were not adequate to allow a full understanding of performance in relation to objectives; thus while we can fully report on the physical indicators, further interpretation of these in relation to sectoral and project objectives is limited.

In preparing this chapter, the following sources were consulted:

- AQUASTAT information for:
    - Burundi
    - Egypt
    - Ethiopia
    - Kenya
    - Rwanda
    - Sudan
    - Uganda
    - (No data are available for Tanzania)
- EWUAP country reports "Rapid Baseline Assessment of Agriculture Sector with special reference to three components of efficient water use for agriculture production" for:
    - Egypt
    - Ethiopia
    - Kenya
    - Sudan
    - Uganda
- World Bank country briefs
- World Bank Africa Development Indicators
- Geographiq
- UNESCO
- ODI report: Regional Nile Synthesis Paper of

Where relevant, information from these reports is included, but while they provide interesting background information about the policy and strategy being followed, none provides basic information about the service delivered to farmers. If best practices are to be identified, these will consist of implementation of policies and strategies at project level, and implementation means specification of hardware and software (management, water rights and delivery, institutions, laws). None of the information provided by the countries allowed an understanding of the details of project operations. Consequently, it is impossible to provide specific guidelines, and most of the practical guidelines are based on general judgement.

This chapter first describes the basic components of water resources management. These are the steps that each level of government must address most especially as water resources development reaches its maximum potential, and water becomes a scarce resource. Next, the general economic and social parameters that could be assembled from the literature are summarized, and then the sector-specific information, again based on available literature.

5.2 Basic elements of water resources management

Sustainable, productive water resources management requires a clear definition of the service to be provided to users – whether the "user" is a factory, a household, an irrigation project, or even a country. This does not mean that the precise quantity of water to be delivered is specified in advance for each user – rainfall and river flows are never certain. Some users will have a high priority, and variations in their supply will be limited; other users (especially agriculture) tend to absorb the variation, though some advantageously located irrigation systems may also get secure supplies.

Especially when water is scarce, water management at each scale requires clear definition of the rules for allocating available supplies – which result in a defined water service. In well managed systems the rules are well known and clear. Conversely, and especially in the case of irrigation, if there is no assurance of the availability of water, management is exceptionally difficult and is unlikely to result in high-productivity agriculture.

At any scale the process is based on five elements:

1. Understanding and measurement of the available water;
2. Agreed priorities among competing users/demands;
3. Rules codifying the priorities under varying hydrological situations;
4. Establishing the agencies to implement the rules;
5. Infrastructure to deliver the resulting "service" to users.

This set of elements applies at all levels, from the basin to a Water User Association responsible for operating part of an irrigation project and distributing water among members. The framework is neutral, in the sense that it embodies no preference for public versus private management, regulated or market allocation of water, agency or stakeholder operation, full or partial cost recovery etc. Rather it focuses on what needs to be done to ensure that each level within the system has a clear idea of what resources are likely to be available. In the absence of this information, managers cannot plan water distribution at the project level, and inevitably productivity of land and water is reduced.

Table 15 outlines how these factors are defined at the basin level and at the irrigation project level. In the case – for example – of a mesqa in Egypt, traditional rules for sharing water among farmers until quite recently ensured reasonable access to all, based on pumping water by a number of sakias, each owned by a group of farmers who shared its output according to internally agreed rules. This stable relationship between water availability and infrastructure was broken by the introduction of individually owned petrol-powered pumps that dramatically increased the demand for water at the mesqa level. Readjusting the rules of allocation and modifying the institutional arrangements (for example by introduction of WUAs and Water Boards) is in progress – demonstrating how an intervention in one element (infrastructure) has implications for other elements.

Table 15 Elements of Water Resources Management

Scale activity	**Basin**	**Country… Region… Sector…**	**Project**
Understanding and measurement of the available water resource	Available flows were measured and documented historically	… ….	Project allocation defined in relation to other projects and sectors.
Negotiating priorities among competing users/demands	Allocation of the available water negotiated	… …	Allocation priorities among projects in case of scarcity/excess are specified
Codifying the priorities into operational rules for any hydrological situation	Allocation specified in an agreement between the two countries including rules for allocation in cases of high/low flow	… … …	Rules determining allocation (quantity and timing) for any level of general availability
Assigning responsibilities to implement the rules	Conformity with the agreement based on defined measuring points, and institutional responsibilities		Assigned power and responsibilities to agencies, WUAs, etc for management, operation and maintenance
Infrastructure to deliver the resulting "service" to users	Storage and diversion facilities are consistent with allocated water quantities.		Pumps, canals, control structures to deliver service to users

5.3 Background information by country

This section presents key economic and other indicators of relevance to the agricultural sector in general. With the exception of Egypt, and to some degree Sudan, the Nile basin countries (Burundi, Egypt, Ethiopia, Kenya, Sudan, Tanzania, and Uganda) are among the poorest in the world. Furthermore, several (Burundi, Ethiopia, Kenya, and Sudan) currently or recently experienced severe social unrest and internal displacement. All have fiscal constraints that limit the capacity of the governments to invest in new infrastructure or subsidize the operation and maintenance of existing infrastructure.

Egypt is a special case in terms of overall development, prosperity and stability (Figure 23 and Figure 24). In 1980, income levels in Egypt were double the average of the other countries; by 2005 the ratio was four times (per capita GDP for Egypt is excluded from Figure 24). The economic disruption of internal conflicts is clear in the cases of Burundi, DRC, Ethiopia, Rwanda, and Sudan. Figure 25, below, shows the importance of the agricultural sector in the economy of the Basin countries.

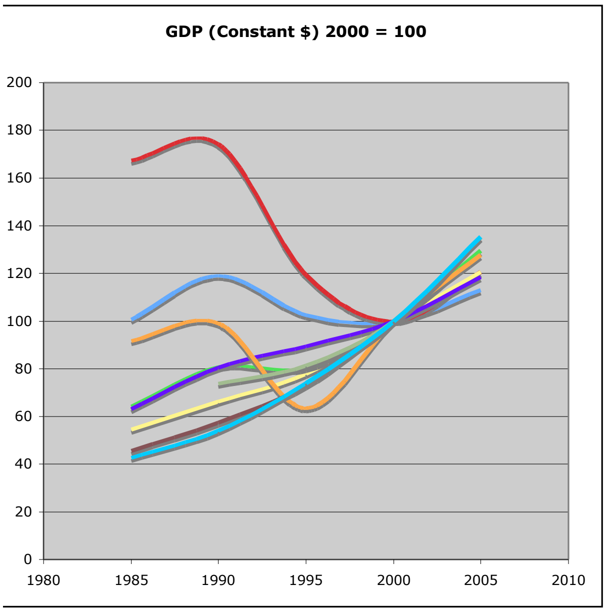


Figure 23 GDP, Constant 2000 $

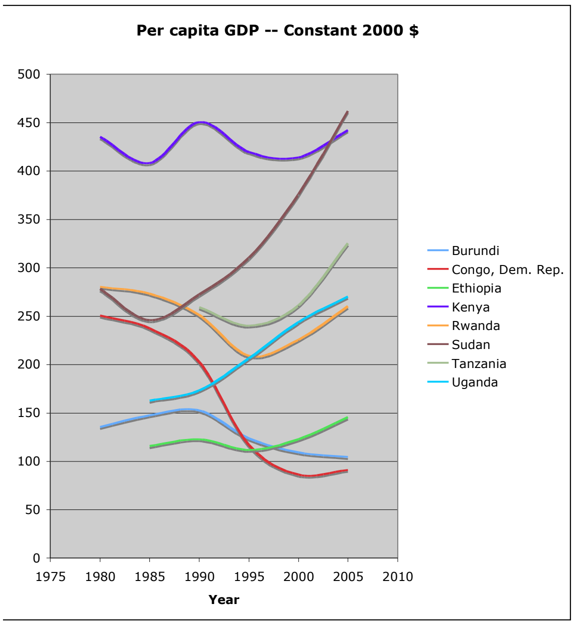


Figure 24 Per capita GDP

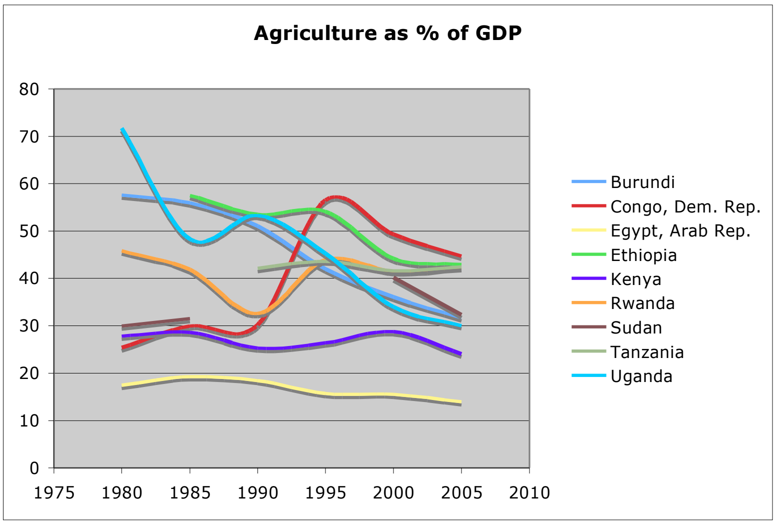


Figure 25 Agriculture as % of GDP – 1980-2005

Again, the distinctive situation in Egypt is clear: the trend is initially slightly upward (reflecting the liberalization of agriculture in the 1980s, when cropping pattern restrictions were lifted and many price controls relaxed). Thereafter the trend is steadily downwards – not because agricultural productivity was declining, but rather because the rest of the economy was growing strongly and agriculture was declining in relative importance.

For other countries the recent trend is downward, but the fluctuations indicate both economic upheaval as well as sensitivity to seasonal weather patterns: as will be shown later, aside from Egypt and to a lesser extent Sudan, the basin countries are heavily dependent on rainfed agriculture.

Although there have been variations within the Nile basin, productivity levels are still low with many of the Nile basin countries dependent on importing a significant proportion of their food needs. The impact of this dependency on external crop production has been highlighted recently with a number of governments being unable to meet demands for wheat. This impacts most on the poor within the Nile basin countries, as they are more vulnerable and less able to purchase the food they need due to price increases.

Table 16 shows some key agricultural and economic data. The cereal yield of the various countries is for instance summarized. The lowest yield is found in Sudan (505 kg/ha, presumably un-irrigated) and the highest yield is Egypt (7280 kg/ha). Note that this numbers are based on census data, and are not retrieved from the remote sensing data described in the previous chapter.

Table 16 Key agricultural and economic data

	Burundi	**D R C**	**Egypt**	**Ethiopia**	**Kenya**	**Rwanda**	**Sudan**	**Tanzania**	**Uganda**
Agricultural exports (current US$M)	36.39	39.60	536.47	341.10	1,033.42	41.37	416.96	452.88	260.41
Agricultural imports (current US$)	23.47	236.90	3,608.62	327.35	510.33	68.58	444.41	330.09	133.96
Imports/exports	**0.64**	**5.98**	**6.73**	**0.96**	**0.49**	**1.66**	**1.07**	**0.73**	**0.51**
Agricultural machinery (tractors/100ha arable)	1.77	3.63	307.94	3.00	27.11	0.67	7.30	19.00	9.29
Agriculture value added per worker (constant 2000 US$)	86.46	164.51	1,856.95	148.90	306.40	201.01	658.47	264.88	221.93
Cereal cropland (% of land area)	7.64	0.88	2.77	7.18	3.31	11.45	2.72	5.88	6.96
Cereal yield (kg per hectare)	1,249.50	782.40	7,280.10	1,115.50	1,374.70	848.30	505.20	1,335.10	1,539.40
Electric power consumption (kWh per capita)	..	90.25	999.41	23.44	111.90	..	63.03	56.96	..
Fertilizer consumption (100 grams per hectare of arable land)	36.46	1.19	4,497.43	157.48	323.79	3.33	25.07	56.01	13.12
Food exports, FAO (current US$)	2.11	4.35	309.10	66.02	227.00	0.01	300.47	184.38	20.19
Food imports, FAO (current US$)	21.41	136.12	2,737.07	296.20	446.91	61.88	346.49	300.24	111.19
Imports/exports	**10.13**	**31.26**	**8.85**	**4.49**	**1.97**	**4,420.00**	**1.15**	**1.63**	**5.51**
Government Effectiveness (percentile rank 0-100)	**8.60**	**1.00**	**64.60**	**37.30**	**25.40**	**48.30**	**3.80**	**41.60**	**49.30**
Health expenditure per capita (current US$)	3.40	9.80	83.00	5.10	18.10	9.00	11.70	10.80	15.60
Improved water source (% of population with access)	77.00	45.00	97.00	22.00	57.00	70.00	69.00	58.00	55.00
Improved water source, rural (% of rural population with access)	75.00	28.00	96.00	12.00	42.00	67.00	63.00	45.00	51.00
Improved water source, urban (% of urban population with access)	93.00	85.00	99.00	81.00	85.00	91.00	79.00	85.00	85.00
Irrigated land (% of crop land)	1.59	0.14	100.00	2.71	1.68	0.78	11.19	3.20	0.13
Illiteracy rate -- Total	52.03	38.61	44.70	60.90	17.58	33.15	42.33	24.99	32.97
Illiteracy rate --Male	43.85	26.90	33.39	52.91	11.12	26.41	30.78	16.13	22.54
Illiteracy rate --Female	59.58	49.79	56.22	68.96	23.98	39.61	53.76	33.50	43.16
Primary completion rate, total (% of relevant age group)	25.14	..	97.34	36.66	..	22.38	38.88	..	..
Road density (road km/1000 sq. km of land area)	442.76	66.64	92.24	32.36	108.58	531.86	4.75	83.47	299.72
Road to arable land density (road km/1000 sq. km arable land)	..	..	..	2.96	14.21	..	..	..	..
Roads, paved (% of total roads)	10	2	81	19	14	19	36	9	23
Rule of Law (estimate)	**-1.01**	**-1.94**	**0.10**	**-0.47**	**-1.03**	**-0.90**	**-1.19**	**-0.26**	**-0.62**
Urban population (% of total population)	8.60	29.80	42.50	14.90	19.70	13.80	36.10	22.30	12.10
Value added in agriculture, growth (%)	0.95	0.88	1.03	1.03	0.99	1.09	1.07	1.03	1.06
Value added, agriculture (% of GDP)	36.01	49.37	15.54	44.21	28.72	41.41	40.13	41.56	33.99

The data above are derived from World Bank, UNESCO (Literacy), Geographic (transportation density)

5.4 National irrigation strategies

Two requests for information about specific sample projects were circulated to the basin countries in March and July 2008. The requests were formulated as questionnaires designed to better understand how each country approached the issues set out in Section 5.1. The underlying purpose was to try and identify the nature of the irrigation service provided by LSIs in the basin countries, and any features that seemed to explain better of worse performance.

The response to the first questionnaire was not complete for any country, while the second, simpler version resulted in provision of a limited amount of information. Unfortunately there was little uniformity of presentation. The key points that were mentioned, together with information extracted from national water policy documents, are summarized below.

Because the information from the Rapid Assessment is particularly informative for Ethiopia, we begin with that country, because it allows the clearest definition of the problem of distinguishing between policy statements and implementation on the ground.

Ethiopia

The national Water Policy goal is "to enhance and promote the efficient, equitable and optimum utilization of the available Water Resources of Ethiopia for significant socio-economic development on a sustainable basis

Policy objectives, inter-alia, include: Equitable and sustainable development of the Water Resources of the country for socio-economic benefit of the people; Allocation and apportionment of water for efficient, equitable and sustainable use, according to integrated plans; prevention and management of drought and related disasters through allocation, distribution, storage and other means; flood control and mitigation through various means; and conservation, protection and enhancement of water resources and aquatic environment on a sustainable basis

The basic principles are the followings: water, as a natural resource, is the common good of the Ethiopian Peoples; every Ethiopian has a right of access to water of sufficient quantity and quality to satisfy basic human needs; water should be recognized as an economic and social good; water resources development shall be rural-centred, decentralized, participatory and integrated in approach; water resources shall be managed according to the norms of social equity, systems reliability, economic efficiency and sustainability; participation of stakeholders, especially women, shall be promoted in water resources development.

In practice, priority is given to domestic use, with irrigation second, and hydropower third. (The response to the questionnaire did not mention industry, which is perhaps seen as part of the domestic/urban sector.)

Irrigation development is designed to promote food security, jobs, production of industrial inputs, and as a means of increasing rural incomes.

Water is reportedly supplied on a volumetric basis, but no data were available on quantities of water supplied to projects of individual farmers.

Responsibilities for the sector are as follows:

Planning:	Central Ministry of Water Resources
Design:	Government, utilizing private local and foreign consultants
Construction:	Local and foreign contractors supervised by government.
O&M:	Local communities, investors
Regulatory:	basin water administration organizations

The Rapid Baseline Assessment (RBA) for Ethiopia raises several important points, as extracted below, which suggest that the policies the government has set out are not yet fully implemented.

Emphasis has been added to particularly important sections.

The prevailing problems are also caused by cumulative effects of poor planning and implementation. Shortcomings attributed to capacity limitations at the planning stage are very common as can be seen from the following example:

- There are many cases of reduction in planned irrigable area due to shortage of water during periods of low flows, which is associated with drought. Alternative measures were not planned for the periods of low flows;
- Shortage of water caused by reservoir sedimentation is also common. This could have been averted if the catchment area were addressed as an integral part of the irrigation scheme.
- Shortage of water caused due to excessive diversion of water by farmers situated towards the head of the supply canal (either to grow sugar cane or to over irrigate their plot) is very common. This could have been addressed by preparing and enforcing appropriate operation guidelines.
- In some schemes farmers anticipate for maintenance tasks either from the government or the financing agency. This could have been handled by participating the community at the early stage of the project cycle.

An assessment conducted in 1999 on one hundred irrigation schemes in Oromia region showed that 17% of the schemes had failed, 42% performed at less than 50% of their capacity and 51% performed at greater than 50% of their capacity. A major problem identified, was insufficient collaboration between the relevant government institutions, which have a stake in irrigation. It was noted that the agricultural extension workers were insufficiently qualified and equipped for the complex extension tasks of irrigation agronomy, soil fertility management, crop protection, etc. Water users associations were insufficiently trained to manage schemes in a technically, economically and socially sustainable way. Input supply was insufficient.

Water use efficiency in irrigation farms situated close to big urban markets is higher compared to those in remote areas. The former earn better income from the sale of their diversified crops. Such better income helps them to invest more in acquiring pumps and pipes and undertaking timely maintenance works.

The Ethiopian water resource management policy and strategy documents clearly noted for the establishment and implementation of tariff structure for water services. The tariff structure is to be based on site-specific characteristics of the schemes, and ensure that water prices lead projects to full cost recovery. Water charges related to domestic water supply are put in to effect through out the country. The only irrigation water charge that has been in effect is at the Awash Valley irrigation farms, which is 3 Birr per 1000 m3 of water. However, there is no detailed legal ground to support the implementation of the water charge. There were times when the clients failed to effect payment and the responsible agency lacked to handle the case in arbitration and/or litigation. All this is attributed to the lack of appropriate regulations. Some of the WUAs do have byelaws but in many cases are breached or not observed. On the other hand, indigenous irrigation schemes have unwritten but effective byelaws.

Conflicts between upstream and downstream water users are increasing in many parts of the country. New diversions or pumps are being installed upstream of existing diversion weirs resulting in shortage of water for the existing schemes. Such cases are being taken to the court and other authorities, but it appears there would be no immediate solution. Farmers are taking the case to the court and relevant authorities whenever a neighbour attempts to dig a well very close to an existing one. But, there are no rules and regulations to address the issues.

There is excessive application of water by farmers situated towards the head of the supply canal resulting in shortage of water by the downstream users. Besides, there is wastage of water resulting from the perception that says “water is a free good “. In some sites, water is diverted to a field canal beyond the capacity of a farmer and results in damaging the land (by water logging or erosion). Often there are conflicts among the users. One possible solution to such problems would be the introduction of water fees, which is not being considered currently.

On the other hand, there are also practices that tend to reduce the water use efficiency, such as the following: (a) Canals are breached at many points so as to take water to individual plots. But, as the breached points are not sealed properly water is lost by leakage; (b) Adjacent plots are planted with different crops at different times. In such cases the supply canal is required to convey variable amount of irrigation water during the growing season in response to the variable demand. However, there is no mechanism to quantify the demand and regulate the flow rate accordingly. Often, unregulated flow is released to the plots located haphazardly in the system and water is lost consequently. The major loss of water occurs at the beginning and towards the end of the irrigation season in connection with the release of excess water to plots located haphazardly in the system; (c) In addition to seepage (due to pervious formation), water is lost by spilling over canal banks caused by reduced canal capacity resulting from sedimentation and growth of weeds in the canal.

The relevant government institutions possess very little information related to the subject in question and yet not properly organized. The inadequacy or lack of data, related to agricultural water use, is among the major constraints noted in various papers prepared by researchers, planners and designers. There is also a gap in formal and systematic information exchange mechanism among institutions and within an institution. Thus, the EWUAP has to address the establishment of database on the use of water for rainfed agriculture, irrigation and livestock. This should include establishing a mechanism to continuously update and avail the data/ information to users.

All of the documents reviewed could not provide adequate information to establish quantitative benchmarks of the best management practices.

The situation implied by the divergence between the policies set out by the government and the information reported from the field should not be interpreted as critical of Ethiopia: every country, in all sectors, has policies – which in effect reflect targets and optima – and the reality, which is the struggle to meet those aspirations and goals.

The problem for this particular study is that unless we know what is actually being implemented in the field, we cannot relate performance to practices.

Burundi

The Rapid Basin Appraisal (RBA) report for Burundi is mainly descriptive of the agricultural sector and the institutions and policies adopted for irrigation.

National policies list the following priorities for allocation of water:

- access to drinking water;
- rural access to hydro-electric energy;
- increased rational use of water resources to satisfy population needs including agricultural and pastoral production;
- sustainable protection of the resource;
- improvement in mechanisms of coordination and ways to support management capacity in the sector of water

Egypt

The RBA report describes the agricultural situation in Egypt, crops grown and the main differences between Upper Egypt, Fayoum, and the Delta. Institutions involved with irrigation are listed.

The National Policy has three major pillars:

1. increasing water use efficiency;
2. water quality protection; and
3. pollution control and water supply augmentation

The National Water Resources Policy includes a number of general institutional measures; it initiated a process of decentralization (to Water Boards) and privatization, including a restructuring of the role of the Ministry of Water Resources and Irrigation.

Cost-sharing and cost-recovery mechanisms will be implemented to make the changes sustainable, in particular with respect to operation and maintenance. Recent projects such as the Integrated Irrigation Improvement and Management Project (IIIMP) provide for full cost recovery of project works from beneficiaries as well

The role of the key stakeholders in water resources management (including farmers) should be enhanced by involving them more fully in water management tasks but also by strengthening their sense of 'ownership'

The process of implementation at a national scale of the IIIMP program makes evaluation of irrigation performance in relation to the institutional environment difficult – in unimproved areas, farmers draw water from below-grade channels that are provided with water on a rotational basis. In improved areas, the irrigation supply is continuous and the aim is to provide water "on demand". Farmer organizations are responsible (in the upgraded areas) for distributing water, and for operation and maintenance of the facilities at tertiary level. Above this level, Water Boards are under formation to manage the secondary level. Thus operation and maintenance are quite different under the two systems, but it was not possible in this analysis to distinguish different performance between the two approaches.

The main objective of LSI in Egypt (which has of course been practiced for thousands of years) is now to improve the system and make it more productive. Food security is mentioned as an objective, but in fact Egypt produces very large quantities of high value export crops while importing a large proportion of its lower value basic food requirements.

Water allocations are guaranteed for companies, factories and drinking water supply companies – implying that agriculture/irrigation is the residual demand that absorbs the variation in supplies from year to year. It is not clear whether commercial irrigators (such as the new "public-private partnerships" in the western delta) receive any preference in water allocations over traditional private farmers.

Apart from these large commercial enterprises, farming in Egypt remains primarily a small scale activity, with almost 60% of farms less than 0.4 ha, and more than 50% of the irrigated area comprising farms of less than 4 ha.

Egypt, as well as being by far the most experienced country in respect of irrigation also enjoys the great benefit of having virtually all its agriculture irrigated – so that research and extension activities can be fully directed to the needs of irrigated farming, and densely populated and developed in the irrigated areas, so that access to markets is excellent.

While not explicitly stated, the goal of the irrigation service in Egypt is to provide farmers with the water they need for a fully irrigated, high-yielding crop. When disputes arise about the adequacy of water availability (for example, if farmers plant more rice than is officially sanctioned in the delta areas), it seems that the Ministry of Agriculture is generally able to get extra water released to meet farmers' needs.

The responsibilities for the sector are as follows:

Planning:	Central and local government agencies
Design:	Government, utilizing private consultants, and with input of beneficiaries
Construction:	Local and foreign contractors supervised by government
O&M:	WUAs with support of Irrigation Advisory Service (government)
Regulatory:	Government, sometimes using private firms to monitor different activities

Kenya

According the to the RBA for Kenya, overall responsibility for water management lies with the Ministry of Water Resources Management and Development (MWRMD), granted through the Water Act 2002. The ministry's current policy (1999) focuses on decentralization, privatization, commercialization and stakeholder participation. The Water Act 2002 has provided the formation of a Water Resources Management Authority, responsible for water pollution, and the management of lakes, aquifers and rivers, and the establishment of a Water Services Regulatory Board, responsible for water supply through licensed water services providers.

Irrigation development in Kenya is under a number of institutions, including both the public and private sector. The National Irrigation Board (NIB), mandated with the development of the national irrigation schemes, and the Irrigation and Drainage Department (IDD), responsible for the promotion of smallholder irrigation with a wide network across the country, are under MWRMD with effect from July 2003. The River Basin Development Authorities (RBDA), with the responsibility of the planning and use of the water and land resources within their jurisdiction, are under the Ministry of Regional Development. Besides these main government institutions, there are a number of non-governmental organizations that support irrigation development.

Irrespective of the institution involved in development, the formation of water users associations (WUA) has been promoted in order to ensure sustainability of the schemes. Most of the structures and water rights for each scheme belong to the irrigating community. Water management within the smallholder irrigation schemes is the responsibility of the WUAs.

The policies and legislation for water management in agriculture are inadequate, which is exemplified by the fact that the only existing legal framework is the irrigation act of 1966 for the establishment of the NIB and management of tenant-based irrigation schemes. A national irrigation policy and legal framework are under formulation in order to comprehensively coordinate and regulate the irrigation sub-sector. A few centrally managed government settlement schemes have been established through the irrigation act of 1966, but they are currently experiencing a lot of institutional and management problems.

Recently, irrigation development is led by the private sector and by smallholder irrigation schemes with great emphasis on sustainable development. The private sector has also spearheaded irrigation development in areas close to urban centers for local vegetables and high value horticultural produce for the export market.

The reasons for considerable areas of the public schemes being non-operational are for example differing opinions between the National Irrigation Board (NIB) and the farmers about the management and running of the schemes or failure of pumping units.

The funding of irrigation development is in transition as the emphasis has shifted from government-led development to participatory and community-driven development. As a result of the change of approach and policy, irrigation development has been categorized so that schemes in the arid and semi-arid lands (ASAL) have to be developed through grants, with the beneficiaries providing contribution in terms of unskilled labour and local materials. Community-based market-oriented irrigation schemes are currently developed through cost-sharing rather than full cost recovery on infrastructure. Full cost recovery approach has been discontinued because it has been found to be a hindrance to irrigation development especially where major infrastructure is involved. In both cases operation and maintenance are the responsibility of the community.

Rwanda

Rwanda has adopted policies setting out priorities for water resources development, but to date, due to lack of funding, progress is limited.

The majority of grants , donations , loans from different donors and development banks are geared to the agricultural sector, mainly “large scale irrigation on marshland” for improving of food security (rice, maize), rural income, job creation, etc.

Water rights are theoretically guaranteed by Law and regulations, but no resources for their monitoring and enforcement is provided. No absolute volumes, proportions, minimum withdrawals up to now, but when is specific water conflict case arises, direct measures are undertaken to enforce water standards by Government.

Farm sizes are very small – mostly 0.1-0.25 ha.

Responsibilities for the irrigation sector in Rwanda are as follows:

Planning:	Government, Ministry of Agriculture and Animal Resources (national staff)
Design:	Government, utilizing private local and foreign consultants
Construction:	Local and foreign contractors supervised by government
O&M:	100% from users. Government only intervenes for major rehabilitation
Regulatory:	Technical regulations come from the Ministry in charge of Agriculture Organisational regulations from the Ministry in charge of Cooperatives Trade / agribusiness/ Marketing/organisations: Ministry of Trade and Industry Health & environmental ones from Local Gvts and specialized Agencies

Sudan

According to the RBA, in 2000, the total area equipped for irrigation was 1,863,000 ha, comprising 1,730,970 ha equipped for full or partial control irrigation and 132,030 ha equipped for spate irrigation. Chapter 2 shows that approximately 1,700,000 has is actually irrigated. In 1995, surface water was the water source for 96 percent of the total irrigated area land, and the remaining 4 percent were irrigated from groundwater (small tube-wells). Most irrigation schemes are large-scale and they are managed by pastoral organizations known as Agricultural Corporations, while small-scale schemes are owned and operated by individuals or cooperatives.

The performance of the major schemes is poor. A study undertaken in the Rahad Scheme based on data from 1977 to 1995 shows that actual crop yields are well below potential yields. The same study also estimated the water use efficiency and found an overall efficiency of 63-68 percent. The distribution efficiency of the network was 93 percent and estimated field losses were 25-30 percent. This information is in agreement with the low biomass production noted in the previous chapters.

In 1992, the national economy was reoriented towards a free economy, a policy shift that impacted the agricultural sector profoundly. The government withdrew from the direct financing of agriculture, provision of inputs and services. The Government within its policy of withdrawal from provision of goods and services handed over all the small- and medium-size irrigation schemes under its control to the farmers. The handing over policy was not successful because farmers were ill-prepared and most of the schemes were in need of rehabilitation. Since 1992, the cropped areas and the productivity of many schemes have sharply declined.

In the Gezira Scheme, a complex mix of financial, technical and institutional problems resulted in a serious fall in the productivity of the scheme and a corresponding drop in farm incomes in the late 1990s, resulting in a drop of cropping intensity from 80 percent in 1991/92 to 40 percent in 1998/99. About 126,000 ha were taken out of production owing to siltation and water mismanagement, leading to a reduced availability of water. Because of bad water management, water supply is about 12 percent below crop water requirements at crucial stages in the growth cycle, while at the same time, as much as 30 percent of the water delivered is not used by crops. However, an initiative aimed at "Broadening farmer's choices on farm systems and water management" by FAO in part of the scheme, meant that productivity of sorghum, cotton and wheat could be increased to 112 percent for 2000/01, compared to the Gezira average of 42 percent.

The Sudan National Water Policy Draft of 2000 (SNWP) sets out the following policy principles:

- Water is a scarce and valuable commodity which has to be equitably, economically and efficiently used
- Access to water for basic human needs is the highest priority in the development of water resources
- Development of water resources must be demand-driven and management should be undertaken at the lowest possible level
- Development and management of water resources, and the operation and maintenance of water services must be economically sustainable through the recovery of costs from those who benefit

LSI in Sudan is dominated by the Gezira and Rahad schemes, where irrigation was originally managed by government with the irrigators as shareholders. The system of irrigation was originally strictly managed – cropping patterns, planting times, fertilizer use and production marketing was all undertaken or controlled by the government, with farmers little more than labourers on their holdings. A critically important result of this situation was that the irrigation infrastructure was designed, constructed and operated to serve a precisely known, uniform cropping pattern – with a system of night storage structures that allowed the main canals to operate continuously while irrigation was only practised during the day. More recently farmers acquired greater freedom to choose crops and the irrigation scheduling system no longer suited the variable (and often increasing demand. The irrigation infrastructure has largely been "modified" by farmers to allow continuous flow.

Tanzania

The national water policy, adopted by Parliament in July 2002, aims to create an enabling environment for provision of efficient water services and changes the role of the Ministry of Water to ensure effective implementation of the policy, through participatory strategies, education and awareness raising campaigns targeting all stakeholders (both national and international).

All water allocations (abstractions) are subject to user fee charges.

The policy prescribes an IWRM approach through comprehensiveness (holistic basin approach), subsidiary (decentralized decision making) and economic approaches (value and costs). The policy provides for stakeholder participation in the planning, design and implementation of management actions and decision making processes

The policy provides and encourages complementary actions or joint efforts in water supply & sewerage, as well as in sanitation services

There is a commitment to develop a framework for management and utilization of trans-boundary water resources and collaboration with other riparian states

The policy includes gender as well as socio-economic issues, with a greater focus on poverty alleviation

Uganda

According to the RBA report, formal irrigation development in Uganda commenced in the 1960s with the following schemes:

- The Mubuku irrigation settlement scheme in the Kasese District was established as a settlement scheme with gravity irrigation and water intakes from Sebwe and Mubuku rivers. Its command area was 600 ha, of which 430 ha were irrigated in 1998.
- The Kiige scheme in the Kamuli District has Lake Nabigaga as a water source for sprinkler irrigation of citrus fruits. Its command area was 150 ha, of which 10 ha were irrigated in 1998.
- The Labori and Odina schemes were abstracting water from Lake Kyoga for sprinkler irrigation; the Labori scheme, in the Soroti District, had a command area of 40 ha but by 1998 no irrigation took place.
- The Ongom scheme in the Lira District is a sprinkler irrigation scheme for citrus fruits with water from a reservoir of 4,500 m3 capacity. The scheme had a command area of 40 ha, of which 10 ha were irrigated in 1998.
- The Atera irrigation scheme in the Apac District was designed to abstract water from the Nile through pumping and subsequent gravitational flow through pipes and water hydrants to the fields. The scheme had a command area of 20 ha but by 1998 no irrigation took place.
- The Agoro self-help irrigation project in the Kitgum District is a gravity-fed scheme with intake from the Agoro River. All of its 120 ha command area was irrigated in 1998.

In the 1970s the Chinese initiated the development of rice schemes, with the Kibimba rice scheme as a rice technology development scheme and the Doho rice scheme for seed multiplication and popularization of production. The Kibimba scheme is in the Iganga District and has a command area of 600 ha, all of which was irrigated by 1998.

The Doho scheme in the Tororo District has a command area of 1,000 ha, all of which was irrigated by 1998. Floriculture private-sector farmers started green houses concentrated in the Lake Victoria area in the 1990s.

The progress with formal irrigation has been very slow and with limited success. One reason is the top-down approach adopted in most schemes. The farmer-based schemes of Mubuku, Doho and Agoro were considerably more successful. On the other hand, informal small-scale irrigation has been increasing, especially for rice, vegetable and fruit production. The increased area of informal rice production is a result of technology adoption from the Chinese in the Kibimba Rice Scheme.

The overall objective of the Water Policy is to manage and develop the water resources of Uganda in an integrated and sustainable manner. The Water Policy is guided by an agreed set of national policy objectives as follows:

- Separation of regulatory powers from user interests; integrated and sustainable development, management and use of the national water resources, with the full participation of all stakeholders
- Regulated use of all water, whether public, private or ground water, other than for "domestic" use
- Sustainable provision of clean and safe water within easy reach, and good hygienic sanitation practices and facilities, based on management responsibility and ownership by users
- Development and efficient use of water in Agriculture in order to increase productivity and mitigate effects of adverse climatic variations on rain-fed agriculture, with full participation, ownership and management by users
- Improvement of co-ordination and collaboration among sector stakeholders to achieve efficient and effective use of financial and human resources; following consistent planning and implementation approaches within the context of decentralization, and policies on private sector participation, the role of NGOs, civil society and beneficiary communities.

This review of the information provided in the RBA reports as well as the other sources consulted reveals considerable similarities among many of the countries. Except for Sudan and Egypt, rainfed agriculture is more important than irrigated agriculture (which has important implications for the organization of agricultural research and extension.)

All the countries are pressing to transfer responsibilities for system operation and maintenance to farmer groups. While the stated rationale for this is to increase stakeholder involvement and participation, worldwide the experience is that transfer of financial responsibility from the government is often a dominant consideration in this process.

Most importantly for the purposes of this study, none of the countries has provided sufficient data to allow interpretation of the physical performance parameters beyond physical interpretation – water consumption per hectare, severity and variability of water stress, and biomass production. Thus the sort of understandings provided in the earlier example about Fayoum cannot be sought based on available data.

In large measure, this is understandable – most of the countries in the basin are at an early stage of water resources development. The exceptions (Egypt and Sudan) are basically pursuing policies of maximum yield per hectare – in Egypt's case because this is the best option where rainfall is minimal; in Sudan's case because excess water is available (current withdrawals are substantially below the agreed figure of 18.5 bcm/year).

Most countries have water strategies and/or reform programs which are at different stages of agreement or implementation. The broad statements on which detailed policies and regulations will eventually be based (application of IWRM, efficient use, equitable allocation, priority to domestic use, stakeholder involvement, etc) are similar in the case of each country, but give no clue as to the details.

A further difficulty with the lack of field data is that the reasons for variations in the physical indicators cannot be assessed to derive conclusions about which types of management or infrastructure are associated with which physical outcome. The most important conclusion in this regards is that areas exhibiting exceptionally good or bad physical indicators should be visited and better understood to derive such conclusions.

Finally, it should be noted that variations in physical performance within countries are similar in magnitude to variations between countries. This is an extremely important conclusion, because political, social and economic conditions should be similar among all LSIs in a country, and to the extent that clear distinctions between countries are not evident, this suggests that these elements are not powerful explanatory factors for performance.

5.5 Economic implications of physical indicators

The return on investment can be (approximately) computed from the biomass production that is presented in chapter 4. Comparison of the biomass production of irrigated land with the cereal yields from rainfed land will allows us to estimate the incremental production due to irrigation (see Table 17). While this approach applies to all Nile basin countries, it does not apply for Egypt that has zero crop production without irrigation. One can see from this data that Tanzania has the highest incremental cereal yield of 6,010 kg/ha. At a market price of $ 0.50/kg, this will be a gross return of 3,005 $/ha.

Table 17 Computation of the net value in LSI schemes in the Nile basin

	Burundi	**Egypt**	**Ethiopia**	**Kenya**	**Rwanda**	**Sudan**	**Tanzania**	**Uganda**
Cereal yield rainfed (kg/ha)	1249	7280	1115	1374	848	505	1335	1539
Biomass production (satellites)	9755	16796	8741	13989	11181	7669	16947	16298
Cereal yield irrigated (kg/ha)	4228	7280	3789	6063	4846	3324	7346	7064
Yield increment	2979	0	2673	4689	3998	2819	6010	5525
Net increment ($/ha)	894	0	802	1407	1199	846	1803	1667

A gross incremental value of production of $3005/ha suggests after correction of operational costs a net value of $1500-2000/ha. This implies that irrigation systems costing less than $10,000 per hectare would probably be viable. Again, more detailed calculations would require full information about crops grown, market prices, inputs, etc.

5.6 Irrigation management responsibilities

Planning of water allocation and distribution within LSI schemes is mainly done by Departments of Irrigation. The Ministry of Agriculture usually has very little influence on water allocations unless the Department of Irrigation is part of the Ministry of Agriculture. Agronomists do research on crop yield, and they provide on-farm irrigation advice to stakeholders. This is an essential task which helps to increase crop yield from irrigation water. The flow from reservoirs and in main canal is however decided by the Ministries of Water Resources.

The transfer of water management from Governments to the farmers or cooperative groups of farmers is often recommended for a more efficient opertion of the LSI (Aw and Diemers, 2005; Giordano et al. 2006; Vermillion and Sagardoy, 1999). Water User Associations (WUA) indeed provide a framework for discussions and group decisions on common issues related to water management. When organized in WUAs, the farmers will not act as individuals, and the WUA gives them negotiating power with water suppliers. The existence of WUAs helps with the maintenance of irrigation canals. Clean canals and well maintained systems will contribute to increased reliability, uniformity and adequacy. At least that is the hypothesis. In the case of shallow water tables in irrigation schemes and drains, the responsibilities go beyond irrigation. A drainage network should prevent the LSIs to become prone to floods. The maintenance of sub-surface and surface drains require considerable attention. Water boards are established in Egypt to better deal with integrated irrigation and drainage management aspects.

The presence of cooperatives of the end-users does not always imply that decisions are made by them. Dictatorial public institutes may have the power to make decisions that are supposed to be made by WUAs. Hence, the real benefit from WUAs is not always straightforward. If the hypothesis that WUAs have a positive impact on the operation of irrigation systems holds true, then better uniformities are expected in certain countries because water will be fairly distributed. The graph below suggests that the countries with the longest irrigation history and strongest research departments and institutions (Egypt and Sudan) have the lowest reliability and uniformity. Despite that from an institutional viewpoint they are well developed, it seems that they fail to get their rules and actions implemented properly (otherwise reliability and uniformity would have been better). Another observation is that these countries have millions of hectare under irrigation and find it difficult to deal with the extra burden of supervising irrigation processes of such vast extent. It is therefore reasonable to conclude that the size of the countries and the area under irrigation have more impact on reliability and uniformity than the intrisic water governance. We cannot say that institutions have no influence, but their role is not apparent.

The district data in part B of the same graph reveals that Sudan is the country with the most diverging reliability and uniformity. In fact, all possible combinations of low and high values occur in Sudan. This seems to suggest that the Federal Governmental influence is not so strong, and that various regional governments take irrigation management decisions in a non-concerted manner. This aspect needs to be further verified for Sudan. The commercial sugar irrigation schemes are certainly in much better condition than LSIs in some districts of western Sudan. Egypt has also reliable LSIs with more uniformity than Sudan, and several of them are as good as the systems of Rwanda (that appear to be the best). But Egypt also has some poor performing systems in the Nile Valley, and they reduce the overall performance.

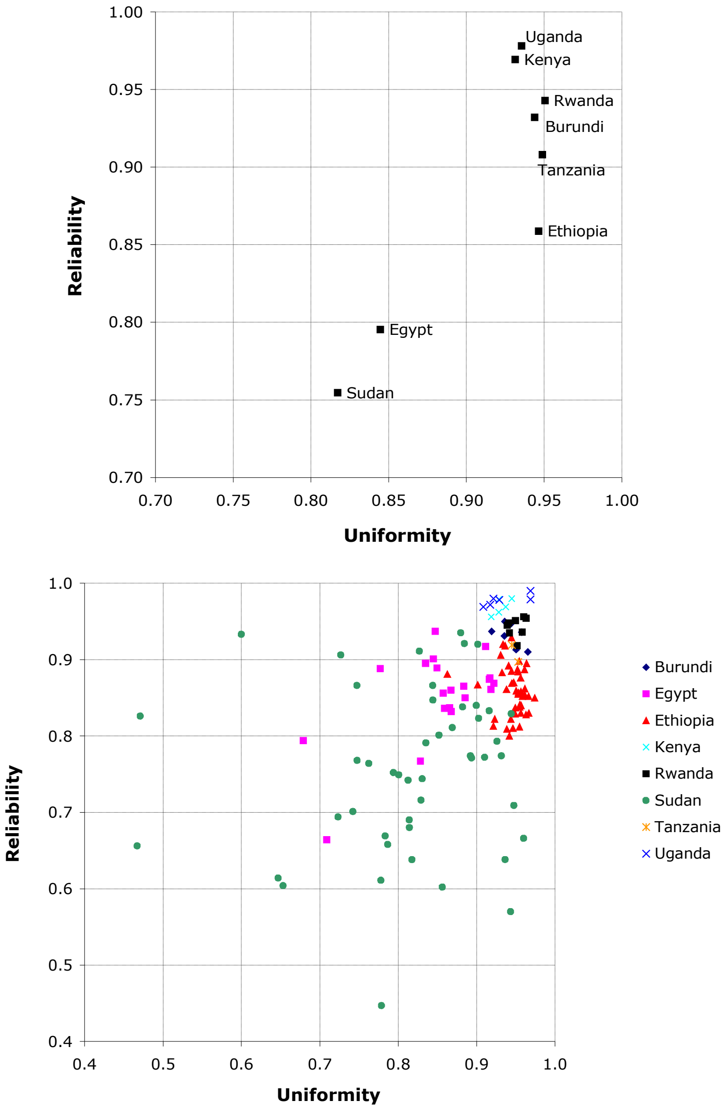


Figure 26 Relationship between uniformity and reliability for all districts with LSIs

A different way to make a qualitative assessment of the institutes is by studying the spatial variations across a given climatic zone (caused by atmospheric circulation processes and their interaction with the geography) vs. the spatial variations in areas with political boundaries (caused by institutional power of influence). The hypothesis is that good water governance results in variations being lower than for a climatic zone.

Productivity in a given country and its variation is mainly a concern of the Ministries of Agriculture. If a country has a more uniform productivity than its climatic zones it shows that agricultural policy making and agricultural research has impact. Figure 27 shows that Sudan and Ethiopia have a significant spatial variation in their results, and that this variation is larger than the climatically induced variations: the ratio of the coefficient of variation of between country values and climatic zone values is more than 1.0. This reflects a weak agricultural policy making process, or a good policyh process that does not have a proper dissemination. This was concluded earlier when we reported on absolute productivity values. Hence lower agricultural production will create more spatial variations, and the agricultural research institutes and agricultural extension services in Sudan and Ethiopia do not have the capacity to improve that situation.

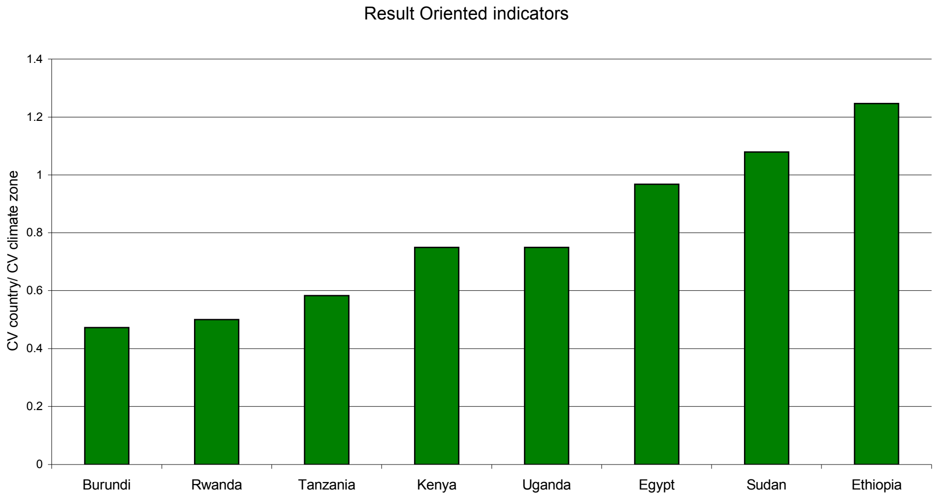


Figure 27 Impact of good water governance on the reduction of spatial variations of Result Oriented indicators (i.e. productivity) as compared to the prevailing climatic system

Interim conclusions:

- Good water governance should reflect in a higher reliability and uniformity
- Countries with the longest irrigation history (Egypt and Sudan) have the lowest reliability and uniformity
- Good water governance on paper has only limited influence on irrigation results
- The size of countries and LSIs has great impact on productivity, reliable services and uniformity in irrigation practices

6 Enabling Environment – Centres of Excellence

6.1 Institutional Reform Processes in the Nile Basin Water Sector

Over the last two decades, most Nile Basin countries have either undertaken or are in the process of completing water sector reforms (Table 18). The regional trend is decentralisation and commercialisation/privatisation of management, operation and maintenance (MOM) of water services. Whereas this fits well into the water supply sector, in the agricultural sector in which some of the players are extremely poor and located in relatively remote rural areas, this is not such a simple process. New laws impact on attitude and the assumption that water is no longer supplied by central government but free to all. Such changes may not necessarily reflect the rights and interests of traditional water users. It is hope that the process of water sector reforms will overcome the poor sector coordination that has hampered irrigation development with duplication of efforts and approaches. Establishment of national, regional and international irrigation networks and associations to enhance synergy and coordination in the sector has been started in a few countries, but needs more political support and understanding to gain the necessary impetus.

There is a wide diversity in institutional capacities of the water sector in the various riparian states and the level of development varies greatly. The capacity for successfully developing the approaches varies and data and knowledge differ considerably. Support for these activities will normally be found within appropriate national research institutions/universities but some are lacking. Considerable scope exists for the improvement and sharing of approaches within the Basin and this has already been initiated.

From Table 18, it can be seen that Kenya, Tanzania and Ethiopia have made most progress in developing river basin organizations. Kenya has established regional Water Resources Management Authorities and Water Services Boards for the six main river basins. Tanzania has formed Basin Water Boards and Basin Offices for the nine main river basins. Ethiopia has established a River Basin Authority outside the Nile basin and a River Basin Authority for the Blue Nile. In the other riparian countries, the river basin is acknowledged as the appropriate management unit for IWRM, however this has yet to result in the establishment of water resources management organizations at basin level.

Table 18 Institutional Reform Processes

Country	National Water Authority	Decentralization	Consultation Platforms	River Basin organizations	Water Users organizations
Burundi	Different ministries	Ongoing discussion	National level	Ongoing discussion	Ongoing discussion
DRC Congo	Different ministries	Ongoing discussion		Ongoing discussion	discussed
Egypt	Different ministries		Piloted at district level	Ongoing discussion	Legal framework for WUA only
Ethiopia	One water ministry	State and district level	State and district level	One established and one prepared	piloted
Kenya	One water ministry	Basin level	Basin and catchment level	Six authorities established	Legal framework established
Rwanda	Different Ministries, Ministry of Water and Mines	Local government authorities; Private sector.	Basin and catchment level; District Level.	Ongoing discussion	piloted
Sudan	One water ministry	State level	Federal level	Two Advisory Committees	Legal framework for Gezira scheme
Tanzania	One water ministry	Local government authorities	National and basin level	Nine offices and boards established	Legal framework not yet established
Uganda	One water ministry	Local government authorities	National and district level	Lake basin authorities	Legal framework established

Source: Adapted from "Needs Assessment and Conceptual Design of the Nile Basin Decision Support System Consultancy, Draft Inception Report, 1 October 2007."

Table 19 Water Resources Responsibilities in Riparian Countries

Country	Remarks
Egypt	Egypt prepared its first water resources policy after the construction of the Aswan High Dam in 1975. The policy has regularly been reviewed and updated. In 1993 the new water policy included several strategies to ensure satisfying the demands of all water use sectors. In 2004 the Ministry of Water Resources & Irrigation (MWRI) formulated the National Water Resources Plan (NWRP) that embraces the concept of Integrated Water Resources Management (IWRM) through a policy for dealing with the water scarcity challenges that will be facing Egypt in the 21st century. The NWRP provides specific actions in the form of an investment plan up until 2017. The current challenge is how to mobilize the required financial resources to implement the NWRM
Sudan	The Federal Ministry of Irrigation and Water Resources (MIWR) formed in 1999 became responsible for developing policies, strategies, legislation and plans for developing the national water resources. It is a multi-disciplinary and multi-sectoral committee to review, integrate and update the 1992 Water Policy. The committee prepared drafts that were discussed with stakeholders and the water related federal ministries and state governments, but failed to obtain approval. The 1992 Water Policy is still the official document. The

	general objective of the Sudan National Water Policy Draft of 2000 (SNWP) is to ensure that Sudan's water resources are properly managed, protected and efficiently utilized for the benefit of the Sudanese population
Ethiopia	The Federal Ministry of Water Resources formed a multi-disciplinary committee tasked to prepare a comprehensive and integrated Water Resources Management Policy. The committee had representatives of various Federal Ministries involved in the water sector and of State Governments. The draft policy document was in-depth discussed with representatives of the regional Bureaus of Water Resources Development and stakeholders of the private and voluntary sectors involved in the water sector. The overall objective of water supply and sanitation policy is to enhance the well-being and productivity of Ethiopian people through the provision of adequate, reliable and affordable clean water supply and sanitation services that meet livestock, industry and other water users' demand. The overall objective of the irrigation policy is to develop the irrigated agriculture potential for production of food crops & raw materials needed for agro-industries in a sustainable way. Water Resources Sector Strategies have been developed with short, medium and long-term sector development programmes prepared for 2002-2016. The strategies include; financing of water resources management & development, creation of an enabling environment, trans-boundary river management; stakeholder participation and gender mainstreaming; disaster prevention and public safety & environmental health standards.
Kenya	The Water Act 2002 granted the overall responsibility for water management in Kenya to the Ministry of Water Resources Management and Development (MWRMD). The Water Act introduced key reforms to the legal framework for the management of the water sector in Kenya which ware: a) separation of the management of water resources from the provision of water services: b) separation of policy making from day to day administration and regulation; c) decentralization of operational functions to lower level state organs; d) the involvement of the non-government entities and communities in the form of Water Resources Users Associations to manage water resources and provide water supply and sanitation services. The Water Master Plan (1992) provided the basic policy framework for Kenya. The plan was updated in 1998. The two semi-autonomous bodies that have been established for the organizational functions of water resources management and water services delivery prepared the National Water Resources Management Strategy and the National Water Services Strategies (2005-2007). The overall goal of the NWRMS is to eradicate poverty through the provision of potable water for human consumption and of water for productive use. Specific goals of the strategy are to improve equal access to water resources for all Kenyans; to promote integrated water resources planning and management at catchment basis; and to enhance the availability of water resources of a suitable quality and quantity.
Uganda	The Government of Uganda created through the National Environment Management Policy (1994), the Water Statute 9/1995 and the National Water Policy (1999) a policy framework for the water sector. The policies enhance property rights, promote environmentally sound land use, enhance water resources conservation and management; improve wetland management, and apply environmental economics and incentives. The statute established the National Environment Management Authority, which in consultation with the leading agencies is mandate to issue guidelines and prescribe measures and standards for the management and conservation of natural resources and the environment. The Water Statute 9/1995 has the objective to allow for the orderly development and use of the water resources for domestic, agricultural and industrial purposes in a manner that minimizes harmful effects to the environment. Domestic use included irrigation of subsistence gardens not exceeding 0.5 ha. Extraction of water from surface or ground water is prohibited unless

	authorized. The National Water Policy proclaimed the formation of a central authority, being the Ministry of Water, Lands and Environment, whose role is to initiate national policies, to coordination between the line ministries, overseeing compliance and to provide technical support services. The policy aims to enhance the role of the private/voluntary sectors through the formulation of policy committees on environment & water at national and local level. These committees aim for active involvement of local authorities, private sector and NGOs in the development & management water supply & irrigation systems. Uganda has developed a framework for water resources management consisting of national legislations and by-laws for promoting sound water resources management and constrains potentially harmful practices. Water Resources Regulations, Water Supply Regulations and Waste Water Discharge regulations are all in place.
Tanzania	The new National Water Policy (NAWAPO) of July 2002 is the outcome of a review of the national water policy of 1991. The review was carried out under the River Basin Management and Smallholder Irrigation Improvement Project (RBMSIIP) and the new policy incorporated the principles of IWRM that were initiated by the Dublin Water Conference. In July 2002 the Government of Tanzania issued the National Water Policy whose main objectives were to establish a comprehensive framework: for sustainable development and management of water resources and for participatory agreements on the allocation of water uses. The policy incorporated the decentralization drive that was launched by the Local Government Reform Programme. The Ministry of Water became responsible for the constitutional and organizational function and the operational function was delegated to Local Government Authorities. Basin Water Offices were established to coordinate water resource management between the Regional and Local Government authorities at river basin level. In February 2005 the Government issued the National Water Sector Development Strategy 2005 to 2015.
Rwanda	The Government of Rwanda formulated it first National Policy on Water Management in 1994. The mandate of water resources management rested under various ministries (Agriculture and Public Works) before it was brought under the Ministry of Lands, Environment, Forests, Water and Mines (MINITERE). The policy formulation process reflected global policy changes and opened the sector for public, private and voluntary sector partnerships and references were made to Integrated Water Resources Management (IWRM) principles. In 2004 the Government of Rwanda held discussions with interested stakeholders and produced a water sector policy document that merged the water sector with lands environment and forestry sectors under MINITERE. The water sector policy was agreed by the Council of Ministers in October 2004. The new water policy introduces an institutional reform process in which a National Commission of Water, interdepartmental coordination, basin and catchments committees, and local water users associations are foreseen to be established. The public sector at sub-national level is expected to collaborate with the voluntary and private sector to manage the water resources and to provide water and sanitation services. The existing informal water users groups that manage local water resources will be organized into catchment committees and water user associations to ensure participatory processes in the planning and management of water projects and programs.

Burundi	The Government of Burundi formulated it first National Master Plan in 1992. The National Water Policy (NWP) and Strategic action plan was completed in 2001 to manage the national water resources in an integrated and sustainable manner. The accompanying Action Plan indicated objectives, actions, performance indicators, institutional responsibilities, budgets and an implementation calendar. The Ministry of Land Management, Environment and Tourism were the overall coordinator, and the Geographical Institute of Burundi was the technical coordinator of the Action Plan that anticipates participation by public sector and local communities through communal administration. However the NWP has never been presented to the Parliament to be accorded to a legal status. The NWP defined rivers, lakes, springs, groundwater, swamps permanently covered with water, islands, hydraulic structures constructed for the purpose of public benefit as public domain resources managed by the Ministry of Land Management, Environment and Tourism. No water intake or water effluent as well as the related water structures can be built in this public hydraulic domain without an authorization or a concession of the national water administration. However water can be abstracted freely from the ground or surface water for domestic purposes (human food supply, hygiene, washing, plant and animal production for domestic consumption). The law also establishes a priority order for the different water uses. Domestic water use enjoys the highest priority, followed by agricultural uses. The later cover water demands of livestock, fisheries and irrigation. These uses are followed by industrial, environmental and recreational water uses in declining order of priority. The holders of the water use rights have to use the water in a rational and economic way as well as to respect the rights of the other legitimate users. The water administration manages the water release of reservoirs on the basis of water needs, hydrologic and meteorological data and can decrease the discharge in case of water shortages.
DRC	The Government of the Democratic Republic of Congo has no unified official water policy in place. Efforts to develop a water policy or a water code with support of UN-organizations have been less successful. There is not single organization responsible the governance functions of water resources management. The functions are shared over various Ministries and the Directorate of Water Resources within the Environmental Department of the Ministry of Environment, Water and Forest is responsible for the development of water policies. However the administrative and managerial capacities of the directorate are limited for its constitutional function. The National Action Committee on Water and Sanitation is responsible for coordination between the ministries and for balancing competing interests in water uses. The committee cannot take the function of water administration that has overall responsibility. The Committee could take an advisory role, however the compromises between conflicting interests would require an organization that has a clear mandate.

6.2 Country-level institutions and centres of Excellence

Burundi

Modern farms where irrigation is overseen by public technical services have been financed by the government or donors.

Four key players are involved in this:

- The Department of Agricultural Engineering and Protection of Land (DAEPL), which deals with hydraulic structures and their maintenance;

- The Provincial Directorates of Agriculture and Livestock (PDAL) for the development of the irrigated areas;
- Financial institutions;
- Beneficiaries who pay a fee (proportional to the size of the property) for the amortization and maintenance of the water infrastructures as well as the payment of agricultural inputs (fertilizers) used

The public holdings include agricultural areas belonging to the state (provinces, municipalities and communities) or to a public or semi-public company. While these farms are relatively large, the irrigated areas are rare and all belong to state companies. In Burundi, there are two farms of this kind where irrigation is provided by the internal technical services of the firm:

- RWIRA farm where food crops (potatoes, onions, tomatoes, cabbage) are irrigated (by gravity) with garden hoses. The water used is collected from sources of Mount NGABWE;
- Sugar Company of MOSO where sugar cane fields are irrigated with water from the diversion dam built on the Mutsindozi river. It is a multi-purpose structure as the system also includes a pumping station (raw water for the production of drinking water) and a night storage tank (irrigation is practiced only during the day) which is at the same time a fish pond.

Egypt

Egypt's long history of irrigation, relatively advanced economic development, complete dependence on irrigation and highly varied cropping patterns have led development of a wide variety of support institutions, including:

The National Water Research Center (NWRC)

The national water research center (NWRC), is a pioneering institution for various water research activities in Egypt. It was established in 1975 as a research origin of the Ministry of Water Resources and Irrigation (MWRI).

Under the jurisdiction for NWRC, twelve research institutes exert concerted efforts to implement a comprehensive research plan serving ongoing MWRI projects and national development in general.

Their names and mission are:

- Water Management Research Institute (WMRI).
- Drainage Research Institute (DRI).
- Water Resources Research Institute (WRRI).
- Nile Research Institute (NRI).
- Hydraulic Research Institute (HRI).
- Channel Maintenance Research Institute (CMRI).

- Ground water Research Institute (GWRI).
- Construction Research Institute (CRI).
- Mechanical and Electrical Research Institute (MERI).
- Survey Research Institute (SRI).
- Coastal Research Institute (CORI).
- Environment and Climate Research Institute (ECRI).

Agricultural Research Center

The Agricultural Research Center (ARC) Created in the early 1970s. Over the past two decades, numerous achievements have been realized, including the development of new varieties, improved agronomic practices, livestock development, maintenance of the national herds and better food processing techniques. New crops and animal breeds have also been introduced and research has been dedicated to problem- solving, side by side with basic science.

Ethiopia

Several water sector institutions have been established at federal and regional levels under the regionalization and decentralization policy.

At the federal level, the public institutions involved in water resources development include:

- The Ministry of Water Resources (MoWR) is responsible for the overall planning, development, management, utilization and protection of the country's water resources, as well as supervising all water development activities carried out by other institutions. Large-scale water supply is also handled by the ministry through its Water Supply and Sewerage Department.
- The Awash Basin Water Resources Management Agency (ABWRMA) is the only basin level institution established for administering and managing the Awash River Water. Most of the medium- and large-scale irrigation projects and salinity and flooding problems are concentrated in this basin.
- The Ministry of Agriculture (MoA) is in charge of water management (irrigation extension), including water harvesting for smallholder irrigated and rainfed agriculture.
- The Environmental Protection Authority (EPA) is responsible for the preparation of environmental protection policy, laws and directives. It is also in charge of evaluating the impact of social and economic development projects, particularly irrigation and hydropower projects, on the environment and is further responsible for follow-up work.

The regional/sub-national institutions involved in the water sector include:

- The Bureaus of Water, Mines and Energy (BoWME) and/or Bureaus of Water Resources Development (BoWRD) which exist in some regions and are responsible for small-scale irrigation and rural water supply as well as small-scale hydropower development

- The Commissions for Sustainable Agriculture and Environmental Rehabilitation (Co-SAER) and the Irrigation Development Authorities which undertake operational activities in line with their mandates (study, design and construction of small-scale irrigation schemes).
- The Bureaus of Agriculture (BoA) have similar functions at the regional scale as the MoA.
- Several NGOs are involved in the water sector, particularly in small-scale irrigation and rural water supply projects.

Kenya

There are a number of relevant institutions. Some are possible twinning institutions because of their long experience in past projects and interventions. The following, listed alphabetically, are considered as the most relevant:

- International Centre for Research in Agroforestry: ICRAF is one of the 16 food and environmental research organizations known as the future harvest centres of the CGIAR. The centers are located around the world conducting research in partnership with farmers, scientists and policy makers to help alleviating poverty and increase food security while protecting the natural resource base. The ICRAF headquarters is located in Nairobi.
- Kenya Agricultural Research Institute: KARI is the national organization responsible for research in agriculture. It has over 25 research centres in the country including centres with responsibilities in the Kenyan lake basin including KARI Kibos, Kakamega, Kitale and Kisii. The national centre for research in Natural Resource Management including soil mapping, soil fertility, irrigation and drainage is the National Agricultural Research Laboratories located in Nairobi. It also has projects operating in the area such as WKIEMP (Nandi, Siaya, Vihiga, Kericho, Nyando and Trans-Nzoia Districts) and KAPP. KARI therefore is the source of land and water, crop management interventions (BMTs, BMPs, training) to the farming community.
- Kenya Sugar Research Foundation: KESREF is responsible for sugarcane research including agronomic, production systems and value chain. With a large part of the area being under sugarcane, KESREF will be valuable in best technologies and practices for sugar cane farming that are efficient in water use.
- Kenya Water Institute: KEWI, located in Nairobi is a training centre for water technicians as well as research functions in water that is carried out by students' under supervision of lecturers for the fulfilment of the course requirement. KEWI is therefore important as a training centre for water technicians
- Lake Basin Development Authority: LBDA is the authority charged with the development of the area and its mandate area is the same as the Kenyan Nile basin. Recently LBDA initiated the Kimira Oluchi Irrigation Project that will see

nearly 15,000 ha of irrigation developed. Thus LBDA has interest in the general development and conservation of the area.

- National Universities: The institutions of higher learning include Nairobi, Jommo Kenyatta University of Agriculture and Technology, Kenyatta University, Moi University, Egerton University, Maseno University, Masinde Muliro University and the Universities of the Great Lakes. Maseno, Masinde Muliro and the Great Lakes Universities are located in the Kenyan basin. The universities have excellent capacity for training and research on environmental issues.
- Ministry of Agriculture: MoA has the extension mandate in agriculture. It is operating the NALEP and KAPP extension projects. The MoA has extension officers operating at different levels and are usually in contact with the farmers.
- Ministry of Water and Irrigation: MWI is responsible for water, irrigation and drainage policies. The Water Resource Management Authority (WRMA) is responsible for water resource management and has the water catchment service boards with the catchment areas, including the lake basin. NIB has West Kano and Ahero schemes within the lake basin which are large public irrigation schemes.
- Ministry of Environment and Natural Resources: MENR is the ministry charged with environmental issues. It is also the ministry responsible for NEMA, the Lake Victoria Environmental Management Programme (LVEMP) and the Kenya forest service. The KFS have working relations with VI Agroforestry which also operates in the lake basin.
- National Irrigation Board: NIB is mandated to coordinate development and management of the public irrigation schemes. NIB has also been performing research functions, mainly on agronomic challenges in its schemes. The public schemes are Mwea, Perkerra, West Kano, Ahero, Hola and Bunyala. In recent years NIB has been implementing IMT in the schemes. The public schemes located in the Kenyan Nile basin are: West Kano, Ahero and Bunyala. NIB has been building the capacity of IWUAs for scheme development, operation and maintenance and IMT.

Other Centres of excellence
Because of experience of farmers and community in past projects and interventions touching on the three project components the following sites and schemes are possible centres of excellence that can be used to show good technologies and practices.

Public Private Managed Irrigation and Community Managed Irrigation
Criteria for the national best practices on PPMI include: Level of farmers organization, Conveyance and on-farm water management efficiency, Crop productivity per unit volume of water used, Potential impact on poverty reduction, Prevalence of pest and diseases, Profitability of the enterprise and Adoption of the technology.

Mwea irrigation scheme is one of the good examples of performing rice schemes. It also offers a good example of farmer organisation. The scheme has excellent training facilities to host farmer groups. Dominion farms Limited fits in the criteria of centres of excellence for Private irrigation. There are also private schemes in Eldoret and around Mount Kenya with good farming practices.

The cluster of irrigation schemes in Nyeri especially Naromoru could be considered as centre of excellence for CMI. These farmers produce for the export market and have used improved technologies mainly ¼ to 1 acre drip irrigation systems to grow for the market. Farmers have combined water harvesting, drip irrigation and marketing (including contracts) to improve on return on investment. Within the lake, Awach cluster is also a possibility since they were built in capacity to improve on production and marketing. Mitunguu irrigation scheme is a low pressure sprinkler irrigation scheme which has shown excellent management by farmers that have led to performance improvement.

KARI promotes small scale drip irrigation kits with each unit capable of irrigating up to ¼ acre (vegetables) to ½ acre (orchards). This concept has been adopted by some irrigation companies but yet to set up distribution outlets away from Nairobi. Although the demand is there, no outlets currently exist in the Basin. Although KARI sales the drip irrigation kits in it’s outlet in Nairobi, it promotes and maintains a list of other kit suppliers.

Rwanda

The main institutions in Rwanda are:

- The Ministry of Agriculture and of Natural Resources (MINAGRI), via the Unit of Civil Engineering and Soil Conservation, is responsible for soil conservation by means of terracing, drainage and irrigation. The MINAGRI is responsible for the effective use of water resources for agricultural purposes;
- The Ministry of Land, Environment, Forest, Water and Natural Resources (MINISTERE), is in charge of rural water infrastructure, water management and sanitation. Its main activities are i) the definition, updating and implementation of the National policies on water and sanitation, ii) defining the strategies for drinkable water supply, iii) the control of water quality; iv) raising people’s awareness on transport problems, on treating and conserving water at home.
- The districts, who own distribution network in rural areas from a legal and institutional point of view. This responsibility is being reinforced by the new policy of decentralization that gives the right to local communities to leave this responsibility to associations or private operators

Sudan

The Ministry of Agriculture and Natural Resources (MANR) supervises the Agricultural Corporations that manage the large irrigation schemes, while the Ministry of Irrigation and Water Resources (MIWR) is responsible for delivering irrigation water.

The Ministry of Irrigation and Water Resources (MIWR) is the federal body in Sudan legally responsible for all water affairs. It offers technical advice and assistance to water projects within the states and the private sector. It is in charge of the groundwater, the non-nilotic streams and valleys under the Groundwater and Wadis Directorate. It undertakes its task in coordination with the relevant sectors, departments and technical offices (agriculture, industry, foreign, electricity, and investment, etc). It has the following responsibilities:

- Satisfaction of the water requirements of the various users through the country;
- Water resources planning, management and development;
- International and regional cooperation concerning the shared water sources;
- Planning, design, execution, operation and maintenance of the different irrigation schemes;
- Control of water abstraction;
- Construction of new irrigation works;
- Operation and maintenance of all large-scale irrigation structures and drinking water facilities;
- Provision of the means for hydropower generation and protection of the water-related environment.

Uganda

In the 1960s responsibility for the identification, planning, development, operation and maintenance of irrigation schemes was split between two institutions: the Department of Water Development in the Ministry of Mineral and Water Resources was responsible for investigation, surveying, design and construction and the Department of Agriculture in the Ministry of Agriculture was responsible for the operation and maintenance of irrigation schemes.

Institutional changes affecting the irrigation sector came into force in 1998. Under the newly restructured Government institutions, the following are directly or indirectly involved with water utilization for agricultural production:

- The Department of Farm Development (DFD) within the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF);
- The Department of Farm Planning (DFP) within MAAIF.

The DFD has the mandate to promote and spearhead sustainable agriculture through the provision of guidance and strategies in, among others, irrigation, drainage and water harvesting and also to promote, test, and popularize the utilization of appropriate machinery and equipment. The DFD’s major responsibility is to modernize agriculture by transforming subsistence agriculture into an economically viable venture, through the promotion of appropriate technologies in the water sector. In this transformation process, irrigation, water harvesting, water conservation and wetland management are major activities. Within the DFD, the sections directly involved with agricultural water utilization are:

- The Irrigation and Drainage Section within the Division of Watershed Management of DFD;
- The Soil and Water Conservation Section within the Division of Watershed Management of DFD;
- The Water for Agricultural Production Section within the Division of Agricultural Engineering of DFD.

The functions of the Irrigation and Drainage Section are to:

- Provide policy guidelines on irrigation and drainage and the utilization and management of wetlands;
- Participate in the planning, selection, design and construction of replicable and sustainable irrigation and drainage systems;
- Provide technical guidance in popularizing farmer-managed smallholder irrigation systems;
- Provide training for staff and other stakeholders in irrigation technology and the sustainable utilization and management of wetlands;
- Coordinate the development of irrigation in the country;
- Monitor and evaluate progress in irrigation activities in liaison with district subject matter specialists.

The functions of the Soil and Water Conservation Section are to:

- Provide guidelines in the formulation of agricultural policies for the conservation of soil and water;
- Plan the promotion of conserving soil and water in farming systems through catchment area approaches;
- Provide technical guidance to promote water harvesting for agricultural production;
- Coordinate all activities in soil and water conservation and watershed development;
- Inspect and provide standards and by-laws for soil and water conservation;
- Provide training and technical backup for staff and other stakeholders on soil and water conservation issues;
- Provide technical advice on the development of fragile lands;
- Provide policy guidelines on sustainable agriculture in semi-arid and marginal lands;
- Participate and coordinate the promotion of agroforestry and other agricultural practices that combat desertification and promote environmental conservation;

- Monitor and evaluate agricultural activities on fragile lands.

The functions of the Water for Agricultural Production Section are:

- The overall coordination and implementation of provision of water for agricultural production;
- To prepare workplans, strategies, management and supervisory schedules for agricultural water use.

Some of the former functions of the MAAIF were diverted to the National Agricultural Research Organization (NARO) and under its new mandate the NARO has to ensure that the technologies, which are generated and developed, reach the end users through various delivery agencies in the districts. It will carry out extension functions at four different levels as follows: national level, zonal level, district level and subcounty level.

The Ministry of Water, Lands and Environment (MWLE) has the overall responsibility for initiating the national policies and for setting national standards and priorities for water development and management. It has the mandate to promote and ensure the rational and sustainable utilization and development and safeguarding of land and water resources and the environment, for social and economic welfare and development as well as for regional and international peace. The central institutions in the MWLE responsible for interventions in the water and sanitation sector are:
The National Water and Sewerage Corporation (NWSC), an autonomous parastatal entity established in 1972 is responsible for the delivery of water supply and sewerage services in 15 large urban centres.

The Directorate of Water Development (DWD) is the leading Government agency responsible for managing water resources, coordinating and regulating all sector activities. The DWD also provides support services to Local Governments and other service providers.

Local Governments (districts, towns and lower Local Governments) together with the communities are responsible for implementation, operation and maintenance of water supply and sanitation facilities in their area of jurisdiction, except in the large urban centres where this is under the NWSC.

The Directorate of Water Development (DWD) works to promote coordinated, integrated and sustainable water resources management and the utilization and provision of water for all social and economic activities. The sector covers water resources management, water for production, rural water supply and sanitation and urban water supply and sanitation. The DWD’s activities include the development of surface water reservoirs such as dams and valley tanks in the drier parts of the country to increase accessibility to water, as well as the rehabilitation of existing dilapidated dams.

7 Best practices in Large Scale Irrigation schemes and best practices sites

7.1 Irrigation objectives

Irrigation water requirement calculations are based on (i) crop water requirements, (ii) water losses from the distribution network and from the fields, and (iii) the likelihood to receive rainfall during the period of irrigation. Furthermore, the crop water requirements should be based on full or reduced crop ET, and this is a fundamental difference in irrigation policies. Chapter 5 has demonstrated that the agricultural water policies of Egypt and Sudan are based on maximizing production. At full ET crops need a lot of water to avoid stress; under conditions of reduced ET, less water is applied and mild stress is tolerated or unavoidably accepted (e.g. Ethiopia). Protective irrigation is meant to keep cropping systems sustainable for subsistence farming, without specific productivity goals. These objectives of LSI are completely different. A reduced irrigation application policy could be applicable for conditions with:

- limited surface water diversion options
- absence of groundwater
- erratic rainfall
- shallow water tables

Intense irrigation of crops on areas with a shallow water table could result in water logging, and it is therefore advisable to apply less than the full crop requirement. Irrigation objectives are thus based either on (i) full or (ii) reduced water supply, and without knowledge on these objectives, it is not self-evident to provide recommendations.

Irrigation management aimed at achieving a specific crop water stress has great impact on the functioning of a given system, and hence also on the type of performance indicators to be used to evaluate these systems, and their values. Irrigation strategies with intended crop water stress should be evaluated on the basis of uniformity and sustainability. Irrigation strategies with the aim to maximize crop production should be evaluated on the basis of land and water productivity.

A set of RO, PO, and SO indicators has been introduced in chapter 3 and applied in chapter 4. It is possible that an irrigation scheme designed for protective irrigation could have a high productivity and adequacy rating, but a poor uniformity rating. In that case, the objective is not met and the investment can be interpreted as being unfavourable. Figure 28 demonstrates that Sudan and Egypt have a poor uniformity and sustainability, which suggest that they are not designed for protective irrigation. This is true indeed, and one would thus expect a high productivity rating. The latter does not appear to be true at country scale with scores less than 3 (although Egypt is with 2.9 very close to the goal of high productivity).

The same graph – but now expressed per district – shows that many systems in Egypt and Sudan meet this expected high productivity and low sustainability / uniformity. But many other LSIs are not performing so well. Chapter 8 will show that there are many research centres, especially in Cairo, which have produced good research results on productivity gains. It seems that the implementation of the agricultural research findings is limited and lagging behind due to inadequate extension activities and support staff. The exchange between centralized institutions in the capital and their regional scale counterparts needs improvement.

The sustainability / uniformity in all other countries then Egypt and Sudan is more than 3.0 for all districts, and this seems to be in accordance with the protective irrigation practices. Many irrigation districts in Ethiopia follow the principles of a high sustainability / uniformity in combination with a low productivity. Also Tanzania and Rwanda are part of this class.

Without background information on the irrigation objectives of each LSI scheme or the LSI schemes located in a given district, it is not feasible to judge whether the management is in agreement with the proposed goals. The graph, however, suggests that the political boundaries are associated to different policy goals.

In the absence of information on the irrigation objectives, it is not justifiable to use selected indicators. Therefore, an evaluation of best practices will be based on all 10 indicators to avoid misinterpretation of results. All RO, PO, and SO indicators will be given for simplicity equal weight. This simplifies the evaluation and weakens the preparation of guidelines. It is better though to have some more general guidelines, then preparing erroneous guidelines. It would be possible to select specific indicators only if the governing bodies of the LSIs of the riparian Nile basin countries define the irrigation scheme boundaries and the irrigation objectives of each scheme. This is as a matter of fact a recommendation for the future irrigation analysis in the Nile Basin.

The NBI as the overarching water institute dealing with shared international resources has specific interests in water productivity. This interest is interwoven in the EWUAP program. Therefore one section will be added in this chapter where best practices will be recommended on the basis of achieving the highest water productivity. Hence, recommendations for the best practices will be based on (i) all indicators and (ii) water productivity indicators.

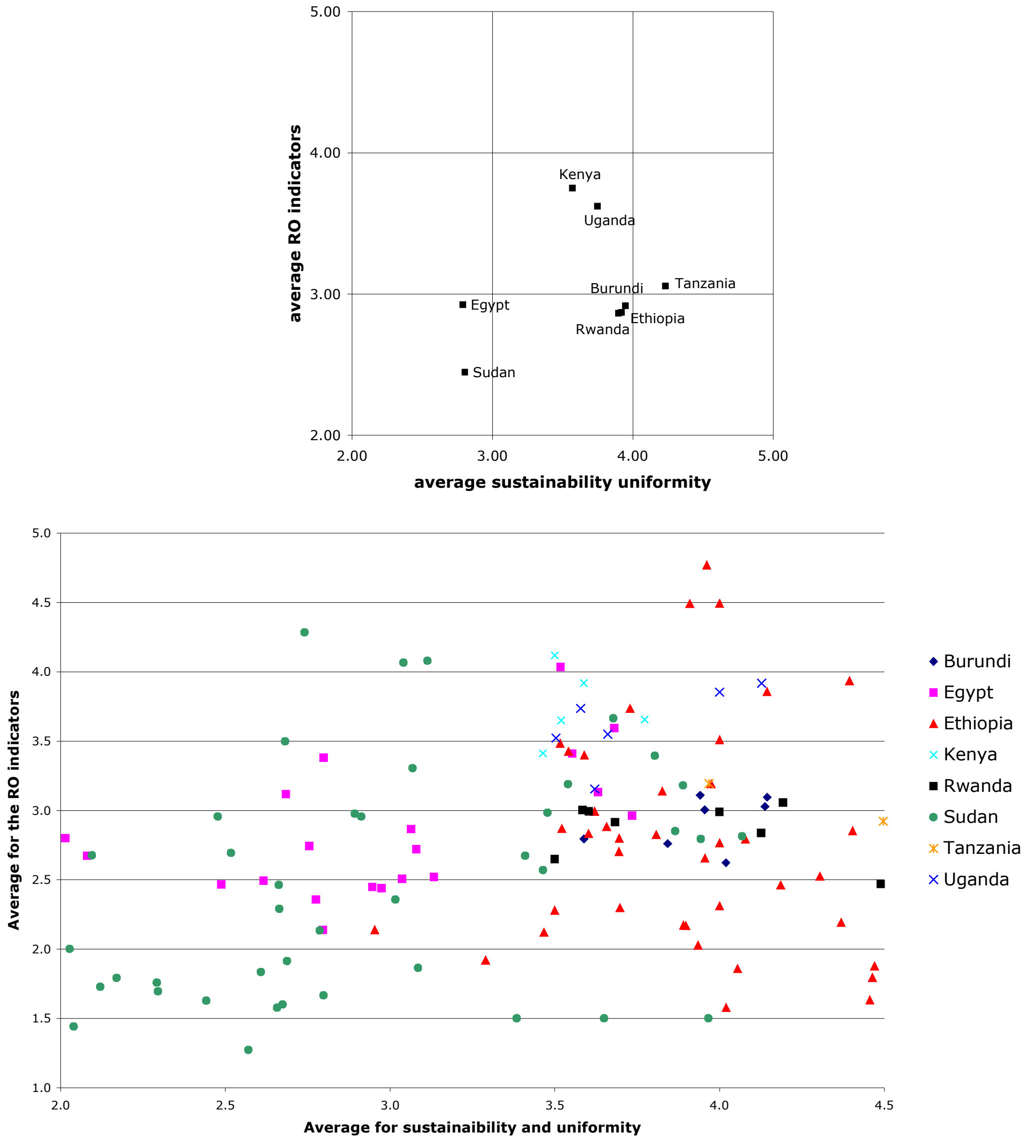


Figure 28 Classification of irrigation objectives into productivity vs. sustainability /uniformity

7.2 Identification of sites with overall best practices

The best practices for one particular LSI scheme are not necessarily favourable for other LSI schemes of the Nile basin. The two major factors that restrain the transfer of best practices across the whole Nile basin are (i) climatic differences and (ii) political and water governance boundaries. The role of climates can be explained by rainfall, temperature and air humidity. The separation by political boundary can be explained by policy, objectives, education, politics, laws etc. Because of these limitations to transferring information, recommendations will be prepared by country. Most countries are located in one climatic zone, except Sudan and Ethiopia.

Figure 29 depicts the best administrative districts in every country. These districts can be considered as having the most favourable LSI schemes. This chapter will focus on the location of the best practice LSI schemes. The parallel report deals with the recommendations.

According to this classification, Kenya has the best irrigation district (Butere Mumais), followed by Wakiso in Uganda. The operational rules and experiences inside these LSIs should be shared with other LSIs in the same country and within the same climatic zone (and not beyond that).

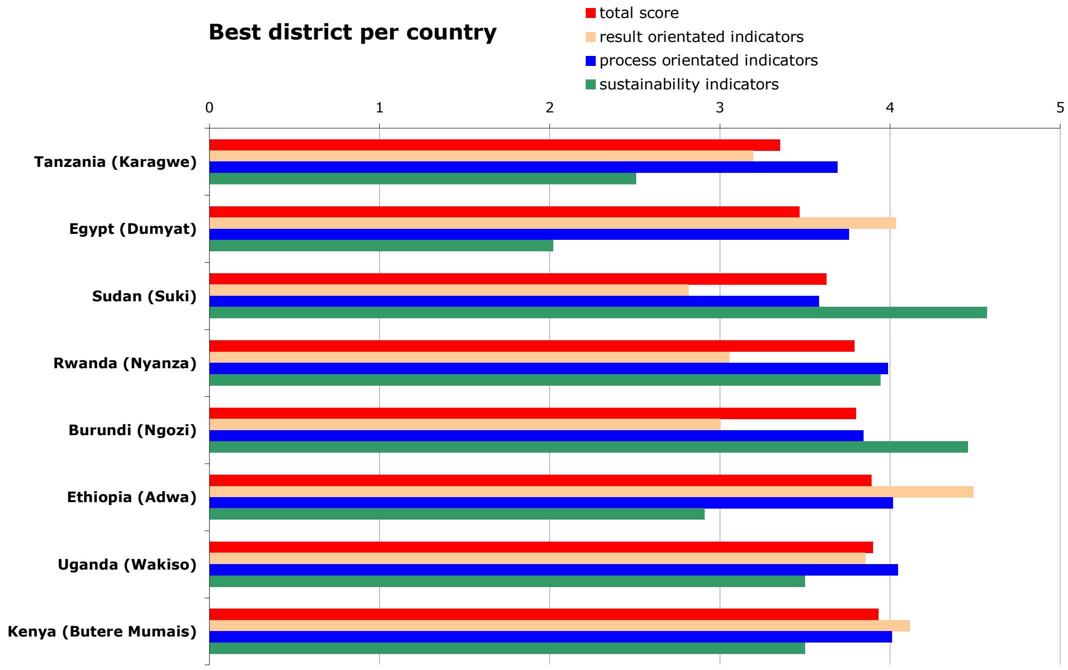


Figure 29 The total score for the best district of each Nile Basin country

Tanzania is the only country with two districts that comprise actually the same LSI. The results for Tanzania are therefore not relevant in the context for searching the best practices at National scale. The Dumyat district in the central-northern Nile delta (see Figure 31) in Egypt hosts the best LSI practices of Egypt. It is interesting to remark that the IIIMP areas and Bahr-El-Nour schemes have a lower rating. Bur Said has the highest water productivity, but Dumyat has a better overall irrigation performance. Dumyat is located on the Left Bank of the Damietta branch of the Nile Delta. It is interesting that the most downstream located LSI has an excellent performance; this means that irrigation water is reaching the tail end of the basin.

The command area in Dumyat is served by the Belamoun canal. Additional data on the Bahr-el-Nour canal command area in Kafr El Sheikh was elaborated on in Chapter 2, being adjacent to the Dakahla Governorate in which Dumyat district takes part. Al Fayyum appeared to be one of the worst functioning LSI schemes of Egypt (see country report). This observation should draw some attention to the institutional strengthening programme that is currently undertaken in Fayyum.

The Suki district in Sudan hosts the El-Suki LSI scheme. The El-Suki scheme at the Blue Nile seems to have the best overall irrigation management practices of Sudan. El-Suki was considered to become part of the bread basket of the Arab world. The scheme is merely selected because of its excellent sustainability. Farmers and water suppliers seem to live in good harmony and have a rewarding agricultural economy (although the productivity is moderate), otherwise the farmers would have quitted. Out of the eight best LSI schemes selected for every country, El-Suki has the lowest RO indicators, as well as the lowest PO indicators. Hence, the irrigation management aspects need to be examined, before recommending their practices to other LSI schemes in Sudan. Overall, the irrigation practices in Rahad turn out to be the second best. The Kassala district has for instance a good water productivity that is ranking no. 15 out of all 150 districts in the Nile Basin. The Aliab & Food Security district is performing also very well in Sudan. More details can be found in the Sudan country irrigation report.

The best LSIs of Rwanda are located in the Nyanza district. Their productivity (RO) is moderate, but the PO processes and sustainability are rating high. Apparently the LSIs are operated with satisfaction, although the final result in terms of productivity could be improved further. Neither Rwanda nor Nyanza is ranking in the top 20 of LSI systems with a high utilization of water resources. In Nyanza they should focus on crop production rather than water productivity as demonstrated in Chapter 4. The Gisagara district in Rwanda has also excellently managed LSI schemes (see also country report). It contains the Kabogobogo LSI of 598 ha.

The Buziga/Ngozi district seems to have the best irrigation management in Burundi. It is like Rwanda and Sudan not the productivity that causes this high rating, but rather the high sustainability and the fact that most physical irrigation processes are operated with satisfaction. The town of Ngozi is located in the center north of the country, not far away from the border of Rwanda. The Bugabira/Kirundo district hosts the second best LSI systems. Burundi has to spent more effort in agricultural research and extension for boosting the crop growth.

The Adwa district in Tigray (Ethiopia) is having impressive levels of irrigation performance. This area is not well known for its LSI schemes, because most of the irrigation activities are done by small holders scattered over the area. The total area of irrigated land in the district is (according to Table 4) 650 ha. The data source of labelling these areas as being irrigation is from FAO-GMIA. Small holders divert water from mountain streams such as Uri Wenz and other. Whilst the irrigation practices are scattered, together they will meet the acreage criterion of LSIs. The information on these highland irrigation practices help to provide a comprehensive picture and understanding of LSI schemes in mountainous areas with limited water resources. The Tigray experience is relevant for Ethiopia as this country intends to expand their LSI schemes to other mountainous areas. Figure 34 provides more insight in the geographical conditions of these areas. In the absence of any data, they could not be presented in Chapter 2. In a recent IWMI report (Awulachew et al., 2007) it was stated that Tigray has 4,932 ha of irrigated land. They stated that 976 ha is medium scale and 3,956 ha is small scale. Most schemes are found between Axum and Mekele (see Figure 30), with the majority of schemes in the vicinity of the Tigray capital Mekele. The Ambasel district located at the eastern edge of the Nile Basin appeared to be the second best LSI scheme of the Ethiopia.

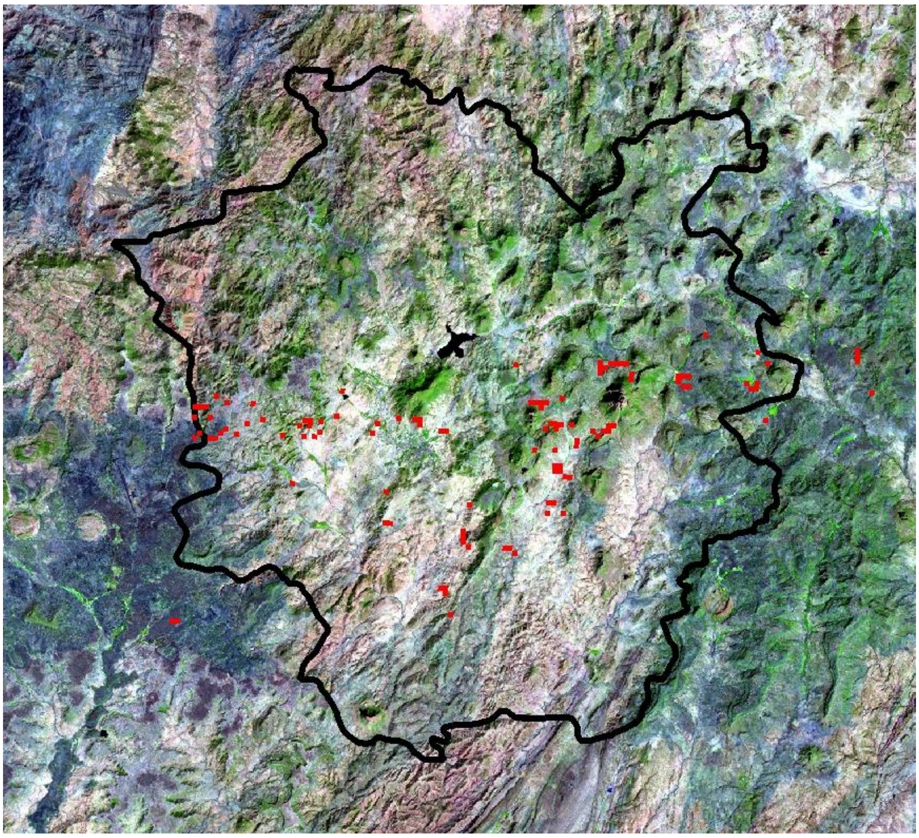


Figure 30 Location of the scattered irrigation systems in the Adwa district (Ethiopia) that meet the criterion of 200 ha per district. The background is a MrSid version of Landsat imagery

The LSI schemes in the Wakiso district belong to the best of Uganda. It scores high on all indicators: productivity (RO), irrigation processes (PO), and sustainability (SO). The land productivity has a higher score than the water productivity. These LSI schemes are located in the swampy land at the north-western edge of Lake Victoria between Kampala and Masaka. The irrigated land in the Entebbe area is also encapsulated into this data set. The Bugiri district has the second best LSI schemes of Uganda.

The best LSI irrigation practices in Kenya – and in fact in the whole Nile basin (after all normalizations and corrections) occur in the Butere Mumais district. These LSI schemes are located between Kisumu and Bungoma at the north-eastern edge of Lake Victoria. Bunyala is one of the major existing irrigation schemes in the area and covers 280 ha under the management of NIB. Fortunately, Bunyala is one the selected LSI schemes in Kenya for which more information was gathered. Its productivity (RO) and processes (RO) are a good example for the rest of Kenya. The land productivity is generally better than the water productivity. The Kisumu district has the second best LSI schemes in Kenya.

