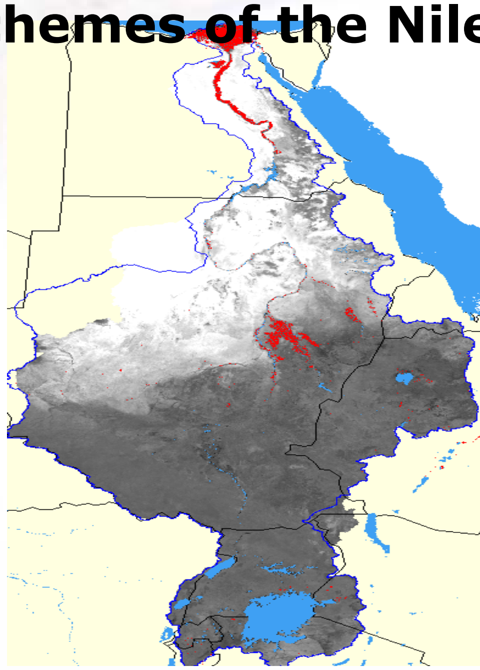
Wim Bastiaanssen, Wageningen, NL
Chris Perry, London, UK

May 2009

Efficient Water Use for Agricultural Production (EWUAP) Project

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



Final Report
By

Wim Bastiaanssen, Wageningen, NL
Chris Perry, London, UK
May 2009

May 2009

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.

Table of contents

List of figures

List of tables

Acknowledgements

Eng. Jean-Marie Bukuru did a formidable job with the collection of background information on the irrigation systems of Burundi. Dr. Hamdy El-Houssainy Khalifa from the Soil and Water Environment Research Institute (SWERI) synthesized all the data for Egypt. Engineer Wendot provided in an early stage some data for the LSIs in Kenya. We are grateful to these persons who collected critical ground data.

We respect the comments provided by Amandus David Wena from Tanzania, Badr Eldin from Sudan and Getaneh Asefa from Ethiopia on the draft version of this final report.

Prof. Fathy El-Gamal from the National Water Research Centre and Eng. Ibrahim Mohammed Mahmoud from the Water Boards & IIIMP project have prepared and guided the study tour to Kafr-El-Sheik and Dina farm in Egypt. Dr. Badr-El-Din Taha and Dr. Salih Hamad Hamid is acknowledged for arranging the field trip to Gezira and Kenana.

Arjen Rotmans from the FAO-Nile office in Entebbe kindly provided the shape file of all administrative districts in the Nile Basin. The inclusion of the district map was fundamental for the presentation of all spatial data.

The authors are extremely grateful to Ian McAllister Anderson, who allowed us access to his material, and for his invaluable additional information and comments on earlier drafts.

Lucie Leclert was not a formal consultant on this project, but did considerable background work on database building and image processing. The authors are indebted to her for this contribution.

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.

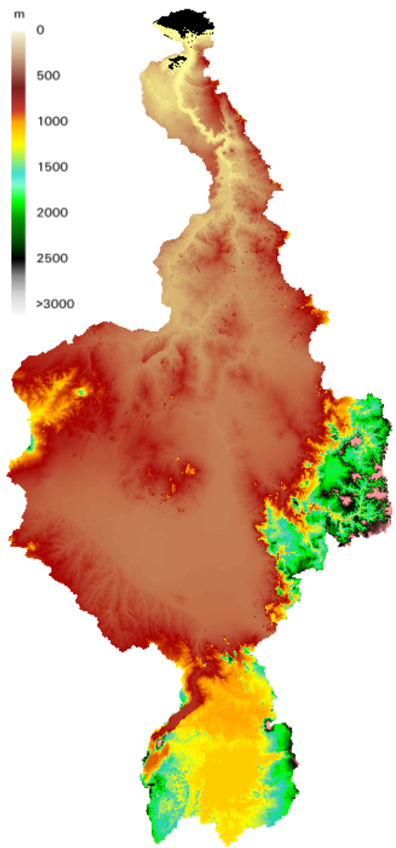


Figure 1 The distribution of terrain elevation in the Nile Basin (source: SRTM – Digital Elevation Model)

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.

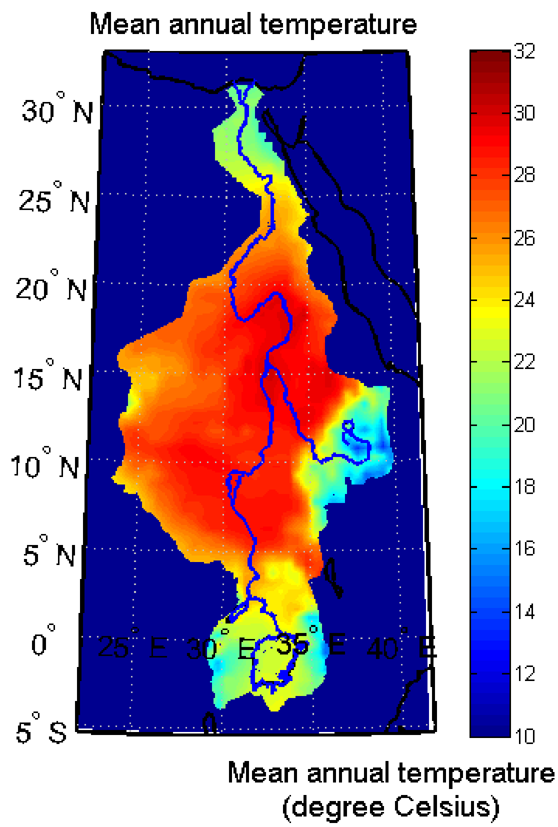


Figure 2 Mean annual air temperature reconstructed from the Climate Research Unit of the University of East Anglia data set TS 2.1 (source: van der Kruijs, 2008)

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.

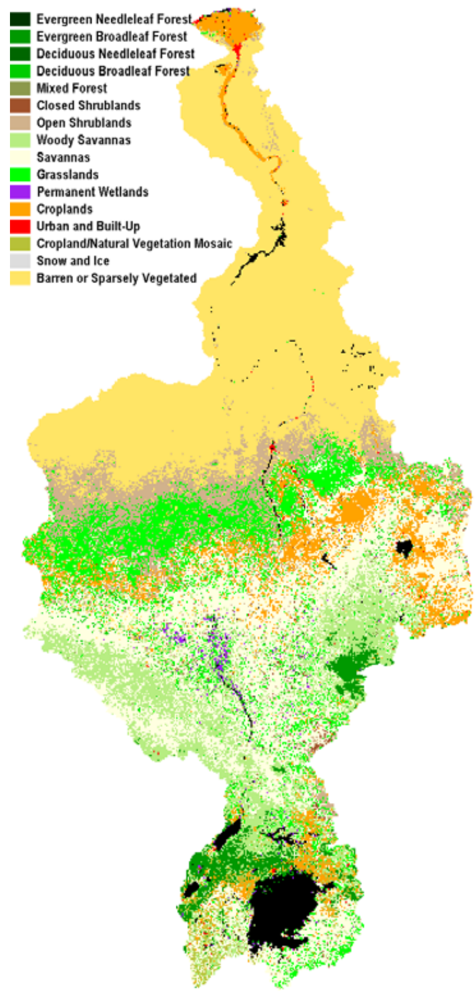


Figure 3 Land cover map of the Nile Basin in the year 2000 (source: International Geosphere Biosphere Project IGBP global land cover map)

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:

[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.

