6 Enabling Environment – Centres of Excellence

6.1 Institutional Reform Processes in the Nile Basin Water Sector

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

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

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

Table 18 Institutional Reform Processes

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

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

Table 19 Water Resources Responsibilities in Riparian Countries

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

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

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

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

6.2 Country-level institutions and centres of Excellence

Burundi

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

Four key players are involved in this:

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

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

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

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

Egypt

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

The National Water Research Center (NWRC)

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

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

Their names and mission are:

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

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

Agricultural Research Center

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

Ethiopia

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

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

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

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

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

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

Kenya

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

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

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

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

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

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

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

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

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

Rwanda

The main institutions in Rwanda are:

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

Sudan

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

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

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

Uganda

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

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

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

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

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

The functions of the Irrigation and Drainage Section are to:

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

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

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

- Monitor and evaluate agricultural activities on fragile lands.

The functions of the Water for Agricultural Production Section are:

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

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

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

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

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

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

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

7.1 Irrigation objectives

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

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

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

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

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

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

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

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

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

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

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

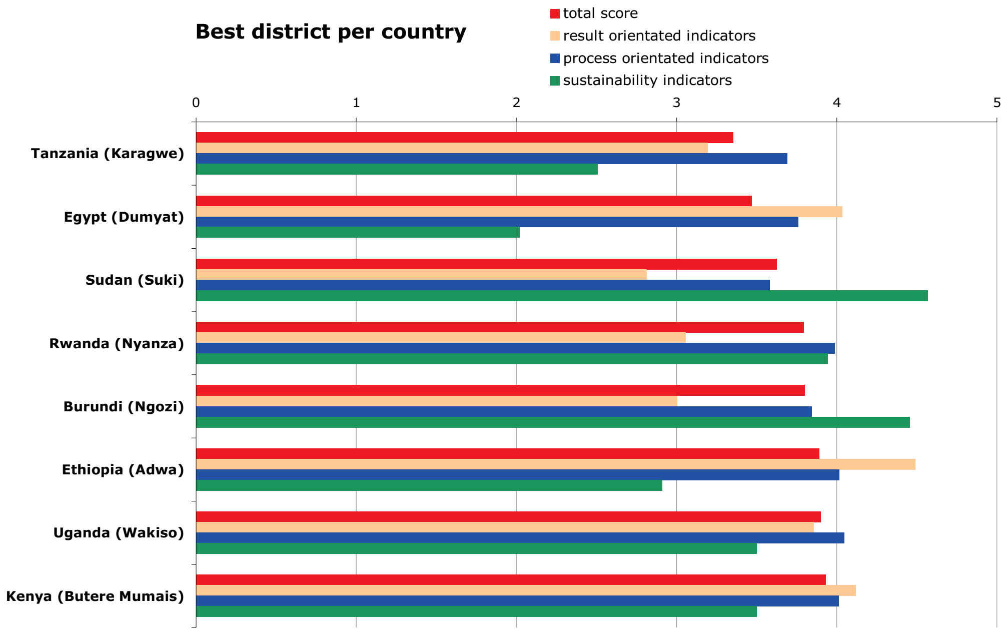


Figure 29 The total score for the best district of each Nile Basin country

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

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

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

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

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

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

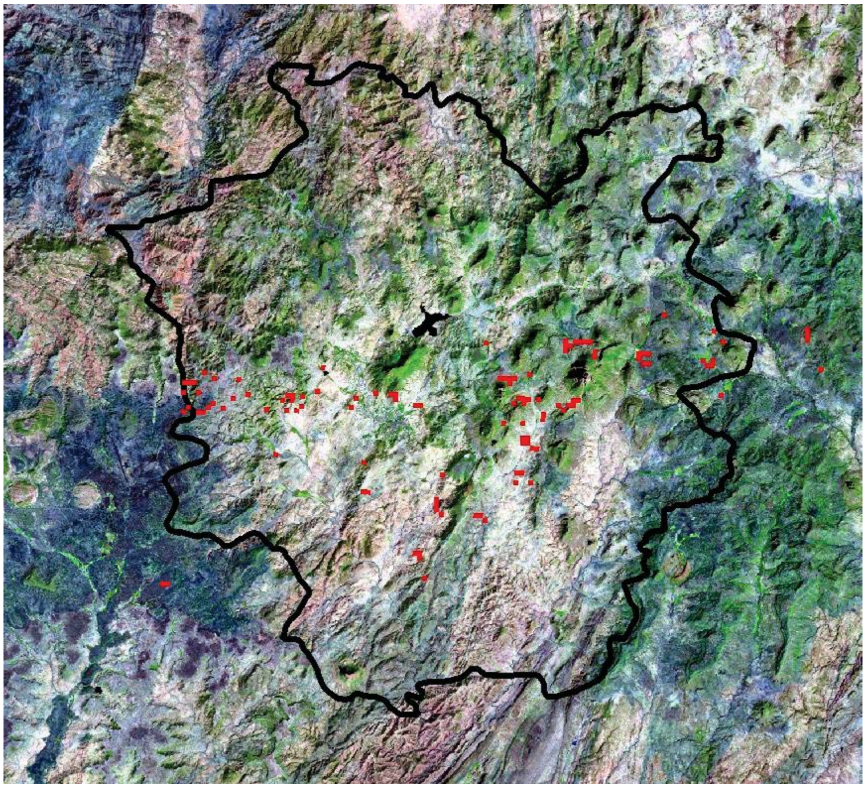


Figure 30 Location of the scattered irrigation systems in the Adwa district (Ethiopia) that meet the criterion of 200 ha per district. The background is a MrSid version of Landsat imagery

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

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

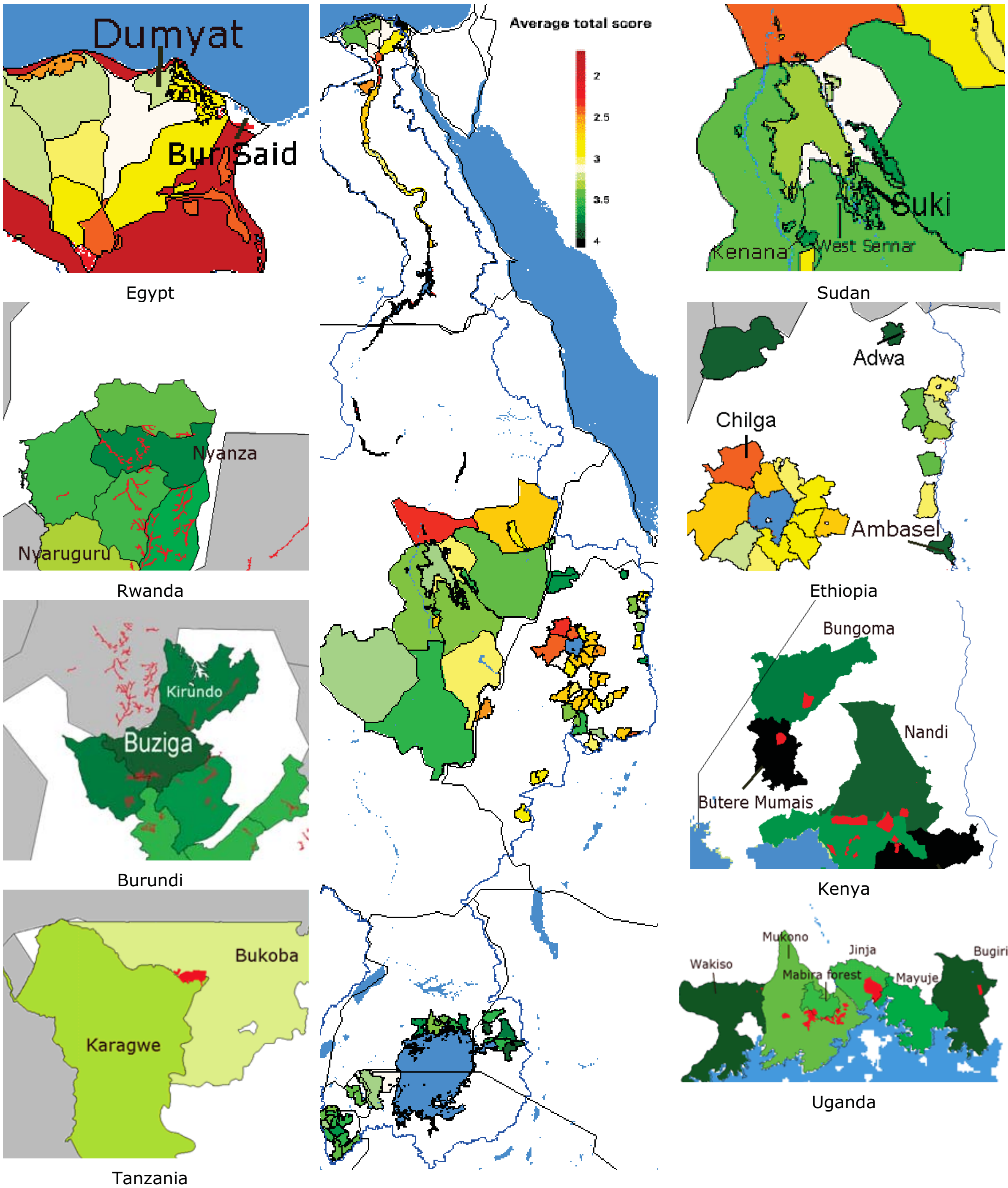


Figure 31 Location of the administrative districts with the best performing LSI scheme per country

7.3 Best practices for general irrigation performance by country

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

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

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

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

7.4 Best practices for general irrigation performance by climatic zone

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

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

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

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

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

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

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

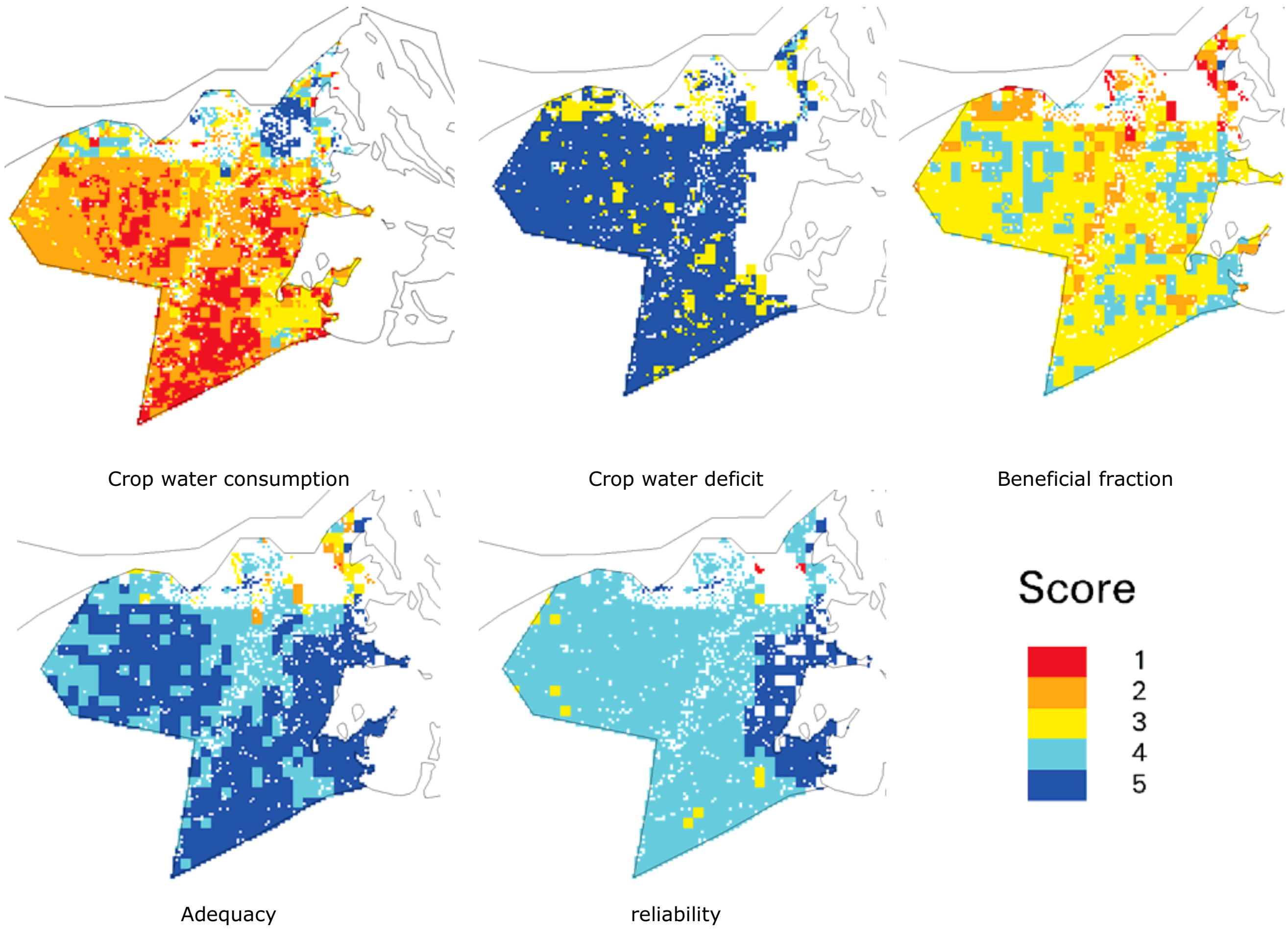


Figure 32 Spatial distribution of each indicator for the district of Dumyat, the best district of climatic zone 1 (hyper-arid climate)