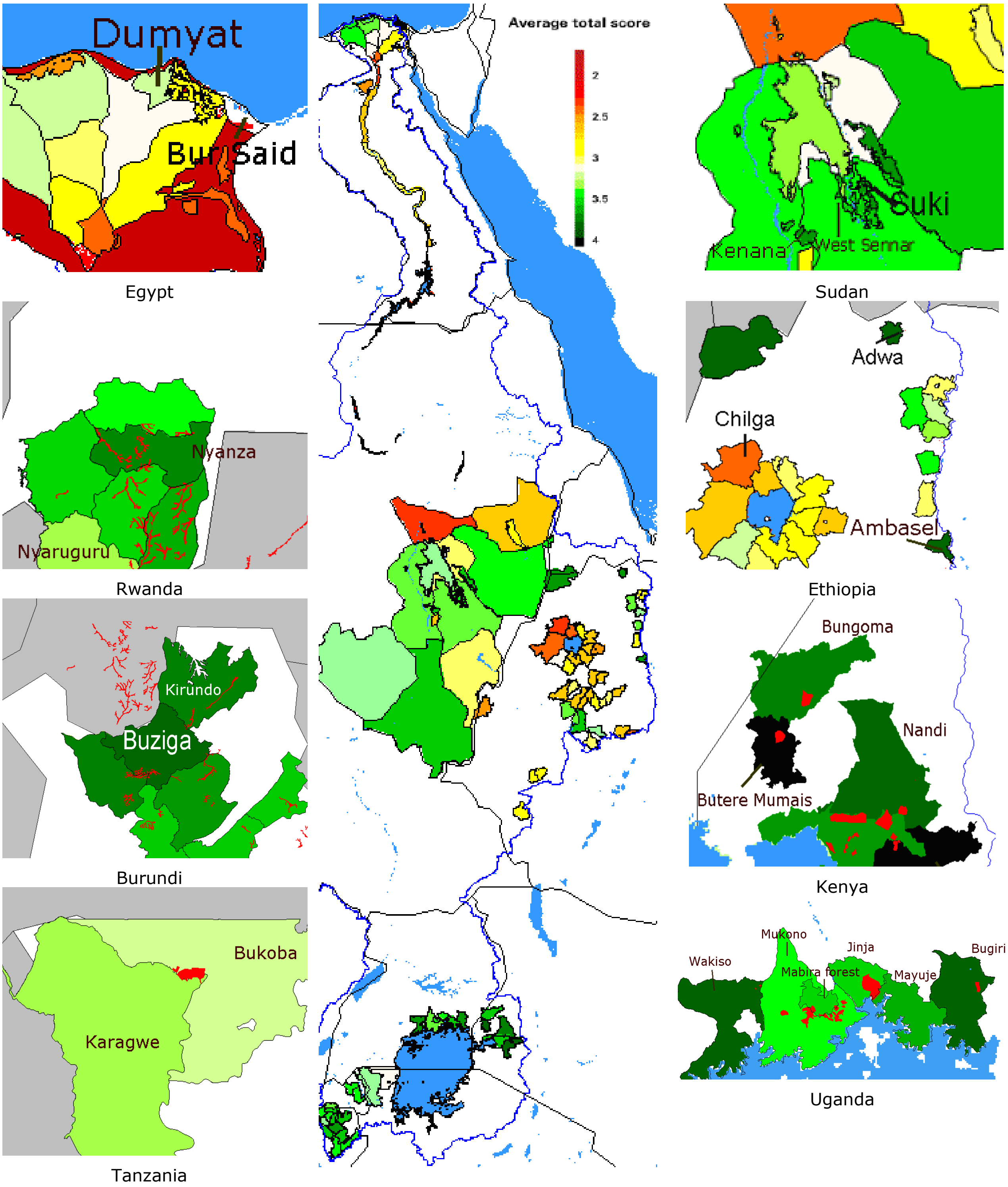


Figure 31 Location of the administrative districts with the best performing LSI scheme per country

7.3 Best practices for general irrigation performance by country

Detailed information on the physical irrigation processes in all districts in a certain country is provided in the appendices. There is an irrigation report for every country. Table 20 summarizes the 10 physical irrigation performance indicators for the LSIs that are considered the best example for that given country. The functioning of irrigation systems are essentially black boxes; the only information known is that the overall outputs are favourable. The inside mechanisms, infrastructure, water rights, breeding programs, reorganization of institutes and water user associations are unknown. Field visits to these regions will be required to determine the real causes of good performance. We can therefore only provide some qualitative recommendations.

Buziga/Ngozi has an excellent sustainability on land and water resources, Dumyat has the ideal range of production and crop water deficit, Adwa is known for its uniformity, Butere Mumais has a highly reliable water supply, Nyanza is favourable for its reliability and and uniformity, Suki is characterized by excellent sustainable irrigation practices, Karagwe is having the right amount of crop water deficit and Wakiso is good in almost everything except a high consumptive use.

Table 20 All irrigation performance indicators of the district with the best irrigation management practices

Country	District	wp	bio	cwc	cwd	bf	ad	un	rel	Spot	amsre
Burundi	Buziga/Ngozi	3.4	3.4	3.2	4.8	3.0	3.4	4	4.8	5.0	5.0
Egypt	Dumyat	4.6	4.6	2.1	4.7	3.0	4.6	4	4.1	1.0	1.0
Ethiopia	Adwa	3.8	3.8	3.4	4.4	3.4	3.8	5	4.0	3.0	3.0
Kenya	Butere Mumais	4.4	4.4	1.8	4.2	4.7	4.4	4	5.0	4.0	4.0
Rwanda	Nyanza	3.2	3.2	3.3	4.9	2.6	3.2	5	5.0	4.5	4.5
Sudan	Suki	3.7	3.7	2.9	3.9	3.1	3.7	4	3.9	5.0	5.0
Tanzania	Karagwe	3.4	3.4	3.1	4.6	3.4	3.4	4	3.5	1.1	1.1
Uganda	Wakiso	4.7	4.7	1.5	3.8	4.2	4.7	5	5.0	4.0	4.0

7.4 Best practices for general irrigation performance by climatic zone

A certain country should study and contact the best LSIs located in their home country first. Since the laws, education systems, subsidies, institutions, etc. are all identical within political boundaries, every LSI has the same constraints and opportunities. If water governance is dominant on the Results Oriented indicators, then RO should score high. In the hypothetical case water governance is not so important as often suggested by donors, the best practices could be copied from other countries that are located in the same climatic zone. Table 21 shows therefore the best districts per climatic zone.

Table 21 Best districts per climatic zone and their score of each category of indicator

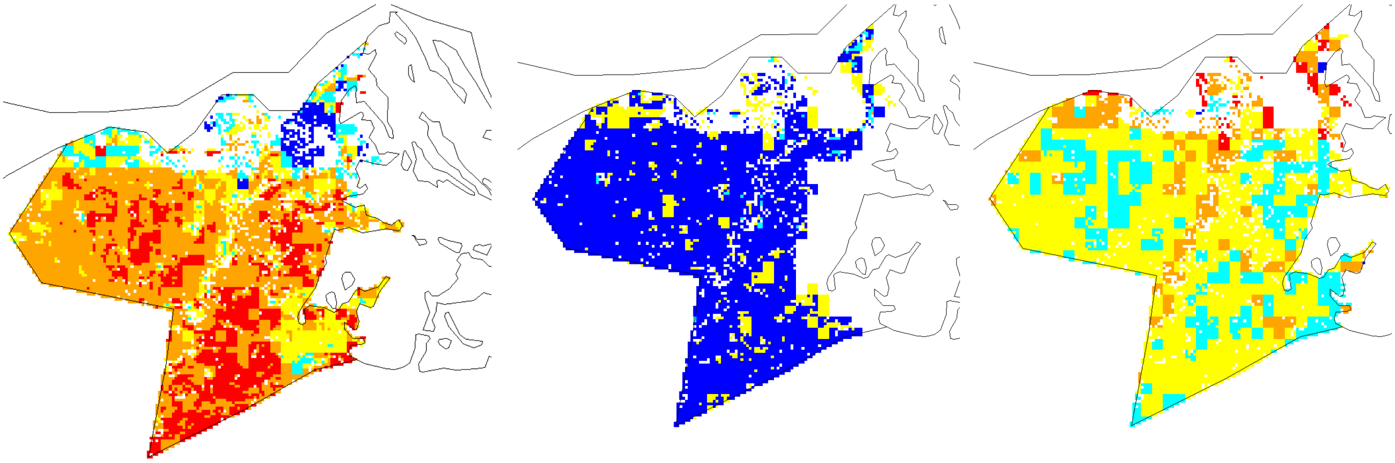
Climatic zone	country	district	average	RO	PO	sustainability
1	Egypt	Dumyat	3.5	4.0	3.8	2.0
2	Sudan	Suki	3.6	2.8	3.6	4.6
3	Sudan	Upper Nile	3.6	4.1	3.6	2.9
4	Uganda	Wakiso	3.9	3.9	4.0	3.5

Table 21 shows that Dumyat in Egypt is the overall best performing district for climate zone 1. This implies that the best practices of Dumyat could also be transferred to the LSI schemes in northern and central Sudan. When moving further south, rainfall will increase due to the influence of the Inter Tropical Convergence Zone (ITCZ). Whereas the LSI schemes of the hyper-arid zones receive no rainfall, the arid zones in central Sudan receive on average 200 to 400 mm of rainfall. El-Suki irrigation scheme seems to be the best in climatic zone 2.

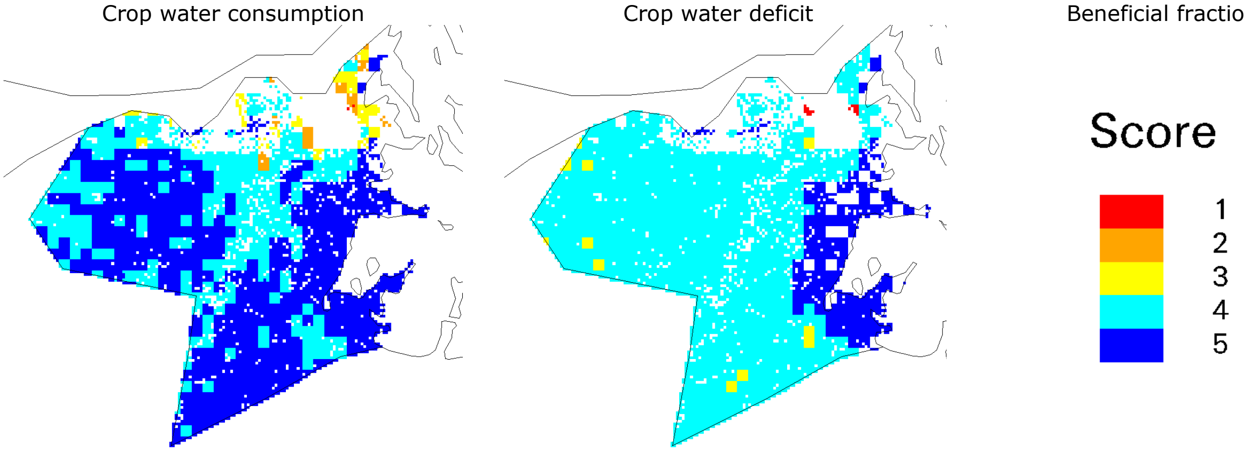
The Upper Nile district in Sudan seems to be the best example of LSI operations in the semi-arid belt of southern Sudan, Ethiopia and Kenya. Upper-Nile was not reported on earlier because Suki had a better overall irrigation performance. The Wakiso district in Uganda can be regarded as having the best overall performing LSI schemes of the equatorial lake region. Hence, Burundi, Rwanda, Tanzania and Kenya should pay attention to the practices of Wakiso. It would be a good gesture of Uganda to provide more information on these systems to NBI.

The spatial distribution of the five PO indicators is displayed. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. A 6.25 ha pixel analysis for these 4 best districts is displayed in Figure 32, Figure 33, Figure 34 and Figure 35. Looking at the within district variation, enables us to get a more comprehensive understanding of good irrigation management. Spatial information makes it feasible to investigate whether the irrigation system is homogeneously managed.

Figure 32 demonstrates that Dumyat has a mild crop water deficit and an adequate water supply to the crops (high adequacy). Classical furrow and border irrigation technologies are used: rice fields are present in this area and they have basin irrigation. There is thus sufficient water. In the absence of rain all this water must originate from irrigation. The water table is shallow. Crops may thus benefit from a continuous water supply to the root zone through capillary rise. This is reflected in the reliability being extremely good. The beneficial fraction is moderately good. It is moderate because there are fallow periods. The only drawback of this system is its high crop water consumption. From the fact that other districts in the same climatic zone have higher scores, one can concluded that a limitation of irrigation water supply should be feasible. The high crop water consumption is however providing above-averaged crop yields and lucrative incomes. Almost unlimited water supply is also intended to create sufficient leaching and drainage of salts brought in by irrigation.



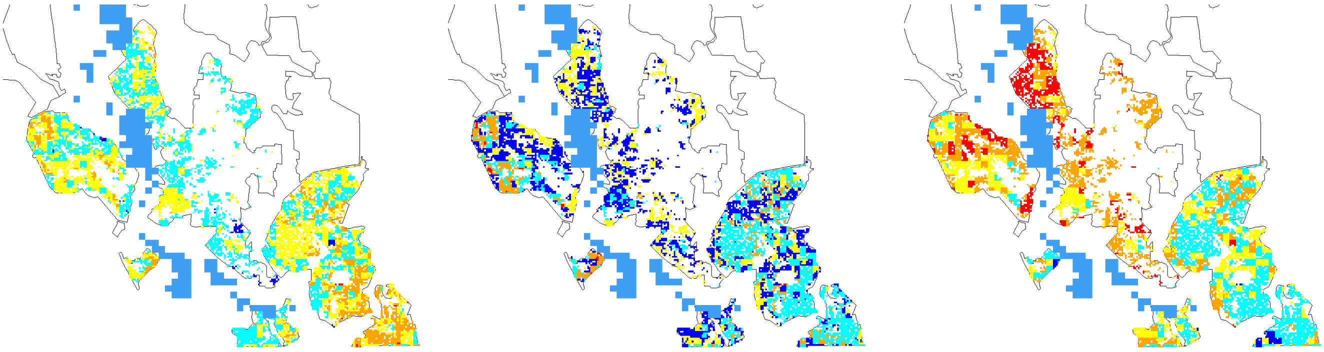
Crop water consumption Crop water deficit Beneficial fraction



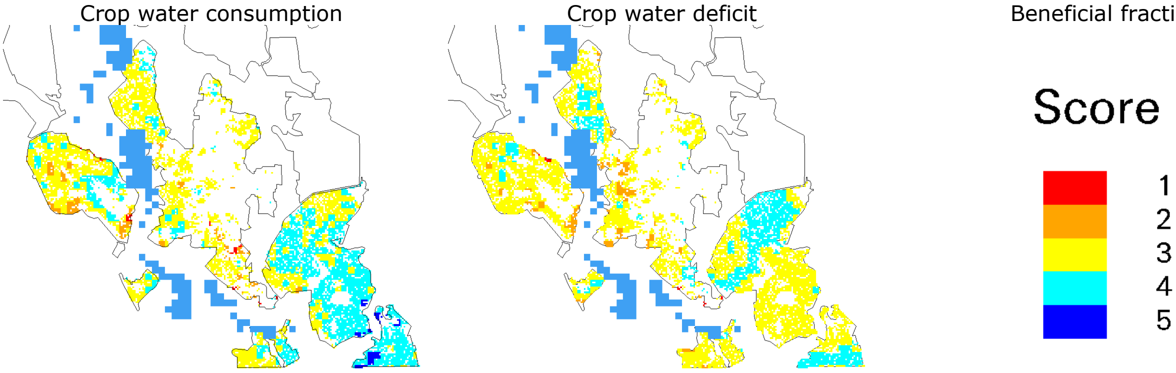
Adequacy reliability

Figure 32 Spatial distribution of each indicator for the district of Dumyat, the best district of climatic zone 1 (hyper-arid climate)

El-Suki is the most favourable LSI in the arid zones. El-Suki appeared to be the third best district in the entire Nile basin considering the average of all the indicators. Both right and left Banks are irrigated. The spatial geometry of El-Suki deviates from the other LSI schemes. It is interesting to see that even though the average beneficial fraction is good, it is not homogeneous. The northern part of the district seems to have a very low beneficial fraction. The spatial distribution of the indicators will indicate localized areas that need to undergo an improvement programme most urgently. Most of the indicators have an intermediate level of performance. The final score is superior.



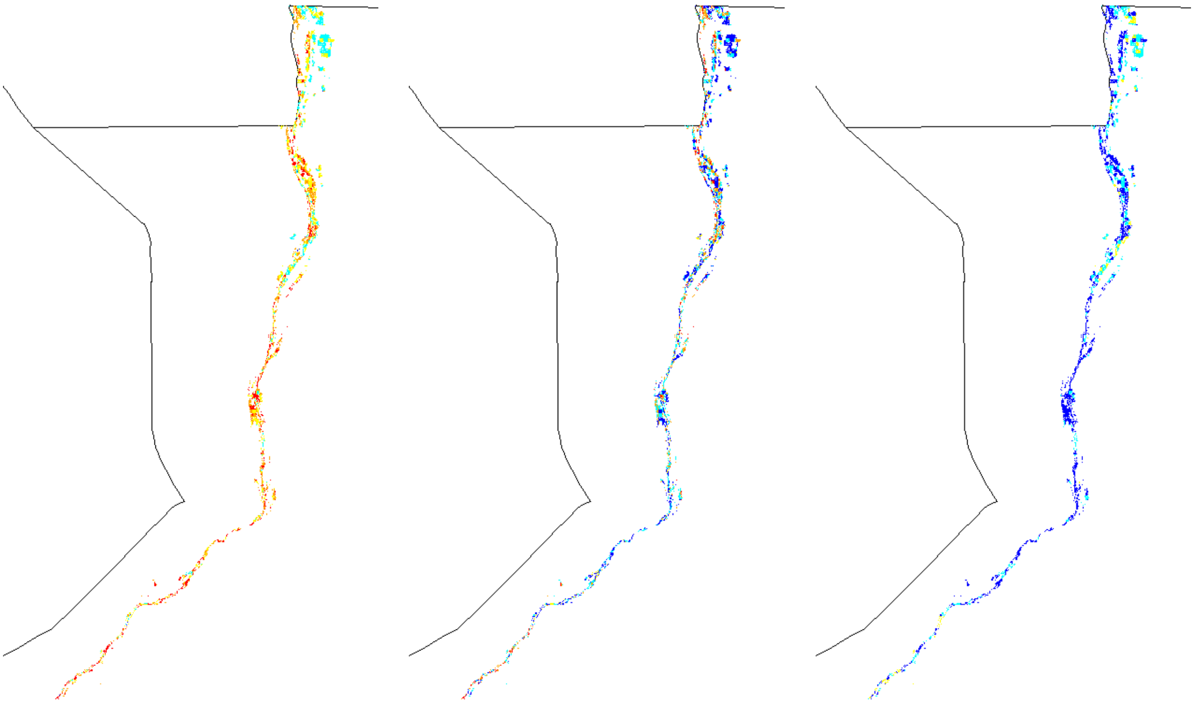
Crop water consumption Crop water deficit Beneficial fraction



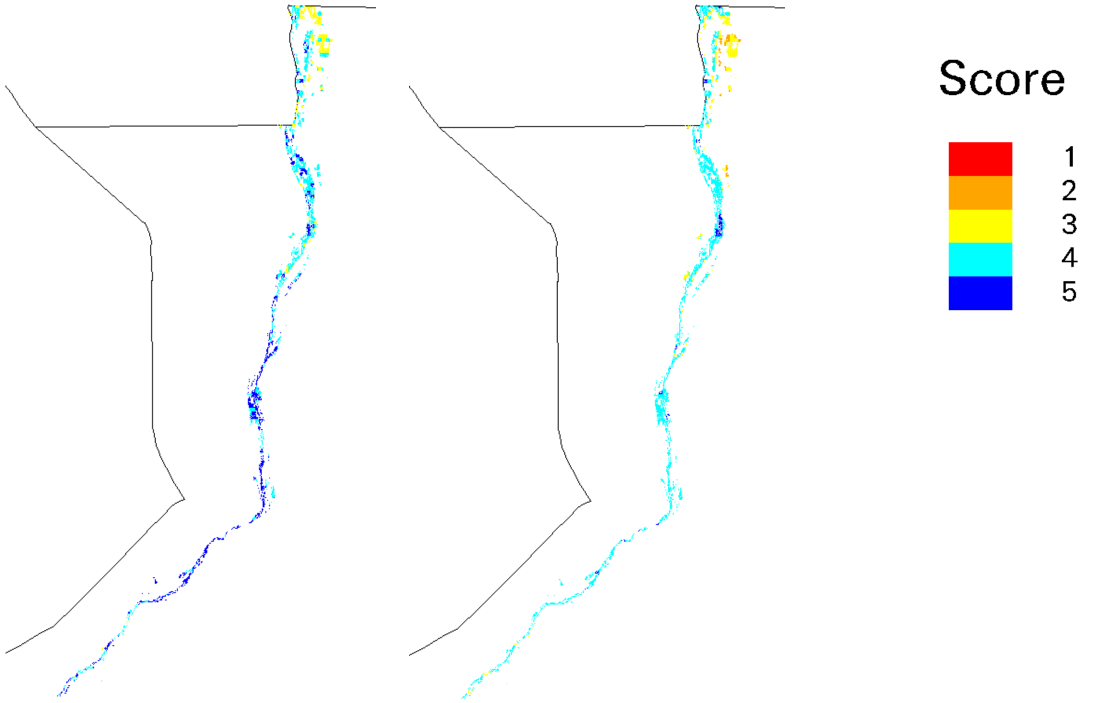
Adequacy reliability

Figure 33 Spatial distribution of each indicator for the district of Suki, the best district of climatic zone 2 (arid climate).

The district with the best LSI practices in the semi-arid zones (climatic zone 3) is the Upper Nile. The area is located in southern Sudan in a long stretch between Malakal at the confluence of the Sobat and the White Nile and Geigar. The irrigation water is taken directly from the Jebel Aulia reservoir. Figure 34 shows characteristics being very similar to Damyut in Egypt. There is little crop water deficit and the moisture supply to the crop is adequate. The system shows great uniformities; there is no heterogeneity noticeable. This is probably related to the fact that the White Nile upstream from Khartoum functions basically as one large reservoir. Plentiful surface water resources are therefore available at short distance from the cropped land, and this is likely to be the main reason for the unstressed conditions. The short distance can also be the main reason for the reliability being so good; farmers may have their own pumps and create an on-demand irrigation system. Consequently, crop consumptive use is high and receives a low score. There seems to be one section in the downstream part of the district where the situation is less ideal: this is a scheme that is operated further away from the main river and reservoir. It is even possible that this piece of land is located outside the valley and on the higher located desert land. It demonstrates that direct access to water is an advantage.



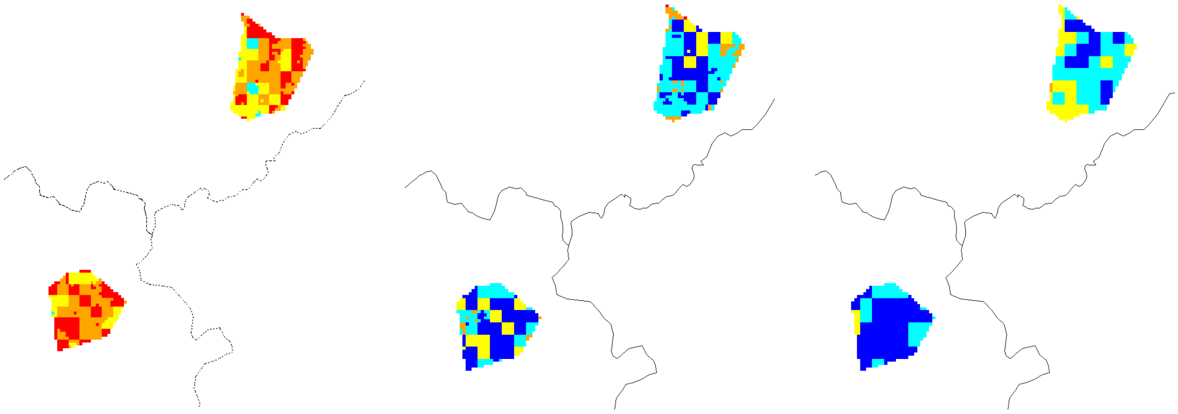
Crop water consumption Crop water deficit Beneficial fraction



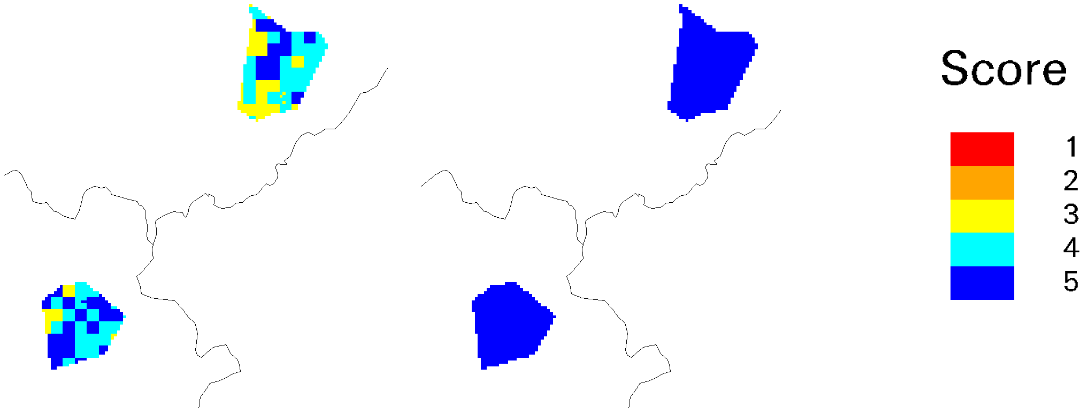
Adequacy reliability

Figure 34 Spatial distribution of each indicator for the district of the Upper Nile, the best district of climatic zone 3 (semi-arid climate).

Figure 35 displays the situation in Butere Mumais (Kenya). Wakiso district has a non-contiguous irrigation system, and is for this reason not shown. Figure 35 demonstrates that crop water consumption is not only the weakest factor at district level but also at pixel level. However, the crop water consumption is not homogeneous. The analysis identifies the pixels with low and high crop ET and knowledge of the fields with good practices can be used to infer information to undertake effective measures.



Crop water consumption Crop water deficit Beneficial fraction



Adequacy reliability

Figure 35 Spatial distribution of each indicator for the district of Bungoma and Butere Mumais in Kenya, the best district of climatic zone 4 (humid climate)

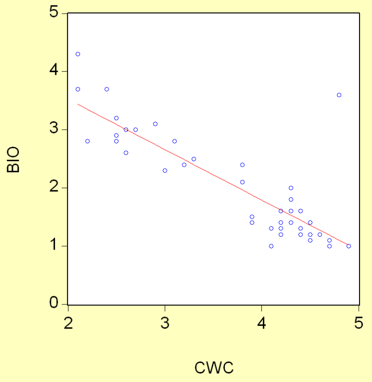
7.5 Physical irrigation processes affecting productivity

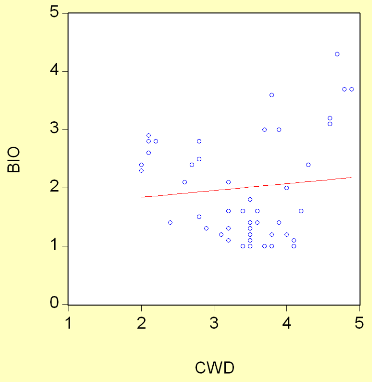
The impact of physical processes on land and water productivity needs to be understood prior to advising on irrigation practices. A system analysis can be accomplished by relating the RO indicators to the PO indicators. The trends (if any) between PO and RO indicators need to be understood for sensible recommendations to be made. A regression analysis was performed on all indicators located in the same climatic zone. Figure 32, Figure 33 and Figure 34 show linear relationships because we are seeking for straightforward recommendations that are generally applicable. No analysis was possible for climatic zone 3, because not enough administrative districts were located in the semi-arid climatic zone to perform a statistical meaningful analysis.

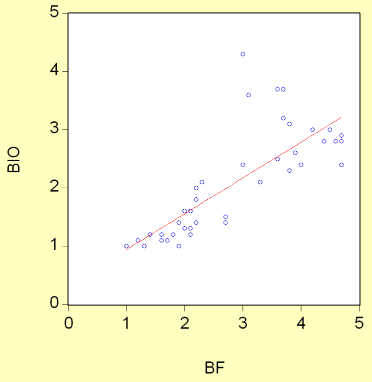
Figure 36 shows the trends between processes and results at administrative district level. Land productivity in the hyper-arid zones (zone 1) of Egypt and Sudan is best correlated with adequacy, crop water consumption, and beneficial fraction. For the arid zones (zone 2) the conclusion is that land productivity can be explained by adequacy and crop water consumption. The role of the beneficial fraction is less pronounced. The results from the humid climates of the Equatorial Lake region (zone 4) suggest that land productivity variations are controlled by adequacy, reliability, and crop consumptive use. This implies that for maximum crop production, irrigation systems should operate on the basis of sufficient supply of water and high crop water consumption. Indeed, this is the classical view on irrigation management when water resources are plentiful: most of the FAO guidelines are based on the principle to avoid crop water stress (Doorenbos and Pruitt, 1977; Allen et al., 1998).

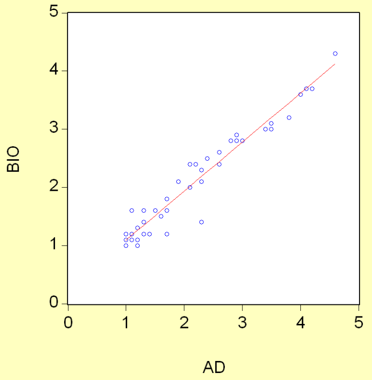
Adequacy is defined in this study as relative transpiration (T_{act}/T_{pot}) and a higher adequacy implies a higher transpiration flux T. This relationship between land productivity and adequacy is analogous to the linear relationship between crop yield and transpiration (T) as suggested in the more recent publications of FAO scientists (Steduto et al., 2007).

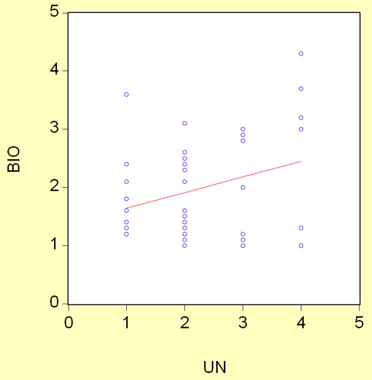
The beneficial fraction has a positive influence on crop production in Egypt and Sudan (climatic zone 1). This can also be explained by the higher transpiration flux T, because T increases with beneficial fraction (T/ET). There are two reasons why Egypt has a significantly higher value for beneficial fraction than Sudan: the canopy cover is higher due to the annual cropping intensity and lower rainfall in Egypt which keeps the soil surface drier than in Sudan. Sudan has a monsoon climate and heavy summer storms occur that wet the soils. Reliability of irrigation water supply seems to be relevant for humid climates (climatic zone 4). This could be related to the fact that rainfall is erratic, and it is thus more difficult to add supplementary irrigation at the right time. Rainfall interferes with the planning of the irrigation applications.

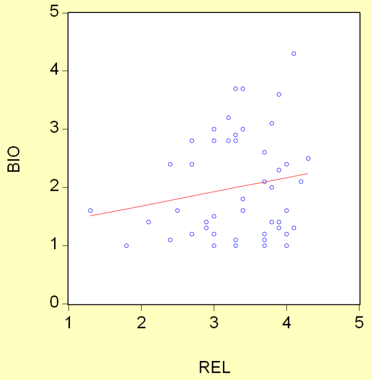

BIO vs. CWC

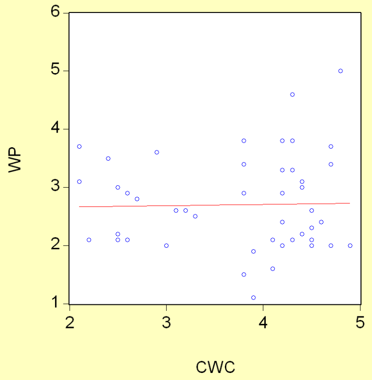

BIO vs. CWD

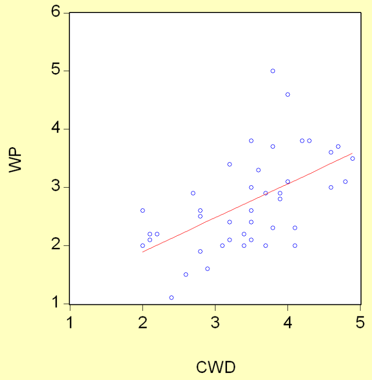

BIO vs. BF

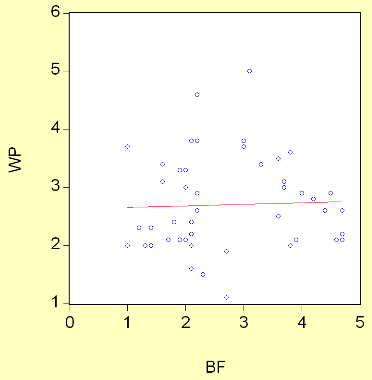

BIO vs. AD


BIO vs. UN


BIO vs. REL


WP vs. CWC


WP vs. CWD


WP vs. BF

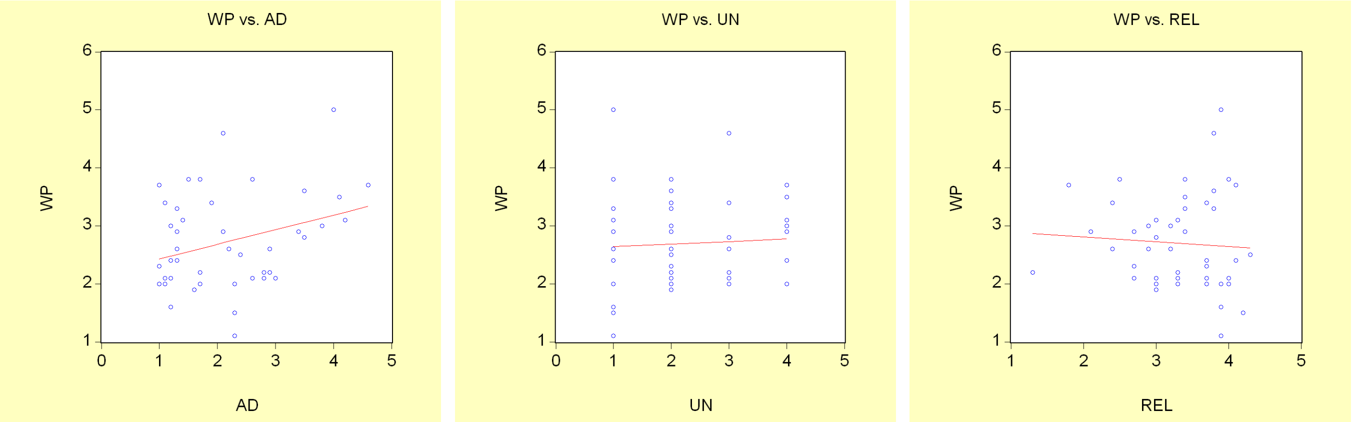
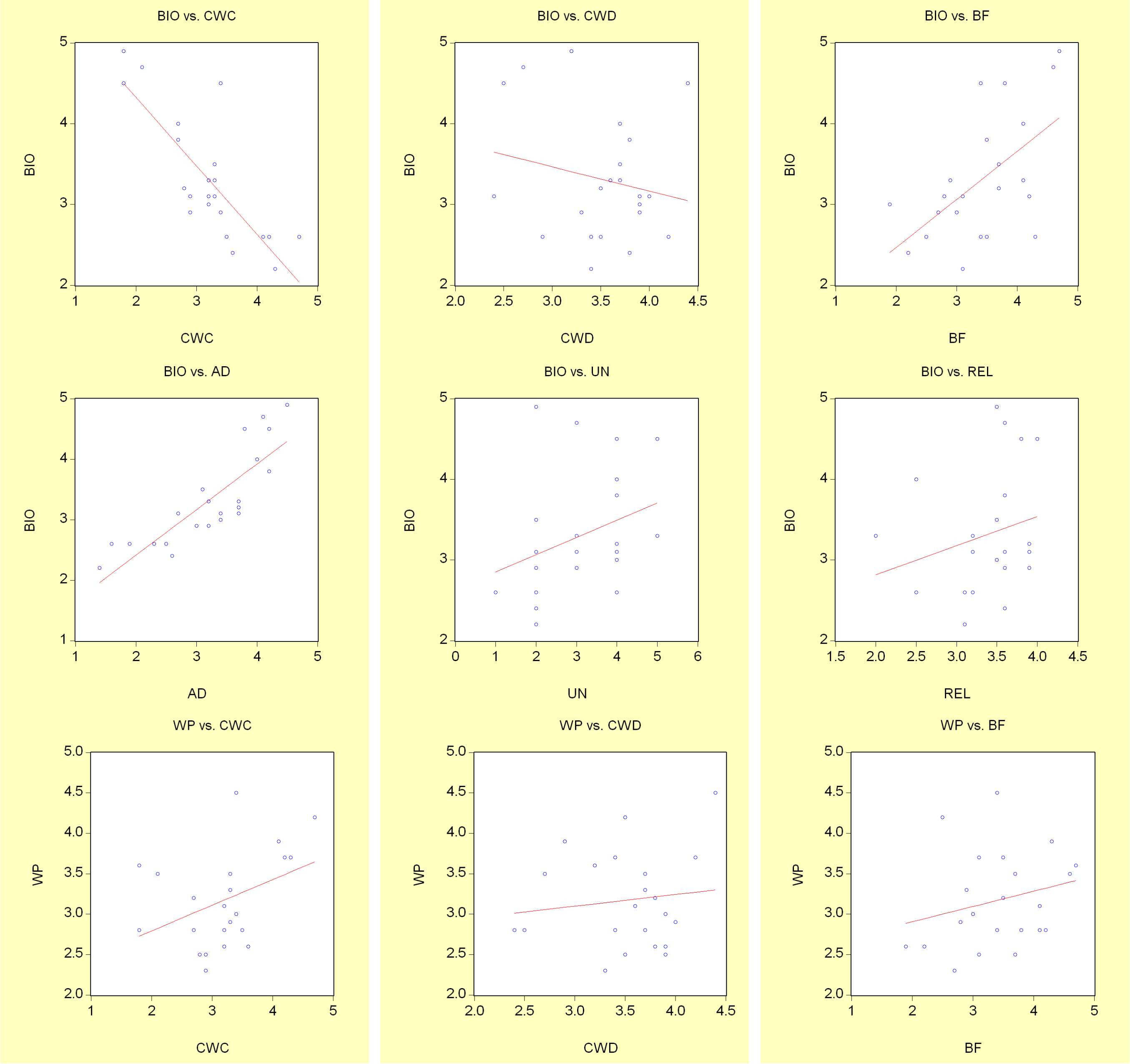


Figure 36 Relationships between RO and PO indicators for the district in the climatic zone 1



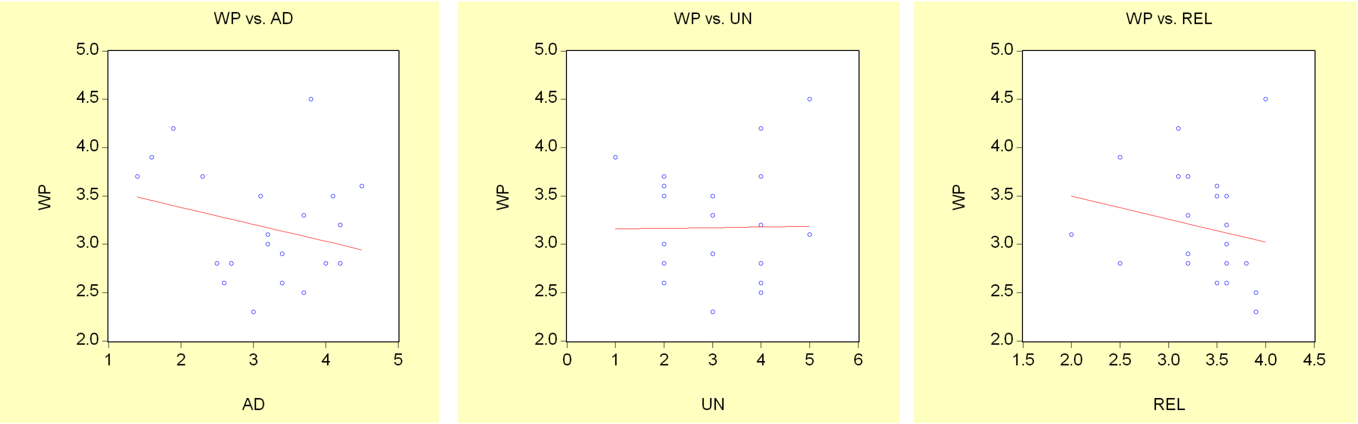
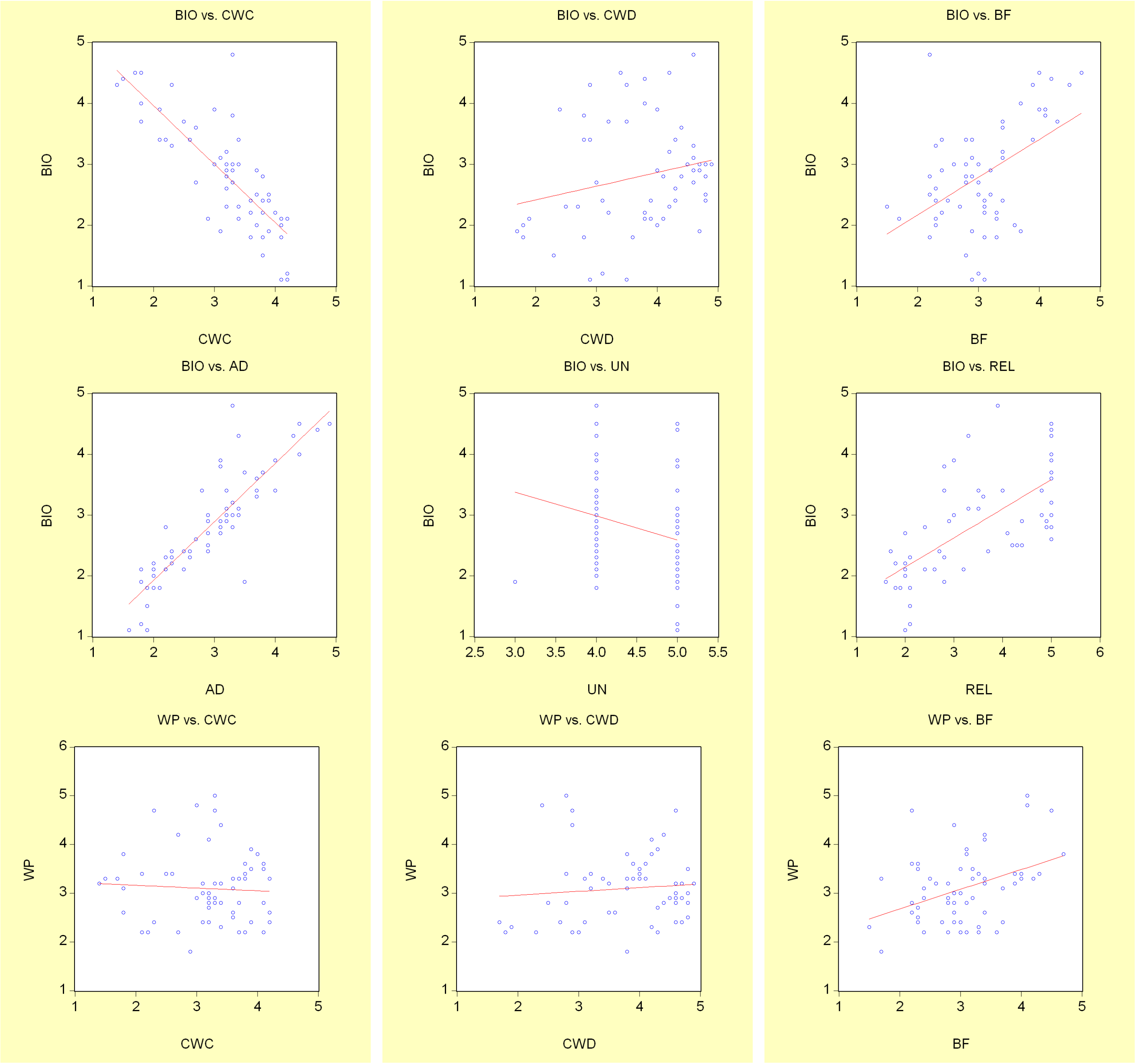


Figure 37 Relationship between RO and PO indicators for the district in the climatic zone 2



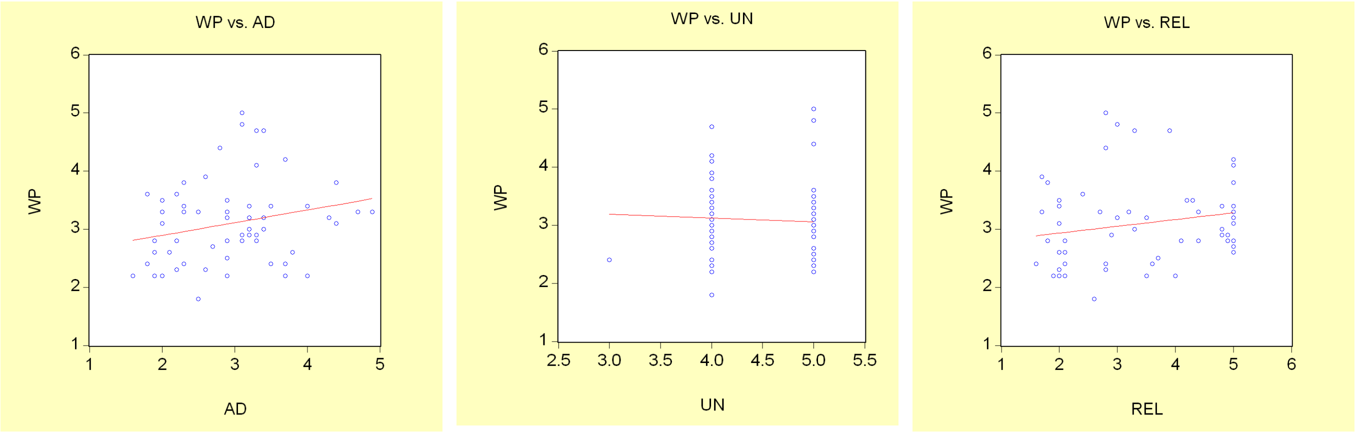


Figure 38 Relationship between RO and PO indicators for the district in climatic zone 3

The water productivity in the hyper-arid zones shows the best correlation with crop water deficit. A higher score of crop water deficit is a consequence of reduced stress level, and wetter soils. Apparently, water productivity in climatic zone 1 is sensitive to the overall land wetness and soil moisture values. It suggests that some stress can be imposed, but only in a controlled manner. The other processes do not have a profound relationship with water productivity. The arid zones of Ethiopia and Sudan show that water productivity is mainly a function of crop consumptive use. The water productivity is linear with ET. Theoretically, a higher ET should result into a lower water productivity. The linear and positive relationship can be explained only by a steep slope between ET and land productivity (i.e. crop yield). Water productivity in the humid zone seems to be better correlated with the beneficial fraction, although the statistical correlation is not very strong.

Water productivity is a result of land production and crop water consumption. The graphs above show the relationship between water productivity and explanatory physical irrigation water related processes. The link between water productivity and crop yield has not been addressed. Figure 39 summarizes agricultural production in relation to crop water consumption by country, and thus indirectly by climatic zone. This key graph shows that a higher water use will generally result in higher agricultural production. The districts in Uganda consume on average 13,000 m^3/ha, while the districts in Sudan consume only 5,000 m^3/ha. Sudan is thus using relatively little water in their LSI schemes, but as a result Sudan also has the lowest crop production (biomass 5,000 kg/ha). While the water consumption in Uganda is 3 times more than in Sudan, the crop production is a factor 6 higher. This implies that water productivity in Uganda is double that of Sudan. This finding shows that water productivity varies significantly and needs to be managed well.

More detailed analyses show that considerable amounts of water that can be saved. The left envelope of the graph in Figure 39 shows the districts that are water conservative. The right envelope shows the districts that are consuming high amounts of water. If irrigation farming shifts conditions from the right to the left without changing land productivity, biomass water productivity can go up from roughly 2,000/10,000=0.20 kg/m^3 to 2,000/6,000=0.33 kg/m^3, an increase of 65 %! Hence the same agricultural production can be achieved with significantly less water.

There are a few interesting outliers in Figure 39. There is one district in Egypt that has a production of 30,000 kg/ha at a consumptive use of 1,500 m^3/ha. This implies a biomass water productivity of 20 kg/m^3. This is an extra-ordinary high value that occurs in the high-tech irrigation systems along the Cairo-Alexandria desert road in the Western Desert of Egypt. These are commercial estates (Dina farm; Centech farm) that drip irrigate their high value crops with just sufficient water to maximize yields. At the other end of the scale is a district in Sudan that only has 4.000 kg/ha but an outrageous crop water use of 15,000 m^3/ha. This is equivalent to a biomass water productivity of 0.26 kg/m^3.

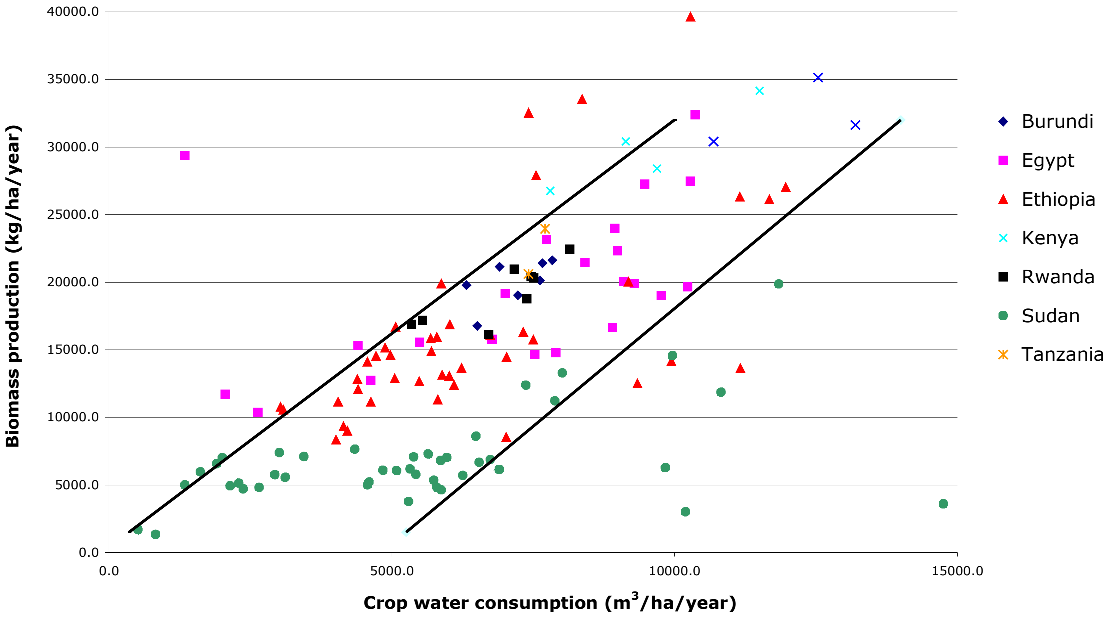


Figure 39 Correlation between biomass production and crop water consumption by country districts. Note that normalization by climatic zones has not been applied

The district data presented in Figure 39 does not include normalization for climatic influences, and for this reasons certain countries show higher water consumption than other countries. After benchmarking the country average values for land productivity and crop water consumption, the situation displayed in Figure 40 arises. The high crop consumptive use of Uganda is associated with a poor score (1.8) and vice versa. For this reason, Sudan now has the best score for consumptive use (3.6).

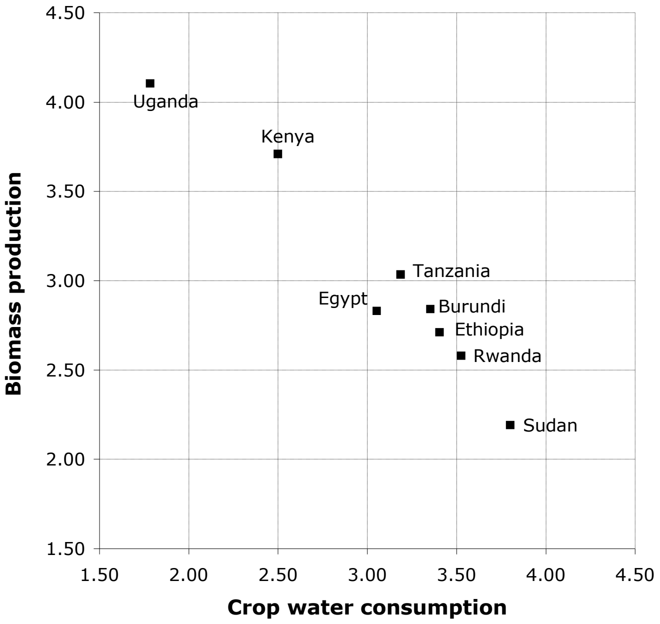


Figure 40 Correlation between land productivity and crop water consumption by country. Note that normalization by climatic

This analysis shows that certain physical irrigation processes have more impact on land and water productivity than other processes. Good irrigation management should put emphasis on these processes because they can be affected by modifying irrigation supply. While evaluating the good irrigation practices in the Nile basin we should keep the key processes for a favourable productivity in mind. A summary of the key processes is presented in Table 22.

Table 22 Key processes in productive irrigation management that require attention

Climatic zone	**For high land productivity**	**For high water productivity**
1 (Egypt, Sudan)	Adequacy high Crop water consumption high Beneficial fraction high	Crop water deficit low
2 (Sudan, Ethiopia)	Adequacy high Crop water consumption high	Crop water consumption high
3 (Ethiopia, Kenya)	Not clear	Not clear
4 (Tanzania, Burundi, Rwanda, Uganda)	Adequacy high Crop water consumption high Reliability high	Beneficial fraction high

The results seem to suggest that the relationships between PO and RO indicators for land productivity have similar patterns in climatic zones 1, 2 and 4. Hence, the absence of climatic zone 3 is not a constraint in this investigation aimed at identifying the most crucial elements that make irrigation systems successful. The recommendations for water productivity are less clear.

Interim conclusions:

- Land productivity is more sensitive to specific attributes than water productivity. The likely reason is that water productivity is derived mainly from land productivity.
- Different physical processes dominate in different climatic zones; irrigation management must therefore be evaluated by climatic zones or at smaller scales such as countries. The advantage of evaluating at country scale is that water education and institutions can be incorporated.
- The maximum crop production is obtained at maximum transpiration
- Actual transpiration rates are manageable through crop water consumption, adequacy and beneficial fraction.
- The challenge is to find the optimum stress level where ET is reduced and crop yields are unaffected.

7.6 Best practices for improving productivity

The districts with the highest land and water productivity in every country can be different from the LSIs that have the overall best performance based on equal weight to all 10 indicators. According to this classification, the Ambasel district in Ethiopia with a score of 4.8 seems to have the best productivity performance (see Figure 41). Egypt and Sudan are almost equal in the second place with the district of Bur Said (score 4.3) and Kenana (score 4.3) respectively. The maximum productivity score in Rwanda and Burundi is 3.1. The variation in maximum productivity for each country is more significant (3.1 to 4.8) than the variation in overall irrigation performance (3.3 to 3.9).

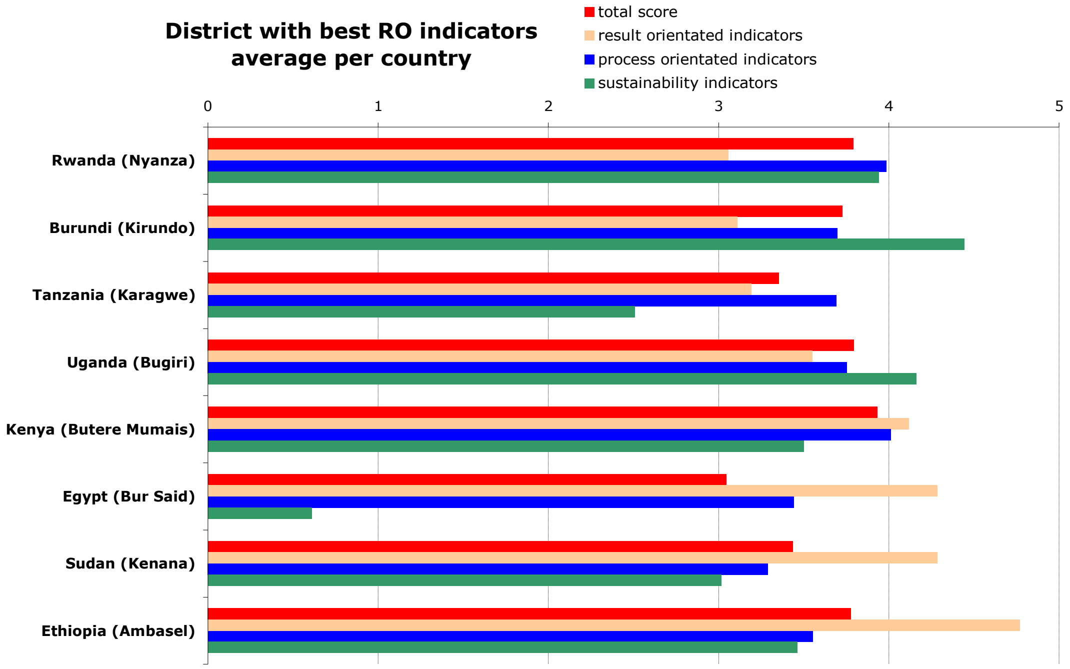


Figure 41 Breaking down the total score per indicator for the districts with the best RO indicators average for each Nile Basin country

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PART 2 Guidelines on Best Practices and Sites

Executive Summary

This sub-report describes the procedures to convert the good practices from selected LSIs to other LSIs within the same typology. The needs for an irrigation typology are described. Such typology should be based on climate, soil, irrigation objectives, irrigation management responsibilities, level of investment, the type of irrigation system and the size of the LSI. Because the current study could not get the required data for a good typology – besides the boundaries of the LSI – this needs to be executed by the Line Agencies responsible for irrigation. It is suggested to prepare a standard questionnaire for the local irrigation engineers, and the contents of such query have been provided.

Some general issues of irrigation management were not discussed in report part #1, and they were address in the current report #2. The importance of the governmental and commercially managed LSI has been highlighted by selecting two contrasting sets of data from Egypt and Sudan. A more detailed analysis for summer and winter crops have been performed and this provides insights in the major difference between the management responsibilities. The requirements of the type of irrigation systems have been elucidated.

A list of major recommendations for transfer of irrigation knowledge is provided. Key elements are the involvement of local stakeholders that have created favourable irrigation systems. These persons should help to explain irrigation practices to the irrigation managers and farmers in less favourable irrigation areas.

Egypt, Sudan and Ethiopia are the countries with the largest irrigated areas. Because of this spatial scale, areas with excellent irrigation practices coexist with areas that have poor practices. For the sake of heterogeneity in irrigation performance, these countries should start first with an improvement program.
The procedures for such improvement program are provided. The countries in the Equatorial Lake region can also work on improvements, but their need is less than in the arid zones of the Nile Basin.

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1 Procedures for transferring best practices

1.1 Need for an irrigation typology

There are many good irrigation practices within the Nile basin which support productive use of water. There are also many practices that should be avoided. Good and poorly managed LSI systems coexist within political boundaries. The essence is to (i) recognize which irrigation practices are good, and (ii) encourage the exchange of good irrigation practices within countries, and across countries (as long as the LSIs are located in the same climatic zone). The sites with the highest productivity and best physical irrigation processes are identified in each country. Unfortunately, there is limited understanding on the underpinning reasons of achieving these best practices, and more work is needed to determine these causes.

A set of good practices for one specific area are not necessarily good for other areas. The earlier example of Fayoum has shown that irrigation rules from the Nile Delta should not be applied in the waterlogged area of Fayoum. Preparation of site specific recommendations cannot be achieved and the major challenge of this study is to prepare more country and climate related advices, apart from overarching recommendations that apply to LSIs within the same irrigation typology.

The upstream and downstream parts of the Nile basin have widely diverging climatic systems (from hyper-arid to humid) and various cultures, political systems and level of responsibilities (Governmental vs. private). This necessitates the classing of LSI schemes in the Nile basin into an irrigation typology. These categories should be kept simple, logical and understandable. The crucial LSI characteristics on which irrigation typology should be based are:

- Climate
- Soil
- Irrigation objectives
- Irrigation management responsibilities
- Level of investments
- Type of irrigation water supply system
- Size of the LSI scheme

These seven key items can ideally be used to classify all LSI schemes of the Nile basin. By absence of both the LSI scheme boundaries and the LSI characteristics, such classifications could not be realized. A typical irrigation category could have been: *arid zone-loamy sand-maximizing productivity-furrow irrigation-10,000 ha-publicly managed-scant investment* and so forth. Because this is not possible, the recommendations for best practices will be based merely on climate zones without consideration of these typology aspects. The typology can be prepared only after conducting local surveys.

Interim conclusions:

- Practical guidelines are tight to certain irrigation typologies, and not mutually transferrable
- The irrigation typology for the Nile Basin could not be prepared
- Practical guidelines need therefore to be prepared by country or by climatic zone

1.2 General LSI characteristics

Governmental vs. commercial management

Privately managed irrigation systems are a minority in the Nile Basin. Sugarcane is a typical crop that is cultivated on privately managed LSI schemes. The commercial farms located on the Desert Road between Cairo and Alexandria grow multiple crops including vegetables, fruit crops, flowers, and conventional commodities such as grain and potatoes. Dairy farming is also widely practiced. These capital investments are made only if (i) the Government provides land concessions of sufficient size and (ii) the irrigators are ready for serious capital injections; which is feasible only if irrigated farming systems are rewarding. The investors will settle if they can apply their own irrigation management without interference from public entities including a guaranteed water supply. To minimize the risk of limited water resources availability, investors usually settle on banks of rivers (e.g. Kenana), lakes (Entebbe, Lake Tana), or on top of high yielding aquifers (e.g. Western Desert). Commercial farms bring employment to the region, and this is a welcome investment for the economy.

Before making statements on commercial irrigation, it is worth evaluating some major differences with conventional irrigation systems and with low investments. Whereas in the Nile delta (Egypt) and Gezira (Sudan) flood irrigation systems are typically managed by the Government, the Dina farm (Egypt) and Kenana scheme (Sudan) are managed by commercial enterprises. Because rainfall has a significant impact on agricultural water management practices, the output of a comparative irrigation systems analysis presented hereafter is by season. The rainfall distribution in Egypt and Sudan is typically bi-modal. Results for irrigation indicators in the summer season are presented in Table 1; the winter season results are shown in Table 23.

Table 1 Irrigation indicators for the management of irrigated summer crops in selected commercial and non-commercial schemes

	Unit	**Purpose**	**Nile Delta**	**Western Desert**	**Gezira**	**Kenana**
			Non-commercial	**Commercial**	**Non-commercial**	**Commercial**
Bio	kg/ha	Land productivity	23,983	12,943	8,307	21,618
ET_{act}	m^3/ha	Crop water consumption	7,060	2,140	4,350	8,560
Bio/ET_{act}	kg/m^3	Water productivity	3.4	6.0	1.6	2.5
T_{act}/T_{pot}	-	Adequacy	0.82	0.54	0.58	0.86
CV T_{act}/T_{pot} time	-	Reliability	0.93	0.93	0.87	0.83
CV T_{act}/T_{pot} space	-	Equity	0.38	0.64	0.92	0.91
T_{act}/ET_{act}	-	Beneficial fraction	0.96	0.93	0.59	0.93

Conclusions for the summer situation:

Public Nile Delta: This area is a large water consumer, but almost all the water is beneficially used. The production per unit of land is very good. There is ample water available with little crop water stress, although the spatial distribution is not uniform (more wet in direction of Mediterranean Sea and variable as a result of soil fertility variation). The reliability of the irrigation service is very high. The water productivity is average.

Commercial Western Desert: The water consumption is very low, and most water is beneficially used. The water productivity is extremely high, partially because there is significant crop water stress. Water is thus used very wisely, but it goes at the costs of crop volume production (but to the benefit of fruit quality). A significant variation in water productivity among farms is apparent. The irrigation service is extremely reliable, due to groundwater supply.

Public Gezira: This area has moderate water consumption rates, and a large fraction of the evaporative water use is non-beneficial due to uncontrollable rainfall rates. The agricultural production is far below average, which designates this area as being poor in productive use of water resources. Due to abundant summer rainfall, water stress is uniformly distributed. The water supply seems insufficient to meet crop water requirements.

Commercial Kenana: This sugarcane estate is the highest water consumer and also the largest food producer of the five areas investigated. The crop water productivity therefore is average. Despite the intensive summer rainfall, the non-beneficial fraction is relatively low, and most water is used for crop production. The land wetness can be classified as moist and uniform. The crop water stress is very low and the agricultural production is close to potential. Some temporal variation in crop water stress is noticeable, which can probably be explained by the difference in age of sugarcane fields and difference in varieties.

Table 23 Irrigation indicators for the management of irrigated winter crops in selected commercial and non-commercial schemes

	Unit	**Purpose**	**Nile Delta**	**Western Desert**	**Gezira**	**Kenana**
			Non-commercial	**Commercial**	**Non-commercial**	**Commercial**
Bio	Kg/ha	Land productivity	18,845	8,611	10,790	17,975
ET_{act}	m^3/ha	Crop water consumption	3,170	710	2,960	5,370
Bio/ET_{act}	Kg/m^3	Water productivity	5.9	12.2	3.6	3.3
T_{act}/T_{pot}	-	Adequacy	0.79	0.48	0.56	0.73
CV T_{act}/T_{pot} time	-	Reliability	0.91	0.91	0.88	0.78
CV T_{act}/T_{pot} space	-	Equity	0.18	0.63	0.88	0.80
T_{act}/ET_{act}	-	Beneficial fraction	0.97	0.89	0.94	0.97

Conclusions for the winter situation:

Public Nile Delta: Due to the climatic conditions in the northern latitude of the Nile Basin, the overall evaporative water use during the winter season is moderate. The production is high and it results in substantially higher crop water productivity during the winter as compared to the summer. There is ample water supply during winter and crop water stress is hardly noticeable. There is a distinct spatial variation in the water availability across this region, despite water service being temporary stable and rather reliable. The same was also observed for the summer season.

Commercial Western Desert: This area has extreme low water consumptions and supreme water productivities. The area is a very good example of productive use of water in agriculture. Like in summer, deficit irrigation is practiced throughout the winter, yielding significant crop water stress values. These practices are systematic, and the management is consistent in this region.

Public Gezira: Both agricultural production and water consumption are low during the winter season. The crops are severely water stressed throughout the area. The stress levels are constant, and this can only be explained by low irrigation water supplies. One possible reason is the sedimentation of rivers and canals. The water productivity is below average.

Commercial Kenana: The warm climate of southern Sudan causes the crop water consumption to be high, also during the winter season. The production is in line with water use. The dry winter will cause the non-beneficial losses to be negligible.

There is a considerable variation of crop water stress noticeable throughout the season.

Findings in relation to the level of investment are:

- Encourage commercial investments because the profits per unit of water are significantly higher than for traditional irrigation systems; the water supply is highly reliable and it brings employment to the region
- Provide water rights, that ensures that high value crops are not suffering from a lack of water resources
- Put a cap on crop consumptive use per farm
- Apply regulated deficit irrigation techniques (if not already done)

Type of irrigation systems

The basic different categories of irrigation systems are (i) surface irrigation methods and (ii) micro-irrigation methods. While the former comprises furrow, border and basin irrigation technologies, the latter relates to sprinklers, center pivots, micro-sprinklers and drip systems. Drip and sprinkler systems are well suited for the application of fertilizers. Regular fertilizer supply will increase the crop canopy development, the transpiration rate, and the harvestable crop yield. The crop yield is proportionally higher than the ET, so that crop water productivity generally increases if micro-irrigation techniques are used. It needs to be mentioned again (see also chapter 3) that micro-irrigation does not automatically result in water saving. Introduction of drip systems to save water should be done with caution (Zwart and Bastiaanssen, 2009).

The investment costs of micro-irrigation systems is approximately $ 15,000/ha. To make profits on these investments, high value crops should be cultivated. Drip and sprinkler installations are tested on commodity crops. While this is common in Morocco and Tunisia, it is uncommon in the Nile Basin (except a few spots in the Egyptian Western Desert); most likely due to the investment risks, and also due to the high tech involved. Micro-irrigation should be used for vegetables, fruit, perennial crops etc. in environments where technical support can be given. Systems that are vulnerable to damage form a certain risk if spare parts are not easily available and the mechanical requirements are high. Wheat, maize, cotton and sugarcane should for these reasons in principle be irrigated with furrows. Rice and fodder should be irrigated in basins. Fodder on coarse sand is very suited for center pivot irrigation systems. Good quality seeds, improved crop varieties, fertilizers, soil tillage, and pesticides and herbicides are essential for best performance practices. Micro-irrigation can be implemented on slopes up to 6%.

In case of small land holdings and flat land (slopes up to 2%), it is possible to apply the classical surface irrigation technologies. The length of the furrows should be limited to 100 m and the land should be leveled regularly. It is a good practice to level land after every cropping season.

General irrigation advice for main irrigation categories:	
In humid climates:	Focus on supplementary irrigation. Ensure that the irrigation system is flexible to accommodate rainfall events. This can be achieved with reservoirs and hydraulic structures
In arid zones:	Plan irrigation water distribution in advance. Create priorities in case of a lack of irrigation water. Transfer irrigation management responsibilities to farmers and WUAs.
For surface irrigation:	Level the land after every crop season. Create plots of a maximum size of 2 ha. Furrows should have limited length
For micro irrigation:	Select high value crops. Provide maximum inputs, other than water. Don't irrigate slopes steeper than 6 %.
Public organization:	Transfer irrigation management to stakeholders. Educate the extension service officers. Intensify exchange between Federal Government and Regional Government Establish and reinforce regional agricultural and water centers Charge water fees that minimally cover the operation & maintenance costs.
Water User Association:	Exclude governmental involvement. Charge water fees to users that minimally cover the operation & maintenance costs for irrigation and drainage.
Agricultural production:	Provide more attention to agricultural research. Develop strong agricultural outreach programs Implement improved agricultural practices. Provide credit for smallholders. Establish funding opportunities for irrigation development. Improve land tenure systems in irrigation development.

1.3 Transfer procedure for best irrigation practices

The key elements for improving irrigation management across countries are in the most simplified form:

(i) The selection of potentially best practices sites
(ii) Diagnosis of the main reasons of success
(iii) Definition of LSIs with similar irrigation topologies and lower performance
(iv) Preparation of a package of interventions to increase that lower performance
(v) Monitoring the improvements

The LSIs with excellent and poor irrigation management have been identified. The excellent practices are specified in the parallel report and the lowest performing schemes for each country are provided in the appendix with the country reports. Experiences should be exchanged within certain typologies, and not beyond that.

Prior to transferring the best practices, site specific investigations should be conducted for getting a more comprehensive picture of the local techno-social-economical processes and the main reasons of success. The most convenient way is to develop a questionnaire that could be used for acquiring all key information in a standard manner. The questionnaire for understanding the reasons of success should cover the following issues:

1. In which category does the irrigation system fall?
   (Individual owner/user; collective small-scale private irrigation, large scale irrigation)

2. What are the objectives for large scale irrigation systems?
   (e.g. food security; increased rural incomes; job creation, profits on investment etc)

3. Is the LSI supply based or demand based and what is the type of irrigation water supply system?
   (surface vs. micro irrigation)

4. In case of a supply based irrigation system, what is the proposed irrigation schedule and how often is the reality deviating from the official schedule?

5. Which type of irrigation infrastructure is in place?
   (Reservoirs, storage capacity, flexible structures, fixed weirs)

6. What is the size of the LSI scheme, and what is the source of water?
   (surface vs. groundwater)

7. Are priorities specified for water allocation of water among sectors?
   (domestic, agriculture, industry, junior/senior water rights)

8. Are water rights specified for major users?
   (absolute volumes, proportional to land holding, guaranteed minimum)

9. If water rights are specified, how are they monitored/enforced?

10. In the large-scale irrigation sector, who is responsible[7] for:
    a. Planning
    b. Design
    c. Construction
    d. Operation and Maintenance[8]
    e. Regulatory functions

11. What are the financing arrangements for construction, management, operation and maintenance of irrigation systems?

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[7] Responsibilities may be with central government, state government, project authority, users, private agency, etc.

[8] Specifically for large scale-irrigation scheme operation, indicate points at which responsibilities are transferred from agency to farmer-organization to individual farmers, as appropriate.

12. Which crop types are cultivated and what are the yields?

13. What are the market prices of the various products?

14. Describe the soil type, depth to the water table and the presence of a drainage system

With the help of these questions and answers, more insight information on the physical and socio-institutional context will be obtained. This is needed to understand why some things are working and why not.

1.4 Priority of technology transfer

Table 24 provides a summary of which countries have the highest potential for improvement. These are the countries with a significant difference between the average and maximum value of that particular country. At small differences, there is little room for improvement. In terms of water productivity, Egypt and Ethiopia have the most work to do to transfer the water productivity knowledge from one LSI to the other. Sudan would be the 3rd country where knowledge transfer is crucial. For Tanzania and Uganda, transferring of water productivity information is not harmful, but also not a real necessity.

The land sustainability shows significant discrepancies between the average and maximum values in Sudan, followed by Egypt and Ethiopia. It can thus be concluded that the three countries with the largest irrigated area require a training and transfer of best practices program. National forums, acquisition of key information and study tours should be established to educate the irrigators throughout the same country, in the same irrigation typology. Irrigation advisors and consultants can facilitate in this process. Education and training in water productivity and sustainability concepts should be held at the Line Agencies. The contours of an irrigation improvement plan that results in more productive use of Nile water for agriculture are summarized in the inset.

Table 24 Ranges of water productivity and sustainability by country to indicate the scope for improvement. The values are expressed as scores

Water productivity			**Land Sustainability**		
Country	**Average value all districts**	**Maximum value all districts**	**Country**	**Average value all districts**	**Maximum value all districts**
Burundi	3.0	3.3	Burundi	3.5	3.9
Egypt	3.0	5.0	Egypt	2.9	3.6
Ethiopia	3.2	5.0	Ethiopia	3.3	4.0
Kenya	3.8	4.2	Kenya	3.1	3.5
Rwanda	3.0	3.5	Rwanda	3.3	4.0
Sudan	2.7	3.9	Sudan	3.1	4.1
Tanzania	3.1	3.2	Tanzania	4.0	4.0
Uganda	3.1	3.4	Uganda	3.2	3.3

2 Recommendations by climate zone and country

The results from the parallel report on diagnosis of best practices are utilized to prepare the recommendations for good practices by climate zone and country.

2.1 Hyper-arid climate (Egypt)

Because rainfall is absent, irrigation water management in hyper-arid climatic conditions is the easiest, at least in theory. The crop water requirements are very predictable as well as the irrigation water requirements. The irrigation water requirements can be substantial, and it requires considerable efforts to get these vast amounts of water to each farm inlet. The operation is, however, not easier as compared to other climate zones. This is the typical situation in northern Sudan and Egypt. The only issue of concern is that Lake Nasser should have sufficient water during years with lower rainfall in the upstream part of the Nile Basin. The maximum storage capacity of Lake Nasser is 157 BCM, but the actual capacity is probably lower due to siltation. This is sufficient to supply Egypt with 3 years of irrigation water.

Whilst the large irrigation water volumes require civil engineering actions, the Delta has also a strong advantage; the combination of a shallow water table and a properly functioning sub-surface drainage system makes irrigation management decisions less critical. The fertile alluvial soils drain away excess water and their suction induces capillary rise of groundwater when the root zone is getting drier.

The irrigation on reclaimed land in the desert, on the contrary, requires very accurate management. The coarse sandy soils have a deep groundwater table. The sand requires precision irrigation with very small time intervals. Irrigation should be given every 2 or 3 days with drip or sprinkler systems. The centre pivot systems are popular in the western and eastern Desert of Egypt because they can cover large areas in an automated way. The hyper-arid climate seems to benefit the quality of the agricultural products. Damage from rain and hail is excluded.

It can be concluded that drier areas can be better equipped with sophisticated irrigation systems and educated manpower to deal with drought situations. While micro-irrigation systems are capital intensive, these systems are rewarding due to their high certainty and flexibility of operation. It will also create the opportunity to cultivate more high value crops, because the risks of water shortage are minimal.

Recommendations for best LSI practices in Egypt:

- Invest in micro-irrigation systems when high value crops are cultivated.
- Invest in micro-irrigation systems on desert land with coarse sand.
- Monitor leaching fractions continuously to avoid soil salinization.
- Determine an optimum schedule to accommodate leaching and crop water savings for conserved crop consumptive use

- Analyze the good practices of Dumyat and Bur Said in more detail and transfer the lessons learnt to other LSIs in Egypt.
- Determine with more devotion why the LSI schemes in the Qena districts are performing below average.
- Pay more notice to the significant differences in general irrigation performance between the Nile Valley, Fayoum Depression and the Nile Delta
- Reduce crop consumptive use, especially in areas with extra-ordinary high crop yields.
- Verify the impact of improved irrigation (continuous water supply) on the water balance, and on ET in particular.
- Focus in water saving projects more on reducing consumptive use, rather than irrigation water supply
- Improve the agricultural extension service in Upper Egypt. It is unacceptable to see the differences in yield between Upper and Lower Egypt
- Monitor the water board style of water management.
- Don’t have over-expectations from Water User Associations. The fact that WUAs are established is no guarantee for proper functioning of irrigation systems. There are signals that the water institutions in Egypt are not very effective.
- Be cautious with horizontal expansion as the Nile delta is not convincingly sustainable.
- Develop a set of target irrigation indicators for each district and start to monitor them.
- Launch a national water productivity programme.

2.2 Arid climate (Sudan)

Due to climatic processes, the semi-arid and arid zones receive concentrated rainfall during short periods. Wet summers in Sudan and Ethiopia are interchanged with dry winters. Whereas irrigation in the wet summer only supplements rain, it has to provide the full crop water demand in winter. Irrigation in summer should thus be tuned to the actual rainfall rates, which is not straightforward if there is a long travel time between the reservoirs and the irrigation plots. This happens in Sudan with water travelling from Roseirres reservoir located in the mountain edge a few hundred kilometres upstream of the irrigated plains of Gezira and other LSIs. In these climates, it is unavoidable to have non-beneficial evaporation losses, because the soil is wetted by rainfall regularly. The rainfall can be so intense – as well as the discharge through the rivers – that the irrigated plains can be exposed to floods. It is recommended to have limited storage of surface water resources closer to the irrigation schemes. Smaller reservoirs can be used to supply water quickly when needed and to stop supply when rain showers appear across the plain areas.

Recommendations for best LSI practices in Sudan:

- Sudan is not utilizing its entitled Nile basin water resources and during the winter season, large tracts of land are kept fallow. Hence, winter irrigation could be encouraged.
- From the fact that sufficient water resources are available in the main rivers and reservoirs (but not on irrigation plots), it can be concluded that the distribution and storage of irrigation water in Sudan is probably not optimal (or farmers are less interested in irrigated crops due to low profits).
- Investigate the explanatory factors for extensive winter irrigation: market prices, siltation of reservoirs with reduced storage capacity and motivation of farmers.
- Launch a LSI rehabilitation and maintenance programme to restore the design capacity of the conveyance network where needed.
- Pay significantly more attention to agricultural production. The Department of Agriculture needs to prepare a strategic plan which gives special attention to the yield of irrigated crops and they need to implement it. If the crop yields increase, the productivity of water (which is currently the lowest of all Nile Basin countries) will increase in the same proportion.
- A general lack of fertilizers is expected to contribute to the low crop yields of Sudan. The introduction of fertilizers and crop protection measures should be part of a national agricultural plan.
- Evaluate potential conflicts between water for hydropower and water for irrigation. If conflicts of allocation occur, then options to import power from upstream Nile basin countries as part of the NBI-based shared benefit principles should be considered.
- Sudan has the capacity to become the bread basket of the Arab world. The Government of Sudan should open their doors for foreign investors to boost irrigated agriculture.
- The regional water governance in Sudan is not functioning optimally. An institutional strengthening programme with intensive exchanges between Khartoum and the regions should be launched.
- Sudan is plagued by significant non-uniformities in irrigation performance that reduce the average water productivities. The areas with low Productivity Oriented indicators and Result Oriented indicators should get priority
- There are good LSI practices in Sudan (El-Suki, Kenana, Upper Nile), and experiences from them should be transferred to areas with below-average performance.
- The irrigation managers of successful LSIs should advise the Ministry of Water Resources and Irrigation on possible improvements and preparing lists of action plans.
- The experiences from the Upper Nile district at the Right Bank of the White Nile are valuable because they are operated by public entities.
- Develop a set of target irrigation indicators for each district and start to monitor them.
- Launch a national water productivity program.

2.3 Semi-arid climate (Ethiopia)

Arid and semi-arid climates have similar characteristics. The main difference is the amount of rainfall and reference ET. The semi-arid climate in the Nile basin encompasses southern Sudan, northern Ethiopia (Tigray), northern Uganda and north-east Kenya. Due to the hilly landscapes, there are not many LSIs present in this climatic zone. Ethiopia has LSIs in both semi-arid and humid parts, but the majority of the systems are located in the semi-arid part, and for this reason Ethiopia is discussed in this section on semi-arid climates. With a growing population, food security is becoming a major concern in Ethiopia. Even during years with good rainfall, Ethiopia cannot meet its large food deficit through rainfed production. Improving the productivity of irrigated land and the intensification of irrigation practices is therefore of utmost importance.

Recommendations for best practices in Ethiopia:

- Most of the LSIs in Ethiopia are non-contiguous. This implies that irrigation infrastructure is hardly present to carry over water from the rainy season to the dry season. Ethiopia should invest in dams (that could also be small dams) for water storage and create more LSI schemes as long as downstream countries are not affected.
- Ethiopia has sufficient amounts of renewable water resources to reclaim unessential natural ecosystems without adverse impacts on downstream users (natural ecosystems consume similar amounts of water than irrigated crops).
- By absence of insufficient water storage facilities, spate irrigation and deficit irrigation is unavoidable in Ethiopia. Deficit irrigation should not be exaggerated, and it is better to practice protective irrigation by irrigating a smaller plot of land with sufficient water. Although the practice is excellent from an agricultural water use point of view, it can reach levels that adversely impact crop production.
- Provide sufficient attention to a potential conflict between water demands for hydropower and for irrigating crops.
- The crop water consumption levels in Ethiopia should be increased. If Ethiopia is going to use more water for agriculture, it will raise both land and water productivity levels.
- Pay significantly more attention to agricultural production. The crop yields in Ethiopia are at the lower end of all Nile basin LSIs.
- Ethiopia should produce or import more fertilizers. Although this aspect has not been investigated specifically, several UN reports express that the low crop production seems to be strongly related to low fertilizer application.
- The Departments of Water Resources and Agriculture should join forces and develop a joint strategic plan to increase agricultural production with more surface water diversions.
- Launch an agricultural production programme, and invite Egyptian agronomists to assist (especially for boosting the yield of maize, wheat and rice)

- The irrigation performance indicators overall have low ratings. While this is disappointing for the current situation, it also creates enormous scope for improvement. Hence, Ethiopia should focus strongly on irrigation improvement because any small improvement will be a great leap forward.
- The water governance in Ethiopia is below normal standards. While there is only 90,000 ha of irrigated land in the Nile Basin, the various institutes are not capable of creating uniformity, reliability, and sustainability. Institutional strengthening programmes should be launched. It lacks organization, inter-institutional co-operation, and stability.
- There are good LSI practices in the Ethiopian highland floodplains (Adwa, Ambasel). The irrigation managers of these successful LSIs with strongly reduced ET should advise NBI on how to achieve this under practical field conditions.
- The considerable rainfall in Ethiopia and the hilly landscape makes the country very suitable for the cultivation of bio-fuel crops. These options should be seriously considered in the remote areas and as long as adverse impact on water for food production is avoided.
- Develop a set of target irrigation indicators for each district and start to monitor them.
- Launch a national water productivity programme.

2.4 Humid climate (Uganda, Kenya, Tanzania, Burundi, Rwanda)

By maintaining soil moisture in a certain preferred range, crop yield can be improved. This supplemental irrigation is essential for productivity improvement in regions with erratic rainfall. Irrigation should be applied in a highly flexible way. It needs to be adjusted continuously, and this requires significant flexibility in operating canal water levels, orifices, weirs, etc. Nevertheless, the graphs on uniformity and reliability in the humid region suggest that this is feasible. The Wakiso and Butere Mumais districts in Uganda and Kenya respectively are good examples of that. Despite *a priori* anticipated difficulties on supplying irrigation water at the right time on the cropped soil in humid climates, it seems that good performance can be obtained. A high score for reliability in irrigation water supply is obtained also in Burundi (Buziga 4.8) and Rwanda (Nyanza, 5.0). Their high overall ranking suggests that they are able to achieve this flexibility.

The humid climates usually have simpler and cheaper investments in irrigation infrastructure because the rewards from irrigation are much less than under arid climates.

Recommendations for the best irrigation practices in Burundi and Rwanda[9] :

- Ensure food security by increasing agricultural production.
- Special attention should be given to introduce or develop agronomic extension services that could advise on the use of fertilizer or improved seed stock.

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[9] These two countries have very comparable climates, geographies and institutional arrangements

- Expand the irrigated surface on alluvial soils with a slope less than 2%.
- Reduce crop consumptive use and slightly increase crop water deficit by cutting back the irrigation water supplies. A reduction of crop consumptive use by 10% and irrigation application depth with 15% is a first step in the proper direction.
- Volumetric water entitlements (absolute volumes, proportions, guaranteed minimum) to major users could help to decrease water consumption.
- By increasing crop yield and simultaneously reducing ET, the water productivity can be increased.
- The government could invest in modernizing the irrigation infrastructures because irrigation systems are outdated.
- Investing in storage of rainfall could also improve the reliability, even though it is already very good. If farmers know that they can fully rely on water supply, they might invest more in agronomical practices.
- The humid tropics keep the soil and crop leaves wet. This leads to high levels of evaporation. Soil evaporation can be reduced by keeping the soil covered by an intercrop of organic fertilizer crop. The row spacing could also be narrowed to increase the Leaf Area Index and decrease the exposure of soil to solar radiation.

The Kenyan irrigation systems seem to be very sustainable. They are all located in the plain areas of Lake Victoria. The air is warm and humid, and this is a good climate for the cultivation of rice. The diagnostic study for Kenya showed good outcomes for most aspects. A few recommendations for Kenya are:

- Limit the crop water consumption to that which is necessary to maintain a good crop yield.
- Reduced pumping will save energy costs. Most irrigation water is pumped from Lake Victoria or Nyando River.
- The government should invest in modernizing of irrigation infrastructures.
- The irrigation managers of LSI schemes present in the Butere Mumais administrative district should advise the Ministry of Water Resources and Irrigation on possible improvements and preparing lists of priorities.
- Kenyan crop yields are rather good, and the rice agronomic practices should be transferred to Rwanda and Burundi.
- Kenya should pay attention to their irrigation sustainability.

Tanzania has flat land with suitable climates for crop cultivation. The Kagera sugar scheme is, according to the information received, the only LSI scheme in Tanzania. The irrigable area of the scheme is 8,000 ha. Recommendations will therefore be provided jointly with those for Uganda. Rice and sugarcane are the two major irrigated crops in these countries. More information on Tanzania is provided in the appendix.

Recommendations for the best practices in Tanzania and Uganda:

- Prepare an accurate map showing irrigated and irrigable land in Tanzania.
- Survey all illegal irrigation activities in Uganda. Unofficial irrigation occupies a significant size
- More focus has to be given to water sustainability.
- Uganda has an above-average crop consumptive use. There are plentiful water resources available in the vicinity of Lake Victoria. Irrigation should occur only when crop water stress (T_{act}/T_{pot}) and ET deficit (ET_{pot}-ET_{act}) exceed certain threshold values. This saves power and reduces the risk of drainage problems.
- A plan for total water withdrawals should be enforced on local irrigators.
- Farmers and water utilization agencies should be advised on how to maintain yield at reduced water consumption.
- Visit the farmers in the vicinity of the district of Wakiso and get exposure to their irrigation water practices. The sustainability in Uganda is just fine, but is threatening to move into a negative direction. It is not clear whether this is related to the economy, drainage, or other problems.

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PART 3- Action plans

Executive Summary

Irrigation development in the Nile Basin is on the agenda of NBI. More food should be produced; more dams need to be build for diversion and hydropower generation; and this should all lead to a better livelihood. The national scale analysis of the water accounts in irrigation has demonstrated that the current pace of agricultural production can be kept if 20% less Nile water is diverted. This is the typical scenario where irrigation is in competition with other countries.

In the case of utilizing the same amount of Nile Water resources, the agricultural production can go up. The scenario of 20% more diversion will push 12 BCM more water into the irrigation systems and 5 BCM extra return flow. The incremental net withdrawal of 7 BCM is the maximum extra extraction that could be achieved. Otherwise the tail end farmers in the Nile Delta will not get sufficient amounts of fresh Nile water, and their land will salinize. Hence, a 20% larger extraction is just possible. Considering that 3 million ha of irrigated land appears on the planning list, and that the current area is 5 million ha, a growth of 67% will not be feasible. A growth of irrigation systems of this magnitude can be accomplished only when land use in the upper and central part of the Nile basin is going to change. Billion cubic meters of water are now evaporated by very low productive savannah, woody savannah and natural pastures. With reclamation of these types of land use, the irrigation plans for ENSAP and NELSAP can be fully realized.

Irrigation development consists of improving the current systems and constructing new systems. It is recommended to install Irrigation Rescue Teams with a very specific mandate to inventory the current set of management practices and modify them according to the set of best practices outlined in the current LSI study and get in touch with the local irrigation engineers and Water User Associations that perform well. The GIS and Remote Sensing data of the current study can be explored for this purpose, and in fact more years should be analysed.

The ENSAP and NILESAP irrigation programs should continue on both lines of (i) monitoring current practices and (ii) plan future LSI schemes with the water accounts provided in this study. The water accounts can also be made for every LSI scheme, and the LSI physical boundaries and names should be inventoried.

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1 Irrigation development in the Nile basin

1.1 Irrigation water resources

There is an international demand for food production in Africa. Several international water programs such as FAO and NGO's promote the development of irrigation systems and efficient use of irrigation water. The national agricultural politicians embrace this development, and most Nile basin countries embarked on preparing national irrigation plans. Ethiopia has for instance prepared a Nile basin irrigation and drainage plan. Egypt has prepared its National Water Resources Plan etc.

Irrigation growth should not necessarily be realized by horizontal expansion, but alternatively by (i) improved irrigation management, (ii) a higher irrigated/irrigable area fraction, and (iii) a higher annual cropping intensity. While most future planning of irrigation by the Governments is based on expanding the irrigated areas, it is not unlikely that solutions need to be sought within the existing LSI schemes.

Prior to any future development the water resources in the current LSIs need to be estimated in a standard way so that countries that share the international Nile waters can be compared. The annual total crop evapotranspiration of all 4.9 million ha of irrigated land in the Nile Basin has been calculated in this study. The total crop water consumption in irrigated agriculture of the Nile Basin is 36.9 billion m^3 (BCM). A breakdown is provided in Part 3. This number is considered to be on the low side but without proof, we will use this 36.9 BCM tentatively as a working number to base planning upon. It is not unlikely that the year 2007 is not representative.

The net irrigated area is 4.9 million ha. Hence the annual average crop water consumption per unit irrigated land is 753 mm. This average crop water consumption of 753 mm (7531 m^3/ha/yr) varies considerably across the basin. The minimum values are 100 mm and the maximum values as much as 1400 mm/yr. The total crop land area in the Nile Basin is 23.7 million ha, out of which 4.9 million ha (21 %) is irrigated. The remaining part (18.8 million ha) is thus rainfed land. The total crop water consumption in agriculture is 184.6 billion m^3/yr, and the 36.9 BCM accounts for 20 % of the agricultural water consumption in the Nile Basin. The 36.9 billion m^3 is mainly a result of irrigation and it is thus a manageable flow, which justifies further investigations. Over against that, the water supply to rainfed crops cannot be modified, and water savings will be difficult. The majority of the irrigation water is consumed in Egypt (65 %) and Sudan (30 %). Ethiopia appeared to be the 3rd largest consumer of irrigation water.

From a social and cultural angle it is essential to maintain a proper balance between irrigation of staple and cash crops. Sharing the benefits is a principle widely adopted by NBI and this implies that several groups of farmers (subsistence and commercial agriculture) need to be involved in irrigation. Against this background and on basis of the results presented in previous chapters guidelines for best irrigation practices will be presented.

Table 25 Breakdown of consumptive use in the irrigation sector by country

Country	Irrigated areas (ha)	Irrigation intensity (%)	Irrigation potential (ha)	ET$_{act}$ (mm)	ET$_{act}$ (10^6 m^3)	ET$_{act}$ (%)
Burundi	14,625	180%	215,000	716	104.7	0.3
Egypt	2,963,581	167%	4.42 M	809	23,975.3	65.0
Ethiopia	90,769	116%	5,7 M	665	603.6	1.6
Kenya	34,156	113%	539,000	1006	343.6	0.9
Rwanda	17,638	100%	-	756	133.3	0.4
Sudan	1,749,300	87%	2,78 M	623	10,898.1	29.5
Tanzania	7,006	72%	-	754	528.2	1.4
Uganda	25,131	100%	200,000 to 400,000	1280	321.7	0.9
Total	4,902,206				36,908.5	100.0

The ET data presented above reflects the annual ET from irrigated land. If we consider the rainfall from the Tropical Rainfall Measurement Mission (TRMM) satellite, and include a number of reasonable assumptions, it will be possible to develop an estimate of the water budget of all irrigation systems for each country. This is not a hydrological analysis, but instead a simple water accounting for LSIs to get some first order estimates of diversions and opportunities to change this into the future.

Let's make the following assumptions to make the irrigation water accounting feasible for political boundaries:

- The net rainfall is a certain percentage of the gross rainfall, and the difference between gross and net rainfall is runoff and drainage. Runoff is computed from the runoff coefficient that changes with the type of rainfall. We adapt a relationship recently established for Ethiopia as a=0.0005P+0.032. Hence when P is 1000 mm/yr, a will become 0.53 and the runoff 530 mm/yr.
- The ET of a non-irrigated crop is identical to net rainfall (i.e. gross rainfall minus runoff). This implicitly assumes zero soil moisture changes in the root zone
- The partitioning of ET into E and T will be done by using the beneficial fraction. This value is included in the database for every country.
- The ET from irrigation is the difference between the total ET (from the remote sensing data base) and the ET from rainfall. The ET from rainfall is approximated as the net rainfall, i.e. gross rainfall – runoff
- The irrigation efficiency is 50%. This implies that 50% of the diverted water is consumed by crop ET, and the remaining part recharges the aquifer, is drained away or runs off into streams

- The recoverable fraction of percolating water is 80%, which implies that 80% of all non-consumed water goes into streams and aquifers from where it can be re-used by downstream users. The remaining 20% will go to contaminated aquifers, sinks and other un-exploitable locations.