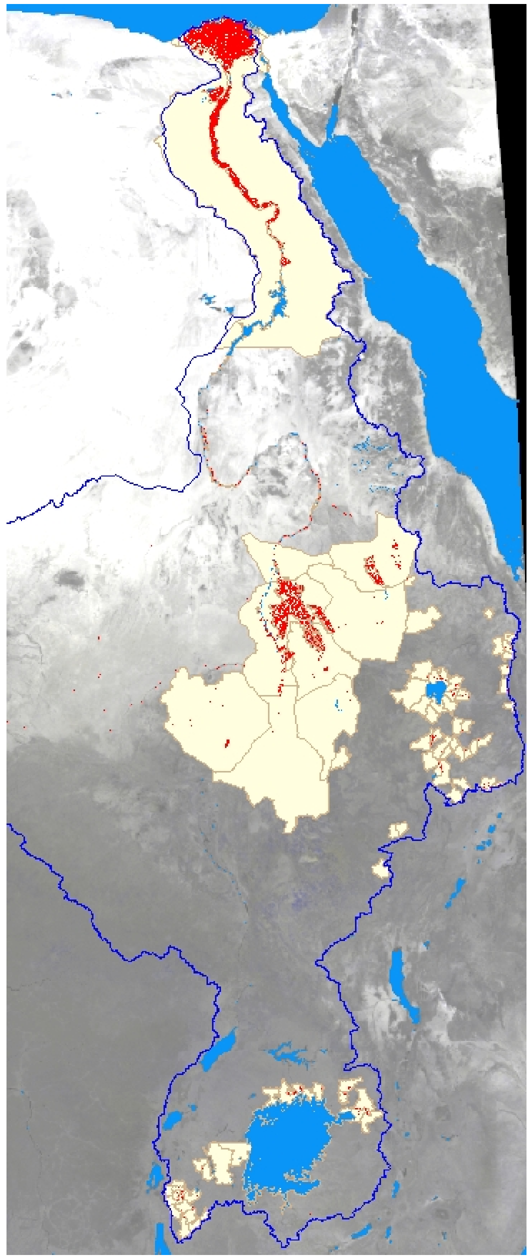


Figure 4 Distribution of administrative boundaries of areas across the Nile Basin which contain LSI systems. These boundaries were used for the presentation of aggregated irrigation data results. The red dots and clumps of dots refer to LSI schemes

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.

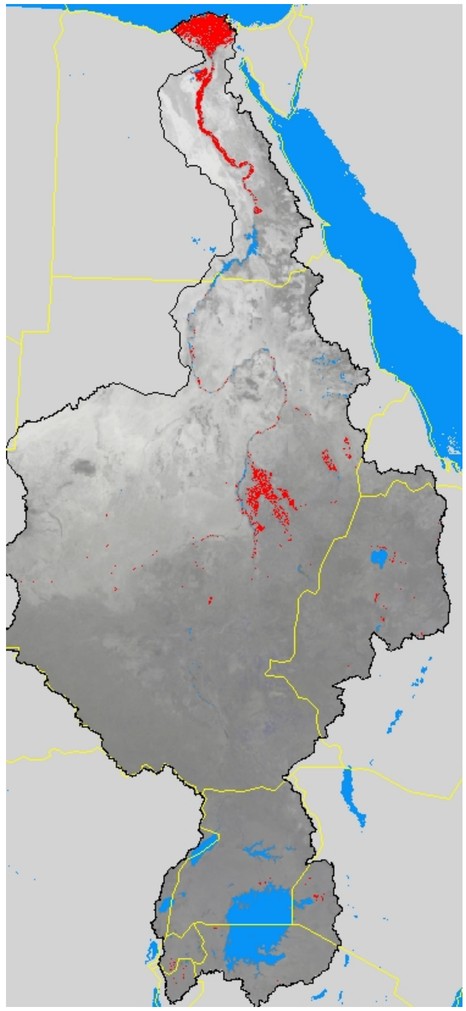


Figure 5 Distribution of irrigated areas across the Nile Basin, indicated by red dots (source: this study). The spatial resolution is 250 m. The country boundaries are superimposed

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]

[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.

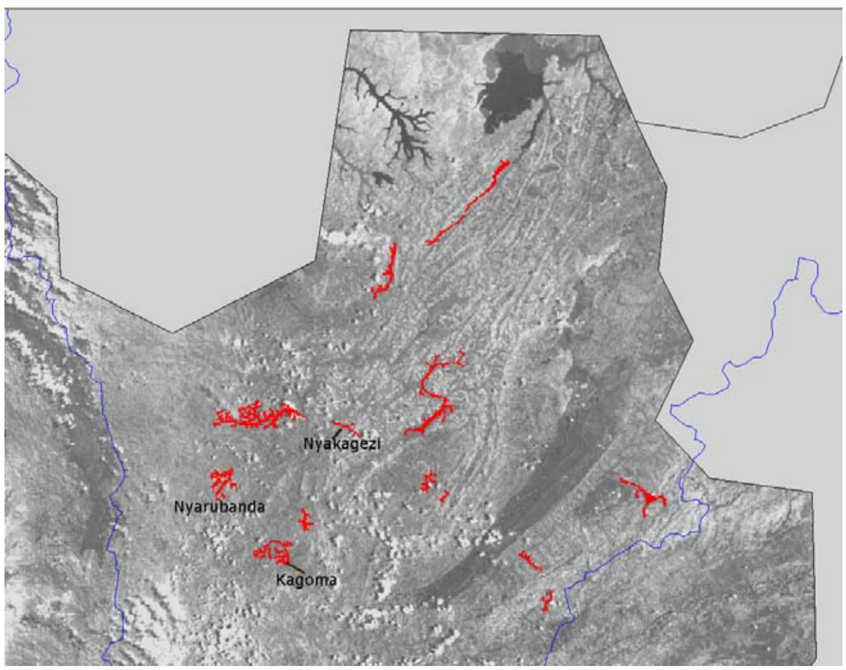


Figure 6 Location of selected irrigation schemes in Burundi for in-depth study. The background is from a Landsat image.

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.

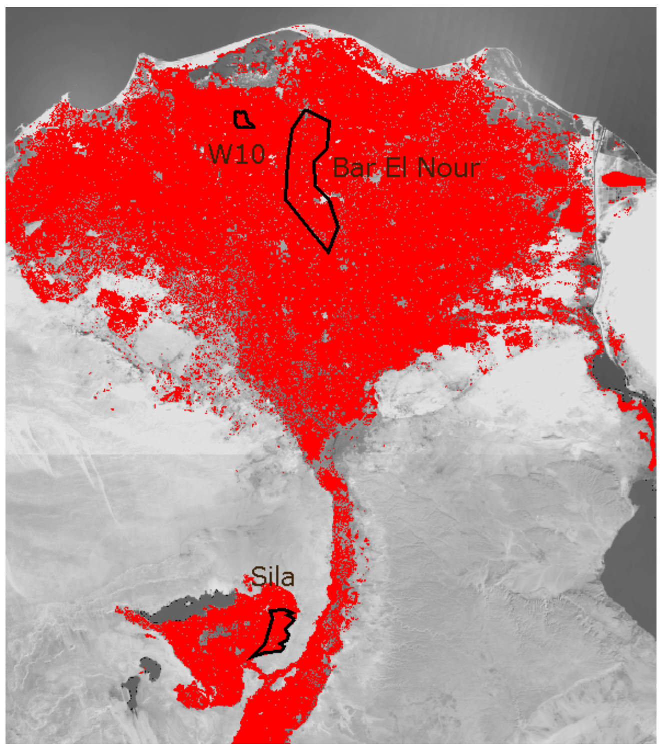


Figure 7 Location of selected irrigation schemes in Egypt for in-depth study. The background is from a Landsat image.