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

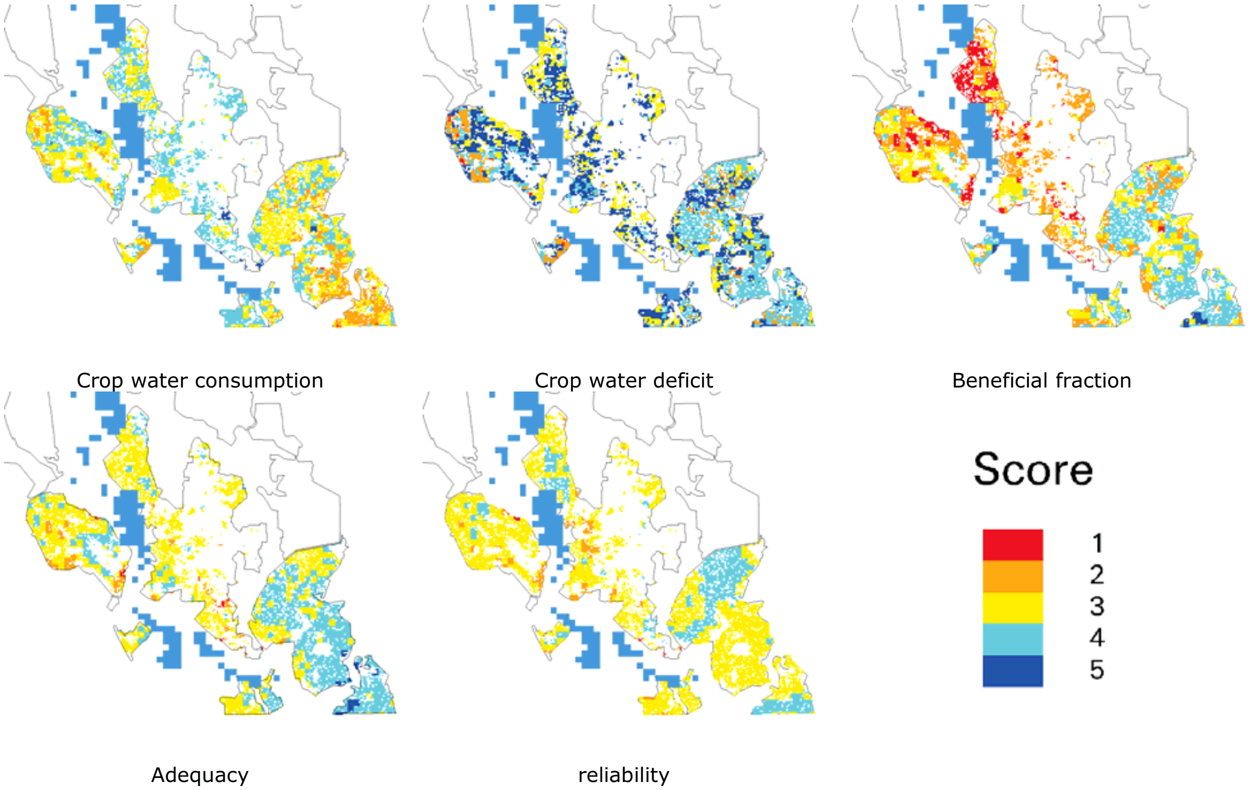


Figure 33 Spatial distribution of each indicator for the district of Suki, the best district of climatic zone 2 (arid climate).

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

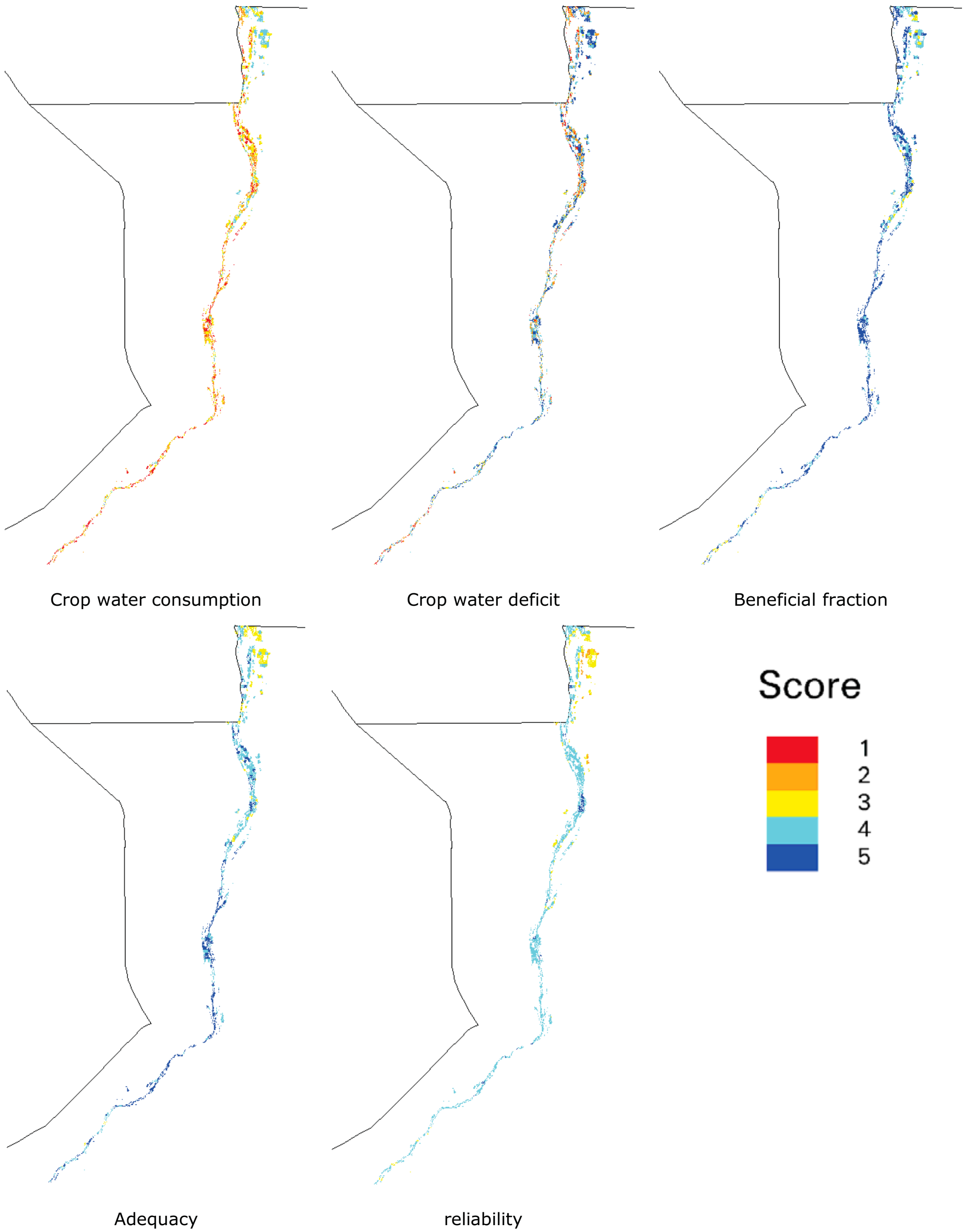


Figure 34 Spatial distribution of each indicator for the district of the Upper Nile, the best district of climatic zone 3 (semi-arid climate).

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

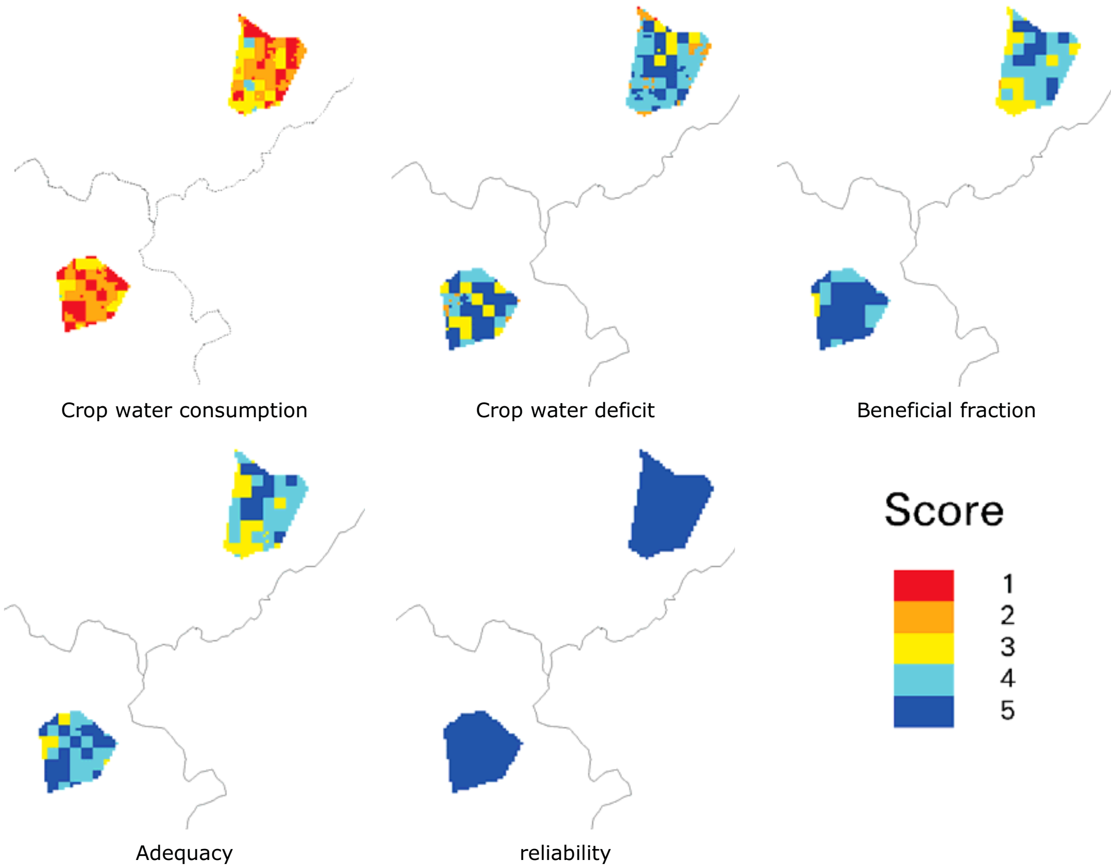


Figure 35 Spatial distribution of each indicator for the district of Bungoma and Butere Mumais in Kenya, the best district of climatic zone 4 (humid climate)

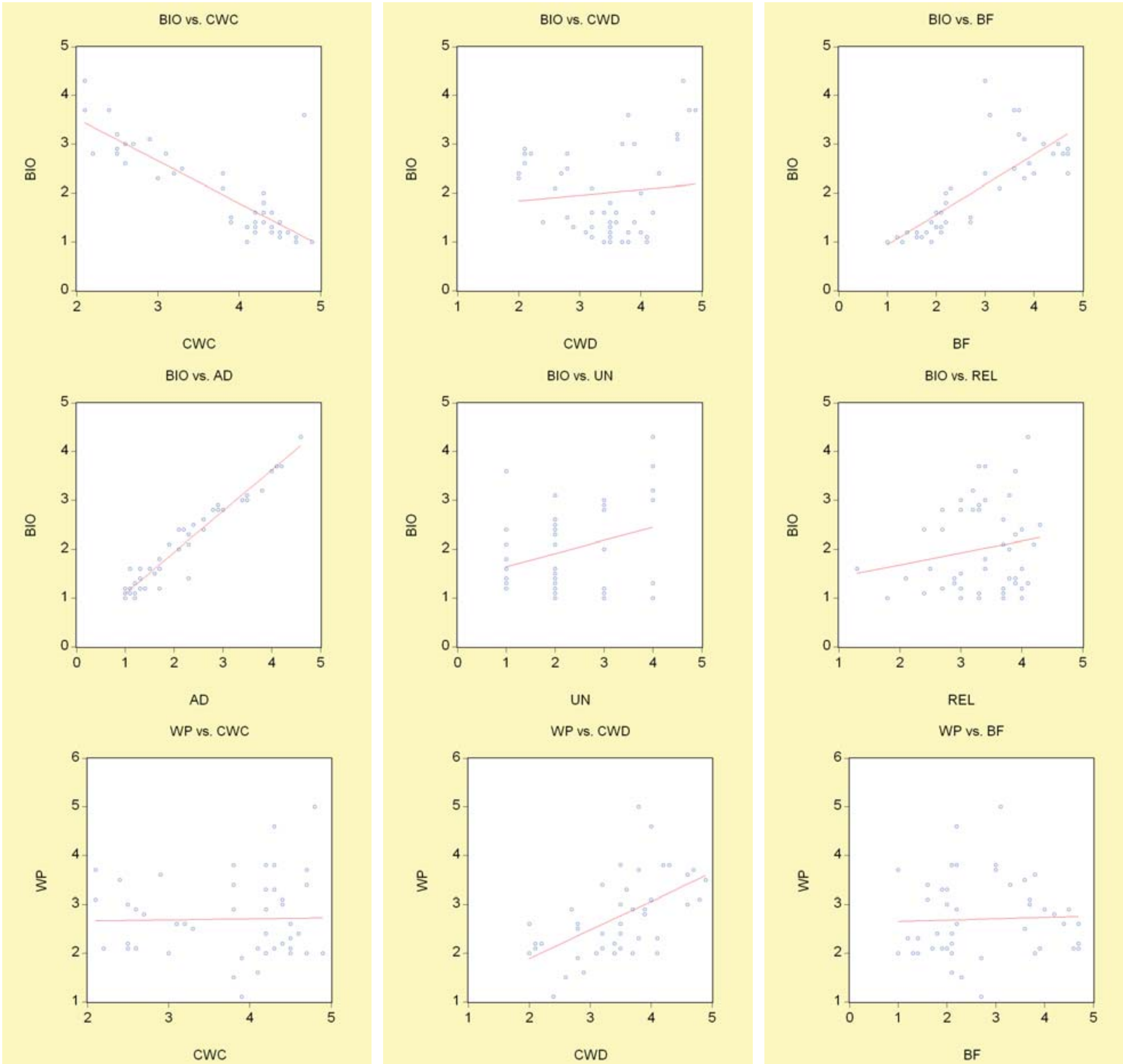
7.5 Physical irrigation processes affecting productivity