With this information it will be possible to prepare the water accounting for all irrigated land together for each country. An example is provided for Burundi (see Table 26), and all other countries will be computed in the same manner. The gross rainfall over irrigated land in Burundi is with 1100 mm significant (from TRMM satellite). Due to the runoff coefficient, 640 mm will immediately go to streams. The remaining part will be evaporated by the crop (E: 138 mm and T: 322 mm). This ET from rainfall is lower than the total ET estimated from MODIS images. The difference in ET is the incremental ET that can be attributed to irrigation. For Burundi this appears to be an E of 77 mm and a T of 179 mm. At an irrigation efficiency of 50%, this implies that 512 mm of irrigation water is supplied on the average of all irrigated plots in Burundi. The latter is equivalent to an amount of 74.9 MCM of irrigation water being supplied. By definition, the irrigation losses (runoff and drainage) will be 50% or 37.4 MCM. An amount of 80% of 37.4 MCM is recycled, i.e. 29.9 MCM and is not a real loss. This water can be used for other water use sectors, or flows to downstream countries of the Nile Basin. The net diversion of Nile water resources is the difference between gross withdrawals (75 MCM) and the return flow of (30 MCM), being 45.0 MCM/yr.

Table 26 Water balance for the irrigation systems of Burundi, which are located in the Nile Basin. The irrigated area is 14,625 ha. The beneficial fraction for Burundi is 0.7. The total ET is 716 mm and the irrigation efficiency is 50%

IN			**OUT**		
	(mm)	**MCM (10^6 m^3)**		**(mm)**	**MCM (10^6 m^3)**
Gross rainfall	1100	161	Rainfall evaporation	138	20.2
Irrigation supply	512	75	Irrigation evaporation	77	11.3
			Rainfall transpired	322	47.1
			Irrigation transpired	179	26.2
			Runoff and drainage from rainfall	640	93.6
			Runoff and drainage from irrigation	256	37.4
TOTAL	1612	236	TOTAL	1612	236

The ET of irrigated crops in Burundi is 104.8 MCM/yr (add all E's and T's together). The total T is 73.3 MCM (501 mm). The energy balance calculations of biomass production showed an average dry matter production for Burundi of 19,746 kg/ha/yr. This is equivalent to a biomass water productivity of 2.75 kg/m^3 per unit of water consumed. Taking an average harvest index of 0.35 for cereals, this will be a crop water productivity of 0.97 kg/m^3 for fresh crop yield. This is a very reasonable value and in agreement with the international values derived in Chapter 4. In the subsequent sections, the water budget of all countries will be provided following the same computational procedures.

Table 27 Water balance for the irrigation systems of Egypt. The irrigated area is 2,963,581 ha. The beneficial fraction for Egypt is 0.94. The total ET is 809 mm and the irrigation efficiency is 50%

IN			OUT		
	(mm)	**MCM (10^6 m^3)**		**(mm)**	**MCM (10^6 m^3)**
Gross rainfall	33	978	Rainfall evaporation	2	56
Irrigation supply	1,555	46,089	Irrigation evaporation	47	1,383
			Rainfall transpired	30	875
			Irrigation water transpired	731	21,662
			Runoff and drainage from rainfall	2	47
			Runoff and drainage from irrigation	778	23,045
TOTAL	1588	47,068	TOTAL	1588	47,068

Table 28 Water balance for the irrigation systems of Ethiopia that are located in the Nile basin. The irrigated area is 90,769 ha. The beneficial fraction for Ethiopia is 0.71. The total ET is 665 mm and the irrigation efficiency is 50%

IN			OUT		
	(mm)	**MCM (10^6 m^3)**		**(mm)**	**MCM (10^6 m^3)**
Gross rainfall	990	899	Rainfall evaporation	136	123
Irrigation supply	393	357	Irrigation evaporation	57	52
			Rainfall transpired	332	302
			Irrigation water transpired	139	127
			Runoff and drainage from rainfall	521	474
			Runoff and drainage from irrigation	196	179
TOTAL	**1,383**	**1,256**	**TOTAL**	**1,383**	**1,256**

Table 29 Water balance for the irrigation systems of Kenya that are located in the Nile basin. The irrigated area is 34,156 ha. The beneficial fraction for Kenya is 0.85. The total ET is 1006 mm and the irrigation efficiency is 50%

IN			OUT		
	(mm)	**MCM (10^6 m^3)**		**(mm)**	**MCM (10^6 m^3)**
Gross rainfall	1,511	516	Rainfall evaporation	48	17
Irrigation supply	1,370	468	Irrigation evaporation	103	35
			Rainfall transpired	273	93
			Irrigation water transpired	582	198
			Runoff and drainage from rainfall	1,189	406
			Runoff and drainage from irrigation	684	234
TOTAL	**2,881**	**984**	**TOTAL**	**2,881**	**984**

Table 30 Water balance for the irrigation systems of Rwanda that are located in the Nile basin. The irrigated area is 17,638 ha. The beneficial fraction for Rwanda is 0.68. The total ET is 756 mm and the irrigation efficiency is 50%

IN			OUT		
	(mm)	**MCM (10^6 m^3)**		**(mm)**	**MCM (10^6 m^3)**
Gross rainfall	1,075	190	Rainfall evaporation	148	26
Irrigation supply	586	103	Irrigation evaporation	93	17
			Rainfall transpired	315	56
			Irrigation water transpired	199	35
			Runoff and drainage from rainfall	612	108
			Runoff and drainage from irrigation	293	52
TOTAL	**1,661**	**293**	**TOTAL**	**1,661**	**293**

Table 31 Water balance for the irrigation systems of Sudan that are located in the Nile basin. The irrigated area is 1,749,300 ha. The beneficial fraction for Sudan is 0.69. The total ET is 623 mm and the irrigation efficiency is 50%

IN			OUT		
	(mm)	MCM (10^6 m^3)		(mm)	MCM (10^6 m^3)
Gross rainfall	235	4,111	Rainfall evaporation	61	1,083
Irrigation supply	846	14,804	Irrigation evaporation	131	2,294
			Rainfall transpired	137	2,412
			Irrigation water transpired	292	5,107
			Runoff and drainage from rainfall	35	614
			Runoff and drainage from irrigation	423	7,402
TOTAL	**1,081**	**18,915**	**TOTAL**	**1,661**	**18,915**

Table 32 Water balance for the irrigation systems of Tanzania that are located in the Nile basin. The irrigated area is 475 ha. The beneficial fraction for Tanzania is 0.77. The total ET is 754 mm and the irrigation efficiency is 50%

IN			OUT		
	(mm)	**MCM (10^6 m^3)**		**(mm)**	**MCM (10^6 m^3)**
Gross rainfall	1,337	6	Rainfall evaporation	92	0.4
Irrigation supply	707	3	Irrigation evaporation	81	0.4
			Rainfall transpired	308	1.5
			Irrigation water transpired	272	1.3
			Runoff and drainage from rainfall	936	4.4
			Runoff and drainage from irrigation	353	1.7
TOTAL	**2,044**	**10**	**TOTAL**	**2,044**	**10**

Table 33 Water balance for the irrigation systems of Uganda that are located in the Nile basin. The irrigated area is 25,131 ha. The beneficial fraction for Uganda is 0.81. The total ET is 1280 mm and the irrigation efficiency is 50%

IN			OUT		
	(mm)	MCM (10^6 m^3)		(mm)	MCM (10^6 m^3)
Gross rainfall	1,287	323	Rainfall evaporation	79	20
Irrigation supply	1,725	433	Irrigation evaporation	163	41
			Rainfall transpired	338	85
			Irrigation water transpired	698	175
			Runoff and drainage from rainfall	869	218
			Runoff and drainage from irrigation	862	217
TOTAL	**3,012**	**757**	**TOTAL**	**3,012**	**757**

Having all these water balances, it is informative to synthesize the diversions of Nile water and to understand the gross and net withdrawals (see Table 34). The data shows that an estimated 62 BCM is diverted from the Nile via headworks, offtakes and pumping stations. Not all percolated water from unlined canals, lined canals, pipelines, distribution works, and fields is recoverable. Taking the 80% recoverable fraction again, the return flow can be updated and the net diversion can be calculated. The total consumptive use (i.e. ET + non recoverable loss) together is 38 BCM/yr (see Table 34). This is close to the approximation of 40 BCM/yr made in Chapter 1. This analysis shows the substantial difference between gross and net diversion. Despite the fact that these vast amounts of recycled water cannot go somewhere else than to streams and aquifers (otherwise new sinks would arise), it is still very useful to understand these flow paths and the related water quality.

Table 34 Synthesis of Nile water diversions for the sake of irrigation, and the related return flows

Country	**Gross diversion**	**Return flow irrigation (100%)**	**Return flow irrigation (80%)**	**Net diversion**	**Rainfall contribution**
	(MCM/yr)	**(MCM/yr)**	**(MCM/yr)**	**(MCM/yr)**	**(MCM/yr)**
Burundi	75	37	30	45	94
Egypt	46,089	23,045	18,436	27,653	47
Ethiopia	357	179	143	214	474
Kenya	468	234	187	281	406
Rwanda	103	52	42	61	108
Sudan	14,804	7,402	5,922	8,882	614
Tanzania	3	2	2	1	4
Uganda	433	217	174	259	218
Total	62,332			37,396	1,965

1.2 Future irrigation scenarios

The total gross withdrawal related to Nile water diversion for all the eight countries analyzed is 62 BCM/yr. The net diversion is 38 BCM/yr. Note that an additional amount of 2 BCM/yr of rainfall percolates from the irrigation systems. If we consider this amount as compensation, the net diversion of all irrigated land will reduce to 36 BCM/yr. Sudan is with 614 MCM/yr the best contributor of rainfall to compensate for the gross diversions. These simple calculations show that when referring to the amounts of Nile water used in LSIs, it is essential to define which part of the irrigation hydrological cycle is referred to.

The lower end of the Nile in the northern part of the Nile delta is adequately irrigated (i.e. sufficient soil moisture levels) and is very productive. This is feasible only if sufficient irrigation water resources are available. Indeed, the Egyptian National Water Resources Plan (2005) refers to 14.5 BCM/yr that is flowing to the Mediterranean Sea, and 0.2 BCM/yr flowing out via the Damietta and Rosetta branches of the Nile river. At an inflow of 55.5 BCM/yr, this is a leaching fraction of 14.7/55.5x100%=26.5%. Egypt needs a minimum leaching fraction to wash out salts. By using more irrigation water leaching will be reduced and result in increased salinization risks.

A better understanding of the gross and net diversions helps to identify alternative options for future development of new irrigation systems. The gross diversion could remain the same, because it is an historical right and international agreements and treaties have been made on these shares. Because not all countries are using their irrigation water entitlements, and water is flowing through drains to the Mediterranean Sea, there is some room for irrigation expansion. We have looked at the scenario of a 20% increase in gross diversion and not more because of reserving water for salt leaching. A 20% reduction in gross diversion has been added also, and this is based on the perspective that irrigation will get less water allocated in the future of the Nile due to competition with other water use sectors. This is a very likely scenario.

The same water budget computations were performed with changes in irrigation efficiency, water productivity and beneficial fraction. These are the major management interventions that could alter the water accounts of a LSI. Improved irrigation efficiency assumes that the gross diversion remains unchanged, but that the ET increases due to higher ET/supply fraction. An improved water productivity scenario assumes that more crop yield is harvested from the same amount of crop consumptive use. The basis for an improved beneficial fraction is that a larger portion of ET goes to T, and hence more biomass production. The assumption is that biomass production and T are linear. The variations in gross diversions, irrigation efficiencies, water productivities, and beneficial fractions have been all computed by a list of scenarios (S1 to S12).

The alternative options are:

S1	Reference
S2	Same gross diversion, and improved irrigation efficiency of 30%
S3	Same gross diversion, and improved water productivity of 30%
S4	Same gross diversion, and improved beneficial fraction by 20%
S5	Reduced gross diversion (20%) and reference values
S6	Reduced gross diversion (20%) and improved irrigation efficiency of 30%
S7	Reduced gross diversion (20%) and improved water productivity of 30%
S8	Reduced gross diversion (20%) and improved beneficial fraction by 20%
S9	Increased gross diversion (20%) and reference values
S10	Increased gross diversion (20%) and improved irrigation efficiency of 30%
S11	Increased gross diversion (20%) and improved water productivity of 30%
S12	Increased gross diversion (20%) and improved beneficial fraction by 20%

The outputs are summarized in Table 35. The results are expressed in net diversions of irrigation water and total food production (expressed as biomass production).

Figure 42, Figure 43, Figure 44 and Figure 45 show examples for Burundi and Sudan. These countries are arbitrarily chosen. There are a few general issues that appear in both countries, and it is likely to occur in all the other countries: the net diversion is only changing with irrigation efficiency. This can be explained by the fact that in the case of water productivity and beneficial fraction, the total ET remains the same. Percolation is the difference between irrigation supply and ET (ignoring storage changes). If the irrigation supply and ET are kept constant and the production variable, then the net diversion remains constant. In the case of irrigation efficiency, a large component of the diverted water is converted into ET, and hence less water is percolated and returns back. As a consequence, the net diversion increases with higher irrigation efficiencies.

For both Burundi and Sudan the agricultural production in terms of total biomass increases whichever scenario is considered. In the case of better irrigation efficiencies and higher beneficial fractions, the transpiration T goes up (and so does biomass production). This means that with the same water used more yield is produced. In the case of the water productivity scenario, T remains unchanged but the Biomass/T ratio increases due to for instance fertilizers. It should be mentioned that in all cases, the water productivity scenarios are the most powerful intervention to increase production.

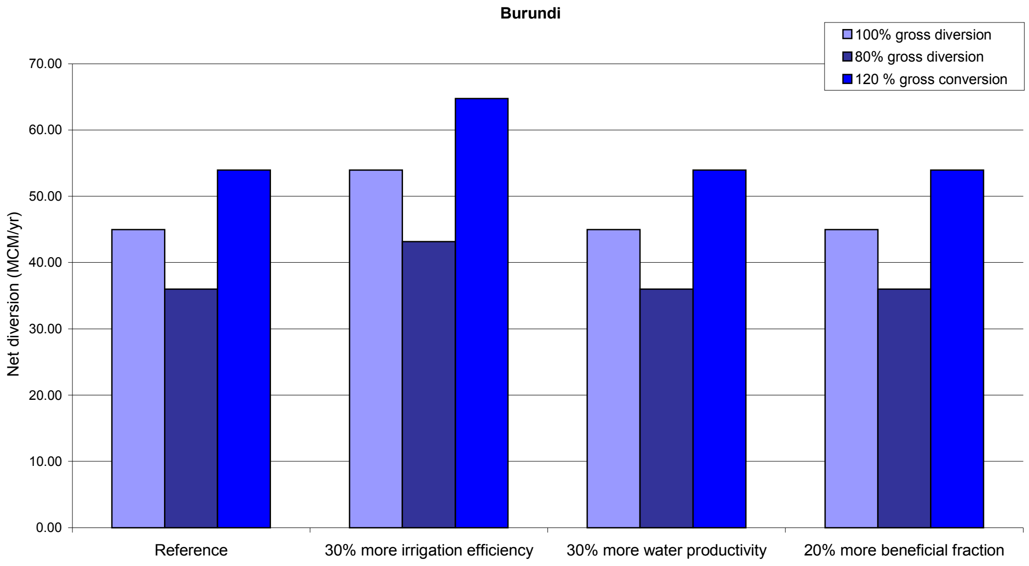

Figure 42 Net diversion scenarios Burundi

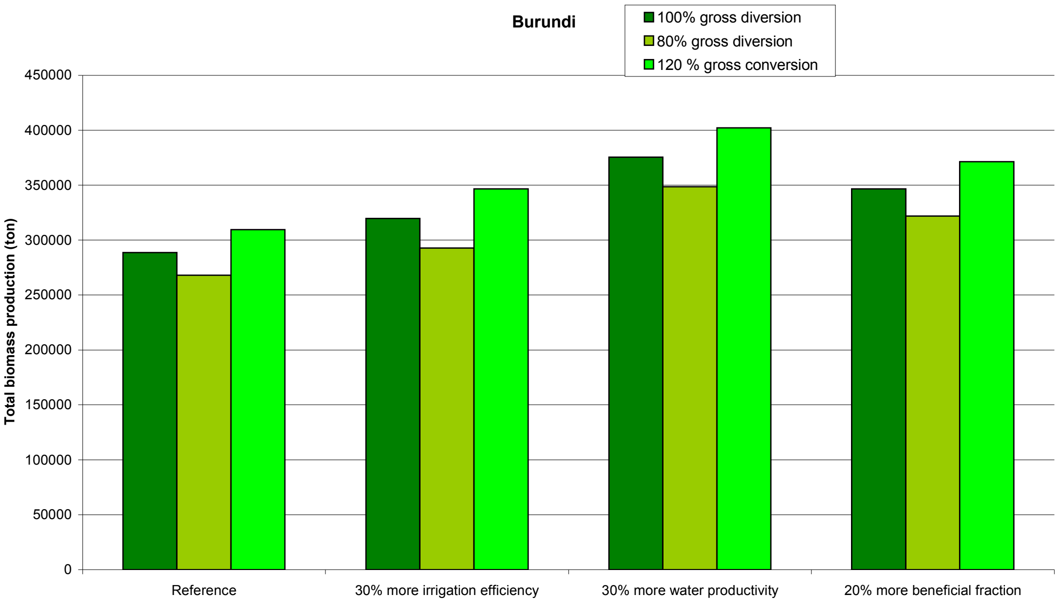

Figure 43 Biomass production scenarios Burundi

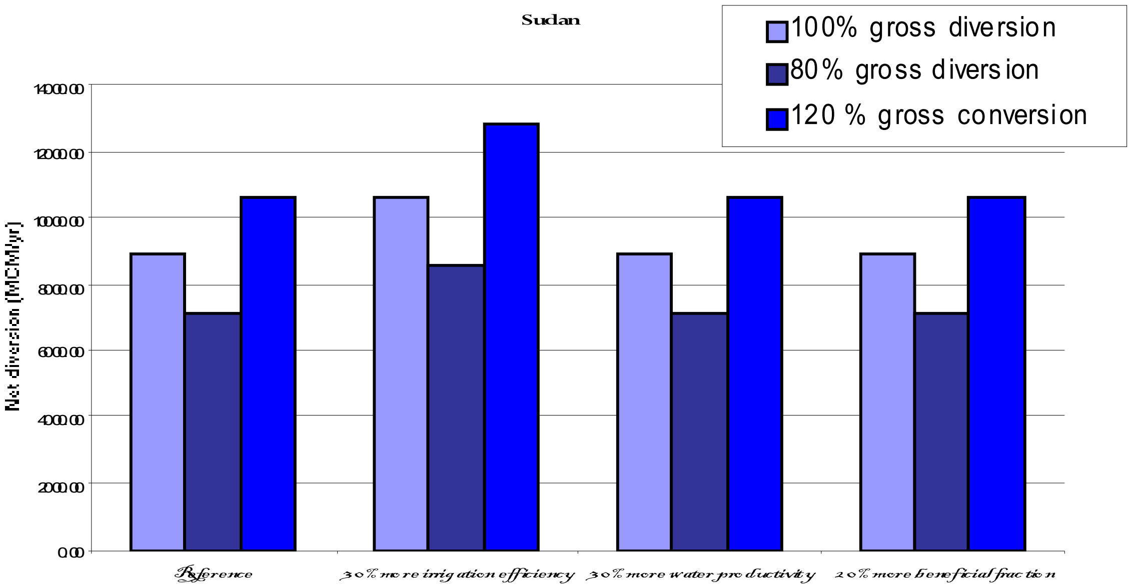

Figure 44 Net diversion scenarios Sudan

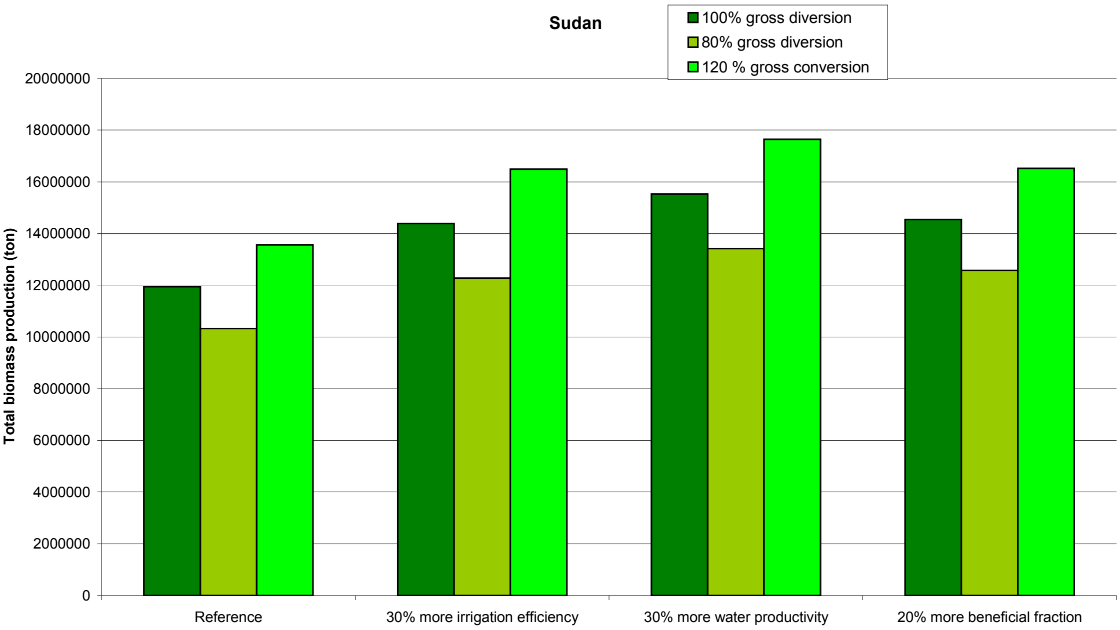

Figure 45 Biomass production scenarios Sudan

The country total food production from irrigated areas in association with the net diversion forms an ideal data set for determining the impact of Nile water diversions on production. This is strategic information that is of paramount importance. Table 35 demonstrates that without exception, scenario 7 (S7) will give the highest biomass productivity per unit of net diversion of Nile water resources for all countries. For Egypt, scenario S3 and S11 have the same impact. All these favourable scenarios (S3, S7, and S11) are related to water productivity improvement. Due to the negligible rainfall in Egypt the extent of the gross diversion does not seem to play a major role. Scenario S8 with a 20% increase in beneficial fraction and 20% reduction of gross diversion gives encouraging results in Ethiopia and Rwanda.

Total biomass production is a result of rainfall and irrigation. Due to the higher rainfall contribution in the humid tropics, the water productivity per unit net diversion is substantially higher than in the arid tropics where the contribution of rainfall to biomass production is minimal.

Scenario 10 appears to be one of the least effective solutions. S10 is related to increased irrigation efficiency in conjunction with increased gross diversions. This is the scenario classically perceived as being superior. Also within NBI, there is a group of experts that support this solution for the future of irrigated agriculture in the Nile Basin. The current analysis shows that it is a typical an example of "*doing the wrong thing*" if NBI is embarking in this direction.

The outcome of S7 suggests that gross Nile water diversions can be reduced by 20% as long as water productivity is increased by 30%. This combination will yield a higher total agricultural production than achieved under the reference scenario. Hence, it is technically possible to maintain the same agricultural production with less water resources. In case that the same or more net withdrawals can continue, the irrigation sector can increase its production. This clearly shows that there is significant potential for irrigation growth in the Nile basin. Considering the result of S7, it is strongly recommended to launch a crop water productivity program in the Nile Basin, and discard irrigation efficiency as an objective.

Table 35 Future irrigation conditions for different combinations of gross diversions, irrigation efficiency, water productivity and beneficial fraction

Country	Scenario	Net diversion irrigation (MCM/yr) (A)	Total biomass production (Ton/yr) (B)	Water productivity (kg/m^3) (A/B)
Burundi	S1	45	288,785	6.4
Burundi	S2	54	319,785	5.9
Burundi	S3	45	375,420	8.3
Burundi	S4	45	346,542	7.7
Burundi	S5	36	268,119	7.4
Burundi	S6	43	292,918	6.8
Burundi	S7	36	348,554	9.7 highest
Burundi	S8	36	321,742	8.9
Burundi	S9	54	309,451	5.7
Burundi	S10	65	346,652	5.3 lowest
Burundi	S11	54	402,287	7.4
Burundi	S12	54	371,342	6.9
Egypt	S1	27,653	63,660,683	2.3
Egypt	S2	33,184	82,017,635	2.5
Egypt	S3	27,653	82,758,888	3.0
Egypt	S4	27,653	56,888,270	2.1
Egypt	S5	22,123	51,422,716	2.3
Egypt	S6	26,547	66,108,277	2.5
Egypt	S7	22,123	66,849,531	3.0 highest
Egypt	S8	22,123	45,952,214	2.0 lowest

Egypt	S9	33,184	75,898,651	2.3
Egypt	S10	39,821	97,926,993	2.5
Egypt	S11	33,184	98,668,246	3.0 !
Egypt	S12	33,184	67,824,327	2.0
Ethiopia	S1	214	1539170	7.2
Ethiopia	S2	257	1675772	6.5
Ethiopia	S3	214	2000921	9.3
Ethiopia	S4	214	1820990	8.5
Ethiopia	S5	171	1448102	8.4
Ethiopia	S6	206	1557384	7.6
Ethiopia	S7	171	1882533	11.0 !
Ethiopia	S8	171	1713247	10.0
Ethiopia	S9	257	1630238	6.3
Ethiopia	S10	309	1794160	5.8 lowest
Ethiopia	S11	257	2119309	8.2
Ethiopia	S12	257	1928732	7.5
Kenya	S1	281	1044935	3.7
Kenya	S2	337	1258361	3.7
Kenya	S3	281	1358415	4.8
Kenya	S4	281	1032641	3.7
Kenya	S5	225	902650.5	4.0
Kenya	S6	269	1073391	4.0
Kenya	S7	225	1173446	5.2
Kenya	S8	225	892031.1	4.0
Kenya	S9	337	1187219	3.5 lowest
Kenya	S10	404	1443330	3.6
Kenya	S11	337	1543384	4.6
Kenya	S12	337	1173251	3.5
Rwanda	S1	62	371580	6.0
Rwanda	S2	74	414815	5.6
Rwanda	S3	62	483054	7.8
Rwanda	S4	62	459010	7.4
Rwanda	S5	50	342757	6.9
Rwanda	S6	60	377344	6.3
Rwanda	S7	50	445583	9.0
Rwanda	S8	50	423405	8.5
Rwanda	S9	74	400403	5.4
Rwanda	S10	89	452285	5.1 lowest
Rwanda	S11	74	520524	7.0
Rwanda	S12	74	494615	6.6
Sudan	S1	8882	11,945,970	1.3
Sudan	S2	10658	14,380,028	1.3
Sudan	S3	8882	15,529,761	1.7
Sudan	S4	8882	14,542,920	1.6
Sudan	S5	7106	10,323,264	1.5
Sudan	S6	8526	12,270,511	1.4
Sudan	S7	7106	13,420,243	1.9
Sudan	S8	7106	12,567,452	1.7

Sudan	S9	10568	13,568,675	1.3
Sudan	S10	12790	16,489,545	1.3
Sudan	S11	10658	17,639,278	1.6
Sudan	S12	10658	16,518,387	1.5
Tanzania	S1	2	10351	5.1
Tanzania	S2	2	11807	4.9
Tanzania	S3	2	13457	6.7
Tanzania	S4	2	11292	5.6
Tanzania	S5	2	9380	5.8
Tanzania	S6	2	10545	5.5
Tanzania	S7	2	12195	7.6
Tanzania	S8	2	10233	6.3
Tanzania	S9	2	11322	4.7
Tanzania	S10	3	13069	4.5 lowest
Tanzania	S11	2	14719	6.1
Tanzania	S12	2	12351	5.1
Uganda	S1	260	859832	3.3
Uganda	S2	312	1033619	3.3
Uganda	S3	260	1117782	4.3
Uganda	S4	260	891678	3.4
Uganda	S5	208	743974	3.6
Uganda	S6	250	883004	3.5
Uganda	S7	208	967166	4.6
Uganda	S8	208	771528	3.7
Uganda	S9	312	975690	3.1 lowest
Uganda	S10	374	1184235	3.2
Uganda	S11	312	1268397	4.1
Uganda	S12	312	1011827	3.2

2 Action plan

2.1 Plot level

This report is not a manual for irrigation management. There are sufficient textbooks available that describe how land should be irrigated. We will neither describe how advancing waves in furrows should be managed, nor the ideal pressure of drip systems. We will focus instead on the actions that could make a LSI more productive at strategic level and at field level. The specific concerns at plot scale are to:

- regulate water supply and demand;
- increase irrigation efficiency;
- increase beneficial fraction;
- increase crop yield; and
- decrease crop water consumption.

Regulating water supply and demand
It is a misconception that more irrigation leads to a higher crop production. The soil can only retain a certain amount of moisture, and all water that is provided in excess to the soil water holding capacity, will flow away from the root zone. Excess water will recharge the unconfined aquifer in the case of a deep water table. Although the travel time can be long, percolating water will ultimately recharge the saturated zone. A leaking irrigation system may well cause a rise in the groundwater table. This process of recharge is on the one hand undesirable because it conveys contaminants from the root zone to the aquifer. It is also a waste of energy because more water is pumped than needed to satisfy crop water requirements.

On the other hand, recharge can be beneficial: (i) percolating water feeds aquifers that often have declining groundwater levels; or (ii) excess water feeds rivers through lateral flow and help to keep them perennial; or (iii) it can be recycled and used for another irrigation cycle. This brief discussion demonstrates that irrigation in excess of the soil water holding capacity is only useful when aquifers require recharge, or the soil profile requires leaching, or recycling is required and possible. In other cases, the irrigation water supply should be in line with the irrigation water requirements and the soil water holding capacity. Over-irrigation is not useful and does not help to increase crop yield.

If irrigation supply is lower than the crop water requirement, the root zone runs the risk of being depleted with a resultant rise in tension in the root zone and consequent difficulties for the roots to extract soil moisture. Insufficient supply of water to the crop causes leaf water potential to rise, stomata to close and a reduction in crop production and yield.

The challenge is to apply an irrigation amount that is just enough to maintain maximum crop yield. The following procedures should be applied to effectively regulate supply and demand:

- Calculate crop water requirements (potential ET). This can be achieved by using reference ET as described in FAO56 (the world standard). Reference ET relates to short clipped and moist grass. A crop coefficient is required to correct for the differences in biophysical properties of grass and a given crop. The crop coefficients can be taken from generic FAO tables or from local agricultural research results.
- Potential ET can alternatively be computed directly from real biophysical parameters of the crop under actual growing conditions. These parameters include Leaf Area Index, albedo, and surface roughness, which can be derived from operational satellite products. This approach excludes the use of generalized crop coefficients. Although this is not commonly applied, it is a very good alternative to the standard FAO56 approach.
- Daily and weekly irrigation water requirements can be derived from crop water requirements, provided that the net precipitation and irrigation efficiency is known. Weather forecasts can be used to estimate net precipitation and expected reference ET.
- Irrigation efficiency describes the losses from canals and field plots. These losses comprise conveyance losses, tail-end water, drainage water and deep percolation. It is recommended that field measurements of the water balance are conducted to estimate these losses, and hence the efficiency for converting crop water requirements into irrigation water requirements.
- Soil water holding capacity can be computed from soil moisture at field capacity and wilting point. The soil water that is available for the crop without inducing stress can be derived from this information. The combination of irrigation water requirements and the easily available water for plants determines the amount and frequency of irrigation.
- Water saving can be achieved by inducing moderate stress, i.e. allowing the soil moisture levels to become slightly lower than the desirable moisture value to reach potential ET.

The practical guidelines for regulating supply and demand are:

- Measure or estimate the soil water holding capacity from soil texture information.
- Determine the soil moisture level that triggers crop water stress.
- Select a certain irrigation strategy in terms of protective irrigation, deficit irrigation, or full irrigation.
- Target the ideal range of soil moisture and schedule accordingly.
- Compute reference ET from data from a nearby weather station following FAO56 procedures and compute potential ET as reference ET x k_c (with k_c being the crop coefficient).

- Ask NBI to deliver spatial data on crop coefficients and potential ET from satellite data; compare the two methods.
- Estimate irrigation efficiency from field measurements and compute irrigation water requirements.
- Relate irrigation requirements with soil water holding capacity, and prepare irrigation schedules.
- Establish relationships between total water supply at the farm gate and the opening hours of that gate

Increase irrigation efficiency

Irrigation efficiency is dependent on the amount of water lost from canals and structures (i.e. conveyance efficiency) as well as losses from an irrigated plot of land (i.e. application or on-farm efficiency). The nature of these losses is widely diverging. Losses from canals are related to seepage from earthen canals or faults/breaks in the concrete. The remedy is to seal the canals or repair the leaks. Concrete can be poured in earthen secondary and tertiary irrigation canals. As a consequence more water reaches the farm gate. This could save water delivered to the farm, but often the farmer uses the extra water to increase irrigation application depth (>mm), or to increase the area under irrigation (>ha). The potential water savings due to investments in canal sealing is then offset by an increase in consumption. Further down is a typical example illustrating how consumptive use is increasing, rather than decreasing (see example).

The on-farm losses are related to tail-end water that did not infiltrate into the soil and that is left over. Tail-end water can evaporate from ponding, or flow into a nearby drainage system. Another classical field loss is excessive water supply to the root zone, which arises if the irrigation application exceeds the soil water holding capacity (see section on "regulating supply and demand"). The resulting percolation water flows into drains when the water table is shallow. Under conditions of deep water tables, the percolation potentially feeds the unconfined aquifer.

These losses from the irrigation system are non-consumable losses, and constitute a total loss at plot scale. At a larger scale such as a LSI, this water is reusable by pumping from drains, capillary rise to root zones, tubewell extractions, or baseflow to rivers. While at plot scale this water is lost, it is still available at regional scale. This scale issue needs more attention when considering irrigation in a basin context.

The implementation of water saving programs implies a reduction of losses, but the savings may not always reach downstream users. Sometimes these losses from canals and fields are considered to be favourable for groundwater recharge. Irrigation management should thus look beyond the plot level. Due to return flows, net withdrawal from river systems is lower than gross withdrawal, and the losses described above are thus not real losses. The overall problem is that very little information is available on return flows. This requires more international research.

Example: irrigation efficiency

A typical situation of low efficiency (45%) and no rainfall:

- Gross water diversion from the river is 100 units.
- Water arriving at the farm gate is 80 units; 20 units are lost from earthen canals. The conveyance efficiency is 80%.
- The irrigation water supply exceeds the water holding capacity: 35 units are lost from the field and percolate downwards.
- The crop ET is 45 units. The application efficiency is 56% (45/80*100%)
- The deep percolation is 20 units from the conveyance network of 35 units from the irrigation plots. This leakage water will ultimately feed the river. At full recoverable flow, 55 units flow back to the river.
- The gross withdrawal is 100 units and the net withdrawal is 45 units.

A typical situation of improved efficiency (75%) and no rainfall; the ideal case:

- The conveyance efficiency has improved to 90% due to canal lining.
- The application efficiency has improved to 83% through reduced irrigation applications.
- The gross diversion is adapted to 60 units.
- The crop is evaporating 45 units because cultivation practices are unchanged.
- The total deep percolation is 15 units only.
- The gross withdrawal is 60 units and the net withdrawal is 45 units.
- A zero sum gain (but less energy costs and less non-source pollution).

A typical situation of improved efficiency (75%) and no rainfall; the worst case:

- The conveyance efficiency has improved to 90% due to canal lining.
- The application efficiency has improved to 83% through reduced irrigation application.
- The gross diversion is not modified and is still operated at 100 units.
- The crop now evaporates 75 units due to horizontal expansion of the irrigated area.
- The total deep percolation is 25 units.
- The gross withdrawal is 100 units and the net withdrawal is 75 units.
- The net withdrawal of river water has increased, despite the efficiency improvement. The goal of water saving has not been reached; the opposite has occurred

The practical guidelines for increasing irrigation efficiency are:

- Describe the irrigation water flow path first (especially the recoverable fraction) before commencing on irrigation efficiency improvement programs, so that more insight in gross and net withdrawals are obtained.
- Estimate the use of downstream water users (irrigators, wetlands) and assess the impact of upstream irrigation efficiency improvement (if there is any) on them. Depending on the recoverable fraction, there is no or little saving on net withdrawals.
- If losses are reduced by means of canal lining and better on-farm irrigation technologies, then the gross withdrawal should be cut back. This saves energy costs and reduces non-source pollution.
- Do not irrigate more than the water holding capacity because it will unnecessarily increase energy costs (fuel and electricity).
- In cases of non-recoverable losses, estimate where the majority of the losses occur: in the field or from the conveyance network.
- Line earthen canals and reduce surface irrigation application depth in case of non-recoverable losses.

Increase beneficial fraction (T/ET)
Soil evaporation, evaporation of intercepted water on leaves, evaporation of spray (due to sprinkling) and evaporation from ponding water on irrigated land are all examples of non-beneficial consumption. The water is evaporated and disappears into the atmosphere. This water is no longer available to the crop whereas excess water lost through percolation (which is also not available for the crop) can potentially be recovered through aquifers and streamflow. Water evaporating into the atmosphere however, has a large chance of being advected away and will return as rainfall somewhere else.

The benefits of evaporating water are insignificant. Crop photosynthesis does not depend on evaporation (although moist air over a wet soil has little positive impact on the stomatal aperture). A high ET that is composed of a high E and a moderate T, is thus undesirable; it does not produce biomass. The aim of irrigation is to increase T. There are basically two different approaches for enhancing T/ET:

- Reduce E (so that more latent heat energy goes into T)
- Increase T

E can be reduced by avoiding wet soil. It is feasible to keep the soil surface dry and the roots wet by means of micro-irrigation technologies. Micro-sprinklers and drip systems supply irrigation water to the roots, and will not wet the entire soil. Strips of bare soil in between row crops can be kept dry if micro-irrigation techniques are in place. Traditional border and basin irrigation techniques wet the soil completely, and large E values will arise. The only means of reducing E in the case of surface irrigation is to increase the time between consecutive irrigation applications; it is better to irrigate once in two weeks, rather than once a week. Care should be taken not to exceed the soil water holding capacity (otherwise percolation losses will occur).

Mechanical or organic mulching can be used to regulate E. It aerates the soil and prevents soil water losses to the atmosphere due to a lower soil hydraulic conductivity. Plastic mulching will also increase soil temperature and enhance crop growth, especially in colder climates.

Rainfall wets the soil and leaves and increases E. This is why E losses in humid climates are always higher then E losses in arid climates such as for example in Egypt which indeed turned out to have a good score for the beneficial fraction. This is thus not a consequence of good irrigation management, but a result of the climate.

A high T/ET fraction will imply a low E because there is only a specific amount of energy available for ET (i.e. latent heat flux). T can be increased by means of intercropping. Intercropping will increase the Leaf Area Index (LAI) and intercept more radiation which then is partitioned into T (and which is thus not available for E). Other means to increase LAI will have the same effect. LAI can be increased by smaller row spacing and a higher plant density. Planting alternative crops between rows or after the harvest in the wet season could also be an option to increase T and reduce E.

Example: beneficial fraction

A typical situation with wet soils:

- Annual crop ET is 930 mm.
- Soil is wetted regularly; the annual E is 300 mm.
- Annual T is 630 mm which produces 15750 kg/ha (at biomass transpiration conversion of 2.5 kg/m^3).
- Beneficial ratio is 68 %.
- Biomass water productivity is 15750 / 9300 is 1.69 kg/m^3.

A situation with partially wet soils due to mechanic mulching:

- Annual crop ET is 930 mm.
- Soil is regularly dry; the annual E is 200 mm.
- Annual T is 730 mm which produces 18250 kg/ha (at biomass transpiration conversion of 2.5 kg/m^3).
- Beneficial ratio is increased to 78 %.
- Biomass water productivity is 18250 / 9300 is 1.96 kg/m^3
- The water productivity has increased from 1.69 to 1.96 kg/m^3, being 16%.

The loss of significant amounts of non-beneficial soil evaporation is an issue in the Gezira scheme (Sudan) and the LSIs in Burundi and Rwanda. The situation in Ethiopia is highly variable, and no clear conclusion can be drawn for Ethiopia.

The practical guidelines for increasing beneficial fraction are:

- Use micro-irrigation - if this is economically feasible for high value crops – and keep the soil dry. This recommendation applies to arid climates.
- Increase the time interval between consecutive irrigation applications when surface irrigation techniques are applied. This recommendation applies especially for arid climates where the soil surface dries out, and to lesser extent for humid climates.
- Enhance LAI by means of intercropping and narrower row spacing.
- Apply mechanical or organic mulching for aeration of the soil and reduction of E.
- Apply plastic mulching in areas with cold temperatures.

Increase crop yield (Y)

The crop yields in the irrigation systems of Sudan, Ethiopia, Rwanda and Burundi are also low. There are many ways to increase crop yield. The agronomical best practices are related to the selection of good quality seeds, early sowing, and crop protection from diseases and insects, timely application of fertilizers, etc. The application of irrigation water can help to avoid crop water stress during flowering, which is a critical stage in the growth cycle of crops and which affects the final crop yield.

Soil treatment is important for aeration, soil fertility, stimulation of root growth, etc. Good breeding programs have contributed substantially to a new generation of seeds that produces higher crop yields (such as during the Green Revolution). The rice varieties of Egypt are a good example of that. Advice on crop production goes beyond the scope of the present study, but is fundamental for increased water productivity.

The practical guidelines for increasing crop yield are:

- Plough or harrow the land every year for aeration and to maintain a soil structure that is favourable for roots, that provides moisture from deeper soil layers during elongated periods of drought.
- Avoid soil crusting, so that rainfall can easily infiltrate into the soil.
- Level the plots every year to enhance a uniform distribution of irrigation water and to avoid ponding after rainfall and irrigation.
- Add organic or other fertilizers to the soil.
- Fertigation can be applied for high value crops such as fruits, orchards and vegetables.
- Purchase good quality seeds (high yielding variety) that can be grown over a short period.
- Plant in narrow spacing to get full canopy closure and a high LAI as soon as possible.
- Consider intercropping in the humid tropics.
- Protect the crop from insects and diseases.

- Apply Nitrogen throughout the cropping season to maintain the required Nitrogen content in the leaves and harvestable product
- Control weeds effectively. It reduces non-beneficial consumption and diminished the competition for natural elements.
- Apply agricultural treatments uniformly across fields.
- Enhance carbon intake in crops by avoiding water stress during crop flowering and grain filling.

Decrease water consumption (ET)

The LSI analyses described in the main report showed that considerable differences exist between crop ET at the same level of biomass production. It is thus possible to reduce ET and maintain production. The reduction in ET can be accomplished by reducing E (as discussed above). A reduction in E will increase the beneficial fraction, but not necessarily ET because T could go up. While a higher T is desirable for production, water managers are keen to reduce the total ET and keep more water physically present in the basin. The difficulty is to find an optimum between a higher T for crop yield and a lower T for decreasing total ET. While classically a higher yield is associated with a higher T, the results suggest that the same production can be achieved with a reduced T. Note that T denotes an accumulated value for the growing season. The solution is to reduce T during vegetative phases when stems and leaves are produced. A lower LAI will not necessarily reduce the yield, although a real low LAI could adversely affect the light interception and photosynthesis process. The aim is to reduce T during the growth of stems and leaves. T should not be reduced during flowering and grain filling stages.

Another option to reduce T is to reduce the length of the growing season. While plant breeders do this merely for allowing farmers to have multiple crops per year, it will reduce the accumulated T for a given crop. Rice crops can now be cultivated in 100 days, instead of the traditional 130 days. This is a reduction of 23 % in the growing period.

Generally speaking, crop water consumption is reduced in areas with high air humidity. In countries with mountain ranges, it is worth investigating the potential to irrigate alluvial plains in mountains (if not already done).

There is also research ongoing to spray canopies with chemicals to restrict T. While this could lead to interesting decreases in T, the technology has not been sufficiently tested for wide scale application in the Nile Basin.

The practical guidelines are:

- Reduce the crop growing season by using improved crop varieties.
- Apply regulated deficit irrigation practices to intentionally stress the crop and reduce T during specific stages in the growing season.
- The LAI could be reduced in arid countries to limit T; a lower LAI on dry soils will not increase E. This cannot be accomplished in humid climates.
- The LAI should be sufficient to intercept adequate solar radiation.

- If the topography and infrastructure allows it, cultivate crops on higher altitudes that are colder and more humid.

Example: water productivity improvement

A typical wheat crop duration is 150 days.
Daily ET is 2.9 mm/d, hence the accumulated ET is 430 mm.
Average LAI at full cover is 2.5, leading to an average beneficial fraction (70%).
Total T is 301 mm and E is 129 mm.
Fertilizer application is marginal, hence transpiration biomass conversion is 2.0 kg/m^3.Total biomass production will be 6,020 kg/ha.
At a harvest index of 0.3, this provides a wheat yield of 1806 kg/ha.
The water productivity is 1806/4300 = 0.42 kg/m^3.

Optimal wheat crop duration is 130 days (20 day reduction due to shortening season).
Daily ET is 2.6 mm/d due to deficit irrigation, hence the total ET is 338 mm.
Average LAI at full cover is 4.5, which reduces E and holds T constant (higher due to higher LAI, but lower due to deficit irrigation).
Total T is 301 mm and E will be 37 mm.
The beneficial fraction will be 89%.
Fertilizer application is excellent, with a transpiration biomass conversion of 3.0 kg/m^3.Total biomass production will be 9,030 kg/ha.
At a harvest index of 0.4 due to better seed quality and lower stress during vegetation phase, this is equivalent to a wheat yield of 3612 kg/ha. This is a doubling of the land production.
The water productivity is 3612/3380 = 0.95 kg/m^3.

The water productivity has increased by 126% due to a shorter growing season, deficit irrigation practices, reduction of E, higher beneficial fraction, and higher yield due to favourable harvest index and adequate nitrogen applications.

2.2 Country level

The provision of water resources at the farm gate depends on higher level irrigation decision making. Irrigation investments are substantial, but are not automatically economically rewarding, unless high value crops are produced. The aim of irrigation goes – however - beyond economic issues: food security and poverty alleviation are considered to be major objectives in the national water policy. Hydropower can in addition be generated from the elevated water levels in reservoirs.

The first step in irrigation planning and evaluation is to decide whether to improve existing schemes or to construct new schemes. This decision can be made only if the functioning of the existing schemes is known better. It makes sense to invest in new schemes only if existing schemes cannot be improved.

2.2.1 Existing schemes

The current study provides valuable material on the functioning of all LSIs. Improving irrigation entails (i) increasing yield and (ii) improving water management. Economic issues- although highly relevant – are outside the sphere of influence of irrigation management.

Crop yield increment is mostly a matter of good extension work.

Discussions with farmer cooperatives, water user associations and water boards are key for acquiring a better overall performance. The discussion can be supported by good information on the indicators defined in the current study. If systems have a low crop water deficit and consumption lies at the higher end of the spectrum, then water saving strategies should be discussed with the irrigation beneficiaries. Discussions between the irrigation engineers who operate the canals and the farmers who are the beneficiaries of the water supply will be of most assistance. Involvement of irrigation engineers and beneficiaries from other areas with a higher score on the same indicators is essential to create trust and appreciation for alternative solutions. If local staff can be convinced that a certain modification is to their own benefit, then the chance is high that they will adopt other practices. The Government may enforce water conservation plans, but it is better to prepare these plans jointly with the beneficiaries, to identify the advantages, and to clarify understanding, reasons, and motivations.

The definition of target values for a given LSI can help to motivate the stakeholders involved. It provides a frame of reference for what they could achieve. The targets should be compared continuously against the actual situation, so that actions can be undertaken during the irrigation season to ensure minimal deviations from the target values. The following two aspects are necessary requirements for good irrigation management:

- Define target values of irrigation performance indicators.
- Real-time monitoring of these target values.

Considering the benefits of having regular, consistent and real time data from satellites, the technical approach demonstrated in the current study should continue. Weekly updates of the minimum indicators should be prepared and shared with the irrigation districts, branch canal operators and water user associations. With updated spatially distributed information, it is possible to monitor progress and take timely remedial measurements if necessary. This is technically feasible and will be discussed in more detail under "the way forward".

The main recommended action at national scale is to establish an Irrigation Rescue Team. This should be a team of irrigation experts that have the task to (i) identify LSIs with problems; (ii) identify LSIs that are successful; (iii) acquire more background information on the reasons of success (using the standard questionnaire introduced); (iv) establish an irrigation typology for all LSIs; (v) transfer the good practices within certain typologies; and (vi) monitor these changes. An Irrigation Rescue Team should have a clear objective with a mandate that goes beyond the normal responsibilities of water allocation, maintenance, fee collection, GIS analysis, etc. The rescue team should embody a range of appropriate skills, ranging from practical aspects to scientific experiences.

The country reports prepared under this study are a good first step in that direction. Because productivity of land and water resources are key outputs of any irrigation system, every country should first study the results described in the annexes of this report and make a political decision whether they accept these variations. Egypt, Sudan and Ethiopia have wide diverging ranges of productivity, and these countries in particular are encouraged to start with an improvement program. The GIS and remote sensing data prepared under this consultancy encompass all irrigated land in the Nile Basin. The data is handed over to the National Project Coordinators.

The inventory of LSIs and their level of operational performance for 2007 has been completed as part of this study. A single year is rather short for basing decisions upon. This type of analysis should be repeated to include more years.

If LSIs proof to be unsuccessful despite modified operational management or because there are insurmountable limitations (physical, social or economical) the development of new schemes should be considered.

2.2.2 New schemes

New LSIs require large amounts of water. It does not make sense to plan new irrigation schemes if the required water resources are not available. Water accounting of irrigation schemes is thus a fundamental element in the planning of new schemes. Emphasis should be paid to predicted difference in Nile flows before and after construction of a LSI scheme. The difference is the net withdrawal from the Nile. In general terms, increase in net withdrawal represents the incremental ET which will arise from potential future LSIs. Irrigation in desert land will have a significant incremental ET because the current ET levels of Saharan desert are only 20 to 50 mm/yr. The incremental ET in the savannas of Sudan is significantly less, because the current ET is 700 mm already. Woody savannah in Ethiopia can have ET rates that exceed 1000 mm/yr. Converting woody savannah into LSI schemes will thus result in a relatively small incremental ET, and thus a much smaller net withdrawal than irrigation in the desert.

The net withdrawal is water that is removed permanently from the river Nile. This amount should not exceed the amount specified in the policies. More renewable water resources could be made available in the Nile basin for distribution to LSIs by modifying land use systems. The vast majority of the water resources are evaporated from natural ecosystems such as deserts, savannah and grasslands. ET can be reduced by changing these land use systems.

The type of infrastructure determines the amount of water that is stored and distributed to LSIs. The advantage of large dams is well recognized in the Nile Basin. It provides water during the dry season, and it creates hydropower that helps with meeting the fast growing energy needs. The environmental drawbacks of such structures need to be studied and compared against the prosperity that it brings to a region. Environmental impact assessments should also consider the impact of having a few large dam sites, vs. many small dams. Smaller dams allow storage to be spread across more streams. A simpler network of canals would then suffice, and water does not need to be transported across large distances. The evaporation from water bodies will increase if there are more small reservoirs with a shallow depth; one large and deep reservoir will have less evaporation losses.

The action plans for national irrigation planning should contain the following elements:

Existing LSI schemes

- Consider another year of irrigation performance analysis (dry, wet and average year).
- Establish an Irrigation Rescue Team with the mandate to prepare an action plan for irrigation improvement.
- The rescue team should have the support of GIS and Remote Sensing experts and be able to explore spatial databases.
- Rank the LSI per country, essentially on the basis of productivity oriented indicators (see country reports).
- Determine, in addition to Process Oriented indicators and Sustainability indicators, the technical-social-economical reasons behind the best practices, using the standard questionnaire.
- Define an irrigation typology.
- Transfer the best practices from good to poor performing LSIs.
- Establish Water User Associations for easier communications.
- Involve the stakeholders of good LSI practices and use them to motivate the beneficiaries of poor performing LSIs.
- Stimulate exchanges between Federal and Regional Governments.
- Establish GIS / Remote Sensing units to support irrigation management.

New LSI schemes

- Encourage local responsible bodies and decentralized decision making.
- Distinguish between gross and net withdrawals.
- Define the maximum amounts of net withdrawals that has no adverse impact on downstream water users.
- Plan new LSIs on sites with recoverable flows.
- The LSI sites should preferably be on alluvial soils that allow simple surface irrigation methods.
- Micro-irrigation methods should be planned in areas with a coarse soil structure and on slopes that exceed 1 %.
- Clay soils generally provide higher crop yields than sandy soils.

- Define staple and cash crops, maintain a good balance between them, and determine the size of LSI on the basis of anticipated ET rates and net withdrawals.
- Identify suitable sites for small or larger dams.
- Try to limit the area of open water bodies (reduced E losses) and select sites which will have a large head (more hydropower).
- Establish GIS / Remote Sensing units to support irrigation management.

3 Way forward

3.1 SAP

The NBI has launched a basin wide Shared Vision Program (SVP); and 2) Subsidiary Action Programs (SAPs). The SVP includes a series of technical, socio-economic, confidence building, and training focused projects to be implemented basin-wide to help establish a foundation for trans-boundary regional cooperation and create an enabling environment for investments and action on the ground. The Efficient Water Use for Agricultural Production (EWUAP) project is one of the eight projects of the Nile Basin Initiative's (NBI) Shared Vision Program (SVP).

The outcome of EWUAP and other SVP programs need to be imbedded into the SAPs. The SAPs should have access to the irrigation directions of all countries. They should facilitate with technical discussions on how this can be best achieved in a political neutral sense. NELSAP has an agricultural program, and the current LSI study could contribute by:

- Assessing where investments should be made to improve the management of the current LSISs.
- Providing the total agricultural production in irrigated agriculture fore each administrative district using the future scenarios outlined in the previous chapter.

Production information is the basis for a common regional market which operates efficiently and effectively in the basin, and enhances regional agricultural trade. There is a relationship between water productivity and agricultural trade that becomes apparent from the scenarios demonstrated. The effects of a 30% increase in water productivity on total biomass production in each country are demonstrated. A similar type of analysis can be achieved for each district.

Hence, once the countries have made choices on gross diversion, net diversion, irrigation efficiency, water productivity and beneficial fraction, annual irrigation intensity (which is a political issue and irrigation is primarily a national activity) it will become more clear what the changes in the total biomass production from LSIs will be. The 30% increase is realistic, and the investment costs are relatively small. Examples have been provided on how to achieve increase water productivity.

Another key element of trade is the fact that a kilogram of banana biomass or rice does not have the same value. Hence, for good agricultural trade policies, information on coarse cropping patterns is needed. This is possible with remote sensing techniques, provided that the proper algorithm is chosen[10]. A crop map is also crucial for a proper agricultural economic analysis and assessment of cost recovery of irrigation systems. With dwindling prices for major staple crops, extensive LSI developments could meet the challenge of future food demands. This

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[10] This task was not included in the Terms of Reference of the current study

may be difficult for most Nile Basin riparian countries. Hence there is a need for incremental and trans-boundary support and development.

The following issues would be worth considering by NELSAP and ENSAP for follow-up activities in irrigation implementations:

1. Stimulating and coordination of improvement of irrigation management of the existing LSI schemes using the best practices guidelines provided
2. Safe irrigation growth without detrimental effect on downstream water resources availability using the development scenarios (S) described in chapter 1 of this report
3. Surveying areas being potentially suitable for land reclamation and development of irrigation systems.

1) Improvement of irrigation management on existing LSI schemes using the best practices guidelines

The current LSI study detected significant spatial variations of water productivity within countries and within irrigation LSI systems. The reasons for low water productivity are identified and action programs should be defined to alleviate the poor use of valuable Nile water, and establish more spatial uniformity. The LSI systems need to be improved to better meet field water requirement and to maximize rainfall utilization. The main objective therefore is:

Develop irrigation strategies for specific regions and irrigation systems to enhance water productivity in consultation with the national coordinators and monitor the impact by a satellite-based measurement system

2) Safe irrigation growth without detrimental effects on downstream water resources availability

The fundamental hydrological processes of an LSI system needs to be understood before impact on downstream water resources availability can be assessed. The gross diversion, ET, and net diversion as a result of water recovery need to be described, as well as how they change after certain interventions. ET from irrigated crops displaces huge amounts of water into the atmosphere and outside the basin. However, the current land use also has certain ET behavior. The incremental ET is the difference between current and future ET, i.e. the enhanced ET due to introduction of irrigation schemes. Theses ET processes need to be understood, in conjunction with the return flow of irrigation water that feeds the river system. Irrigation development needs to be emphasized without exclusive focus on infrastructure delivery. Existing large scale water storage facilities need to be surveyed and recorded along with the needs/risks for future storage. The selection of sub basins with favourable large scale storage should be studied also in conjunction with hydropower needs. The main objective therefore is:

Study the impact of various levels of irrigation growth using net diversions of Nile river water. A safe maximum expansion of the total irrigated areas should be assessed. The impact on infrastructure delivery should be described

3) Surveying areas being potentially suitable for land reclamation

Most national agricultural policies foresee expansion of irrigated land. Ethiopia plans to grow its irrigated land with 1.4 million ha (0.7 million ha in Blue Nile, 0.3 million ha in Tigray/ 0.4 million ha in Atbara). Sudan is involved in the extension of the Rahad-II, Kenana-II and Upper Atabara that totally occupies an area of 1.2 million ha. Egypt is investing in the Nile Valley (0.4 million ha), Northern Sinai (0.1 million ha), Northern Delta (0.1 million ha), Toshka (0.2 million ha), Sinai (0.2 million ha) and West Delta (0.1 million ha) which in Egypt all together adds up to an amount of 1.4 million ha. The total expansion in the Eastern Nile countries is thus 4 million ha. The current irrigated area is approximately 5 million ha, hence a growth of 80%! This is not straightforward, and the amount of Nile water diversion, crop water consumption and return flow via drainage systems and aquifers needs to be totally understood before constructing these new LSIs. The package of hydrological simulation models to be prepared under the Nile Basin DSS should be involved for appraising the hydrological constraints.

Regional irrigation growth plans require certain data, and this data should come from GIS, remote sensing and hydrological models. The table presented below reveals that many data requirements can be met from advanced geographic techniques, being of strategic value for the planning of future irrigation systems. While the current LSI study in the Nile basin is based on MODIS 250 m pixels, it is since 2009 technically feasible to achieve daily measurements with 32 m pixels. This is the DMC satellite. The latter is of fundamental importance to survey the small irrigated fields that are not seen on the 250 m pixels. Hence, it is now technically feasible to measure the entire Nile Basin with daily imagery, provided that cloud free conditions prevail.

Table 36 Irrigation data requirements from ENSAP and the possible contribution from remote sensing data

Irrigation data requirements	**Remote sensing data options**
irrigated areas	Possible with vegetation indices
size, location and boundaries of the irrigation schemes	Possible with segmentation techniques to detect plot boundaries and line objects; manual interpretation required
crop types cultivated	Possible for large fields (>1 ha) and for major crop types after merging remote sensing data with field visits
sources of irrigation water	Only feasible if remote sensing data is integrated with basin scale hydrological models. This is a rather complex endeavor
crop water consumption (ET)	Possible with energy balances
volume of water diverted	Possible only when on-farm field losses due to percolation, runoff, interception and drainage can be estimated
irrigation efficiencies	Possible if crop ET and diverted water are estimated
type of irrigation technology	Not possible
crop production	Biomass production is feasible. Biomass production can be converted into crop yield if the crop types cultivated are known
crop water productivity	Possible if crop production is known. Alternatively, it should be expressed as a biomass water productivity
ownership	Not possible
fertilizer status	Only canopy Nitrogen status can be determined
chemicals	Not possible
drainage systems	Not possible
topography	Possible with laser altimeters
climate	Indirectly possible after merging weather station data with land surface features (wetness, greenness, albedo, roughness)
soil type	Not possible

Horizontal expansion of the current irrigated land and reclamation of new irrigation schemes should occur on suitable locations that will lead to a sustainable development. Surveys need to be undertaken to identify areas potentially suitable for irrigation. It must consider the spatial variations of climate, slope of the land, soil suitability, crop water requirements, and potential agricultural production to allocate areas suitable for irrigation. The flow of nearby streams must be investigated for local irrigation water diversions. The runoff from larger catchments endowed with water resources must be determined to study the options to store excess water in large reservoirs. In the latter case, better infrastructure must be required for conveying irrigation water.

The main objective therefore is:

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PART 4 Summary and way forward

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1 Irrigation development

The irrigation sector is the largest consumer of renewable water resources in the Nile Basin. The total withdrawal from the Nile river system is 80% of the peak river flow as measured near Khartoum. This is the current river flow, and it is probably going to be reduced by upstream land cover changes and climate modifications in the future. There is general agreement by those involved in the Nile Basin Initiative (NBI) that water management of Large Scale Irrigation (LSI) systems in the Nile Basin can probably be improved. The Nile Basin does on the other hand also have some of the best LSI systems of the world. If all LSI systems are objectively and consistently evaluated, useful information could be gleaned from well performing LSIs to improve LSI schemes with a poorer performance. It is necessary to understand not only the nature of the best irrigation practices in the Nile basin, but also where and when they are implemented. From this understanding should follow a program to encourage the transfer of good practices, both from a technical as well as from a socio-economic point of view.

There is approximately 4.9 million ha of irrigated land in the Nile basin. Adding to this figure the areas that are currently equipped with irrigation systems, bring the total irrigable land to 5.6 million ha. The annual cropping intensity is 135%, which means that double cropping is practiced on a large proportion of irrigated land. In general 40% of the GDP in the Nile basin is dependent on agriculture. The five major crops are wheat (16.7% of total crop production), fodder (14.5%), maize (12.0%), cotton (9.2%) and rice (9.0 %). All together they occupy an area of 4.7 million ha. Sixty one percent of the total irrigated area of the Nile basin is located in Egypt; another significant proportion (36%) is located in Sudan. Hence 97 % of all irrigated land is located in the arid zones of the Nile Basin, and just two countries. The other countries of the Nile basin are also interested in irrigation, and have in fact embarked on national irrigation programmes to improve food security and enhance rural agricultural economies. Although irrigation does not play a major role in their national agricultural production, the upstream countries would wish to ensure that their development is productive and cost-effective. Most Nile Basin countries plan to expand their irrigated areas.

Apart from Egypt and Sudan, the countries in the Basin are at an early stage of water resources development. Several of the countries are in post-war situations and irrigation play an insignificant role in the agricultural sector. Most LSIs are located on (i) lowland flood plains, (ii) highland flood plains and (iii) narrow river valleys. Egypt and Sudan are basically pursuing policies of maximum yield per hectare. For Egypt this is the best option because rainfall is minimal, and for Sudan it is best because excess water is available (current consumption is substantially below the agreed figure of 18.5 bcm/year). Ethiopia, Rwanda and Burundi have irrigation policies which aim to ensure crop production with supplementary irrigation, and to sustain subsistence farming. Rice is cultivated in the Equatorial lake region, and several schemes in Kenya and Uganda also aim at maximizing production. The major irrigation systems in the basin – in Egypt and Sudan – have long histories, and were originally managed very strongly by government. Cropping patterns were prescribed, and water deliveries were scheduled to meet the resulting demand. More recently, cropping patterns have been liberalized, and farmers are, with some restrictions, free to choose what they wish to grow, and when. In recent years, high-tech irrigation systems have been introduced by commercial investors to reclaim desert and savannah land for agriculture.

Extension of irrigated area can be accomplished by intensifying the use of existing facilities by increasing the annual cropping intensity, or by construction of new infrastructure to serve savannah or desert land.

Either strategy results in additional surface water withdrawals and additional water consumption by irrigated crops, and thus will affect the water availability to other water users and sectors, and it is important to be transparent on this issue and have well coordinated irrigation development strategies. In line with the global trend, the irrigation sector should also be prepared to produce more food from less renewable water resources and options need to be studied on a country-by-country basis. A common view, guidance, and implementation of activities to expand irrigation, should be developed under NBI by ENSAP and NELSAP programmes. It is possible to maximize the productivity of consumed water, and minimize wasteful and non-productive consumption, provided that proper strategies are deployed. The challenge is now to develop these proper strategies and detect best irrigation practices, and transfer these practices to other areas where the climate and irrigation typologies are similar.

The LSI schemes are located in different climatic zones, geographical settings, and socio-economic conditions. An inventory of practices, results and sustainability of the current LSIs is necessary to identify best practices and assess the scope for improvement. The current study has therefore a diagnostic character. Due to the vast areas and unavoidable differences between design and practice, it is – unfortunately – not feasible to fully understand the operational characteristics of LSIs whose performance has been assessed. The current study therefore focuses more on measurable outputs of LSIs, rather than internal mechanics, infrastructure, water allocations and management practices. Future studies must focus more on these processes for effective and equitable water utilization in LSIs.

Successful water management is increasingly understood to require a basin-level approach. This is especially important as water scarcity and competition for water increase – as is now happening in the Nile Basin. As this happens, traditional irrigation engineering concepts of irrigation efficiency, water savings, and the impact of modernization become misleading for two main reasons: first, "losses" in one location are often recovered for productive use elsewhere (or even locally as groundwater) so what appears to be a saving when observed at the field or project scale is not a saving in the broader basin context.

Second, the impact of modernization and improvement of irrigation systems on water savings is not straightforward. While land productivity may indeed improve due to micro-irrigation, conversion to on-demand flow and more fertilizer applications, the crop consumptive water use, which is a primary determinant of production, may rise in proportion. This implies that more water in a given region is evaporating, and hence less water is available for downstream users.

While drip systems and micro-sprinklers require lower amounts of water supply, they convert a significantly larger fraction of the water supply into ET. While the water supply may have *decreased*, the ET may have *increased*! When evaluating the impact of changes in technology or management of an irrigation system, it is therefore crucial to understand what is happening to *consumptive use*, which is what affects the availability of water to other users. This is not to argue that there are no benefits from hi-tech irrigation technologies – but rather to point to the need to focus on water consumed rather than water diverted as the measure of impact.

Building further on this, International NGOs supported by the scientific literature and international research programmes such as the CGIAR Comprehensive Assessment of Water Management in Agriculture, increasingly argue that a key objective of irrigation is to maximize the productivity of consumed water. Water productivity describes the crop production resulting from irrigation water consumed (kg/m^3).

2 Materials and methods

The LSIs do not seem to have processes in place to verify existing performance or even design criteria. During the construction phase many maps and plans must have been prepared. Now in the digital era, the location of canals, boundaries of canal command areas and irrigation schemes are not systematically archived in central GIS databases. Pieces of information are no doubt in the possession of different line agencies, entities, advisors, consultants, private persons, and on archives and electronic databases created under recent projects, but the data are scattered and not readily accessible to support national and international irrigation analysis and decision making processes such as NBI. The consultants involved in this report have for example not been provided with this type of information. Irrigation databases in the Nile basin are either non-existent or incomplete.

During the execution of the project, it was twice attempted to acquire standardized datasets, especially with regard to operational rules and responsibilities of water allocation and water distribution for specific study areas. While certain countries have not replied at all, other countries have provided rather hypothetical or incomplete figures. All these materials are in generalities in terms of actual "practices". A practice is what is done; a policy is a statement of intent to do something. It is essential to quantify the difference between policy making and practices, and this has not been possible on the basis of the information available.

Agricultural statistical data are usually collected by means of field surveys. Most of these secondary data are transferred to government statistical offices, and sometimes passed (in aggregated form) to FAO and other organizations for database development. Although the quality of the data is questionable, (the Global Map of Irrigated Areas is inappropriate for most irrigation systems below 10° N), it at least forms a basis for acquisition of quantitative information. However, most of the data are not geo-referenced, so it is not clear where certain crops grow and what the site-specific yields are. Disaggregated yield data for irrigated crops are not common. The absence of reliable yield data poses a problem for the determination of the economic returns of LSIs.

Canal water flows are rarely measured. Canal water levels are sometimes measured near main structures, but reliable rating curves are not available to derive volumetric discharges. Most available flow data are based on canal design capacities or the water allowance at the farm gate (main d’eau). It is not possible to deduce diversions and deliveries from this general information without records of flow duration, water levels, and rating curves. In the absence of spatial data on water flows, it is impossible to understand the functioning of irrigation systems, whether water is reaching the crop, and how frequently water is applied, and how this relates to the planned operation. The water balance of irrigation systems are not known, except in cases where special hydrological modelling studies were performed.

Independent observations are needed to quantify irrigation processes in a uniform and standard way for all Nile Basin countries. Remote sensing is a relatively new technology that contributes substantially to this requirement. Remote sensing can provide information on crop evapotranspiration (ET), which is an attractive alternative source when quantitative flow information is absent. Satellite measurements of soil moisture, leaf area index, vegetation cover and solar radiation are used to compute different ET fluxes: reference evapotranspiration (ET_0), actual soil evaporation (E), actual crop transpiration (T_{act}), potential crop transpiration (T_{pot}) and most importantly actual evapotranspiration (ET_{act}). Since most water flow data relate to the actual situation, ET_{act} can also be expressed as ET. An energy balance method has been used to estimate the ET values for 250 m pixels in the Nile basin on all areas that are irrigated. ET is computed from the latent heat energy required to evaporate water, and this has the advantage that no additional water flow data is need to derive at ET. Comparisons of ET against ET_0 and ET_{pot} make it possible to indirectly estimate soil water availability. If a certain amount of soil water availability is estimated in absence of rainfall, than this can be attributed to irrigation processes.

In addition biomass production can be calculated from the same energy balance. The biomass production is a good surrogate for crop yield, and can be used to express spatial and temporal variation in agricultural production, without becoming crop specific.

While all these RS indicators contribute substantially to the understanding and evaluating irrigation system performance, the absence of conventional information presents the current analysis with considerable difficulties, because performance of an irrigation system cannot be measured independently of the operational objectives being pursued: if, for example, a commercial sugarcane plantation is compared with a project designed to provide limited water supplies over a large are in order to maximize the number of beneficiaries, then the intensity of irrigation, yields per hectare and variability of cropping patterns would be entirely different because the operational objectives are different: concluding that one project was “better” than the other would thus be inappropriate.

The comparative analysis therefore had to be done on the basis of spatially distributed data from satellite measurements and using several indicators instead of tailor made indicators for specific purposes. The results are presented in 3 different categories. The first category is referred to as Results Oriented (RO) indicators, which denote land and water productivity (n=2). The second category reflects part of the physical processes that affect the results, i.e. Process Oriented (PO) indicators. The processes considered are related to adequacy, reliability, uniformity etc. (n=6). The last category relates to the sustainability of the LSIs. The Sustainability Oriented (SO) indicators are evaluated on the basis of 23 years of satellite time series (n=2).

By combining the 10 spatially distributed indicators, it is possible to prepare irrigation reports for countries and for smaller administrative units throughout the Nile basin. The irrigation reports are used to evaluate the adequacy of LSIs irrigation performances. The 10 indicators have different units, which creates a compatibility problem. A system was thus introduced to allocate scores on a scale of 1 to 5 to each indicator. The maximum score is adjusted according to the prevailing climate. With this normalization, systems and themes can be compared.

3 Diagnostic results

In the absence of maps identifying specific irrigation schemes, the administrative districts have been used as the unit for data presentation, with the identified irrigated areas within each district aggregated to the district level. Note that differences in names between districts and LSI schemes exist. When computing the average value for all districts, the following overarching result can be presented: Kenya appears to have the best water productivity, Uganda the best agricultural production, Ethiopia the best water conservation, Uganda the best adequacy, Egypt the best beneficial fraction, Ethiopia the best uniformity, Uganda the best reliability and Tanzania and Sudan have the best sustainability.

Kenya and Uganda have the highest country average performance for their LSIs. The districts hosting the LSI schemes with the very best practices are Butere Mumais (Kenya) and Wakiso (Uganda). A ranking of the highest indicator scores (on most of the 10 indicators) per country was done next. The administrative districts with the best scores in every country are presented in the Table below. Differentiation is built in to look at overall performance and to water productivity more specifically.

Country	**Average score all 10 irrigation performance indicators**	**Average score water productivity**	**District with overall best irrigation performance**	**District with best water productivity**
Burundi	3.5	3.0	Ngozi	Bugabira
Egypt	3.1	2.9	Dumyat	Bur Said
Ethiopia	2.9	3.1	Adwa	Ambasel
Kenya	3.7	3.5	Butere Mumais	Butere Mumais
Rwanda	3.5	3.0	Nyanza	Nyanza
Sudan	3.2	2.7	Suki	Kenana
Tanzania	3.1	3.1	Karagwe	Karagwe
Uganda	3.7	2.9	Wakiso	Bugiri

Because of its importance as competition and scarcity increase, water productivity is discussed in more detail. Nationally, Kenya is the most productive user of irrigation water. The LSI schemes with the best water productivity in the Nile basin are Guduru-Ethiopia (score 5.0), Bur Said-Egypt (score 5.0), and Abay Chomen-Ethiopia (score 4.8). Ethiopia has the best rating for conservative water use in irrigated crops, because irrigation events seem to occur at crucial times just when water is needed the most to prevent the crop from wilting. Irrigation is applied only when absolutely necessary. It goes however in the case of Ethiopia clearly at the cost of crop yield. Land and water productivity should be given equal weight for purposes of describing the final result of good irrigation management. Sudan has the lowest crop water productivity, especially because the crop yield is below average.

Another key observation from this table is that average water productivity *excluding* Kenya and Sudan, is essentially the same for all other countries (ranging only from 2.9-3.1). Further, we should note that the two countries with very large operational units (Egypt and Sudan, where several thousand hectares are operated as a contiguous unit) have relatively low overall performance indicators. It seems intrinsically likely that providing a good service when a substantial proportion of farmers are several kilometers from even the intermediate control structure is harder than in the other countries, with LSIs comprising a few hundred hectares and all the farmers are within easy reach of the main diversion structure.

Irrigation practitioners have the formidable task to find a balance between a high crop yield to ensure income and sustainability, and to conserve water for the environment. For all countries, a linear and positive relationship between crop water consumption and production was found. This is explained by a higher crop transpiration creating a higher agricultural production. In general, a strategy to maximize production per hectare will lead to higher production per unit of water consumed. This is also a good strategy for securing the food situation. By looking into more detail, however, it is clear that ET could be reduced without detriment to crop yield. This important fact was observed in all Nile countries. The reasons for this conclusion are, however, not uniform. In the arid environments of Sudan, the primary opportunity to reduce water consumption is by minimizing non-productive E, and this is achieved by *intensive* cropping, which maximizes leaf cover and hence reduces evaporation from the soil. Egypt performs very well at this particular issue of beneficial fraction having a rating of 4 points. Additional improvements to water productivity may be possible in some crops through deliberate, carefully timed under-irrigation.

In the wetter climates elsewhere in the basin, the productivity of irrigation water can be improved by *extensive* irrigation – providing enough irrigation water to ensure a moderately high yield per hectare over a large area, and then relying on rainfall to give a free boost to production. This strategy captures more rainfall for productive use than a strategy of intensive irrigation. At this moment, Kenya and Uganda deliver too much irrigation water.

In present circumstances, where there is little evidence of actual water scarcity, improving land productivity is probably a good strategy for most countries. As irrigation management becomes more sophisticated, simultaneous reductions in crop water consumption by inducing a mild crop water stress can be attempted. The best irrigation practice for optimum water consumption differs considerably from the conventional scheduling strategy to keep the soil at field capacity. Irrigation for maximum productivity requires a different set of operational rules and evaluation indicators than irrigation to sustain a crop. It is therefore recommended to assist the irrigators with this more advanced GIS/Remote Sensing based irrigation management systems based on water productivity. Due to differences in irrigation objectives, good practices at one site cannot be transferred to other sites. It is therefore advised to classify the various irrigation systems into a typology, and the ingredients for this typology are provided in chapter 7.

The reasons for variations in the physical indicators cannot be assessed in order to derive conclusions about which types of management or infrastructure are associated with a certain physical outcome. The most important conclusion in this regard is that areas exhibiting exceptionally high or low scores for physical indicators should be visited and understood better to derive sound conclusions.

The humid climates seem to have a higher uniformity in overall irrigation performance as compared to arid zones. Fine tuning of crop water demand and irrigation water supply in arid zones are thus more difficult, although it was expected that excluding rainfall as an uncertainty could be an advantage. While irrigation management under the arid conditions of the Nile delta and the western desert of Egypt appeared very good, this is not the case in the Nile Valley of Upper Egypt. In Sudan it also appeared not possible to keep the irrigation performance uniform. Climatic rainfall and ET processes at the land-atmosphere interface are thus dominating irrigation processes. This is probably related to the regulating moisture mechanisms of alluvial soils: as long as they are regularly wetted by rainfall and irrigation, crops will survive easily, despite that irrigation water delivery is inaccurate.

While it is not possible on the basis of the available data regarding irrigation strategy, facilities, infrastructure, etc to make a comprehensive review of best practices, a number of interesting anomalies were observed.

First, the Fayoum area of Egypt shows more water stress than other areas. This is consistent with known operating procedures there, which limit the water deliveries because of drainage problems. This shows that the remote sensing data can provide measured indicators relevant to field operations.

Second, Upper Egypt exhibits far less favourable indicators than the delta. There is no clear explanation for this – policies, infrastructure, operational procedures are similar in both areas. This needs investigation.

Third, the commercial sugar estates in Egypt and Sudan performed much better than surrounding areas in the same climatic conditions. (See further, below)

Fourth, there appears to be significant differences in the LSI outputs within and between countries. After comparing variations in LSI performance between political boundaries and between climatic zones, it became apparent that irrigation performance in most countries is more uniform than the performance between climatic zones. This suggests that the irrigation water policies may be a contributing actor to performance – though of course non-irrigation policies (extension services, input supplies and marketing are also country-specific and may be the cause).

The highest uniformities, reliabilities and sustainability occur in Uganda and Kenya, countries that on paper have a less strong institution. The long experience of Egypt as an irrigation country was reflected in relatively low reliabilities and uniformities. This poses the question whether institutions are really contribution to irrigation outputs (for sure they will contribute to internal irrigation processes). But as already noted, the size of irrigation projects in Uganda and Kenya do not compare with the areas in Sudan and Egypt – and size may be an important determinant of manageability.

4 Socio-economic and institutional aspects

Good water governance, i.e. research institutes, education, extension service, water act, water rights and financial viability should result in improved irrigation performance. The definition of "improved" is not unambiguous, and should be related to policy objectives, which in turn should be evaluated on measurable outputs. The Nile basin hosts a variety of institutions, centres of excellence and the hypothesis was tested whether good water governance improves the outcome. The output was defined as uniformity of irrigation processes, reliability of the water service, sustainability, and productivity per unit of land and water. It was concluded that – after correction for climatic influences – countries with the best water governance on paper, show the poorest results. There is no evidence to say that strong institutions are a key to success in the Nile basin. It is therefore rather uncertain whether the role of institutions is as great as often suggested.

This statement can be further verified by comparing the irrigation performance of certain commercial farms in Egypt and Sudan with maximum freedom compared to farming systems in their neighbourhoods where public agencies govern decisions at the higher levels of operation, with WUAs responsible at lower levels – at least in theory. The commercial Kenana sugarcane farm in Sudan has a land productivity which is 160% and 76% higher during the summer and winter respectively than in the neighbouring Gezira scheme. The water productivity was 24% higher. The same conclusion was found in Egypt: the Dina and Centech farms had 91% higher water productivity as compared to Government managed LSIs. The Kenana scheme turned out to be one of the best systems in the Nile basin. Hence, there are excellent LSI schemes in the Nile basin, and the ones with more freedom and less Government involvement usually have a better performance. This finding reinforces the earlier findings that the government water institutions are not positively influencing the major outputs of irrigation systems. However, as already noted, it may be that the private systems (which are major companies with considerable power) are able to ensure better water supplies and input levels than individual farmers.

Most countries have water strategies and/or reform programs which are at different stages of agreement or implementation. The broad statements on which detailed policies and regulations will eventually be based (application of IWRM, efficient use, equitable allocation, priority to domestic use, stakeholder involvement, etc) are similar in the case of each country, but give no clue as to the details at the level of individual schemes.

Finally, it should be noted that variations in physical performance within countries are similar in magnitude to variations between countries. This is an extremely important conclusion, because political, social and economic conditions should be similar among all LSIs in a country, and to the extent that clear distinctions between countries are not evident, this suggests that these elements are not powerful explanatory factors for performance.

While there are good performing LSIs in the Nile Basin, the country reports contain lists of LSIs that are operated with dissatisfaction. The poor performing systems need extra attention, and it is proposed to establish Irrigation Rescue Teams that implement a list of actions. The actions are provided in the parallel report. The dialogue among the various stakeholders can be facilitated if farmers are irrigated by means of Water User Associations. A local organized system will make it easier to detect the real reasons for low performance, and get consensus on the way forward. The existence of Water User Associations and other forms of local cooperatives are not a guarantee that water management is appropriate. It helps in getting messages across, and this is not always the message in achieving a more favourable functioning of the LSI.

5 Irrigation development

Irrigation development in each country is feasible only after making a water budget, and study the impact of modifying the gross diversions on downstream water availability and total agricultural production. Such water budget model is prepared as part of this study. The alternative options investigated to acquire more food from less water resources include (i) increase irrigation efficiency, (ii) increase water productivity and (iii) increase beneficial fraction.

The gross diversion has been reduced by 20% as compared to the reference situation (100%), anticipating that water resources availability in the future will diminish (the main report contains scenarios with 100% and 120% gross diversion values). The results of 80% diversions are presented in the table below. The good news is that all countries will be able to get more agricultural production from less water resources. The scenario with higher water productivity provides the best contribution to reach this goal. Once the current operating procedures, technologies, etc have been properly related to the performance indicators identified in this report, a basin wide water productivity program could be established.

The impact of irrigation efficiency or beneficial fraction depends on the country. Irrigation efficiency is preferred above beneficial fraction in Egypt, Kenya, Tanzania and Uganda, because canopy cover is already high in these countries, and beneficial fraction cannot be improved much further. Improving irrigation efficiencies only saves water if the “losses” are not recoverable. Therefore, emphasis should be refocused on identifying where excess flows are not recoverable (near saline sinks; over polluted or extremely deep aquifers) and improving irrigation technology in these areas. Non-productive consumption (evaporation, water used by weeds) should always be avoided.

Country	Scenario	Net diversion irrigation (MCM/yr)	Total biomass production (ton)
Burundi	Reference	45	288,785
Burundi	30% increase irrigation efficiency	43	292,918
Burundi	30% increase water productivity	36	348,554
Burundi	20% increase beneficial fraction	36	321,742
Egypt	Reference	27,653	63,660,683
Egypt	30% increase irrigation efficiency	26,547	66,108,277
Egypt	30% increase water productivity	22,123	66,849,531
Egypt	20% increase beneficial fraction	22,123	45,952,214
Ethiopia	Reference	214	1,539,170
Ethiopia	30% increase irrigation efficiency	206	1,557,384
Ethiopia	30% increase water productivity	171	1,882,533
Ethiopia	20% increase beneficial fraction	171	1,713,247
Kenya	Reference	281	1,044,935
Kenya	30% increase irrigation efficiency	269	1,073,391
Kenya	30% increase water productivity	225	1,173,446
Kenya	20% increase beneficial fraction	225	892,031
Rwanda	Reference	62	371,580
Rwanda	30% increase irrigation efficiency	60	377,344
Rwanda	30% increase water productivity	50	445,583
Rwanda	20% increase beneficial fraction	50	423,405
Sudan	Reference	8,882	11,945,970
Sudan	30% increase irrigation efficiency	8,526	12,270,511
Sudan	30% increase water productivity	7,106	13,420,243
Sudan	20% increase beneficial fraction	7,106	12,567,452
Tanzania	Reference	2	10,351
Tanzania	30% increase irrigation efficiency	2	10,545
Tanzania	30% increase water productivity	2	12,195
Tanzania	20% increase beneficial fraction	2	10,233
Uganda	Reference	260	859,832
Uganda	30% increase irrigation efficiency	250	883,004
Uganda	30% increase water productivity	208	967,166
Uganda	20% increase beneficial fraction	208	771,528

6 Way forward

6.1 Observations

- Irrigation for maximum water productivity requires a different set of operational rules and monitoring and evaluation indicators than irrigation with the purpose to hold the soil at field capacity. For arid countries, this means intensive irrigation that minimizes evaporation. For wetter countries, extensive limited irrigation to supplement rainfall is more productive.
- The crop yield per hectare is disappointingly low at places. More intensive communications with agronomists and Ministries of Agriculture are required. The agricultural research in Egypt and Sudan is good, but the message and extension survive is not getting across to the regions. Land and water productivity should be given equal weight for purposes of describing the final result of good irrigation management.
- The humid climate of the Equatorial Lake region is very suitable for crop production and supplementary irrigation systems. Although rainfall is erratic and often considered as a disrupting factor, it study provides evidence that it is easier to irrigate under humid conditions, than under arid conditions.
- The commercial estates have overall a good approach to irrigation management. More agribusiness farming should be encouraged for spurring good irrigation management practices and create local examples that could be adopted by governmentally managed systems. Governments should give them water rights to guarantee their access to sufficient water resources.
- The role of water governance to improve irrigation systems is sometimes exaggerated. Although it is essential to have a clear set of rules in place, and it can facilitate internal irrigation processes, the existence of large and powerful irrigation-related institutions does not appear to be reflected in the major outputs of the LSIs. However, this conclusion may be biased by the extreme variation in the definition of LSI" among countries: a larger central bureaucracy is required to manage a scheme of 200,000 ha than one of 200 ha.
- From the fact that the spatial variation in agricultural performance is widely diverging, and the soil-climate physical conditions are comparable, it is concluded that certain regional centres are more active than other centres. The presence of strong regional extension services and Departmental representations is thus important
- Increased production can, in the short term be best accomplished by pursuing yield improvements as well as more intensive utilization of the existing infrastructure. Hence, part of the irrigation improvement has a pure agricultural character. This includes sufficient water and nutrient inputs.
- In the longer term, crop consumptive use should be limited by water conservation programs and advanced techniques described above.

6.2 Conclusions

- Improve the Nile basin irrigated area map with local irrigation and GIS consultants. Particular emphasis should be given to the smaller LSI systems in the humid climates of the Nile Basin
- The ICID minimum set of indicators assumes that canal flow is measured at structures. At best only water levels are measured at gauges, but there are hardly any volumetric flow measurements devices present in the Nile Basin. As long as such system is not in place, it is recommended to use remote sensing estimates of consumptive water use as an alternative data source to estimate spatially distributed flow.
- Focus on water accounting in terms of beneficial and non-beneficial use, recoverable and non-recoverable flows instead of irrigation efficiency as a means to use irrigation water better.
- The irrigation maps and data obtained from individual public servants, consultants, retired staff, filed archives should be synthesized in electronic databases. The Nile basin countries should invest in irrigation science before embarking on developments. This includes the recoverable water flows that are non-consumed. The knowledge base is a fundamental component that facilitates irrigation developments
- Irrigation performance against defined targets should be monitored. Such monitoring systems with satellite images should be established under the Decision Support System (DSS) of the NBI - WRPM programme. The current report provides the contours of such system. The DVD in the back of this report contains the database examples for all irrigated land in the Nile basin.

6.3 Recommendations

- The main focus in the near future should be on increasing utilization of existing facilities, intensifying irrigation, and increasing yields per hectare.
- In the longer term, increasing water productivity, i.e. maximizing crop production per unit of water consumed will be required. It is recommended to launch a basin wide water productivity programme.
- All LSIs with alluvial soils and a favourable climate have a good performance. Soil types and soil tillage are therefore considered to be crucial for low-tech surface irrigation systems. High-tech micro-irrigation systems could be introduced anywhere, even on coarse structured desert soils
- Establish an Irrigation Resource Team and forums to discuss irrigation developments for the Nile basin with a broad range of stakeholders at regional, national, and community levels; discuss the challenge to produce more food from less water resources because pressure is now mounting to reduce the amount of water allocated to agriculture.
- The best practices in the Nile basin can be best transferred within countries first. The best LSI schemes are now identified, and their practices can be copied. The local irrigation engineer can have a crucial role in this, especially when the analytical link between local actions and outputs is better understood. Knowledge of the current systems, their current level of performance, and their

maximum level of performance from other LSI systems within the irrigation typology, should be all integrated to define irrigation targets. Base decisions on knowledge, and not on rumours related to the operation of irrigation systems

- The good and recommend management practices for every country are summarized in the table below. This may assist the Nile basin countries in the defining the shorter term priorities.

Country	**Is excellent in**	**Should improve on**
Burundi	Deficit irrigation; keeping soils wet	Crop yield: beneficial fraction
Egypt	Reliability: beneficial fraction	Crop consumptive use: uniformity
Ethiopia	Crop consumptive use: uniformity	Crop yield: avoiding significant transpiration stress
Kenya	Reliability: uniformity	Crop consumptive use: crop water deficit
Rwanda	Crop water deficit: reliability	Crop yield: beneficial fraction
Sudan	Sustainability; reliability	Water productivity: uniformity
Tanzania	Deficit irrigation: uniformity	Water productivity: reliability
Uganda	Reliability: uniformity	Crop consumptive use: water productivity

6.4 Operational remote sensing service

The results of this study are based on 2007 data. The key satellite data on Leaf Area Index and AMSR-E soil moisture are available since 2002, and all data is archived in the electronic data archives of NASA and USGS. Time series can be created from historically archived data, and these series will continue into the future. This is a great opportunity to set up an irrigation-watch type of product. The most significant efforts are related to the definition of such a product and to defining target values for all LSIs. This includes the identification of irrigated areas and a reasonable attempt for a Nile irrigation mask has been made. Refinements can be made by more ground truthing and field visits. An irrigation mask for the Nile basin can also be used for integrated water resources management.

The Decision Support System (DSS) of the Water Resources Project Management unit in Addis Ababa is designed to provide remote sensing data in a regular way. The creation of the spatial database for irrigation should be done according to the methodology and technical approach outlined in the current study. There is at this moment no alternative solution available to collect all the received irrigation data. The DSS unit has specifically defined in their Terms of Reference the need for a remote sensing monitoring system and this more generic system could include an application to support the irrigation monitoring and irrigation development into the Nile Basin.

The availability of an irrigation monitoring system creates the opportunity to foster interest and enthusiasm amongst end-users. Once a monitoring system is operational it can be used to see if local irrigation improvements are realized. This can be accomplished by defining target values for the 10 irrigation indicators, and monitor their progress. The irrigation typology should be used to fix reasonable target values for the indicators. The spatial scale of monitoring could be at a 250 m x 250 m pixel level, or a district (as applied in this report) level, or a canal command area level. The latter brings back the need to establish a digital database of the areas serviced by certain distribution canals. An example of monitoring crop water deficit of a given field by remote sensing data on a weekly basis is shown in Figure 46.

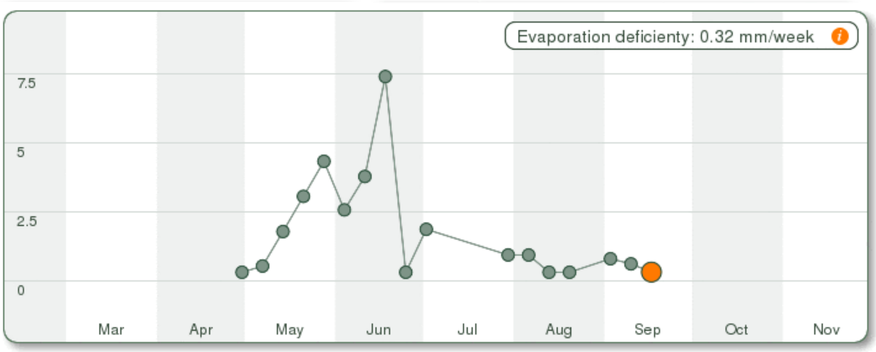

Figure 46 Trend in evaporation deficit (ET_{pot}-ET_{act}) during the growing season based on weekly MODIS satellite images. Every dot represents the average value of a field. The field could also be a canal command area.

An increase in irrigation performance encourages the various stakeholders to continue with the extra efforts; the district engineer, gate keeper, ditchmen, and farmers will become more involved, and see the results. While a web-based application will be attractive for the Federal Government to monitor the progress in various LSIs in a country, the involvement of local operators without access to internet is fundamental. Hard copies and printouts of monitoring processes should be provided to the extension servicers, Water User Associations, and other forms of farmer cooperatives. A data dissemination process could be adapted similar to other forms of communication that Ministries of Water Resources and Agriculture apply.

The institutes need to be trained in basic remote sensing and GIS technologies. The necessary software should be made available to ensure an active involvement.

6.5 Way forward

This LSI study was obliged to work with administrative boundaries, instead of the physical boundaries of the LSI systems. Because there are contradictory views on whether certain fields are irrigated, first the irrigation map of the Nile basin needs to be further perfected.

Because of the importance of LSI for the international water resources, it is essential that NBI continues with EWUAP type of activities. EWUAP could facilitate the establishment of a central database on the physical infrastructure, crop types, crop yields and water accounts. Such central database could be used by the riparian countries. While the DSS unit of WRPM will partially take care for these actions, the application and interpretation is very specific. The irrigation and drainage programs of ENSAP and NELSAP should take over the EWUAP tasks, although the authors of this report believe that the shared vision developments are still ongoing. The whole issue of return flow, role of institutions and micro-agro-economical mechanisms are not fully understood. The EWUAP program ends to soon, and not all common pieces related to LSI are well enough investigated. The water budget for every LSI exceeding 50,000 ha should for instance be known, either from field measurements (being almost impossible) or from the combination of satellite measurements and models (possible). Some first attempts are made in this LSI study for the sake of standardization. These water budgets could be refined using satellite data of more years, and to integrate with locally available flow data and the hydrological models to be prepared under the DSS.

ENSAP and NELSAP should encourage projects that aim at rehabilitation and improvement of the management of current LSIs with poor irrigation performance. The current 5 million ha of irrigated land can be managed more alertly and examples are needed that proof that more profits and benefits can be created. The second major task of the SAPs is to assist and coordinate the planning of new irrigation systems. They could give advice on the steps to be taken, and for instance evaluate the Environmental Impact Assessment and the Feasibility Plans of new LSI schemes. An example is for instance the new tunnel and hydropower plant in the Tana-Beles basin, Ethiopia. The tunnel seems to be over-dimensioned, and if not properly operated, the lake levels of Tana decline and more water is provided for irrigation than being consumed. The slopes of the Beles basin are namely steeper than desirable for flood irrigation. While drip irrigation could technically be a good solution, it is not straightforward to implement these high tech solutions in the savannah of Ethiopia. The SAPs can provide a general assistance on these issues to the National Governments.