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.

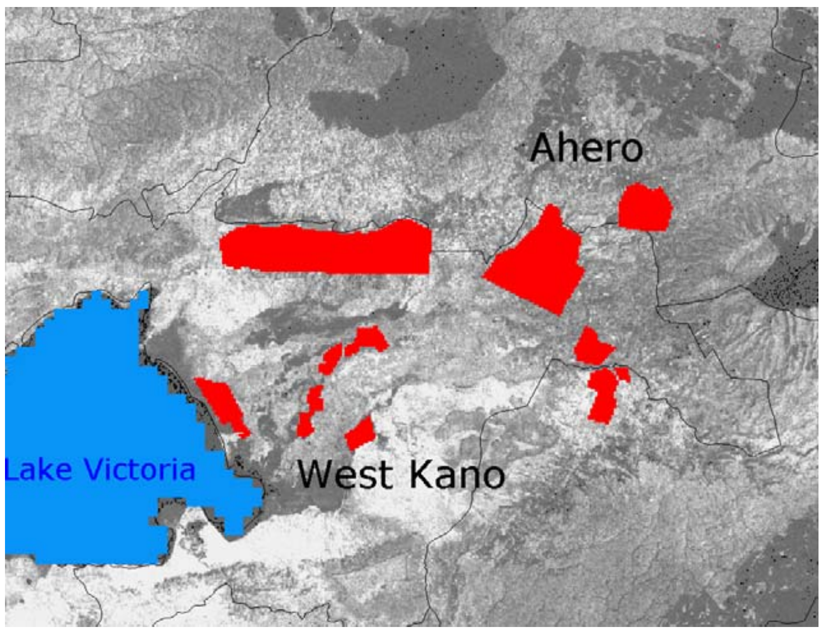


Figure 8 Location of selected irrigation schemes in Kenya for in-depth study. The background is from a Landsat image

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.

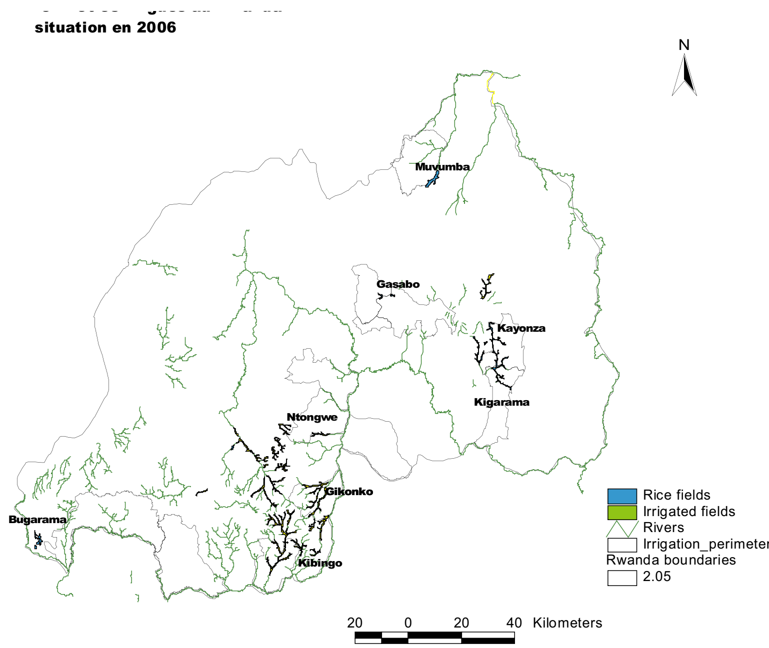


Figure 9 Location of the detailed study areas in Rwanda

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.

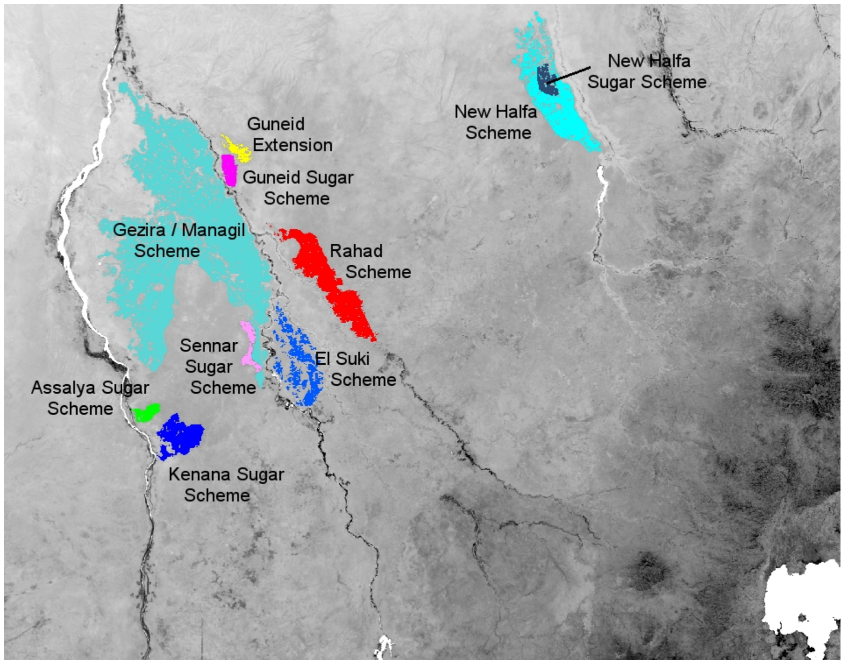


Figure 10 Location of the detailed study areas in Sudan (source: WaterWatch, 2006)

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.

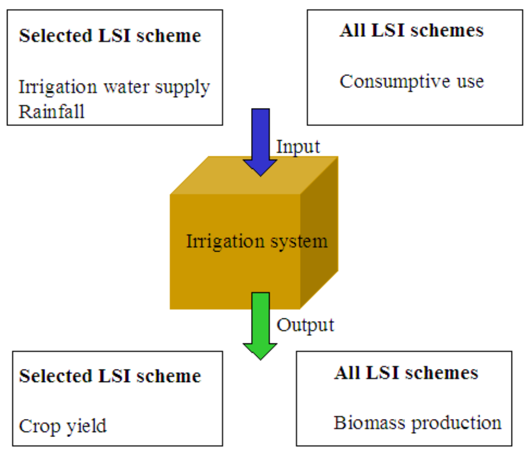


Figure 11 Schematic diagram showing the different expressions for land and water productivity

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).

[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.

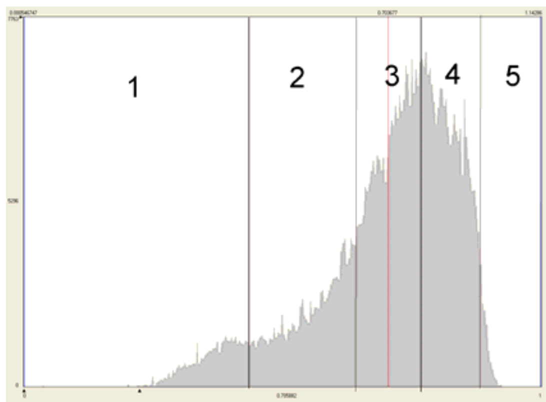


Figure 13 Frequency distribution of the values of one specific irrigation performance indicator. The values can be grouped into 5 classes

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.