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

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

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

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


BIO vs. CWC
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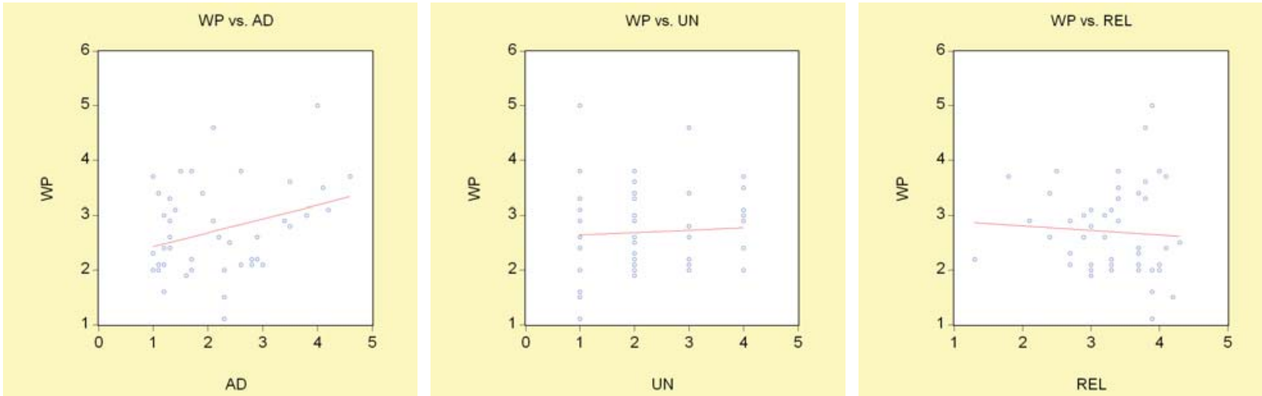
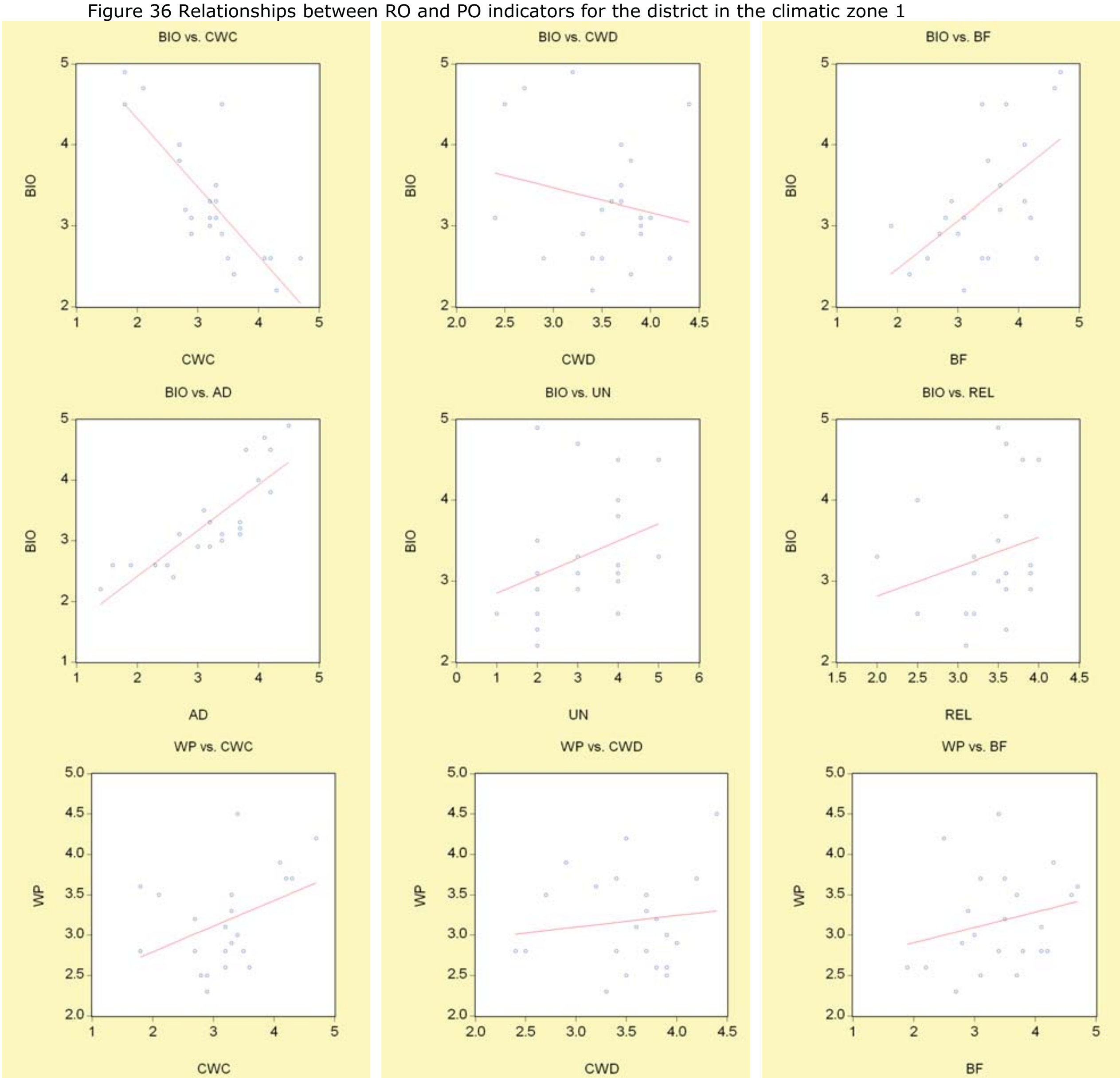


Figure 36 Relationships between RO and PO indicators for the district in the climatic zone 1



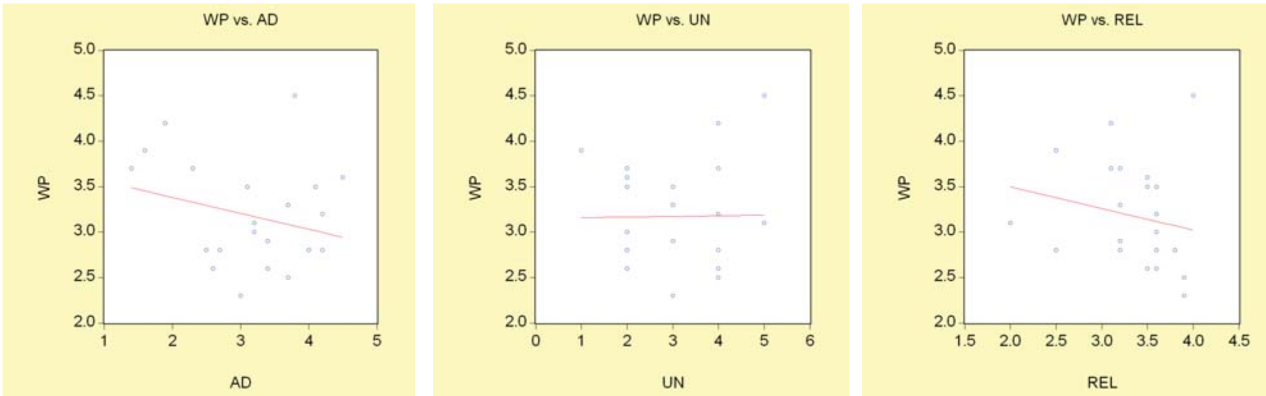
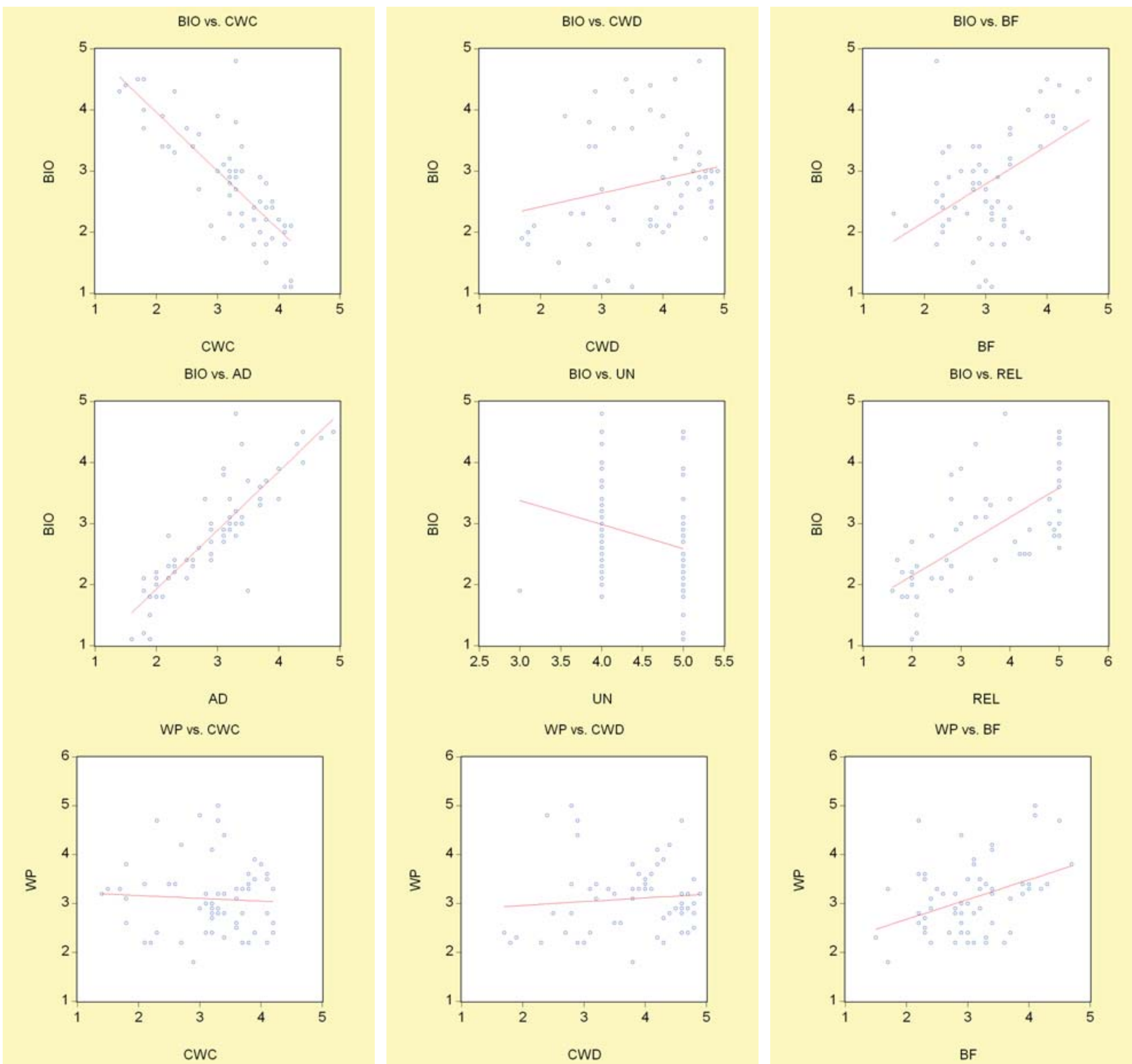


Figure 37 Relationship between RO and PO indicators for the district in the climatic zone 2