Now all LSIs in the Nile Basin are benchmarked for 2007, Governments should take action. The National governments should embark on a program that systematically evaluates the performance of their irrigation schemes: a benchmarking. Egypt provides for instance all attention to the Nile Delta, and wants to improve these areas even further by means of modernization. The attention and investments in Upper Egypt are lower and the best is to provide extra efforts to the management of poorly operated LSIs. The various ministries of Irrigation and Water Resources should ideally define the future targets of the indicators, and then prepare a technical plan to achieve that.

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APPENDICES

Appendix A Information needs for the assessment of irrigation system performance

Wim Bastiaanssen & Chris Perry (WaterWatch consultants)

March 7th, 2007

We have numerous reports from the Nile Basin Initiative and elsewhere regards the *general* status of irrigation development in basin countries, as well as broad policy statements. However, to fully understand how a large scale irrigation system is working, and particularly to assess what contributes to good performance and poor performance, we need information at the project level.

At the national level, the questions are:

1. Is there a national policy on water resources? (If so, please provide copy)
2. Does it cover surface and groundwater?
3. Are priorities specified for water allocation of water among sectors (domestic, agriculture, industry...)?
4. Are objectives specified for large scale irrigation systems (eg food security; increased rural incomes; job creation, etc)
5. Are water rights (absolute volumes, proportions, guaranteed minimum) specified to major users?
6. Are licensing procedures in place for new uses?
7. If water rights are specified, how are they monitored/enforced?
8. What are the categories of irrigation system (individual owner/user; collective small-scale private irrigation, large scale irrigation).
9. In the large-scale irrigation sector, who is responsible* for:
    f. Planning
    g. Design
    h. Construction
    i. Operation and Maintenance**
    j. Regulatory functions

    * Responsibilities may be with central government, state government, project authority, users, private agency, etc.

    **Specifically for large scale-irrigation scheme operation, indicate points at which responsibilities are transferred from agency to farmer-organization to individual farmers, as appropriate.

10. What are the financing arrangements for construction, management, operation and maintenance of irrigation systems?

Additional project-specific questions are set out on the following page. We would appreciate receiving information related to a few selected irrigation schemes, that can be considered to be representative for a given country or agro-ecological zone. We aim at compiling a few good quality and complete datasets for selected schemes (not more than 3 per country).

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Chris Perry: chrisjperry@mac.com

Scheme name				
Location				
Describe purpose of project:				
(eg food security; area development, commercial plantation)				
General description				
(irrigation technology, responsibilities of agency and farmers in crop planning and water distribution)				
Average farm size (ha)				
Technical Information:				
Area equipped for irrigation (ha)				
Cropping seasons	(months)			
1				
2				
3				
Main crops PLANNED	Name	Season(s)	% area	Yield (t/ha)
1				
2				
3				
4				
5				
Main crops ACTUAL	Name	Season(s)	% area	Yield (t/ha)
1				
2				
3				
4				
5				
		m3/sec		
Principal water source	Pumped from river			
	Diverted from river			
	Groundwater			
Availability (continuous, seasonal…)				
Seasonal entitlement (000 m3)				
Season 1				
Season 2				
Season 3				
Availability (always, most years…)				
Season 1				
Season 2				
Season 3				
Other sources:				
Type				
Capacity (m3/sec)				
Cropping seasons	(months)			
1				
2				
3				
Main crops	Name	Season(s)	% area	
1				
2				
3				
4				
5				
Rainfall (Monthly)	Mean	Highest 10%	Lowest 10%	
Jan				
Feb				
Mar				
Apr				
May				
Jun				
Jul				
Aug				
Sep				
Oct				
Nov				
Dec				
Cost of Operation & Maintenance				
Currency				
Amount/year				
Sources of funds				
Government				
Water charges				
Responsibilities in operation:				
Agency				
Farmers				
Responsibilities in maintenance:				
Agency				
Farmers				

Appendix B Study Tour to Best Practice Sites of Large Scale Irrigation (LSI) Schemes in Egypt

1. Introduction

The diagnosis of the irrigation peformance in the Nile basin showed that the Governorate General of Kafr-el-Sheik appeared to be the most favourable area. A short study tour was organized to visit some of the irrigated farms in this region. The irrigation activities in the Western Desert appeared also to be extra-ordinary good in terms of using modern technologies that save water, and it was believed interesting to visit these contrasting areas: old land with surface irrigation systems vs. new land with modernized irrigation systems. The program balances technical issues with institutional aspects. This report describes the major findings of the two-day study tour. The detailed program is attached in Appendix 1. The list of course participants is specified in Appendix 3.

Objective of study tour: Exposing irrigation professionals and policy makers from the Nile basin countries to the irrigation conditions and institutions in Egypt; Understanding the reasons behind best practices

The EWUAP project is indebted to Engineer Ibrahim Mohamed Mahmoud and his colleagues who invited the international guests to their ongoing Integrated Irrigation Improvement and Management Project (IIIMP) areas. The service of Dr. Fathy El-Gamal and his colleagues in the facilitation of this study tour and provision of further technical and logistical support is also acknowledged.

2. Monday 15 September 2008

The traditionally irrigated alluvial soils of the Nile Delta were visited during the first day of the study tour. Two mini-busses left early from Cairo to Kafr-El-Sheik. Introduction to the irrigation practices in Egypt and some background information on the IIIMP improvement project was shared by various speakers with the participants of the study tour. The aims of the IIIMP project are:

- increase uniformity of access to irrigation water resources;
- increase agricultural production; and
- reduce operational costs of pumping.

The IIIMP has a few pilot areas, and the Mit Yazeed main canal is one of them. Mit Yazeed is located in the Kafr El Sheik region, and this area was visited for a closer inspection. The inlet of one of the branch canals has been visited. The inlet has now an orifice type of inlet structure that can be remotely controlled (also manually). The excursion continued to the meska and marwa improvements. There is one central lifting point for the meska and the water is put under pressure and brought to individual fields by a burried pipeline. The water is continuously available and it is a true on-demand water supply system: open the tap and irrigate. Due to the growing intensive rice cultivation, there are short periods that the water demand cannot be met. The farmers (who first denied this type of interventions) are happy with the change because:

- less petrol costs by abandoning individual diesel pumps;
- less competition during rotational flow when the branch canal receives water;
- tail end farmers can now irrigate with canal water (before from the drain);
- they can cultivate a larger fraction of rice (they are liberal to sell rice);
- the yields went up by 10 to 15% due to better water quality and reduced crop water stress; and
- it also gives them more flexibility to select the crop since it is feasible to grow 3 crops per year.

The water managers are satisfied because:

- farmer complaints have stopped;
- there is less on-farm water losses because excessive irrigations doesn’t occur any longer; and
- the amount of water supply (‘gross supply’) has been reduced.

Rice is the major crop in Kafr-El-Sheik. The area is very flat, the water table is shallow and the alluvial soils are of excellent quality. Farmers can acquire fertilizers and seed against a relatively low price. The seeds are continuously improved through the breeding programs of the Ministry of Agriculture. The rice season duration is short (90 days after transplantation) and the grain/straw ratio is very favourable. These conditions are fundamental for acquiring 10 ton/ha, an extremely good achievement. The short duration can be hold largely responsible for reducing the total water consumptive use (approximately 600 mm/season).

The LSI analysis also showed an excellent performance in the vicinity of Rasheed (see Appendix 2 with examples of satellite images). This can be largely explained by the presence of orchards and date palm gardens. These permanent crops seem to be suited for constant and good irrigation practices.

3. Tuesday 16 September 2008

During the second day, a trip was organized towards the new land with the main objective to understand modern irrigation systems and impact on irrigation performance. Also a visit was paid to a district water board for getting exposure to institutional changes and arrangements.

Dina farms (www.dinafarms.com)

The farm was established in 1987 with 1500 feddan, and it abstracts groundwater from the Marmarica aquifer. The wells are approximately 200 m deep and the groundwater table can be found at 100 m. Due to the establishment of several new estate farms and absence of groundwater regulations in the new lands along the desert road, over-exploitation of groundwater have been emerging. The commercial farmers - together as a cooperation - will pay the cost of construction of a new pipe line that conveys Nile surface water resources to augment the lack of groundwater resources. The World Bank is providing a loan to the enterprises for facilitation of the capital investment. Dina farm is currently covering 12000 feddan. It employs 2000 workers.

Dina farm has 86 centre pivots. The average size is 60 hectare. The pivots are cultivated with alfalfa and maize for animal feed. Each pivot has its own well. The wells are connected to a network for ensured irrigation water supply.

Dina farm also produces several high value horticultural products. They are sold to the national and international market, hence the timing of the harvesting is of paramount importance. The table below provides some indications on the type of fruits and vegetables grown.

Crop type	Yield
	(ton/ha)
Fruits	Table grapes (30 ton/ha); Strawberries; Oranges (45 to 55 ton/ha) ; Mango (40 ton/ha) ; Apricot ; Lemon; Apple; Bananas; Dates; Olives; Peaches
Vegetables	Onions; potatoes
Field crops	Alfalfa (5 to 6 cuts); maize

The crop water requirements under desert conditions are 1500 mm/yr. This represents the potential evapotranspiration. The centre pivot system is considered to be ideal because irrigation can be provided with much more precision than with surface irrigation methods. Further to water related arguments, it was mentioned that expensive fertilizers and pesticides are not leached out. US-based Siematic pivots were first installed and used (US$ 45,000), and they are nowadays replaced by Egyptian made systems (US$ 35,000). Despite these high costs, it is believed that centre pivots provide a positive renumeration due to reduced pumping costs, reduce water consumption and diminish leaching of fertilizers.

It must be recognized that the sandy desert soils are not suitable for surface irrigation methods, and hence there is not much of an alternative, except the installation of drip systems. The managers remarked that they would also opt for center pivot systems on alluvial soils in the Delta.

Centech farm (www.egyptgreen.com)

Centech farm (600 acres) is part of the El Shorouk farm that sells the EgyptGreen brand name products. The farm aims to achieve a high economic water productivity by intendently optimizing the net profits per unit of water ($/m^3). This is in full line with the approach taken by the LSI study. Cutflowers and ornamental plants are superior for economic returns (upto 12 US$/m^3). Centech has imported irrigation and agronomical technologies from Chili (grapes), South Africa (grapes & mango's) and Morocco. This reveals that taking the best practices from other countries is a wise principle.

Virtually all irrigation on Centech farm occurs with drip systems. Each well has a capacity of 120 m^3 of water/hour and each well serves 50 acres. It is a system of fertigation where fertilizers are applied via the drip system. For safeguarding water supply throughout the farm, the minimal distance between the wells is kept at 50

m. Centech is experimenting with low tech sprinklers for overhead irrigation (20 ha). Irrigation is computed daily on the basis of weather station data and soil moisture measurements. Traditional irrigation in Egypt can be as high as 3200 m^3/feddan/month (26 mm/d) because 50% of the water resourcse will not be available to the crop and all soil in staple crop fields is covered by canopies. The sandy soils with drip systems need only 700 m^3 of water/feddan/month (5.6 mm/d) because:

- the supply is fine-tuned with the demand and losses are minimal; and
- the demand is low because not all soil is covered by canopies

For the above mentioned reasons, actual crop evapotranspiration can be kept low. Most crops are cultivated on high ridges (60 cm tall) for the purpose of salt leaching, easier access to the crop for protection and harvest, and for maintaining strips of bare soil to reduce the consumptive use at plot scale. The wide furrows of 2 meter are kept free from weeds mechanically. Underground fertilizer application and soil structural improvement is realized for reclamation of desert soil. The sandy soils are highly permeable and have a low Cation Exchange Capacity. The experience is that the soil fertility largely improves after 20 years of cultivation. The following crop types are cultivated on Centech farm, among others:

Crop type	
Fruits	Bananas, pear, apricots, pears, olives, citrus
Vegetables	Straberries, tomatoes, asperagus
Ornamental plants	Cutflowers, indoor plants
Nurseries	Citrus, mango, fruits and vegetables

The ornamental plants are cultivated in greenhouses. Some indications on the crop yield can be derived from the table below:

Crop type	Yield
Table grapes (seedless)	15 ton/ha (price is US$ 3.6/kg)
Citrus	58 to 63 ton/ha (price is US$ 0.5/kg)
Bananas (illegal)	63 ton/ha
Olives	15 (pickles) to 25 (processing) ton/ha

District Water boards

It is unique in Egypt to establish district level water boards. The newly established water board in Bustan is one of the first endeavours to combine governmental decision making processes on (i) water allocation and (ii) canal maintenance with the requirement of the commercial farmers. In fact, the water board hosts both small and large holder irrigators in good harmony. The members of the board are freely elected. The board appears to be powerful and decisions between various stakeholder groups are made more transparently. The water board consists of 5 committees:

- irrigation and improvement;
- irrigation;

- drainage;
- environment; and
- pollution

The board meets monthly and more intensively when so required. They believe that the board has contributed to higher crop yields and lower water use. Convincing data to demonstrate this argument were not given. It was however clear that the board members were happy with this new institutional direction.

4. Best irrigation practices in Egypt

On the basis of the several introductions and the discussion with policy makers, researchers, water managers, water boards, water user associations and farmers, it is concluded that various perceptions on the best practices exist. The best practices brought forward by the Egyptians are:

1) Excellent breeding program that have shortened the rice growing period after transplantation to 90 days (e.g. Hakili variety). The maximum harvest index (grain ratio) is 67%. Rice yields of 9 to 10 ton/ha are nowadays normal and potential yield is increasing further;
2) tuned irrigation supply to cropping pattern through the mechanism of planning via agricultural department and irrigation districts;
3) maintenance of constant water level in branch canals by means of continous flow so that on-demand irrigation practices can be applied at mesqa level;
4) intensive extension services through Irrigation Advisory Service, especially at the onset of the project for fostering interaction between farmers and irrigation district managers;
5) proper maintenance of canals;
6) district water boards for merging commerical farmers with public services to detect common interest;
7) surface irrigation on alluvial soils and sprinkler/drip on sandy soils; and
8) cultivation of high value crops and timely access to markets

Overall, it is an integrated or a holistic approach (delivery of water, seed, fertilizer, pesticide, credit, management practices, and extension services) to agricultural productivity improvement that has contributed to existing conditions. In addition to that, it is likely that the natural conditions of soil, groundwater table and climate have a great contribution, that is not sufficiently recognized.

Annex 1.1: Program of the study tour

Saturday / Sunday 13 & 14 September

Arrival of participants from various countries and checking in to the Flamenco Hotel in Cairo (Zamalek Island)

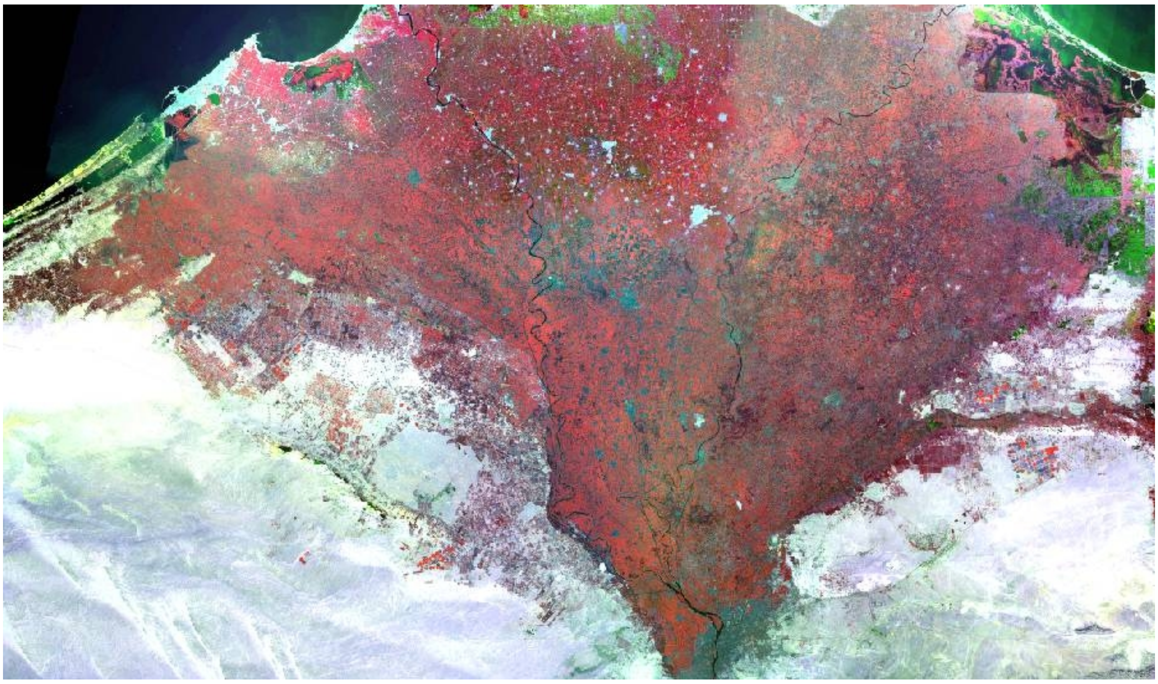
Monday 15 September

6.15 Breakfast at Flamenco Hotel
7.00 Departure by mini-bus
9.15 Arrival at the IIIMP office at Kafr-El-Sheikh – Nile Delta
9.30 Introduction to the irrigation systems in Egypt
Prof. Fathy El-Gamal (National Water Research Centre)
10.00 Institutional issues and irrigation improvement
Eng. Ibrahim Mohamed Mahmoud (Waterboards & IIIMP project)
10.30 Agronomical practices and crop yields
Dr. Hassan Shams (Min. of Agriculture)
11.00 Irrigation performance in the W10 area
Prof. Dr. Wim Bastiaanssen
11.30 Departure to the field
Visiting main and branch canals
Visiting improved mesqa
Discussion with water user association & farmers
Understand best practices
14.30 Departure to Cairo
17.30 Arrival at Flamenco Hotel

Tuesday 16 September

7.15 Breakfast at Flamenco Hotel
8.00 Departure from Cairo
9.30 Arrival at Dina Commercial Estate in the Western Desert (http://www.dinafarms.com/about_who.shtml)
9.45 Introduction to the irrigation management on the farm
Drip irrigation systems, water consumption, groundwater depletion, aquaduct, crop yields, and market prices
10.30 Tour on the farm and departure
11.0 Arrival at CENTECH Farm, Dr. Adel Ghandour
(http://www.egyptgreen.com/)
11.15 Presentation about Irrigation Practices. Production
11.45 Tour on the farm and departure
12.45 Arrival at Bostan District Water Board
13.00 Reception at the District
13.10 Explanation of the objectives and achievements
14.00 Tour through the traditionally irrigated area
15.30 Departure to Cairo
17.00 Arrival at Flamenco Hotel

Annex 1.2: Examples of satellite images of the Nile Delta



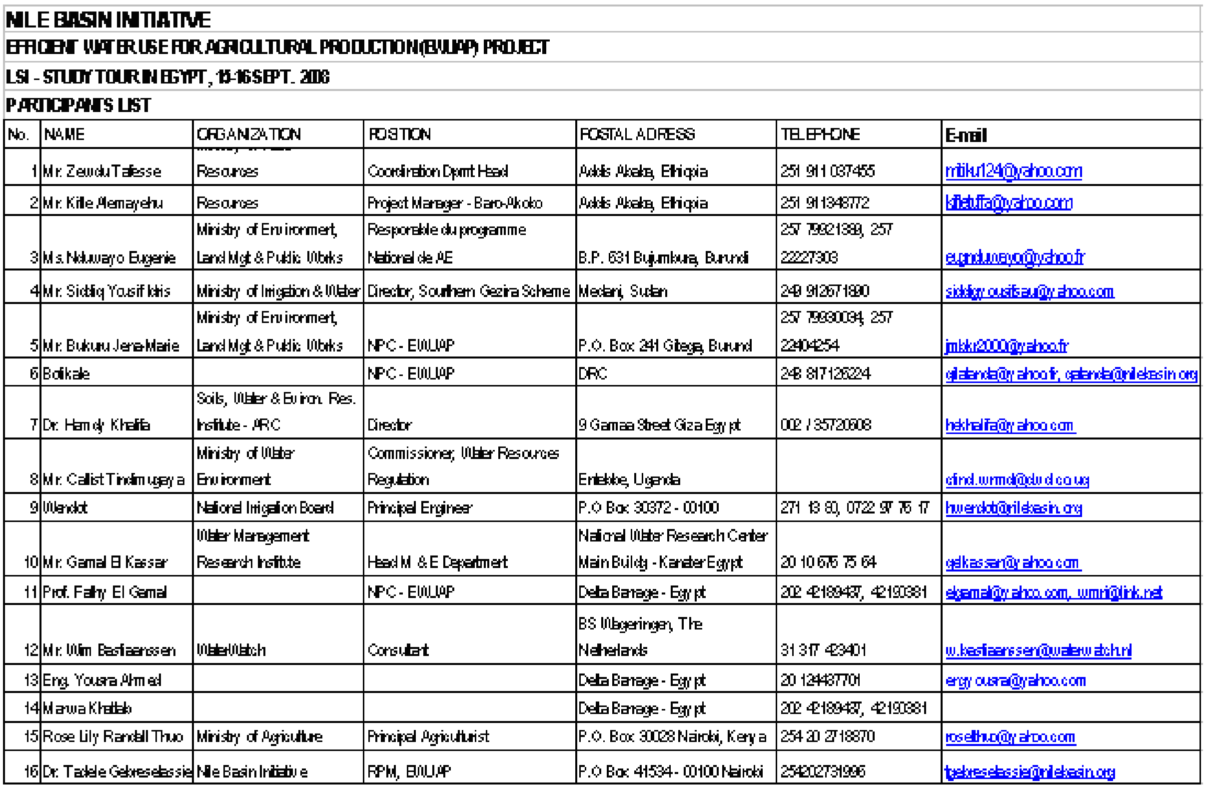
False Colour Composite (FCC) images based on Landsat Thematic Mapper measurements. This FCC images is compiled from different individual Landsat images for the purpose of covering the entire Nile Delta. Red colours express a high near-infrared reflectance, being a characteristic for vigorous crop growth. The more red, the better the agricultural production. The white areas are bright desert sandy soils.

Detailed False Color Composite of a Landsat Thematic Mapper image acquired on 25 June 2008. In this case green represents a high near-infrared reflectance, being a characteristic for vigorous crop growth. The more green, the better the agricultural production. The Western branch of the river Nile (Rosiette Branch) is visible. The purple color represents urban areas (light purple) or sand dunes and beach (bright purple). The black color are wetlands and fishponds. The inset with the yellow boundaries diplayed is the W10 area, being a pilot zone of the IIIMP project. The W10 tertiary irrigation system has been visited during the study tour. The white lines represent irrigation canals. A detailed picture is portrayed on the next page*

*Crop water productivity of rice and cotton fields in the W10 tertiary unit and surrounding area. The background images in green represents the False Colour Image. All black and white pixesl are rice and cotton fields. The pixels with the highest crop water productivity are displayed in white (>1.6 kg/m^3) and in grey are approximately 1.0 kg/m^3. Dark *pixels need to undergo an improvement program. It is interesting to note that the area west of W10 has the best utilization of irrigation water resources. This example demonstrates the capacity to monitor crop water productivity on a field by field basis*

Detailed Landsat Thematic Mapper picture of the Dina farm along the Desert Road. This commercial farm was visited on September 16th. The circular features are center pivot systems present on the farm with sprinkling irrigation. The rectangular structures show orchards with drip systems. The white line from southeast to northwest is the Desert road.

Annex 1.3: List of participants



NILE BASIN INITIATIVE

EFFICIENT WATER USE FOR AGRICULTURAL PRODUCTION (EWUAP) PROJECT

LSI - STUDY TOUR IN EGYPT, 15-16 SEPT. 2008

PARTICIPANTS LIST

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Appendix C Study tour Sudan: Remote Sensing Analysis of Gezira and Kenana, Sudan

Background

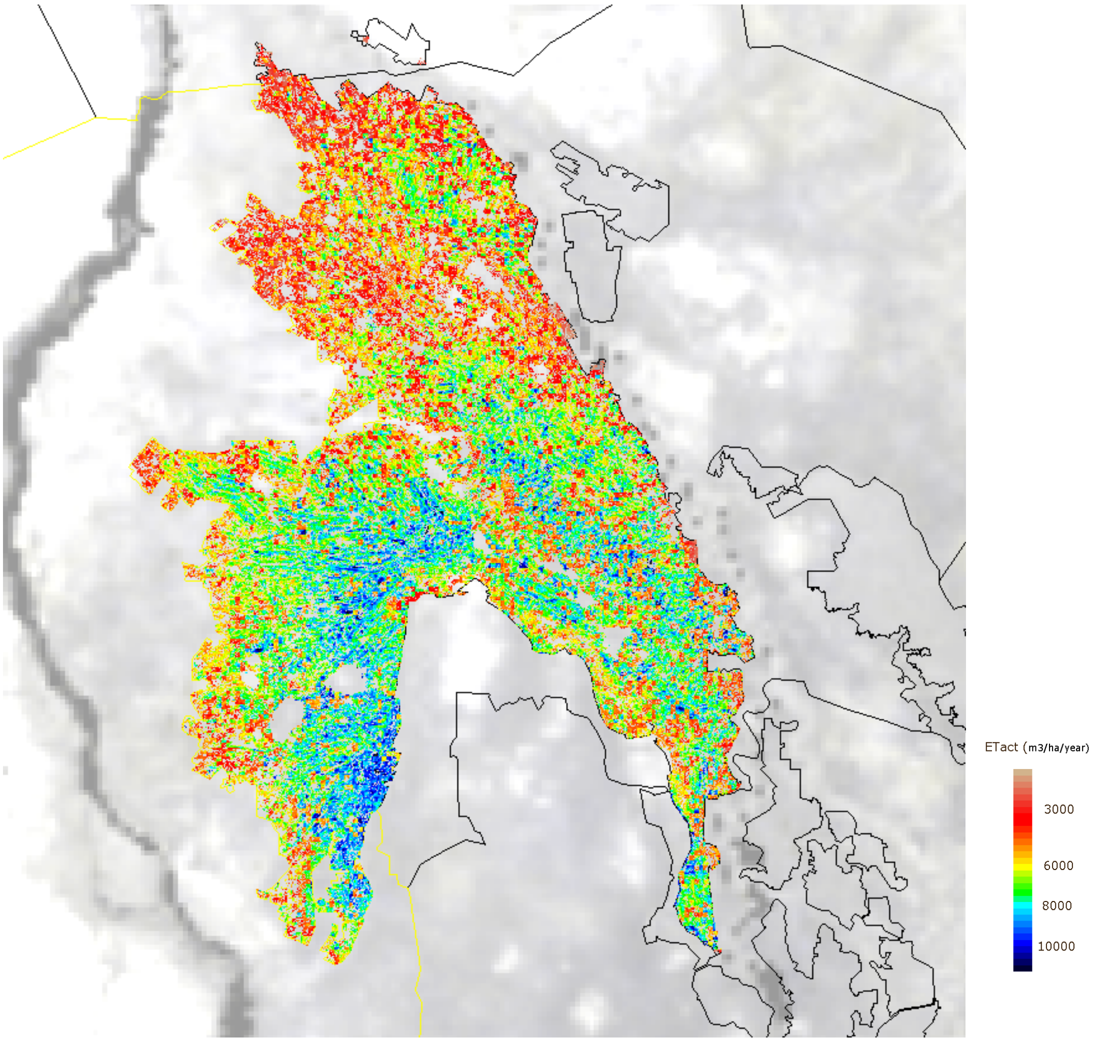
A study tour is organized to the irrigation schemes of Gezira and Kenana as part of the ongoing NBI-EWUAP project on Large Scale Irrigation systems analysis. This memo has been prepared to support the field excursion. It will show the irrigation conditions in these two contrasting areas. These maps could be used when meeting with irrigation managers in the field.

Gezira

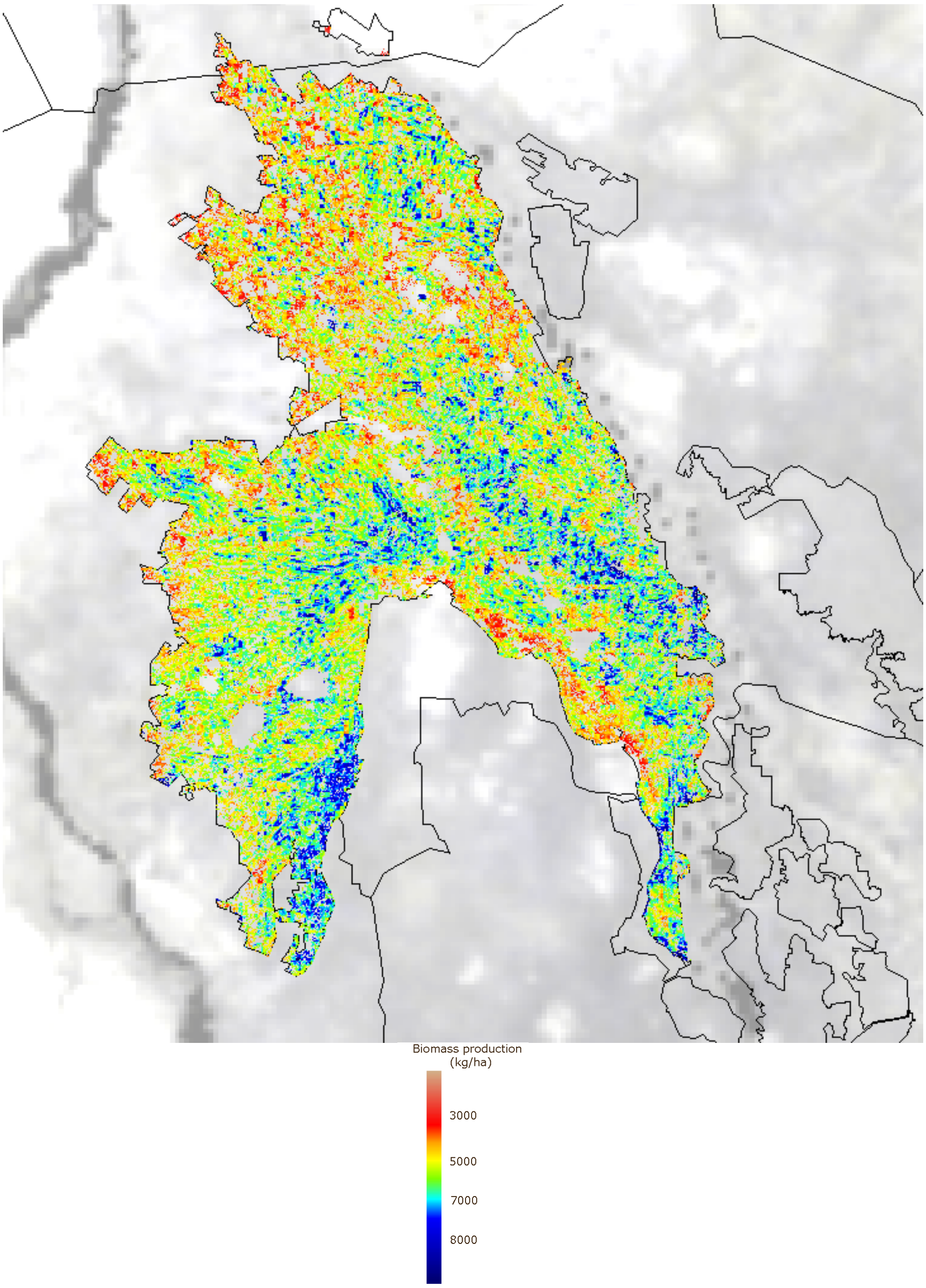
ة The Gezira Scheme (Arabic: مخطط الجزيرة) is one of the largest irrigation projects in the world. It is centered on the Sudanese state of Al Jazirah, just southeast of the confluence of the Blue and White Nile rivers at the city of Khartoum. The economy of Sudan was historically based on agriculture prior to the beginning of oil exports in the late 1990s. Before independence in 1956, the scheme main objective was to produce cotton raw material to feed textile the textile factories in the United Kingdom. The national government had designated social development as one of the main objectives of the scheme. An appreciable portion of the profit was directed to overwhelming social development projects. The Gezira Scheme started in 1911 with an area of 250 feddans (1=1039 acres) for growing cotton. As cotton proved to be successful the area was increased year after another. At the same time it was decided to construct a dam at Sinnar on the Blue Nile. In 1925 when Sinnar Dam officially inaugurated gravity irrigation started and the area increased to 2.1 million feddans by the end of 1962.

The Gezira Scheme distributes water from the Blue Nile through canals and ditches to tenant farms lying between the Blue and White Nile rivers. Farmers cooperate with the Sudanese government and the Gezira Board. This network of canals and ditches is 2,700 miles (4,300 kilometers) long, and the irrigated area covers 8,800 km^2. The main crops grown in Gezira Scheme are: Cotton, Dura (Sorghum), Wheat, Groundnuts, Vegetables, Fruits, and Fodder.

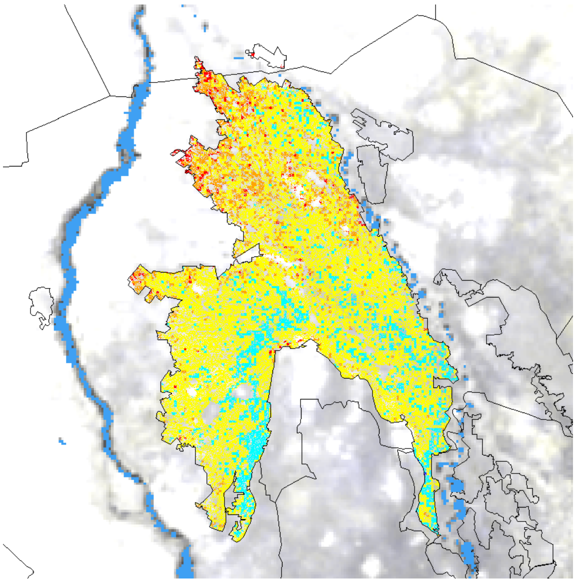
The total water consumption and biomass production have been computed for the year 2007. The results are shown on the next page. The map of actual evapotranspiration shows ET values of 8,000 to 10,000 m^3/ha/yr in the southwestern part of the scheme. This water is conveyed across a long distance. Except for this part, in general it can be observed that the head end of the system, receives more water than the tail end of the system near Khartoum. In general terms it seems that irrigation in the Northern tail end is very extensive. This could be related to limited irrigation water availability, or to the fact that farmers have abandoned their land. Also it is expected that more vegetables are grown in the vicinity of Khartoum.



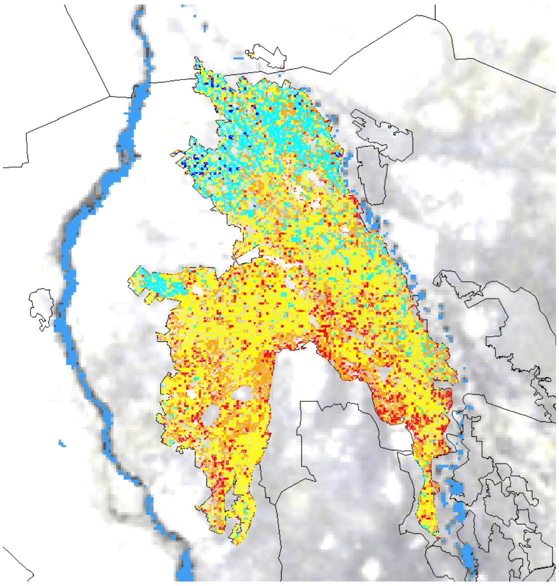
The spatial patterns of biomass production is similar to ET. The largest agricultural production levels are obtained at the southwestern tip of the Gezira scheme. The impression exists that there is a deviating cropping pattern in this part of the LSI system. From a climatic point of view, this could be systems with sugarcane or rice, but this information needs to be confirmed from the field. It could also be related to a double cropping system because 8,000 m^3/ha is basically sufficient for cultivating two seasonal crops.



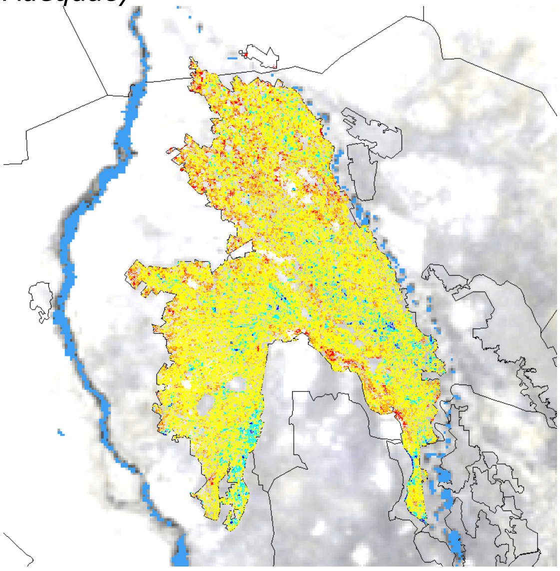
The score for every irrigation indicator has been computed for every 250 m pixel. The values of the score vary between 1 (minimum=brown) to 5 (maximum=blue). The sustainability and reliability of Gezira is high. This implies that there is a very regular pattern of irrigation water supply, and that the longer term trend of these patterns is stable. It implies that the farmers and irrigation department have obtained a stable mutual understanding and expectation. The same cropping patterns and irrigation intensities are irrigated with similar amounts of water, year after year. The adequacy map shows interesting differences in soil water status. The adequacy and crop water consumption maps are by absence of flow measurements good proxies for the real irrigation water distribution in Gezira. Adequacy and crop water consumption are inversely related in terms of score. A good score on adequacy implies that the water has reached the crop. If the crop is consuming lots of water due to frequent irrigations, the score in consumptive use is low. The fact that the beneficial fraction is low implies that the soil evaporation losses are significant. The latter suggests over-irrigation. It is interesting to remark that the highest water productivities are obtained at the tail end near to Khartoum, and the reason is the low crop water consumption. Hence, the huge water amounts evaporated by crop in the southwest are not used productively.



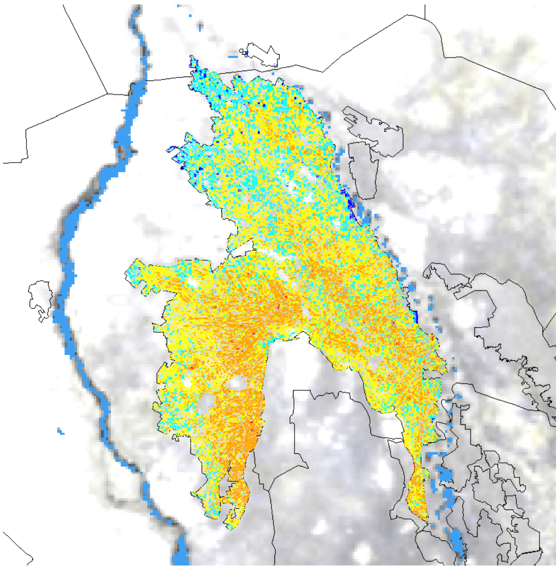
Adequacy



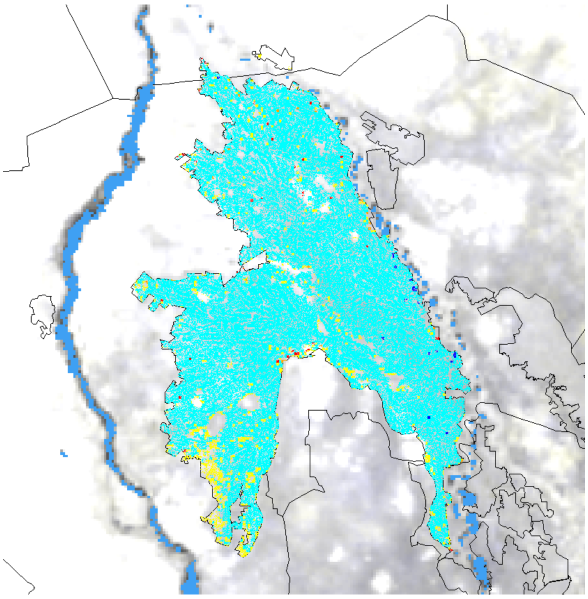
Beneficial fraction



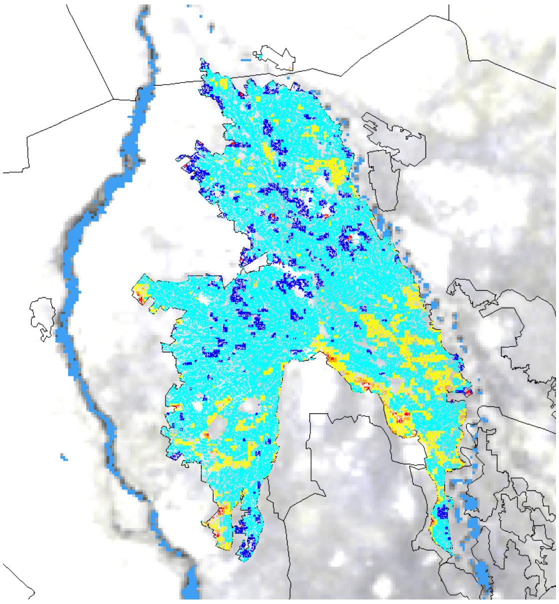
Biomass production



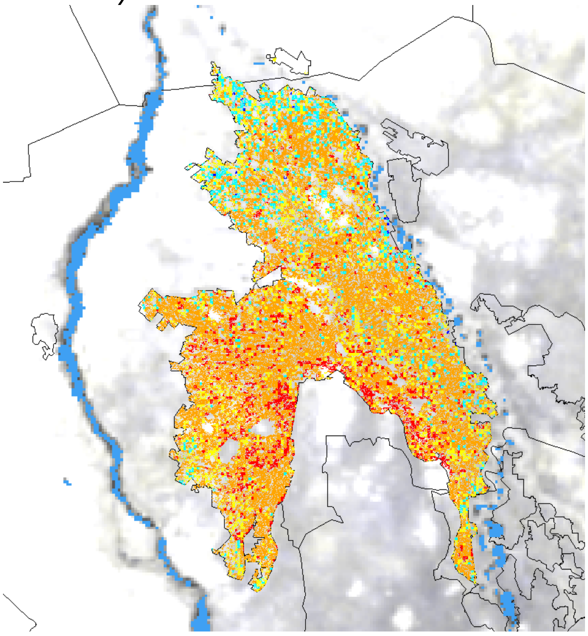
Crop water consumption



Reliability



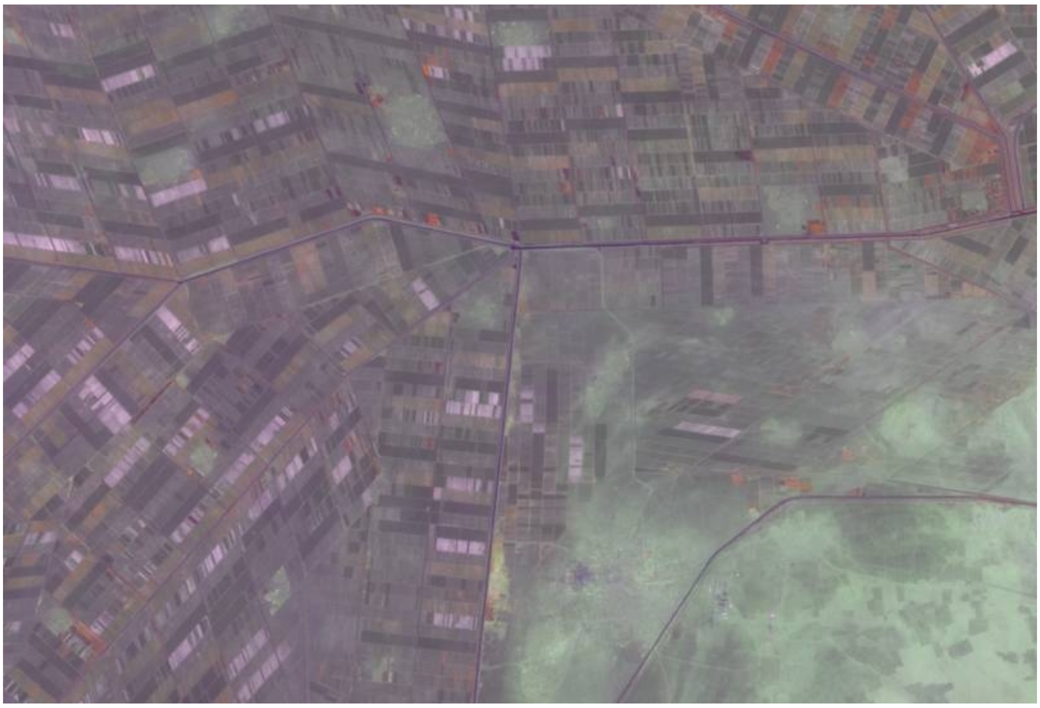
Sustainability



Water productivity

Score

🟥 1
🟧 2
🟨 3
🟦 4
🟦 5

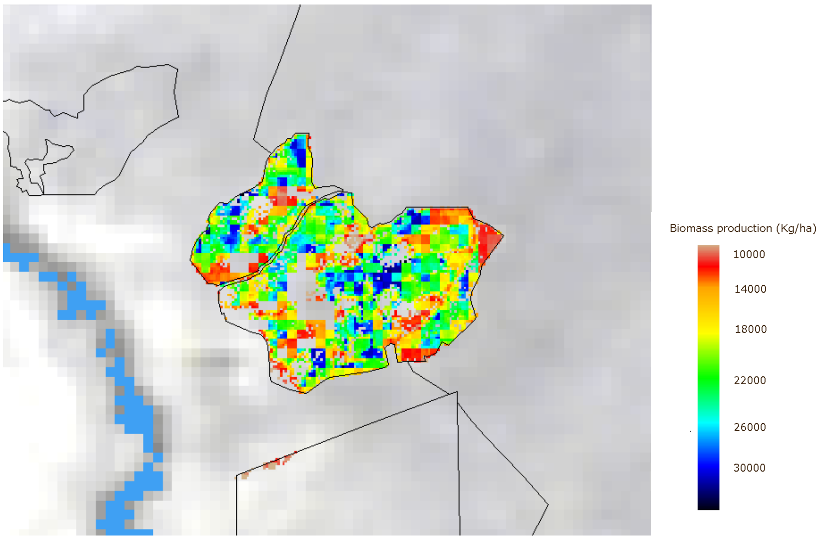


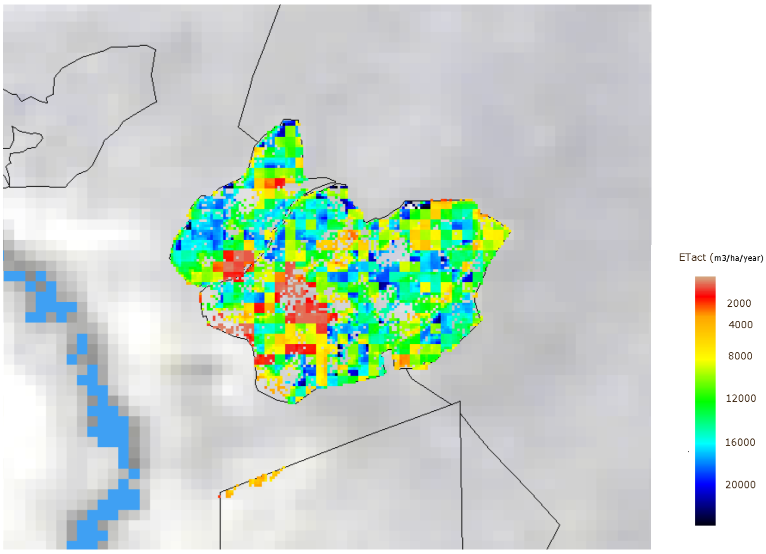
Landsat image of the central part of the Gezira scheme. Fields with a red color are cropped. The dark colored fields are bare. The fields with white color are vegetables with specific mulch treatments

Landsat image of Kenana farm. Red color can be associated with vigorous sugarcane. The grey plots are fallow or recently planted sugarcane shoots

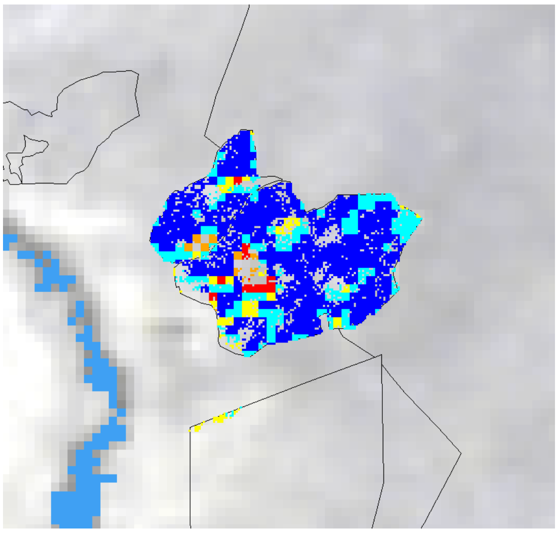
Kenana

The sugarcane estate of Kenana comprises some 50,000 ha of irrigated land. It is a commercial enterprise and the water is diverted directly from the White Nile. This area has been selected for the sake of comparison against the publicly managed Gezira scheme. The results reveal that the crop water consumption is generally much higher than for Gezira. The average value is approximately 12,000 m^3/ha/yr and certain sections reach even values up to 20,000 m^3/ha/yr. These values are in agreement with the ET values considered to be normal for sugarcane. The resulting biomass production varies from 20,000 to 30,000 kg/ha/yr. This is equivalent to an approximated fresh cane yield of 60 to 100 ton/ha. The picture shows that certain plots have low levels of cane production. These are either areas that are fallow, or planted with young shoots.

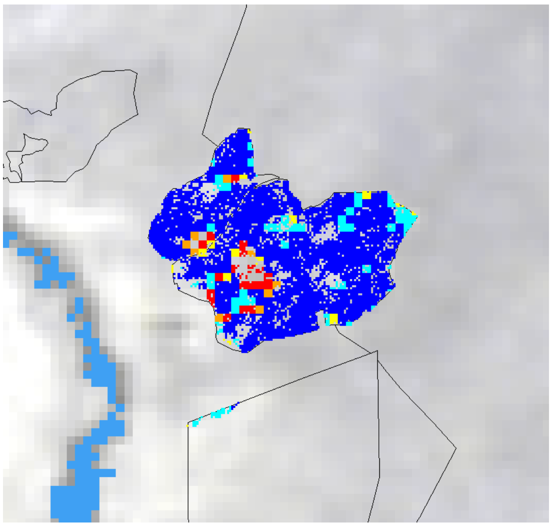




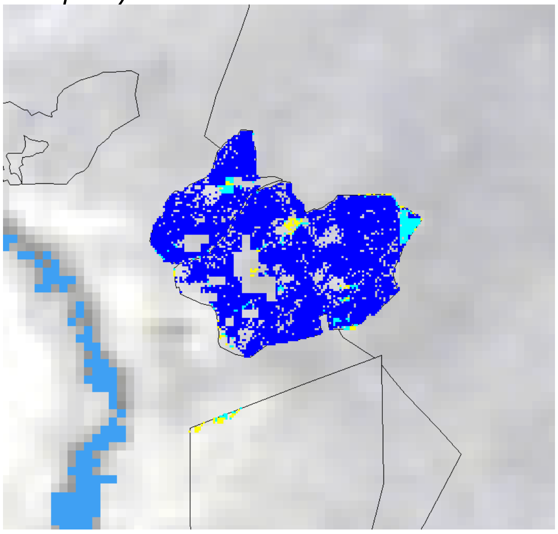
The adequacy and beneficial fraction have both a very good score (blue). This implies that irrigation water is supplied with sufficient quantities and that most water is consumed by beneficial crop transpiration. The non-beneficial evaporation losses are thus very small in Kenana (in contrary to Gezira). For this reason, the beneficial fraction is very high. The biomass production values are the highest of the region, and they have a score of almost 5.0. The crop water consumption is quite high for achieving this significant sugar production. That is also the chief reason for the water productivity being moderate. Most of the pixels have a score of 3.0, which is better than Gezira, but lower than other values attainable under the same climatic conditions. The reliability is good, but could be improved for a commercial mono-cropping sugar estate. The areas with a lower reliability reflect with a lower crop ET and a negligible biomass production. The overall sustainability is satisfactory, although certain fields on the farm are not ideal. This pixel based irrigation performance can help the irrigation management on the Kenana farm.



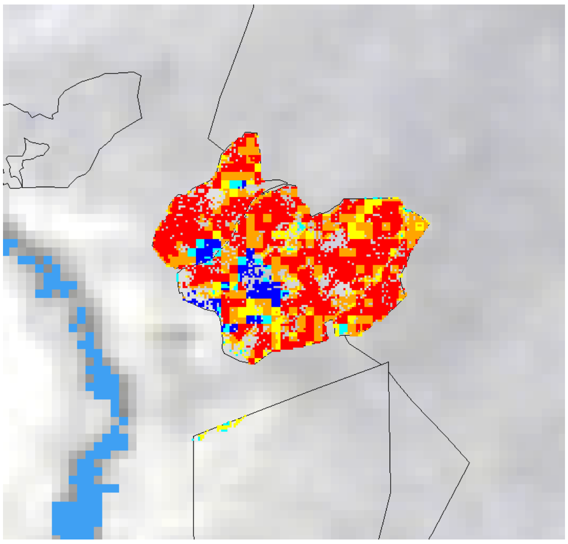
Adequacy



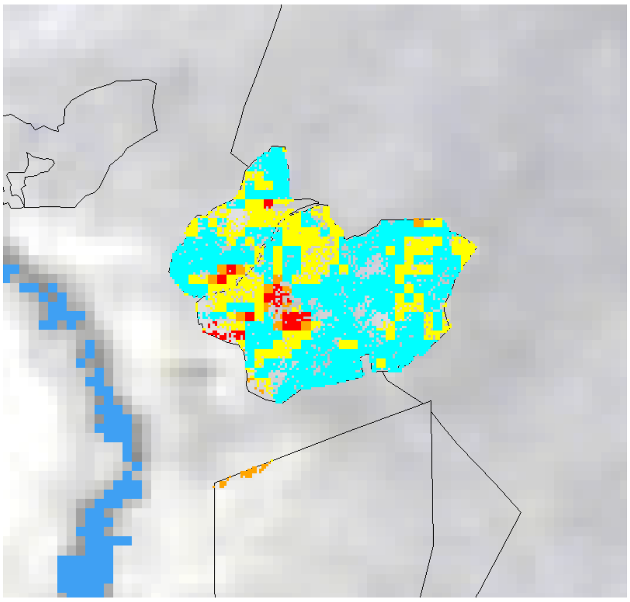
Beneficial fraction



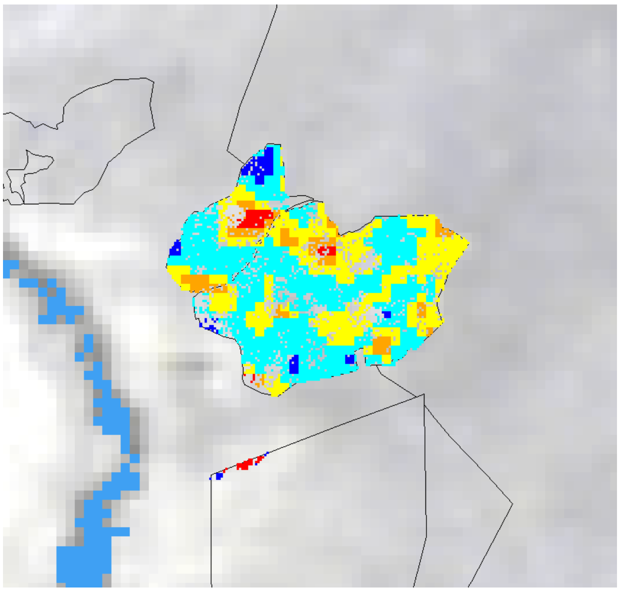
Biomass production



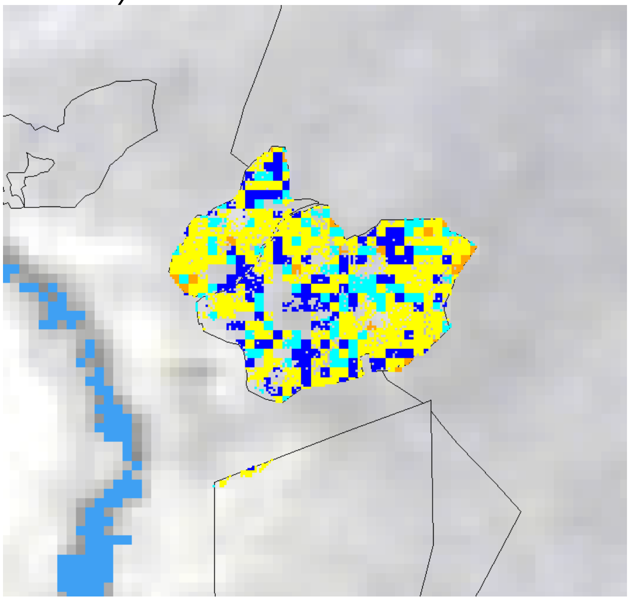
Crop water consumption



Reliability



Sustainability



Water productivity

Score

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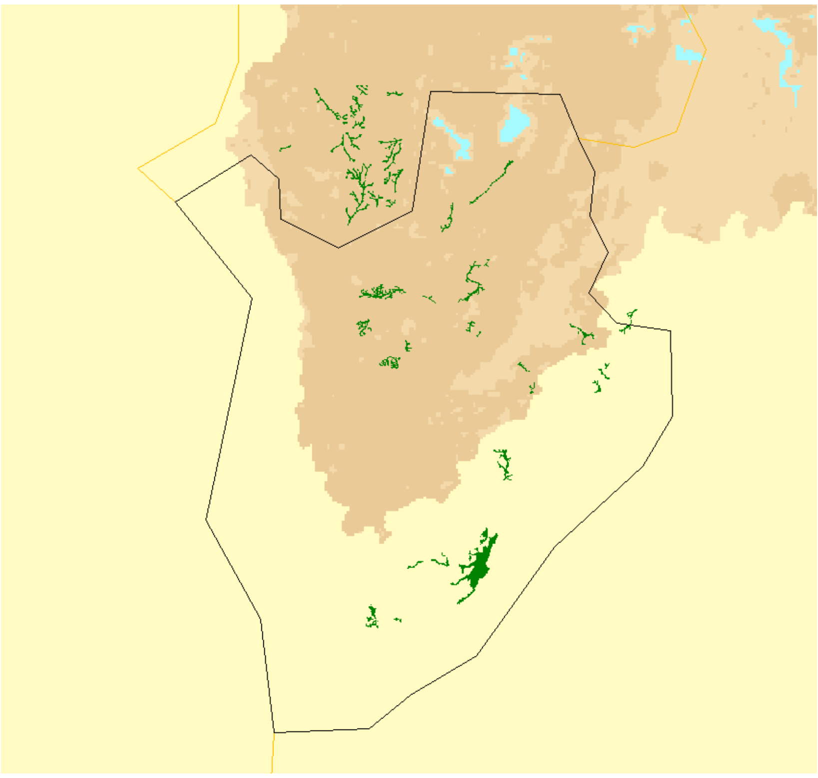
🟧 2
🟨 3
🟦 4
🟦 5

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Burundi



Appendix D

January 2009

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Part 1 Overview of irrigated areas
Part 2 Climate
Part 3 Raster and vector-based irrigation performance analysis
Part 4 Recommendations for improvement

Purpose of this report:

This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Burundi and will become an integral component of the final LSI report that will combine results from all countries.

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

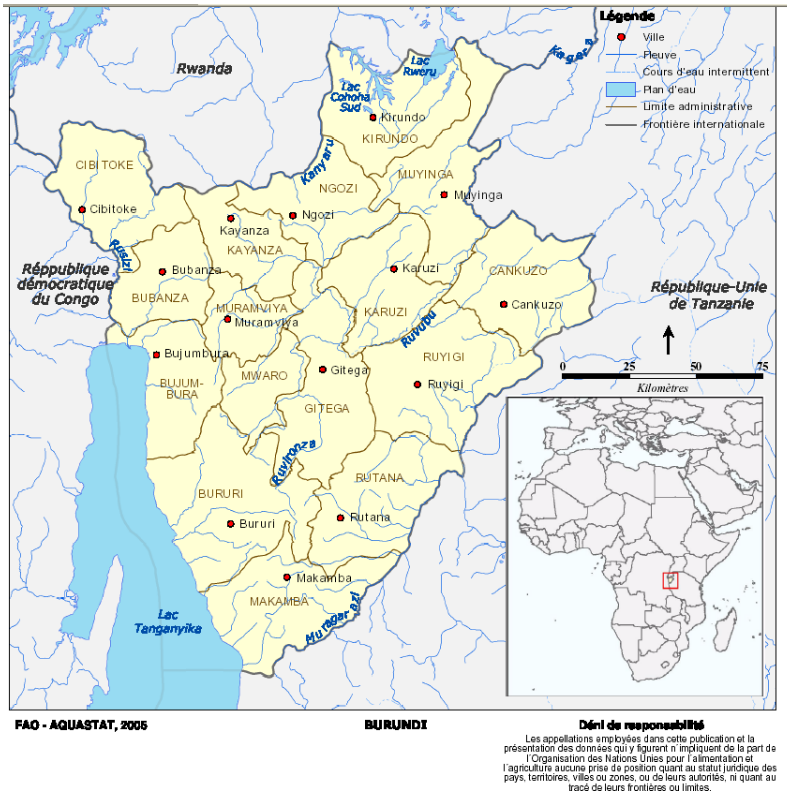
Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

Burundi is landlocked between Rwanda in the North, DRC Congo in the West, and Tanzania in the East (Figure 1). It covers an area of 27,834 Km^2 and in 2002 the cultivated area was approximately 1,350,000 ha.

Burundi is located in two basins: 13,800 km² of Burundi lies in the Nile Basin (delineated by the blue line in Figure 2); the southern and western part of the country drain into the Congo basin. The irrigated areas in the latter portions of the country are thus not included in the current analysis.

The agricultural sector in Burundi is very important for the national economy, even though the undulated topography and steep slopes are not very favourable for agriculture. The agricultural techniques are therefore still primitive and the irrigated area per household is on average low (about 0.5 ha). In the areas in the vicinity of streams and wetlands, some lands are being irrigated (represented by the red areas on Figure 2) but it represents a very small percentage of the total agricultural area.



Déni de responsabilité
Les appellations employées dans cette publication et la présentation des données qui y figurent n´impliquent de la part de l´Organisation des Nations Unies pour l´alimentation et l´agriculture aucune prise de position quant au statut juridique des pays, territoires, villes ou zones, ou de leurs autorités, ni quant au tracé de leurs frontières ou limites.

Figure 47 Burundi and its administrative districts

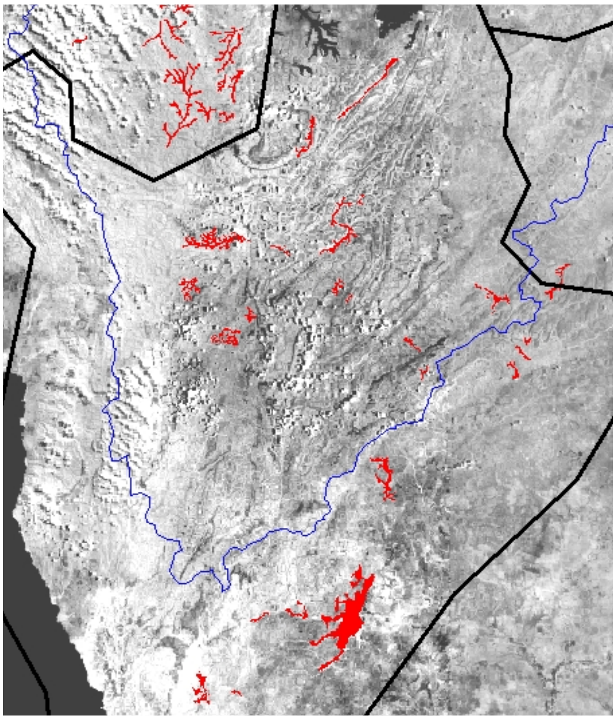


Figure 48 Map showing the distribution of the irrigated areas within the Nile Basin according to the LSI participants of Burundi.

Table 37 shows that an area of 14,625 ha of irrigated land is located in the Nile Basin. It is relatively small compared to the estimated potential irrigable surface of 215,000 ha, according to a survey carried out by the Department of Rural Engineering. The predominant irrigation method is surface irrigation which derives water from rivers by pumping and from small diversion dams. Storage dams are not yet needed as the extent of irrigation is limited and the period of rice cultivation corresponds with the rainy season (December-January to May).

Table 37 Different sources for the irrigation statistics for Burundi

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Burundi	14,400
IWMI – GIAM	Entire Burundi	11,793
Current study	Nile Basin component of Burundi	14,625

According to the FAO AQUASTAT (2005) the main irrigated crop in Burundi is rice, with a total surface of about 4,200 ha, as shown in Figure 3. The rice yield varies between 3 to 3.5 ton/ha (Gitega province). The other main irrigated crops are sugarcane, maize, beans, vegetables and coffee. Other major crops are banana (first in terms of volume production) and cotton. A land use map of Burundi is provided in Annex 2. Figure 4 displays the cropping calendar.

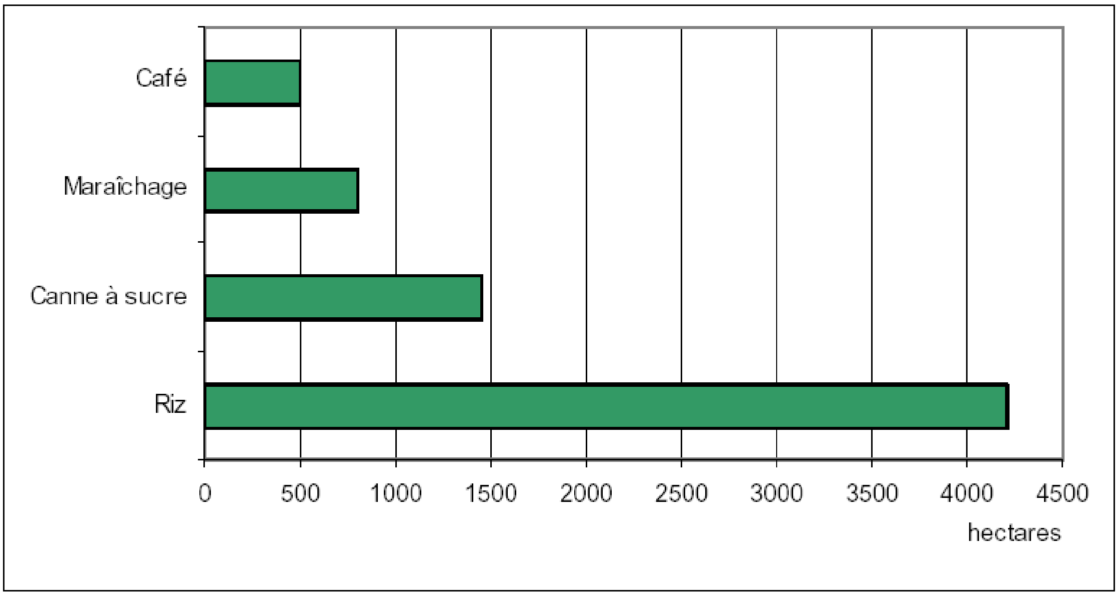
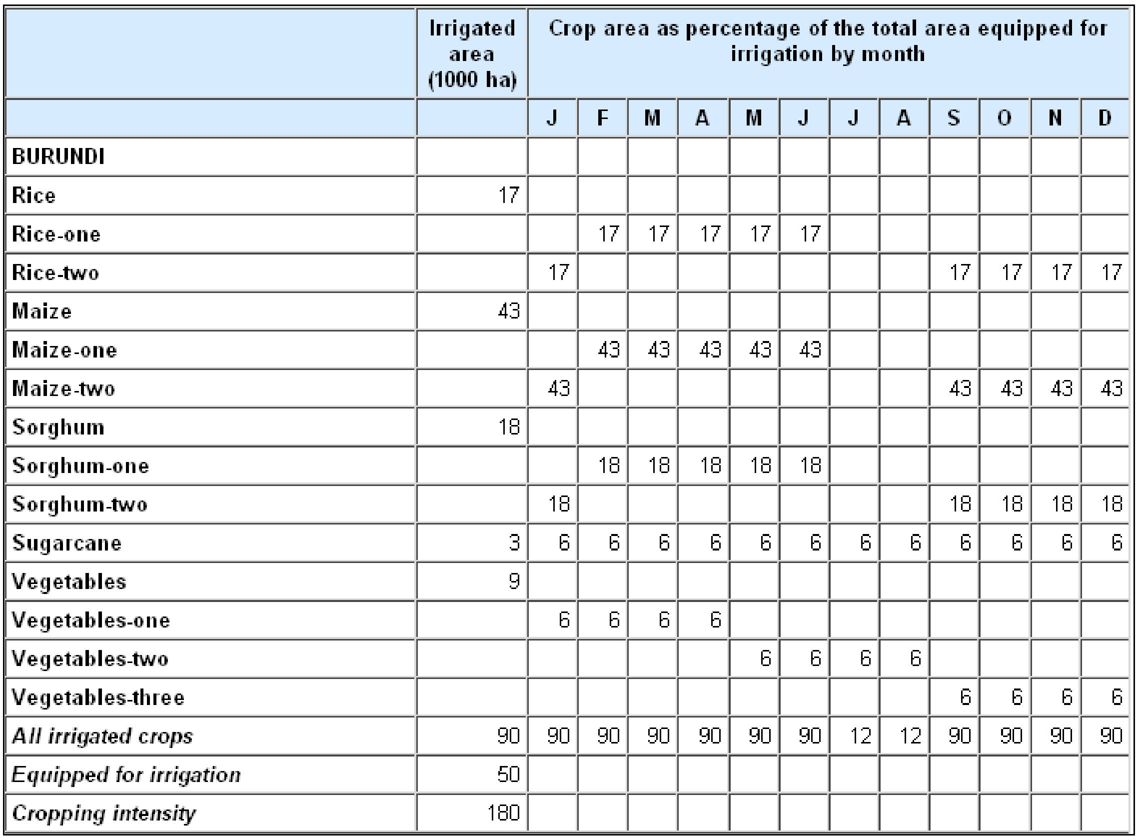


Figure 49 Main irrigated crop in 2000 (source: AQUASTAT 2005)
(café=Coffee; Maraichage=vegetables; Canne a sucre= sugar cane; Riz= Rice)



	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
BURUNDI													
Rice	17												
Rice-one			17	17	17	17	17						
Rice-two		17								17	17	17	17
Maize	43												
Maize-one			43	43	43	43	43						
Maize-two		43								43	43	43	43
Sorghum	18												
Sorghum-one			18	18	18	18	18						
Sorghum-two		18								18	18	18	18
Sugarcane	3	6	6	6	6	6	6	6	6	6	6	6	6
Vegetables	9												
Vegetables-one		6	6	6	6								
Vegetables-two						6	6	6	6				
Vegetables-three										6	6	6	6
All irrigated crops	90	90	90	90	90	90	90	12	12	90	90	90	90
Equipped for irrigation	50												
Cropping intensity	180												

Table 38: Cropping calendar for Burundi (source: AQUASTAT, 2005)

1.2 Description of LSI

Even though the unit of analysis in this study is the district, information on the irrigation systems within these districts, and the sources of irrigation water is informative (Table 39).

Table 39 Description of a few irrigation districts

Irrigation district	Province	Commune	Surface equiped with irrigation	Irrigation water
NYAMUGARI	KARUSI	BUHIGA	148 ha	Surface Irrigation Diverted from river
KAGOMA	NGOZI	NGOZI	187 ha	Surface Irrigation Diverted from river
NYAKAGEZI	KAYANZA	MUHANGA	123 ha	Surface Irrigation Diverted from river
NYARUBANDA	KAYANZA	MATONGO	187 ha	Surface Irrigation Diverted from river

These four districts have the same characteristic: river water is available throughout the year. There are three main cropping seasons: rice is cultivated in the first season, which starts in November-December. This corresponds with the rainy season. Maize is the main crop cultivated in the second season, which starts in May-June, followed sometimes by a third season in which mainly beans are cultivated.

More detailed information concerning irrigation in Burundi can be found in Annex 4.

Part 2 Climate

2.1 Climatological conditions

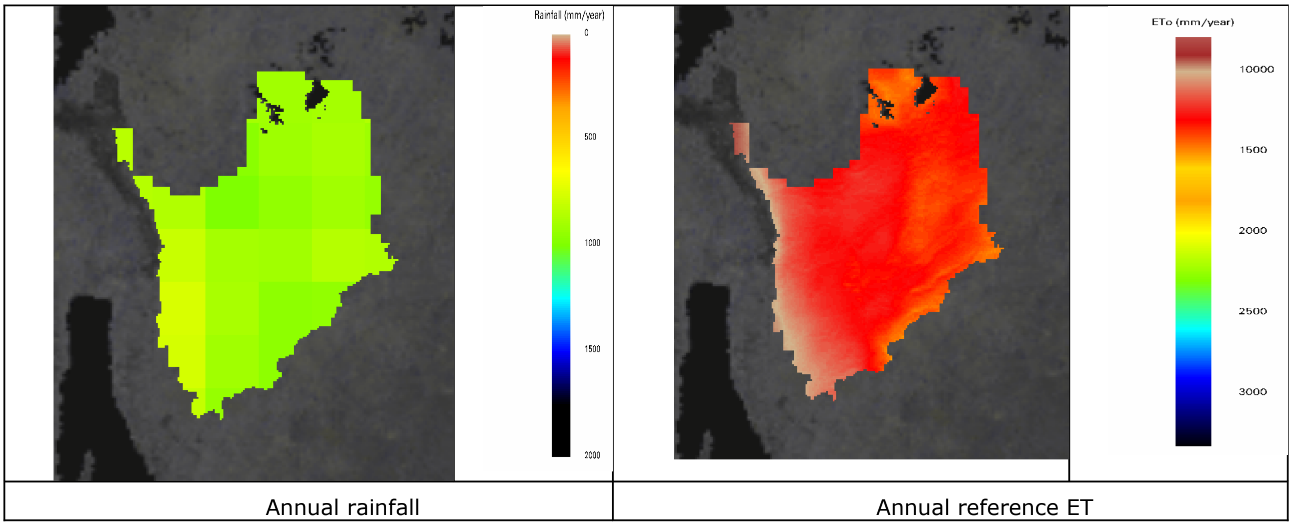
Burundi receives a significant amount of rainfall. The rainfall season is continuous and long, running from September to May. June, July and August are dry, and this is the period that irrigation is typically needed. According to the Ministry of Territorial Development and Environment (2001) and to FAO (AQUASTAT,2005) the water balance for a normal year is as follows:

- Average annual rainfall: 1274 mm
- Average evapotranspiration (ET): 872 mm

Table 40 shows the monthly values for rainfall and reference evapotranspiration (ET_0). The rainfall is based on TRMM satellite data. The ETo is computed with the standardized Penman-Monteith equation specified in FAO56.

Table 40 Monthly values for rainfall and ET_0.

Month	Rainfall (in mm)	ET_0 (in mm)	Aridity (P/ET_0)
January	97	105	0.92
February	106	101	1.05
March	131	108	1.21
April	181	95	1.91
May	91	99	0.92
June	8	107	0.07
July	1	122	0.01
August	17	132	0.13
September	59	125	0.47
October	97	122	0.80
November	146	102	1.43
December	106	99	1.07
TOTAL	1040	1317	



Annual rainfall

Annual reference ET

Figure 50 Spatial variation of rainfall (left) and ET_0 (right) for the part of Burundi that is located in the Nile Basin.

ET_0 exceeds rainfall during seven months and this shows the need of irrigation systems. The monthly water shortage occurs in June to September when the aridity index is lower than 0.5. The highest ET_0 rates occur in the plain area at the east side near Tanzania. Due to the long rainfall season, Burundi is more commonly known as a rainfed agricultural country, rather than an irrigation country.

2.2. Climatic zones

The current study aims to provide information for improved irrigation practices in the Nile Basin and covers various climate zones. This hampers a comparison between countries and among schemes. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities. Unexpected rainfall can for instance reduce the irrigation efficiency, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences on the basis of diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

The irrigation schemes of Burundi are located in climate zone 4 (humid tropics).

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on the data send by the LSI representatives of Burundi. The first step was to compute all the indicators per pixel. All the RO and PO indicators have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. These annual accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

Sustainability indicators were obtained by investigating the last five year's trends of vegetation index (from the SPOT-Vegetation satellite) and soil moisture (from the AMSR-E satellite). It indicates the slope of the trend line over these past years.

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined. A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 6).

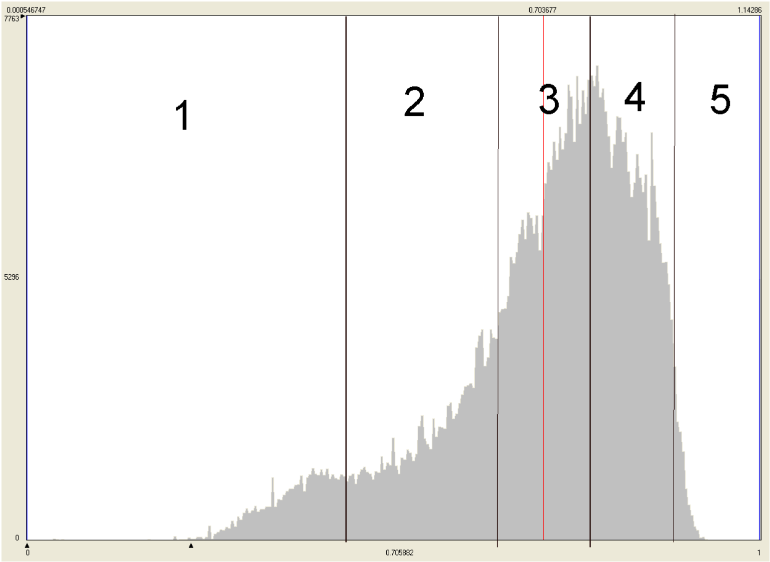


Figure 51 Distribution of the values of one indicator over 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems included in different climatic zone, different benchmark values are considered to avoid any climatic bias in the allocation of the score. Burundi is located in climatic zone 4.

Table 41 Benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
Bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
Cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
Cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
Bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
Ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
Un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
Rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
Spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
Amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, district average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at Country level

As displayed in Figure 7, the average score considering all the indicators together for all the 14,625 ha of irrigated land is 3.6, which is an above average score (the average score being 3). It shows that the irrigation systems in Burundi are sound. This average is translated into scores for each individual indicator. The aspects that Burundi should provide more attention to are those with a relative low score.

The scores of 2.8 for land productivity and 2.9 for water productivities are lower than average but still reasonable.

Concerning the PO indicators, more attention should be given to beneficial fraction. A low beneficial fraction shows a significant amount of non-beneficial ET losses. The lower than expected performance of this last indicator might explain the wide range of the land and biomass water productivity. Because the crop water consumption is quite high and the beneficial fraction low, it leads to relatively low biomass water productivity. On the other hand, there is good performance in terms of reliability, uniformity, and crop water deficit. Because irrigation water supply is continuous in time (as mentioned in 1.3), farmers are not restricted in their application of water; so the crop water deficit is low (it gets a high score). Similarly, they can rely on timely availability of water; so reliability is high.

The sustainability of irrigation practices in Burundi seems to be very good. Compared to the previous years, irrigated land is becoming greener (as the score for the land sustainability is higher than 3), hence the irrigation systems are healthy and continuous. The soils are gradually getting wetter (water sustainability gets the maximum score of 5).

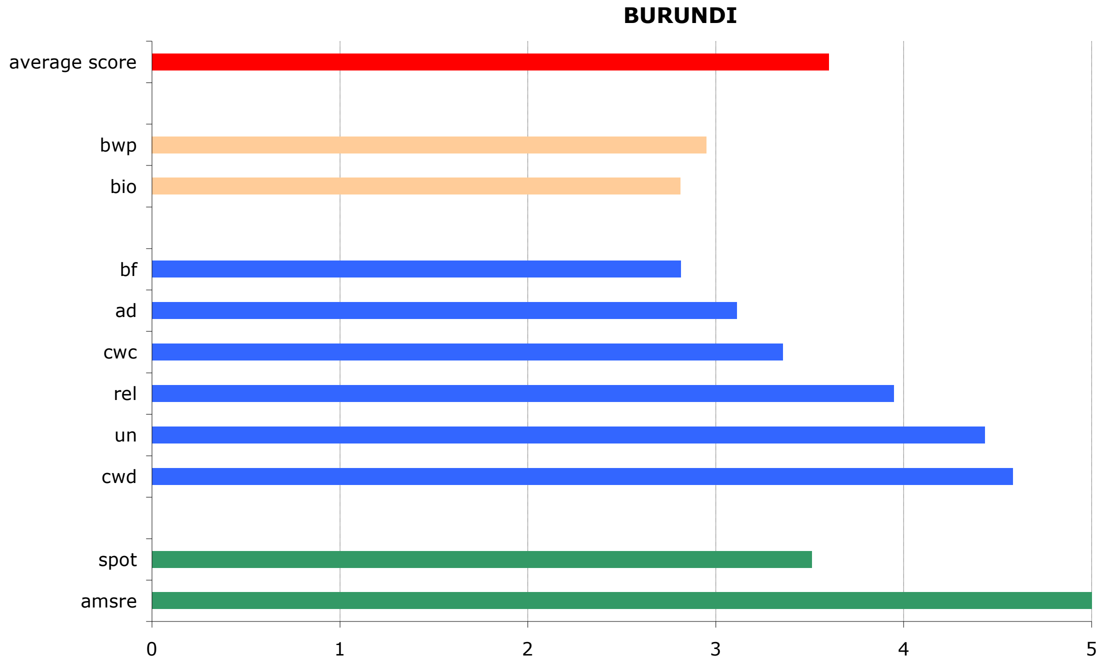


Figure 52 Representation of the average score for each indicator in Burundi.

3.3 Results at district level

3.3.1. Average per district

In Burundi, seven districts[11] have more than 187.5 ha of irrigated land (more than 30 pixels of 6.25 ha). In Figure 8 the average scores for all indicators per district are compared. It can be noticed that all the districts have a good and uniform performance on average, ranking from 3.6 and 3.8, the best district being Buziga and the poorest performing one Bugendana (see Figure 9 for their location). The equal performance per district results in an excellent score for the country level.

---

[11] According to the LSI representatives, there are more than 7 districts with more than 187, 5 ha of irrigated land. There are for example 349, 35 ha in the district of Buhiga (province of Karuzi) and Gitaramuka in the province of Karuzi with 293 ha.

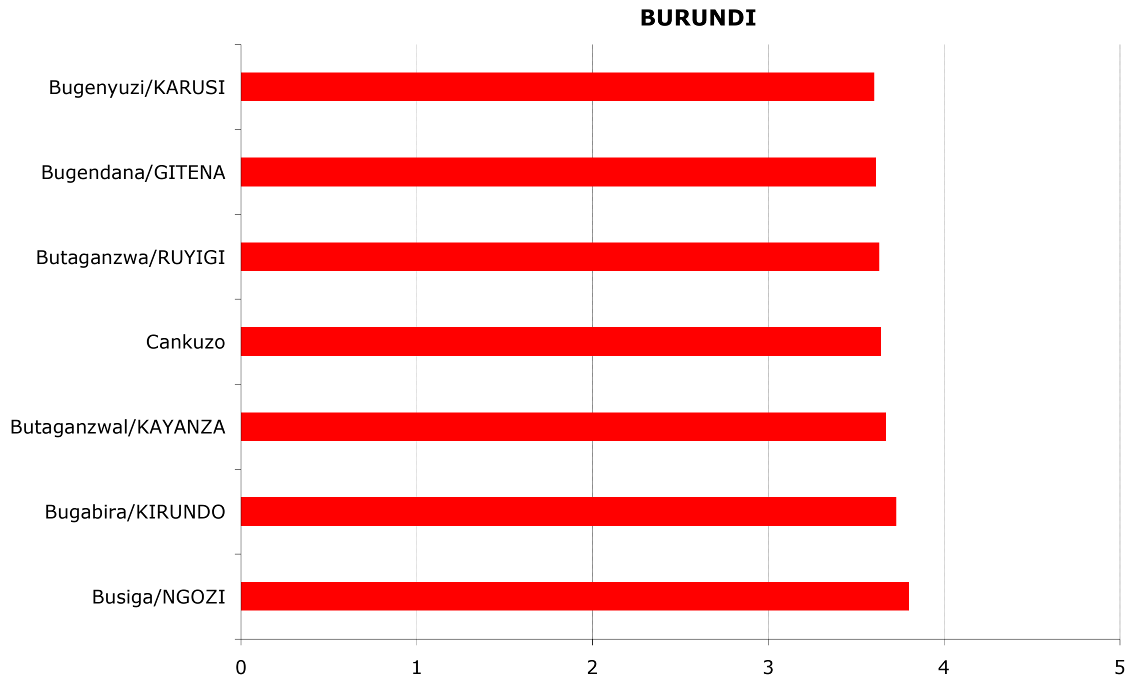


Figure 53 Representation of the total score for Burundi for each district.

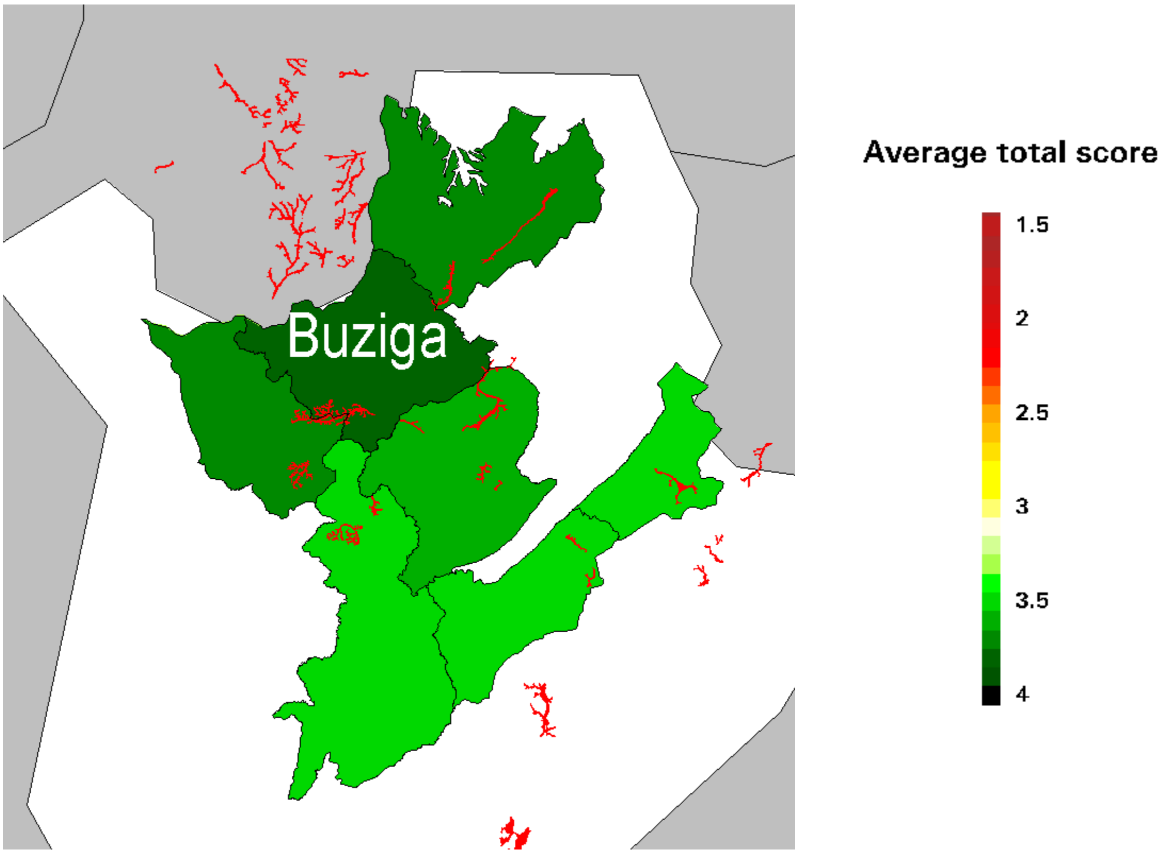


Figure 54 Map showing the total score per irrigated district.

3.3.2. Breaking down the total score into RO indicators, PO and sustainability indicators.

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 10 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance and enables ranking of the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

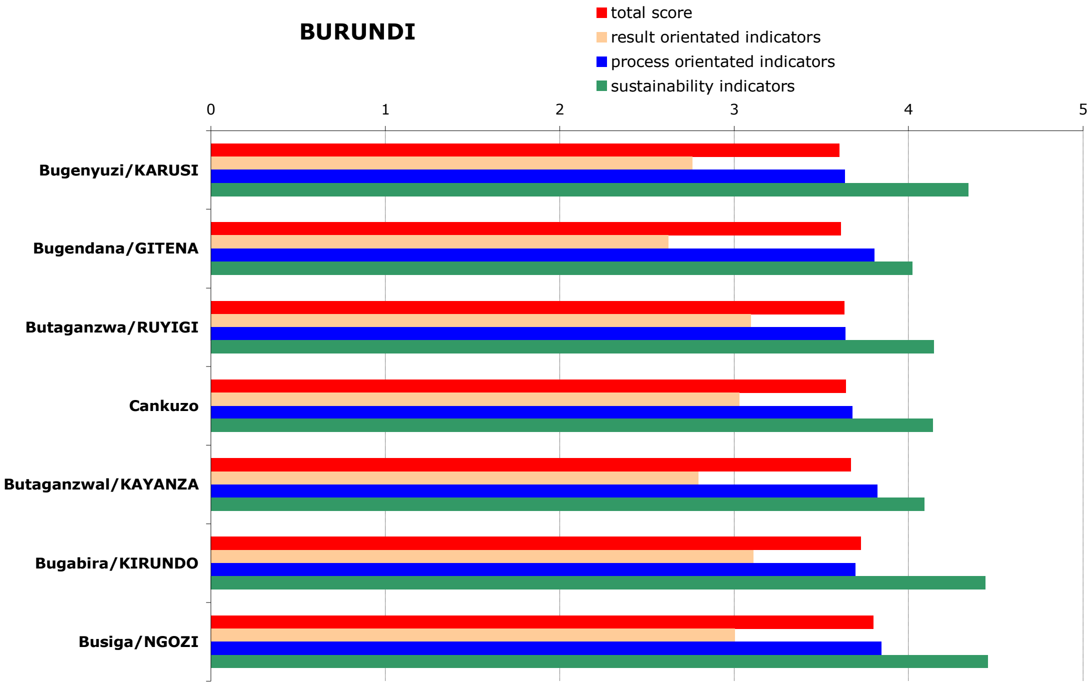


Figure 55 Breaking down the total score per indicator

The first aspect that draws attention is that each of the 7 districts of Burundi presents more or less the same score for each category of indicators, which in turn is linked to the uniform conditions encountered at country level. This could be ascribed to the relative small size of the country and the uniform climate.

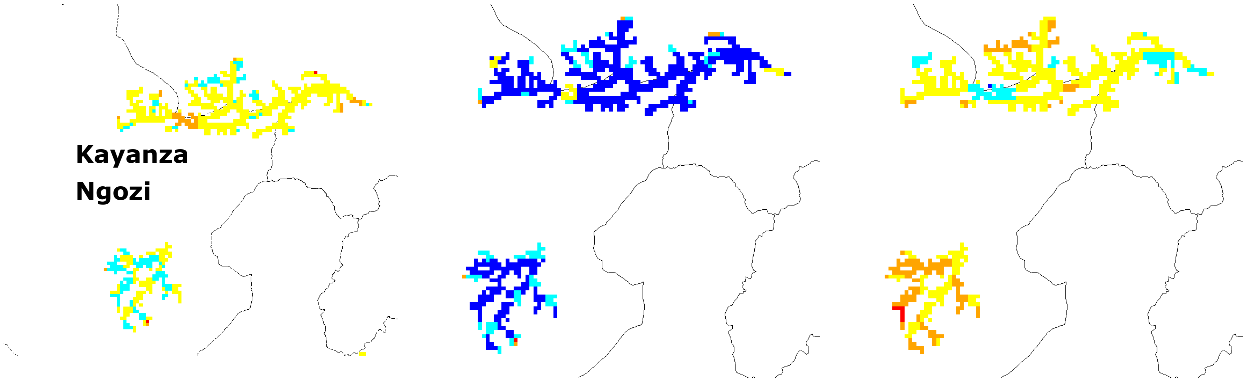
As far as the RO indicators are concerned, the average of the water and land productivity is quite low (between 2.6 and 3.1). Hence, irrigation should become more output orientated.

Concerning the PO indicators, the seven districts of Burundi get a good and homogeneous score, ranking from 3.6 to 3.8. These high scores make it difficult to draw improvement recommendations relating to the functioning of the irrigation systems.

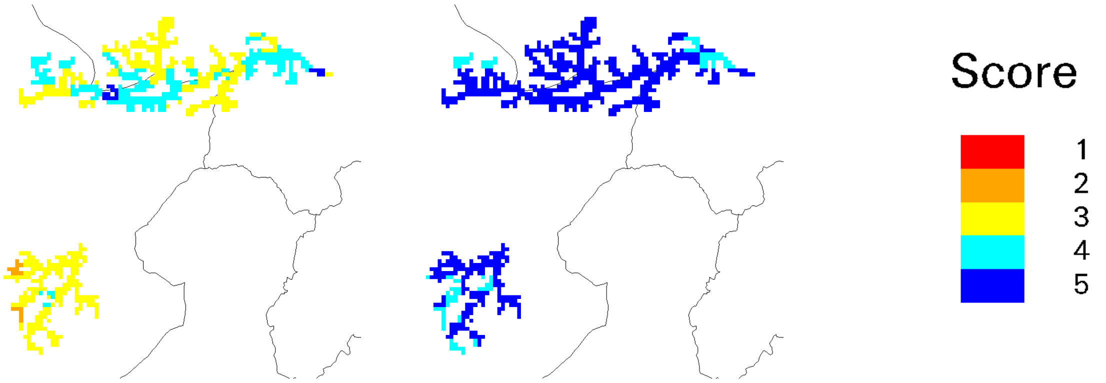
Regarding the land and water sustainability, it is really good. The score for all the districts are comprise between 4 and 4.4.