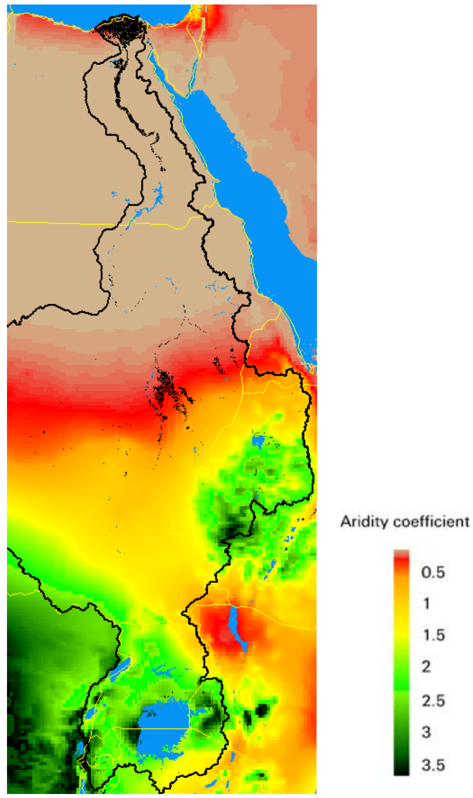


Figure 14 Spatial patterns of rainfall/reference ET across the entire Nile basin to emphasize climatic differences. The irrigation mask is superimposed

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.

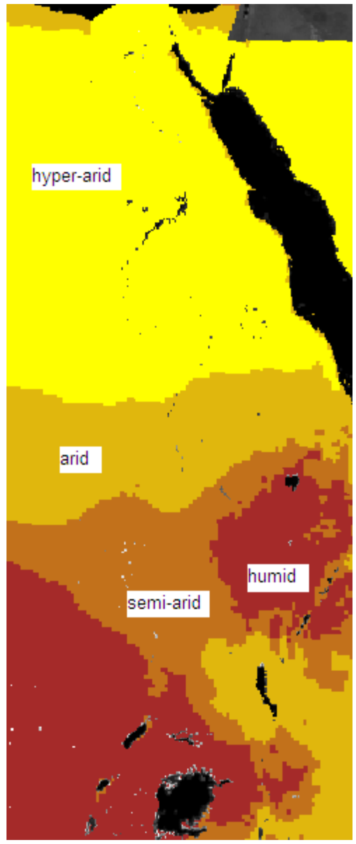


Figure 15 Different climatic zones in the Nile Basin

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.

[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

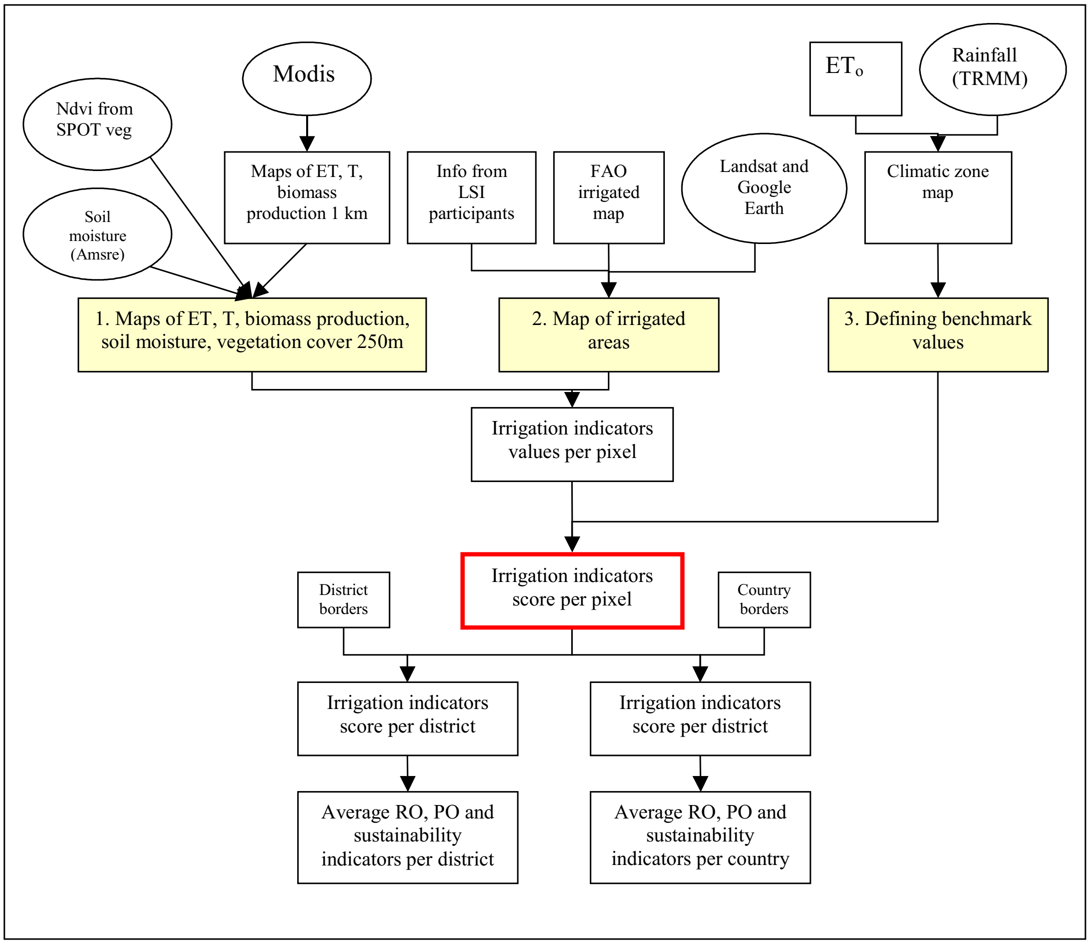


Figure 16 Computational schedule for the irrigation performance indicators

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.