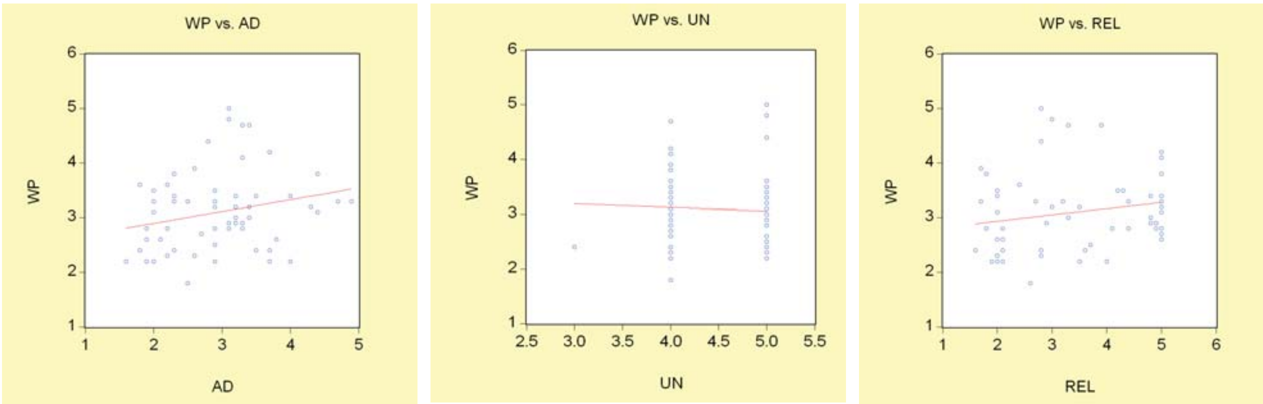


Figure 38 Relationship between RO and PO indicators for the district in climatic zone 3

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

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

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

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

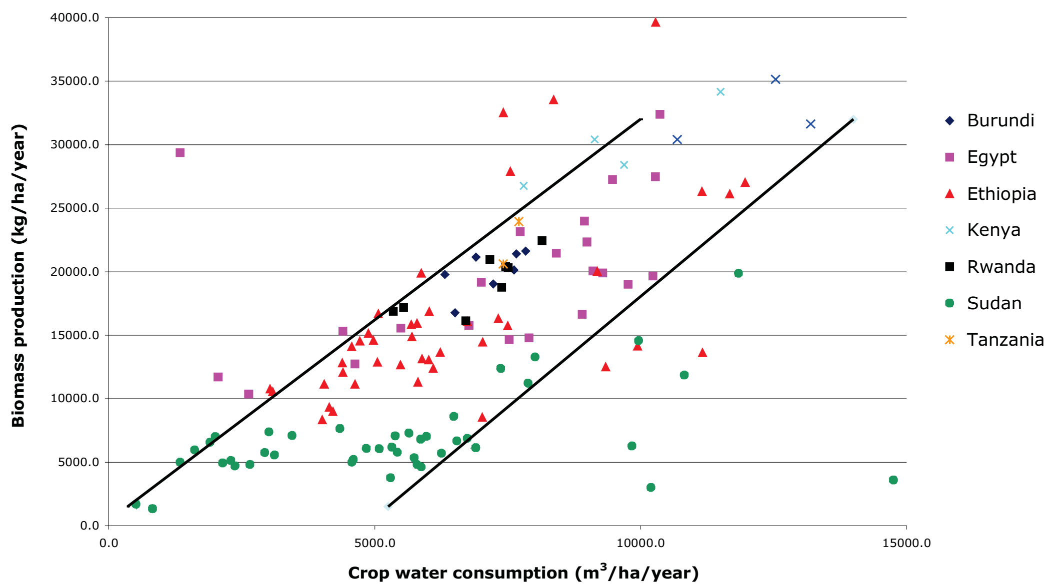


Figure 39 Correlation between biomass production and crop water consumption by country districts. Note that normalization by climatic zones has not been applied

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

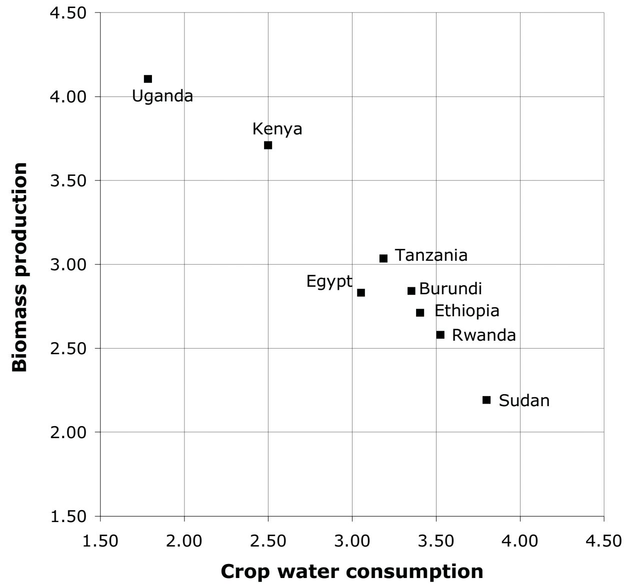


Figure 40 Correlation between land productivity and crop water consumption by country. Note that normalization by climatic

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

Table 22 Key processes in productive irrigation management that require attention

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

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

Interim conclusions:

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

7.6 Best practices for improving productivity

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

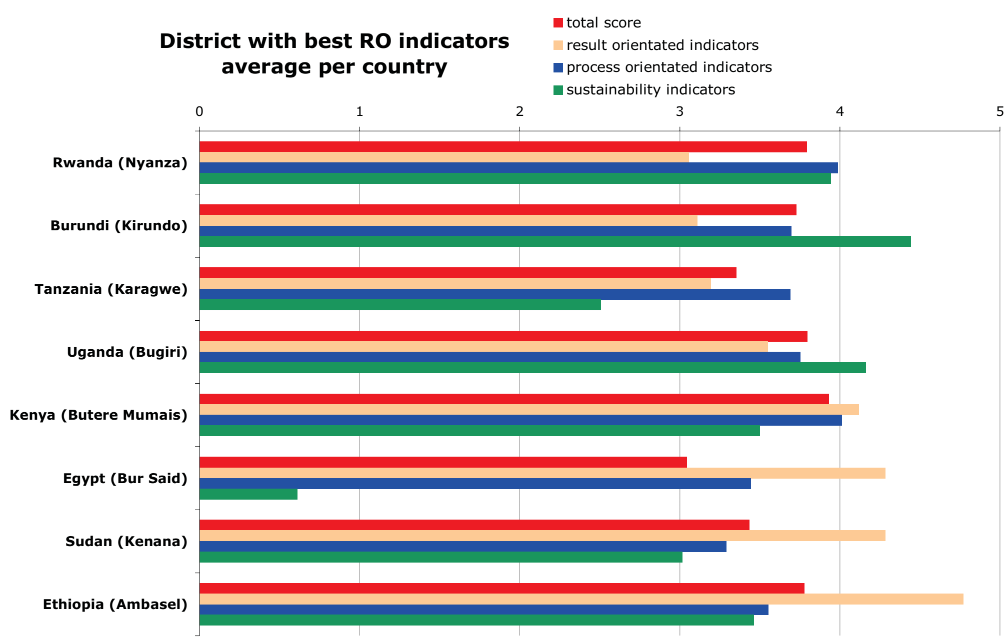


Figure 41 Breaking down the total score per indicator for the districts with the best RO indicators average for each Nile Basin country

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PART 2 Guidelines on Best Practices and Sites

Executive Summary

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

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

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

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

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1 Procedures for transferring best practices

1.1 Need for an irrigation typology

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

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

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

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

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

Interim conclusions:

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

1.2 General LSI characteristics

Governmental vs. commercial management

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

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

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

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

Conclusions for the summer situation:

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

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

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

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

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

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

Conclusions for the winter situation:

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

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

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

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

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

Findings in relation to the level of investment are:

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

Type of irrigation systems

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

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

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

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

1.3 Transfer procedure for best irrigation practices

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1.4 Priority of technology transfer

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

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

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

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

2 Recommendations by climate zone and country

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

2.1 Hyper-arid climate (Egypt)

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

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

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

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

Recommendations for best LSI practices in Egypt:

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

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

2.2 Arid climate (Sudan)

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

Recommendations for best LSI practices in Sudan:

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

2.3 Semi-arid climate (Ethiopia)

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

Recommendations for best practices in Ethiopia:

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

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

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

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

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

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

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

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

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

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

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

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

Recommendations for the best practices in Tanzania and Uganda:

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

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PART 3- Action plans

Executive Summary

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

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

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

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

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1 Irrigation development in the Nile basin

1.1 Irrigation water resources

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1.2 Future irrigation scenarios

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

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

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

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

The alternative options are:

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

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

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

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

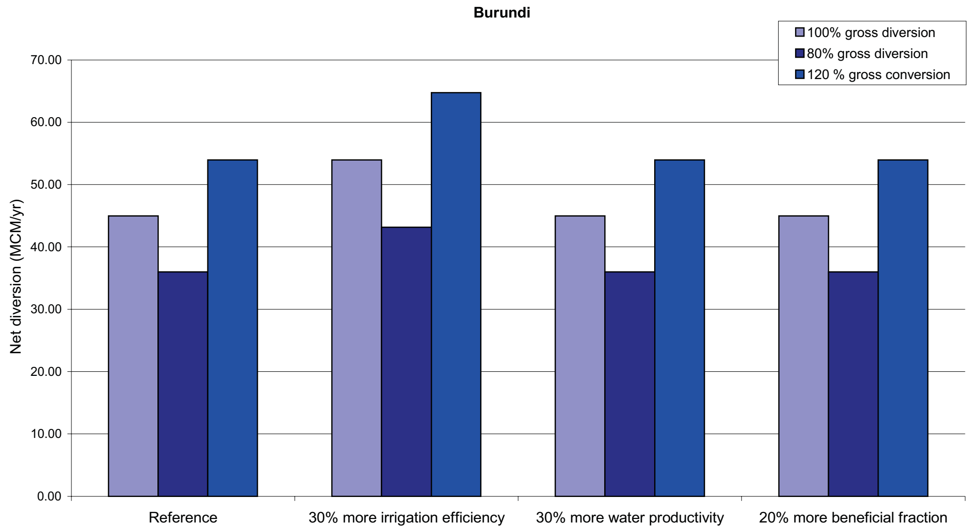

Figure 42 Net diversion scenarios Burundi

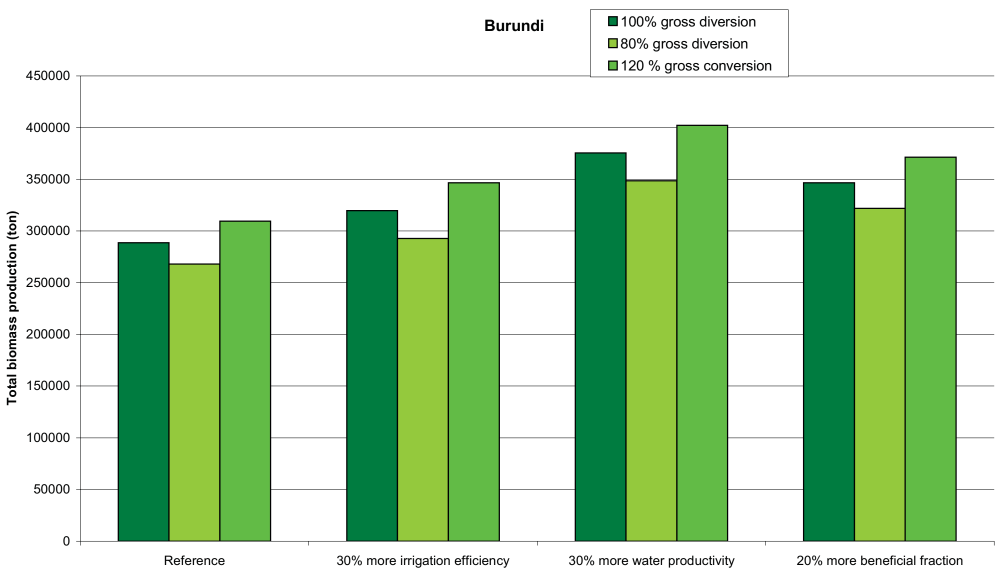

Figure 43 Biomass production scenarios Burundi

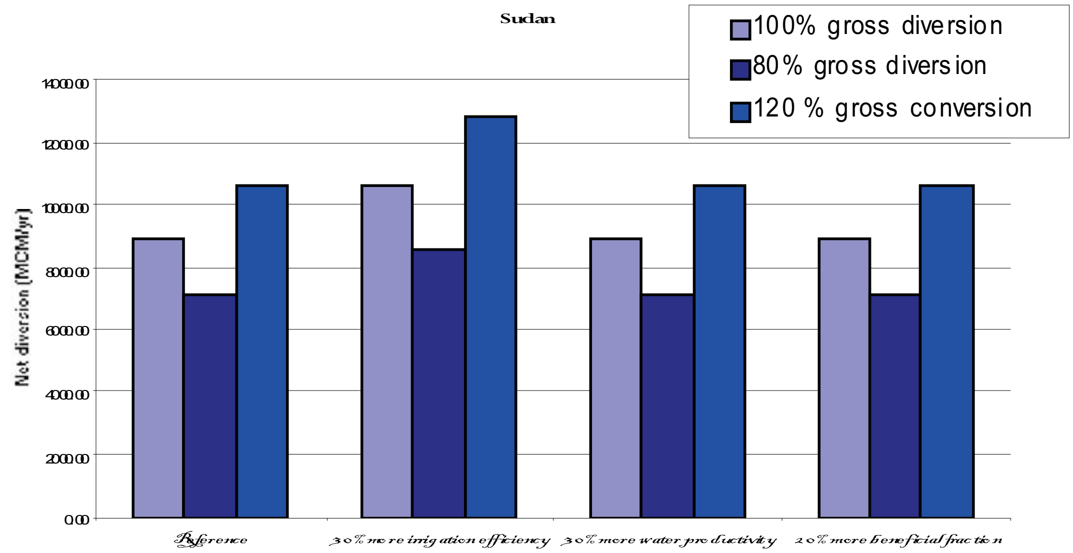

Figure 44 Net diversion scenarios Sudan

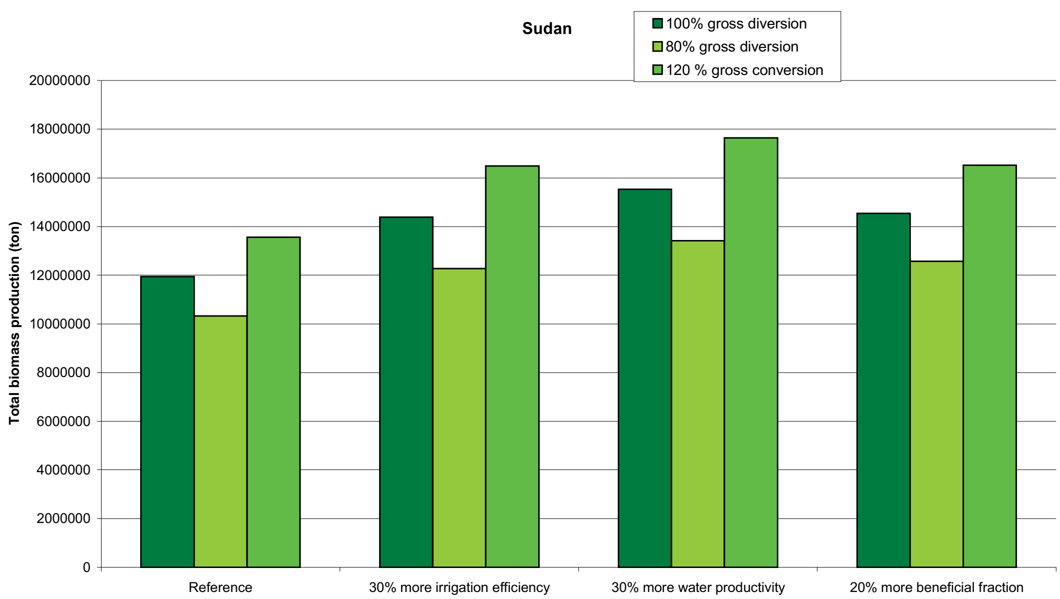

Figure 45 Biomass production scenarios Sudan

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

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

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

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

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

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

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

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

2 Action plan

2.1 Plot level

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

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

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

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

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

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

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

The practical guidelines for regulating supply and demand are:

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

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

Increase irrigation efficiency

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

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

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

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

Example: irrigation efficiency

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

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

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

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

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

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

The practical guidelines for increasing irrigation efficiency are:

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

Increase beneficial fraction (T/ET)

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

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

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

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

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

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

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

Example: beneficial fraction

A typical situation with wet soils:

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

A situation with partially wet soils due to mechanic mulching:

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

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

The practical guidelines for increasing beneficial fraction are:

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

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

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

The practical guidelines for increasing crop yield are:

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

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

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

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

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

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

The practical guidelines are:

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

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

Example: water productivity improvement

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

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

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

2.2 Country level

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

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

2.2.1 Existing schemes

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

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

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

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

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

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

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

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

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

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

2.2.2 New schemes

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

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

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

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

Existing LSI schemes

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

New LSI schemes

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

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

3 Way forward

3.1 SAP

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3) Surveying areas being potentially suitable for land reclamation

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

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

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

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

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

The main objective therefore is:

Determining irrigable areas that can lead to sustainable agricultural practices characterized by favourable crop production and acceptable water productivity performance levels

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PART 4 Summary and way forward

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1 Irrigation development

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

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

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

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

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

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

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

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

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

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

2 Materials and methods

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

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

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

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

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

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

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

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

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

3 Diagnostic results

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4 Socio-economic and institutional aspects

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

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

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

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

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

5 Irrigation development

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

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

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

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

6 Way forward

6.1 Observations

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

6.2 Conclusions

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

6.3 Recommendations

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

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

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

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

6.4 Operational remote sensing service

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

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

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

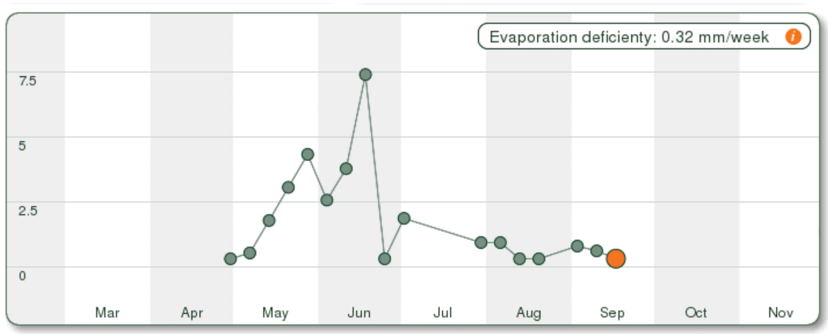

Figure 46 Trend in evaporation deficit (ET_{pot}-ET_{act}) during the growing season based on weekly MODIS satellite images. Every dot represents the average value of a field. The field could also be a canal command area.

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

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

6.5 Way forward

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

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

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

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

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APPENDICES

Appendix A Information needs for the assessment of irrigation system performance

Wim Bastiaanssen & Chris Perry (WaterWatch consultants)
March 7th, 2007

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

At the national level, the questions are:

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

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

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

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

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

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Chris Perry: chrisjperry@mac.com

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

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

1. Introduction

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

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

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

2. Monday 15 September 2008

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

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

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

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

The water managers are satisfied because:

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

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

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

3. Tuesday 16 September 2008

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

Dina farms (www.dinafarms.com)

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

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

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

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

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

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

Centech farm (www.egyptgreen.com)

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

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

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

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

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

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

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

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

District Water boards

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

- irrigation and improvement;
- irrigation;

- drainage;
- environment; and
- pollution

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

4. Best irrigation practices in Egypt

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

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

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

Annex 1.1: Program of the study tour

Saturday / Sunday 13 & 14 September

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

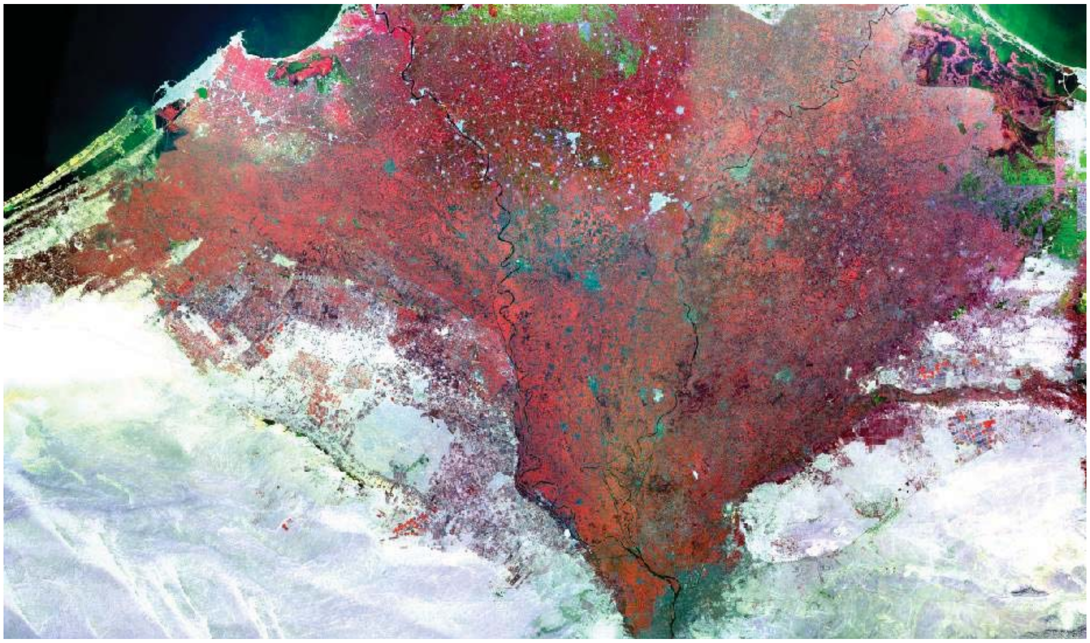
Monday 15 September

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

Tuesday 16 September

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

Annex 1.2: Examples of satellite images of the Nile Delta



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

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

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

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

Annex 1.3: List of participants

NILE BASIN INITIATIVE						
EFFICIENT WATER USE FOR AGRICULTURAL PRODUCTION (EWUAP) PROJECT						
LSI - STUDY TOUR IN EGYPT , 13-16 SEPT. 2006						
PARTICIPANTS LIST						
No.	NAME	ORGANIZATION	POSITION	POSTAL ADRESS	TELEPHONE	E-mail
1	Mr. Zewdu Tafesse	Resources	Coordination Dpmt Head	Addis Ababa, Ethiopia	251 911 037455	mtiku124@yahoo.com
2	Mr. Kifle Alemayehu	Resources	Project Manager - Baro-Akobo	Addis Ababa, Ethiopia	251 911348772	kifletuffa@yahoo.com
3	Ms. Nduwayo Eugenie	Ministry of Environment, Land Mgt & Public Works	Responsable du programme National de AE	B.P. 631 Bujumbura, Burundi	257 79921389, 257 22227303	eugnduwayo@yahoo.fr
4	Mr. Siddiq Yousif Idris	Ministry of Irrigation & Water	Director, Southern Gezira Scheme	Medani, Sudan	249 912671890	siddigyousifsau@yahoo.com
5	Mr. Bukuru Jena-Marie	Ministry of Environment, Land Mgt & Public Works	NPC - EWUAP	P.O. Box 241 Gitega, Burund	257 79930034, 257 22404254	jmbkr2000@yahoo.fr
6	Bolikale		NPC - EWUAP	DRC	243 817126224	gilalanda@yahoo.fr, galanda@nilebasin.org
7	Dr. Hamdy Khalifa	Soils, Water & Environ. Res. Institute - ARC	Director	9 Gamaa Street Giza Egypt	002 / 35720608	hekhalifa@yahoo.com
8	Mr. Calist Tindimugaya	Ministry of Water Environment	Commissioner, Water Resources Regulation	Entebbe, Uganda		ctind.wrmd@dwd.co.ug
9	Wendot	National Irrigation Board	Principal Engineer	P.O Box 30372 - 00100	271 13 80, 0722 97 76 17	hwendot@nilebasin.org
10	Mr. Gamal El Kassar	Water Management Research Institute	Head M & E Department	National Water Research Center Main Buildg - Kanater Egypt	20 10 676 75 64	gelkassar@yahoo.com
11	Prof. Fathy El Gamal		NPC - EWUAP	Delta Barrage - Egypt	202 42189437, 42190381	elgamal@yahoo.com, wmri@link.net
12	Mr. Wim Bastiaanssen	WaterWatch	Consultant	BS Wageningen, The Netherlands	31 317 423401	w.bastiaanssen@waterwatch.nl
13	Eng. Yousra Ahmed			Delta Barrage - Egypt	20 124437701	engyousra@yahoo.com
14	Marwa Khattab			Delta Barrage - Egypt	202 42189437, 42190381	
15	Rose Lily Randall Thuo	Ministry of Agriculture	Principal Agriculturist	P.O. Box 30028 Nairobi, Kenya	254 20 2718870	roselthuo@yahoo.com
16	Dr. Tadele Gebreselassie	Nile Basin Initiative	RPM, EWUAP	P.O Box 41534 - 00100 Nairobi	254202731996	tgebreselassie@nilebasin.org