3.4 Analysis per pixel for an irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the neighboring districts of Butaganzwal/KAYANZA and Buziga/NGOZI, which are the two best districts in terms of performance. The 6th PO indicator uniformity cannot be displayed as it is an indicator at district level. This example demonstrates that at certain places, crop water consumption and beneficial fraction should be managed better (Figure 11).



crop water consumption crop water deficit beneficial fraction



adequacy reliability

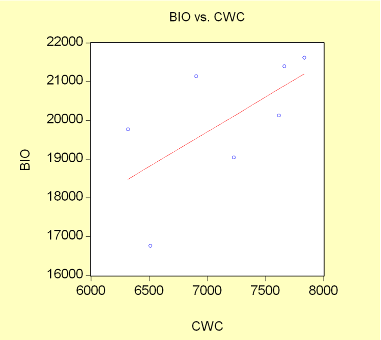
Figure 56 Spatial distribution of each indicator for the districts of Butaganzwal/KAYANZA and Busiga/NGOZI

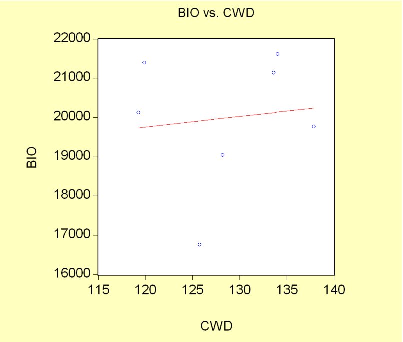
Part 4 Recommendations for improvement

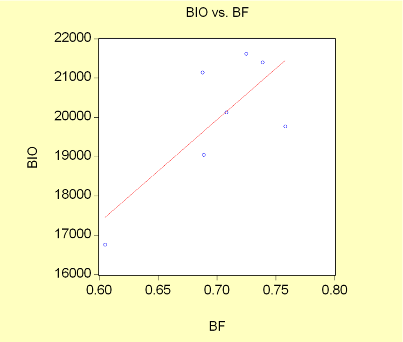
4.1 Explaining the irrigation results

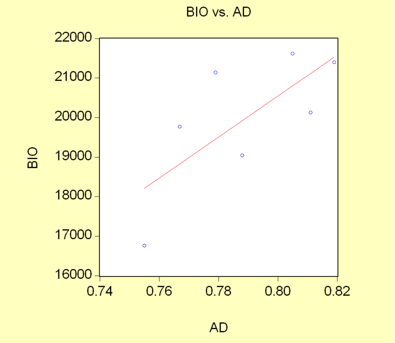
To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the seven districts. It showed that beneficial and crop water consumption are the two main explanatory factors for biomass water productivity and biomass production. An increase in beneficial fraction leads to an increase in biomass production and biomass water productivity. An increase in crop water consumption leads to an increase in biomass production but a decrease in biomass water productivity. No clear relationships could be identified for the other indicators.

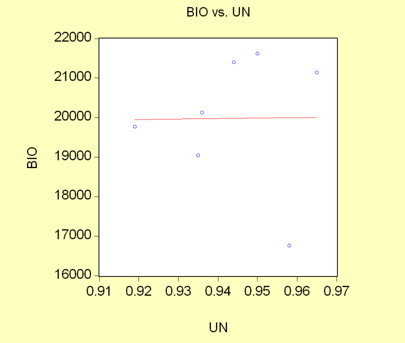
This shows that methods should be investigated to convert non-beneficial evaporation into transpiration. This can be achieved with intercropping and other measures that increase Leaf Area Index.

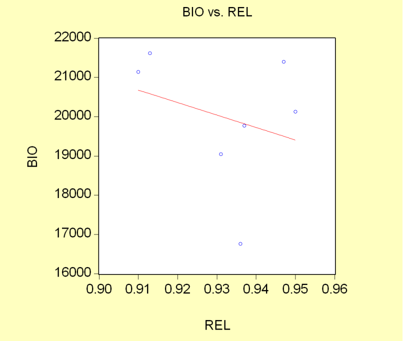


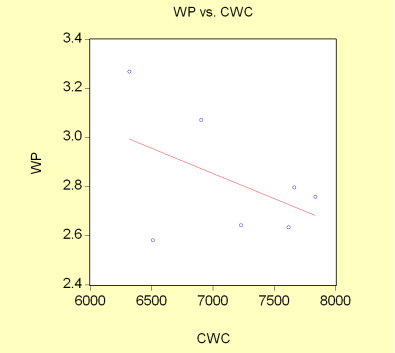


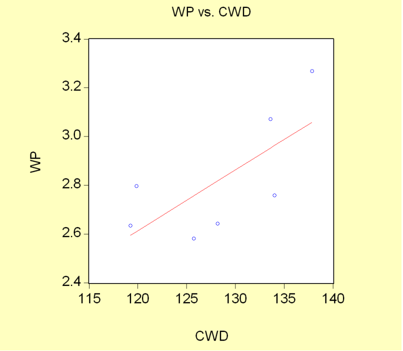


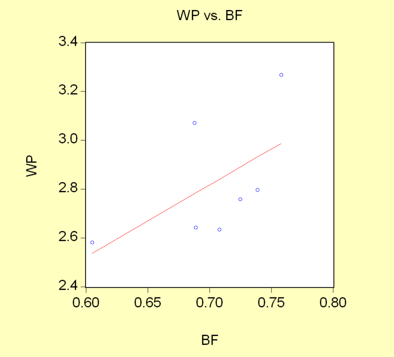












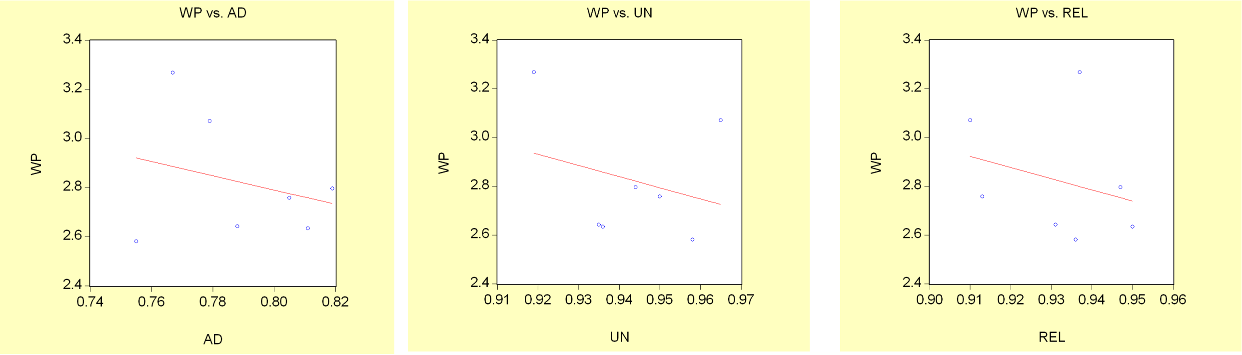


Figure 57 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationships between the indicators are better understood, the next step is to identify the weakest elements per districts. In Table 42, the best and poorest indicators are presented.

It appeared that all irrigation districts function relatively similarly. Beneficial fraction and adequacy are the main problems (it is the worse indicator for almost all districts), as well as the low biomass production and the low beneficial fraction. On the other side of the scale crop water deficit, reliability and uniformity always appear to be the best indicators. These results typically apply to a humid country with high rainfall rates.

Table 42 Best and poorest PO irrigation indicator per district

District	Lowest		2nd lowest		2nd best		Best	
Bugenyuzi/KARUSI	bf	2.79	ad	3.06	rel	4.05	cwd	4.59
Bugendana/GITENA	bf	2.18	ad	3.06	cwd	4.76	un	5.00
Butaganzwa/RUYIGI	bf	2.79	ad	2.95	cwd	4.69	un	5.00
Cankuzo	bf	2.90	ad	2.92	cwd	4.59	un	5.00
Butaganzwal/KAYANZA	bf	2.80	ad	3.15	cwd	4.76	rel	4.86
Bugabira/KIRUNDO	bf	3.17	ad	3.32	cwd	4.04	rel	4.39
Buziga/NGOZI	bf	2.99	cwc	3.16	rel	4.77	cwd	4.77

4.3 Recommendation countrywide

According to the LSI country participants, the purpose of LSI systems in Burundi is to ensure food security, increase rural incomes, and create jobs. However, it has also been mentioned in different reports that food production is relatively unstable and is unable to keep pace with the rise in population (after Rwanda, Burundi is the second biggest country in terms of population density: ranging from 254 persons/km^2 to 400-500 persons/km^2). Ensuring food security should definitely be high on the agenda.

The results of this study are confirming that fact. It has shown than one of the weakest aspects of irrigated agriculture in Burundi is the land productivity. Expanding the irrigated surface could enable higher food production, but it is probably better to in the first place invest on improving the performance of the existing irrigation systems. The idea is to increase land productivity for the existing irrigated areas without increasing crop water consumption, because it is already too high. Thus, special attention should be given to introduce or develop agronomic extension services that could advise on the use of fertilizer or improved seeds stock.

According to LSI country participants there are no water quotas for LSI systems. Specifying water rights (absolute volumes, proportions, guaranteed minimum) to major users could help to decrease water consumption. Also, priorities are not specified for water allocation amongst the sectors (domestic, agriculture, industry, etc.). Implementing an irrigation policy in the future could also help with allocating the water more evenly between the sectors.

Reducing erosion and loss of soil fertility is also one major aspect to focus on according to different reports. The fact that soils are degrading is not coming out of our results as Land sustainability gets a score higher than 3, but it may be because of the short period covered by our report (our analysis only reflects the trend over the past 5 years).

According to LSI country participants, government departments are responsible for planning, design, construction, operation and in some cases maintenance, of LSI schemes, if not delegated to water user associations. The government could also invest in modernizing the irrigation infrastructures. Irrigation systems are outdated and insensitive to climatic variations. Investing in storage of rainfall could also improve the reliability, even though it is already very good. If farmers know that they can rely on the supply of water, they might use it more efficiently and apply irrigation at more appropriated times, which would also help to increase biomass water productivity as well as the beneficial fraction.

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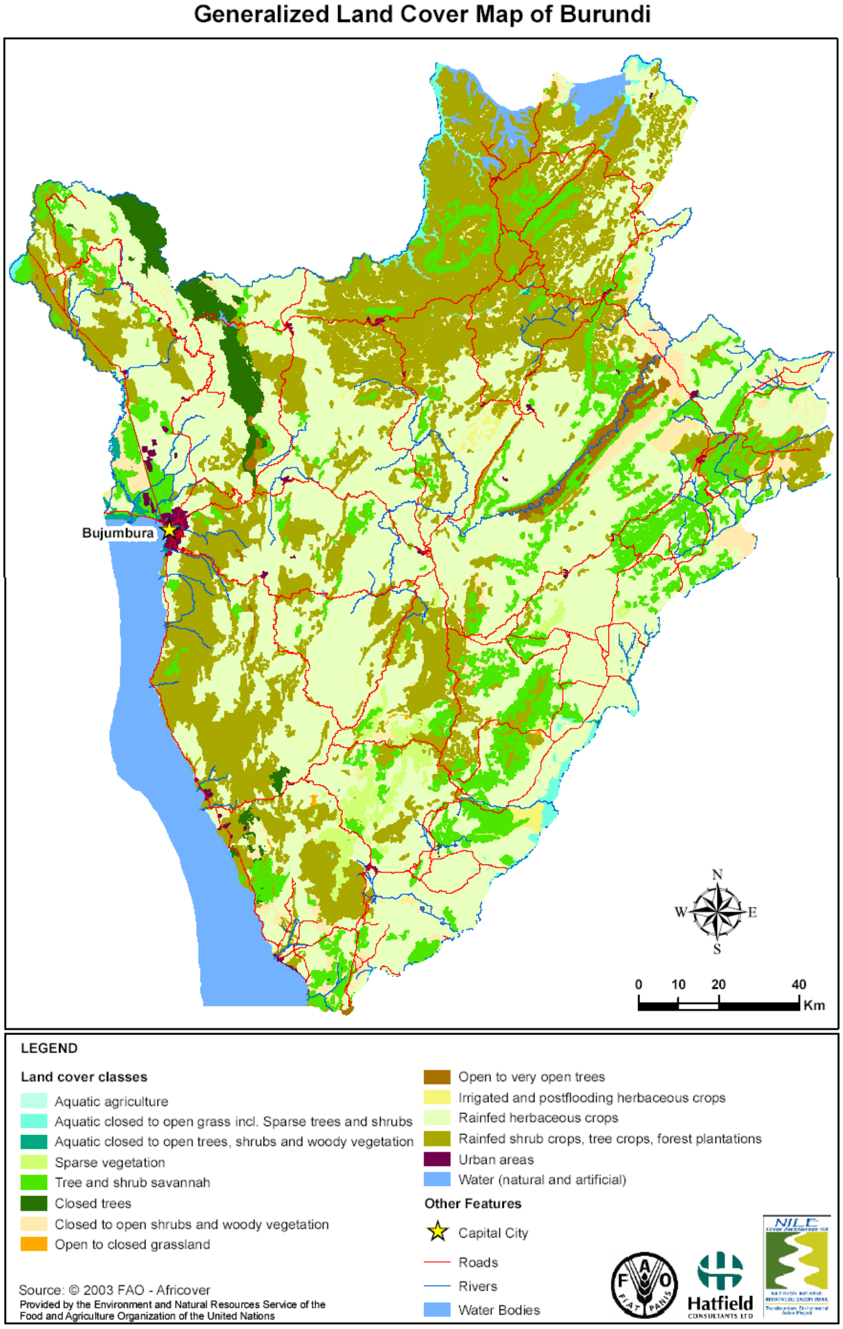
Ntamavukiro, A. 2007. Projet «Utilisation efficace de l'eau pour la production agricole». Initiative du Bassin du Nil. Etat des lieux sur l'utilisation de l'eau pour la production agricole. Cas du Burundi. Bujumbura, août 2007

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m^3	Bio/ET_{act}	High return from total water used by a crop
PO	Crop Water Consumption	cwc	$M^3/ha/year$	ET_{act}	Saving of water resources
	Crop water deficit	cwd	$M^3/ha/year$	$ET_{pot}-ET_{act}$	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	T_{act}/ET_{pot}	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	T_{act}/T_{pot}	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	$1-CV(T_{act}/T_{pot})(x,y)$	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	$1-CV(T_{act}/T_{pot})(t)$	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 Burundi Land cover (FAO, 2003)

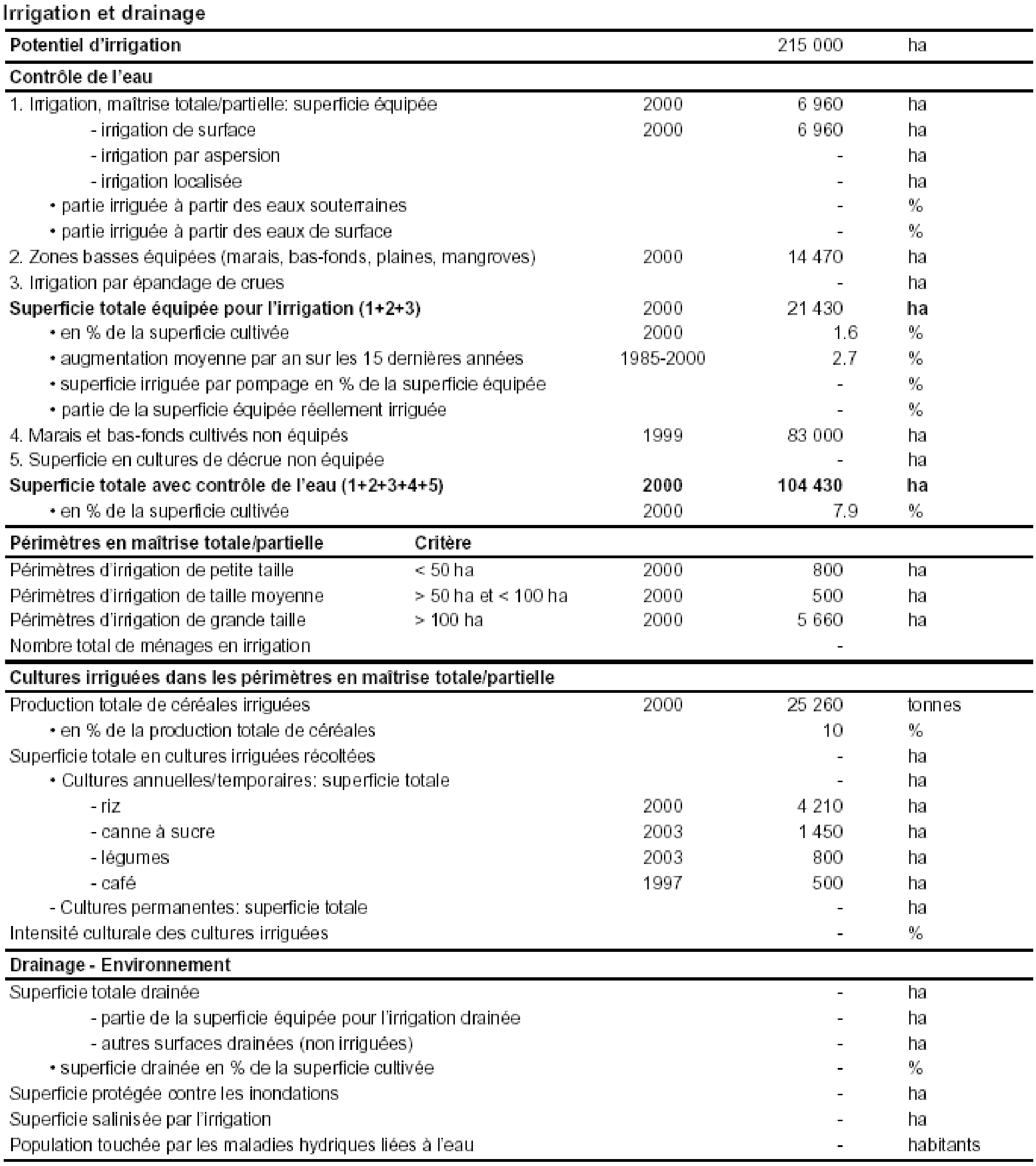


Generalized Land Cover Map of Burundi

Source: © 2003 FAO - Africover
Provided by the Environment and Natural Resources Service of the Food and Agriculture Organization of the United Nations

Disclaimer - The boundaries, colors, denominations and any other information does not imply, on the part of the NBI, any judgement or legal status of any territory, or any endorsement or acceptance of such boundaries.

Annex 3 General information on irrigation conditions in Burundi (FAO, 2005)



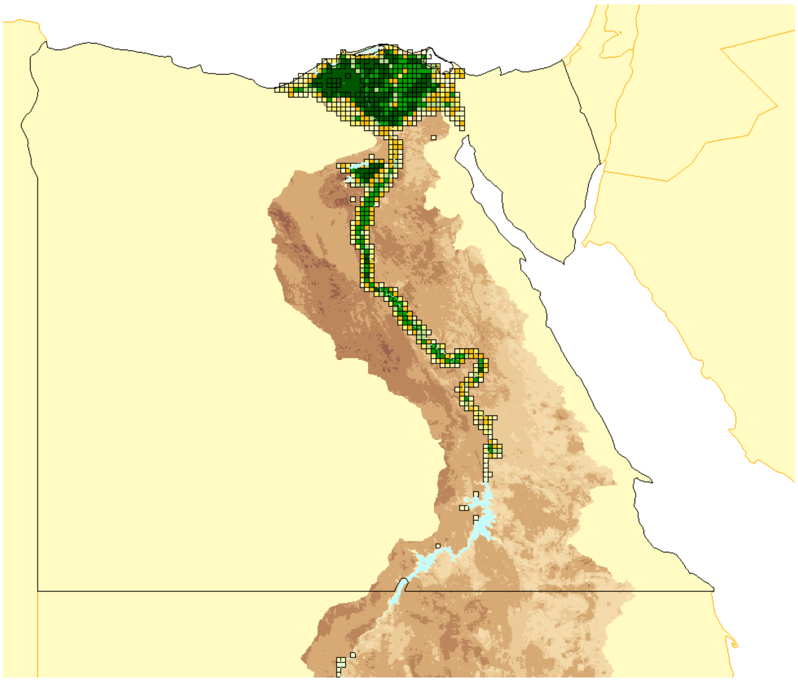
Irrigation et drainage

Potentiel d'irrigation			215 000	ha
Contrôle de l'eau				
1. Irrigation, maîtrise totale/partielle: superficie équipée		2000	6 960	ha
- irrigation de surface		2000	6 960	ha
- irrigation par aspersion			-	ha
- irrigation localisée			-	ha
• partie irriguée à partir des eaux souterraines			-	%
• partie irriguée à partir des eaux de surface			-	%
2. Zones basses équipées (marais, bas-fonds, plaines, mangroves)		2000	14 470	ha
3. Irrigation par épandage de crues			-	ha
Superficie totale équipée pour l'irrigation (1+2+3)		2000	21 430	**ha**
• en % de la superficie cultivée		2000	1.6	%
• augmentation moyenne par an sur les 15 dernières années		1985-2000	2.7	%
• superficie irriguée par pompage en % de la superficie équipée			-	%
• partie de la superficie équipée réellement irriguée			-	%
4. Marais et bas-fonds cultivés non équipés		1999	83 000	ha
5. Superficie en cultures de décrue non équipée			-	ha
Superficie totale avec contrôle de l'eau (1+2+3+4+5)		**2000**	**104 430**	**ha**
• en % de la superficie cultivée		2000	7.9	%
Périmètres en maîtrise totale/partielle	**Critère**			
Périmètres d'irrigation de petite taille	< 50 ha	2000	800	ha
Périmètres d'irrigation de taille moyenne	> 50 ha et < 100 ha	2000	500	ha
Périmètres d'irrigation de grande taille	> 100 ha	2000	5 660	ha
Nombre total de ménages en irrigation			-	
Cultures irriguées dans les périmètres en maîtrise totale/partielle				
Production totale de céréales irriguées		2000	25 260	tonnes
• en % de la production totale de céréales			10	%
Superficie totale en cultures irriguées récoltées			-	ha
• Cultures annuelles/temporaires: superficie totale			-	ha
- riz		2000	4 210	ha
- canne à sucre		2003	1 450	ha
- légumes		2003	800	ha
- café		1997	500	ha
- Cultures permanentes: superficie totale			-	ha
Intensité culturale des cultures irriguées			-	%
Drainage - Environnement				
Superficie totale drainée			-	ha
- partie de la superficie équipée pour l'irrigation drainée			-	ha
- autres surfaces drainées (non irriguées)			-	ha
• superficie drainée en % de la superficie cultivée			-	%
Superficie protégée contre les inondations			-	ha
Superficie salinisée par l'irrigation			-	ha
Population touchée par les maladies hydriques liées à l'eau			-	habitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Egypt



Appendix E

January 2009

NILE BASIN INITIATIVE
Initiative du Bassin du Nil

Table of contents

Part 1 Overview of irrigated areas
Part 2 Climate
Part 3 Raster and vector-based irrigation performance analysis
Part 4 Recommendations for improvement

Purpose of this report:

This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Egypt and will become an integral component of the final LSI report that will combine results from all countries

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

FAO - AQUASTAT, 2005

EGYPT

Disclaimer

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Figure 58 Map of Egypt and its districts

Egypt has a history of 6000 years of irrigation. The uncertain and erratic flow of the Nile river, and the need for water supply throughout the entire year has inspired the Egyptians and the British imperial rulers to construct large storage reservoirs in the Nile such as at Aswan. The high Aswan dam was constructed in 1964 and can store 169 BCM water. The presence of huge storage facilities has inspired the development of double and even triple cropping systems. The soils of the delta – and also in the river valley – have rich sediments, and are extremely suitable for irrigation practices. Figure 58 displays the different districts in Lower Egypt that will be used as units of analysis in this study.

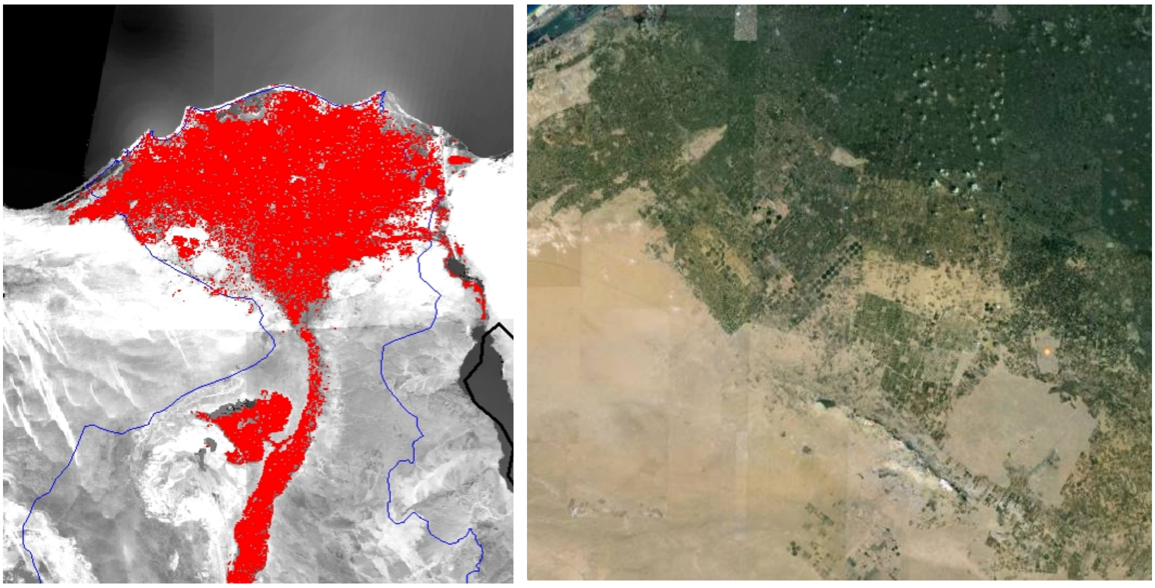


Figure 59 Map showing the distribution of irrigated areas in Lower Egypt according to the FAO-GMIA product, and being refined in the current study. The red dots on the left hand side represent irrigated land

This study estimates the irrigated area to be 3 million ha, of which 85% is in the Nile Valley and Delta. The total irrigated area is 7, 2 million feddan (one feddan is 0.42 ha). Our estimate is larger than the IWMI estimates (2.1 million ha) and smaller than the FAO estimates (3.2 million ha). The irrigated area in Egypt is approximately 60% of all irrigated land present in the Nile Basin.

Table 43 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Egypt	3,245,650
IWMI – GIAM	Entire Egypt	2,144,099
Current study	Nile Basin component of Egypt	2,963,581

1.2 Description of LSI

Around 3 million ha is intensively cultivated annually and 85% of this is in the Nile Valley and Delta. The irrigation system in the old land of the Nile Valley is a combined gravity and water lifting system (lift: about 0.5-1.5 m). The irrigation system in the new lands (reclaimed areas) is based on a cascade of pumping stations from the main canals to the fields, with a total lift of up to 50 m. Surface irrigation is banned by law in the new reclaimed areas, which are located at the end of the systems, and are more at risk of water shortage. Farmers have to use sprinkler or drip irrigation, which are more suitable for the mostly sandy soil of those areas.

Egypt’s irrigation system extends over 1,200 km, from Aswan to the Mediterranean Sea and includes 2 storage dams at Aswan, and 7 major barrages on the Nile that divert river water into an extensive network of irrigation canals. This includes 13,000 km of main public canals, 19,000 km of secondary public (Branch), and 100,000 km of tertiary private watercourses (mesqas). The mesqa systems are owned, operated and maintained by farmers. They form the main water distribution system to farmer's fields. Complimentary drainage networks cover about 272,000 km with 17,500 km of main drains, 4,500 km of open secondary drains, and 250,000 km of covered secondary & tile drains. While the traditional irrigation systems are all government operated and exists of small land holdings, new settlements in the Western Desert along the Cairo – Alexandria road arose through private investments and full blown commercial agro-business operations. These systems also occur along the Ismailaya Road. These new estates use micro-irrigation technologies on light textured soils, as opposed to surface irrigation methods on heavy textured soils in the Delta and Valley.

In the case of Egypt, the following classification is used to differentiate the irrigation systems according to their scale (according to the LSI participants from Egypt):

- 450 ha is considered a small scale irrigation scheme;
- Between 450 and 4,500 ha, it is considered a medium size irrigation system
- 4,500 ha is considered a large scale irrigation scheme.

Private owners most of the time have irrigation schemes of between 0.2 and 10,000 ha and the private firms have irrigation schemes between 10 and 450 ha.

More detailed information concerning irrigation in Egypt can be found in Annex 2.

1.3 Agricultural conditions

The agriculture year is divided into three separate seasons: winter (October to February), summer (March to June), and Nili (July to September) as displayed in Table 44. Most crops are grown both in the Delta and in the Valley, with the exception of rice (Delta mainly) and sugarcane (Valley). The main winter crops are wheat and fodder or Berseem (Trifolium alexandrinum). Berseem is grown either over 3 months with 2 cuts as feeds and a soil improver (short Berseem) usually preceding cotton, or over 6-7 months either with 4-5 cuts as a fodder crop or grazed by tethered cattle (long Berseem). Minor winter crops are, amongst others, pulses, barley and sugar beet. The main summer crops are maize, rice and cotton, the latter being the most important Egyptian export crop. In 2002, yields were 6.4 ton/ha for wheat, 8.1 ton/ha for maize, 9.4 ton/ha for rice and 2.6 ton/ha for cotton. Figure 60 shows the different crops per hectare according to the FAO-

AQUASTAT. More detailed information concerning irrigation in Egypt can be found in Annex 2.

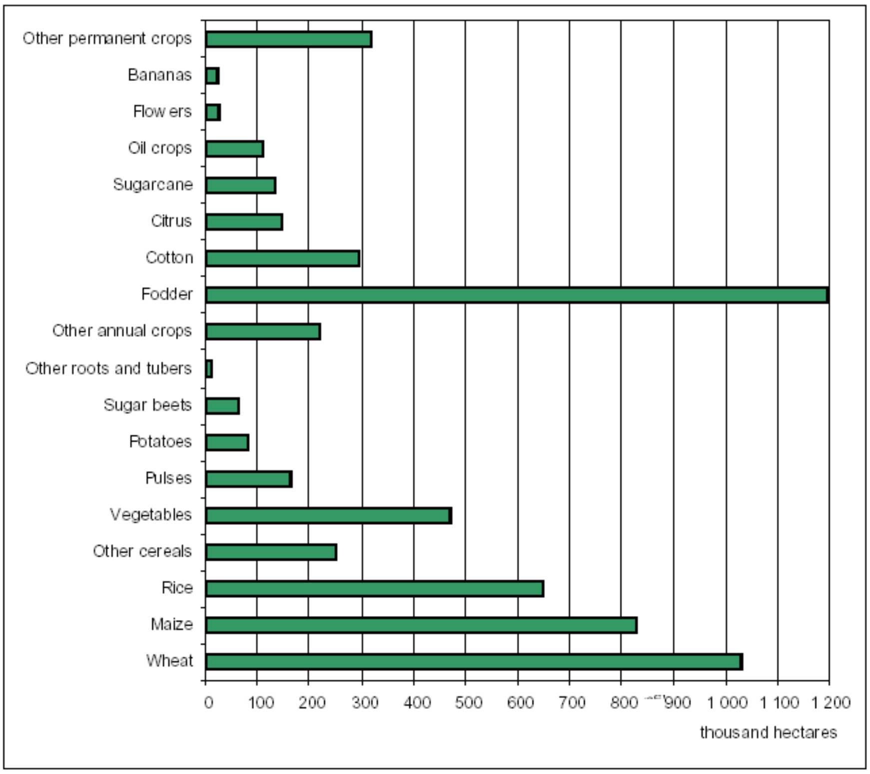


Figure 60 Irrigated crops in Egypt (source: FAO-AQUASTAT, 2005)

Table 44 Cropping seasons (source: FAO-AQUASTAT, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
EGYPT													
Wheat	1021	31	31	31	31	31						31	31
Rice	607						19	19	19	19	19		
Maize	795						24	24	24	24	24		
Barley	58	2	2	2								2	2
Sorghum	158	5	5	5								5	5
Potatoes	85		3	3	3	3	3						
Sugarbeet	41					1	1	1	1	1	1		
Sugarcane	124	4	4	4	4	4	4	4	4	4	4	4	4
Pulses	178				5	5	5	5	5				
Vegetables	421												
Vegetables-one				6	6	6	6						
Vegetables-two								6	6	6	6		
Citrus	132	4	4	4	4	4	4	4	4	4	4	4	4
Fruits	311	10	10	10	10	10	10	10	10	10	10	10	10
Oil crops	20	1	1	1	1	1	1	1	1	1	1	1	1
Groundnut	49					2	2	2	2	2			
Cotton	321	10						10	10	10	10	10	10
Fodder	1098	34	34	34	34							34	34
All irrigated crops	5419	100	93	99	98	67	79	86	86	80	79	100	100
Equipped for irrigation	3246												
Cropping intensity	167												

Part 2 Climate

2.1 Climatological conditions

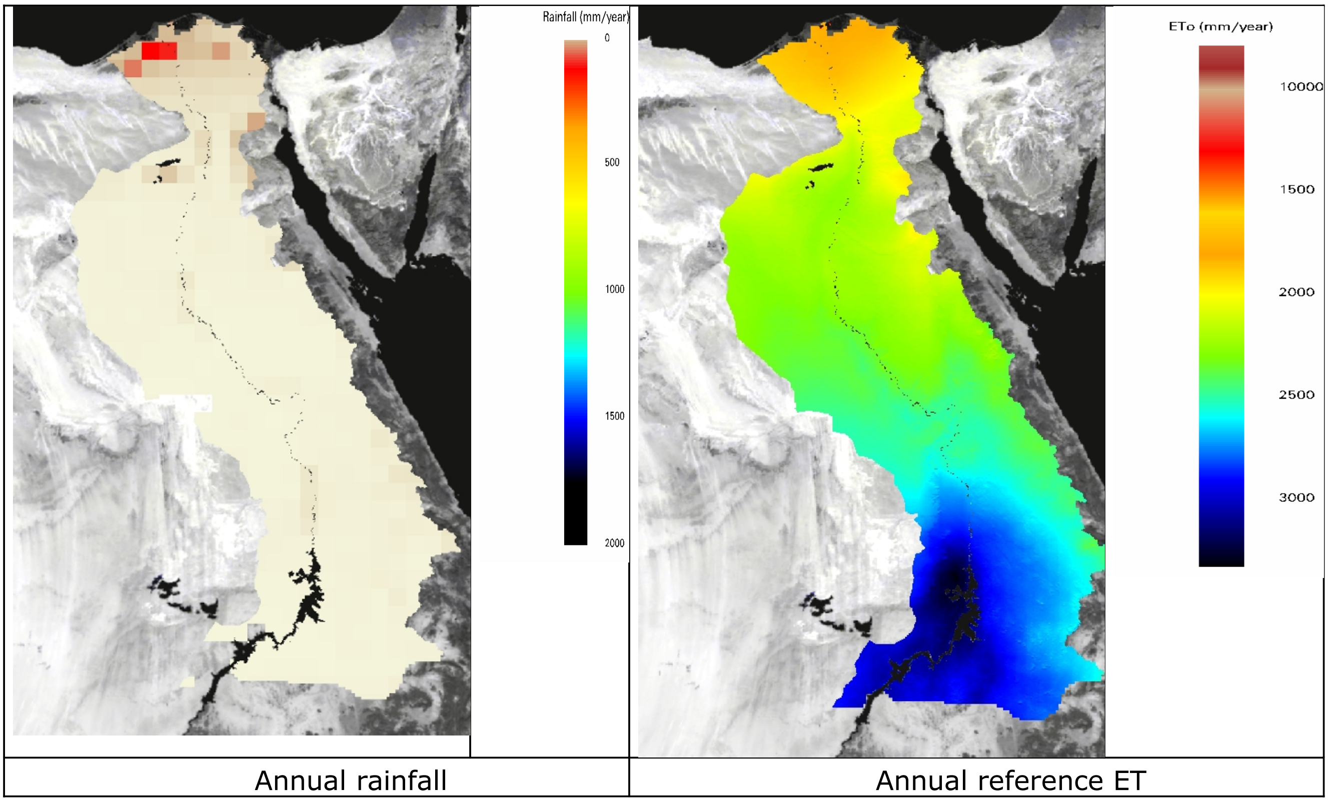
In this study, the reference evapotranspiration (ET_0) is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007. Table 45 shows the monthly values for rainfall and $ET_{0.}$

Egypt is a typical desert country. There is some rainfall along the shore line of the Mediterranean Sea, but a hundred kilometer inland this rainfall reduces to virtually nothing. The average rainfall for Egypt is only approximately 10 mm/yr. Agriculture is thus not feasible without irrigation. The uncertain rainfall factor can be ignored in the planning of water resources. This makes it easier to operate the canals and plan the on-farm irrigation practices.

The temperatures are cool in the winter and hot during the summer. ET_0 varies from 3.5 to 9 mm/d. This is related to the dry and hot desert climate. The winters are mild, and very well suited for various crops. The summer crops must be heat tolerant; hence rice, cotton and sugarcane (grown in Upper-Egypt) are common.

Table 45 Monthly values for rainfall and reference evapotranspiration (ET0).

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	3	80	0.01
February	2	98	0.01
March	1	146	0.01
April	0	190	0
May	0	239	0
June	0	250	0
July	0	232	0
August	0	210	0
September	0	179	0
October	0	152	0
November	1	100	0.01
December	2	81	0.01
TOTAL	9	1957	



Annual rainfall

Annual reference ET

Figure 61 Spatial variation of rainfall (left) and ET0 (right).

2.2 Climatic zones

The current study, aimed at providing information for improved irrigation practices in the Nile basin, covers various climatic zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as on percolation rates and irrigation efficiencies. Unexpected rainfall can for instance reduce the fraction of beneficial transpiration, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences based on the diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climatic zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on (i) the data sent by the LSI representatives of Egypt, (ii) the FAO irrigated areas, and (iii) manual digitization of visually recognizable irrigated system using Google earth and Landsat images.

The first step was to compute all the indicators per pixel. All the RO and PO indicators described have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), the Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. The annually accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

The sustainability indicators have been obtained by investigating the last five year's trends in the vegetation index (from the SPOT-Vegetation satellite) and the soil moisture (from the AMSR-E satellite).
The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, 4 different benchmark values were defined. A score between 1 and 5 has been given to each pixel; 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 62).

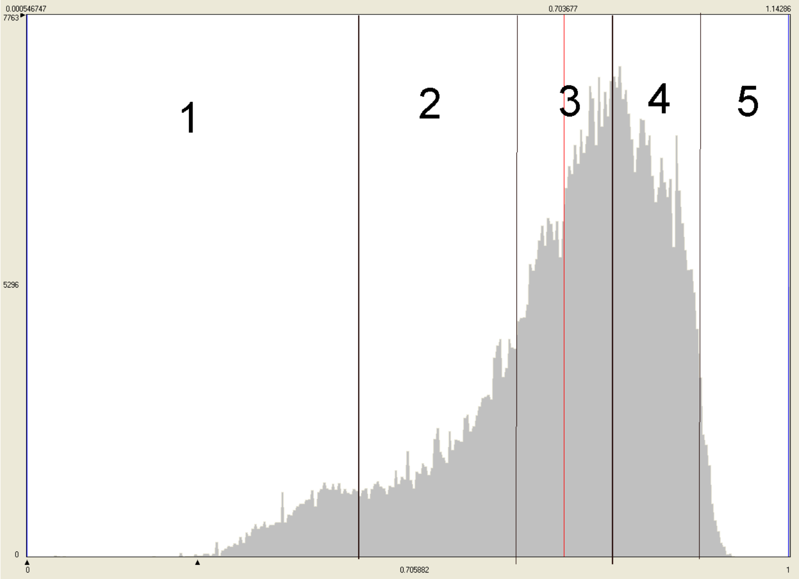


Figure 62 distribution of the values of one indicator in 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems in different climatic zones, different benchmark values are considered to avoid climatic bias in scoring. In the case of Egypt, irrigation systems are located in climatic zone 1 (Table 46).

Table 46 benchmark values for pixel located in climatic zone 1

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<7,000	<16,000 and >7,000	<28,000 and >16,000	<32,000 and 28,000	>32,000
bwp	Kg/ m3	<1.5	<2.3 and >1.5	<2.8 and >2.3	<3.3 and >2.8	>3.3
cwc	M3/ha/year	>12,500	<12,500 and >9,000	<9,000 and >5.700	<5,700 and >1,000	<1,000
cwd	M3/ha/year	<340 and >250	>500	<500 and >340	<250 and >130	<130
bf	-	<0.7	<0.9 and >0.7	<0.94 and >0.9	<0.97 and >0.94	>0.97
ad	-	<0.45	<0.64 and >0.45	<0.74 and >0.64	<0.86 and >0.74	> 0.86
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.75	<0.82 and >0.75	<0.88 and >0.82	<0.95 and >0.88	>0.95
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, districts average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at Country level

The average score considering all the indicators together for all the 3 million ha of irrigated land is 3.1. Figure 63 shows the country average for each indicator. The elements with a relative low score are the ones that Egypt should provide more attention to.

Values of 3.0 and 2.9 for land and water productivity respectively, are considered average.

Values of 2.8 and 2.6 respectively for PO indicators, crop water consumption and uniformity are below average. This shows that the access to water resources is not equal everywhere in the Egyptian irrigation systems. This is likely related to the large areas and differences between crop physical systems in upper, middle and lower Egypt. Adequacy and the reliability are slightly above average. Crop water deficit and the beneficial fraction are on the other side of the scale and appear very good at country level.

Sustainability of the land resources does not seem to be fully under control. The irrigated land is constantly green, and there is no clear signal that the system is deteriorating. However, the soil moisture levels show a decline over the last 5 years. This is an interesting issue, because Egypt is expanding its land horizontally, and more irrigation water is now brought from the traditional areas in the valley and delta to the desert. This is occurring already in Sinai and plans exist to convey Nile water resources to the Western Desert to supplement groundwater resources. Although no firm conclusion can be drawn from this finding, decreasing soil moisture values should be treated with caution. The preservation of land wetness definitely needs to get special attention during the monitoring of the irrigation systems.

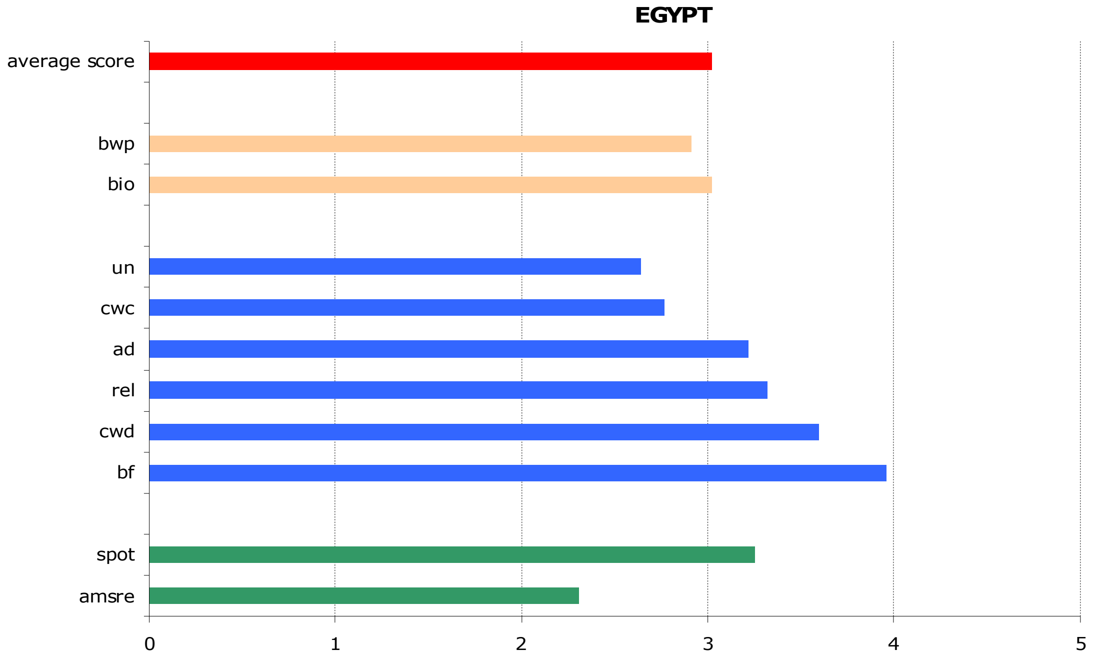


Figure 63 The average score for each indicator in Egypt.

3.3 Results at district level

3.3.1 Average per district

In Figure 64 the average score for all the indicators per district are compared. The western Delta appears to have the best score. Twenty two districts having more than 30 pixels of 6.25 ha have been identified. In terms of total average score, the best irrigation district is Dumyat, with an average of 3.6. The district that has the lowest average is Al Jizah, with an average of 2.5 (see Figure 64 for their locations).

Dumyat is based in the Delta (Lower Egypt) and Al Jizah on the fringes of the Nile valley (Upper Egypt). The soil in Al Jizah is sandy and this could be an explanation for the low performance.

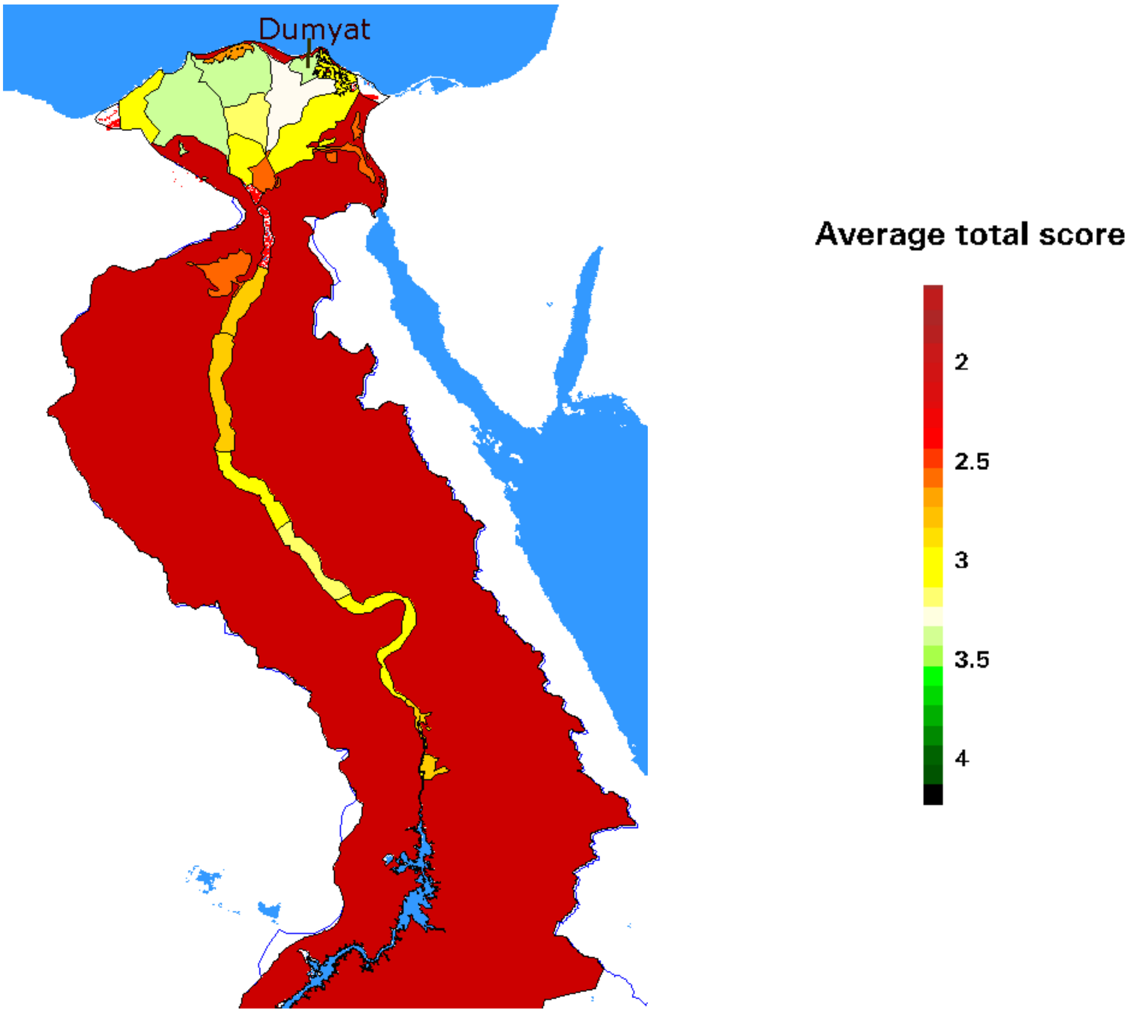


Figure 64 Map of Egypt showing the total score per irrigated district

3.3.2 Breaking down the total score into RO, PO and sustainability indicators

By breaking down the total score into 3 types of indicators (RO, PO and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 65 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance and enables ranking of districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

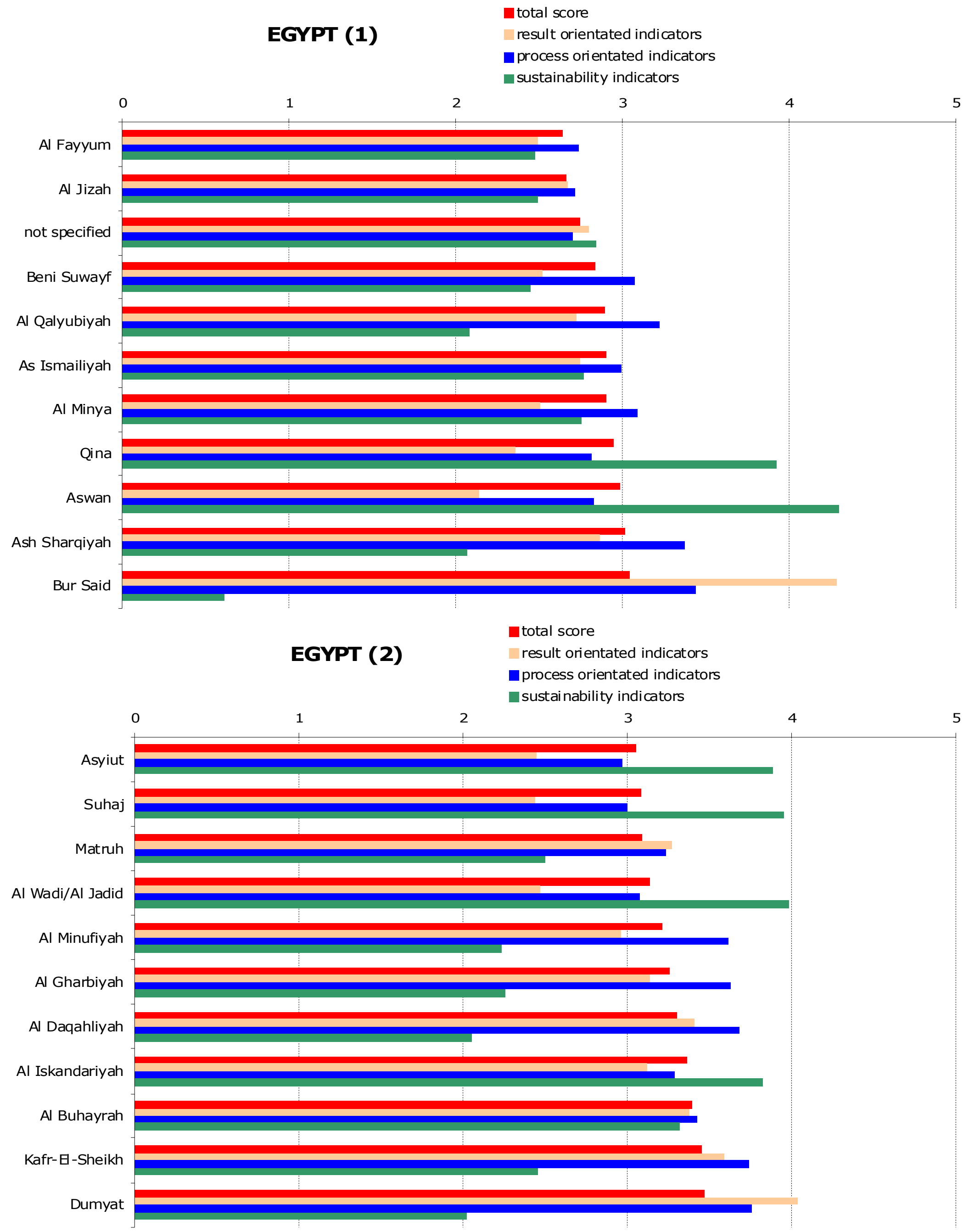


Figure 65 A breakdown of the total score per indicator per district

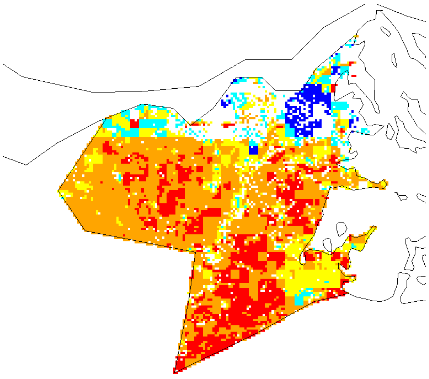
A good total score does not always mean a good performance in terms of results. Similarly, a poor average score does not mean that the district does not have good results.

Considering the total average score for Bur Said, it seems to be an average district. However, by looking at the average of the RO indicators, it appears to be the best performing district, with an average score of 4.3. The low global average that leads to ranking Bur Said amongst the districts with average to poorest irrigation performance is explained by the very low score obtained in terms of sustainability. The managers of Bur Said seem to over-utilize their land and water resources, resulting in unsustainable practices. A good total performance does not mean a sustainable system. This example shows once again the relevance of breaking the irrigation performance down into different types of indicators. It would be valuable to find the main reasons for this un-sustainability.

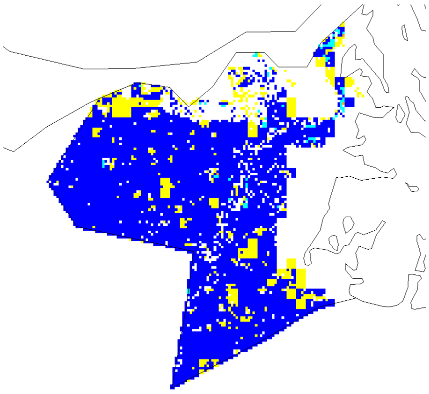
The 22 districts of Egypt have a very variable RO score, ranking from 2.1 to 4. The PO indicators vary too from one district to another, from 2.7 to 3.8. This variation complicates general improvement recommendations at a country scale. In line with the LSI assignment, relevant improvement recommendations should be made district per district by looking at the different scores of every single indicator for each district.

3.4. Analysis per pixel for the best irrigation system

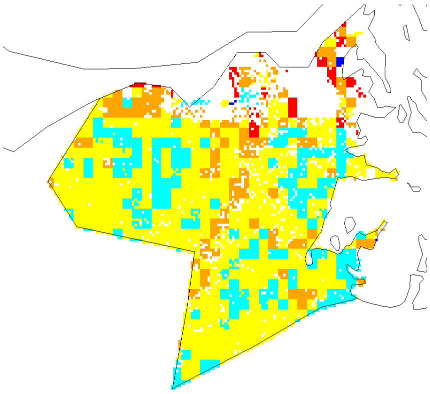
Looking at what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see where which processes need more attention. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the district of Dumyat, which is the best district in terms of performance. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. Figure 66 demonstrates that crop water consumption is too high (over 12,500 m^3/ha/year) and that many precious water resources are lost by non-beneficial evaporation. Overall the system is very reliable and adequate.



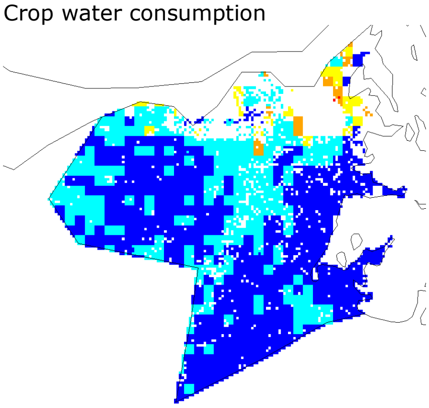
Crop water consumption



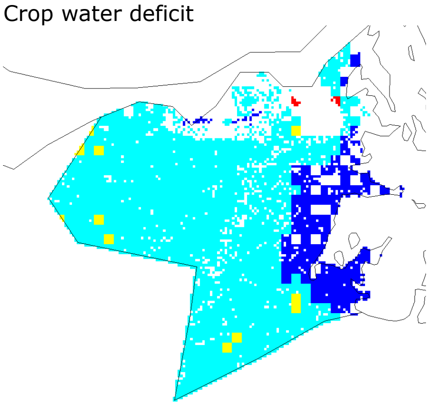
Crop water deficit



Beneficial fraction



Adequacy



reliability

Score

🟥 1
🟧 2
🟨 3
🟦 4
🟦 5

Figure 66 Spatial distribution of each indicator for the district of Dumyat

Part 4 Recommendations for improvement

4.1. Explaining the irrigation results

To be able to give appropriate recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the 7 districts. As far as the biomass production is concerned, it appears to be well correlated to adequacy and crop water consumption. The higher the crop water consumption or the adequacy, the more biomass will be produced. While this is good for crop production, it will go at the cost of a high irrigation water usage. It is positively linked to the beneficial fraction and negatively linked to the crop water deficit. No clear relationship between biomass and uniformity, or reliability is apparent.

For a high biomass water productivity, crop water consumption should be low. The highest biomass water productivity occurs when crop water consumption is low and crop water deficit is limited. This is helpful for optimizing either biomass production or biomass water productivity.

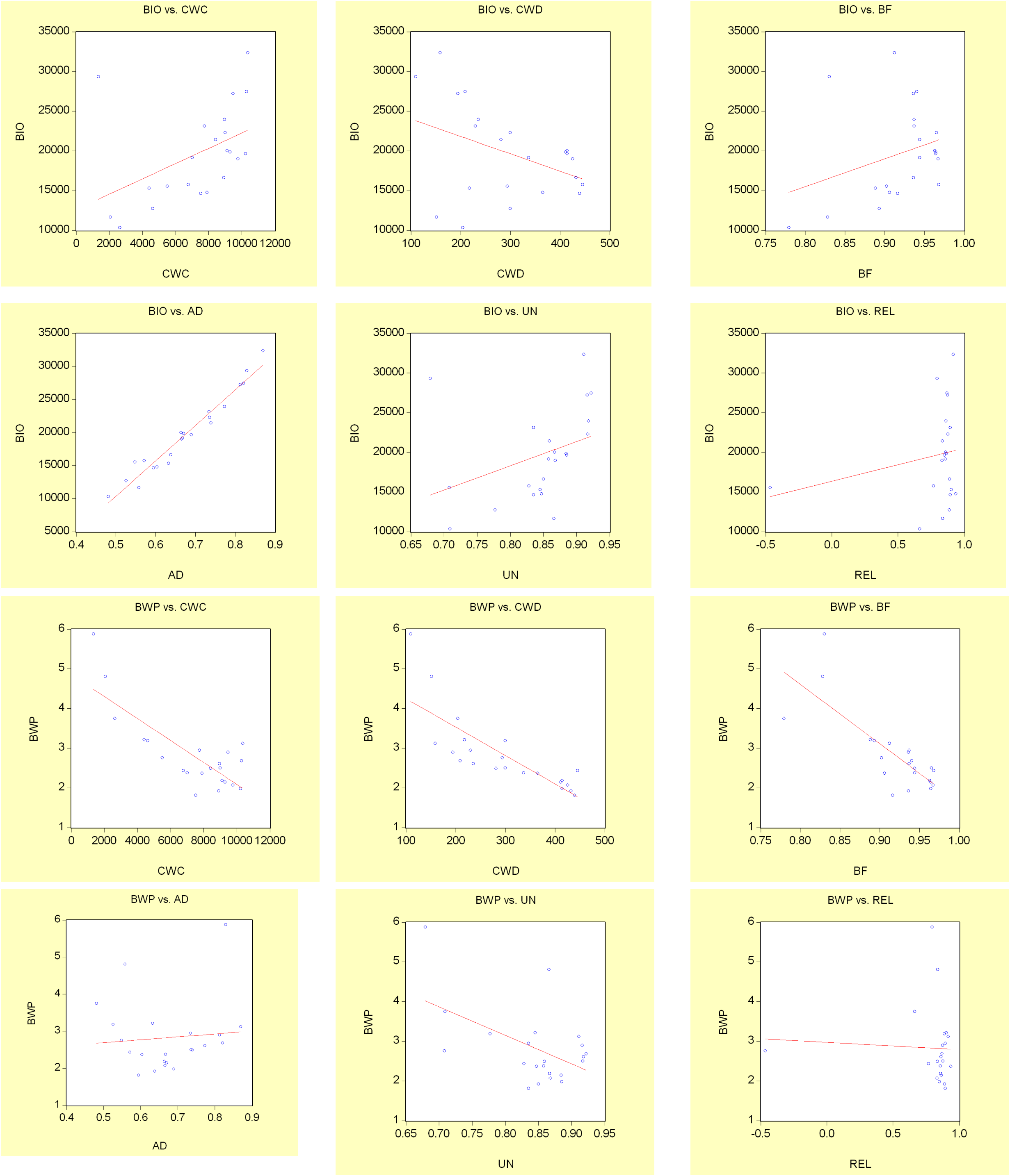


Figure 67 Relationships between RO indicators and PO/Sustainability indicators

4.2. Weak and strong aspects per district

Once the relationship between indicators is better understood, the next step is to identify the weakest elements per districts. In Table 5, the best and poorest indicators are presented.

Table 47 Best and poorest PO irrigation indicators per district

district	lowest score		2nd lowest		2nd best		best	
Al Fayyum	ad	1.69	cwd	1.98	cwc	3.21	bf	4.70
Al Jizah	un	1.00	ad	2.10	cwc	3.82	bf	3.95
not specified	un	1.00	ad	2.17	cwd	3.50	cwc	4.35
Beni Suwayf	cwd	2.17	cwc	2.49	ad	3.97	bf	4.68
Al Qalyubiyah	ad	1.93	cwd	2.78	rel	3.20	bf	4.38
As Ismailiyah	un	2.00	ad	2.06	rel	3.75	cwc	3.81
Al Minya	cwd	2.15	cwc	2.50	rel	3.34	bf	4.66
Qina	un	2.00	cwd	2.10	rel	3.70	bf	3.86
Aswan	un	2.00	cwd	2.03	bf	3.77	rel	3.89
Ash Sharqiyah	cwc	2.70	ad	2.87	cwd	3.89	bf	4.19
Bur Said	un	1.00	ad	2.62	rel	3.93	cwc	4.81
Asyiut	cwd	2.08	cwc	2.46	ad	3.47	bf	4.72
Suhaj	cwd	2.13	cwc	2.23	rel	3.03	bf	4.58
Matruh	bf	2.24	ad	2.83	cwd	3.96	cwc	4.33
Al Wadi/Al Jadid	un	2.00	ad	2.57	bf	3.61	rel	4.34
Al Minufiyah	cwc	2.56	ad	3.03	un	4.00	bf	4.54
Al Gharbiyah	cwc	2.54	rel	3.17	un	4.00	cwd	4.58
Al Daqahliyah	cwc	2.14	rel	3.33	un	4.00	cwd	4.79
Al Iskandariyah	un	2.00	bf	2.99	rel	3.97	cwd	4.32
Al Buhayrah	un	2.00	cwc	2.90	ad	4.16	cwd	4.57
Kafr-El-Sheikh	cwc	2.39	rel	3.42	ad	4.08	cwd	4.89
Dumyat	cwc	2.14	bf	3.03	ad	4.55	cwd	4.73

The elements with low scores indicate the aspects that each district should provide more attention to. Generally, aspects with scores lower than 3 needs to be critically considered. It seems that many districts have a problem with uniformity. The beneficial fraction as well as crop water deficit seem to be the best indicators for many districts. Beneficial fraction can be improved by soil, straw and plastic mulching. Crop water deficit can be regulated by means of shorter irrigation intervals and sufficient supplies. But once again, each district seems to function differently and therefore should be looked at independently.

4.3. Recommendation countrywide

Ancient Egyptians irrigated their land and a rich experience has been built up in agricultural water management. This is reflected in an overall good irrigation system, especially in the areas with alluvial soils at the downstream end of the Nile. Overall, the irrigation performance in upper Egypt is less favourable. The fact that the country is so large will inevitably result in a wide scatter in ranking of irrigation performance.

The most limiting resource for Egyptian agriculture is irrigation water. Management of its water resources has always been the central feature of the country's development strategies. There is indeed insufficient water to meet all demands for competing users and the potential for increasing the amount of available water is limited. Therefore, increasing water productivity should be a priority whereas it seems that all attention is given to production.

Land, next to water, is also a limiting factor. The Delta region contributes to 80% of all arable land in the country and despite the extremely limited land available for agriculture, urbanization is growing. The desert reclamation activities launched in the eighties have been quite successful, albeith the groundwater resources did not appear to be sustainably managed.

The absence of rainfall is an advantage to Egypt, because erratic rain storms can jeopardize and interfere with the irrigation planning. By absence of these events, it is easier to schedule water in the canals. While this works out quite well in the Delta, the performance in the Nile Valley is much less favourable.

The irrigation systems in the downstream end of the Rosetta and Damietta branch are among the best in the world. The national agronomical skills of Egypt and the agricultural policies could be of overriding importance in establishing this success. The short duration varieties are surely debet to that.

The Government of Egypt could focus on the following aspects:

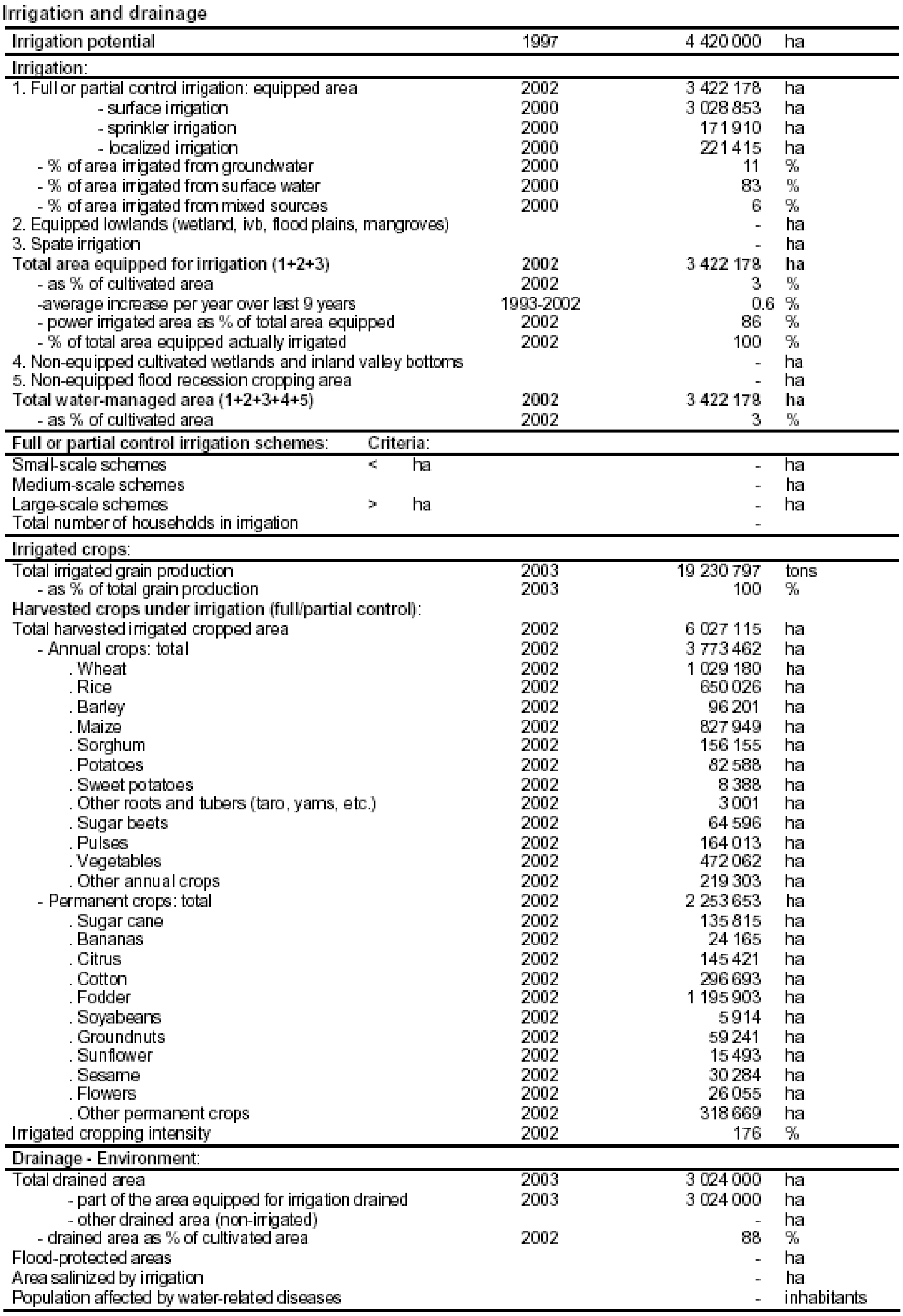
- Provide maximum attention to a proper monitoring technology. There could be undesirable consequences for unlimited horizontal expansion. It is basically a stransfer of water from the old land to the new land
- The minimum drainage flows should be monitored for keeping the leaching fraction of the Nile basin in proper ranges
- Determine the reasons for below-average irrigation performance in certain administrative districts in Egypt.
- There are signals that the institutional capacity in Egypt is not working properly. A critical evaluation should be held by outsiders to detect where in the decision making process aspects can be improved

- Evaluate the operation and maintenance rules for irrigation water management and try to draw lessons that could be used in the arid irrigation systems of Sudan and Ethiopia.
- Continue to invest in extension services and formation of water boards. This could help in making the water distribution more uniform.

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m^3	Bio/ET$_{act}$	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M^3/ha/year	ET$_{act}$	Saving of water resources
	Crop water deficit	cwd	M^3/ha/year	ET$_{pot}$-ET$_{act}$	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	T$_{act}$/ET$_{pot}$	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	T$_{act}$/T$_{pot}$	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	1-CV(T$_{act}$/T$_{pot}$)(x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	1-CV(T$_{act}$/T$_{pot}$)(t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 General information on irrigation conditions in Egypt (AQUASTAT, 2005)



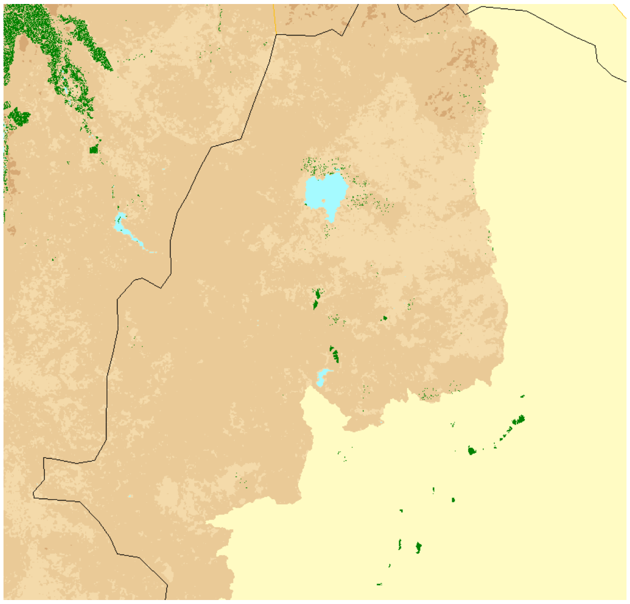
Irrigation and drainage

Irrigation potential		1997	4 420 000	ha
Irrigation:				
1. Full or partial control irrigation: equipped area		2002	3 422 178	ha
- surface irrigation		2000	3 028 853	ha
- sprinkler irrigation		2000	171 910	ha
- localized irrigation		2000	221 415	ha
- % of area irrigated from groundwater		2000	11	%
- % of area irrigated from surface water		2000	83	%
- % of area irrigated from mixed sources		2000	6	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)			-	ha
3. Spate irrigation			-	ha
Total area equipped for irrigation (1+2+3)		**2002**	**3 422 178**	**ha**
- as % of cultivated area		2002	3	%
-average increase per year over last 9 years		1993-2002	0.6	%
- power irrigated area as % of total area equipped		2002	86	%
- % of total area equipped actually irrigated		2002	100	%
4. Non-equipped cultivated wetlands and inland valley bottoms			-	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		**2002**	**3 422 178**	**ha**
- as % of cultivated area		2002	3	%
Full or partial control irrigation schemes:	**Criteria:**			
Small-scale schemes	< ha		-	ha
Medium-scale schemes			-	ha
Large-scale schemes	> ha		-	ha
Total number of households in irrigation			-	
Irrigated crops:				
Total irrigated grain production		2003	19 230 797	tons
- as % of total grain production		2003	100	%
Harvested crops under irrigation (full/partial control):				
Total harvested irrigated cropped area		2002	6 027 115	ha
- Annual crops: total		2002	3 773 462	ha
. Wheat		2002	1 029 180	ha
. Rice		2002	650 026	ha
. Barley		2002	96 201	ha
. Maize		2002	827 949	ha
. Sorghum		2002	156 155	ha
. Potatoes		2002	82 588	ha
. Sweet potatoes		2002	8 388	ha
. Other roots and tubers (taro, yams, etc.)		2002	3 001	ha
. Sugar beets		2002	64 596	ha
. Pulses		2002	164 013	ha
. Vegetables		2002	472 062	ha
. Other annual crops		2002	219 303	ha
- Permanent crops: total		2002	2 253 653	ha
. Sugar cane		2002	135 815	ha
. Bananas		2002	24 165	ha
. Citrus		2002	145 421	ha
. Cotton		2002	296 693	ha
. Fodder		2002	1 195 903	ha
. Soyabeans		2002	5 914	ha
. Groundnuts		2002	59 241	ha
. Sunflower		2002	15 493	ha
. Sesame		2002	30 284	ha
. Flowers		2002	26 055	ha
. Other permanent crops		2002	318 669	ha
Irrigated cropping intensity		2002	176	%
Drainage - Environment:				
Total drained area		2003	3 024 000	ha
- part of the area equipped for irrigation drained		2003	3 024 000	ha
- other drained area (non-irrigated)			-	ha
- drained area as % of cultivated area		2002	88	%
Flood-protected areas			-	ha
Area salinized by irrigation			-	ha
Population affected by water-related diseases			-	inhabitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Ethiopia



Appendix F

January 2009

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Part 1 Location of irrigated areas
Part 2 Climate
Part 3 Raster and vector-based irrigation performance analysis
Part 4 Recommendations for improvement

Purpose of this report:

This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Ethiopia and will become an integral component of the final LSI report that will combine results from all countries.

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

Part 1 Location of irrigated areas

1.1 Location of the irrigated areas

Ethiopia is located in the transition zone between the vast irrigation schemes of Egypt and Sudan towards the downstream end of the basin, and the small holder irrigation in the upstream Nile Basin. The Nile Basin in Ethiopia is one of four major drainage systems: (i) Nile basin; (ii) The Rift Valley; (iii) Shebelle–Juba basin (iv) north-east Coast. It represents 32% of the total area of about 1.13 million km^2 and comprises the Abbay, Tekeze and Baro-Akobo rivers. Both the Blue and White Nile drain from Ethiopia (part of the White Nile also drains from Uganda) and together they provide almost 70% of the annual runoff (122 BCMs m^3) of the country. There are several lakes in the country (covering about 7,000 km^2), but only Lake Tana, the source of Abbay River is within the Nile Basin.

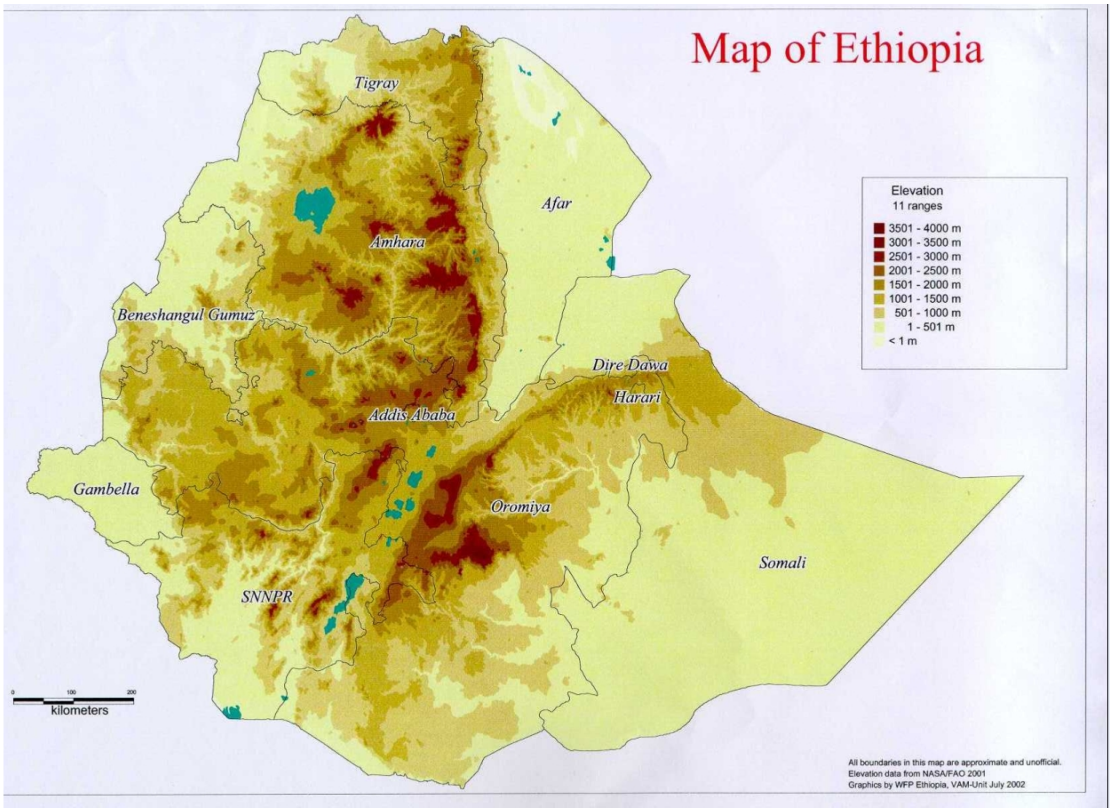


Figure 68 Topographical map of Ethiopia

The alluvial soils in the vicinity of streams and rivers and lakes are used for irrigation (see Figure 69). Irrigation in Ethiopia dates back several centuries, if not millennia, while "modern" irrigation was started by the commercial irrigated sugar estate established in the early 1950s.

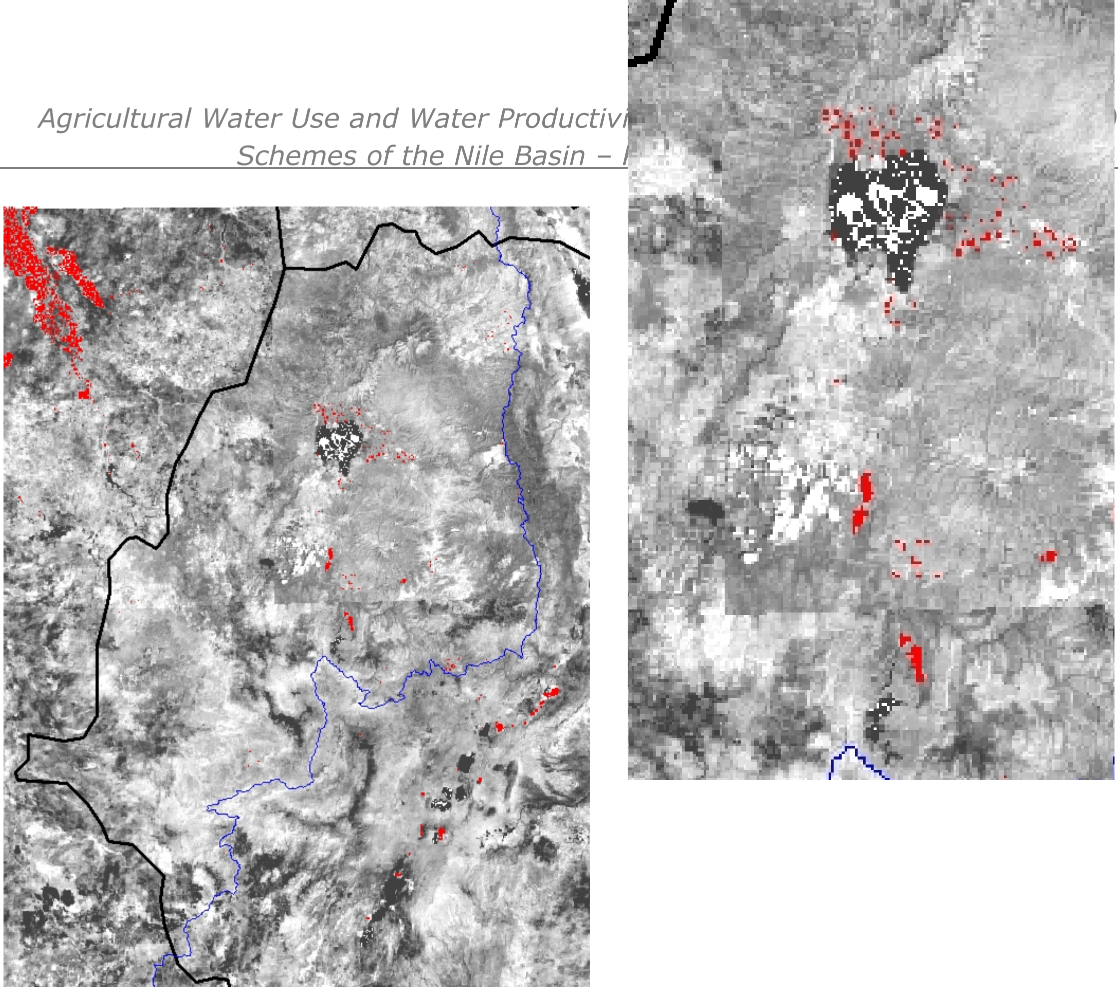


Figure 69 Distribution of the irrigated areas within the Nile Basin according to the FAO-GMIA product, and being refined within the current study. The red dots represent the irrigated areas.

Table 48 shows that 90,769 ha of irrigated land is present in the Nile Basin component of Ethiopia. It also suggests that there is much more irrigation outside the Nile Basin region, which is true. Several irrigation schemes are located in the Awash river basin and the Central Rift Valley. Awulachew et al. (2007) report an amount of 107,265 ha of irrigated land in Ethiopia.

Table 48 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Ethiopia	184,239
IWMI – GIAM	Entire Ethiopia	160,785
Current study	Nile Basin component of Ethiopia	90,769

Irrigation potential has been estimated at about 2.7 million ha, considering the availability of water and land resources, technology and finance (AQUASTAT, 2005). According to the LSI representative, the total gross irrigation potential estimate of the country is even higher : 3.7 million ha. The surface water resource potential of the country is indeed impressive, but little has been developed so far. Since recently, Ethiopia has embarked on an irrigation master development plan in the Nile basin ("the Nile irrigation and drainage project"), and it is expected that the irrigated areas will be expanded in the future. The combined Tana-Beles river basin has for instance is foreseen to expand by 240,000 ha.

1.2 Description of LSI

Four categories of irrigation schemes can be distinguished:

(i) Traditional irrigation schemes (1-100 ha) developed by the farmers themselves and covering about 155,014 ha with about 639,031 farmers involved. They are mainly used for the production of vegetables for the local market and experience problems with faulty irrigation systems stemming from lack of technology and knowledge.

(ii) Modern small-scale irrigation schemes: (up to 200 ha) constructed by the government/NGOs with farmer participation. They are generally based on direct river diversions. About 51,198 ha was equipped for irrigation in 2004 involving about 198,393 farmers. The operation and maintenance of the schemes are the responsibility of the water users, supported by the regional authorities/bureaus in charge of irrigation development and management.

(iii) Modern private irrigation: Private investment in irrigation has recently re-emerged with the adoption of a market-based economic policy in the early 1980s. Virtually all irrigated state farms were privately owned farms until nationalization of the private property in the mid 1970s. At the end of 2000, private investors had developed about 5,500 ha of irrigated farms.

(iv) Public irrigation schemes: comprise medium/large-scale irrigation schemes (>200 ha) covering about 97,700 ha. They are constructed, owned and operated by public enterprises along the Awash River and were built in the 1960s−70s as either private farms or joint ventures.

More detailed information concerning irrigation in Ethiopia can be found in Annex 2.

1.3 Agricultural conditions

Agriculture is a very important sector for the Ethiopian national economy as it involves 74% of the active population and represents 57% of the GDP. It is mainly rainfed agriculture and is dominated by subsistence small holder farms. Irrigation accounts for about 5 %. Export crops such as coffee, oilseed and pulses are mostly rainfed but industrial crops such as sugar cane, cotton and fruit are irrigated. Other irrigated crops include vegetables, fruit trees, maize, wheat, potatoes, sweet potatoes and bananas (Figure 70). The cropping seasons are represented in Table 49.

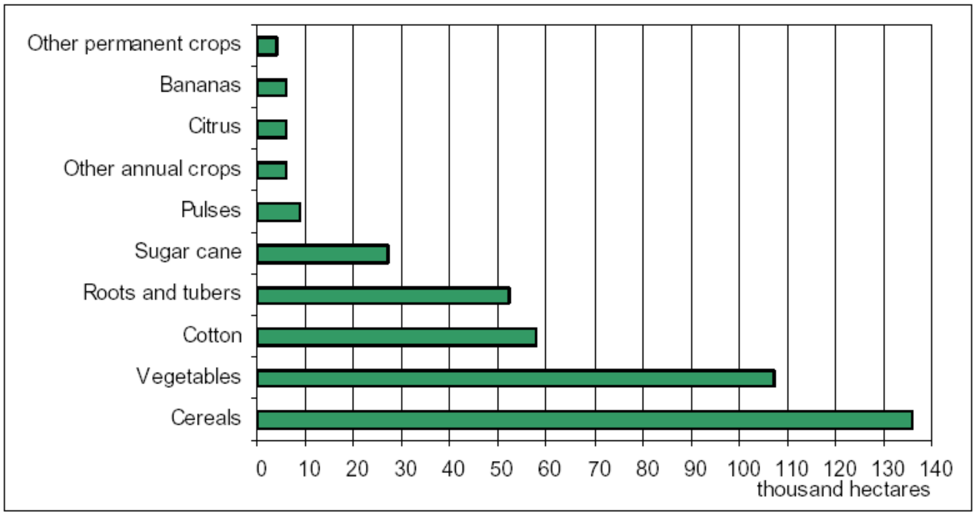


Figure 70 Irrigated crops in Ethiopia (FAO, AQUASTAT, 2005)

Table 49 Cropping calendar in Ethiopia (FAO, AQUASTAT, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
ETHIOPIA													
Maize	23						14	14	14	14	14		
Sorghum	20						12	12	12	12	12		
Sugarcane	17	11	11	11	11	11	11	11	11	11	11	11	11
Pulses	2	1	1	1								1	1
Vegetables	70	43	43	43								43	43
Bananas	1	1	1	1	1	1	1	1	1	1	1	1	1
Citrus	3	2	2	2	2	2	2	2	2	2	2	2	2
Soybean	4	2	2	2								2	2
Tobacco	4	2	2	2								2	2
Cotton	43				27	27	27	27	27	27	27		
All irrigated crops	187	63	63	63	40	40	66	66	66	66	66	63	63
Equipped for irrigation	161												
Cropping intensity	116												

Part 2 Climate

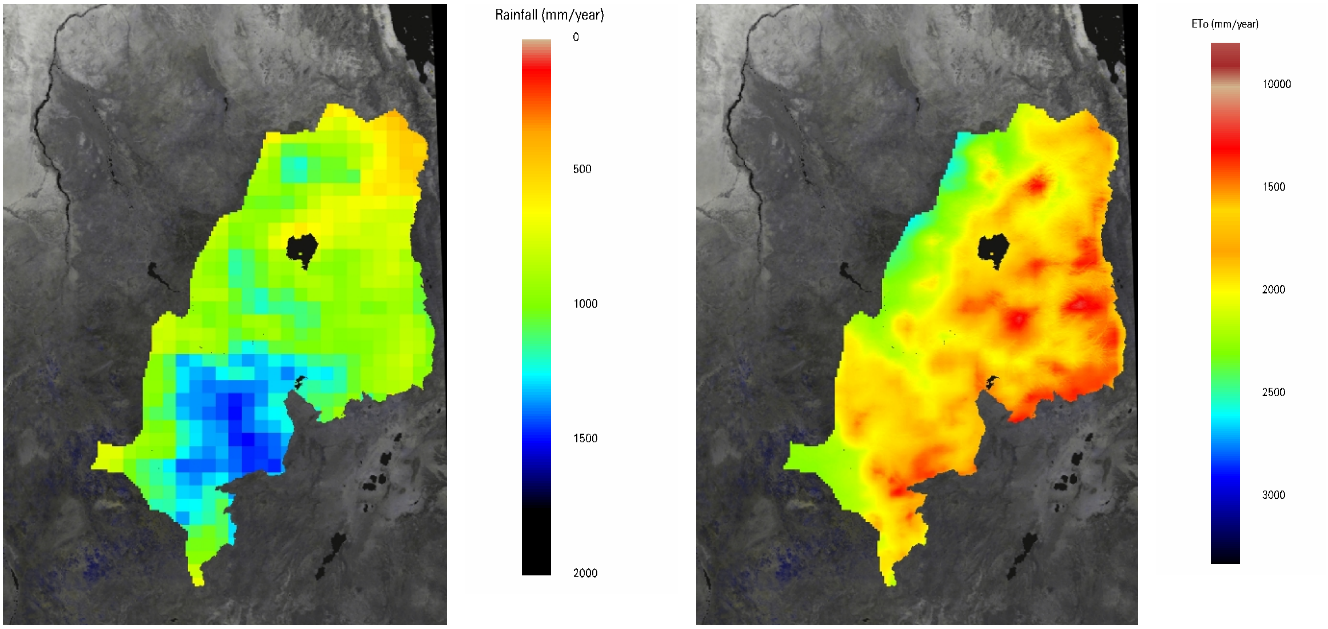
2.1 Climatological conditions

Ethiopia has a tropical monsoon climate with wide topographic-induced variations. Three climatic zones are identified: a cool zone consisting of the central parts of the western and eastern section of the high plateaus, a temperate zone between 1,500 m and 2,400 m above sea level, and the hot lowlands below 1,500 m. Mean annual temperature varies from less than 7−12ºC in the cool zone to over 25 ºC in the hot lowlands. Mean annual potential evapotranspiration varies between 1,700−2,600 mm in arid and semi-arid areas and 1,600−2,100 mm in dry sub-humid areas. Average annual rainfall is 848 mm, varying from about 2,000 mm over some parts of south-west Ethiopia to less than 100 mm over the Afar Lowlands in the north-east.

In this study, the reference evapotranspiration (ET_0) is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007. Table 50 shows that the winter months November to March have hardly any rainfall. ET_0 exceeds rainfall during ten months. Therefore irrigation systems are needed for maintenance of soil moisture of cropland. Only the monsoon rains in July and August induce an aridity index that exceeds 1.0. As Figure 71 shows, the highest rainfall occurs in the south-western part of Ethiopia due to the south-west monsoon that hits the highlands upstream of Gambella plain i.e. orographically induced rainfall. The highest reference ET occurs near the border of Sudan in the lower part of the Beles basin.

Table 50 Monthly values for rainfall and ET0 for the year 2007.

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	0	162	0
February	0	166	0
March	8	196	0.04
April	23	190	0.12
May	74	177	0.42
June	137	152	0.90
July	324	121	2.68
August	298	117	2.55
September	118	131	0.90
October	45	141	0.32
November	11	138	0.08
December	2	146	0.01
TOTAL	1040	1837	



Annual rainfall

Annual reference ET

Figure 71 Spatial variation of rainfall and ET0.

2.2 Climatic zones

The current study, aimed at providing information for improved irrigation practices in the Nile basin, covers various climate zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as the irrigation efficiencies. Unexpected rainfall can for instance reduce the irrigation efficiency, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences based on the diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

The irrigation schemes across Ethiopia are included in three climatic zones: semi-arid climate (zone 2), arid climate (zone 3) and the humid climate (zone 4) (see Figure 72). Very few areas are located in climate zone 3.

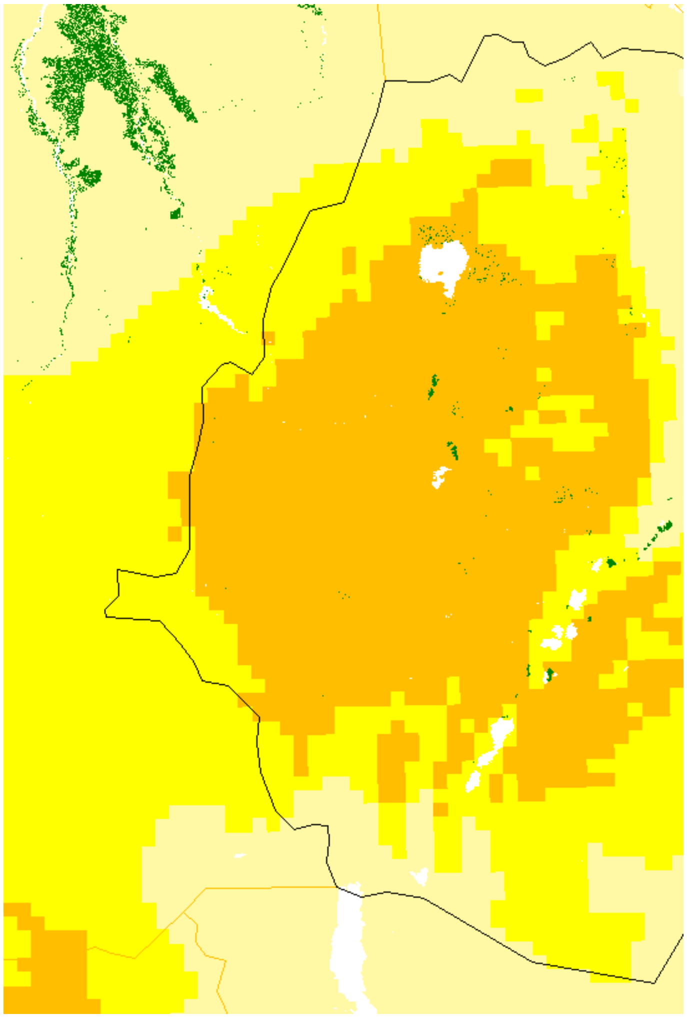


Figure 72 Climate zones distinguished for the mapping of best irrigation practices. The irrigated areas of Ethiopia are located in all the three climate zones identified (light yellow: arid; yellow: semi-arid; orange: humid tropics)

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on (i) the data send by the LSI representatives of Ethiopia, (ii) the FAO irrigated areas, and (iii) manual digitization of visually recognizable irrigated system using Google earth and Landsat images.