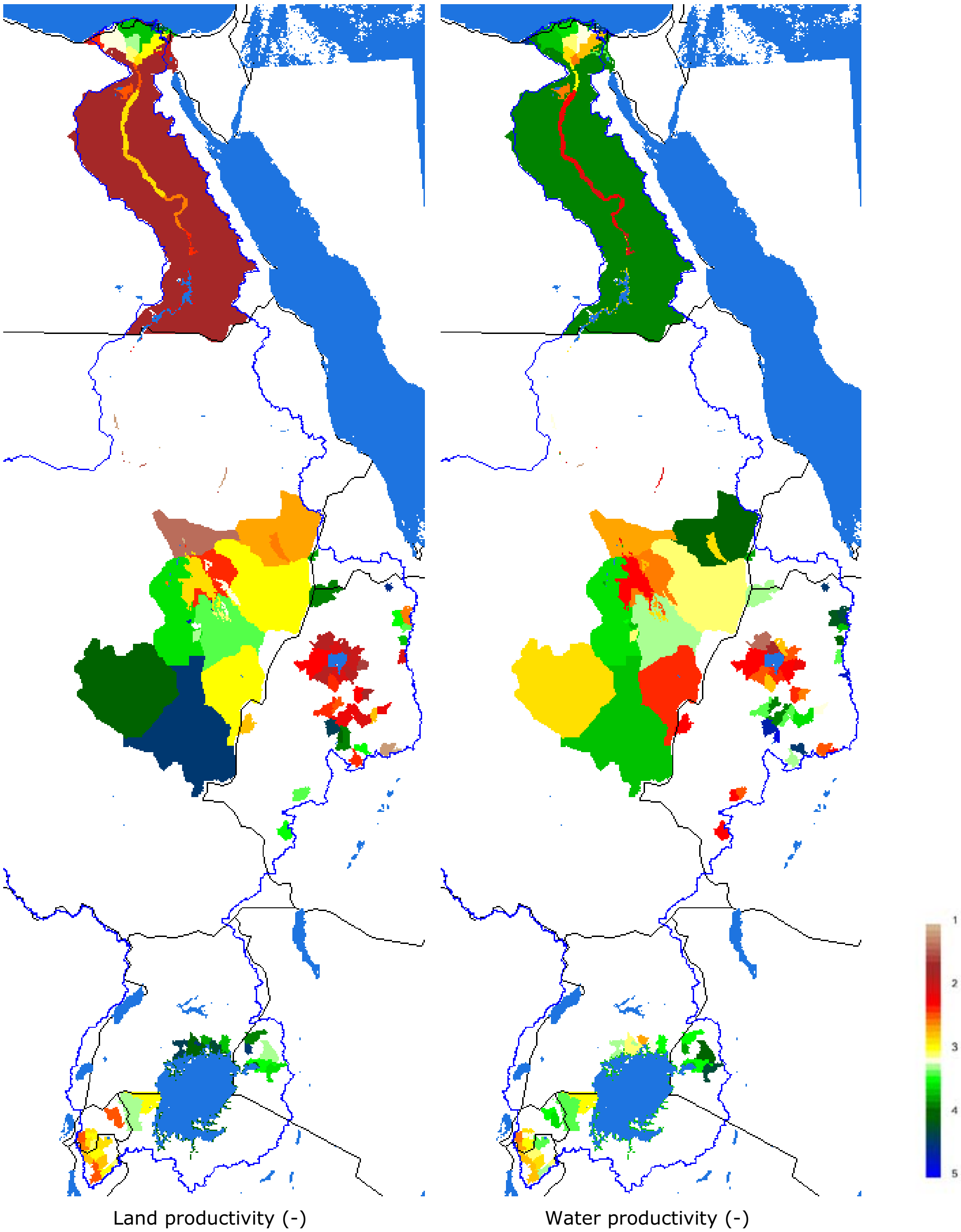


Figure 17 Spatial variation of the land and water productivity in the Nile Basin across all administrative districts based on remote sensing data. The value is expressed as a score between 1 (very poor) to 5 (excellent). The Nile Valley has a larger administrative unit with pockets of irrigation at the 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/m³)	(kg/m³)
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

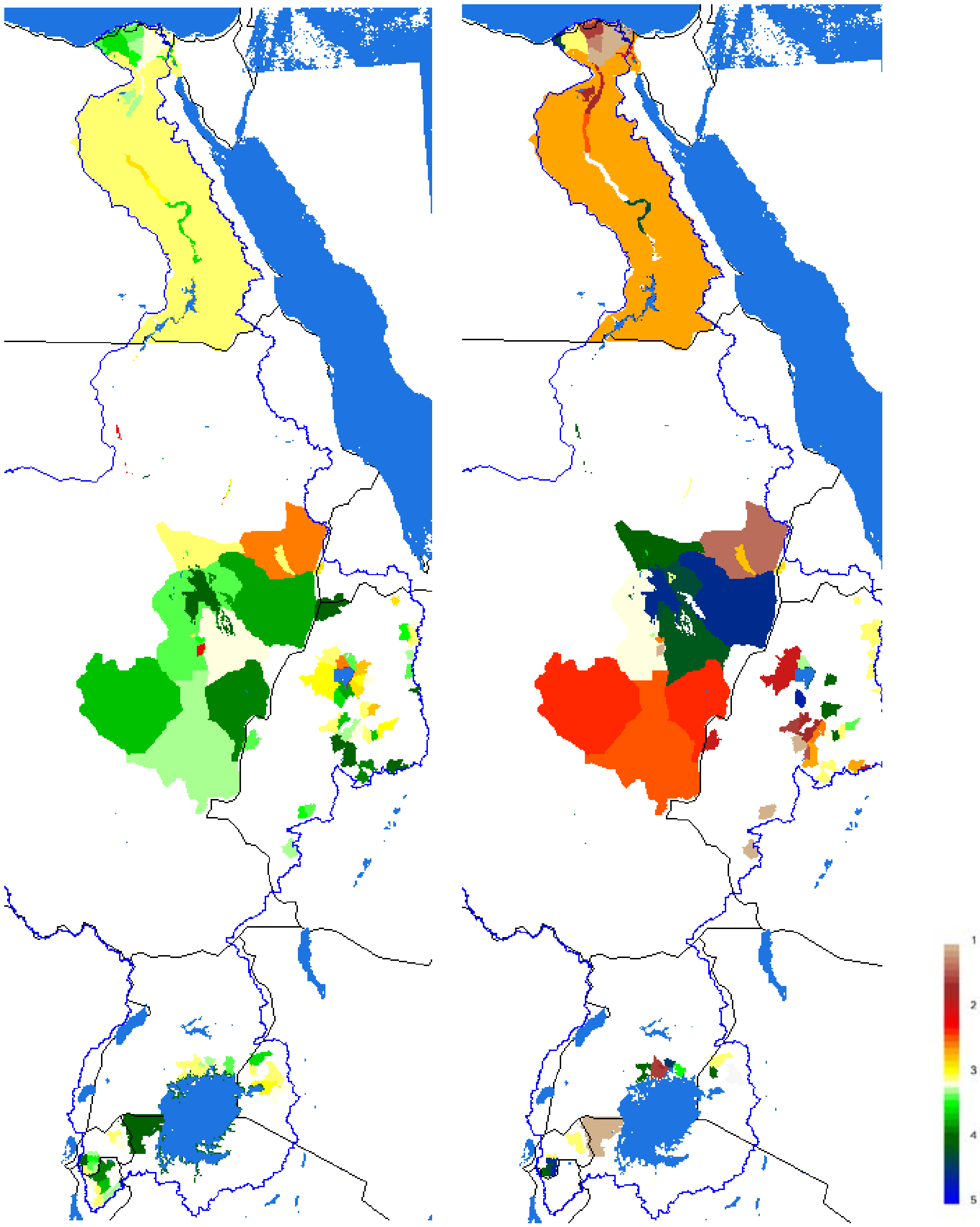
[6] This sugar estate is located just outside the Nile basin near Addis Ababa, but representative for the public sugarcane sector of Ethiopia

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:

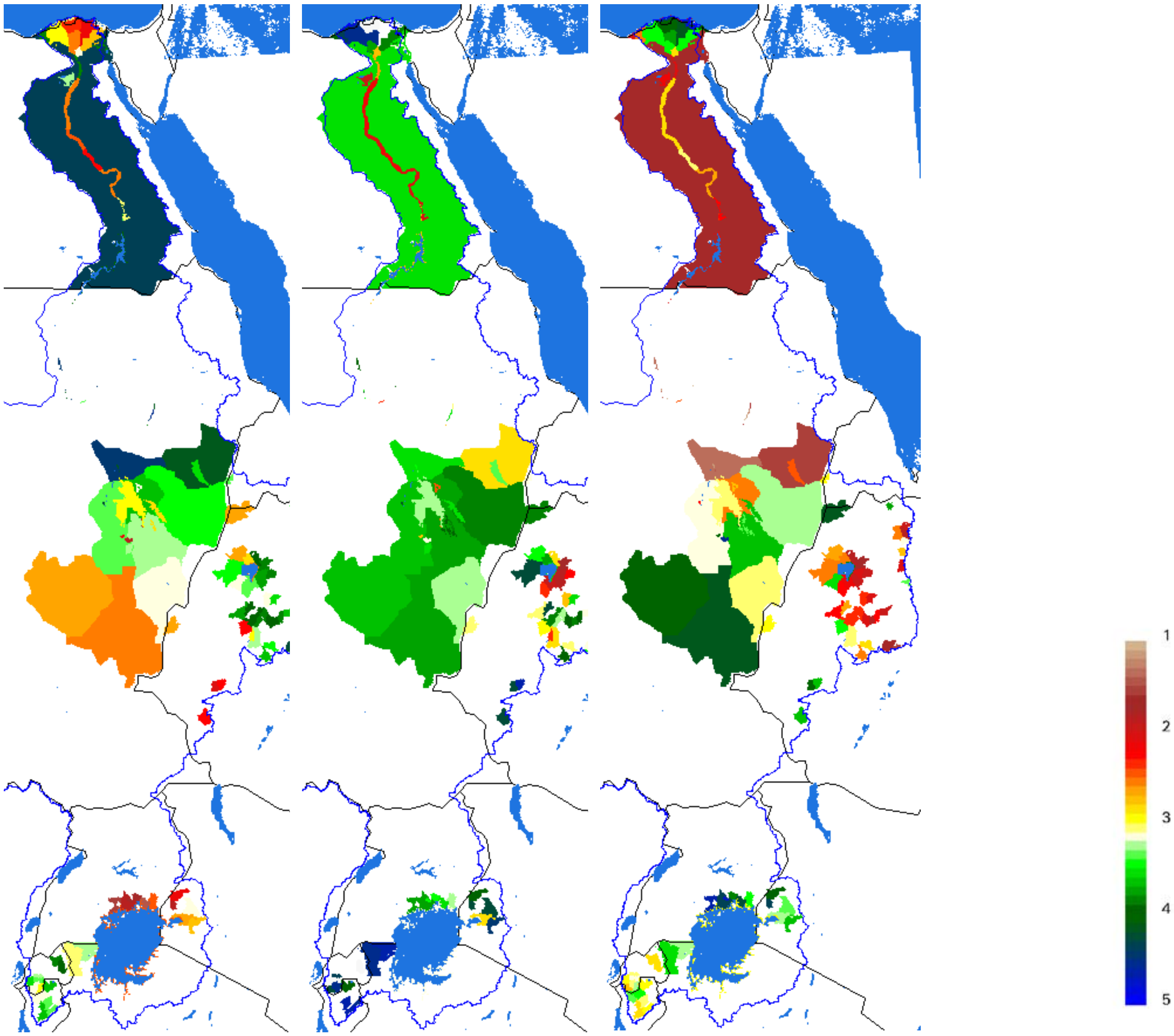
- Most LSI schemes in Sudan, Burundi and Tanzania are sustainable.
- The irrigation systems in Sudan seem to be more sustainable than in Egypt.
- Ethiopia is close to having sound LSI schemes (not good; not bad). Most schemes have either a problem with the sustainability of the land and crops or with 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.


1
2
3
4
5

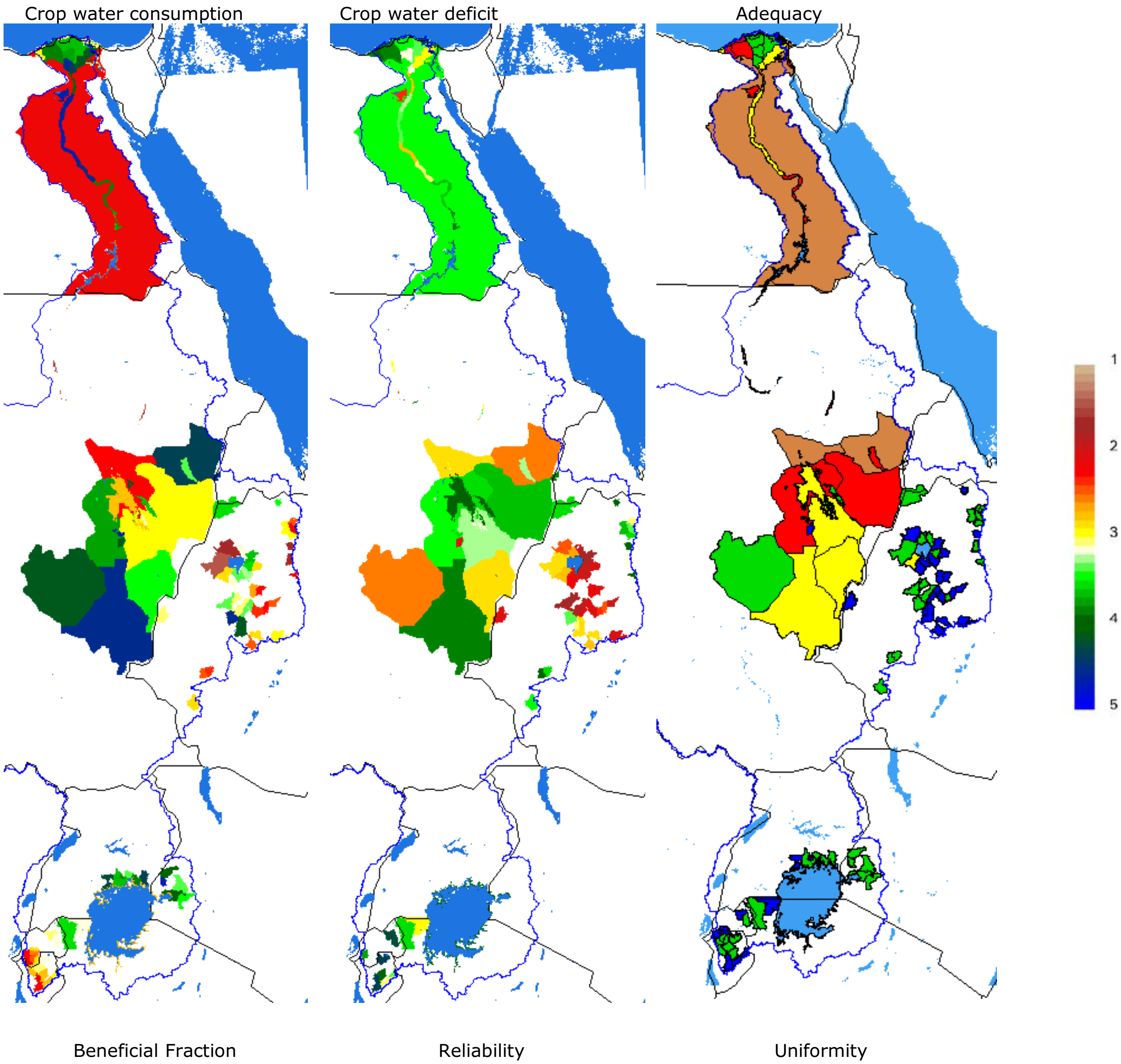


Figure 19 Spatial variation of the physical processes that occur in LSI schemes in the Nile Basin across all administrative districts. The value is expressed as a score between 1 (very poor) to 5 (excellent). The Nile Valley has a larger administrative unit with pockets of irrigation at the fringes with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