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

Background

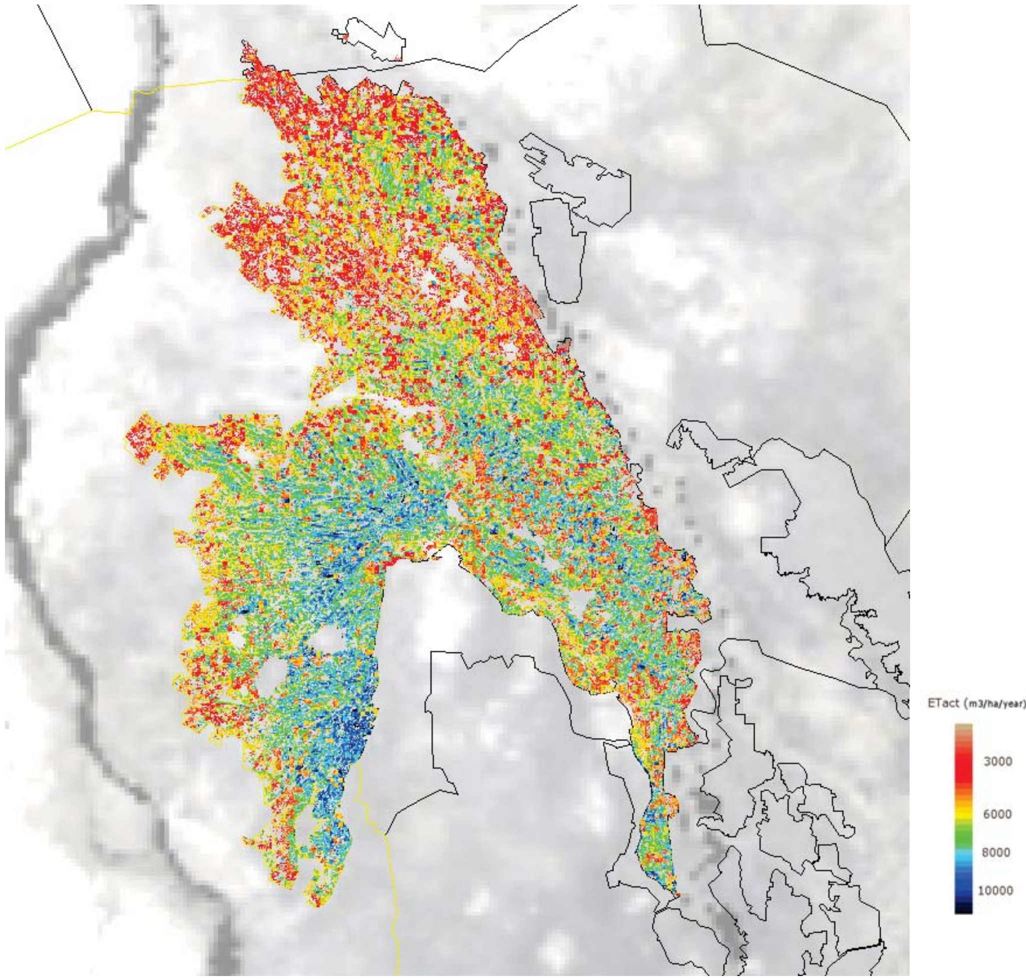
A study tour is organized to the irrigation schemes of Gezira and Kenana as part of the ongoing NBI-EWUAP project on Large Scale Irrigation systems analysis. This memo has been prepared to support the field excursion. It will show the irrigation conditions in these two contrasting areas. These maps could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

Gezira

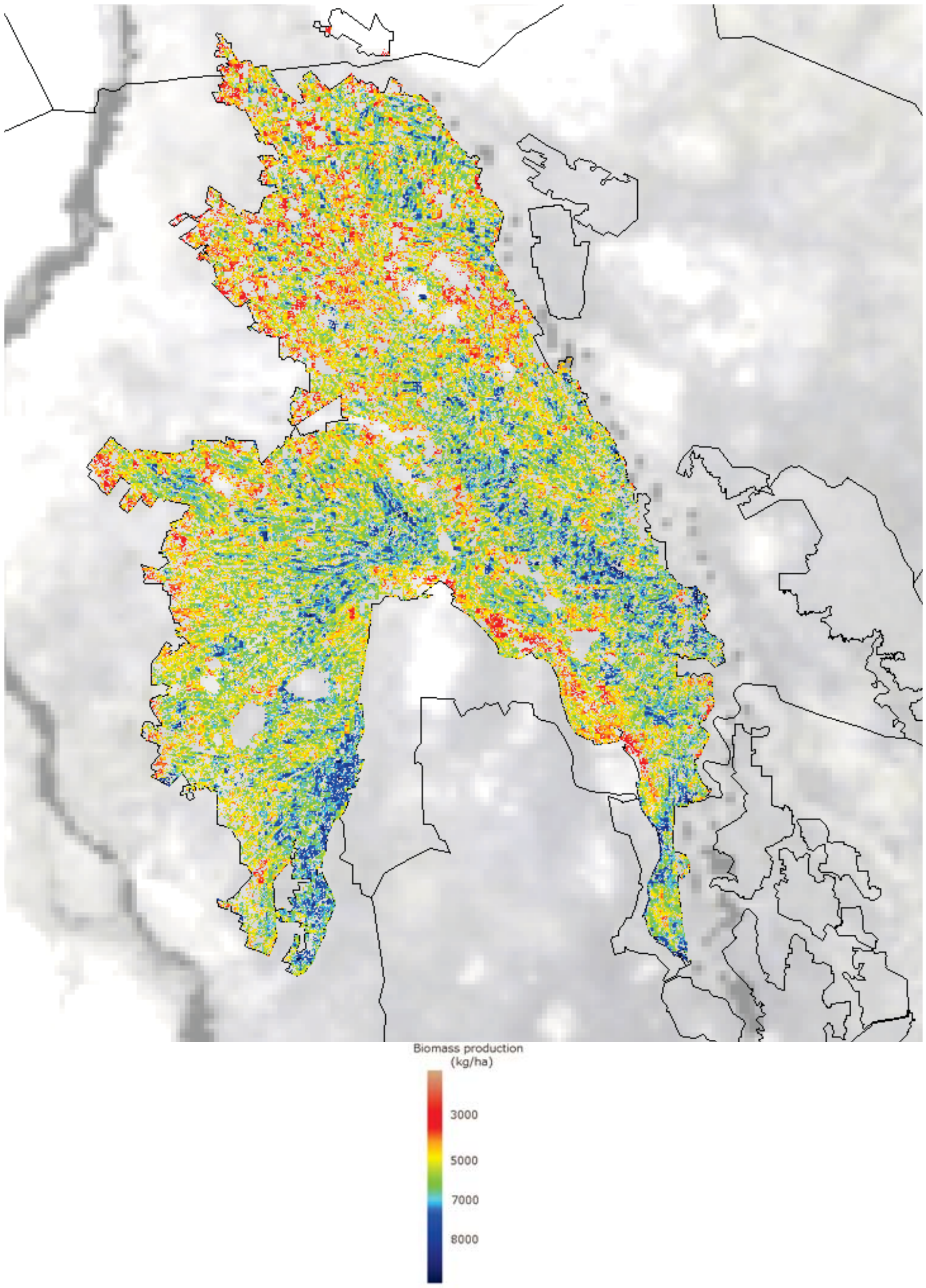
ة The Gezira Scheme (Arabic: مخطط الجزيرة) is one of the largest irrigation projects in the world. It is centered on the Sudanese state of Al Jazirah, just southeast of the confluence of the Blue and White Nile rivers at the city of Khartoum. The economy of Sudan was historically based on agriculture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

The Gezira Scheme distributes water from the Blue Nile through canals and ditches to tenant farms lying between the Blue and White Nile rivers. Farmers cooperate with the Sudanese government and the Gezira Board. This network of canals and ditches is 2,700 miles (4,300 kilometers) long, and the irrigated area covers 8,800 km². The main crops grown in Gezira Scheme are: Cotton, Dura (Sorghum), Wheat, Groundnuts, Vegetables, Fruits, and Fodder.

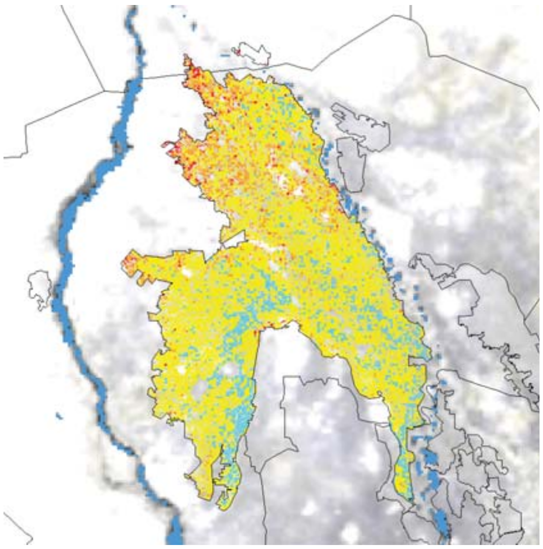
The total water consumption and biomass production have been computed for the year 2007. The results are shown on the next page. The map of actual evapotranspiration shows ET values of 8,000 to 10,000 m^3/ha/yr in the southwestern part of the scheme. This water is conveyed across a long distance. Except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



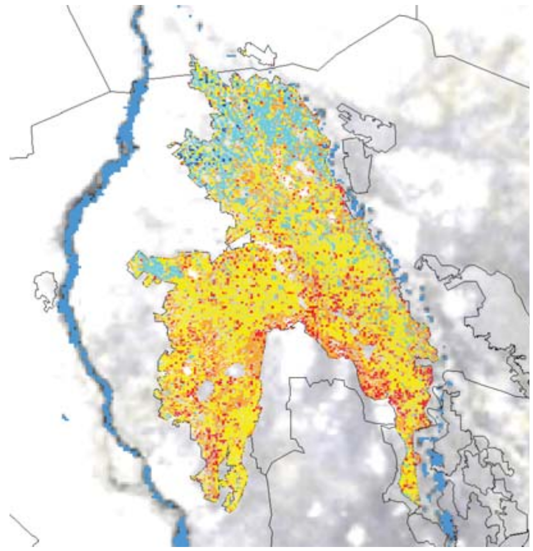
The spatial patterns of biomass production is similar to ET. The largest agricultural production levels are obtained at the southwestern tip of the Gezira scheme. The impression exists that there is a deviating cropping pattern in this part of the LSI system. From a climatic point of view, this could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



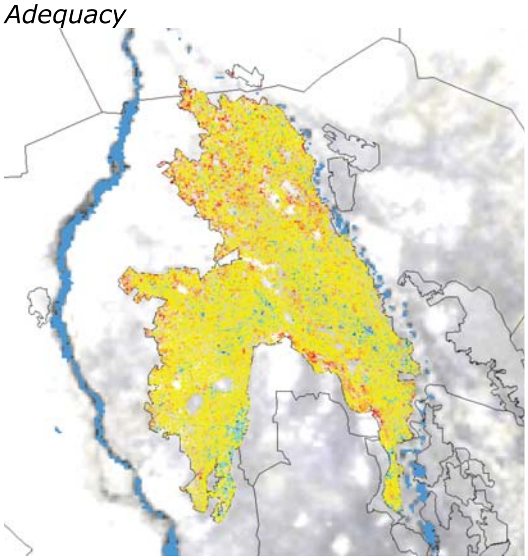
The score for every irrigation indicator has been computed for every 250 m pixel. The values of the score vary between 1 (minimum=brown) to 5 (maximum=blue). The sustainability and reliability of Gezira is high. This implies that there is a very regular pattern of irrigation water supply, and that the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