The first step was to compute all the indicators per pixel. All the RO and PO indicators have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. The annually accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

The sustainability indicators have been obtained by investigating the last five year's trends in the vegetation index (from the SPOT-Vegetation satellite) and the soil moisture (from the AMSR-E satellite).

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, 4 different benchmark values were defined. A score between 1 and 5 has been given to each pixel; 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 73).

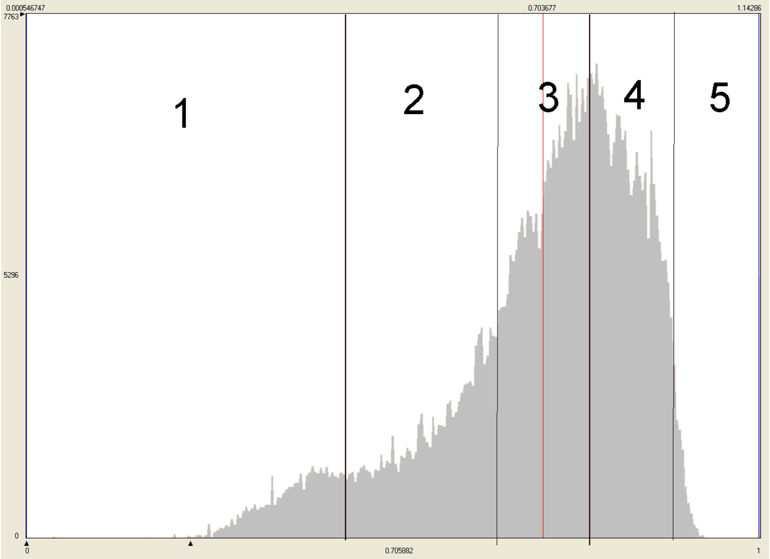


Figure 73 Distribution of the values of one indicator in 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems included in different climatic zones, different benchmark values are considered to avoid any climatic bias in the allocation of the score (Table 51, Table 52, Table 53). Ethiopia, it is located in climatic zone 2, 3 and 4. The benchmark values for each climatic zone will be displayed in the tables below. The benchmarks for Tigray are based on what is physically feasible in the semi-arid zone, which is more comparable to the climate of Sudan, than to the humid tropics of Gambella plain.

Table 51 benchmark values for pixel located in climatic zone 2

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<3,300	<4,400 and >3.300	<7,800 and >4,400	<10,000 and >7,800	>10,000
bwp	Kg/ m3	<0.7	<1 and >0.7	<1.5 and >1	<2.3 and >1.5	>2.3
cwc	M3/ha/year	>11,600	<11,600 and >7,600	<7,600 and >4,400	<4,400 and >2,000	<2,000
cwd	M3/ha/year	<390 and >280	>500	<500 and >390	<280 and >168	<168
bf	-	<0.47	<0.62 and >0.47	<0.75 and >0.62	<0.86 and >0.75	>0.86
ad	-	<0.40	<0.47 and >0.4	<0.58 and >0.47	<0.7 and >0.58	> 0.7
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.56	<0.72 and >0.56	<0.80 and >0.72	<0.90 and >0.8	>0.90
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Table 52 benchmark values for pixel located in climatic zone 3

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5

bio	Kg/ha/year	<7,000	<10,500 and >7,000	<13,500 and >10,500	<15,000 and >13,500	>15,000
bwp	Kg/ m3	<1.3	<2.2 and >1.3	<2.5 and >2.2	<3 and >2.5	>3
cwc	M3/ha/year	>10,200	<10,200 and >7,000	<7,000 and >5,300	<5,300 and >4,000	<4,000
cwd	M3/ha/year	<110	<175 and >110	<310 and >220	>310	<220 and >175
bf	-	<0.5	<0.7 and >0.5	<0.83 and >0.7	<0.88 and >0.83	>0.88
ad	-	<0.56	<0.63 and >0.56	<0.70 and >0.63	<0.78 and >0.70	> 0.78
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.74	<0.8 and >0.74	<0.86 and >0.8	<0.92 and >0.86	>0.92
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Table 53 benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80

bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, districts average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at country level

The average score considering all the indicators together for all the irrigated land is 2.9, which is a relatively poor score. Figure 74 shows the country average for each indicator. The elements with a relative low score are the ones that Ethiopia should provide more attention to.

The score of 3.1 for biomass water productivity is about average. The score of 2.4 for land productivity tends to indicate poor practices.

Concerning the PO indicators, there is very good performance in terms of uniformity, and average performance in terms of crop water deficit and crop water consumption and reliability. The weakest aspect of Ethiopian irrigation seems to be adequacy and, to a lesser extent, the beneficial fraction.

The land sustainability of irrigation practices seems to be under control. From the last years, the irrigated land have remained relatively constant in terms of soil moisture and greenness (as the score for the land and water sustainability is around 3), hence the irrigation systems are quite healthy and continuous. The soils are being relatively well maintained. Hence, the irrigation system in Ethiopia is relatively sound but special attention should be given to avoid water sustainability to get worse.

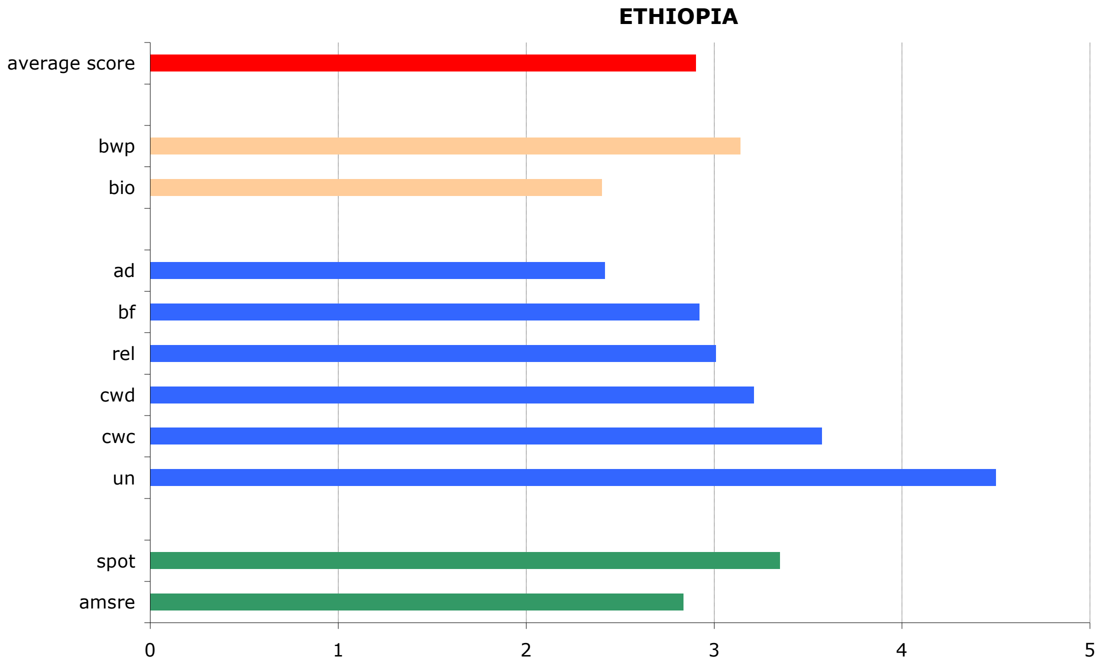


Figure 74 Representation of the average score for each indicator in Ethiopia.

3.3 Results at district level

3.3.1 Average per district

In Figure 75 the average score for all the indicators per district are compared. In Ethiopia, 42 districts with more than 30 pixels of 6.25 ha have been identified.

In terms of total average score, the best irrigation district is Adwa, with an average of 3.9. The district that has the lowest average is Chilga, with an average of 2.6 (see Figure 76 for their locations). Hence, there is a significant variability in the irrigation practices in Ethiopia. This shows that local solutions and management practices can make a difference.

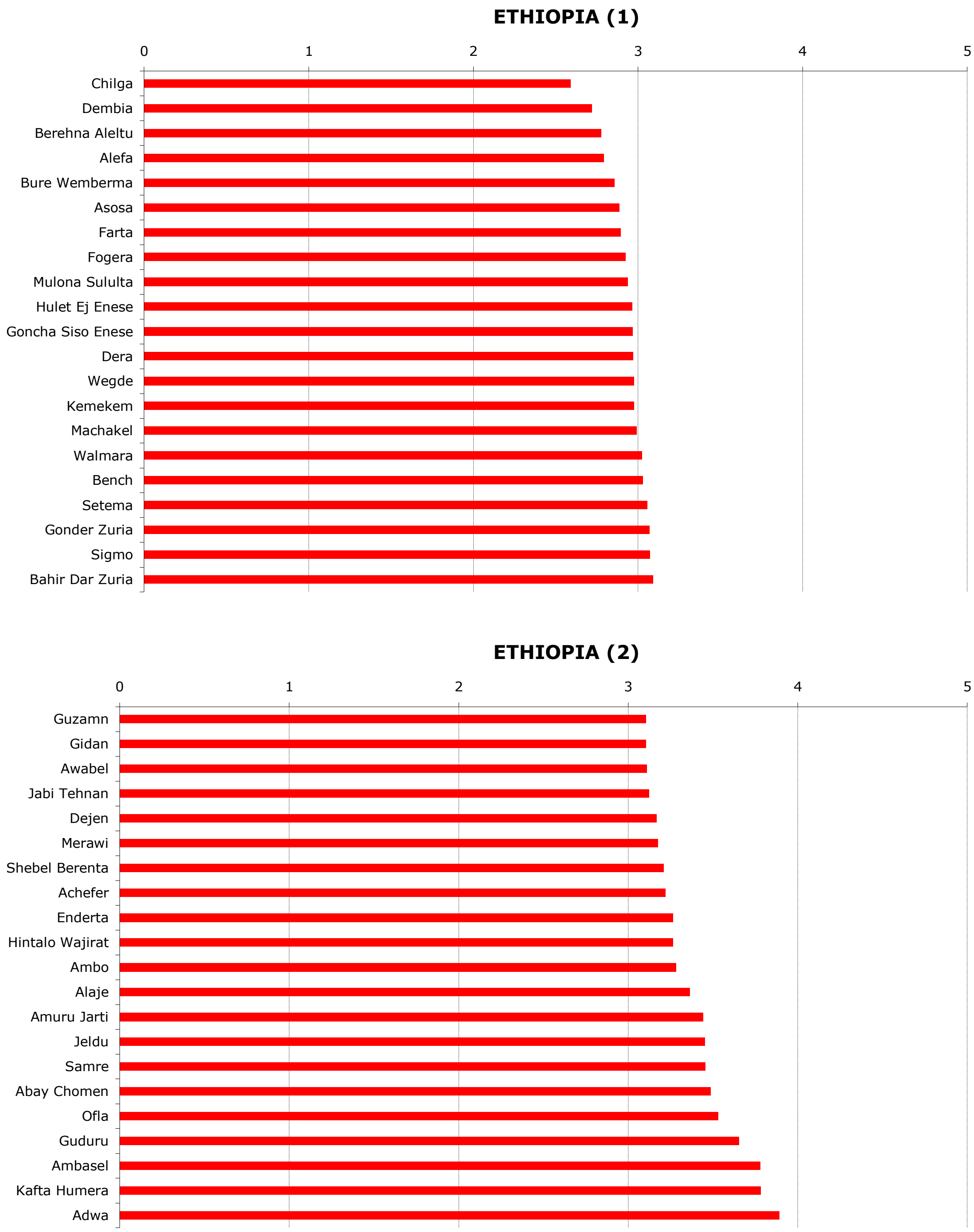


Figure 75 Representation for the average total score for Ethiopia for each district.

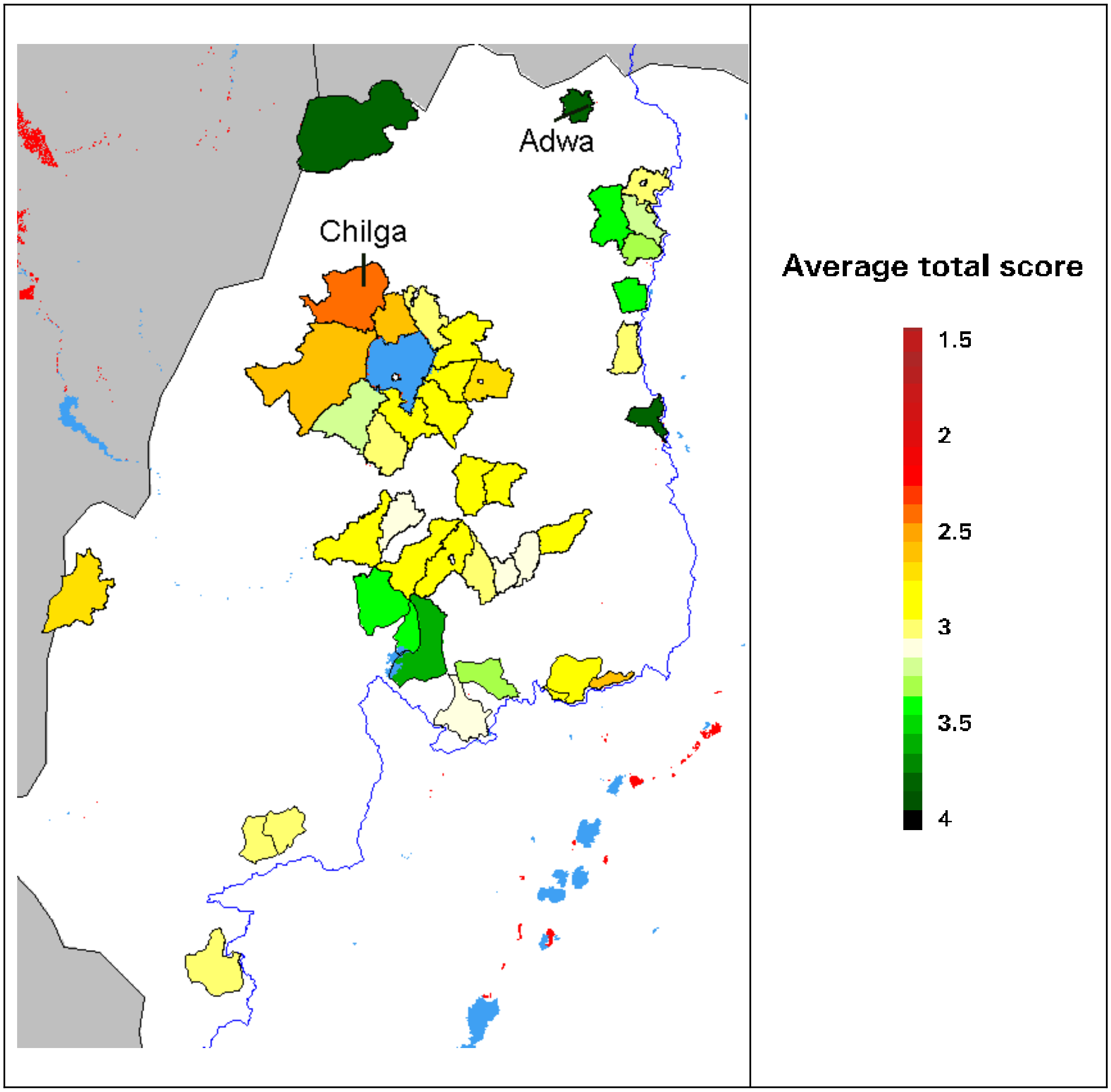
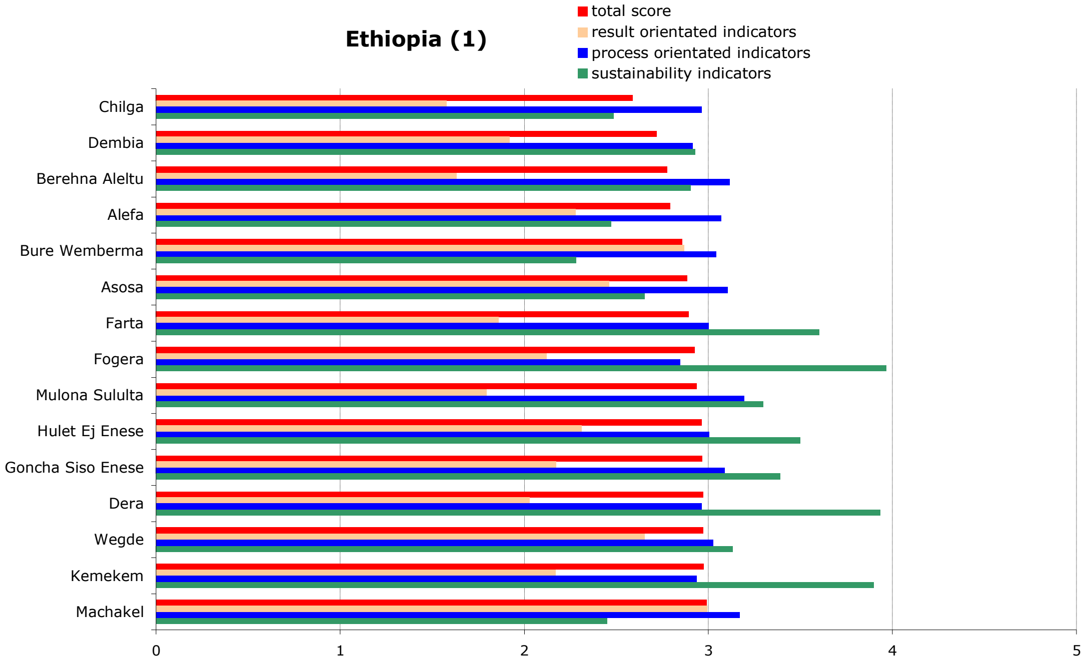
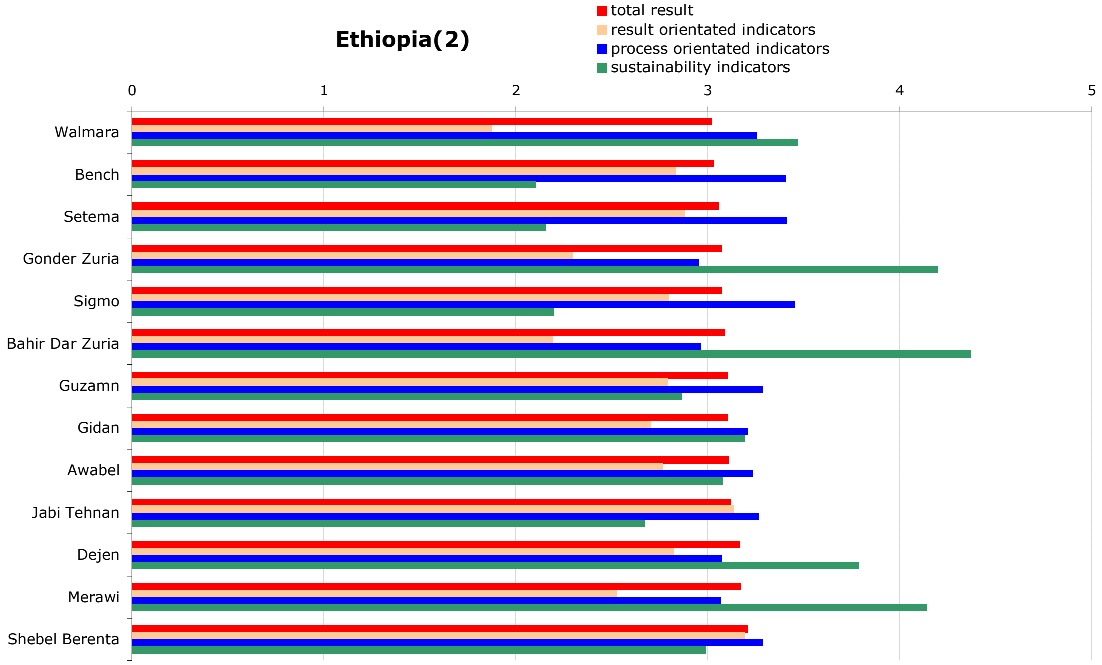


Figure 76 Map showing the total score per irrigated district.

3.3.2 Breaking down the total score into RO, PO and sustainability indicators

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 77 provides the average score per group of indicators. Considering the total score or the average for all indicators for each district gives an idea of the total performance. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.


Ethiopia (1)
total score
result orientated indicators
process orientated indicators
sustainability indicators
Chilga
Dembia
Berehna Aleltu
Alefa
Bure Wemberma
Asosa
Farta
Fogera
Mulona Sululta
Hulet Ej Enese
Goncha Siso Enese
Dera
Wegde
Kemekem
Machakel
0
1
2
3
4
5


Ethiopia(2)
total result
result orientated indicators
process orientated indicators
sustainability indicators
0
1
2
3
4
5
Walmara
Bench
Setema
Gonder Zuria
Sigmo
Bahir Dar Zuria
Guzamn
Gidan
Awabel
Jabi Tehnan
Dejen
Merawi
Shebel Berenta

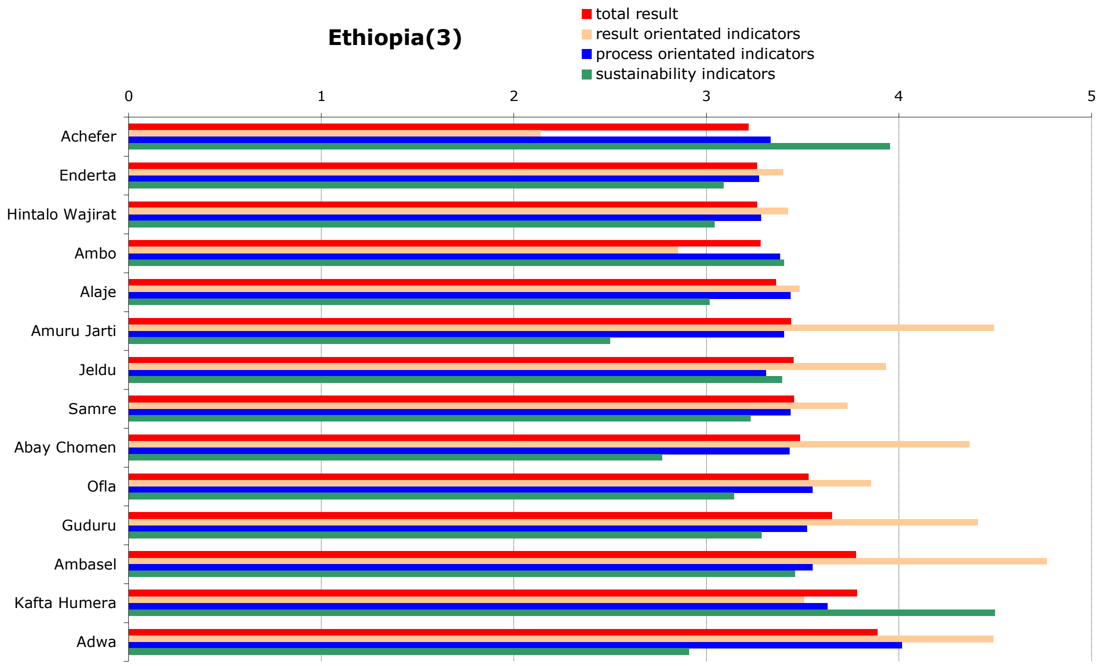


Figure 77 Breaking down the total score per indicator

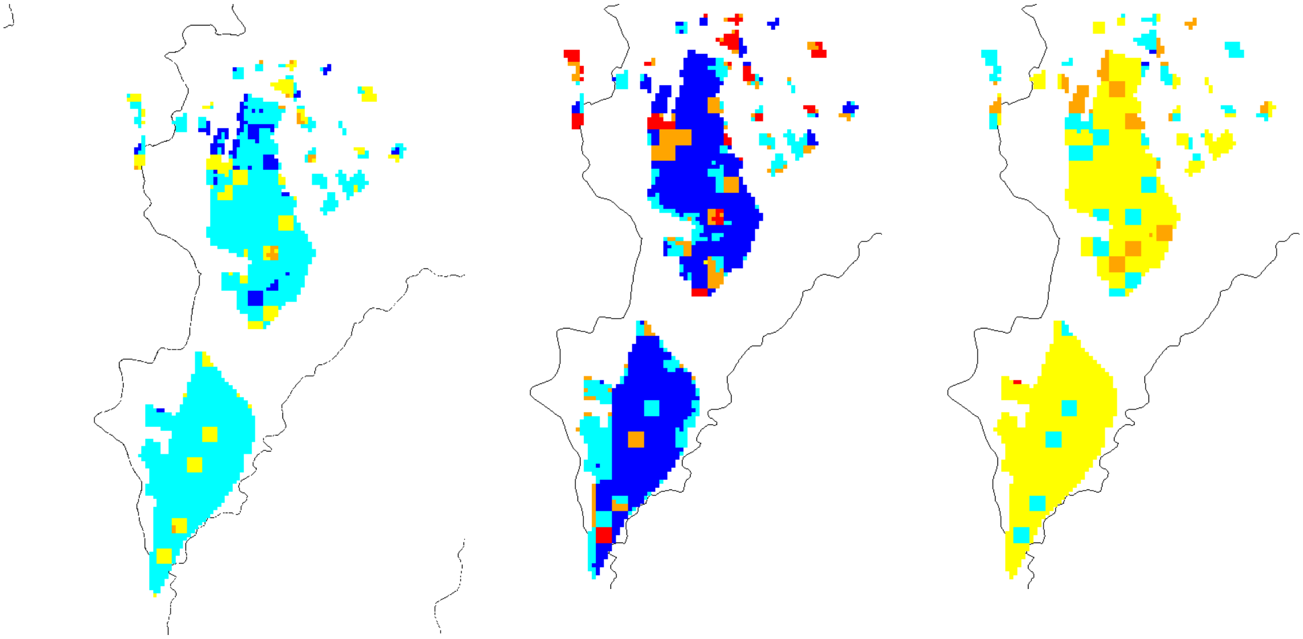
A good total score does not always mean a good performance for the three categories of indicators: RO, PO and sustainability. Indeed, if one looks at the average score for the RO indicators, Bahir Dar Zuria is fourth best in terms of total score whilst it has a low score in terms of land and biomass water productivity. This is due to the fact that its score for land and water sustainability is really good. Hence, a favourable total performance does not mean a sustainable system. In fact, considering the score for the sustainability indicators, there is no obvious difference between the good performing and the bad performing districts. This shows once again the relevance of breaking the irrigation performance down into different types of indicators.

The upper third best performing districts have a good to very good score in terms of RO indicators. On the contrary, the other districts have a better score in terms of the PO indicators average score than in terms of RO indicators. It means that even though the management of the irrigation systems seems quite good, other factors are limiting the land and water productivity. These factors might be linked to agricultural practices such as crop types or application of fertilizers. Relevant improvement recommendations should be made district per district by looking at the different scores of every single indicator.

3.4 Analysis per pixel for an irrigation system

Looking at what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators are displayed for the irrigated pixel in the district of Jabi

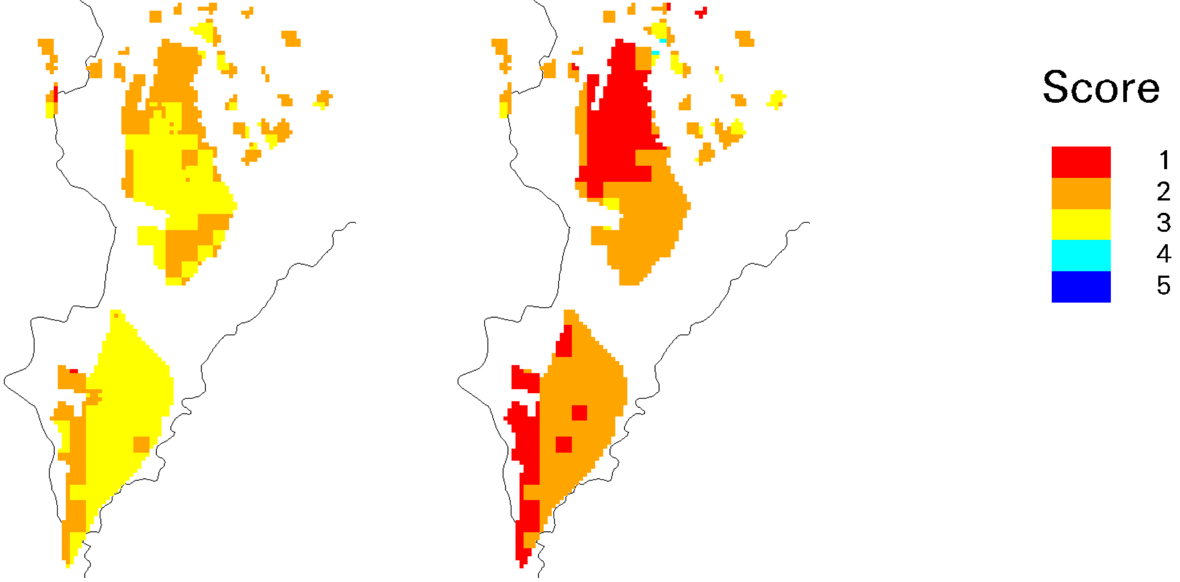
Tehnan, which is an average district in terms of performance. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. This example demonstrates that reliability and adequacy need to be managed better (Figure 78).



crop water consumption

crop water deficit

beneficial fraction



adequacy

reliability

Figure 78 Spatial distribution of each indicator for the districts of Jabi Tehnan

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators and the sustainability indicators influence the RO indicators mostly. A regression analysis was performed with the values for all indicators of the 42 districts. It showed that crop water consumption, reliability, and adequacy are the three main explanatory factors for biomass production. Hence the timely delivery of adequate irrigation amounts should get more attention in Ethiopia.

Besides, an increase in beneficial fraction leads to an increase in biomass production and biomass water productivity. An increase in crop water consumption leads to an increase in biomass production but a decrease in biomass water productivity. It seems that the lower the crop water consumption and the higher the beneficial fraction, the better the biomass water productivity. But none of the relationships depicted is clear. It is thus better to focus on increasing biomass production rather than biomass water productivity.

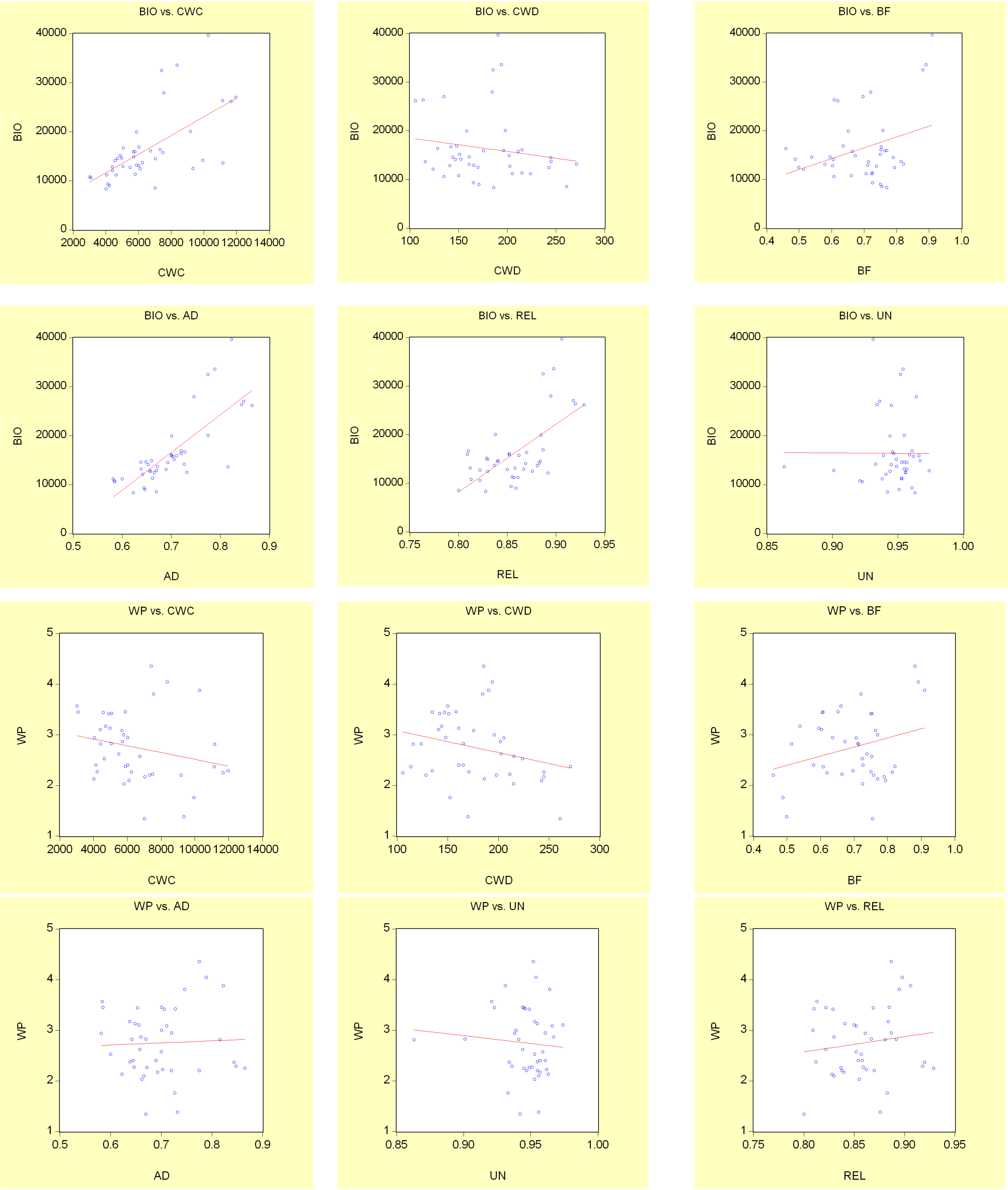


Figure 79 Relationships between RO indicators and PO indicators

4.2 Weak and strong aspects per district

In Table 54, the best and poorest indicators are presented. This helps to identify which elements of irrigation performance need improvement.

Adequacy, beneficial fraction, and reliability seem to be the main problem factors for the majority of the districts. On the other side of the scale, crop water deficit and uniformity are often mentioned as being the best indicators.

Table 54 best and poorest PO irrigation indicator per district

district	lowest score		2nd lowest		2nd best		best	
Chilga	ad	1.55	bf	1.67	cwd	3.42	un	5.00
Dembia	bf	1.65	rel	2.63	cwd	3.77	un	4.00
Berehna Aleltu	ad	1.79	rel	2.03	cwc	4.13	un	5.00
Alefa	bf	1.49	ad	2.30	un	4.00	cwd	4.16
Bure Wemberma	rel	1.74	ad	2.57	cwc	3.77	un	4.00
Asosa	ad	1.93	rel	2.01	bf	3.01	un	5.00
Farta	rel	2.10	cwd	2.30	cwc	3.84	un	5.00
Fogera	cwd	1.80	ad	1.88	cwc	3.70	un	4.00
Mulona Sululta	ad	2.02	rel	2.10	cwc	4.19	un	5.00
Hulet Ej Enese	rel	2.13	ad	2.31	cwc	3.17	un	5.00
Goncha Siso Enese	ad	1.77	rel	2.09	cwc	3.56	un	5.00
Dera	cwd	1.85	rel	1.92	cwc	3.78	un	5.00
Wegde	ad	1.96	rel	1.96	cwc	3.62	un	5.00
Kemekem	rel	1.64	cwd	1.68	cwc	3.85	un	5.00
Machakel	rel	1.85	ad	1.87	cwc	3.98	un	4.00
Walmara	rel	2.01	ad	2.05	cwc	4.20	un	5.00
Bench	ad	2.00	cwc	2.20	un	4.00	cwd	4.26
Setema	ad	1.87	cwc	2.28	un	4.00	cwd	4.59
Gonder Zuria	rel	1.83	ad	2.32	un	4.00	cwc	4.06
Sigmo	ad	1.94	cwc	2.07	un	4.00	cwd	4.27
Bahir Dar Zuria	cwd	1.92	rel	2.03	cwc	3.36	un	5.00
Guzamn	rel	2.03	ad	2.30	cwc	3.81	un	5.00
Gidan	bf	1.73	ad	2.92	cwd	4.08	cwc	4.22
Awabel	ad	1.81	rel	2.00	cwc	4.08	un	5.00
Jabi Tehnan	rel	1.70	ad	2.16	un	4.00	cwd	4.29
Dejen	ad	2.22	bf	2.30	un	4.00	cwc	4.09
Merawi	rel	2.10	ad	2.22	cwc	3.44	un	5.00
Shebel Berenta	bf	2.22	rel	2.40	cwd	4.06	un	5.00
Achefer	rel	2.78	bf	2.87	ad	3.69	cwd	4.71
Enderta	bf	2.47	rel	3.11	un	4.00	cwc	4.65
Hintalo Wajirat	bf	2.16	rel	3.38	un	4.00	cwc	4.73
Ambo	bf	2.47	rel	2.72	cwd	3.94	un	5.00
Alaje	ad	2.54	bf	2.87	cwc	3.68	un	4.00
Amuru Jarti	cwc	2.34	cwd	2.86	ad	4.00	bf	4.53
Jeldu	ad	2.77	rel	2.83	cwc	3.40	un	5.00
Samre	ad	2.82	bf	2.89	un	4.00	cwc	4.06
Abay Chomen	cwd	2.39	cwc	2.97	bf	4.13	un	5.00

Ofla	bf	1.71	ad	3.45	cwc	4.10	un	5.00
Guduru	rel	2.82	cwd	2.83	bf	4.12	un	5.00
Ambasel	bf	2.19	ad	3.31	un	4.00	cwd	4.58
Kafta Humera	cwc	2.68	bf	3.53	cwd	3.81	un	4.00
Adwa	cwc	3.41	bf	3.44	cwd	4.43	un	5.00

4.3 Recommendation countrywide

With a growing population, food security is becoming a major concern in Ethiopia even though it has a high agricultural potential (the total arable land is estimated to be 55 million ha according to FAO). However, improvements in rainfed agriculture will fail to make up the deficits and keep pace with the increasing demand resulting from population growth. Since 1991, a combination of the positive effects of policy initiatives and good rains allowed the country to achieve food self-sufficiency and food exports in 1996/97. But bad weather – a combination of rainfall deficits during the growing season and excess rainfall during the ripening and harvest season – has reversed that situation in 1997/98, demonstrating the dependence of agriculture on climatic factors. Even in good years Ethiopia cannot meet its large food deficit through rainfed production. Improving the productivity of irrigated land should be on the agenda. The fact that on average, the performance of the LSI is quite low offers the greatest possibilities for improved productivity and for meeting the demand for food within the country.

The weakest aspect is more on the agronomical side than on the irrigation side.
As the population is growing fast, food deficit is getting bigger and bigger.
If the country is to address its serious problems of poverty and food deficits due to the fast growing population, it is important to increase the productivity of existing irrigation systems. Biomass production can be increased if sufficient irrigation water (adequacy) is applied at the right time (reliability). To do so, investments should be made to improve agronomical research and extension services: more qualified and equipped staff able to advice on application of fertilizers.

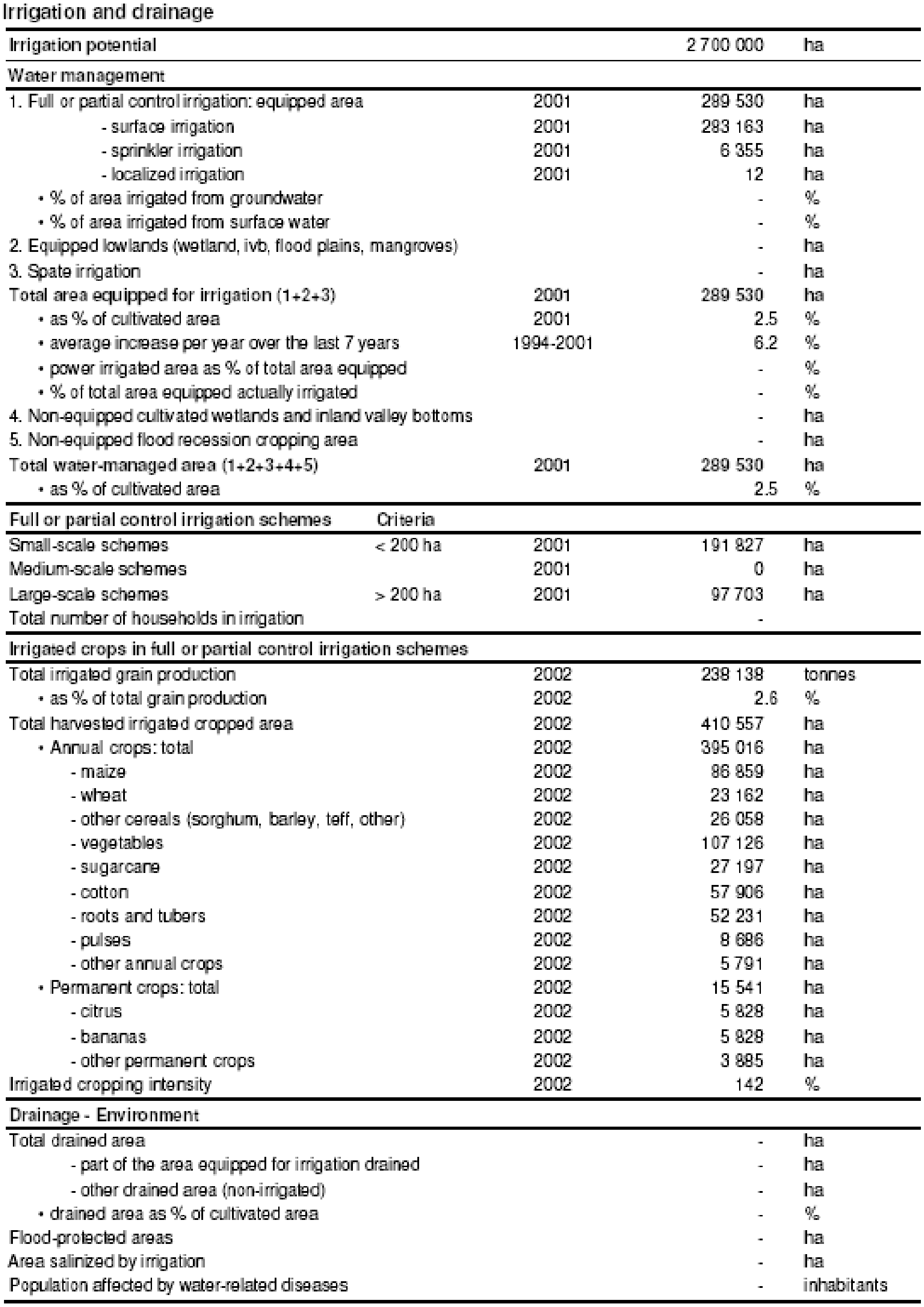
According to an IWMI study, the limitation in the availability of water in semi arid areas (like Ethiopia) is not caused by low rainfall but lack of capacity for sustainable management and use of the available water. Neither the farmers nor the extension services are attempting to generate/implement practices that can retain the temporary excess rain water for use during dry spells. The agronomical research has an important role to play to find crop varieties and practices that could tolerate the temporary water logging problems and the sporadic dry spells.

The institutional context does not seem to favour the cooperative management of the irrigation systems, such measures because of its lack of organization, different institution involved, and its instability (in the irrigation sector).

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m3	Bio/ETact	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M3/ha/year	ETact	Saving of water resources
	Crop water deficit	cwd	M3/ha/year	ETpot-ETact	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	Tact/ETpot	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	Tact/Tpot	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	1-CV(Tact/Tpot)(x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	1-CV(Tact/Tpot)(t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
					Indication of changes of water resources availability
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 General information on irrigation conditions in Ethiopia (Aquastat, 2005)



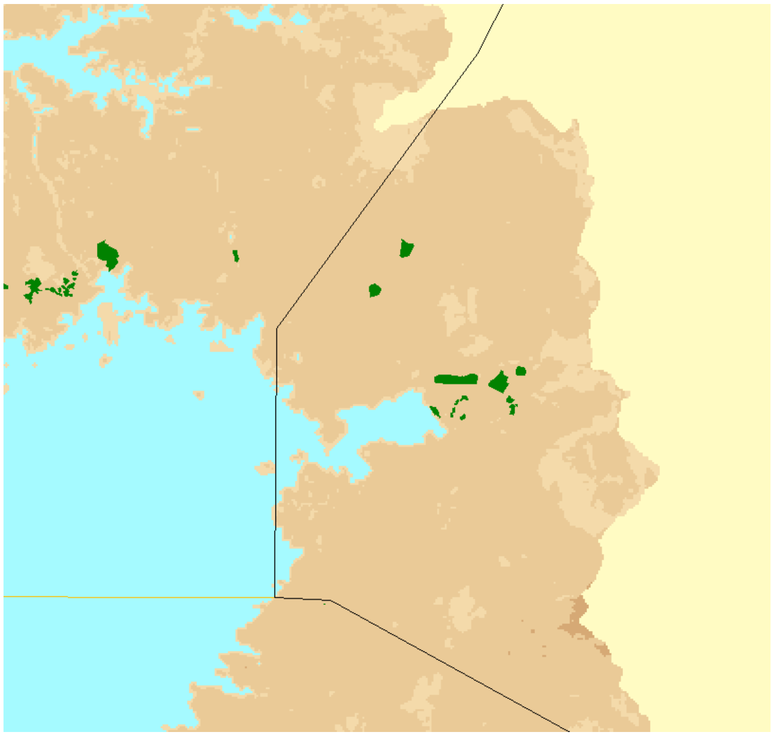
Irrigation and drainage

Irrigation potential			2 700 000	ha
Water management				
1. Full or partial control irrigation: equipped area		2001	289 530	ha
- surface irrigation		2001	283 163	ha
- sprinkler irrigation		2001	6 355	ha
- localized irrigation		2001	12	ha
• % of area irrigated from groundwater			-	%
• % of area irrigated from surface water			-	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)			-	ha
3. Spate irrigation			-	ha
Total area equipped for irrigation (1+2+3)		2001	289 530	ha
• as % of cultivated area		2001	2.5	%
• average increase per year over the last 7 years		1994-2001	6.2	%
• power irrigated area as % of total area equipped			-	%
• % of total area equipped actually irrigated			-	%
4. Non-equipped cultivated wetlands and inland valley bottoms			-	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		2001	289 530	ha
• as % of cultivated area			2.5	%
Full or partial control irrigation schemes	Criteria			
Small-scale schemes	< 200 ha	2001	191 827	ha
Medium-scale schemes		2001	0	ha
Large-scale schemes	> 200 ha	2001	97 703	ha
Total number of households in irrigation			-	
Irrigated crops in full or partial control irrigation schemes				
Total irrigated grain production		2002	238 138	tonnes
• as % of total grain production		2002	2.6	%
Total harvested irrigated cropped area		2002	410 557	ha
• Annual crops: total		2002	395 016	ha
- maize		2002	86 859	ha
- wheat		2002	23 162	ha
- other cereals (sorghum, barley, teff, other)		2002	26 058	ha
- vegetables		2002	107 126	ha
- sugarcane		2002	27 197	ha
- cotton		2002	57 906	ha
- roots and tubers		2002	52 231	ha
- pulses		2002	8 686	ha
- other annual crops		2002	5 791	ha
• Permanent crops: total		2002	15 541	ha
- citrus		2002	5 828	ha
- bananas		2002	5 828	ha
- other permanent crops		2002	3 885	ha
Irrigated cropping intensity		2002	142	%
Drainage - Environment				
Total drained area			-	ha
- part of the area equipped for irrigation drained			-	ha
- other drained area (non-irrigated)			-	ha
• drained area as % of cultivated area			-	%
Flood-protected areas			-	ha
Area salinized by irrigation			-	ha
Population affected by water-related diseases			-	inhabitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Kenya



Report G

January 2009

NILE BASIN INITIATIVE
Initiative du Bassin du Nil

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Part 1 Overview of irrigated areas
Part 2 Climate
Part 3 Raster and vector-based irrigation performance analysis
Part 4 Recommendations for improvement

Purpose of this report:

This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Kenya and will become an integral component of the final LSI report that will combine results from all countries.

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

The Nile Basin in Kenya covers only 8.5% of the total area of the country but contains over 50% of the national freshwater resources with seven major rivers (Nzoia, Yala, Nyando and Sondu Miriu, Kuja-Migori, Mara and Sio-Malaba) draining directly in to Lake Victoria. While the western part of Kenya is endowed with a high amount of total rainfall, the irregular character of rainfall motivates the stakeholders to invest in irrigation systems. Figure 80 shows the location of the main irrigation systems according to this study. Figure 81 shows the area with potential irrigation.

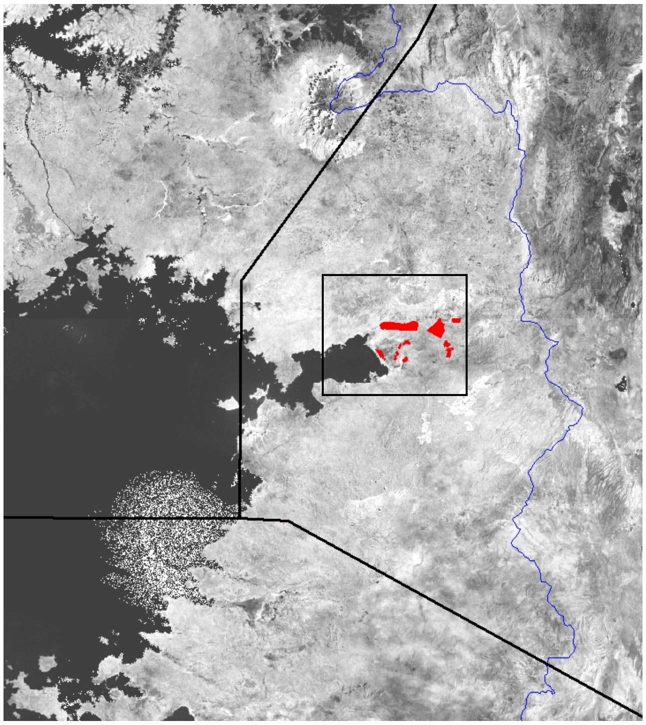
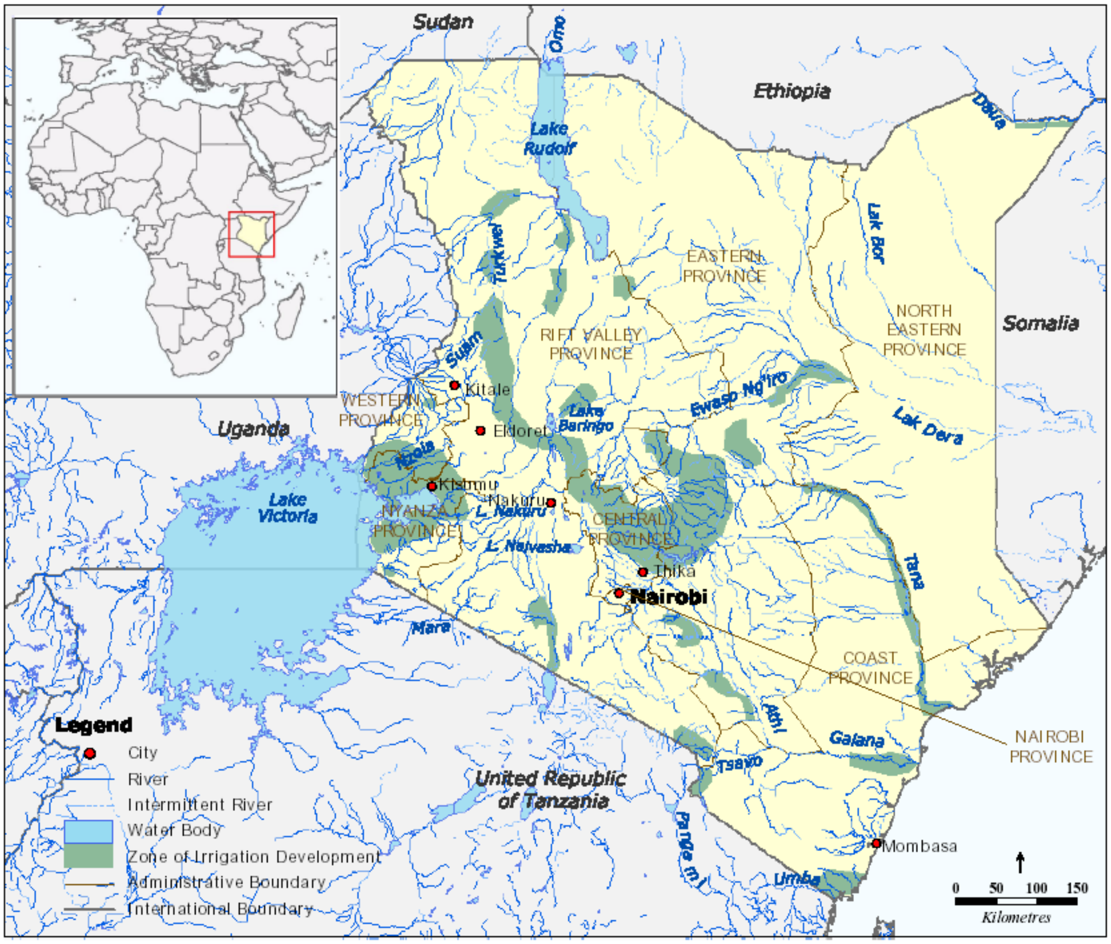


Figure 80 Map with the distribution of irrigated areas within the Nile Basin according to this study. The red dots represent the irrigated areas



FAO - AQUASTAT, 2005

KENYA

Disclaimer

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 81 Map of the potential irrigation systems in Kenya

According to this study, a total of 34,154 ha of land is irrigated in the Nile basin component of Kenya (Table 55).

Table 55 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Kenya	66,610
IWMI – GIAM	Entire Kenya	85,401
Current study	Nile Basin component of Kenya	34,156

1.2 Description of LSI

Kenya has an irrigation potential of 539,000 ha out of which 105,800 ha (or 20%) have been developed. 50% of this has been achieved over the last 20 years. Private, public and smallholder categories account for 42,800 ha (40%), 16,000 ha (15%)

and 47,000 ha (44%) of the total respectively. In the lake Victoria basin, an irrigation potential of 200,000 ha has been estimated which is 37% of the national potential.

Public and private irrigation schemes in the Kenyan Nile basin include West Kano, Ahero and Bunyala irrigation schemes. Almost all irrigation is achieved through developments using river water, but about 4,100 water pans and small dams and 15 large dams have also been built. The former being located in the arid areas and the latter in the medium potential zones. Basin, furrow and flood irrigation methods are used in most community irrigation schemes with sprinkler and drip schemes being used on some private farms especially for the cultivation of flowers and horticultural crops. Table 56 displays the main characteristics of some irrigation scheme located in the district of the Nile Basin.

Table 56 Summary of some key data of Kenyan irrigation schemes that are located in the Nile Basin (source: National Kenya Irrigation Board)

Scheme name	Location (Town/district/ Basin)	Irrigation area (ha)	Main Crop	Crop yield (ton/ha)	Water abstraction Method	Abstraction
1 Ahero	Ahero/Nyando*/Lake Victoria	960	Rice	3.5	Pumped – River Nyando	4 pumps each 600l/s
2 West Kano	Kabonyo/Kisumu/Lake Victoria	900	Rice	3.5	Pumped – Lake Victoria	2 pumps each 750 l/s

* Nyando district is a fairly new district in Kenya which broke away from Kissumu district in Nyanza province in 1998. In this study, we worked with an older district distribution. The irrigation districts of Nyando are included in the district of Kisumu in the report.

More detailed information concerning irrigation in Kenya can be found in Annex 2. There are other water user association irrigated schemes within the Nile Basin region; these could command approximately 3,000 ha inclusive of the privately owned Yala swamp which is about 500 ha.

1.3 Agricultural conditions

Large scale agriculture accounts for 30% of marketed produce comprising tea, coffee, horticultural produce, maize and wheat (see Figure 82 for the national number). The cropping calendar is represented in Table 57.

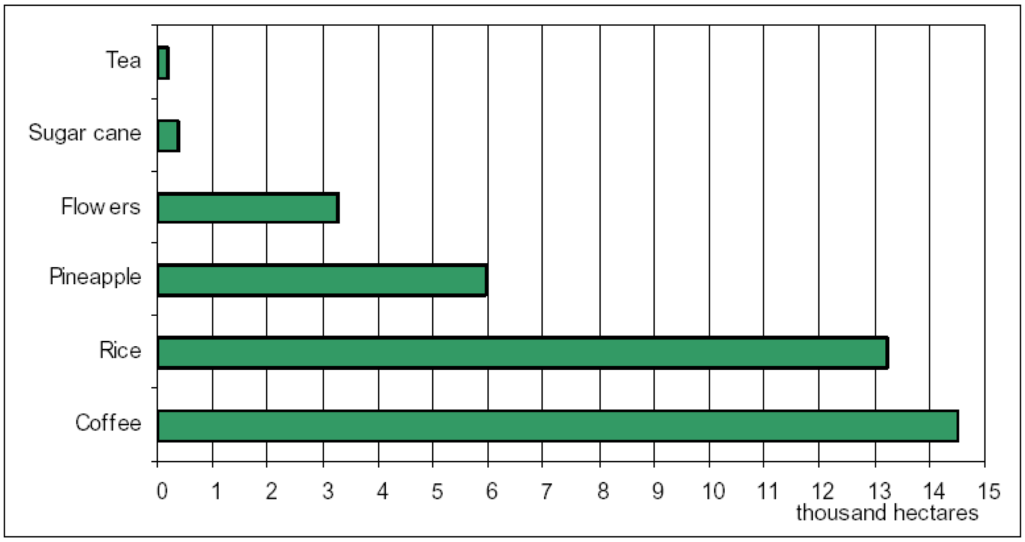


Figure 82 Main irrigated crops in Kenya in 2003 (Aquastat, 2005)

Table 57 Cropping calendar in Kenya in 2003 (Aquastat, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
KENYA													
Rice	18				26	26	26	26	26				
Maize	4				6	6	6	6	6				
Sugarcane	2	3	3	3	3	3	3	3	3	3	3	3	3
Vegetables	26	38	38								38	38	38
Bananas	1	1	1	1	1	1	1	1	1	1	1	1	1
Citrus	5	7	7	7	7	7	7	7	7	7	7	7	7
Coffee	18	26	26	26	26	26	26	26	26	26	26	26	26
Cotton	3	4	4	4						4	4	4	4
All irrigated crops	77	81	81	43	71	71	71	71	71	43	81	81	81
Equipped for irrigation	68												
Cropping intensity	113												

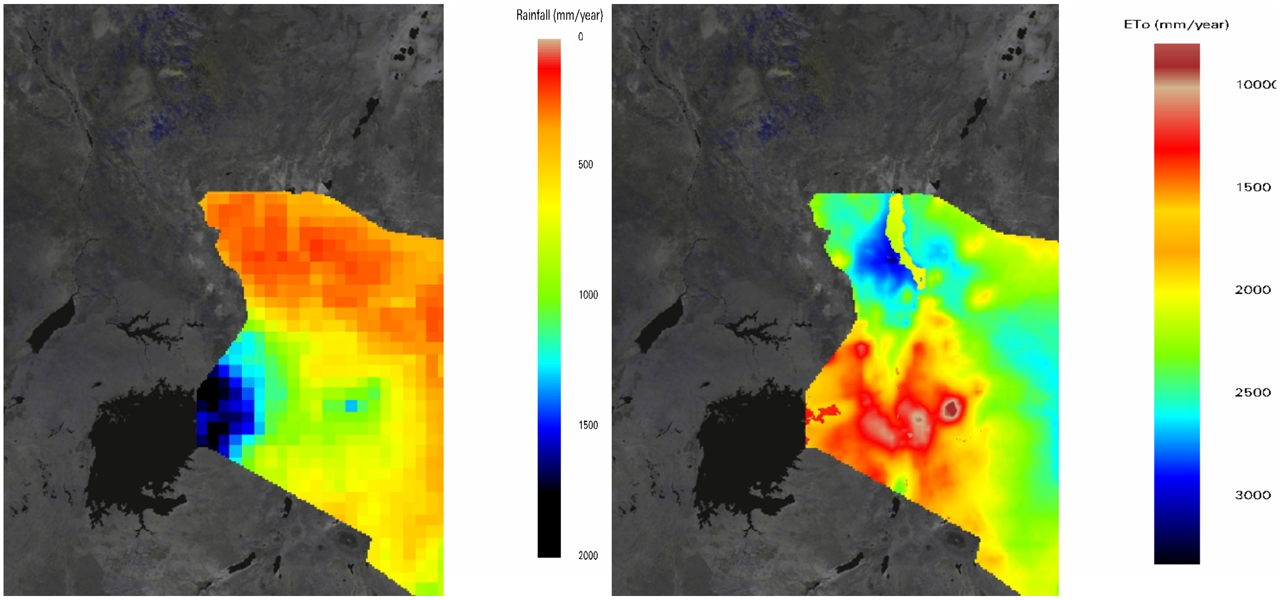
Part 2 Climate

2.1 Climatological conditions

In this study, the reference evapotranspiration (ET_0)is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007. According to this study (Table 58), the rainy season starts in May and continues up to November. Only the winter months are dry, with monthly aridity values of approximately 0.3. Figure 83 shows that the western part of Kenya receives a significant amount of rainfall (1155 mm/yr).

Table 58 Monthly values for rainfall and reference ET_0

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	58	169	0.34
February	47	156	0.30
March	13	168	0.08
April	34	138	0.25
May	178	133	1.29
June	113	124	0.91
July	137	124	1.10
August	141	134	1.05
September	108	142	0.76
October	150	152	0.99
November	119	141	0.84
December	54	156	0.35
TOTAL	1155		



Annual rainfall Annual reference ET

Figure 83 Spatial variation of rainfall and ET_0

2.2 Climatic zones

The current study, aimed at providing information for improved irrigation practices in the Nile basin, covers various climate zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as the irrigation efficiencies. Unexpected rainfall can for instance reduce the irrigation efficiency, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences on the basis of diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones. All Kenyan irrigation schemes located in the Nile basin are included in climate zone 4 (humid tropics).

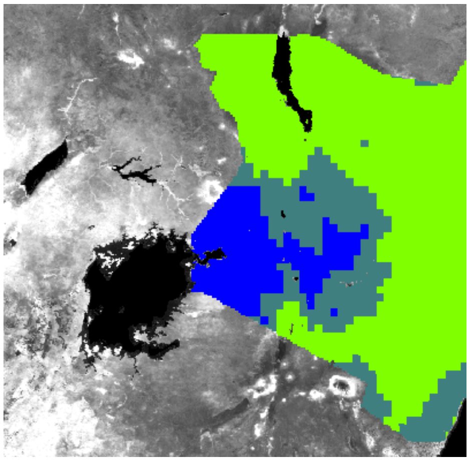


Figure 84 Climate zones distinguished for the irrigation performance mapping in Kenya. The irrigated areas are only located in the climate zone humid tropics, displayed in blue.

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on manual digitization of visually recognizable irrigated systems using existing irrigation reports, Google earth and Landsat images.

The first step was to compute all the indicators per pixel. All the RO and PO indicators have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). These were computed for the year 2007. The annual accumulated values are the results of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

Sustainability indicators have been obtained by looking at the last five year's trend of the vegetation index (from the SPOT-Vegetation satellite) and the soil moisture (from the AMSR-E satellite). It indicates the slope of the trend line over these past years.

Table 59 Definition of the performance indicators selected to describe the LSI for each Nile Basin country. A more detailed description is given in Appendix 2.

Indicator	Acronym	Unit	Formula
Biomass productivity	bio	Kg/ha/year	Bio
Biomass water productivity	bwp	Kg/m3	Bio/ET_{act}
Crop Water Consumption	cwc	M3/ha/year	ET_{act}
Crop water deficit	Cwd	M3/ha/year	$ET_{pot}-ET_{act}$
Beneficial fraction	Bf	-	T_{act}/ET_{pot}
Adequacy (Crop Water stress)	Ad	-	T_{act}/T_{pot}
Uniformity	Un	-	$1-CV(T_{act}/T_{pot})(x,y)$
Reliability	Rel	-	$1-CV(T_{act}/T_{pot})(t)$
Land sustainability	spot	1/year	Slope ndvi spot
Water sustainability	amsre	1/year	Slope soil moisture

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined as displayed in Table 60. A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 85).

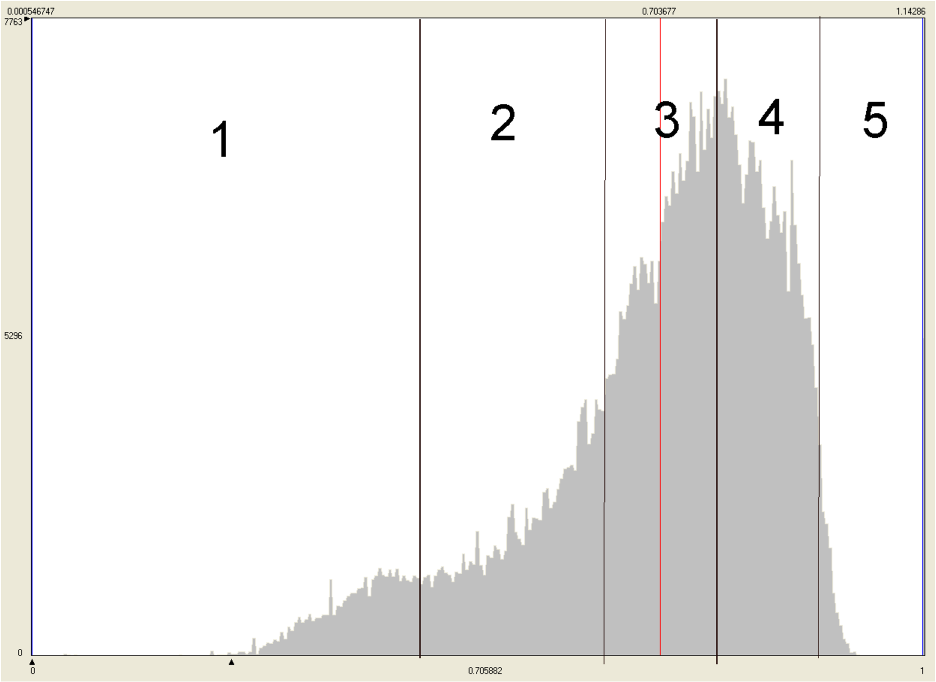


Figure 85 Distribution of the values of one indicator over 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems included in different climatic zones, different benchmark values are considered to avoid any climatic bias in the allocation of the score. Kenya is located in climatic zone 4.

Table 60 Benchmark values for pixel located in climatic zone 4

	Unit	**Score of 1**	**Score of 2**	**Score of 3**	**Score of 4**	**Score of 5**
Bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91

ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, districts average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Analysis at Country level

Figure 86 shows the country average for each indicator. The average score considering all the indicators together for all the 34,156 ha of irrigated land is 3.7, which is a good score. The country average is calculated on a pixel base. . The elements with a relative low score are the ones that Kenya should provide more attention to.

The first comment to make is that, except for crop water consumption, all the indicators are above average, which shows the good global performance of irrigated system in Kenya.

The scores of 3.6 for land productivity and 3.5 for water productivity are good.

The PO indicators show very good performance in terms of beneficial fraction, uniformity, and reliability. Crop water deficit and adequacy are also good. Crop water consumption seems to be the weakest point, with an average score of 2.5. Hence the crop consumptive use is very high and need to be reduced.

Water sustainability seems to be under control. From the last years, the irrigated land is becoming wetter (as the score for the water sustainability is higher than 4.6). The land sustainability seems to be stagnant, with an average score of 3. The latter implies that irrigation intensity is constant in most irrigated land.

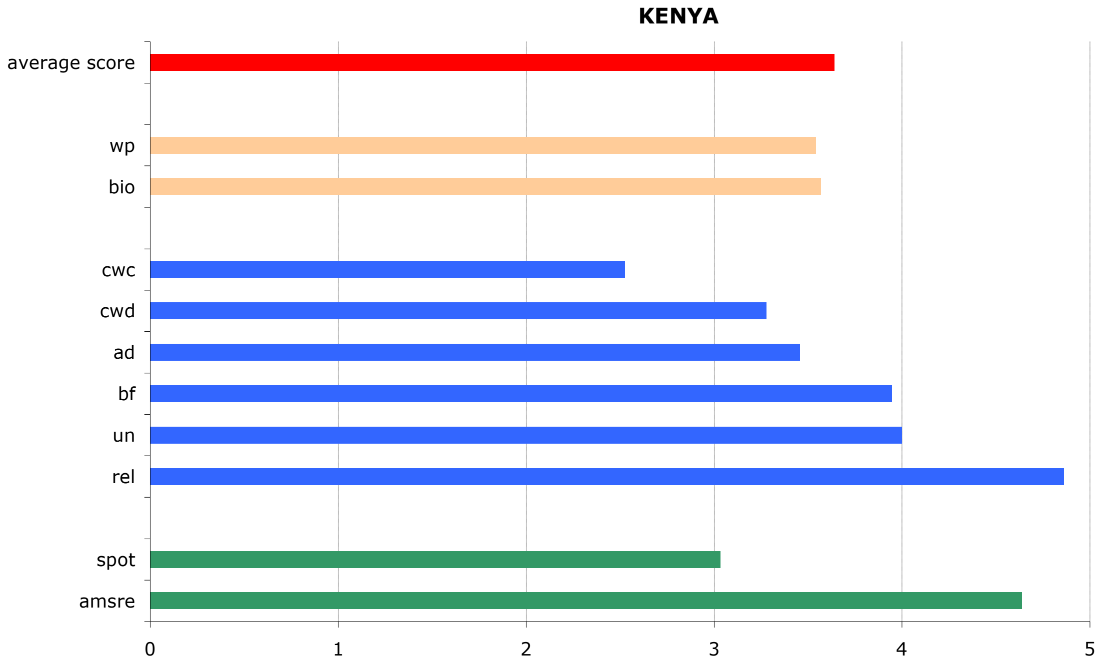


Figure 86 Representation of the average score for each indicator in Kenya.

3.3 Analysis at district level

3.3.1. Average per district

In Figure 87 the average score for all the indicators per district is compared. In Kenya, five districts having more than 30 pixels with 6.25 ha have been identified.

In terms of total average score, the best irrigation districts are Butere Mumais and Kericho, with an average of 3.9. The district that has the lowest average is Kisumu, with an average of 3.6 (see Figure 88 for their location). The average score for these 5 districts is high to very high, which already indicates the good performance of irrigation in Kenya. This good performance was already reflected in the country scale analysis.

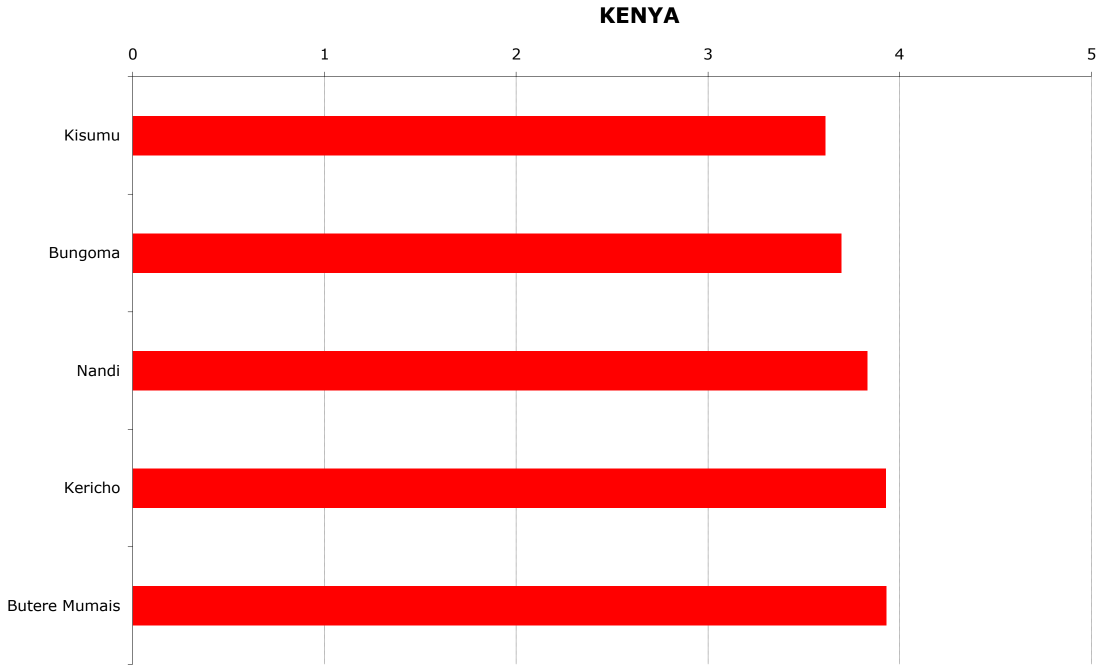


Figure 87 Total scores for Kenya for each district

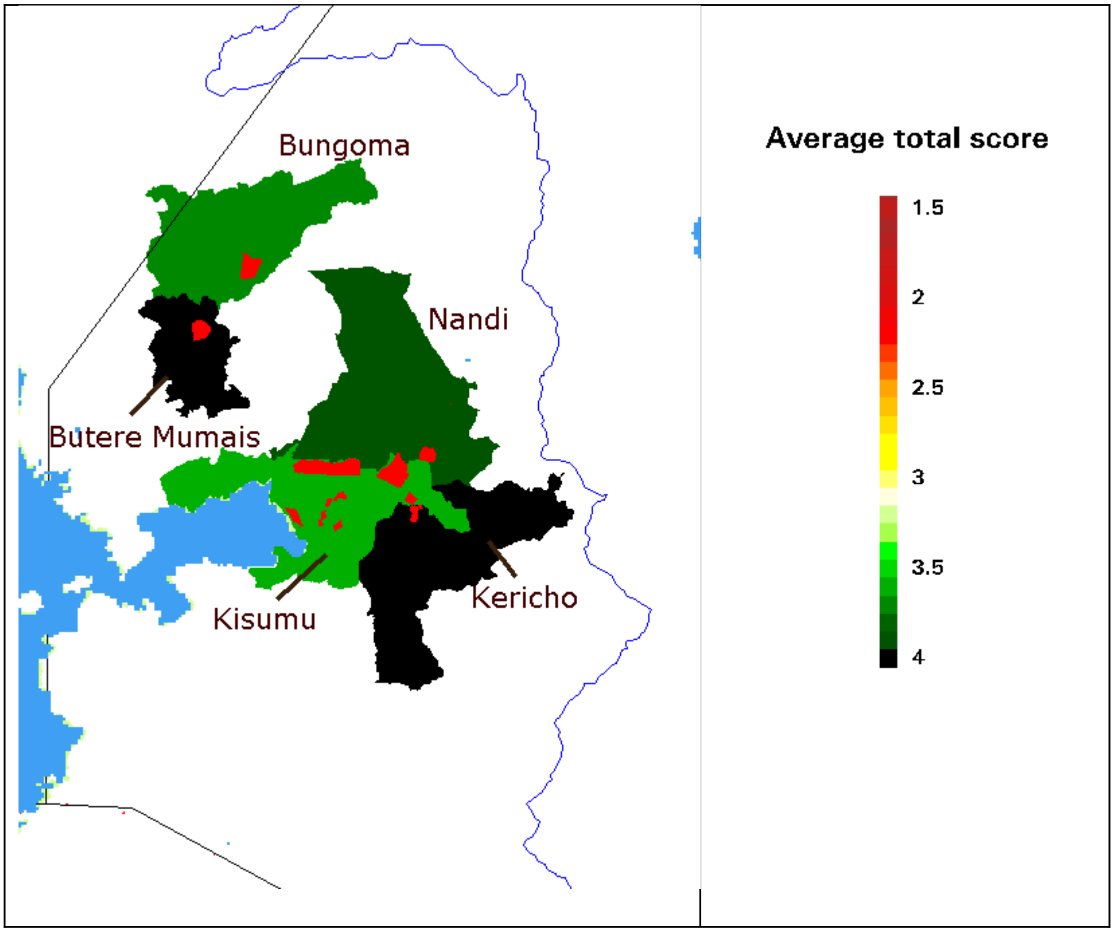


Figure 88 Map showing the average total score per irrigated district in the Nile basin component of Kenya

3.3.2. Breaking down the total score into RO, PO and sustainability indicators

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 89 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators (see Figure 85). Considering the total average score for all indicators for each district gives an idea of the total performance and enables to rank the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

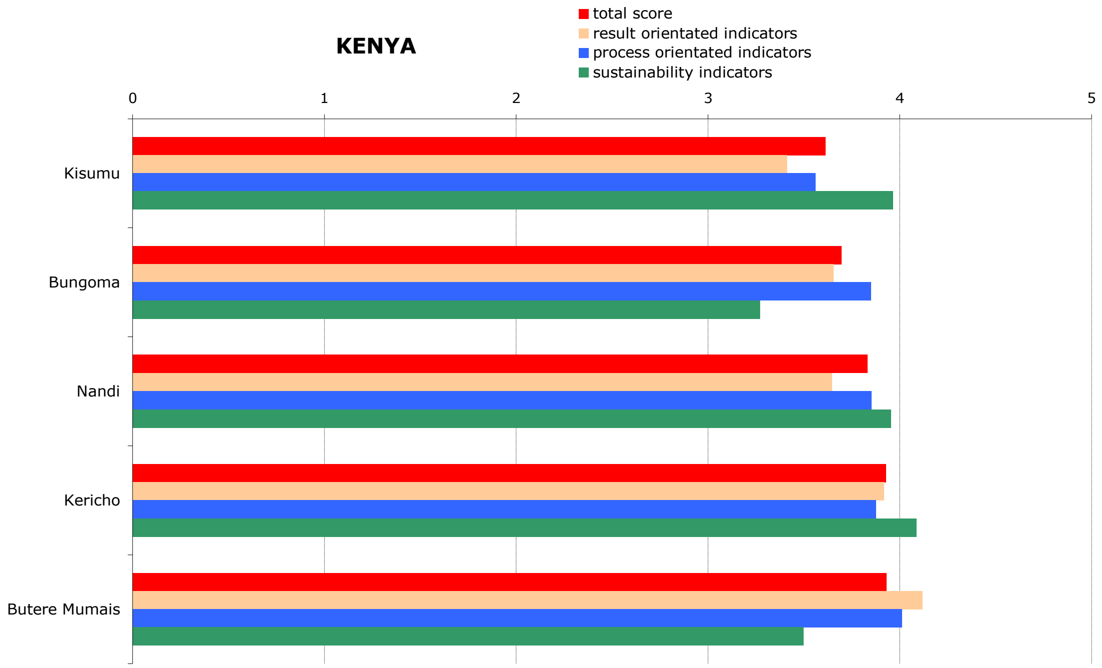


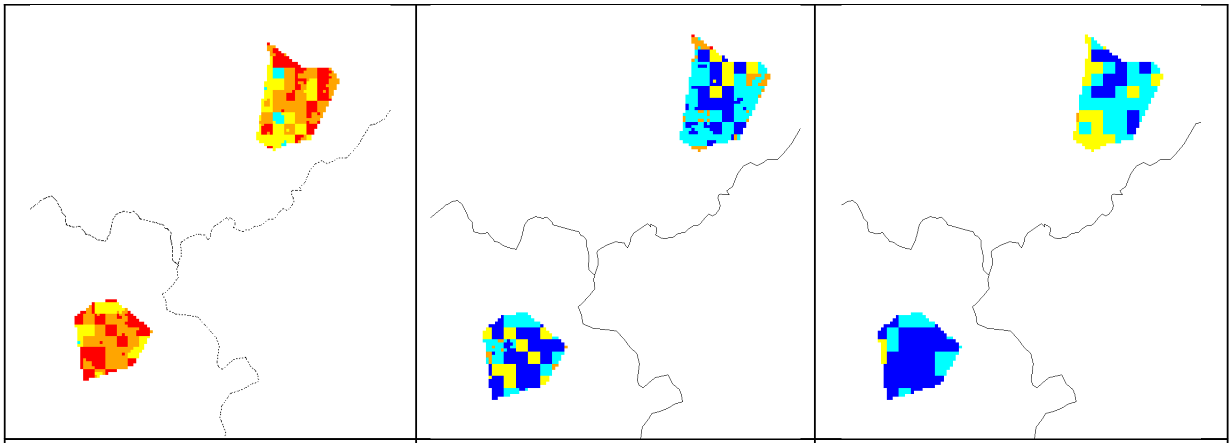
Figure 89 Representation of the average score for the irrigated districts in Kenya.

The first aspect that draws attention is that there is little variation between the districts in the total score. This total score is also broken down into the three indicators. The RO indicators vary only between the good score of 3.4 and 4.1; the PO indicators vary between 3.6 and 4 and the sustainability indicators vary only between 3.3 and 4.1. This is linked to the fact that the uniformity is very good overall in the country, as shown previously.

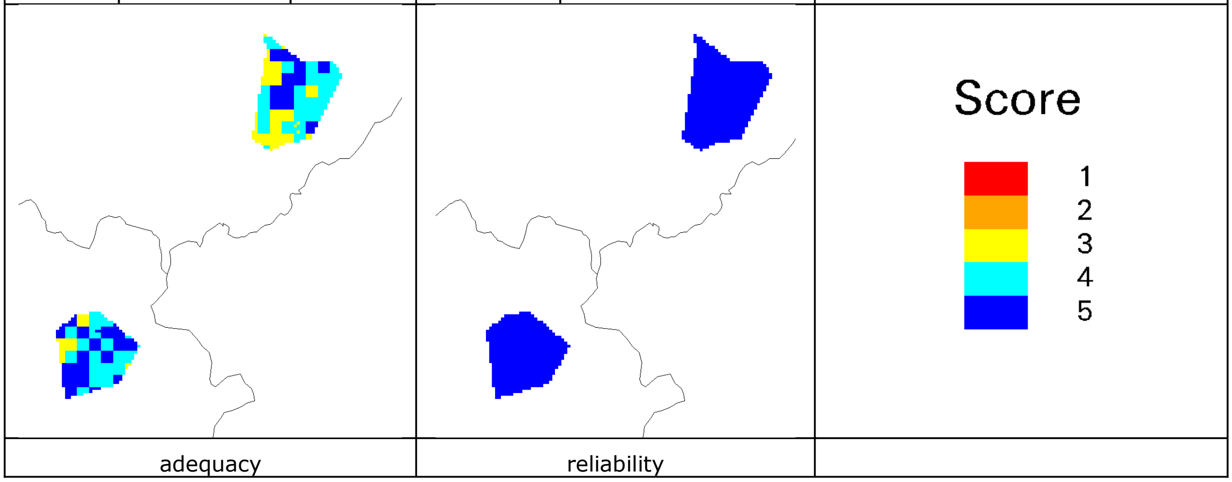
These good scores indicate generally good management of irrigation systems in Kenya, which makes recommendations for improvements on a country level unnecessary. Relevant improvement should be made on district level by considering different scores of every single indicator for each district.

3.4 Analysis per pixel for the best irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the neighbouring districts of Bungoma and Butere Mumais. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. This example displayed in Figure 90 demonstrates that crop water consumption is probably the weakest aspect at district level but also at pixel level. However, the crop water consumption is not homogeneous. Such an analysis helps to indentify where exactly crop water consumption is too high.



Crop water consumption | Crop water deficit | Beneficial fraction



adequacy | reliability

Figure 90 Spatial distribution of each indicator for the district of Bungoma and Butere Mumais.

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the 5 districts. It showed that the higher the beneficial fraction, crop water consumption, reliability and adequacy, the higher the biomass production. The correlation with crop water deficit is negative. Concerning the biomass water productivity, the links are less clear (Figure 91).

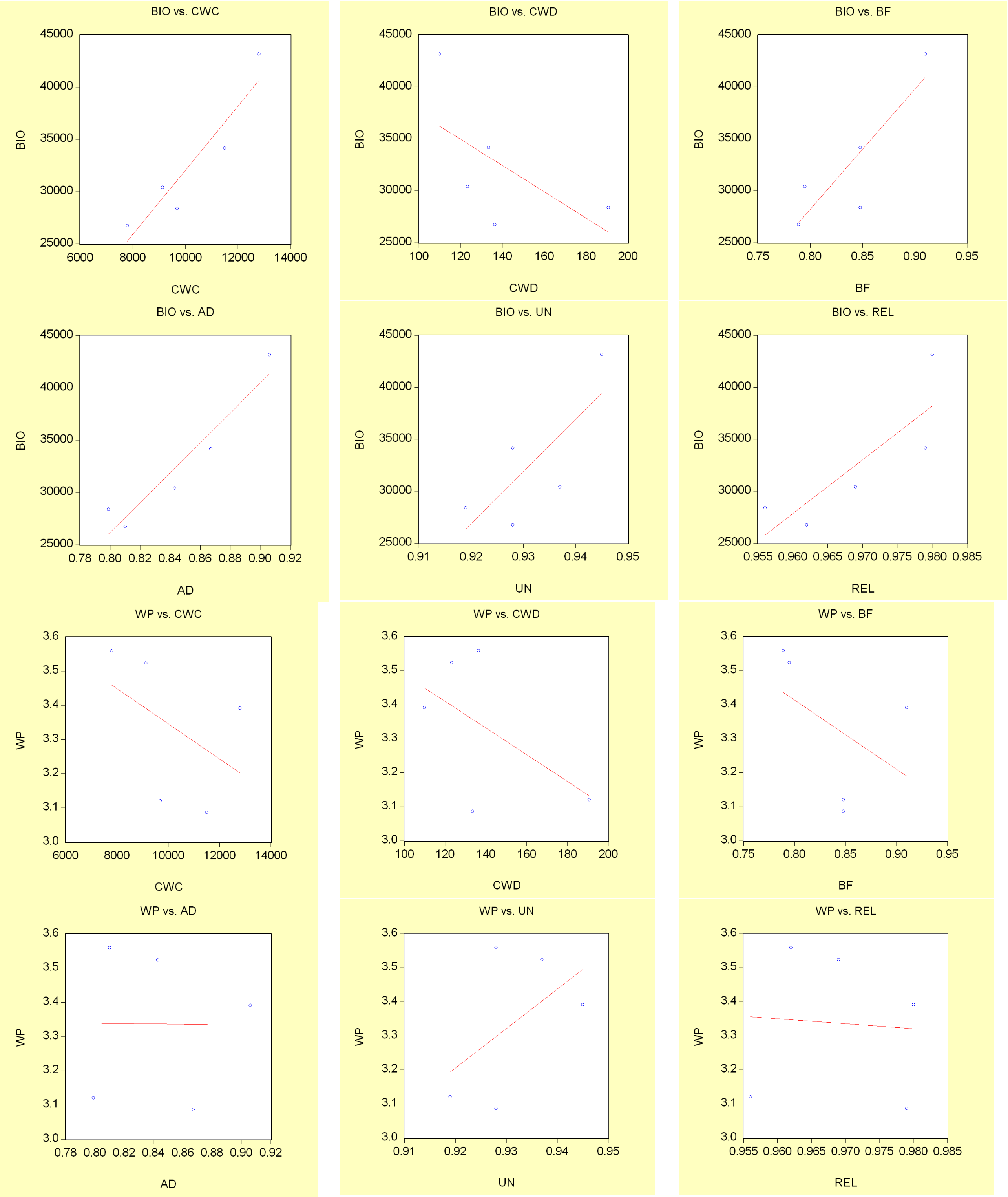


Figure 91 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationship between the indicators is better understood, the next step is to identify the weakest elements per district. In Table 61, the best and poorest indicators are presented.

Table 61 Best and poorest PO irrigation indicator per district

District	Lowest		2nd lowest		2nd best		Best	
Kisumu	cwc	2.62	cwd	2.81	un	4.00	rel	4.79
Bungoma	cwc	2.14	ad	3.34	cwd	4.04	rel	5.00
Nandi	cwc	3.18	bf	3.37	cwd	4.22	rel	5.00
Kericho	cwc	2.74	bf	3.44	cwd	4.41	rel	5.00
Butere Mumais	cwc	1.82	un	4.00	bf	4.68	rel	5.00

It appears once again that the irrigation districts function relatively similarly. Crop water consumption seems to be the main problem for all the districts. Reliability is the best indicator in all districts. Crop water deficit is cited three times as the second best indicator.

4.3 Recommendation countrywide

The LSI schemes considered in this study are performing well. However, special attention should be given to saving water. If Kenya is planning to develop irrigation to achieve its target towards improving food and income security for the local people, abundant water consumption should be avoided.

The following recommendations apply:

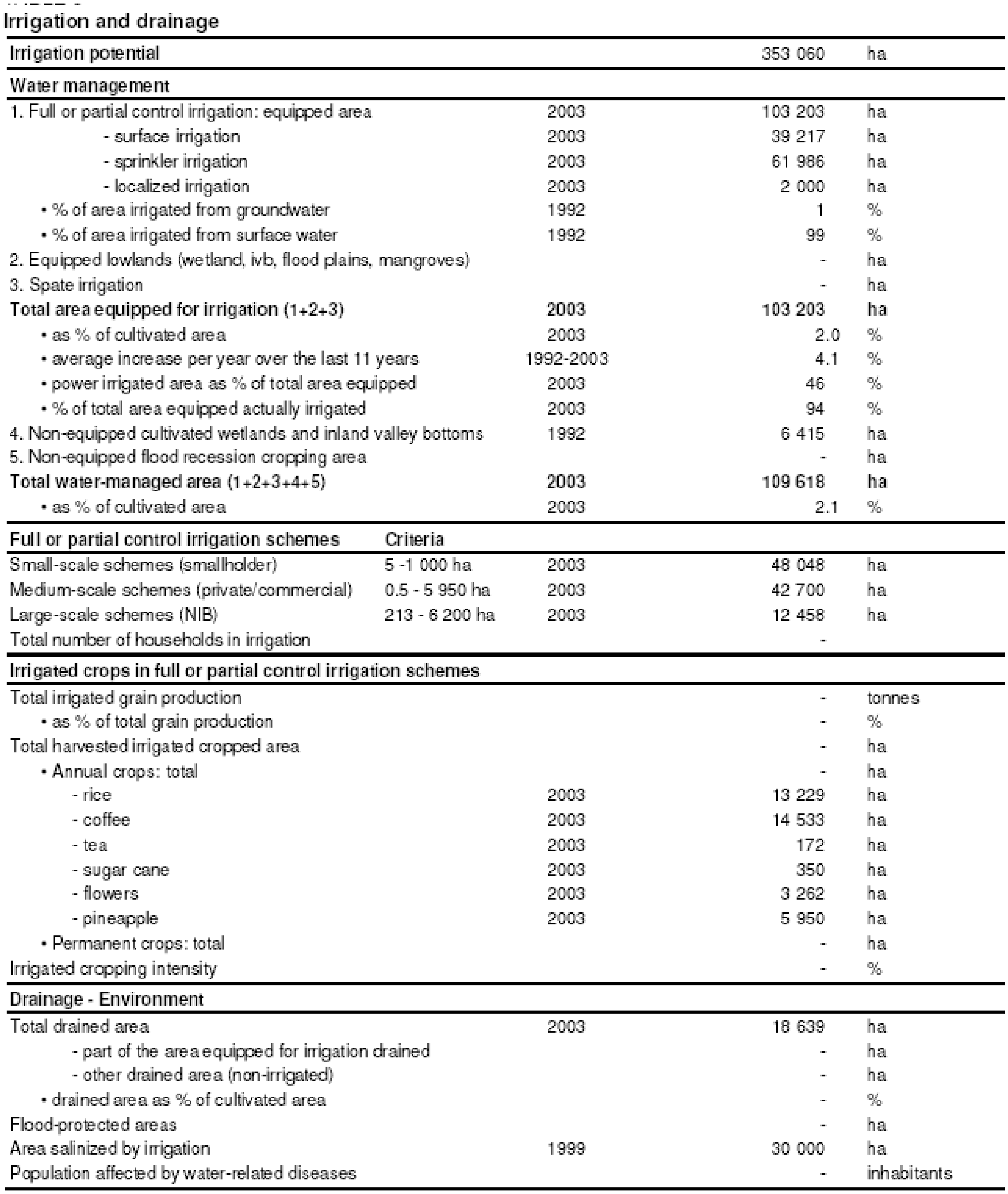
- Introduce water saving plans during the main cropping season and limit crop water use to approximately 3000 m^3/ha
- Only irrigate when crop water stress (T_{act}/T_{pot}) and ET deficit ($ET_{pot}-ET_{act}$) exceed a certain threshold value. Otherwise pumping from rivers and lakes is not needed.
- Focus more on non-uniformity. Although it is good at country level, it could push up the biomass water productivity.
- Advise farmers and water utilization agencies regarding best practices and to become familiar with the optimum quantities of water to be used for their needs.
- The government should invest in modernizing of irrigation infrastructures.
- Give attention to land sustainability.