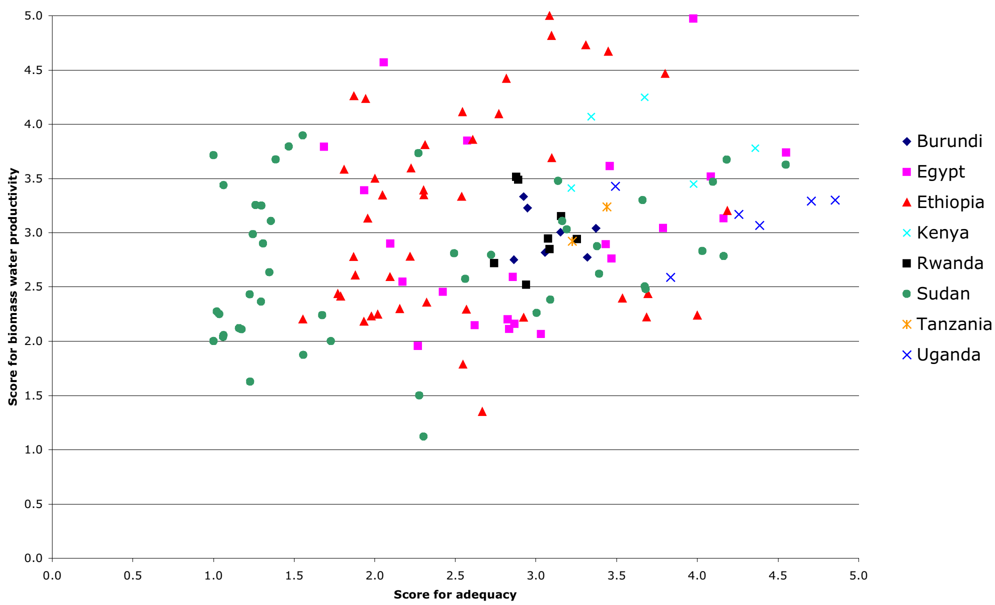


Figure 20 Relationship between biomass water productivity and adequacy for all districts with LSI schemes in the Nile Basin. The optimum level of water productivity is achieve at mild transpiration stress

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.

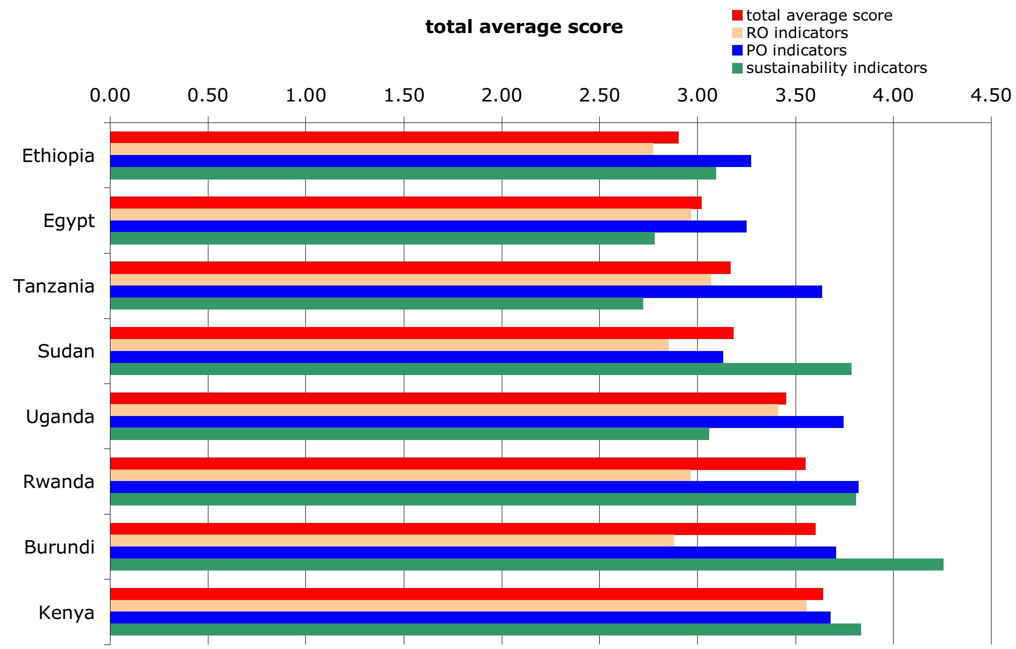


Figure 21 Breakdown of the average irrigation performance scores (RO, PO, and SO and their average values) by country in the Nile Basin

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.

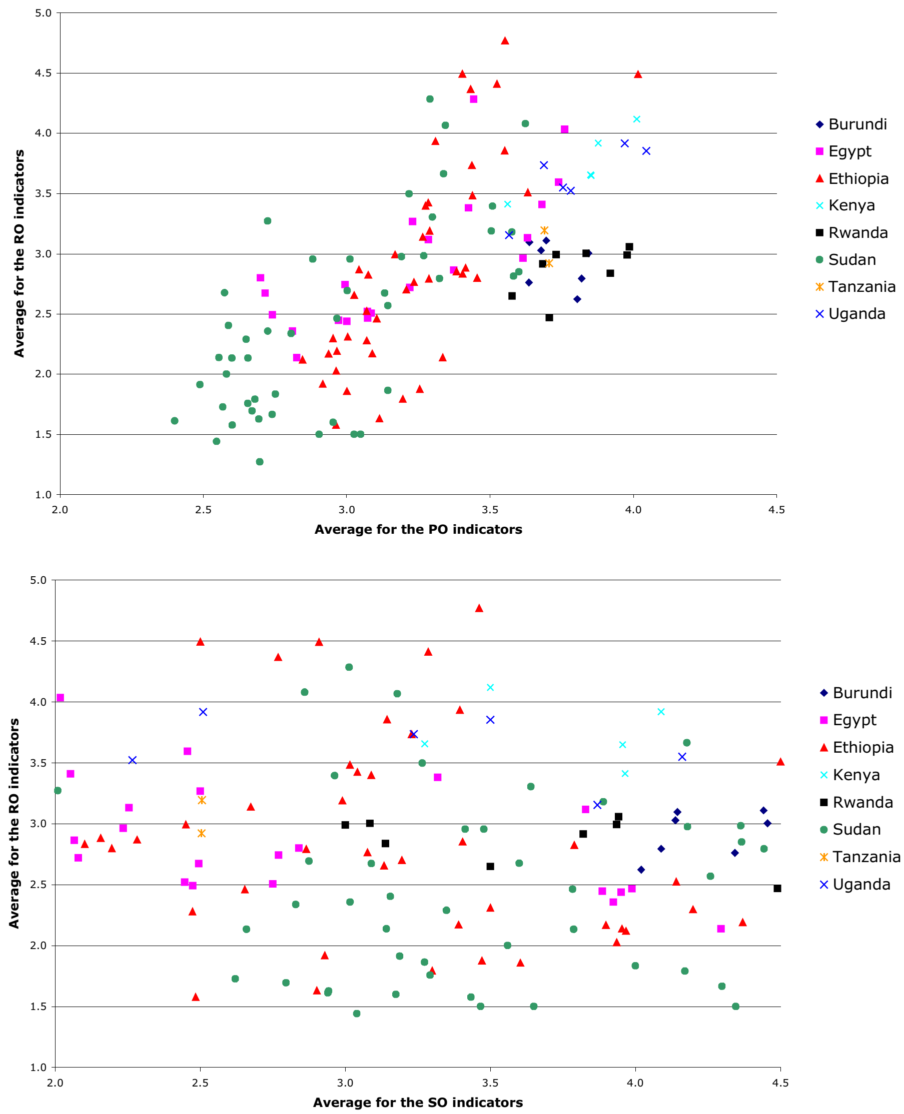


Figure 22 Major differences in management characteristics between all LSI schemes

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 (kg/ha)	Maize (kg/ha)	Wheat (kg/ha)	Cotton (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 (Ton/ha)	Rosegrant et al. (2002) Data from 1995 (Ton/ha)	Molden et al. (2007) Data from 2000 (Ton/ha)	IRRI (Ton/ha)	Lui (2007) (irr and rainfed) (Ton/ha)	Zwart and Bastiaanssen (2004) (Ton/ha)	Zwart and Bastiaanssen (2006) (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.