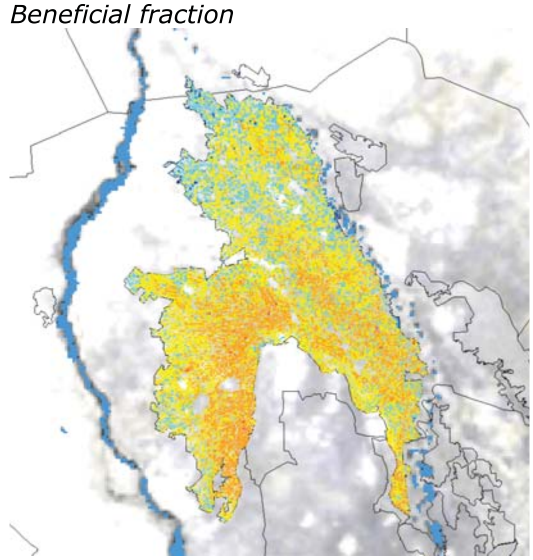
Adequacy



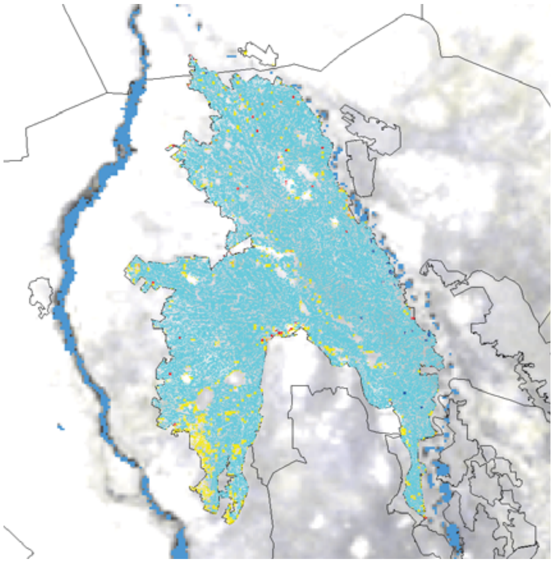
Beneficial fraction



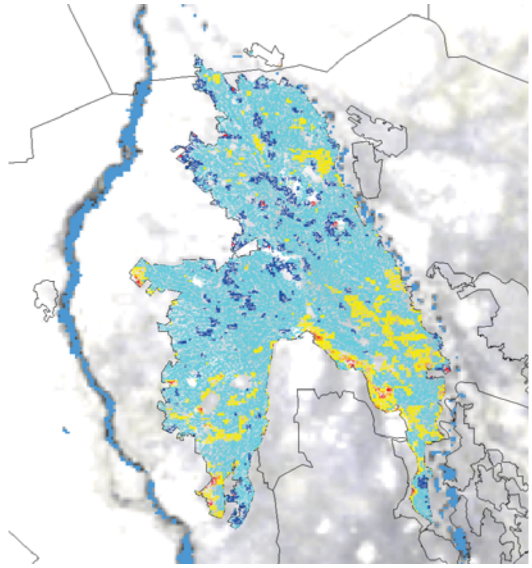
Biomass production



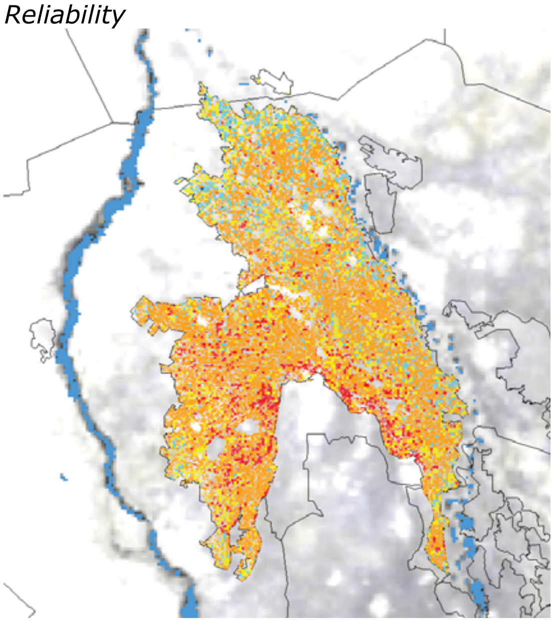
Crop water consumption



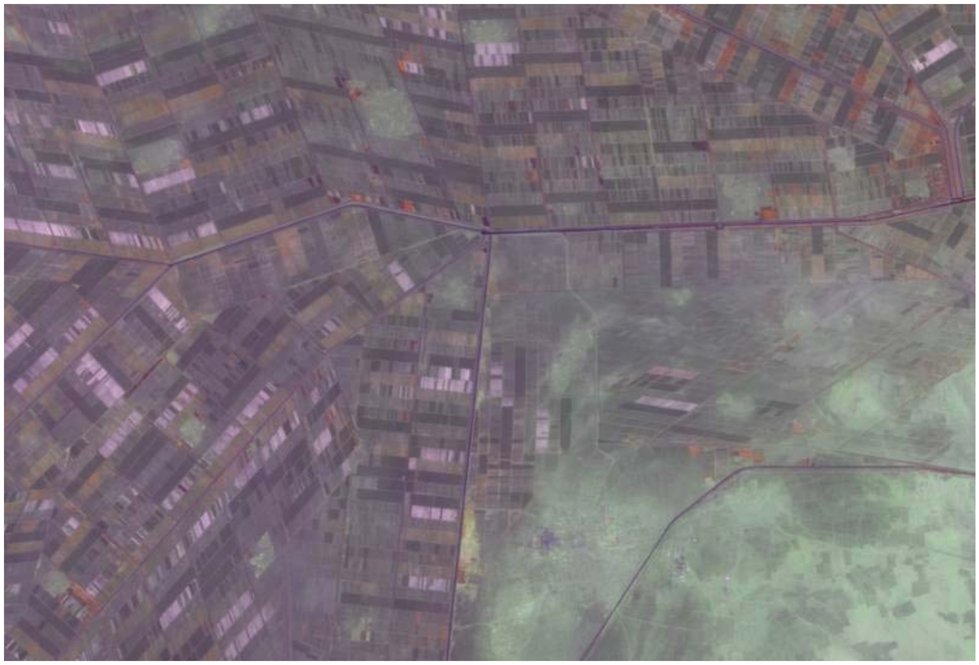
Reliability



Sustainability



Water productivity

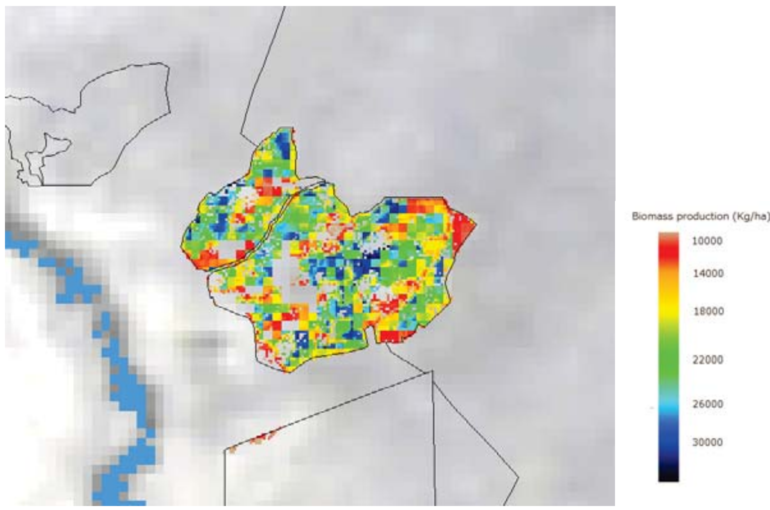


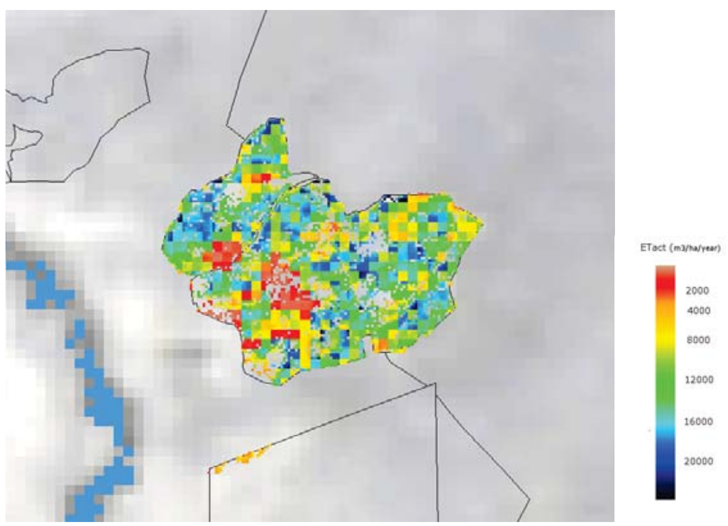
Landsat image of the central part of the Gezira scheme. Fields with a red color are cropped. The dark colored fields are bare. The fields with white color are vegetables with specific mulch treatments

Landsat image of Kenana farm. Red color can be associated with vigorous sugarcane. The grey plots are fallow or recently planted sugarcane shoots

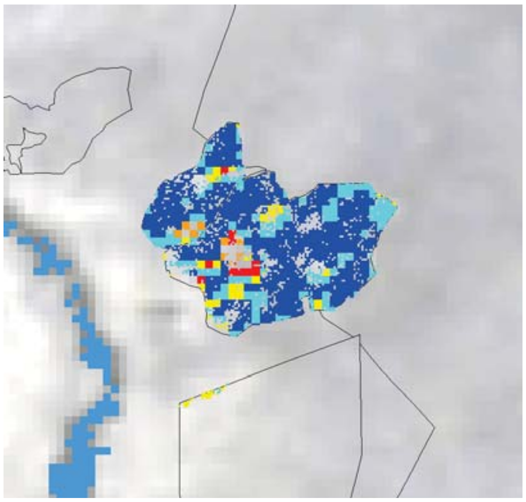
Kenana

The sugarcane estate of Kenana comprises some 50,000 ha of irrigated land. It is a commercial enterprise and the water is diverted directly from the White Nile. This area has been selected for the sake of comparison against the publicly managed Gezira scheme. The results reveal that the crop water consumption is generally much higher than for Gezira. The average value is approximately 12,000 m³/ha/yr and certain sections reach even values up to 20,000 m³/ha/yr. These values are in agreement with the ET values considered to be normal for sugarcane. The resulting biomass production varies from 20,000 to 30,000 kg/ha/yr. This is equivalent to an approximated fresh cane yield of 60 to 100 ton/ha. The picture shows that certain plots have low levels of cane production. These are either areas that are fallow, or planted with young shoots.

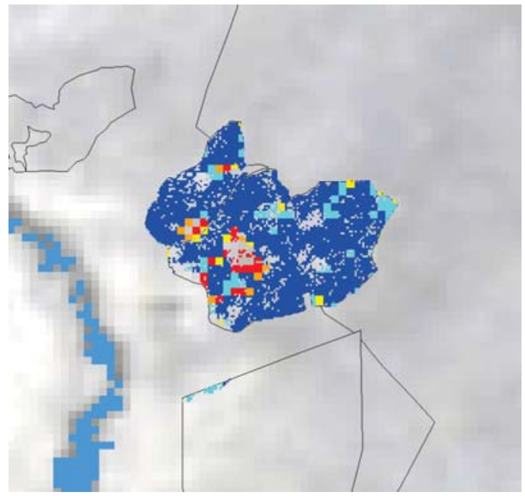




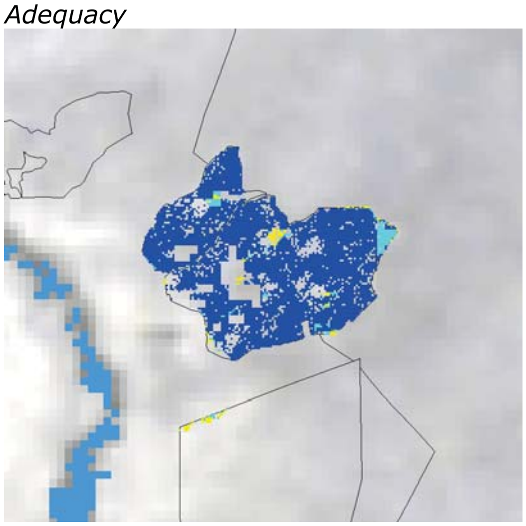
The adequacy and beneficial fraction have both a very good score (blue). This implies that irrigation water is supplied with sufficient quantities and that most water is consumed by beneficial crop transpiration. The non-beneficial evaporation losses are thus very small in Kenana (in contrary to Gezira). For this reason, the beneficial fraction is very high. The biomass production values are the highest of the region, and they have a score of almost 5.0. The crop water consumption is quite high for achieving this significant sugar production. That is also the chief reason for the water productivity being moderate. Most of the pixels have a score of 3.0, which is better than Gezira, but lower than other values attainable under the same climatic conditions. The reliability is good, but could be improved for a commercial mono-cropping sugar estate. The areas with a lower reliability reflect with a lower crop ET and a negligible biomass production. The overall sustainability is satisfactory, although certain fields on the farm are not ideal. This pixel based irrigation performance can help the irrigation management on the Kenana farm.