In Kenya, the irrigated areas have been digitalized manually based on Landsat images and Google Earth. After the emission of the report first draft, the LSI representatives indicated that there is no irrigation systems in the provinces of Butere Mumais and Bungoma. Upon double checking with the Landsat images, irrigated areas appear to be really present. We advice the Kenyan delegates to visit the areas with following center coordinates : 0˚33’ N, 34˚40 E and 0˚22’ N, 34˚32’ E. The LSI representatives also mentioned that only Kisumu has irrigation whilst the districts of Nandi and Kericho are displayed as having irrigation in the present analysis. This is due to the lack of accuracy of the shape file used for the districts limits.

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m^3	Bio/ET$_{act}$	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M^3/ha/year	ET$_{act}$	Saving of water resources
	Crop water deficit	cwd	M^3/ha/year	ET$_{pot}$-ET$_{act}$	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	T$_{act}$/ET$_{pot}$	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	T$_{act}$/T$_{pot}$	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	1-CV(T$_{act}$/T$_{pot}$) (x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	1-CV(T$_{act}$/T$_{pot}$) (t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex **2** General information on irrigation conditions in Kenya (Aquastat, 2005)



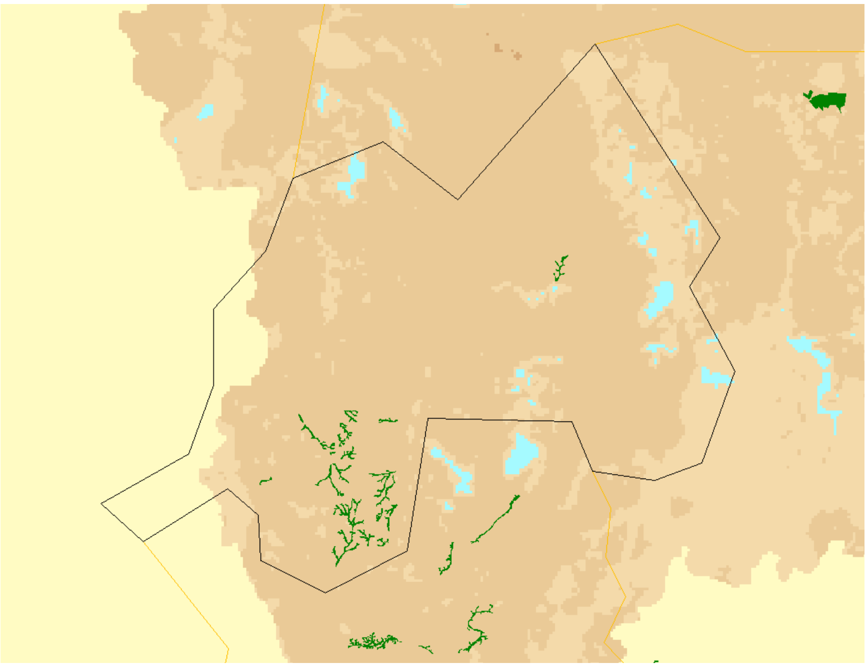
Irrigation and drainage

Irrigation potential			353 060	ha
Water management				
1. Full or partial control irrigation: equipped area		2003	103 203	ha
- surface irrigation		2003	39 217	ha
- sprinkler irrigation		2003	61 986	ha
- localized irrigation		2003	2 000	ha
• % of area irrigated from groundwater		1992	1	%
• % of area irrigated from surface water		1992	99	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)			-	ha
3. Spate irrigation			-	ha
Total area equipped for irrigation (1+2+3)		**2003**	**103 203**	**ha**
• as % of cultivated area		2003	2.0	%
• average increase per year over the last 11 years		1992-2003	4.1	%
• power irrigated area as % of total area equipped		2003	46	%
• % of total area equipped actually irrigated		2003	94	%
4. Non-equipped cultivated wetlands and inland valley bottoms		1992	6 415	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		**2003**	**109 618**	**ha**
• as % of cultivated area		2003	2.1	%
Full or partial control irrigation schemes	**Criteria**			
Small-scale schemes (smallholder)	5 -1 000 ha	2003	48 048	ha
Medium-scale schemes (private/commercial)	0.5 - 5 950 ha	2003	42 700	ha
Large-scale schemes (NIB)	213 - 6 200 ha	2003	12 458	ha
Total number of households in irrigation			-	
Irrigated crops in full or partial control irrigation schemes				
Total irrigated grain production			-	tonnes
• as % of total grain production			-	%
Total harvested irrigated cropped area			-	ha
• Annual crops: total			-	ha
- rice		2003	13 229	ha
- coffee		2003	14 533	ha
- tea		2003	172	ha
- sugar cane		2003	350	ha
- flowers		2003	3 262	ha
- pineapple		2003	5 950	ha
• Permanent crops: total			-	ha
Irrigated cropping intensity			-	%
Drainage - Environment				
Total drained area		2003	18 639	ha
- part of the area equipped for irrigation drained			-	ha
- other drained area (non-irrigated)			-	ha
• drained area as % of cultivated area			-	%
Flood-protected areas			-	ha
Area salinized by irrigation		1999	30 000	ha
Population affected by water-related diseases			-	inhabitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Rwanda



Report H

January 2009

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Part 1 Overview of irrigated areas

Part 2 Climate

Part 3 Raster and vector-based irrigation performance analysis

Part 4 Recommendations for improvement

Purpose of this report:

This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Rwanda and will become an integral component of the final LSI report that will combine results from all countries.

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

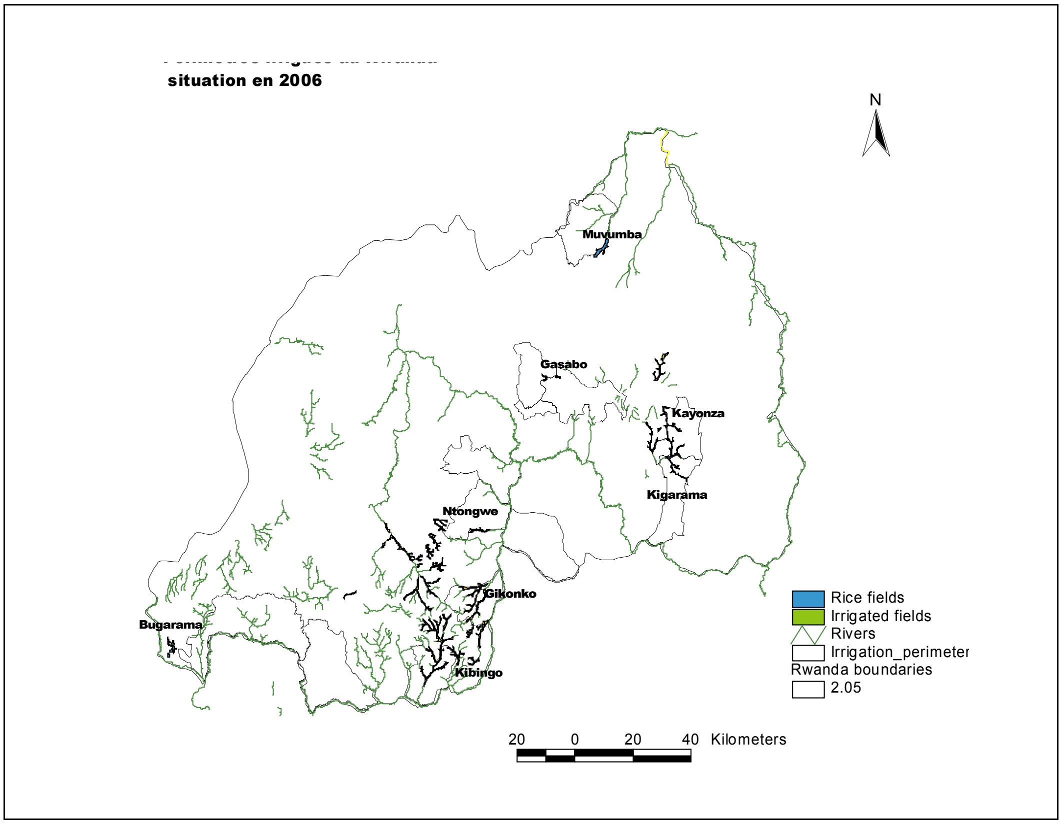


Figure 92 Irrigated areas in Rwanda in 2006 according to the LSI participants

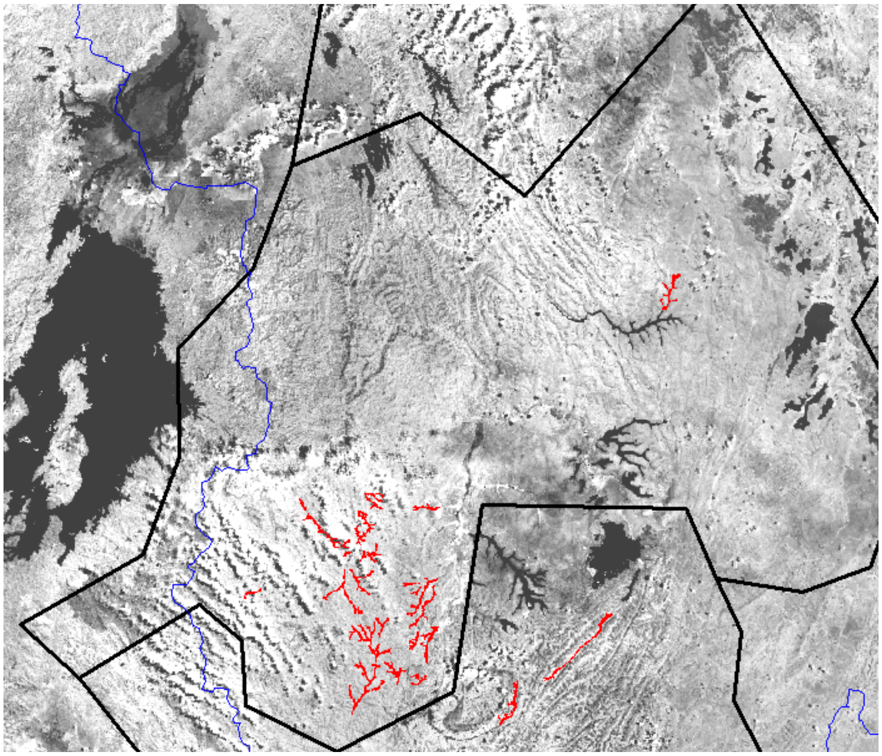


Figure 93 Map with the distribution of the irrigated areas in Rwanda within the Nile Basin according to the LSI participants.

Rwanda is one of the smallest of the Nile Basin countries with most of the country in the Nile Basin (83%) and the remainder in the Congo basin. More than 90% of the national water resources drain to the Nile Basin through the two main rivers of the Nyabarongo and Kagera. Arable land covers 1,385,000 ha, (52% of the country). The cultivated area is 852,000 ha (62% of arable land; 31% of the total area of the country). Agriculture is the principal water consuming activity (68% of the total water resources). Figure 93 shows that irrigation most of the time takes place in alluvial soils with streams and wetlands. An area of 17,638 ha of irrigated land in Rwanda is located in the Nile Basin according to this study (Table 62).

Table 62 Different sources for the irrigation statistics

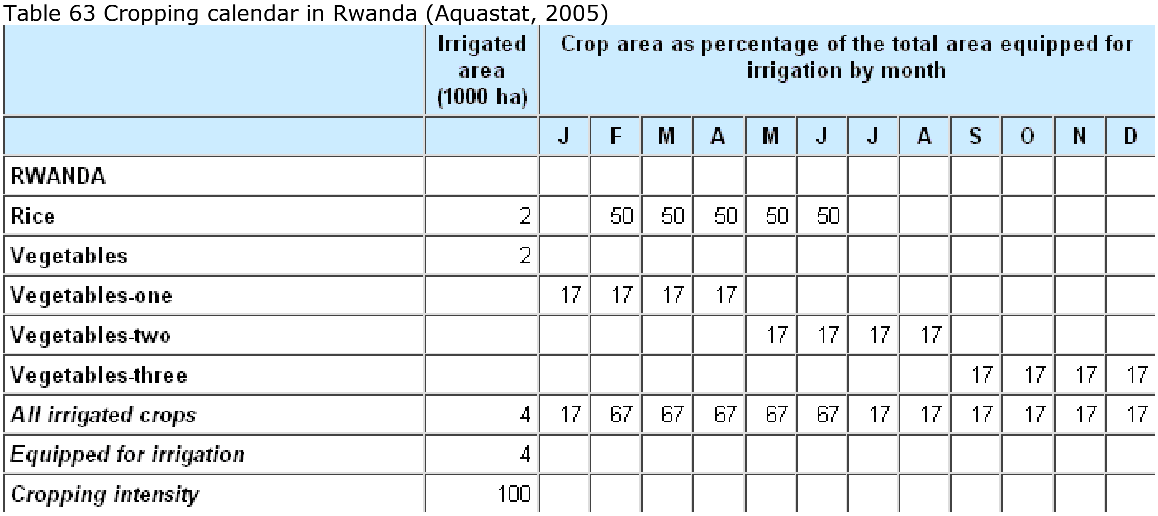
Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Rwanda	4,000
IWMI – GIAM	Entire Rwanda	80,067
Current study	Nile Basin component of Rwanda	17,638

More detailed information concerning irrigation in Rwanda can be found in Annex 2.

1.2 Agricultural conditions

Farming is the principal economic activity and is carried out by more than 1.4 million households. Forty five percent of the land area is classified as arable. The main irrigated crops are rice and vegetables. Table 63 displays the cropping calendar with the surface per crop in Rwanda.

Table 63 Cropping calendar in Rwanda (Aquastat, 2005)



	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
RWANDA													
Rice	2		50	50	50	50	50						
Vegetables	2												
Vegetables-one		17	17	17	17								
Vegetables-two						17	17	17	17				
Vegetables-three										17	17	17	17
All irrigated crops	4	17	67	67	67	67	67	17	17	17	17	17	17
Equipped for irrigation	4												
Cropping intensity	100												

Part 2 Climate

2.1 Climatological conditions

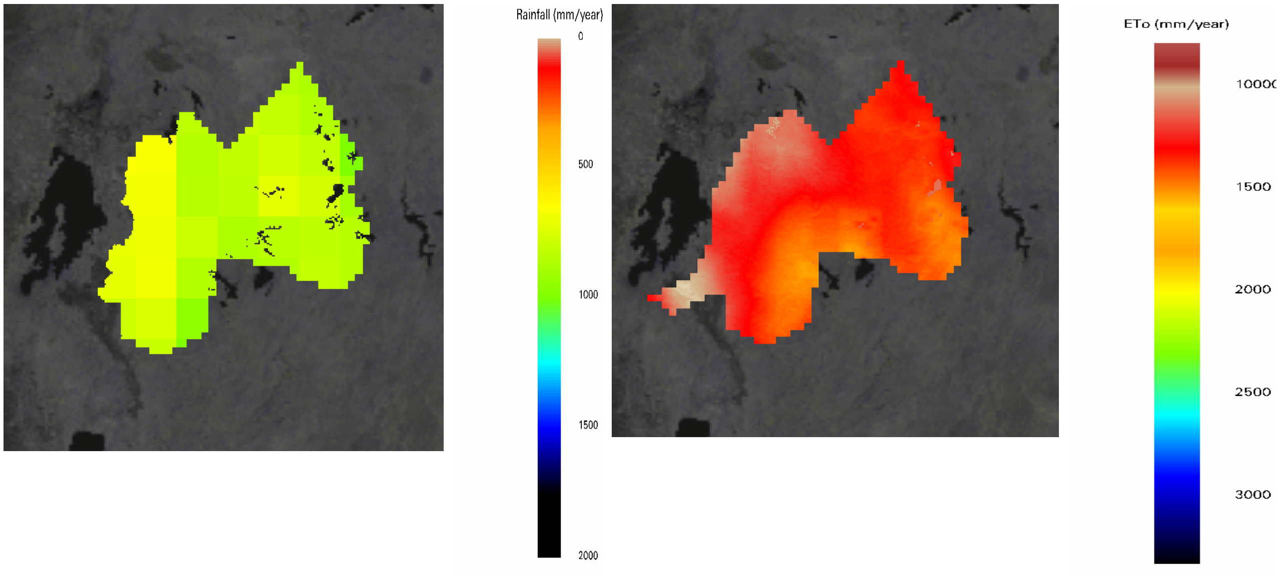
In this study, the reference evapotranspiration (ET_0) is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007.

Rwanda receives a significant amount of rainfall (997 mm/yr). The rainfall season is from September to May. June, July and August are dry, and this is the period that irrigation is typically needed.

According to Table 64, ET_0 exceeds rainfall during seven months. The monthly water shortage occurs in June to September when the aridity index is lower than 0.5. The highest rainfall (± 950 mm/yr) and ET_0 rates occur in the southern side near Burundi (± 1500 m/yr) (Figure 94). For this relative long period with sufficient water to meet ET_0, Rwanda is more commonly known as a rainfed agricultural country rather than an irrigation country.

Table 64 Monthly values for rainfall and reference ET_0.

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	86	106	0.81
February	101	101	1.00
March	115	108	1.06
April	180	97	1.86
May	98	97	1.01
June	10	107	0.09
July	1	121	0.01
August	21	128	0.16
September	65	120	0.54
October	93	119	0.78
November	133	103	1.29
December	94	103	0.91
TOTAL	997	1310	



Annual rainfall

Annual reference ET

Figure 94 Spatial variation of rainfall (left) and ET_0 (right).

2.2 Climatic zones

The current study, aimed at providing information for improved irrigation practices in the Nile basin, covers various climate zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as the irrigation efficiencies. Unexpected rainfall can for instance reduce the irrigation efficiency, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences on the diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

The irrigation schemes of Rwanda are located in climate zone 4 (humid tropics).

Part **3** Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on the data send by the LSI representatives of Rwanda.

The first step was to compute all the indicators per pixel. All the RO and PO indicators described have been computed based on the annual accumulated values for the year 2007 of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). These annual accumulated values are the results of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

Sustainability indicators were obtained by investigating the last five year's trend of the vegetation index (from the SPOT-Vegetation satellite) and the soil moisture (from the AMSR-E satellite). It indicates the slope of the trend line over these past years.

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined (Table 65). A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 95).

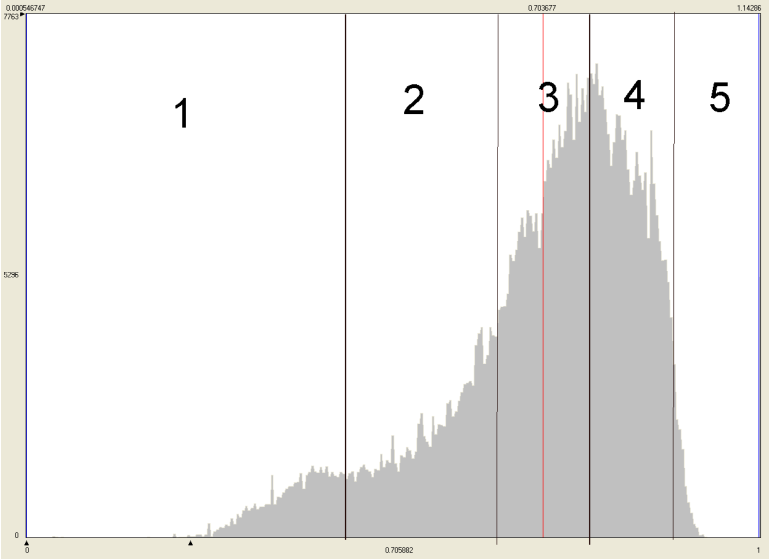


Figure 95 Distribution of the values of one indicator over 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems included in different climatic zone, different benchmark values are considered to avoid any climatic bias in the allocation of the score. Rwanda is located in climatic zone 4.

Table 65 benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, districts average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at country level

As displayed in Figure 96, the average score considering all the indicators together for all 17,638 ha of irrigated land in the Nile Basin component of Rwanda is 3.6, which is above average (the average score being 3). This average is translated into scores for each individual indicator, as demonstrated in Figure 96. The aspects that Rwanda should provide more attention to are the elements with a relative low score (bf, ad, cwc).

The score of 2.9 for land productivity and 3 for water productivities are slightly lower than average but still reasonable.

Concerning the PO indicators, more attention should be given to beneficial fraction. The relatively low performance of this indicator might explain the wide range of the land and biomass water productivity. Because the crop water consumption is quite high (between 6,700 m^3/ha/year) and the beneficial fraction low, it leads to relatively high non-beneficial soil evaporation and low biomass water productivity. On the other hand, there is a good performance in terms of reliability, crop water deficit, and uniformity. Because irrigation water supply is continuous in time (as reliability gets a score of 4.8), farmers are not restricted in their application of water. Crop water deficit is therefore low (so it gets a high score of 4.6).

The sustainability of irrigation practices in Rwanda seems to be under control. Compared to the last years, the irrigated land is becoming greener (as the score for the land sustainability is higher than 3), showing that the irrigation systems are healthy and continuous. The soils are gradually getting wetter (water sustainability gets the high score of 4.3).

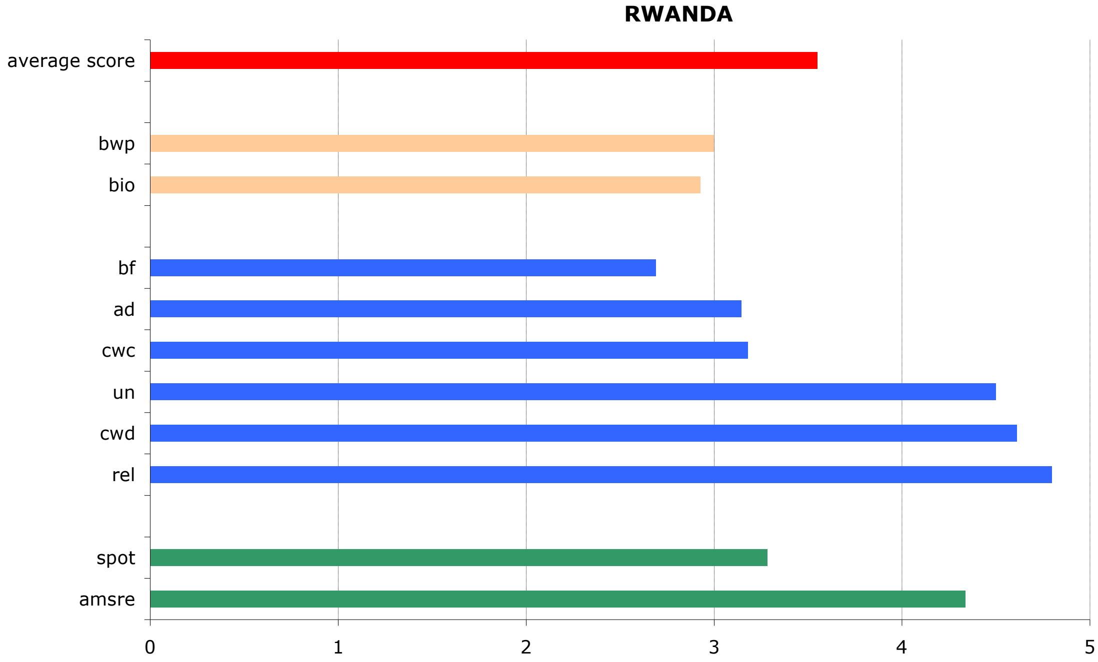


Figure 96 Representation of the average score for each indicator in Rwanda.

3.3 Results at district level

3.3.1 Average per district

In Rwanda, eight districts have more than 187.5 ha of irrigated land (more than 30 pixels of 6.25 ha). In Figure 97 the average score for all indicators per district is compared. All the districts have a good and uniform performance on average, ranking from 3.4 and 3.8, the best district being Nyanza and the poorest performing Nyaruguru (see Figure 98 for their locations). The equal performance per district gives an excellent score for uniformity at country level.

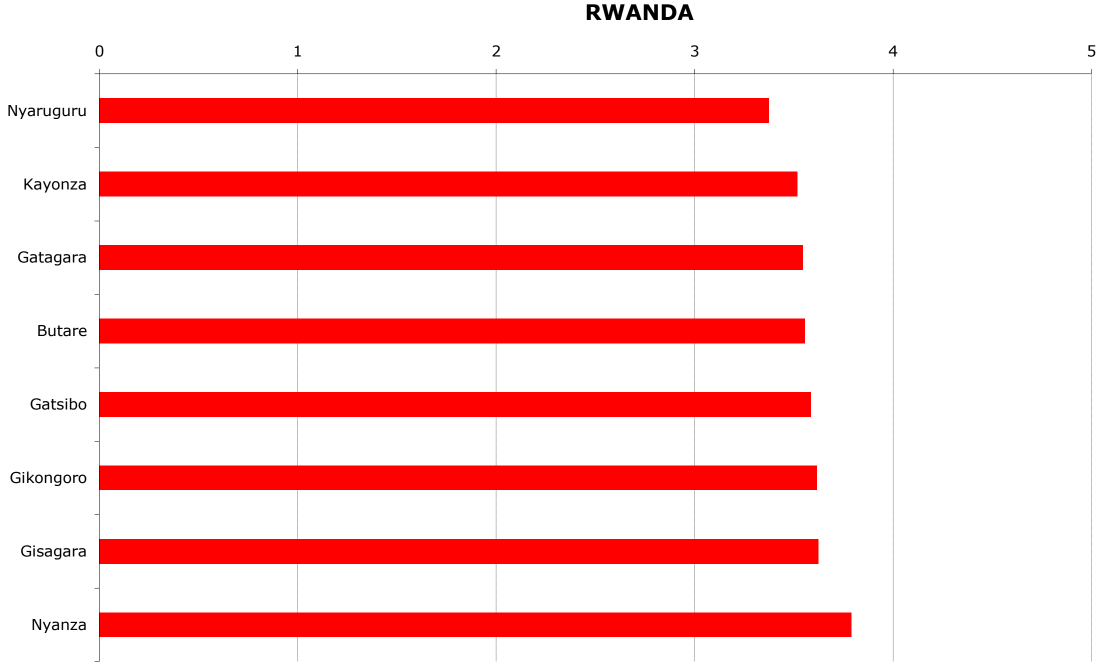
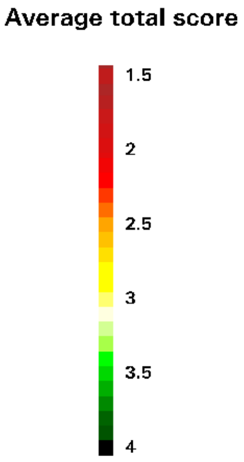


Figure 97 Representation for the total average score for each district in Rwanda.



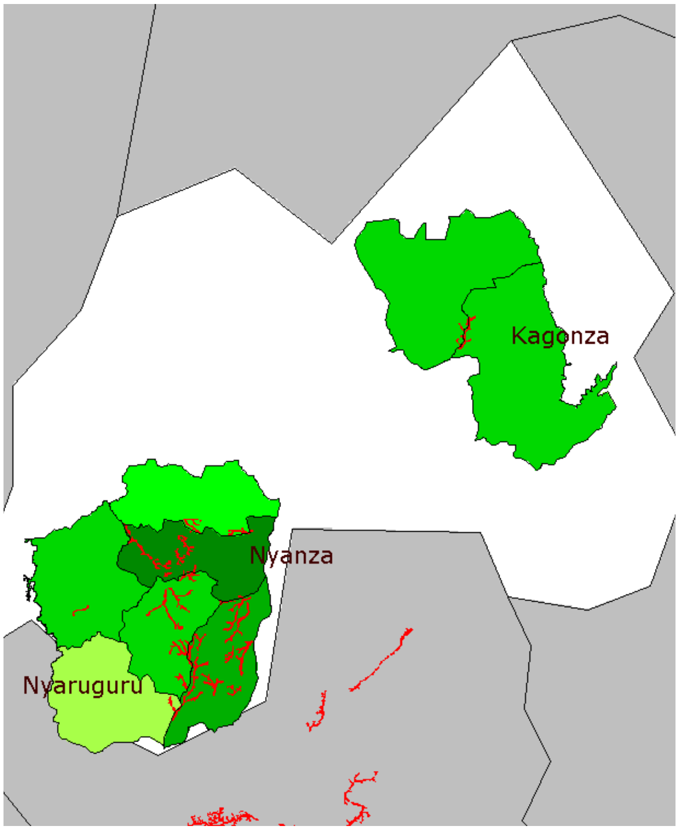


Figure 98 Map showing the total average score per irrigated district

3.3.2 Breaking down the total score into RO indicators, PO and sustainability indicators

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 99 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance and enables to rank the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

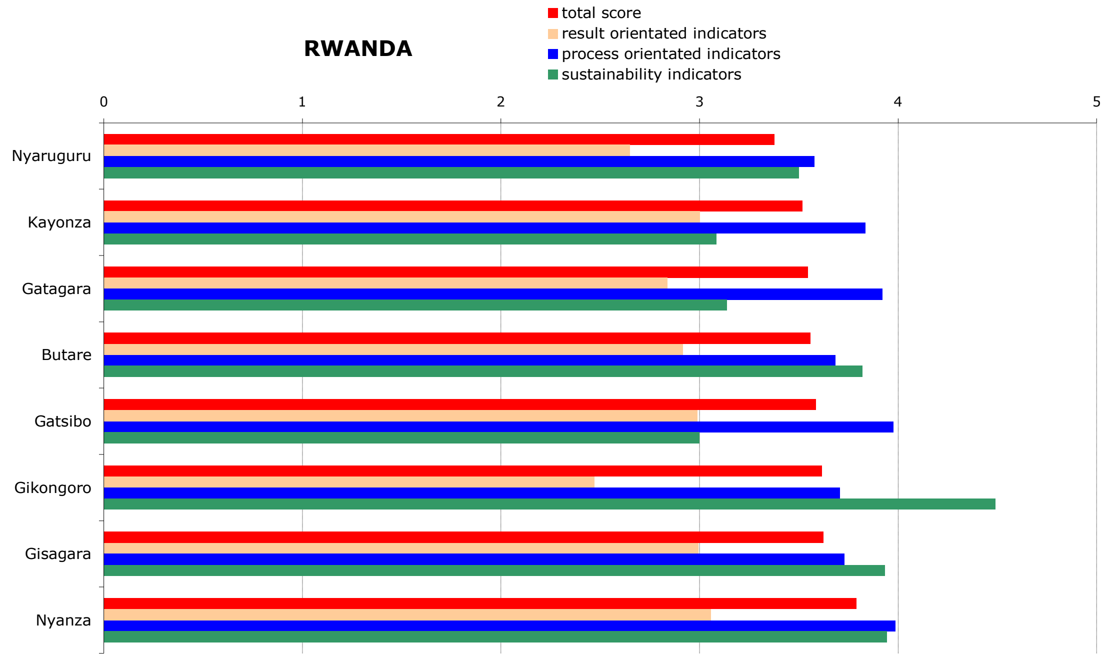


Figure 99 Total score per indicator per irrigated district in Rwanda

The first aspect that draws attention in the breaking down of the total performance score is that each of the eight districts of Rwanda has more or less the same score for each category of indicators, which once again is linked to the uniform conditions encountered at country level. This could be ascribed to the relative small size of the country and the uniform climate.

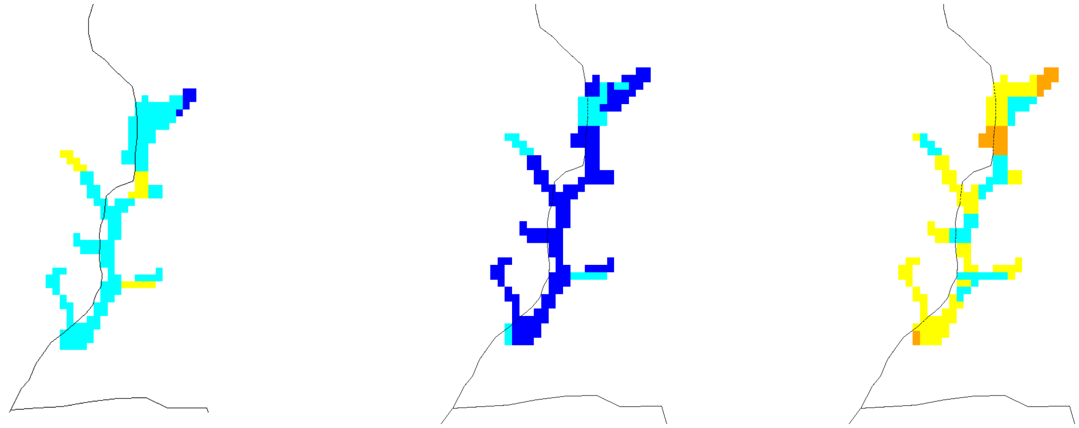
As far as the RO indicators are concerned, the average of the water and land productivity is quite low (between 2.7 and 3.1). Hence, irrigation should become more output orientated.

Concerning the PO indicators, the eight districts of Rwanda get a good and homogeneous score, ranking from 3.6 to 4. These high scores make it difficult to draw improvement recommendations relating to the functioning of the irrigation systems. It is remarkable to see that PO indicators are good and RO indicators are adequate only. The breakdown in Part 4 provides more insights.

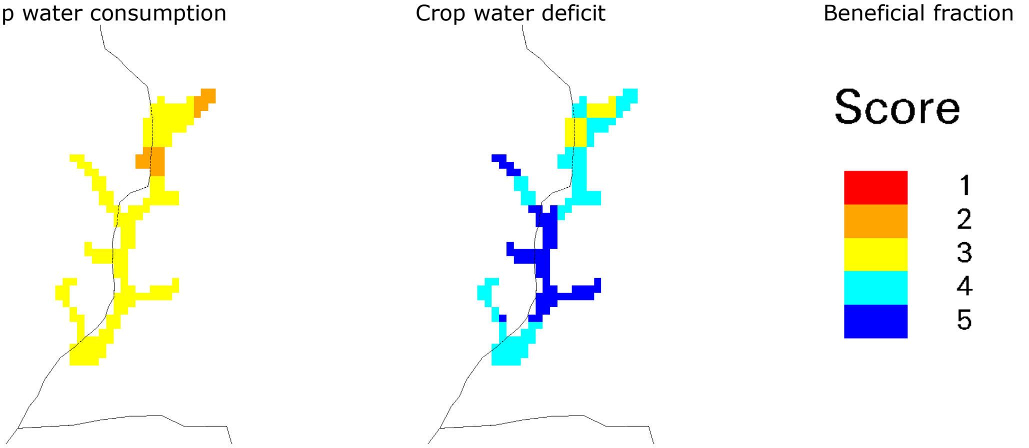
Land and water sustainability is good. The score for all the districts are between 3.1 and 4.5.

3.4 Analysis per pixel for one irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the neighbouring districts of Gatsibo and Kayonza. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. Figure 100 demonstrates that at certain places, adequacy and beneficial fraction should be managed better. This suggests that the crop is stressed and does not receive sufficient irrigation water. A large part of the irrigation water is not used beneficially and this is probably the reason why the biomass production is below average.



Crop water consumption Crop water deficit Beneficial fraction



adequacy reliability

Figure 100 Spatial distribution of each indicator for the districts of Gatsibo and Kayonza

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the eight districts. Figure 101 shows that crop water consumption, reliability and adequacy are the main explanatory factors for biomass production. An increase in beneficial fraction or a decrease in crop water consumption leads to an increase in biomass water productivity. There are no clear trends for the other indicators.

Practically this relates to the following advice:

- More irrigation water should be converted to crop transpiration (T). The field practices on irrigation should be critically evaluated.
- More irrigation water should be applied directly to the crop so that adequacy is increased.

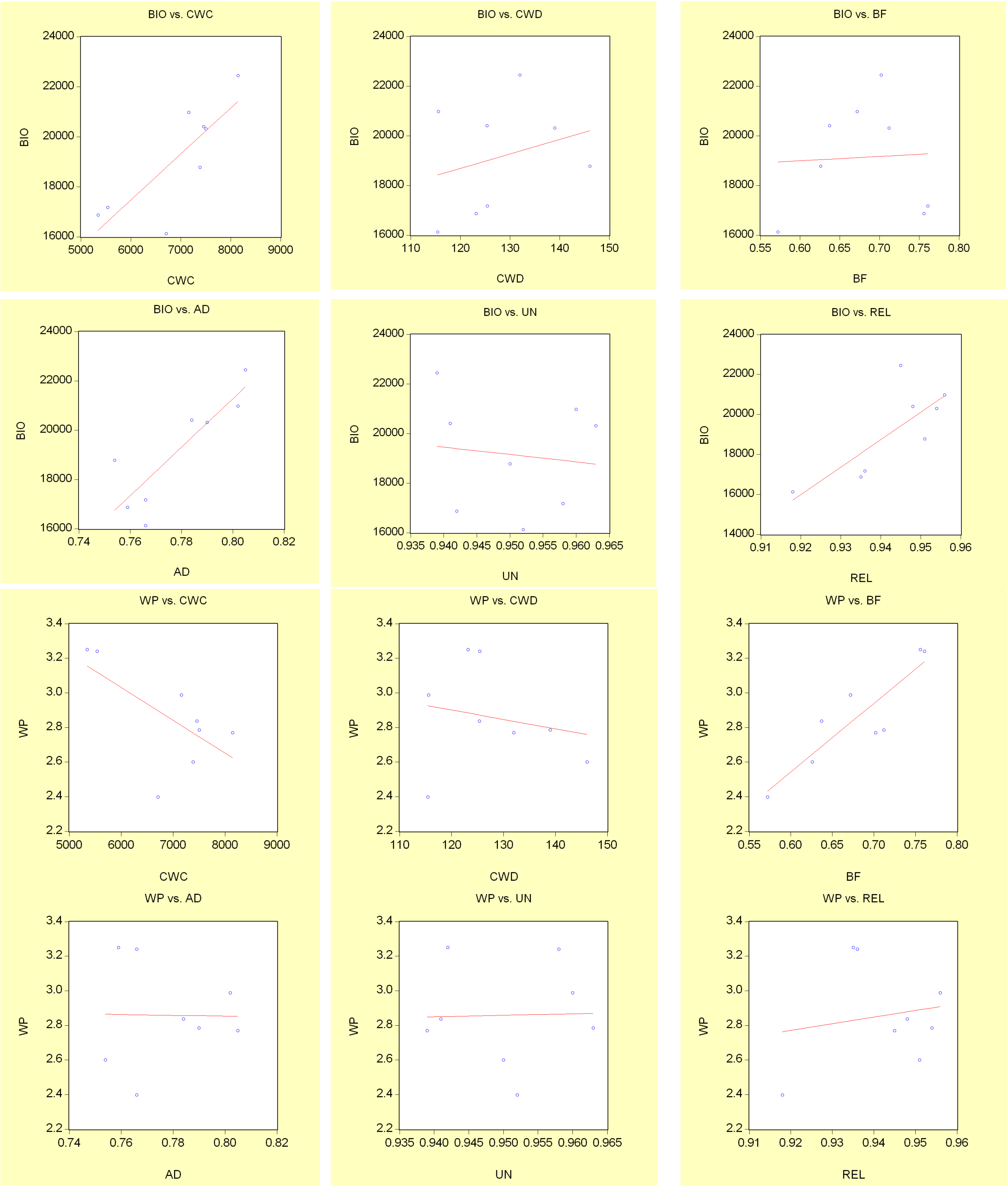


Figure 101 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationship between the indicators is better understood, the next step is to identify the weakest elements per district. In Table 66, the best and poorest indicators are presented.

Each irrigation district appears to function relatively similarly. The beneficial fraction and adequacy seem to be the main problems. On the other side of the scale crop water deficit and uniformity are always the best indicators.

Table 66 Best and poorest PO irrigation indicator per irrigated district in Rwanda

District	Lowest		2nd lowest		2nd best		Best	
Nyaruguru	bf	2.26	ad	2.88	cwd	4.28	rel	5.00
Kayonza	ad	2.74	bf	3.17	rel	4.21	cwd	4.82
Gatagara	bf	2.87	ad	2.89	rel	4.99	un	5.00
Butare	bf	2.42	ad	2.94	cwd	4.55	rel	4.88
Gatsibo	bf	3.04	ad	3.08	cwd	4.78	un	5.00
Gikongoro	bf	2.25	ad	3.08	cwd	4.75	un	5.00
Gisagara	bf	2.83	cwc	3.00	cwd	4.55	rel	4.76

4.3 Recommendations countrywide

The increase in food production is relatively unstable and is unable to keep pace with the rise in population (Rwanda is the biggest country in terms of population density : 343 inhabitants/km^3). Ensuring food security should definitely be high on the agenda. The purpose of the LSI should then be to ensure food security, increase rural incomes and create jobs.

The results of this study confirmed that fact. It showed than one of the weakest aspects of irrigated agriculture in Rwanda is the land productivity. Expanding the irrigated area could help to provide more food for the country, but it is probably better to invest in improved performance of the existing irrigation systems. The idea is to increase land productivity of the existing irrigated areas without increasing crop water consumption, because cwc is already too high. Thus, special attention should be given to introduce or develop agronomic extension services that could advise on the use of fertilizer or improved seed stocks.

The following recommendations apply:

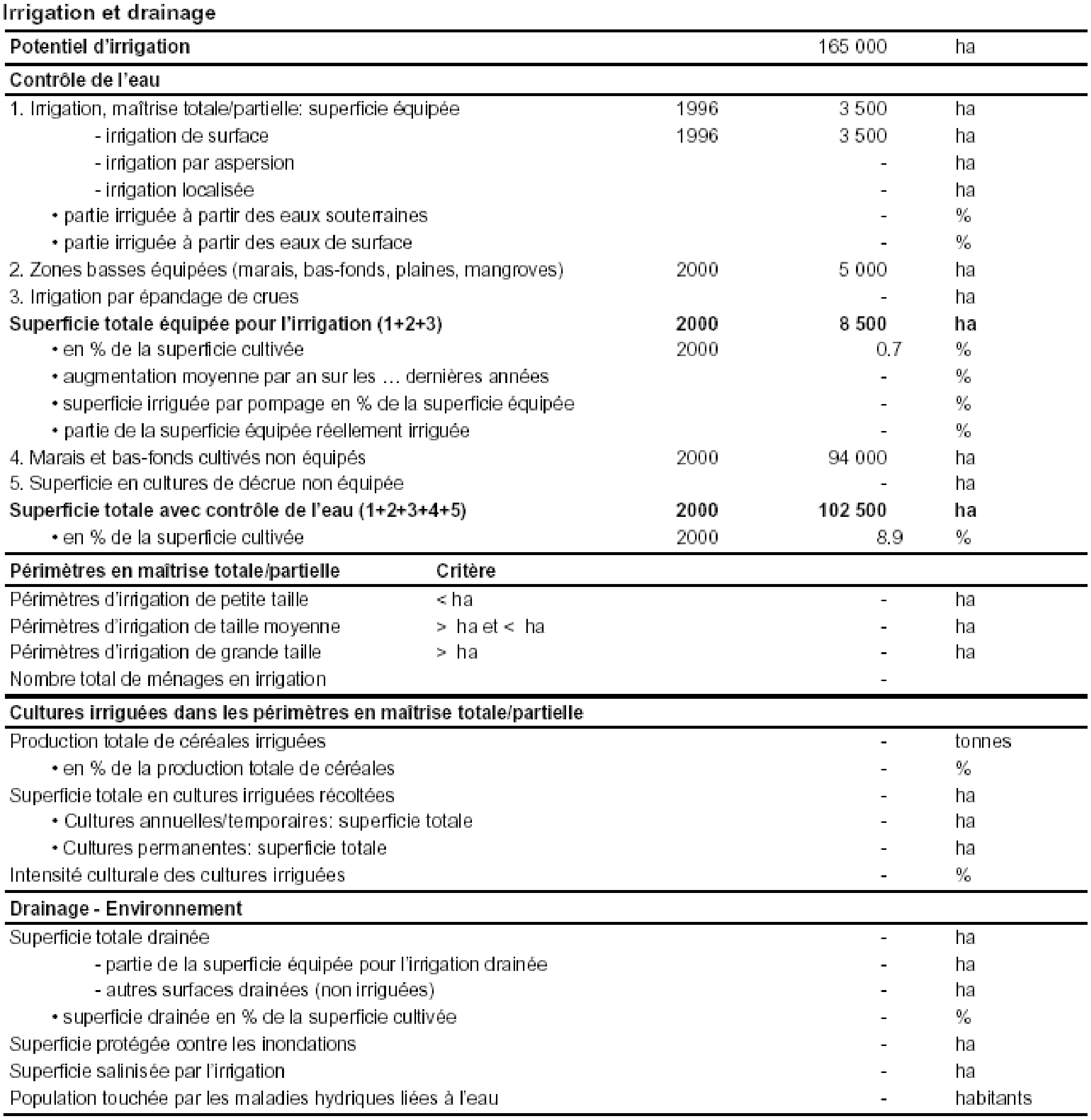
- Introduce or develop agronomic extension services that could advise on the use of fertilizers or improved seed stocks.
- Launch an educational program jointly with agronomists and irrigation engineers to define the timing of irrigation water supply. This should result in an improvement of the biomass production and biomass water productivity.
- Improve the local organization of on-farm water management practices. This could be achieved through the establishment of irrigation study clubs or water user associations that visit other plots to understand minor differences in management that cause local differences in the irrigation reports.

- Start irrigation when crop water stress (T_{act}/T_{pot}) exceeds a certain threshold value. This would improve the adequacy. It also saves power and reduces the return flow from the irrigated plots.
- Visit the farmers in the vicinity from the district of Nyanza and get exposure to their good water conservation practices. The farmers from Gikongoro should be invited to visit Nyanza.

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m^3	Bio/ET_{act}	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M^3/ha/year	ET_{act}	Saving of water resources
	Crop water deficit	cwd	M^3/ha/year	$ET_{pot}-ET_{act}$	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	T_{act}/ET_{pot}	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	T_{act}/T_{pot}	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	$1-CV(T_{act}/T_{pot})$ (x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	$1-CV(T_{act}/T_{pot})$ (t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 General information on irrigation conditions in Rwanda (Aquastat, 2005)



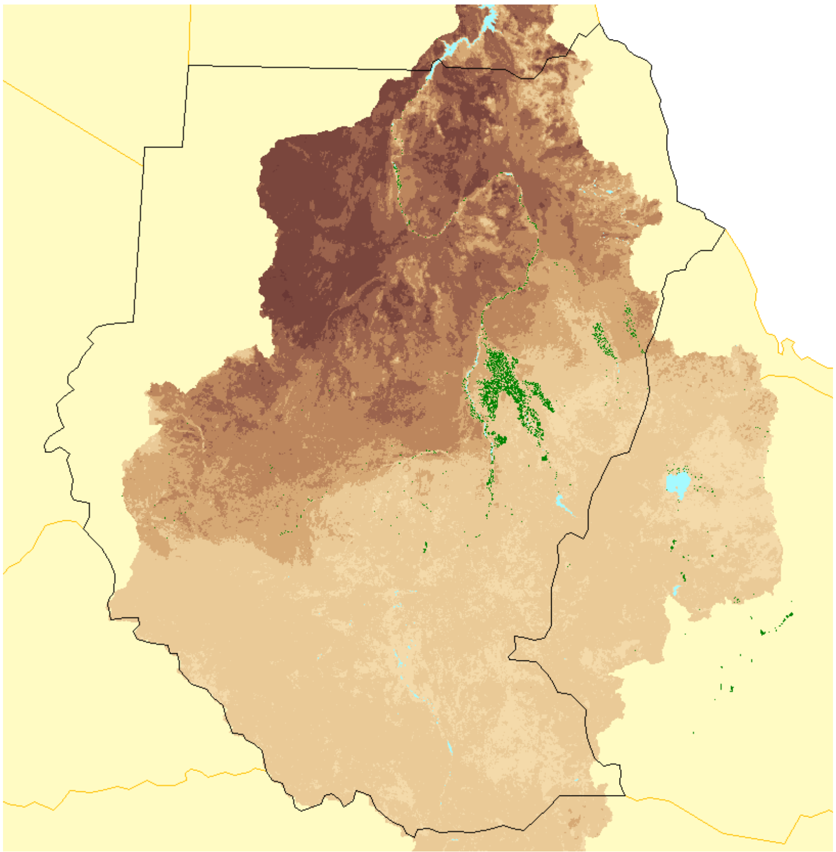
Irrigation et drainage

Potentiel d'irrigation			165 000	ha
Contrôle de l'eau				
1. Irrigation, maîtrise totale/partielle: superficie équipée		1996	3 500	ha
- irrigation de surface		1996	3 500	ha
- irrigation par aspersion			-	ha
- irrigation localisée			-	ha
• partie irriguée à partir des eaux souterraines			-	%
• partie irriguée à partir des eaux de surface			-	%
2. Zones basses équipées (marais, bas-fonds, plaines, mangroves)		2000	5 000	ha
3. Irrigation par épandage de crues			-	ha
Superficie totale équipée pour l'irrigation (1+2+3)		**2000**	**8 500**	**ha**
• en % de la superficie cultivée		2000	0.7	%
• augmentation moyenne par an sur les … dernières années			-	%
• superficie irriguée par pompage en % de la superficie équipée			-	%
• partie de la superficie équipée réellement irriguée			-	%
4. Marais et bas-fonds cultivés non équipés		2000	94 000	ha
5. Superficie en cultures de décrue non équipée			-	ha
Superficie totale avec contrôle de l'eau (1+2+3+4+5)		**2000**	**102 500**	**ha**
• en % de la superficie cultivée		2000	8.9	%
Périmètres en maîtrise totale/partielle	**Critère**			
Périmètres d'irrigation de petite taille	< ha		-	ha
Périmètres d'irrigation de taille moyenne	> ha et < ha		-	ha
Périmètres d'irrigation de grande taille	> ha		-	ha
Nombre total de ménages en irrigation			-	
Cultures irriguées dans les périmètres en maîtrise totale/partielle				
Production totale de céréales irriguées			-	tonnes
• en % de la production totale de céréales			-	%
Superficie totale en cultures irriguées récoltées			-	ha
• Cultures annuelles/temporaires: superficie totale			-	ha
• Cultures permanentes: superficie totale			-	ha
Intensité culturale des cultures irriguées			-	%
Drainage - Environnement				
Superficie totale drainée			-	ha
- partie de la superficie équipée pour l'irrigation drainée			-	ha
- autres surfaces drainées (non irriguées)			-	ha
• superficie drainée en % de la superficie cultivée			-	%
Superficie protégée contre les inondations			-	ha
Superficie salinisée par l'irrigation			-	ha
Population touchée par les maladies hydriques liées à l'eau			-	habitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Sudan



Report I

January 2009

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Part 1 Overview of irrigated areas
Part 2 Climate
Part 3 Raster and vector-based irrigation performance analysis
Part 4 Recommendations for improvement

Purpose of this report:
This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Sudan and will become an integral component of the final LSI report that will combine results from all countries.

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

Sudan is the largest country in Africa with a total area of about 2.5 million km2. It has a special geopolitical location connecting the Arab world to Africa south of the Sahara and shares common borders with nine countries. It has an estimated population of 40 million people. Protracted civil strife and poor economy has meant that poverty is widespread and predominantly a rural phenomenon with over 2/3 estimated to live on less than US$ 1/day.

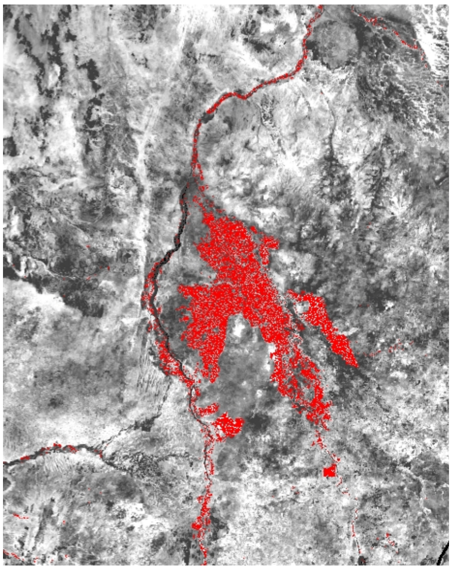


Figure 102 Map showing the distribution of the irrigated areas within the Nile Basin according to FAO-GMIA product, and being refined in the current study

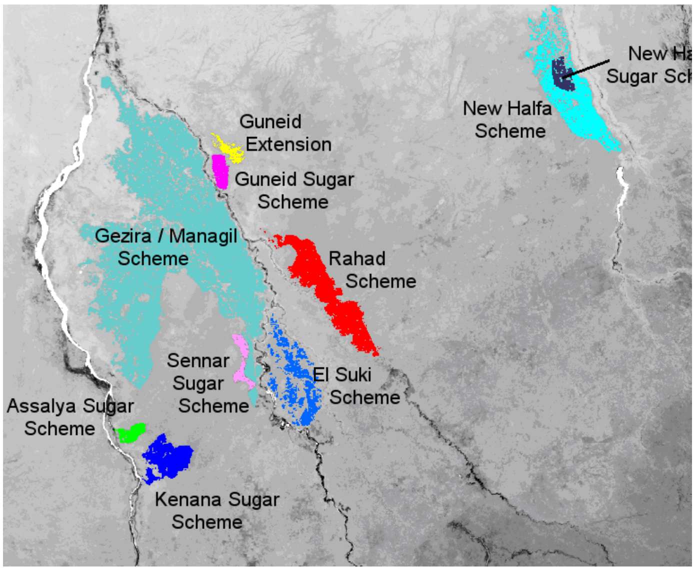


Figure 103 The main irrigation schemes in Sudan

Sudan is endowed with many large scale irrigation systems. It has the largest irrigated area in sub-Saharan Africa and the second largest in all Africa, after Egypt. Indeed, the arid climate of Sudan in conjunction with the manifold rivers that are flowing from the highlands of Ethiopia towards the Nile river system creates good opportunity to introduce irrigated agriculture. These rivers are the Sobat, Blue Nile and Atbara, besides several smaller rivers. According to this study (see Table 67), there is approximately 1.7 million hectare of irrigated land in Sudan. This land is essentially irrigated during the summer period when erratic monsoon rains occur. The irrigation capacity during the winter period is limited, partially because of sediments in reservoirs and in the main canal conveyance system.

Table 67 Different sources for the irrigation statistics for Sudan

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Sudan	1,946,200
IWMI – GIAM	Entire Sudan	1,737,188
Current study	Nile Basin component of Sudan	1,749,300

1.2 Description of LSI

During the colonial era, the Britons developed LSI schemes of which the Gezira Scheme, located south of Khartoum between the Blue and White Nile, is by far the largest. After independence in 1956, the command area of the Gezira Scheme was doubled when the Managil extension was completed. The Gezira scheme is one of the largest irrigation systems of the African continent.

Other new schemes that were established were the New Halfa Scheme and the Rahad Scheme on the right bank of the Blue Nile. Most of the LSI schemes are located inside the Nile basin watershed. Table 68 gives the main characteristics of the major LSIs. In addition to the traditional irrigation practices, several sugarcane estates have emerged during the last years. Among them is the large Kenana farm that is privately managed.

Table 68 LSI schemes in Sudan and their characteristics

Scheme	Source	Major crops	Gross irrigated area*
Assalaya Sugar Scheme	White Nile	sugar	16,613 ha
El Suki Scheme	Blue Nile	Cotton/sorghum	75,375 ha
Gezira/Managil Scheme	Blue Nile	sorghum/cotton/wheat	982,063 ha
Guneid Sugar Scheme	Blue Nile	sugar	20,688 ha
Guneid Extension	Blue Nile	unknown	13,875 ha
Kenana Sugar Scheme	White Nile	sugar	63,531 ha
New Halfa Scheme	Atbara	Cotton/wheat/groundnuts	146,138 ha
New Halfa Sugar Scheme	Atbara	sugar	22,569 ha
Rahad Scheme	Rahad & Blue Nile	sorghum/cotton/groundnuts	153,756 ha
Sennar Sugar Scheme	Blue Nile	sugar	18,925 ha

Source: WaterWatch (2006)

More detailed information concerning irrigation in Sudan can be found in Annex 2.

1.3 Agricultural conditions

Agriculture still remains the major source of income for most of the country’s population and the irrigated sub-sector contributes more than half of the total volume of the agricultural production although the irrigated area constitutes only about 11% of the total cultivated land. It has become more and more important over the past few decades as a result of drought and rainfall variability and uncertainty. The irrigated sector produces 95% of the long stable high quality cotton produced, 100% of sugar production, 36% of sorghum and 32% of groundnuts. Other main irrigated crops are fodder, wheat and vegetables with other crops comprising maize, sunflower, potatoes, roots and tubers and rice. Although (gravity) irrigated agriculture started as early as 100 years ago by Shadoufand Sagia, water productivity is very low. This is attributed to water not delivered at the right time in the right quantity due to poor canal condition (silting, aquatic weeds) and poor management of irrigation water at the field level.

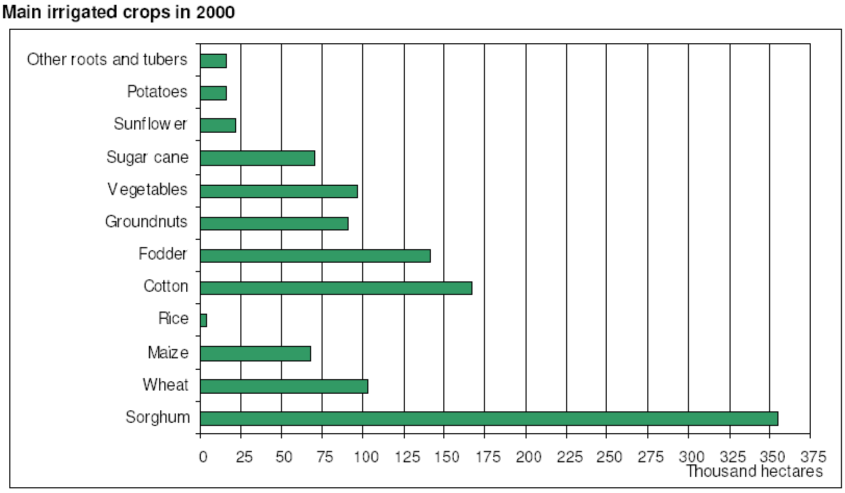
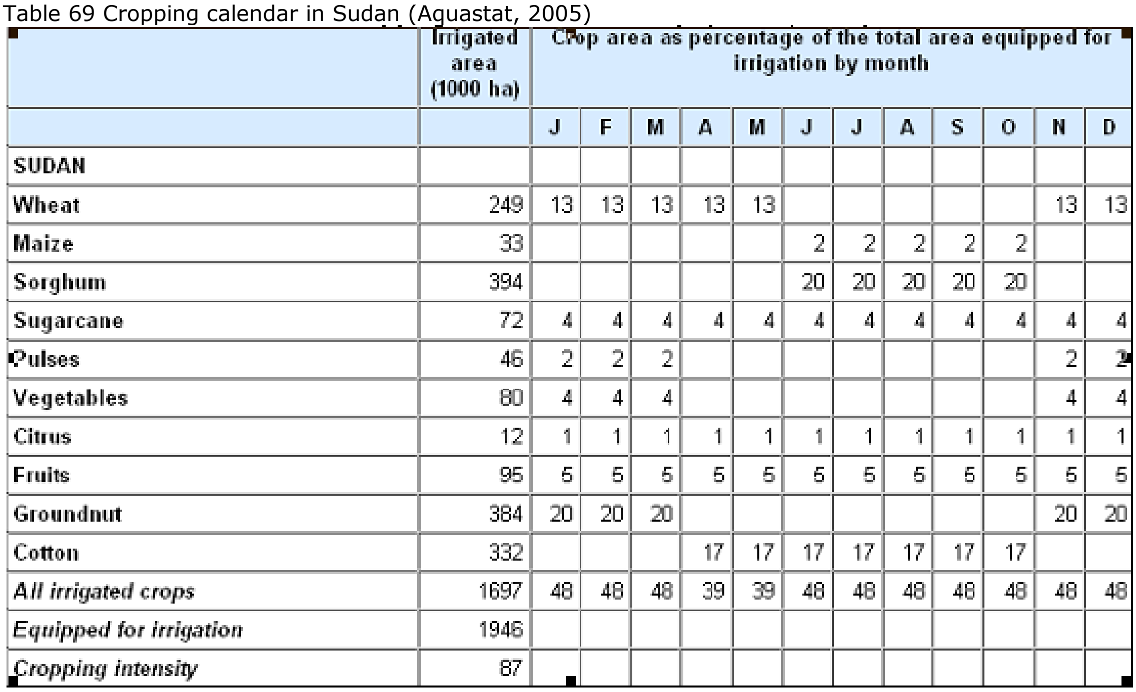


Figure 104 Main crops in Sudan (Aquastat, 2005)

Table 69 displays the cropping calendar in Sudan. The first season is the main irrigation season. This period starts at the end of April, before the rainy season begins. This is a long season and typically reflects the cotton growing season. The crops are thus planted and harvested in dry periods and capture the rains in the middle of their growing season. The second cropping season in Sudan largely overlaps with the first crop. The sowing in July is done typically during the rainy period. Only a low percentage of irrigated land has two irrigation seasons. Hence, in the dry winter period not much irrigation takes place, and it seems that this situation deviates significantly from the design principles to have double crops.

Various reasons are given for this development ranging from sediments, soil salinity, to low market prices.

Table 69 Cropping calendar in Sudan (Aquastat, 2005)



	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
SUDAN													
Wheat	249	13	13	13	13	13						13	13
Maize	33						2	2	2	2	2		
Sorghum	394						20	20	20	20	20		
Sugarcane	72	4	4	4	4	4	4	4	4	4	4	4	4
Pulses	46	2	2	2								2	2
Vegetables	80	4	4	4								4	4
Citrus	12	1	1	1	1	1	1	1	1	1	1	1	1
Fruits	95	5	5	5	5	5	5	5	5	5	5	5	5
Groundnut	384	20	20	20								20	20
Cotton	332				17	17	17	17	17	17	17		
All irrigated crops	1697	48	48	48	39	39	48	48	48	48	48	48	48
Equipped for irrigation	1946												
Cropping intensity	87												

More detailed information concerning irrigation in Sudan can be found in Annex 2.

Part 2 Climate

2.1 Climatological conditions

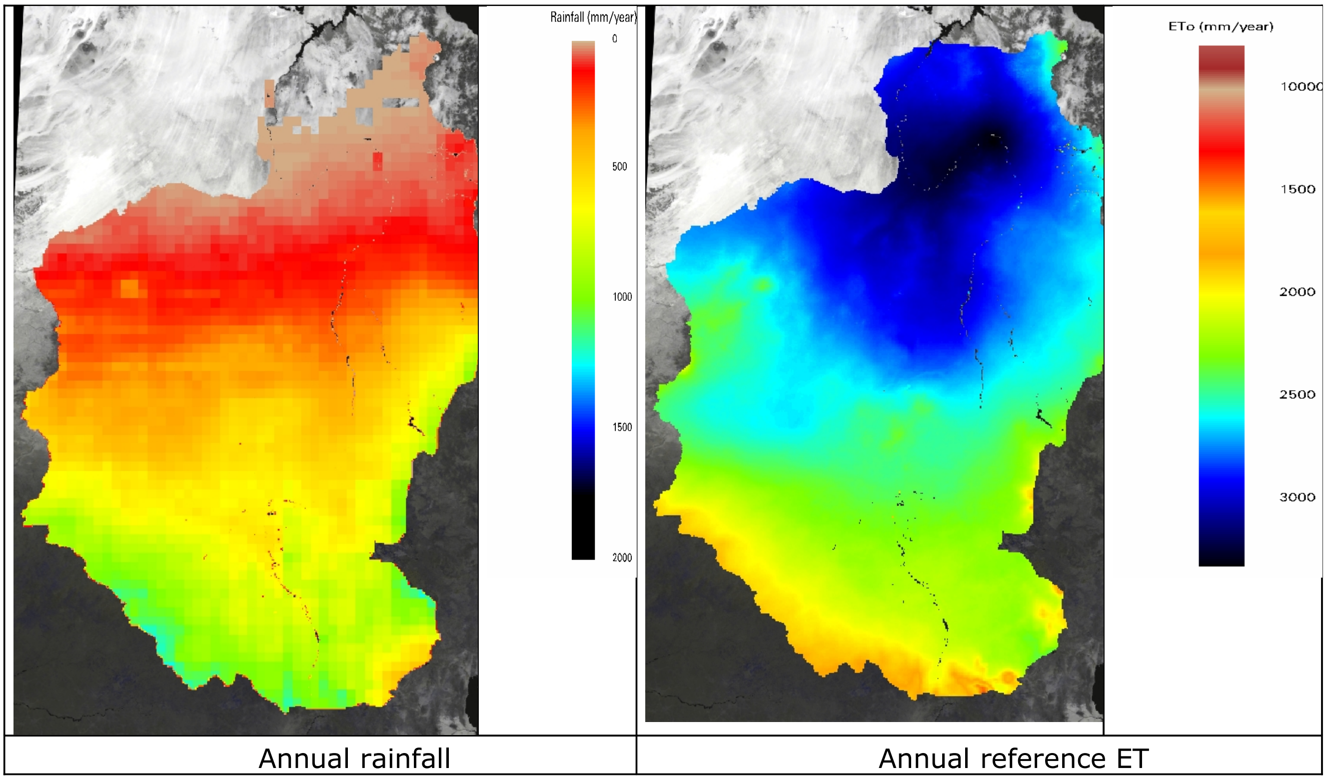
Sudan is located in the transition zone between the wet Equatorial Lake region and the Saharan desert. While the southern part of Sudan has a humid and semi-arid character, the alluvial plain south of Khartoum with all the irrigation system has a clear arid zone.

In this study, the reference evapotranspiration (ET0) is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007. As Table 70 shows, the annual rainfall is 200 mm/yr, and this can increase towards the south up to values of 500 mm/yr (see Figure 105). The rainfall season is short, and takes place in July, August and September. The remaining part of the year is very dry in Sudan with – in essence – no rainfall events. Hence, irrigation is the only option to grow crops.

The (ET0) exceeds rainfall during the entire year. The daily ET0 rates are 6.5 mm/d in December to 10 mm/d in May. This is related to the desert climate with extreme high temperatures and dry air masses with air humidity dropping below 20 and 10%. The highest rainfall (± 1200 mm/yr) occurs at the border with Uganda. The highest ET0 rates were observed in northern Sudan where the Nile flows through the desert. Aridity therefore increases towards the north. This harsh climate is not attractive for agricultural cropping, as crops experience thermal stress under these circumstances. There are thus natural limitations to favourable crop production.

Table 70 Monthly values for rainfall and ET_0.

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	0	206	0
February	0	223	0
March	0	285	0
April	0	290	0
May	1	304	0.01
June	12	281	0.04
July	68	231	0.29
August	88	199	0.44
September	29	201	0.14
October	2	210	0.01
November	0	217	0
December	0	201	0
TOTAL	198	2848	



Annual rainfall

Annual reference ET

Figure 105 Spatial variation of rainfall (left) and ET_0 (right) of the Nile Basin component of Sudan.

2.2 Climatic zones

The current study, aimed at providing information for improved irrigation practices in the Nile basin, covers various climate zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as the irrigation efficiencies. Unexpected rainfall can for instance reduce the fraction of beneficial transpiration, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences based on the diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

The Sudanese climatic division is displayed in Figure 106. The vast majority of the irrigation schemes are located in climate zone 2 (arid). Irrigation in the Nile valley in the northern part of the country occurs in climate zone 1 (hyper-arid). The semi-arid climate in the vicinity of the Roseirres reservoir also hosts some irrigation activities which fall under climate zone 3. Irrigated land in southern Sudan (El Byeara) falls in climate zone 3. Hence, three different zones will be considered.

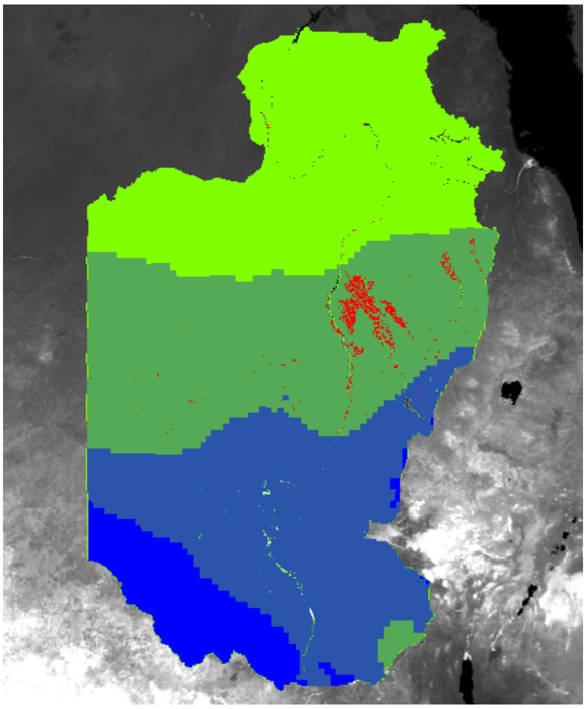


Figure 106 Climate zones identified for the mapping of best irrigation practices. The Sudanese irrigated areas are located in three climatic zones, with the majority in the arid zone (dark green). The locations of the irrigated areas are depicted by the red pixels.

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on the FAO irrigated area map, previous WaterWatch studies and manual digitization of visually recognizable irrigated systems, using Google earth and Landsat images.

The first step was to compute all the indicators per pixel. All the RO and PO indicators described in Table 71 have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. These annual accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin, based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

The sustainability indicators were obtained by investigating the last five year's trends of the vegetation index (from the SPOT-Vegetation satellite) and soil moisture (from the AMSR-E satellite). It indicates the slope of the trend line over these past years.

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined (Table 72, Table 73 and Table 74). A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 107).

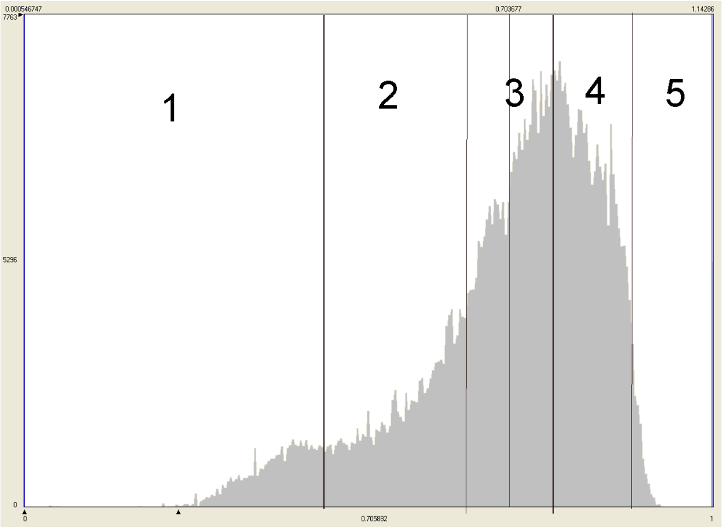


Figure 107 Distribution of the values of one indicator over 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems included in different climatic zone, different benchmark values are considered to avoid any climatic bias in the allocation of the score. In the case of Sudan, it is located in climatic zone 1, 2 and 3.

Table 71 benchmark values for pixel located in climatic zone 1 (hyper-arid)

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<7,000	<16,000 and >7,000	<28,000 and >16,000	<32,000 and 28,000	>32,000
bwp	Kg/ m3	<1.5	<2.3 and >1.5	<2.8 and >2.3	<3.3 and >2.8	>3.3
cwc	M3/ha/year	>12,500	<12,500 and >9,000	<9,000 and >5.700	<5,700 and >1,000	<1,000
cwd	M3/ha/year	<340 and >250	>500	<500 and >340	<250 and >130	<130
bf	-	<0.7	<0.9 and >0.7	<0.94 and >0.9	<0.97 and >0.94	>0.97
ad	-	<0.45	<0.64 and >0.45	<0.74 and >0.64	<0.86 and >0.74	> 0.86
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.75	<0.82 and >0.75	<0.88 and >0.82	<0.95 and >0.88	>0.95
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Table 72 benchmark values for pixel located in climatic zone 2 (arid)

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<3,300	<4,400 and >3.300	<7,800 and >4,400	<10,000 and >7,800	>10,000
bwp	Kg/ m3	<0.7	<1 and >0.7	<1.5 and >1	<2.3 and >1.5	>2.3
cwc	M3/ha/year	>11,600	<11,600 and >7,600	<7,600 and >4,400	<4,400 and >2,000	<2,000

cwd	M3/ha/year	<390 and >280	>500	<500 and >390	<280 and >168	<168
bf	-	<0.47	<0.62 and >0.47	<0.75 and >0.62	<0.86 and >0.75	>0.86
ad	-	<0.40	<0.47 and >0.4	<0.58 and >0.47	<0.7 and >0.58	> 0.7
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.56	<0.72 and >0.56	<0.80 and >0.72	<0.90 and >0.8	>0.90
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Table 73 benchmark values for pixel located in climatic zone 3 (semi-arid)

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<7,000	<10,500 and >7,000	<13,500 and >10,500	<15,000 and >13,500	>15,000
bwp	Kg/ m3	<1.3	<2.2 and >1.3	<2.5 and >2.2	<3 and >2.5	>3
cwc	M3/ha/year	>10,200	<10,200 and >7,000	<7,000 and >5,300	<5,300 and >4,000	<4,000
cwd	M3/ha/year	<110	<175 and >110	<310 and >220	>310	<220 and >175
bf	-	<0.5	<0.7 and >0.5	<0.83 and >0.7	<0.88 and >0.83	>0.88
ad	-	<0.56	<0.63 and >0.56	<0.70 and >0.63	<0.78 and >0.70	> 0.78
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.74	<0.8 and >0.74	<0.86 and >0.8	<0.92 and >0.86	>0.92
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3

amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, districts average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at Country level

As displayed in Figure 108, the average score considering all the indicators together for all the 1.7 million ha of irrigated land is 3.2, which is an average score. The graph underneath shows the country averages for each indicator. The aspects that Sudan should provide more attention to are the ones with relative low scores.

The scores of 3.0 for land productivity and 2.7 for water productivities are reasonable but could be improved, in particular the biomass water productivity.

Concerning the PO indicators, reliability and crop water deficit show good performances. Adequacy, beneficial fraction, and crop water consumption are average. The uniformity seems to be the weakest aspect with an average score of 2.6.

The sustainability of irrigation practices seems to be under control. Compared to the last years, the irrigated land is becoming greener (as the score for the land sustainability is higher than 3), hence the irrigation systems are healthy and continuous. The soils are gradually getting wetter, so there seems to be ample water resources available.

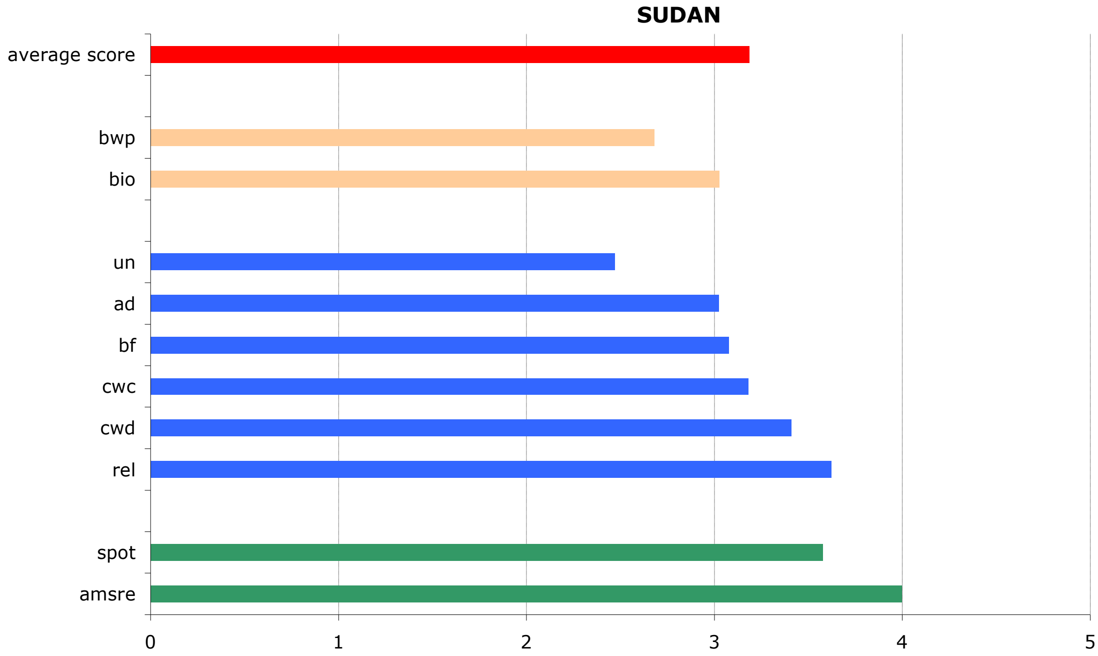


Figure 108 Average scores for Sudan for each indicator.

3.3 Results at district level

3.3.1 Average per district

In Figure 109 the average scores for all the indicators per district is compared. In Sudan, 47 districts having more than 30 pixels of 6.25 ha have been identified.

In terms of total average score, the best irrigation district is Suki, with an average of 3.6. The district that has the lowest average is Aliab & Food Security with an average of 2.3 (see Figure 110 for their locations). The average scores per district show quite a variation between the best district and the lowest district. That explains the below average score for the indicator uniformity at country level. This implies that there is considerable scope for improvement. Sudan is thus a country suitable for irrigation improvement projects.

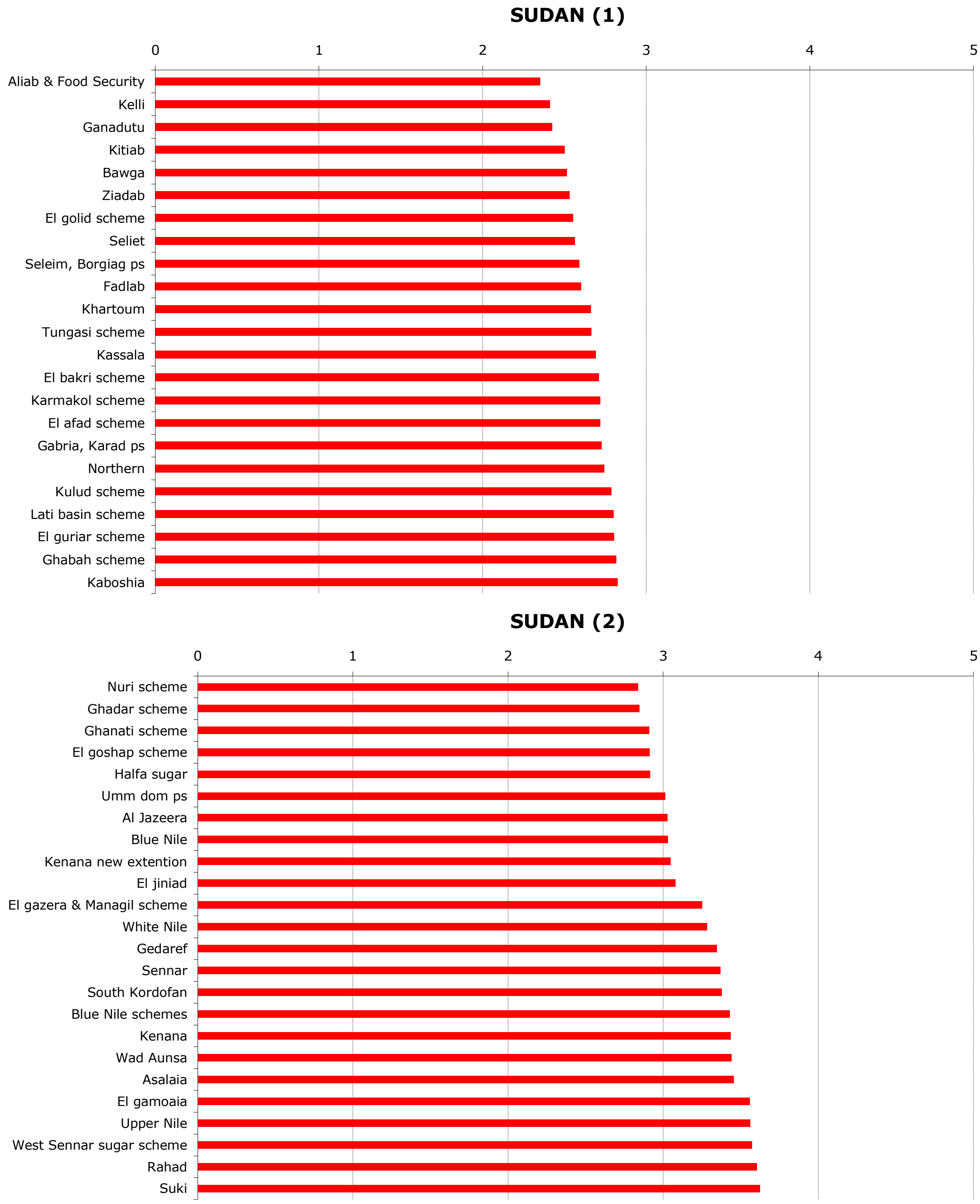


Figure 109 Total score for Sudan for each indicator

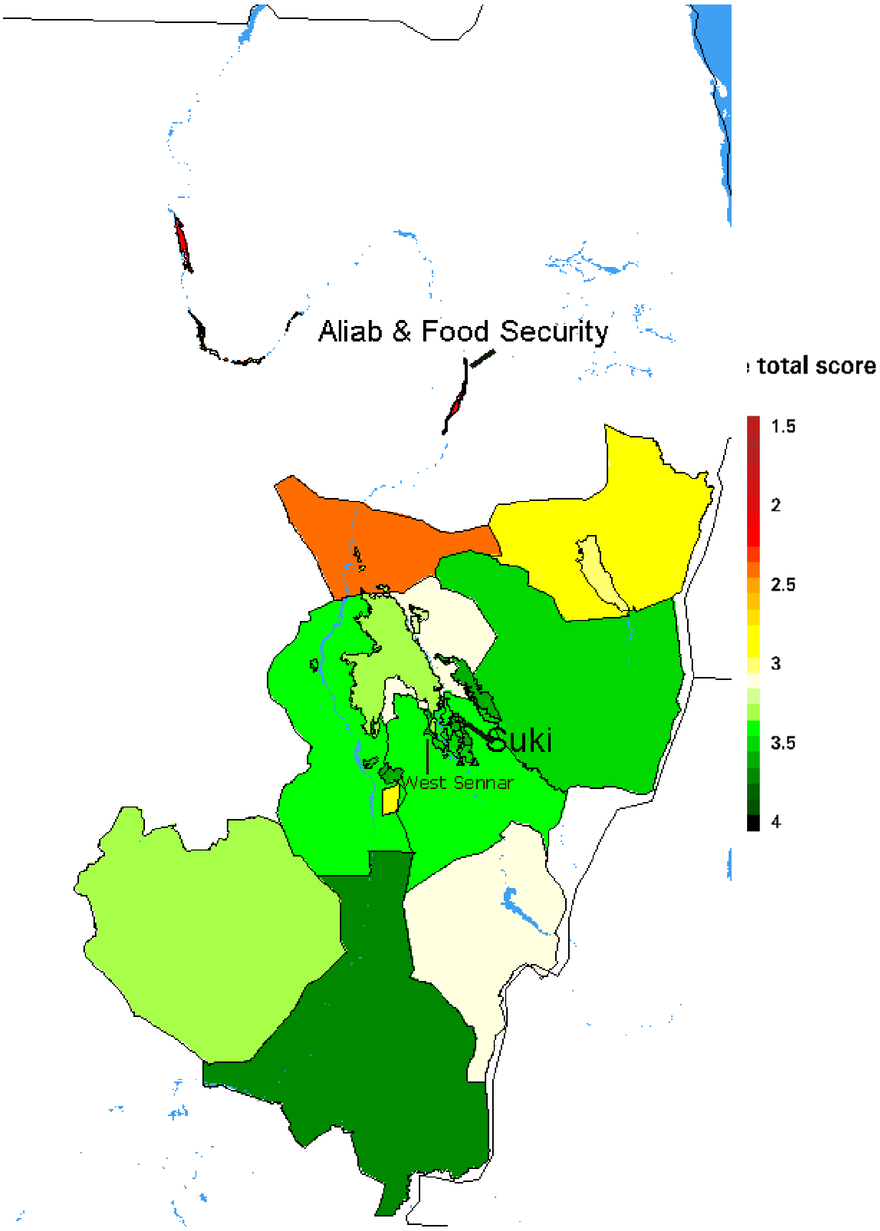
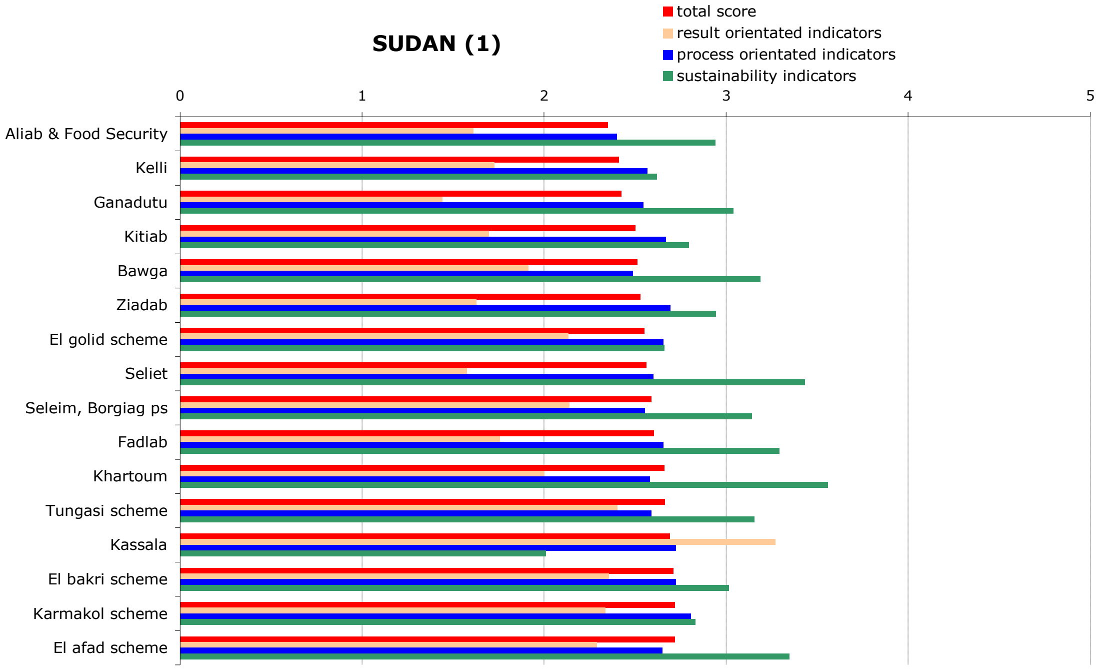
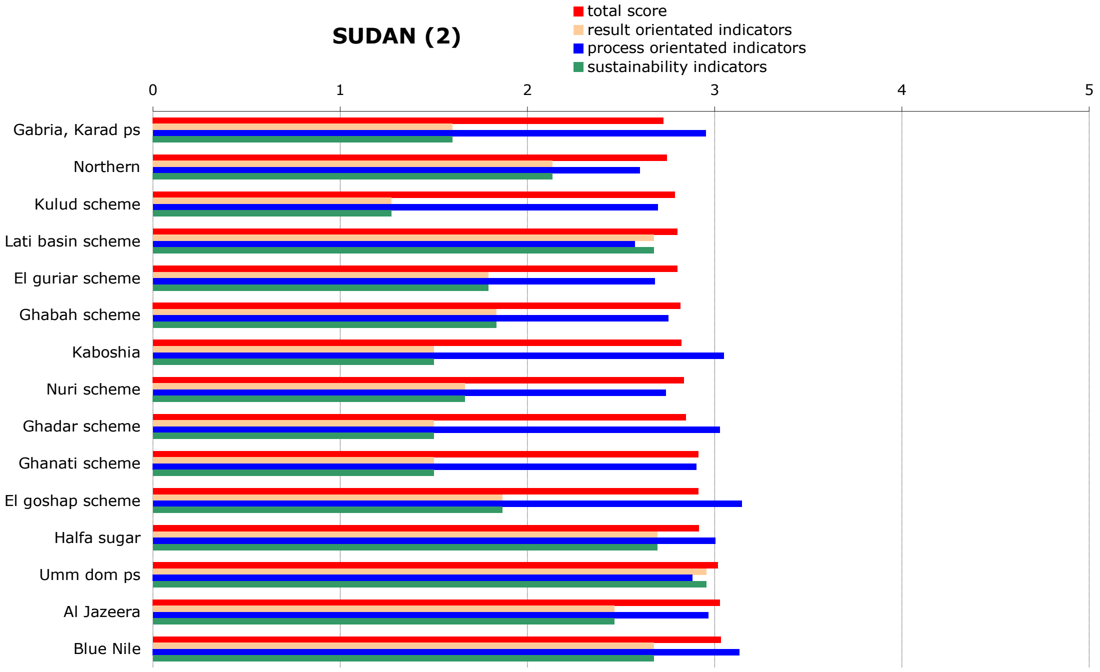


Figure 110 Map showing the total score per irrigated district of Sudan.

3.3.2 Breaking down the total score into RO indicators, PO, and sustainability indicators.

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 111 provides the average score per group of indicators. What is called ‘total score’ in red is the average of the 10 indicators. The total average score for all indicators for each district gives an idea of the total performance and enables ranking of the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.


SUDAN (1)
total score
result orientated indicators
process orientated indicators
sustainability indicators
0
1
2
3
4
5
Aliab & Food Security
Kelli
Ganadutu
Kitiab
Bawga
Ziadab
El golid scheme
Seliet
Seleim, Borgiag ps
Fadlab
Khartoum
Tungasi scheme
Kassala
El bakri scheme
Karmakol scheme
El afad scheme


SUDAN (2)
total score
result orientated indicators
process orientated indicators
sustainability indicators
0
1
2
3
4
5
Gabria, Karad ps
Northern
Kulud scheme
Lati basin scheme
El guriar scheme
Ghabah scheme
Kaboshia
Nuri scheme
Ghadar scheme
Ghanati scheme
El goshap scheme
Halfa sugar
Umm dom ps
Al Jazeera
Blue Nile

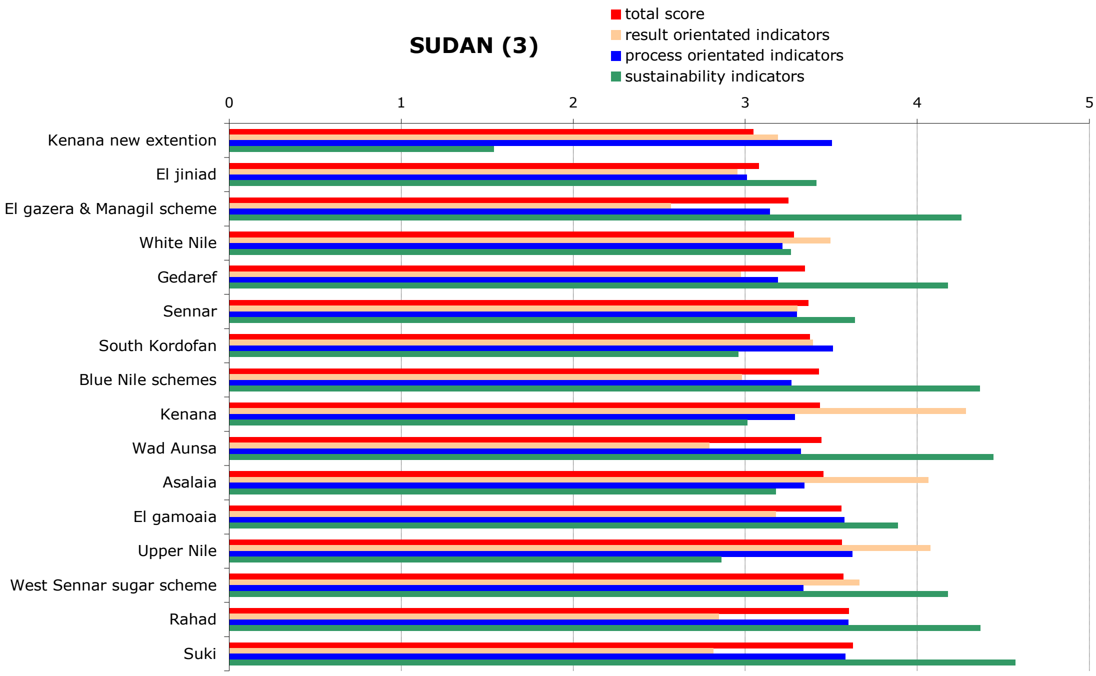


Figure 111 breaking down the total score per indicator for Sudan

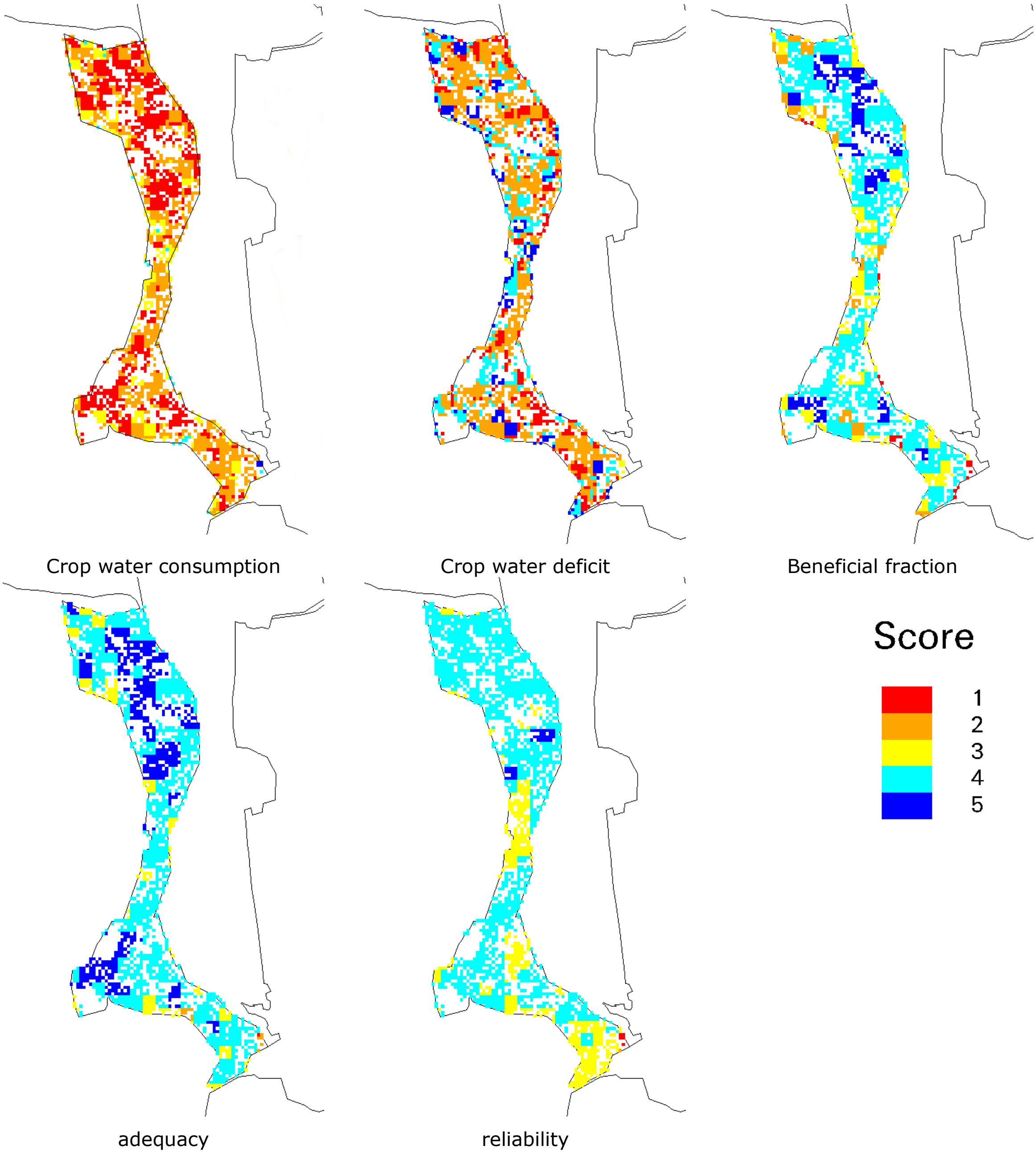
The first aspect that draws attention in the breaking down of the total performance score is that a good total score does not always mean a good performance in terms of results.