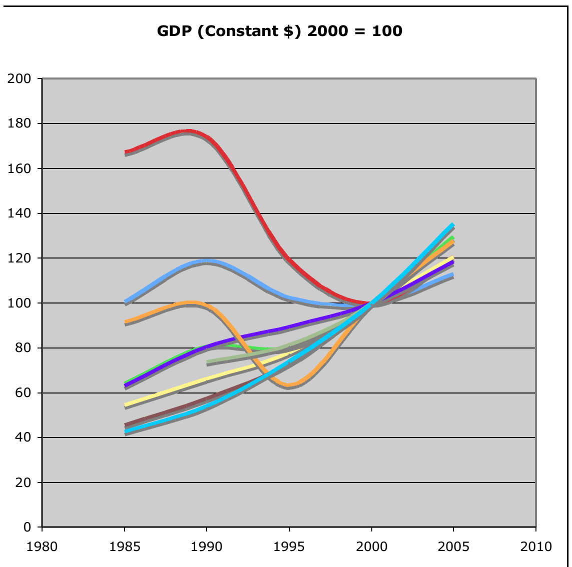


Figure 23 GDP, Constant 2000 $

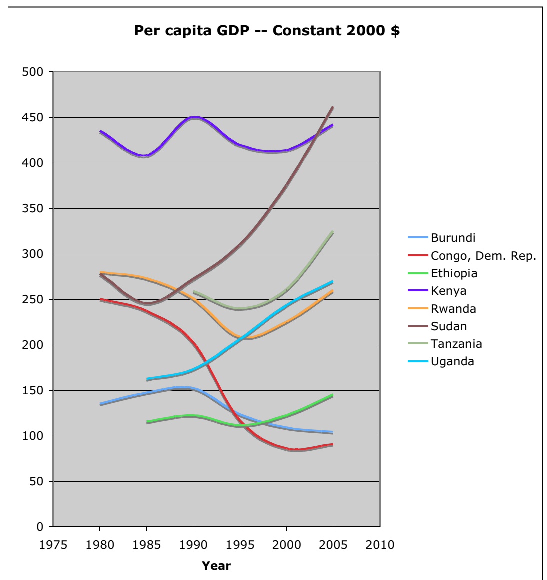


Figure 24 Per capita GDP

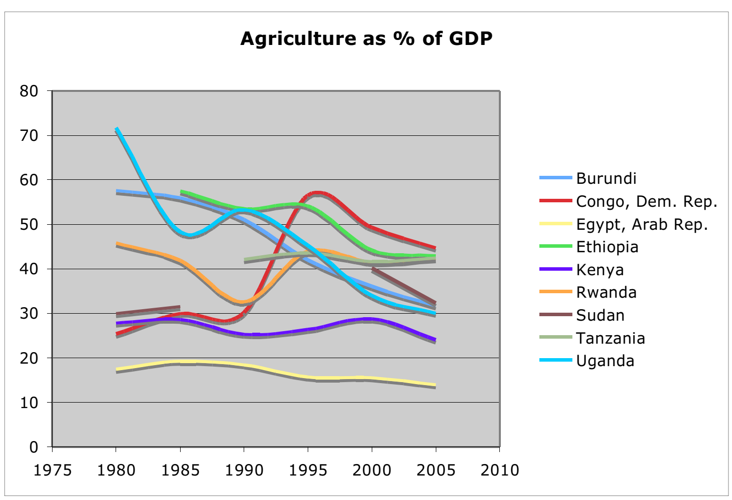


Figure 25 Agriculture as % of GDP – 1980-2005

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 tenantbased 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.

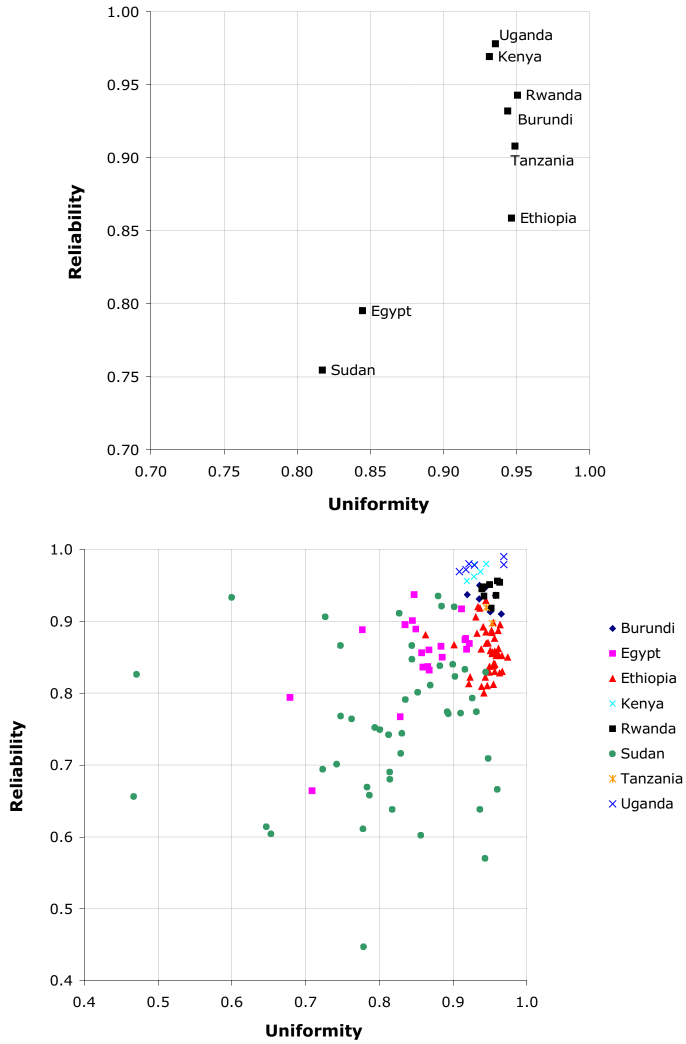


Figure 26 Relationship between uniformity and reliability for all districts with LSIs

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.

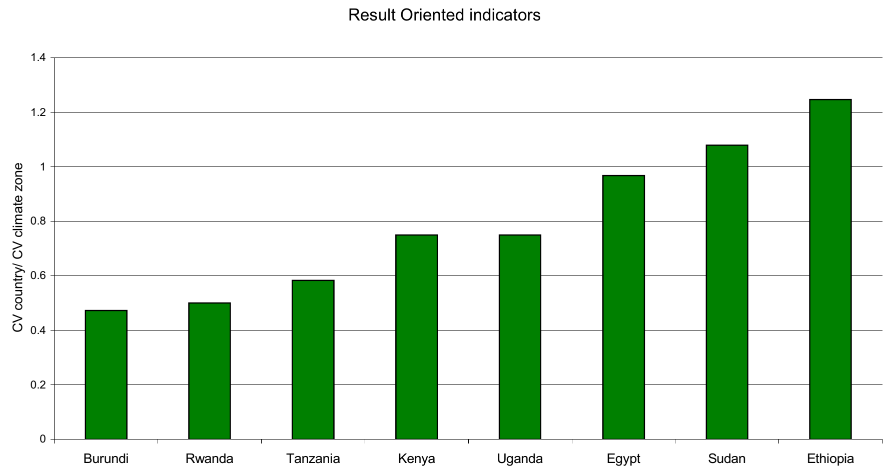


Figure 27 Impact of good water governance on the reduction of spatial variations of Result Oriented indicators (i.e. productivity) as compared to the prevailing climatic system

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