For example, the district Kassala has a low total average (2.7) which could mean that the irrigation district is not performing well. However, it does perform well in terms of results (the average of the RO indicators in 3.3). The low global average that leads to ranking Kassala amongst the districts with the poorest irrigation performance is explained by the lower than average score obtained in terms of PO indicators (2.7) and sustainability indicators (2). In another case (Suki district) the RO score is low (2.8) but the sustainability is good (4.1) as well as the PO indicators (3.6).

Similarly, a good functioning system does not mean it is a sustainable system. The new Kenana district extension is a good example. It is quite a good irrigation district if we look at the total average of all the indicators together (3), or in terms of result (3.2). However, it is not a sustainable system, as indicated by its low score (total average of 1.5) for sustainability indicators. This example shows once again the relevance of breaking irrigation performance down into different types of indicators.

3.4 Analysis per pixel for an irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five indicators is displayed for the irrigated pixels in the district of West Sennar sugar scheme, which is the third best district in terms of performance. The 6th PO indicator uniformity cannot be displayed as it is an indicator at district level. Figure 112 demonstrates that the management of the district is not really homogeneous and that special attention should be given to crop water deficit and crop water consumption at certain places.



Crop water consumption
Crop water deficit
Beneficial fraction
adequacy
reliability

Figure 112 Spatial variation of PO indicators within the West Sennar sugar scheme.

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the 47 districts. Biomass production appears to be well correlated to adequacy and the beneficial fraction (Figure 113). Adequacy should be more than 0.7 to achieve a good yield. A beneficial fraction of at least 0.8 is desirable. It can be achieved by having closed canopies (e.g. Sugar Cane), or by low rainfall, or by modernized irrigation systems. The apparent correlation between crop water deficit and biomass production is not realistic. There are no clear relationships with uniformity and reliability.

Biomass water productivity shows only a weak relationship with crop water deficit. A low crop water deficit of 100 to 150 mm/year provides the best biomass water productivity.

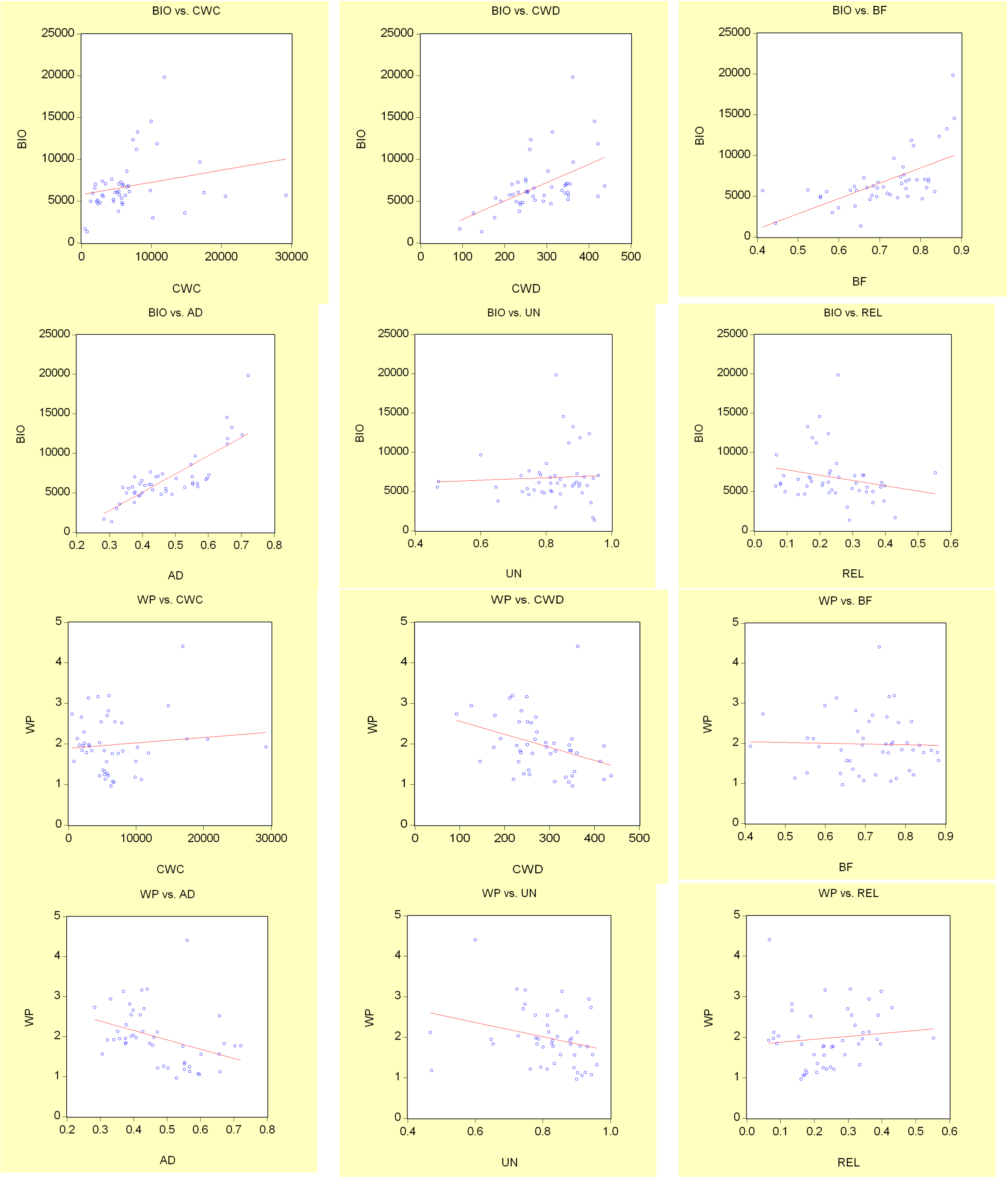


Figure 113 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationships between indicators are better understood, the next step is to identify the weakest elements per district. In Table 74, the best and poorest indicators are presented.

Uniformity and adequacy seem to be the weakest aspects for most of the districts. On the other side of the scale, crop water deficit, crop water consumption, and reliability are often the best indicators. This means that Sudan's water conservation is good.

Table 74 best and poorest PO irrigation indicator per district

district	lowest score		2nd lowest		2nd best		best	
Aliab & Food Security	un	1.00	ad	1.02	cwd	3.05	cwc	4.19
Kelli	bf	1.35	ad	1.73	cwd	3.84	cwc	4.52
Ganadutu	un	1.00	ad	1.23	rel	3.88	cwc	4.13
Kitiab	ad	1.18	un	2.00	rel	3.05	cwc	3.92
Bawga	rel	1.28	ad	1.67	cwd	3.44	cwc	4.40
Ziadab	ad	1.24	bf	1.67	cwd	3.55	cwc	4.51
El golid scheme	ad	1.30	bf	1.97	cwd	3.49	cwc	4.37
Seliet	ad	1.36	bf	1.87	cwd	3.47	cwc	4.13
Seleim, Borgiag ps	un	1.00	ad	1.56	cwd	3.99	cwc	4.41
Fadlab	un	1.00	ad	1.16	rel	3.68	cwc	4.63
Khartoum	ad	1.00	ad	1.00	cwd	3.52	cwc	4.47
Tungasi scheme	un	1.00	ad	1.35	cwd	3.60	cwc	4.18
Kassala	un	1.00	ad	1.06	cwc	4.11	bf	4.27
El bakri scheme	bf	1.00	ad	1.06	un	4.00	cwc	4.73
Karmakol scheme	ad	1.30	bf	1.89	rel	3.80	cwc	4.27
El afad scheme	ad	1.00	bf	1.59	cwd	3.16	cwc	4.65
Gabria, Karad ps	ad	1.26	bf	2.05	rel	4.00	cwc	4.49
Northern	ad	1.55	un	2.00	cwd	3.87	cwc	4.19
Kulud scheme	ad	1.00	ad	1.00	rel	3.87	cwc	3.87
Lati basin scheme	un	1.00	ad	1.31	cwc	4.18	cwd	4.21
El guriar scheme	un	1.00	ad	1.04	cwc	3.77	rel	4.16
Ghabah scheme	ad	1.06	bf	1.97	rel	3.96	cwc	4.33
Kaboshia	bf	1.00	ad	1.47	un	4.00	cwc	4.90
Nuri scheme	ad	1.00	bf	1.17	cwd	4.11	cwc	4.46
Ghadar scheme	bf	1.00	ad	2.30	cwd	4.13	cwc	4.70
Ghanati scheme	bf	1.33	ad	2.28	rel	4.00	cwc	4.69
El goshap scheme	ad	1.23	bf	2.14	rel	4.05	cwc	4.23
Halfa sugar	ad	1.39	un	2.00	bf	3.39	cwc	3.53
Umm dom ps	un	2.00	ad	2.49	cwd	3.44	cwc	4.27
Al Jazeera	un	2.00	bf	2.20	cwc	3.64	cwd	3.82
Blue Nile	rel	2.82	un	3.00	cwd	3.27	bf	3.43
Kenana new extention	rel	2.00	ad	3.16	bf	4.11	un	5.00
El jiniad	un	2.00	cwd	2.44	rel	3.56	bf	4.19
El gazera & Managil scheme	bf	2.73	cwc	2.94	cwd	3.25	rel	3.94

White Nile	un	2.00	ad	3.19	cwd	3.66	bf	3.71
Gedaref	un	2.00	bf	2.97	rel	3.64	cwd	3.92
Sennar	bf	2.91	un	3.00	ad	3.66	cwd	3.71
South Kordofan	ad	2.27	rel	2.54	un	4.00	bf	4.13
Blue Nile schemes	bf	2.76	un	3.00	ad	3.38	cwd	4.00
Kenana	cwc	1.79	un	2.00	rel	3.54	bf	4.66
Wad Aunsa	bf	1.89	cwc	3.20	un	4.00	ad	4.03
Asalaia	cwc	2.07	cwd	2.70	ad	3.68	bf	4.63
El gamoaia	rel	3.20	bf	3.52	cwd	4.22	cwc	4.25
Upper Nile	cwc	2.52	un	3.00	rel	3.80	bf	4.52
West Sennar sugar scheme	cwc	1.76	cwd	2.52	un	4.00	ad	4.18
Rahad	cwc	2.83	cwd	3.51	un	4.00	ad	4.55
Suki	cwc	2.89	bf	3.14	un	4.00	ad	4.16

4.3 Recommendations at country level

Irrigation with flood water that originates from Ethiopia is an historic phenomenon in Sudan. Water is used during the flood season to irrigate crops. The arid climate of Sudan causes a chronic shortage of water for agriculture, and for this reason 1.74 million ha of irrigation systems are in place in Sudan.

As a result of the large area of the country the irrigation performance have a wide scatter in ranking, but does not reach excellent levels. Kenana and West Sennar are modern and privately managed sugarcane estates serviced by the best irrigation systems of the Nile Basin. The Nile valley in the upstream end of the White Nile between Khartoum and the confluence with the Atbara also seems to have patches of well irrigated land.

El Gezira and some other LSI systems have a disappointing irrigation performance (an average total score around 3). A sole reason for this situation is not apparent and it is more likely to be the result of a variety of factors causing below-average operating skills. Water resources may for example be limiting because the canals are not maintained properly and have only a fraction of their design capacity due to siltation. Extreme dry and hot air during the dry season that is not very suitable for growing crops may be another causative factor. The non-flexibility of the water demand for hydropower and irrigation can also be held responsible for water delivery not being tuned with crop water requirements.

From an agronomical point of view, yields within the country are generally poor with low biomass water productivity. Extension support needs to be improved in order to realize the full irrigation potential. Information on technical packages for production and on crop management (improved seeds, fertilizer, pest control, cultural practices, harvest and post-harvest) should be provided.

The Government of Sudan should focus on the following aspects:

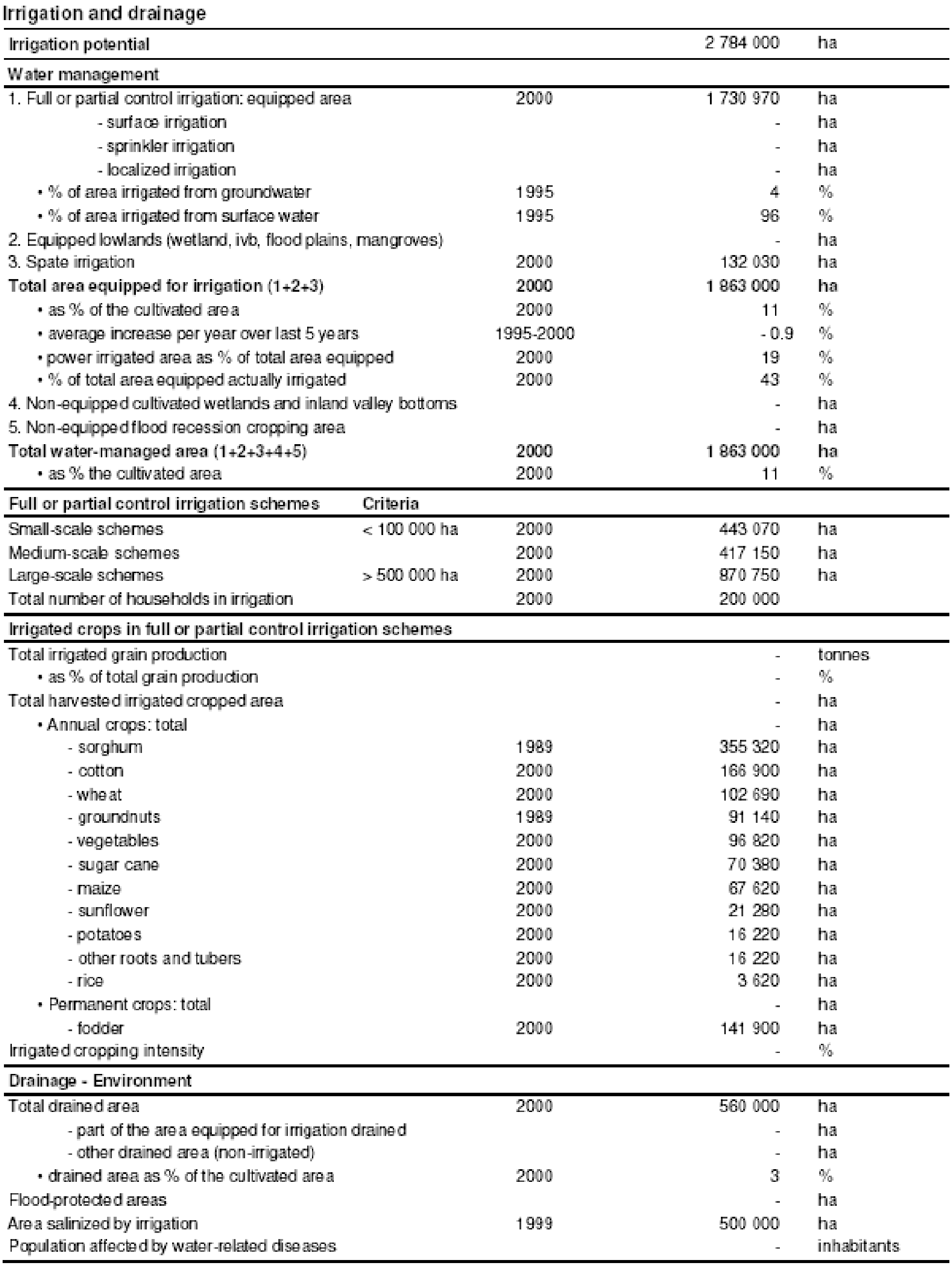
- Investigate the major underlying reasons for low crop yield and find solutions to increase production. Investigate how water productivity can be improved.

- Launch a LSI rehabilitation and maintenance program to restore the design capacity of the conveyance network.
- Determine the water allocation policies between hydropower and irrigation
- Evaluate the operational rules for water allocation and water distribution in governmental managed systems vs. privately managed systems.
- Reduce the interval between consecutive irrigation applications.
- Improve the local organization of on-farm water management practices. This could be achieved through the establishment of water user associations, or any other form of cooperative. There is indeed a need for farmers and water utilization agencies to be advised on best practices and to become familiar with the optimum quantities of water to be used.
- Involve the irrigation managers of the sugar estates in re-designing the national irrigation strategies.

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m3	Bio/ETact	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M3/ha/year	ETact	Saving of water resources
	Crop water deficit	cwd	M3/ha/year	ETpot-ETact	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	Tact/ETpot	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	Tact/Tpot	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	1-CV(Tact/Tpot)(x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	1-CV(Tact/Tpot)(t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 General information on irrigation conditions in Sudan (Aquastat, 2005)



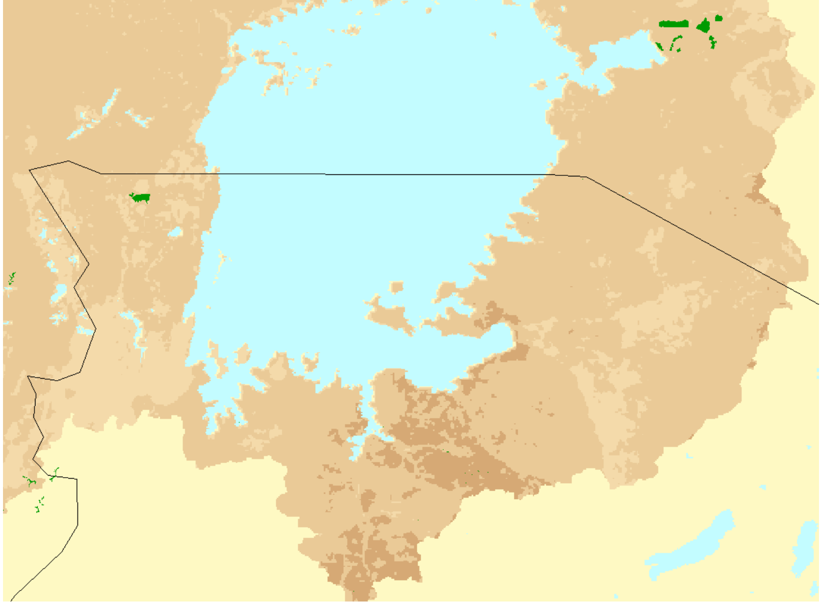
Irrigation and drainage

Irrigation potential			2 784 000	ha
Water management				
1. Full or partial control irrigation: equipped area		2000	1 730 970	ha
- surface irrigation			-	ha
- sprinkler irrigation			-	ha
- localized irrigation			-	ha
• % of area irrigated from groundwater		1995	4	%
• % of area irrigated from surface water		1995	96	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)			-	ha
3. Spate irrigation		2000	132 030	ha
Total area equipped for irrigation (1+2+3)		**2000**	**1 863 000**	**ha**
• as % of the cultivated area		2000	11	%
• average increase per year over last 5 years		1995-2000	- 0.9	%
• power irrigated area as % of total area equipped		2000	19	%
• % of total area equipped actually irrigated		2000	43	%
4. Non-equipped cultivated wetlands and inland valley bottoms			-	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		**2000**	**1 863 000**	**ha**
• as % the cultivated area		2000	11	%
Full or partial control irrigation schemes	**Criteria**			
Small-scale schemes	< 100 000 ha	2000	443 070	ha
Medium-scale schemes		2000	417 150	ha
Large-scale schemes	> 500 000 ha	2000	870 750	ha
Total number of households in irrigation		2000	200 000	
Irrigated crops in full or partial control irrigation schemes				
Total irrigated grain production			-	tonnes
• as % of total grain production			-	%
Total harvested irrigated cropped area			-	ha
• Annual crops: total			-	ha
- sorghum		1989	355 320	ha
- cotton		2000	166 900	ha
- wheat		2000	102 690	ha
- groundnuts		1989	91 140	ha
- vegetables		2000	96 820	ha
- sugar cane		2000	70 380	ha
- maize		2000	67 620	ha
- sunflower		2000	21 280	ha
- potatoes		2000	16 220	ha
- other roots and tubers		2000	16 220	ha
- rice		2000	3 620	ha
• Permanent crops: total			-	ha
- fodder		2000	141 900	ha
Irrigated cropping intensity			-	%
Drainage - Environment				
Total drained area		2000	560 000	ha
- part of the area equipped for irrigation drained			-	ha
- other drained area (non-irrigated)			-	ha
• drained area as % of the cultivated area		2000	3	%
Flood-protected areas			-	ha
Area salinized by irrigation		1999	500 000	ha
Population affected by water-related diseases			-	inhabitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Tanzania



Report J

January 2009

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Part 1 Overview of irrigated areas
Part 2 Climate
Part 3 Raster and vector-based irrigation performance
Part 4 Recommendations for improvement

Purpose of this report:
This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Tanzania and will become an integral component of the final LSI report that will combine results from all countries.

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

Part 1 Overview of irrigated areas

Figure 114 Provinces in Tanzania

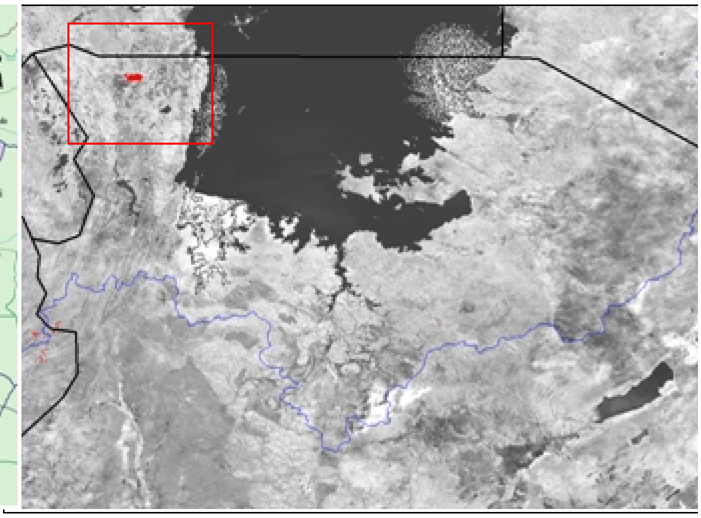
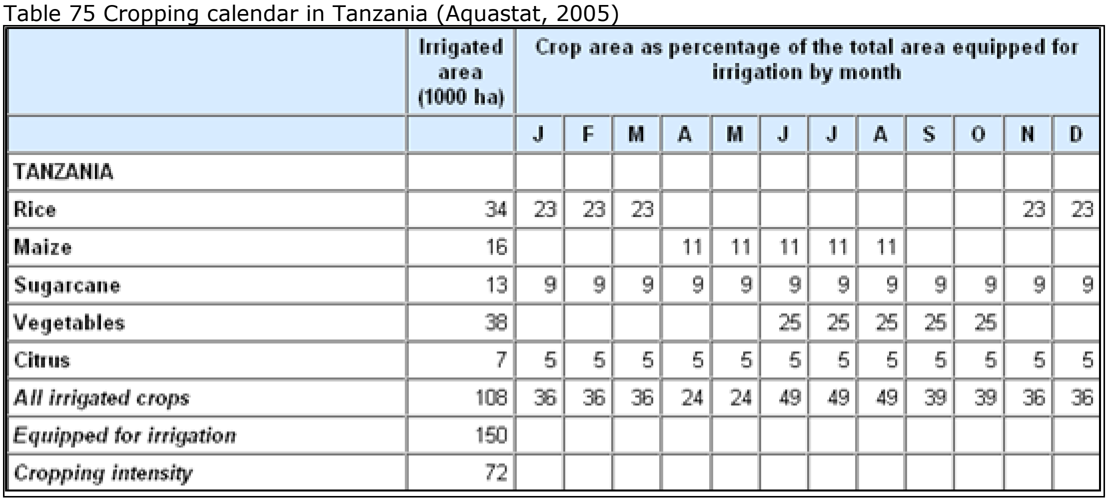


Figure 115 Map showing the only LSI scheme in Tanzania according to this study (in red)

Tanzania, with a population of 38.3 million (estimated in 2005) and a land area of 945,100 km2 is the largest country in eastern Africa and has enjoyed relative political stability since independence. Agriculture is the leading sector of the economy of Tanzania. It has linkages with the non-farm sector through agro-processing, consumption and export; provides raw materials to industries and a market for manufactured goods. About 80% of the population live in rural areas and earn their living mainly from agriculture. In spite of this reasonable growth, the livelihood of the rural population remains unchanged. This has often resulted in localized food insecurity and hunger, which has been exacerbated by the lack of access to external resources by households.

Lake Victoria Basin lies within the Nile Basin in Tanzania. It comprises the four regions of Kagera, Mara, Mwanza and Shinyanga, the last three are famous for cattle rearing and are major growers of cotton with coffee introduced in Mara quite recently (Figure 114). Kagera region is characterized by banana/coffee/horticulture systems. Other crops grown in the basin include maize, rice, sugar, tea and horticultural products. Table 75 displays the main crops grown in Tanzania and the cropping calendar. Note that the majority of these statistics occur outside the boundaries of the Nile basin.

Table 75 Cropping calendar in Tanzania (Aquastat, 2005)



	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
TANZANIA													
Rice	34	23	23	23								23	23
Maize	16				11	11	11	11	11				
Sugarcane	13	9	9	9	9	9	9	9	9	9	9	9	9
Vegetables	38						25	25	25	25	25		
Citrus	7	5	5	5	5	5	5	5	5	5	5	5	5
All irrigated crops	108	36	36	36	24	24	49	49	49	39	39	36	36
Equipped for irrigation	150												
Cropping intensity	72												

The National Irrigation Master Plan (NIMP) in Tanzania indicates that the irrigation potential in Tanzania is 29.4 million hectares, of which 2.3 million hectares are high potential, 4.8 million hectares are medium potential and 22.3 million hectares are low potential. This is substantially more than the current irrigation level. According to the NIMP, approximately 264,388 ha is currently under irrigation, being about 2% of the cultivated area. The latter “official” area is lower than that reported by FAO and IWMI (see Table 76). This signifies the considerable uncertainty about the real area under irrigation in Tanzania. In this study, we identified the Kagera irrigation system of 475 ha of sugar cane (see red dots in Figure 115). Other irrigation spots were found, especially in the South of Lake Victoria, but only LSI scheme are analyzed in this study.

Table 76 Different sources for the irrigation statistics for Tanzania

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Tanzania	184,330
IWMI – GIAM	Entire Tanzania	46,022
Current study	Nile Basin component of Tanzania	475

More detailed information concerning irrigation in Tanzania can be found in Annex 2.

Part 2 Climate

2.1 Climatological conditions

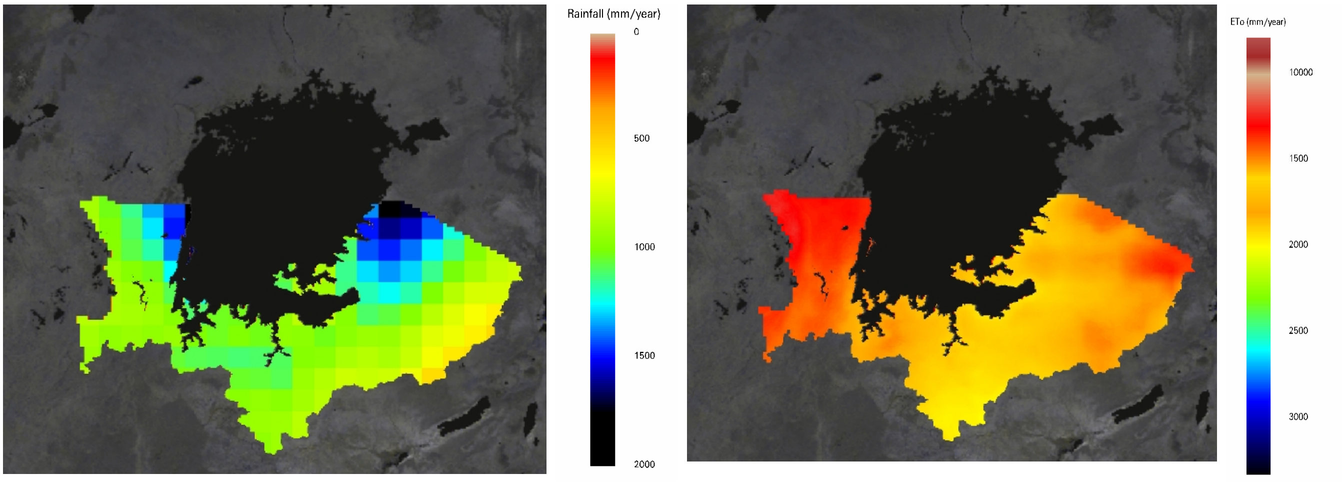
In this study, the rainfall is based on TRMM satellite data. The reference evapotranspiration (ET_0) is computed with the standardized Penman-Monteith equation specified in FAO56.

As displayed by Table 77, the monthly aridity values for June, July, August and September are approximately 0.1 to 0.35 only and without irrigation it is not feasible to grow a crop during this period. In most of the other months the aridity level exceeds 1.0, and there is thus sufficient rainfall for crop production. For this reason, Tanzania is in essence a rain-fed agricultural system. The rainfall season is continuous and long, extending from October to May. January and February are relatively dry and (ET0) exceeds rainfall during these two months. July and August are the dry months. Farmers respond to the shortage of rain water by cultivating wet river valleys and by irrigating maize and vegetables.

The northern part of Tanzania receives a significant amount of rainfall (1091 mm/yr), and the annual rainfall averaged over the whole area ranges from 700 mm to 1300 mm/yr, depending on the year considered (Figure 116). The highest rainfall (± 1600 mm/yr) occurs at the border with Kenya and Uganda.
The highest ET0 rates were observed at the most southern tip of the Nile basin in Shinyanga (± 1900 m/yr). Hence, aridity increases towards the south.

Table 77 Monthly values for rainfall and ET_0 for Tanzania

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	82	135	0.61
February	77	125	0.62
March	142	137	1.04
April	160	118	1.36
May	129	119	1.08
June	20	122	0.16
July	13	129	0.1
August	34	141	0.24
September	49	143	0.34
October	77	148	0.52
November	182	128	1.42
December	124	127	0.98
TOTAL	1091		



Annual rainfall

Annual reference ET

Figure 116 Spatial variation of rainfall (left) and ET_0 (right).

2.2 Climatic zones

The current study aims to provide information for improved irrigation practices in the Nile basin and it covers various climate zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as the irrigation efficiencies. Unexpected rainfall can for instance reduce the irrigation efficiency, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences based on the diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

The Tanzanian irrigation schemes are located in climate zone 4 (humid tropics), see Figure 117.

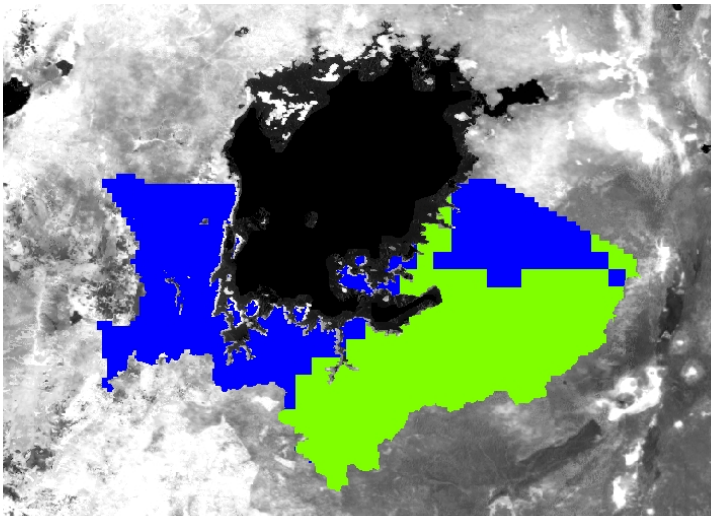


Figure 117 Climate zones identified for the mapping of best irrigation practices. Tanzanian irrigated areas are located in the humid tropics zone (blue))

Part 3 Raster and vector-based irrigation performance

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on the data send by the LSI representatives of Burundi. The first step was to compute all the indicators per pixel. All the RO and PO indicators were computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. These annual accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

The sustainability indicators have been obtained by investigating the last five year's trends of the vegetation index (from the SPOT-Vegetation satellite) and soil moisture (from the AMSR-E satellite). It indicates the slope of the trend line over these past years.

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined. A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 118).

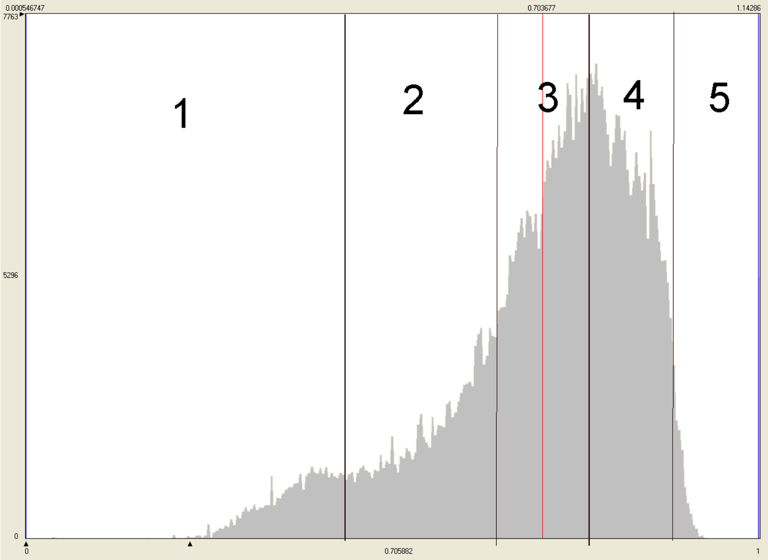


Figure 118 Distribution of the values of one indicator over 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems included in different climatic zone, different benchmark values are considered to avoid any climatic bias in the allocation of the score. Tanzania is located in climatic zone 4.

Table 78 benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, districts average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at Country level

As displayed in Figure 119, the average score considering all the indicators together for all the 475 ha of irrigated land is 3.2, which is good (the average score being 3). This average is translated into scores for each individual indicator. The aspects that Tanzania should provide more attention to are the ones with a relative low score.

Both land and water productivity have scores of 3.1 which is reasonable.

The PO indicators show very good performance in terms of uniformity and crop water deficit. Adequacy, beneficial fraction, crop water consumption, and reliability are above average. This behaviour can be attributed to the mono-culture and single sugarcane system located in the humid tropics.

The sustainability of irrigation practices does not seem to be totally under control. Over the last years, the irrigated land became greener (as the score for the land sustainability is higher than 3) but the soils got gradually dryer.

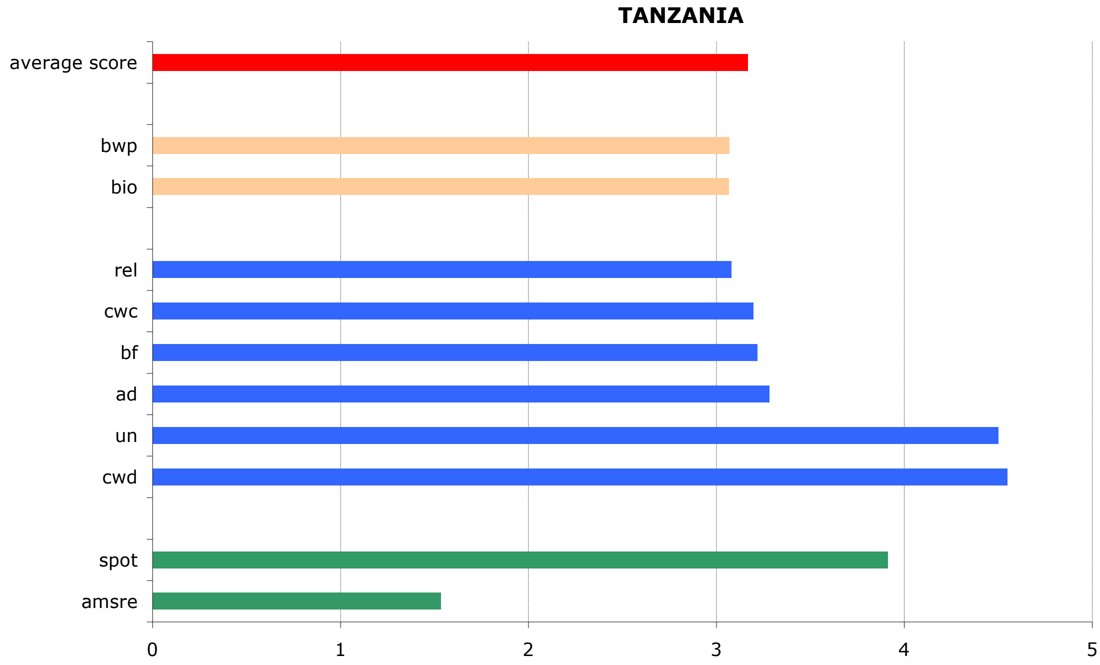


Figure 7: The average score for each indicator in Tanzania.

3.3 Results at district level

3.3.1 Average per district

In Figure 120 the average scores for all the indicators per district are compared. In Tanzania, 2 districts having more than 30 pixels of 6.25 ha have been identified: the district of Bukoba, and the district of Karagwe. But they actually share the same irrigation district. The two districts with irrigation have good total average scores of 3.3 (Bukoba) and 3.4 (Karagwe).

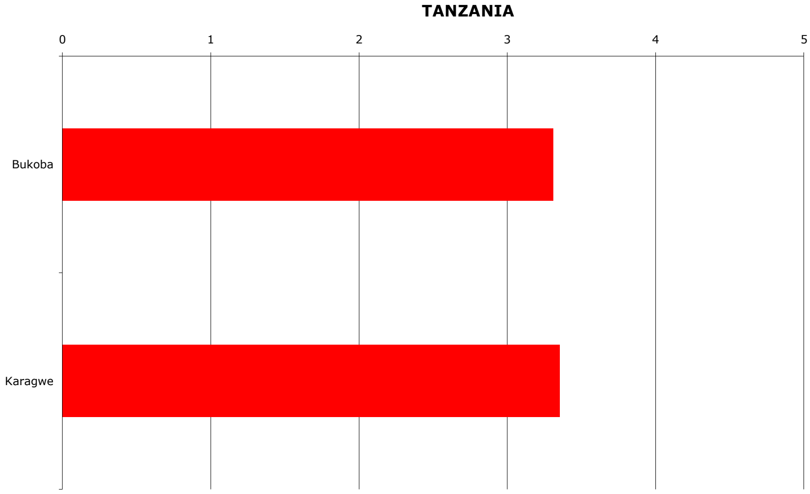


Figure 119 The total score for Tanzania for each district

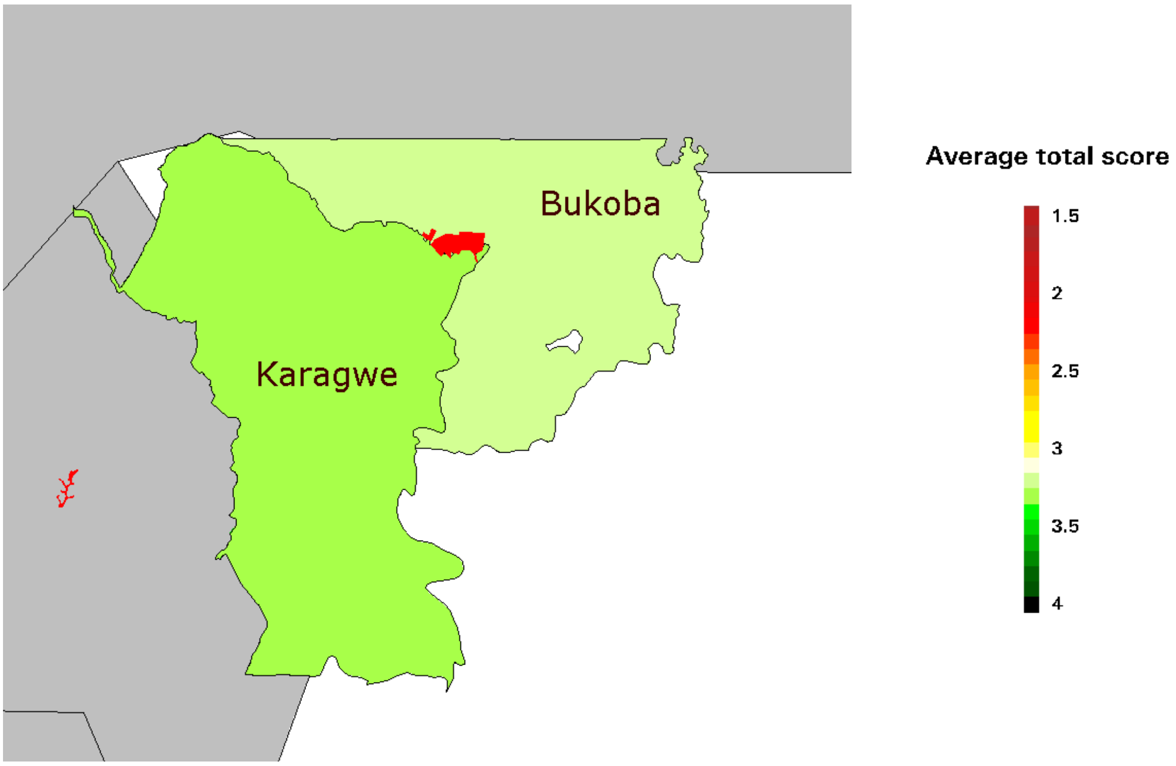


Figure 120 map showing the total score per irrigated district in Tanzania

3.3.2 Breaking down the total score into RO indicators, PO and sustainability indicators.

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 121 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

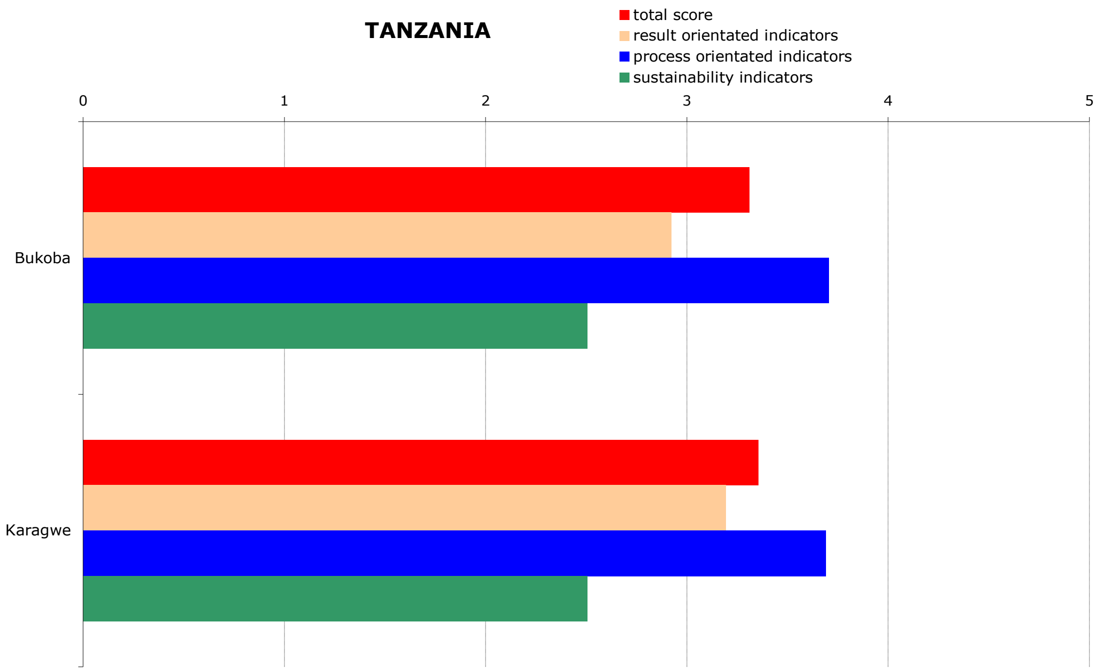
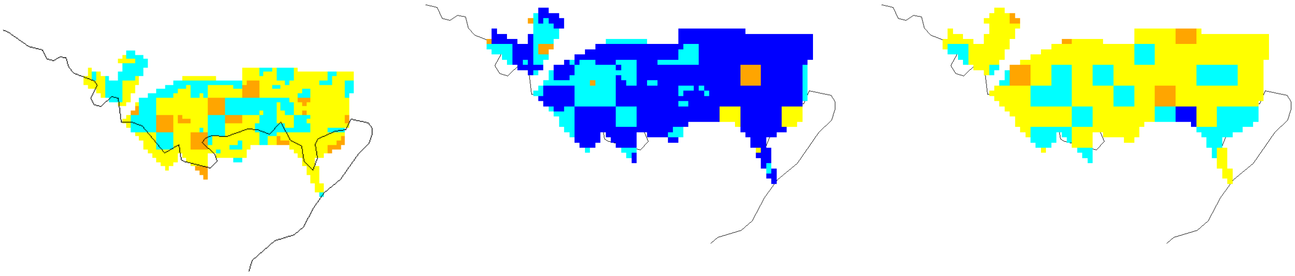


Figure 121 breaking down the total score per indicator in Tanzania

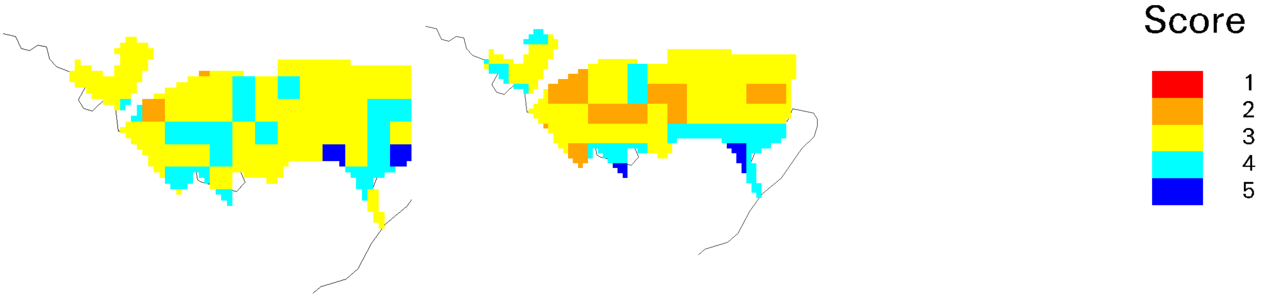
It seems that the irrigation system is well managed, as the score for the PO indicator is high (3.7). The results could be improved (The RO indicators get an average score around 3). This system is however not sustainable: the sustainability indicators have an average score of 2.5, which means that the soil moisture has decreased and the land cover has become less green with time. The Kagera sugarcane scheme thus has a problem to attend to.

3.4 Analysis per pixel for an irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the Kagera scheme. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. This example demonstrates that crop water consumption is really the weakest aspect of this irrigation system. It also helps to identify areas where it is more urgent to reduce crop water consumption (red color) (Figure 122).



Crop water consumption Crop water deficit Beneficial fraction



adequacy reliability

Figure 122 Spatial distribution of each indicator for the districts of Bukoba and Karagwe

Part 4 Recommendations for improvement

4.1 Weak and strong aspects per district

Once the relationships between the indicators are better understood, the next step is to identify the weakest elements per district. In Table 79, the best and poorest indicators are presented. It appears that the irrigation districts function relatively similarly. Crop water consumption and reliability seem to be the main concerns. Uniformity and crop water deficit appear to be the best characteristics of the Kagera sugar scheme.

Table 79 Best and poorest PO irrigation indicator per district

District	Lowest		2nd lowest		2nd best		Best	
Bukoba	rel	2.92	bf	3.16	cwd	4.68	un	5.00
Karagwe	cwc	3.12	bf	3.44	un	4.00	cwd	4.60

4.2 Recommendation countrywide

Irrigation practices are not well established in Tanzania, mainly because of the high rainfall which is also well distributed over the year. Irrigation is probably only useful occasionally, and supplements rainfall in some months. The dry months June, July and August are the only months that may need full irrigation supply. A first recommendation is to prepare an accurate map of the irrigation schemes in Tanzania where irrigation is actually practiced. In this study, only one main LSI was identified, therefore it makes it difficult to provide recommendations countrywide. More focus has to be given to water sustainability.

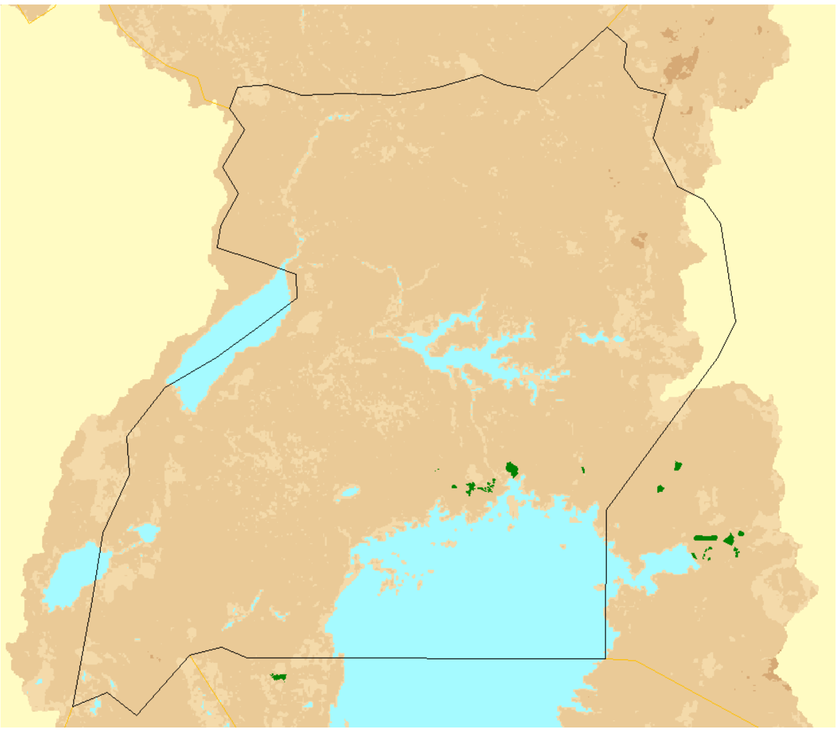
Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m^3	Bio/ET_{act}	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M^3/ha/year	ET_{act}	Saving of water resources
	Crop water deficit	cwd	M^3/ha/year	ET_{pot}-ET_{act}	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	T_{act}/ET_{pot}	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	T_{act}/T_{pot}	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	1-CV(T_{act}/T_{pot})(x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	1-CV(T_{act}/T_{pot})(t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Uganda



Report K

January 2009

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Part 1 Generalities on irrigated areas
Part 2 Climate
Part 3 Raster and vector-based irrigation performance
Part 4 Recommendations for improvement

Purpose of this report:

This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Uganda and will become an integral component of the final LSI report that will combine results from all countries.

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

Part 1 Generalities on irrigated areas

1.1 Location of the irrigated areas

Uganda encompasses the northern part of Lake Victoria. Most of Uganda lies within the Nile Basin and is located on the equator, covering 241,000 km2, 18% of which is occupied by water or swamps. More than two-thirds of the country is 1,000 to 2,500 meters high.

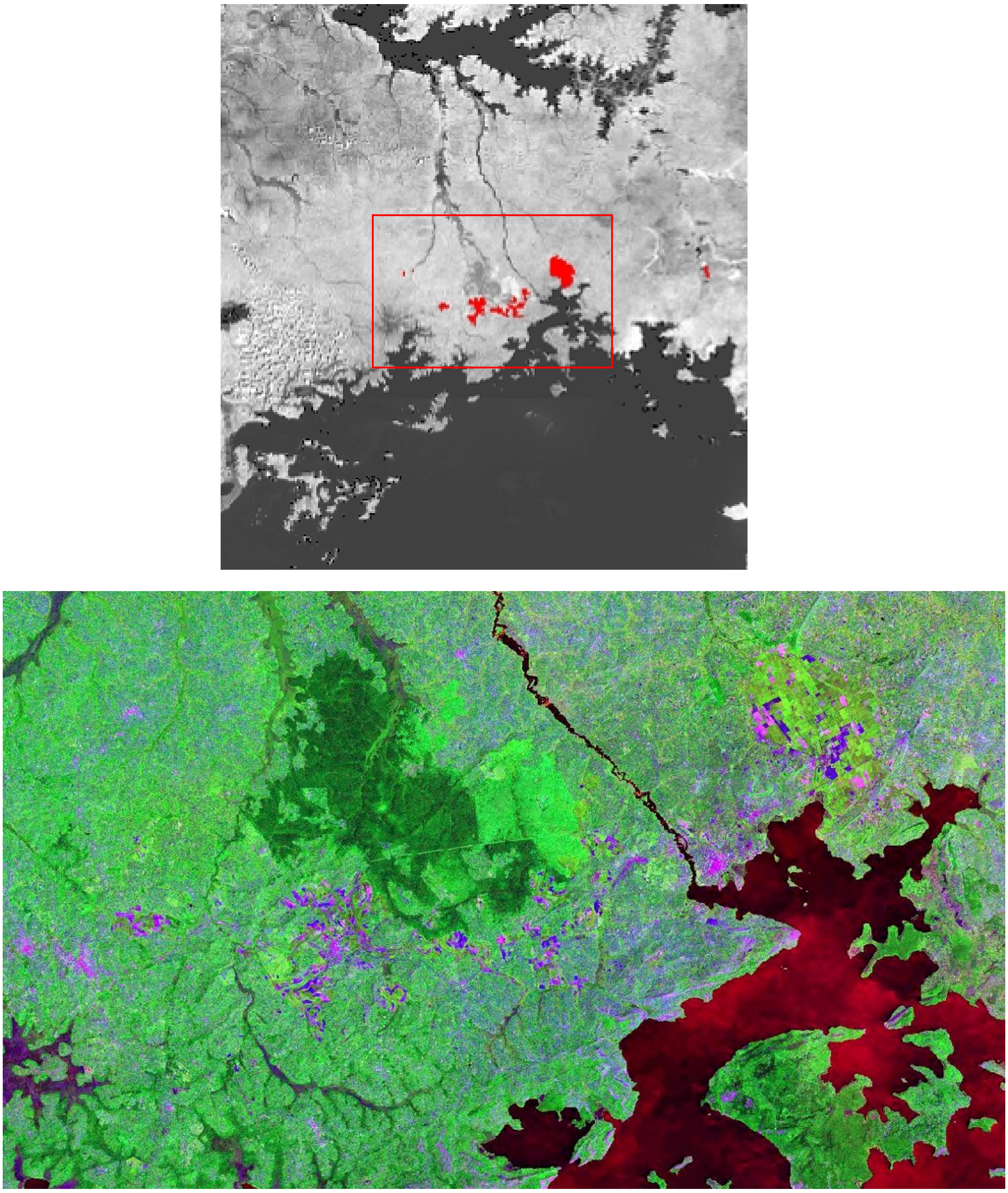


Figure 123 Map with the distribution of the irrigated areas detected within the Nile Basin according to FAO-GMIA product, and being refined within the current study. The red dots on the right hand side figure represent the irrigation schemes

According to this study, an area of 25,131 ha of irrigated land is present in Uganda (Table 80). The alluvial soils close to streams and wetlands often have some patches with irrigated land. The estimates of irrigated areas derived from the IWMI-based product of Uganda are much higher than those from FAO. It is widely known that un-official irrigation takes place over large areas in Uganda: probably up to a total of 75,000 ha. These areas can only be detected after a more detailed study.

Table 80 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Uganda	9,120
IWMI – GIAM	Entire Uganda	30,017
Current study	Nile Basin component of Uganda	25,131

1.2 Description of LSI

Irrigation has been introduced relatively recently as rainfall has been more or less sufficient in the past. Most parts of the country experience at least one long rainy season and this has been sufficient for farmers to produce at least one crop a year. In the past, irrigation was only practiced during the dry season at small-scale informal level with most of this located on the fringes of swamps. Nowadays rainfall has become less reliable and supplementary irrigation is often needed in the rain season. Many irrigation schemes have been developed by smallholders without planning and with little or no technical assistance. The technology used is basic and approaches are sometimes inappropriate. Formal irrigation developments commenced in the 1960s. Most smallholders grow rice and vegetables, with the larger commercial estates cultivating rice and sugarcane. Most irrigation developments use surface methods although the more recent developments (green house irrigated flower farms that started in 1990s) are based on drip and micro sprinklers. The main crops are displayed in Figure 124, and the cropping calendar is shown in Table 81.

More detailed information concerning irrigation in Uganda can be found in Annex 2.

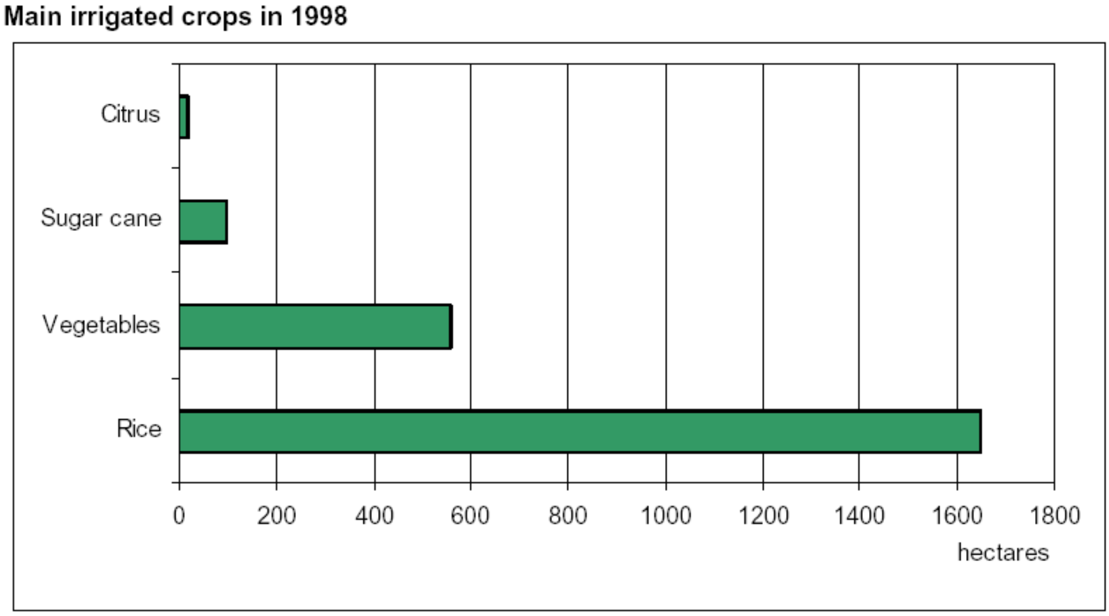
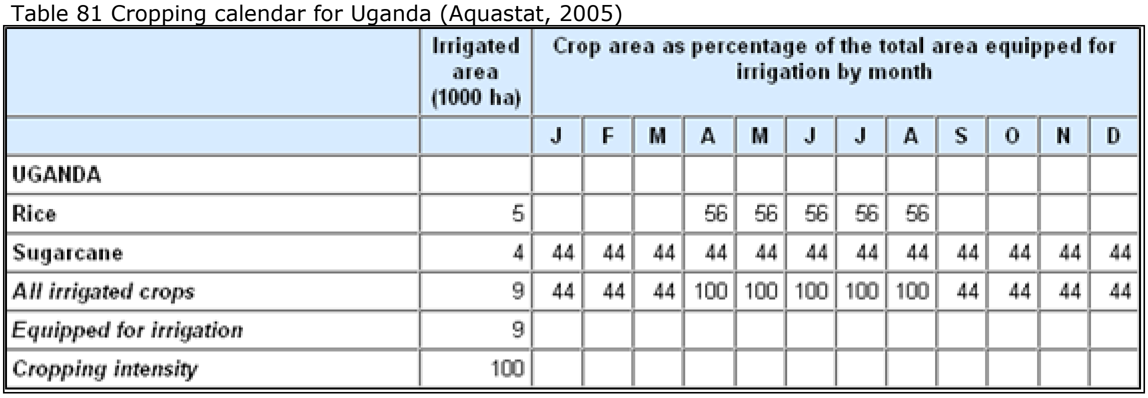


Figure 124 Main irrigated crops in Uganda (Aquastat, 2005)

Table 81 Cropping calendar for Uganda (Aquastat, 2005)



	Irrigated area (1000 ha)	**Crop area as percentage of the total area equipped for irrigation by month**											
		J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
UGANDA													
Rice	5				56	56	56	56	56				
Sugarcane	4	44	44	44	44	44	44	44	44	44	44	44	44
All irrigated crops	9	44	44	44	100	100	100	100	100	44	44	44	44
Equipped for irrigation	9												
Cropping intensity	100												

Part 2 Climate

2.1 Climatological conditions

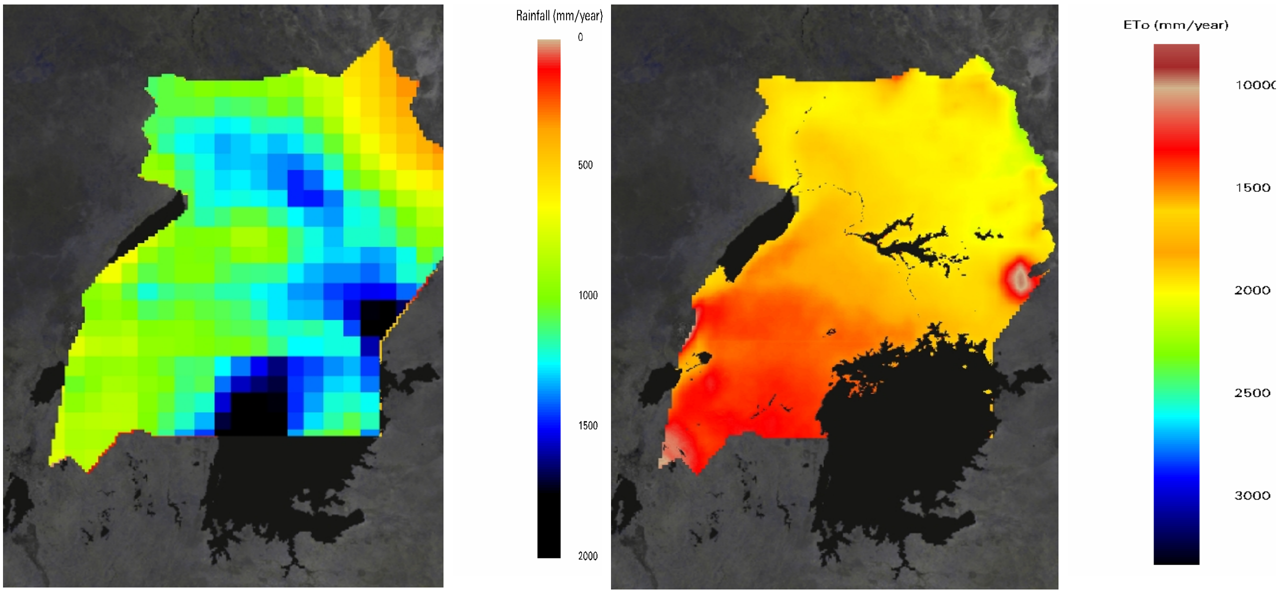
The rainfall data in this report is based on TRMM satellite data. The reference evapotranspiration (ET0) is computed with the standardized Penman-Monteith equation specified in FAO56.

According to Table 82, Uganda receives a significant amount of tropical rainfall (1300 mm/yr). The rainfall season is bi-modal. The first and major rainy season occurs from March to June. The second season is a continuation of the first season, and starts in July and continues to November. The months December, January and February are the driest, although 40 to 60 mm/month is normal. It is therefore never very dry in Uganda.

ET0 exceeds rainfall during ten months. Only the monsoon rains in April and May induce an aridity index that exceeds 1.0. This implies that supplementary irrigation is required during most of the growing season. The high ET0 can be explained by the high solar radiation and air temperatures.

Table 82 Monthly values for rainfall and ET_0.

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	41	157	0.26
February	63	146	0.43
March	118	156	0.76
April	206	131	1.57
May	167	126	1.33
June	96	120	0.80
July	81	122	0.66
August	108	131	0.82
September	119	135	0.88
October	130	144	0.90
November	124	133	0.93
December	58	146	0.40
TOTAL	1311	1647	



Annual rainfall

Annual reference ET

Figure 125 Spatial variation of rainfall (left) and ET_0 (right)

2.2 Climatic zones

The current study, aimed at providing information for improved irrigation practices in the Nile basin, covers various climate zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as the irrigation efficiencies. Unexpected rainfall can for instance reduce the irrigation efficiency, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences based on the diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

The irrigation schemes of Uganda are located in climate zone 4 (humid tropics), see Figure 126.

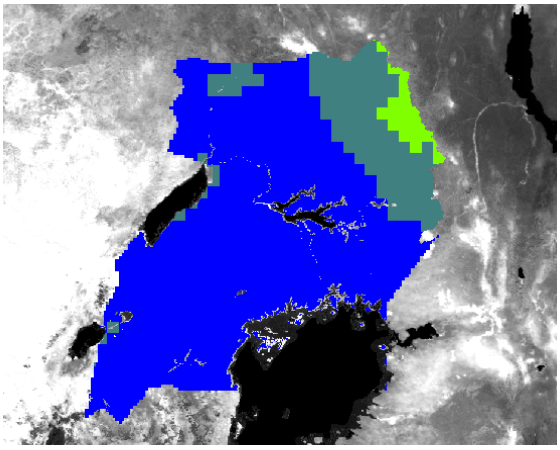


Figure 126 Climate zones distinguished for the mapping of best irrigation practices. The irrigated areas of Uganda are located in the climate zone 4: humid tropics (blue).

Part 3 Raster and vector-based irrigation performance

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on the data send by the LSI representatives of Burundi. The first step was to compute all the indicators per pixel. All the RO and PO have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. These annual accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

The sustainability indicators were obtained by investigating the last five year's trends of vegetation index (from the SPOT-Vegetation satellite) and soil moisture (from the AMSR-E satellite). It indicates the slope of the trend line over these past years.

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined. A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 127).

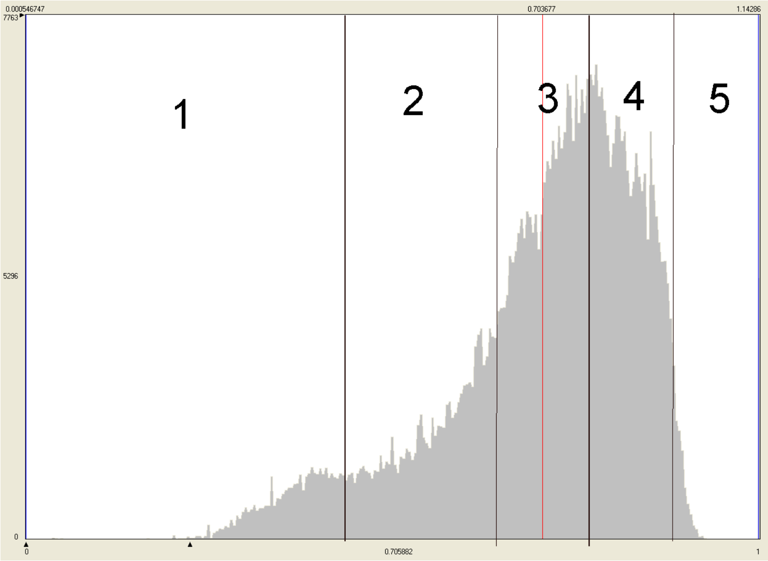


Figure 127 Distribution of the values of one indicator over 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems included in different climatic zone, different benchmark values are considered to avoid any climatic bias in the allocation of the score. Uganda is located in climatic zone 4.

Table 83 benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, districts average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at Country level

As displayed in Figure 128, the average score considering all the indicators together for all the 25,131 ha of irrigated land is 3.45, which is good (the average score being 3). This average is translated into scores for each individual indicator. The aspects that Uganda should provide more attention to are those with a relative low score.

Land productivity has a score of 3.9 which is very good and water productivity 2.9, which is reasonable.

Concerning the PO indicators, all are above average, except for the crop water consumption with a score of 1.8. The reliability seems to be the strongest indicator as it reaches the excellent score of 4.9.

The sustainability of irrigation practices seem to be relatively under control. Compared to previous years, the irrigated land has maintained its greenness (as the score for the land sustainability is around 3). The soils are well maintained and show a constant soil moisture rate over the years. Hence, the irrigation system in Uganda is quite sound.

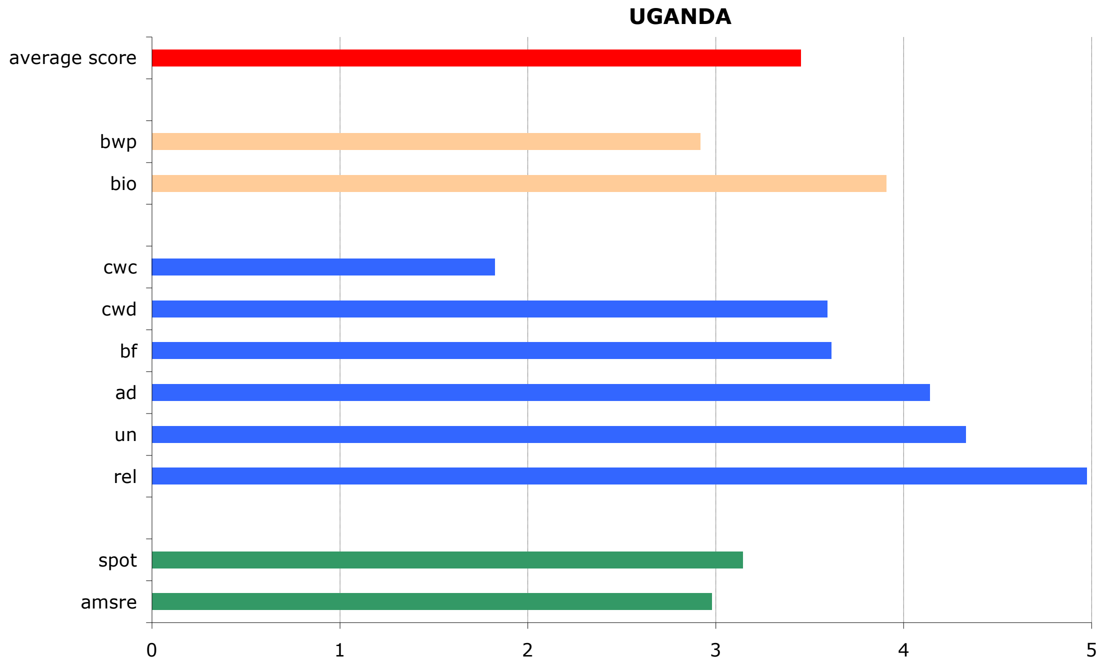


Figure 128 Representation of the average score for each indicator in Uganda.

3.3 Results at district level

3.3.1 Average per district

In Figure 129 the average scores for all the indicators per district are compared. In Uganda, six districts having more than 30 pixels with 6.25 ha have been identified. One district is called Mabira forest. It is mainly forest but because the boundaries of the districts are not very accurate, some irrigated fields that might belong to the Mukono district are included in Mabira forest in this study.

In terms of total average score, the best irrigation district is Wakiso, with an average of 3.9. The district that has the lowest average is Mukono, with an average of 3.4 (see Figure 130 for the location). The average scores for these six districts are high to very high, which already indicates the good performance of irrigation in Uganda. This good performance was already reflected in the country scale analysis.

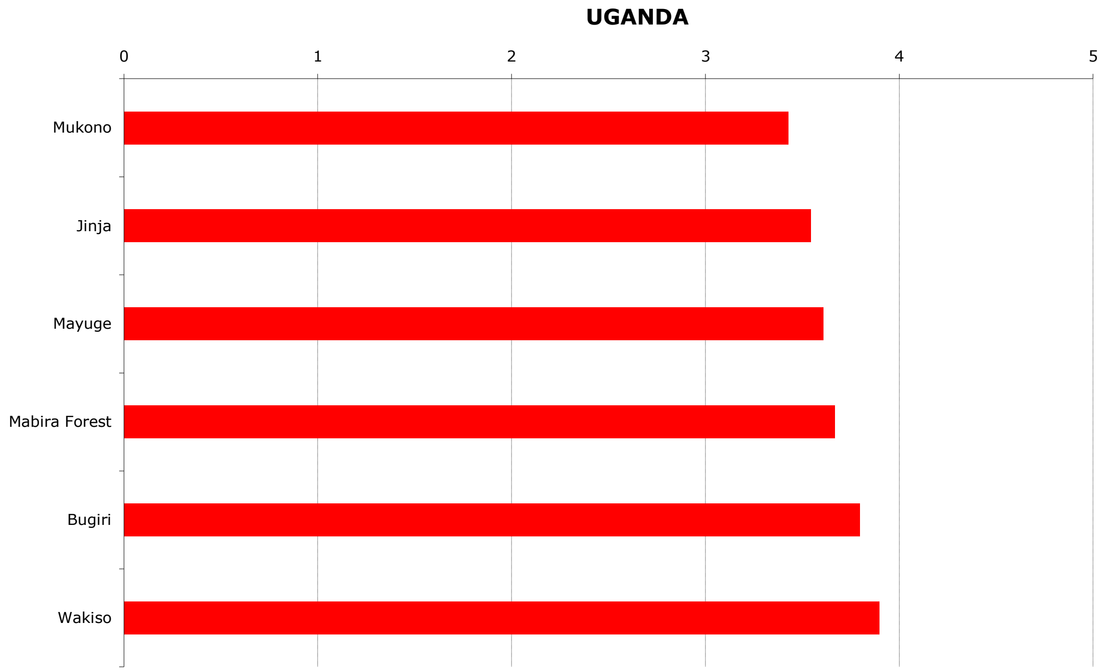


Figure 129 Total score for each district in Burundi.

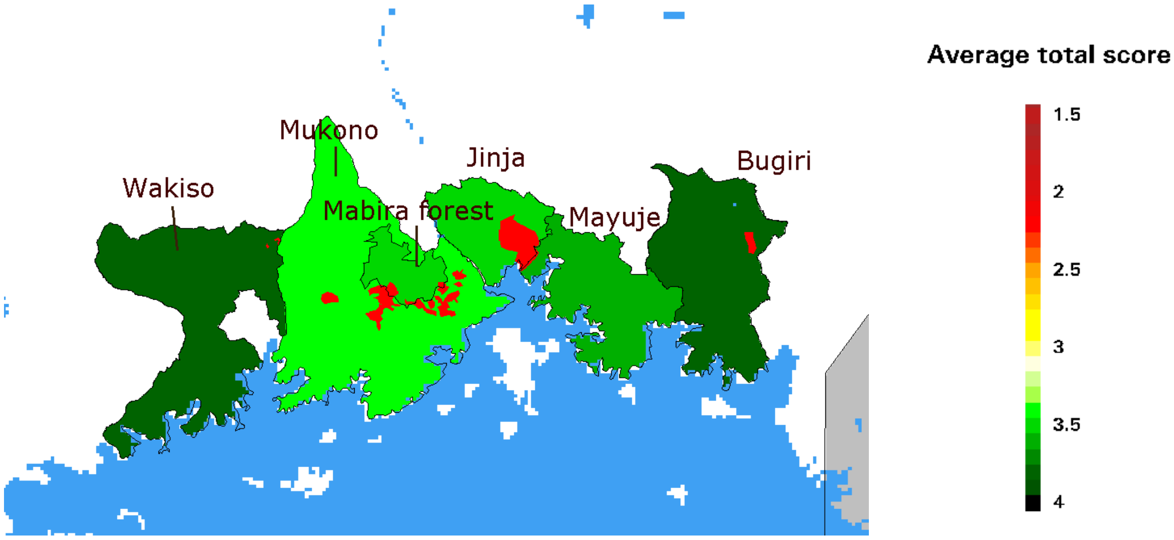


Figure 130 map showing the total score per irrigated district.

3.3.2 Breaking down the total score into RO indicators, PO, and sustainability indicators.

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 131 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance and enables ranking of the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

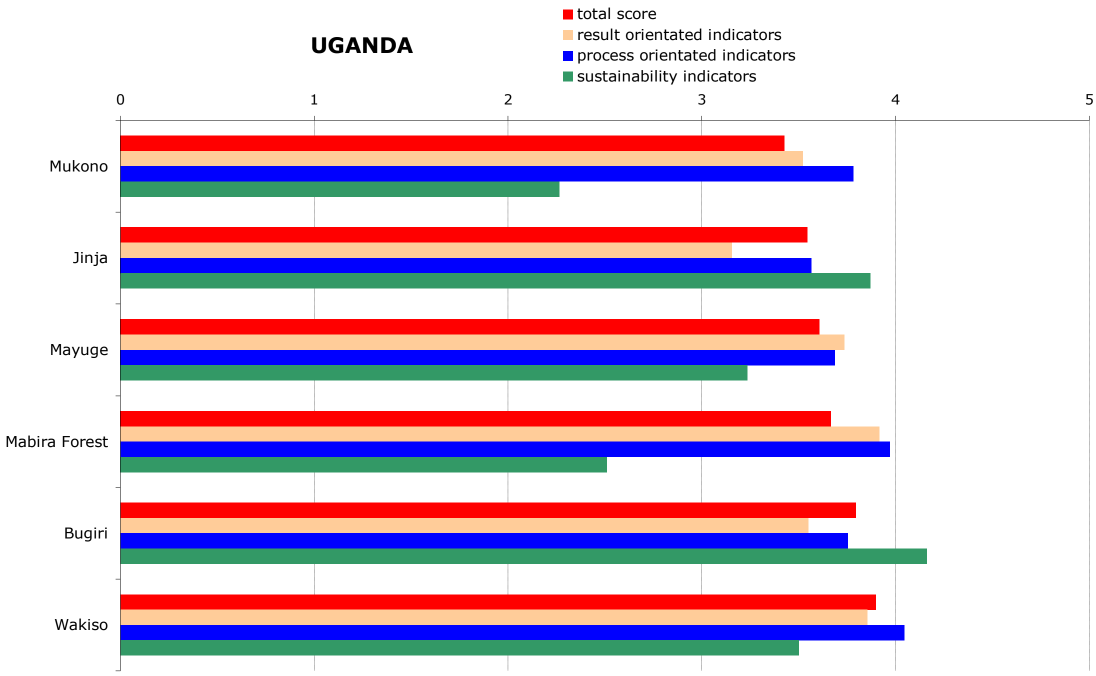


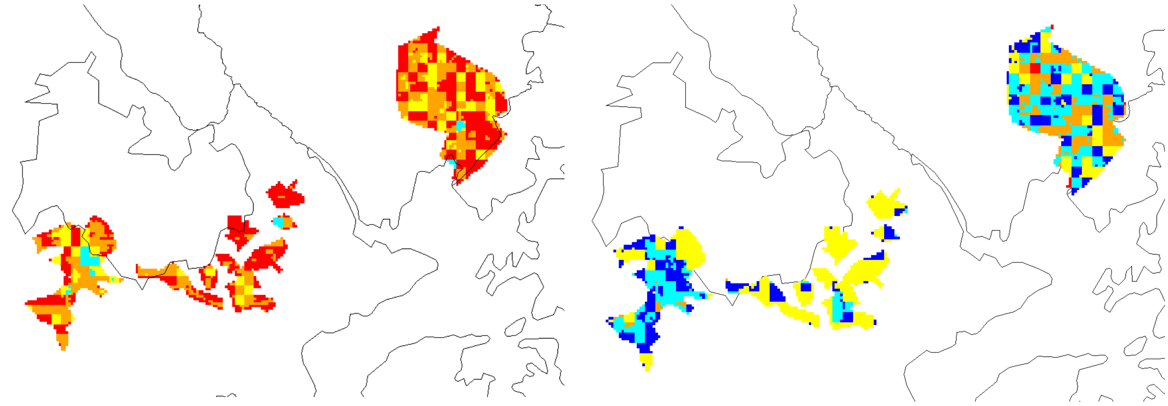
Figure 131 breaking down the total score per indicator

The first aspect that draws attention is that all the six districts of Uganda have a good average score for the RO and for the PO indicators. These high scores make it difficult to draw improvement recommendations relating to the functioning of the irrigation systems. However, good total performance does not mean a sustainable system.

Indeed, if one looks at the total average score for Mabira Forest, it seems to be a good district (total average of 3.7). However, its low score for the sustainability indicators (average score of 2.5) indicates that it is not a sustainable system.

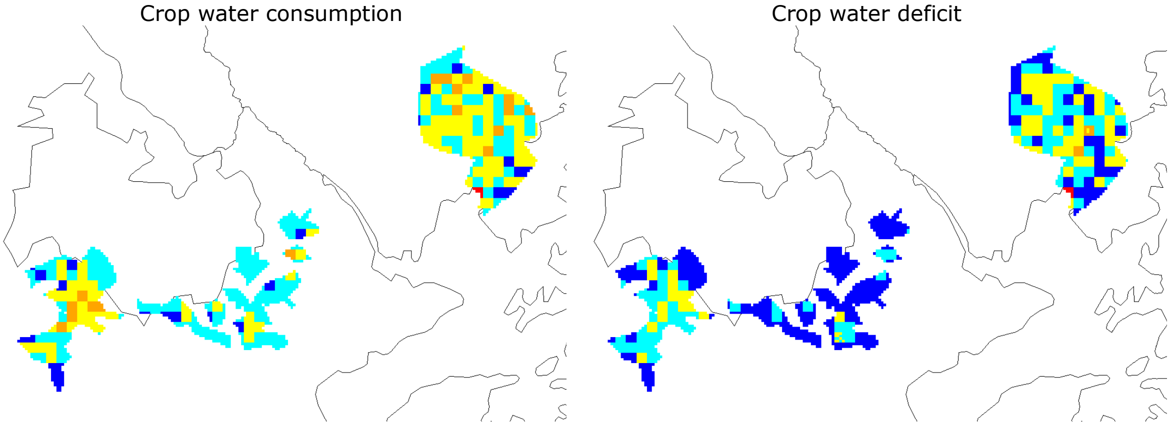
3.4 Analysis per pixel for an irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the neighbouring districts of Jinja and Mukono, which are the two lower performing districts. The 6th PO indicator uniformity cannot be displayed as it is an indicator at district level. This example demonstrates that crop water consumption is really the weakest aspect of these irrigation systems. It also helps to identify areas where it is urgent to reduce crop water consumption (red color) (Figure 132).



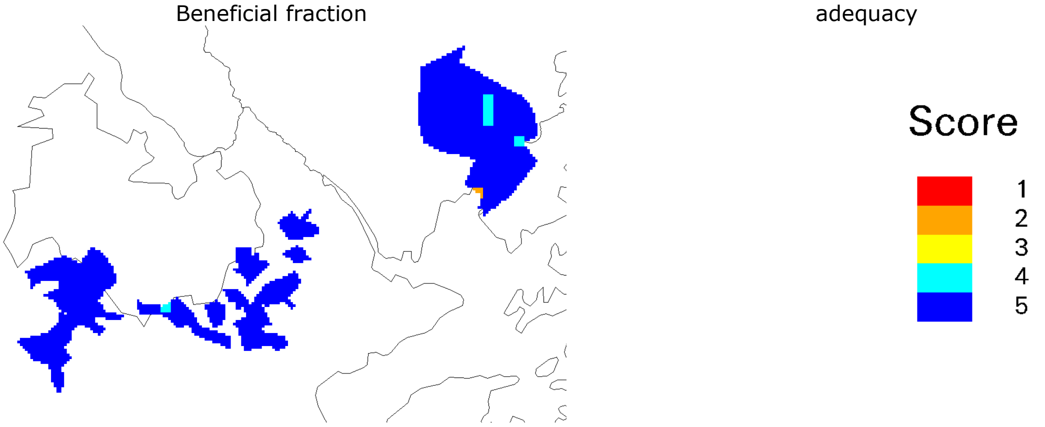
Crop water consumption

Crop water deficit



Beneficial fraction

adequacy



reliability

Figure 132 Spatial distribution of each indicator for the districts of Jinja and Mukono

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the six districts. It showed that crop water consumption, reliability and adequacy are the three main explanatory factors for biomass production. Hence the timely application of adequate irrigation should get more attention in Uganda. No clear relationships with biomass water productivity are evident. It is thus better to focus on increasing biomass production rather than biomass water productivity.

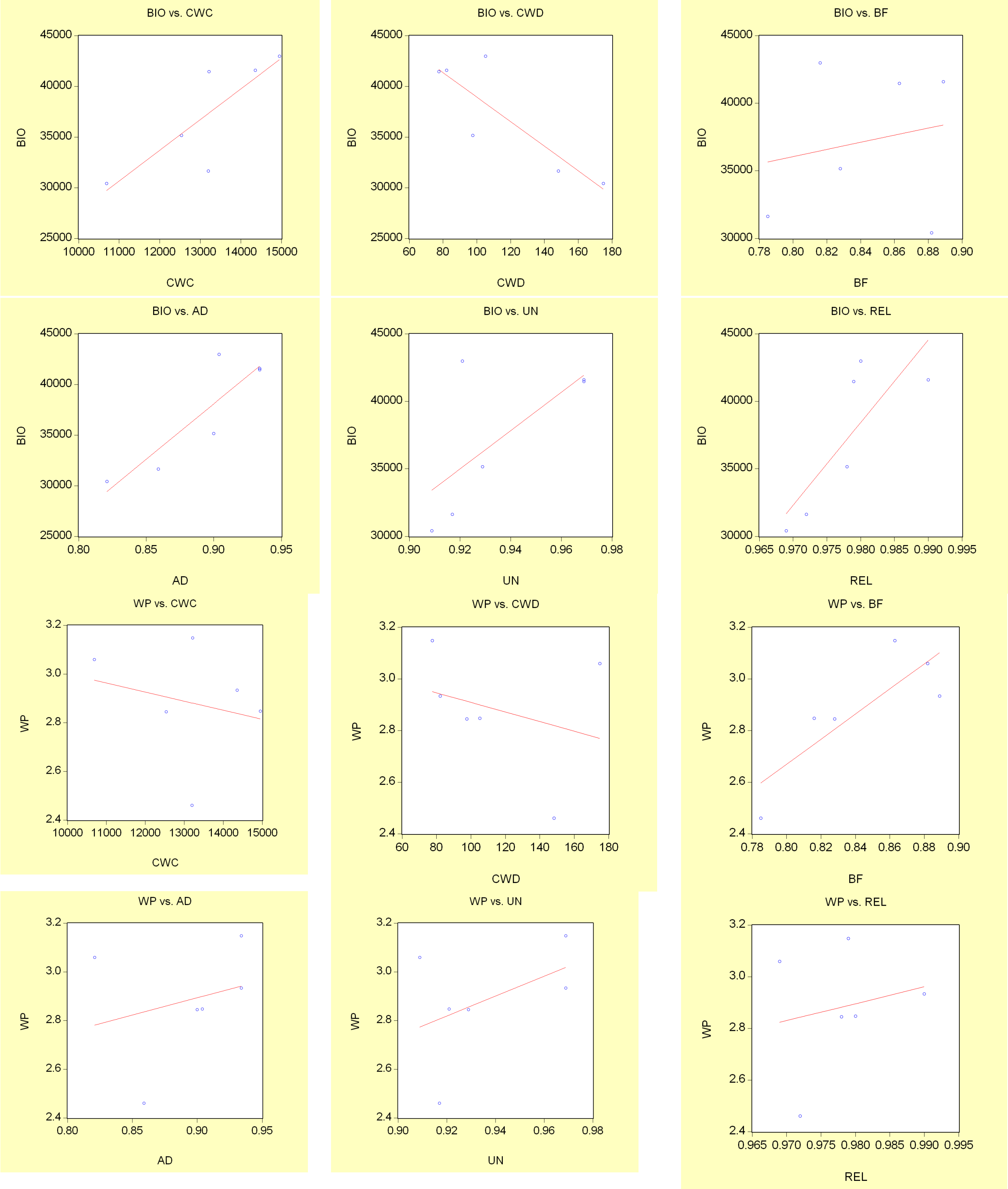


Figure 133 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationships between indicators are better understood, the next step is to identify the weakest elements per districts. In Table 84, the best and poorest indicators are presented.

It appears that the irrigation districts function relatively similarly. Crop water consumption seems to be the main problem for all the districts. Reliability or uniformity is the best indicator.

Table 84 best and poorest PO irrigation indicator per district

District	Lowest		2nd lowest		2nd best		Best	
Mukono	cwc	1.83	bf	3.70	ad	4.39	rel	5.00
Jinja	cwc	1.78	bf	3.36	un	4.00	rel	4.96
Mayuge	cwc	1.44	ad	3.49	un	4.00	rel	4.97
Mabira Forest	cwc	1.65	cwd	3.40	rel	4.96	un	5.00
Bugiri	cwc	2.47	cwd	3.25	ad	4.85	rel	5.00
Wakiso	cwc	1.54	cwd	3.83	un	5.00	un	5.00
Mukono	cwc	1.83	bf	3.70	ad	4.39	rel	5.00

4.3 Recommendation countrywide

Uganda has irrigation schemes in specific regions of the country. These schemes are the legal ones, and it is not unlikely that many more illegal schemes are diverting water from rivers, streams and lakes. There are organized large irrigation activities in the country.

Recent policies outline irrigation as a key intervention for food security and income generation. The land productivity is very good, but the drawback is that vast amounts of water are used due to the climatic water demand of crops. The price for a favourable agricultural production is a high crop water consumption. This leads to a below average biomass water productivity. Like in the other Equatorial Lake region, the irrigation systems are quite well managed in terms of reliability, adequacy and uniformity. If Uganda is planning to develop irrigation to achieve its target towards improving food and income security of the local people, water has to be used more efficiently.

Recommendation can be the following:

- Only irrigate when crop water stress (T_{act}/T_{pot}) and ET deficit (ET_{pot}-ET_{act}) exceed a certain threshold value. Otherwise pumping from rivers and lakes is not needed. This saves power and reduces the return flow from the irrigated plots.
- A reduced return flow will bring less pollutants towards the drainage systems and swamps
- Advise farmers and water utilization agencies on how to maintain yield at reduced water consumption
- Most administrative districts have a problem with the sustainability of the water and sometimes also with the land resources. More investigation is needed to find out why land is degrading, and take measures to prevent it from worsening.
- Visit the farmers in the vicinity of the district of Wakiso and get exposure to their good water conservation practices.

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m^3	Bio/ET_{act}	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M^3/ha/year	ET_{act}	Saving of water resources
	Crop water deficit	cwd	M^3/ha/year	$ET_{pot}-ET_{act}$	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	T_{act}/ET_{pot}	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	T_{act}/T_{pot}	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	$1-CV(T_{act}/T_{pot})(x,y)$	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	$1-CV(T_{act}/T_{pot})(t)$	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 General information on irrigation conditions in Uganda (Aquastat, 2005)

Irrigation and drainage

Irrigation potential			90 000	ha
Water management				
1. Full or partial control irrigation: equipped area		1998	5 580	ha
- surface irrigation		1998	5 350	ha
- sprinkler irrigation		1998	230	ha
- localized irrigation			-	ha
• % of area irrigated from groundwater			-	%
• % of area irrigated from surface water			-	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)		1987	3 570	ha
3. Spate irrigation			-	ha
Total area equipped for irrigation (1+2+3)		**1998**	**9 150**	**ha**
- as % of the cultivated area		1998	0.1	%
- average increase per year over the last ... years			-	%
- power irrigated area as % of total area equipped			-	%
- % of total area equipped actually irrigated		1998	64.5	%
4. Non-equipped cultivated wetlands and inland valley bottoms		1998	49 780	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		**1998**	**58 930**	**ha**
• as % of the cultivated area		1998	0.8	%
Full or partial control irrigation schemes	**Criteria**			
Small-scale schemes	< 50 ha	1998	100	ha
Medium-scale schemes	50 – 500 ha	1998	680	ha
Large-scale schemes	> 500 ha	1998	4 800	ha
Total number of households in irrigation			-	
Irrigated crops in full or partial control irrigation schemes				
Total irrigated grain production			-	tonnes
• as % of total grain production			-	%
Total harvested irrigated cropped area			-	ha
• Annual crops: total			-	ha
- rice		1998	1 650	ha
- vegetables		1998	560	ha
- sugar cane		1998	100	ha
• Permanent crops: total			-	ha
- citrus		1998	20	ha
Irrigated cropping intensity			-	%
Drainage - Environment				
Total drained area			-	ha
- drained area in full or partial control irrigated areas			-	ha
- drained area in equipped wetland and ivb			-	ha
- other drained area			-	ha
• drained area as % of the cultivated area			-	%
• power drained area as % of total drained area			-	%
Flood-protected areas			-	ha
Area salinized by irrigation			-	ha
Population affected by water-related diseases			-	inhabitants