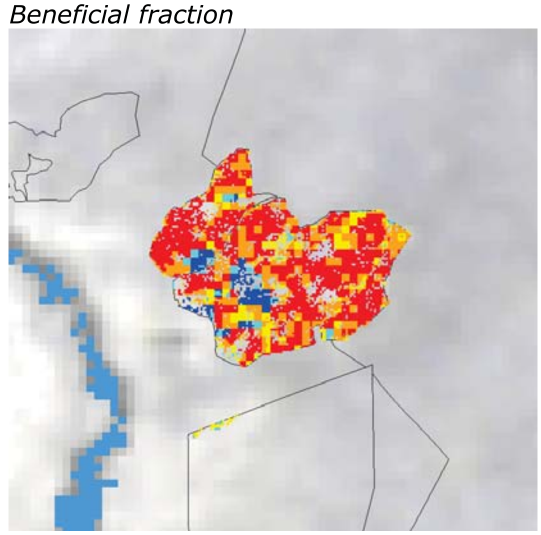
Adequacy



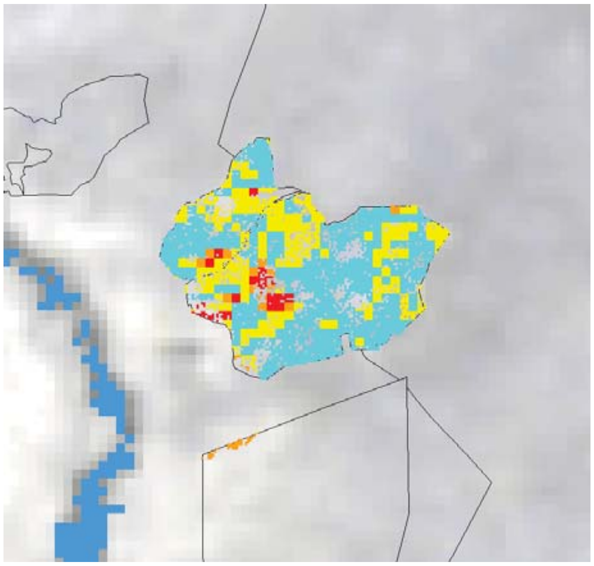
Beneficial fraction



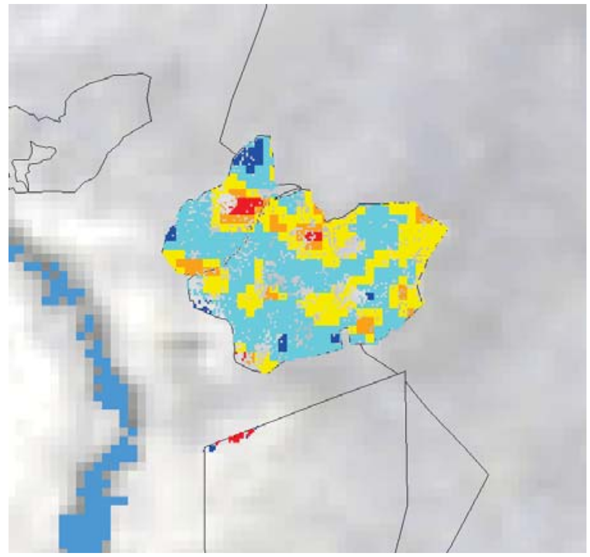
Biomass production



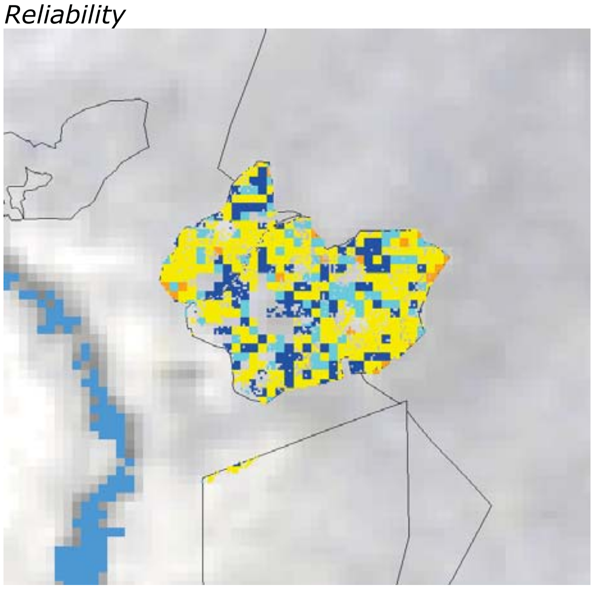
Crop water consumption



Reliability



Sustainability

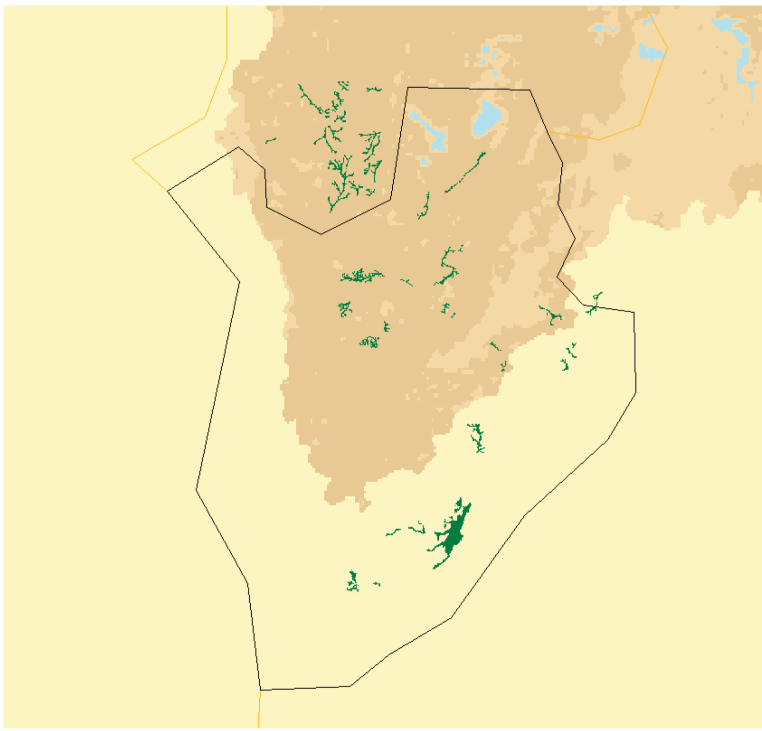


Water productivity

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Burundi



Appendix D

January 2009

Table of contents

Purpose of this report:

This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Burundi and will become an integral component of the final LSI report that will combine results from all countries.

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

Burundi is landlocked between Rwanda in the North, DRC Congo in the West, and Tanzania in the East (Figure 1). It covers an area of 27,834 Km^2 and in 2002 the cultivated area was approximately 1,350,000 ha.

Burundi is located in two basins: 13,800 km² of Burundi lies in the Nile Basin (delineated by the blue line in Figure 2); the southern and western part of the country drain into the Congo basin. The irrigated areas in the latter portions of the country are thus not included in the current analysis.

The agricultural sector in Burundi is very important for the national economy, even though the undulated topography and steep slopes are not very favourable for agriculture. The agricultural techniques are therefore still primitive and the irrigated area per household is on average low (about 0.5 ha). In the areas in the vicinity of streams and wetlands, some lands are being irrigated (represented by the red areas on Figure 2) but it represents a very small percentage of the total agricultural area.

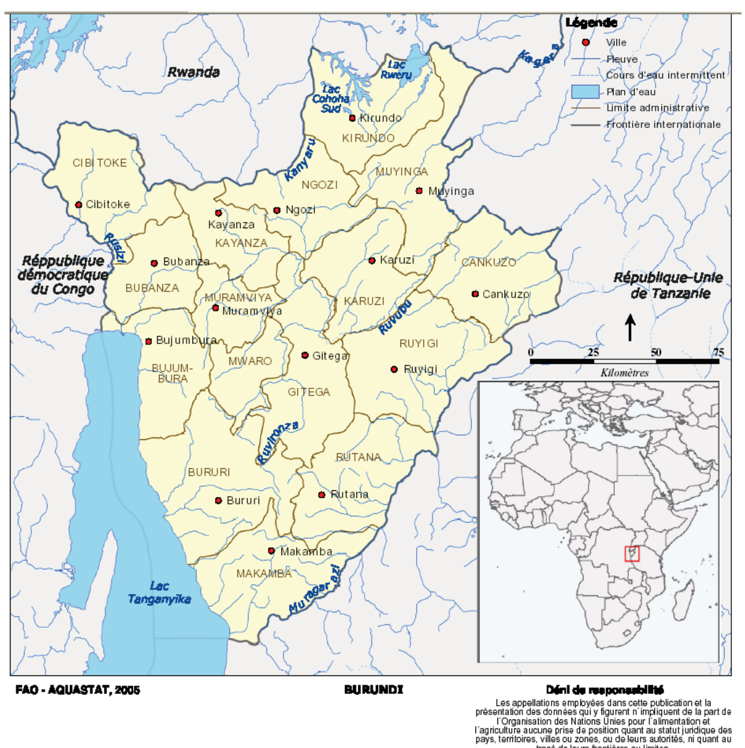


Figure 47 Burundi and its administrative districts

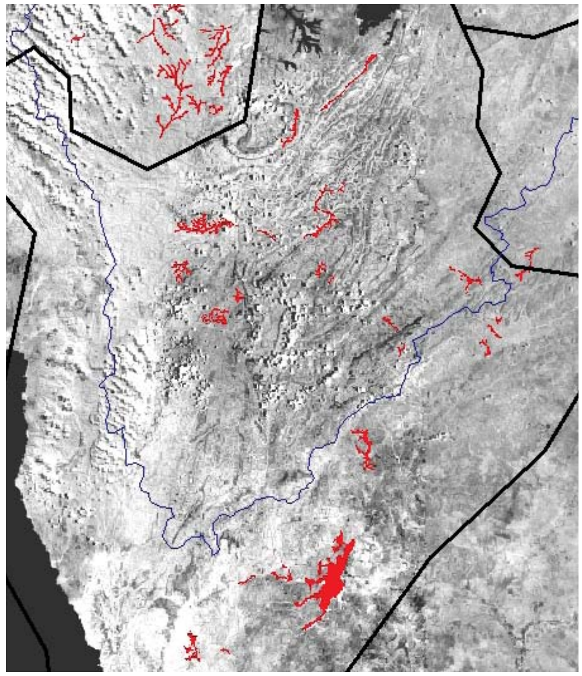


Figure 48 Map showing the distribution of the irrigated areas within the Nile Basin according to the LSI participants of Burundi.

Table 37 shows that an area of 14,625 ha of irrigated land is located in the Nile Basin. It is relatively small compared to the estimated potential irrigable surface of 215,000 ha, according to a survey carried out by the Department of Rural Engineering. The predominant irrigation method is surface irrigation which derives water from rivers by pumping and from small diversion dams. Storage dams are not yet needed as the extent of irrigation is limited and the period of rice cultivation corresponds with the rainy season (December-January to May).

Table 37 Different sources for the irrigation statistics for Burundi

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Burundi	14,400
IWMI – GIAM	Entire Burundi	11,793
Current study	Nile Basin component of Burundi	14,625

According to the FAO AQUASTAT (2005) the main irrigated crop in Burundi is rice, with a total surface of about 4,200 ha, as shown in Figure 3. The rice yield varies between 3 to 3.5 ton/ha (Gitega province). The other main irrigated crops are sugarcane, maize, beans, vegetables and coffee. Other major crops are banana (first in terms of volume production) and cotton. A land use map of Burundi is provided in Annex 2. Figure 4 displays the cropping calendar.

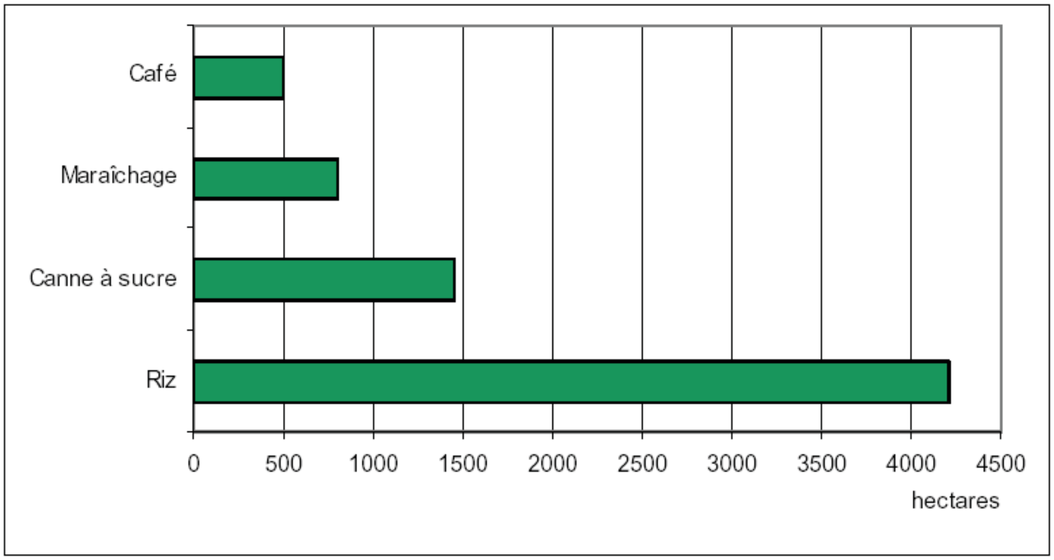


Figure 49 Main irrigated crop in 2000 (source: AQUASTAT 2005)
(café=Coffee; Maraichage=vegetables; Canne a sucre= sugar cane; Riz= Rice)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
BURUNDI													
Rice	17												
Rice-one			17	17	17	17	17						
Rice-two		17								17	17	17	17
Maize	43												
Maize-one			43	43	43	43	43						
Maize-two		43								43	43	43	43
Sorghum	18												
Sorghum-one			18	18	18	18	18						
Sorghum-two		18								18	18	18	18
Sugarcane	3	6	6	6	6	6	6	6	6	6	6	6	6
Vegetables	9												
Vegetables-one		6	6	6	6								
Vegetables-two						6	6	6	6				
Vegetables-three										6	6	6	6
All irrigated crops	90	90	90	90	90	90	90	12	12	90	90	90	90
Equipped for irrigation	50												
Cropping intensity	180												

Table 38: Cropping calendar for Burundi (source: AQUASTAT, 2005)

1.2 Description of LSI

Even though the unit of analysis in this study is the district, information on the irrigation systems within these districts, and the sources of irrigation water is informative (Table 39).

Table 39 Description of a few irrigation districts

Irrigation district	Province	Commune	Surface equiped with irrigation	Irrigation water
NYAMUGARI	KARUSI	BUHIGA	148 ha	Surface Irrigation Diverted from river
KAGOMA	NGOZI	NGOZI	187 ha	Surface Irrigation Diverted from river
NYAKAGEZI	KAYANZA	MUHANGA	123 ha	Surface Irrigation Diverted from river
NYARUBANDA	KAYANZA	MATONGO	187 ha	Surface Irrigation Diverted from river

These four districts have the same characteristic: river water is available throughout the year. There are three main cropping seasons: rice is cultivated in the first season, which starts in November-December. This corresponds with the rainy season. Maize is the main crop cultivated in the second season, which starts in May-June, followed sometimes by a third season in which mainly beans are cultivated.

More detailed information concerning irrigation in Burundi can be found in Annex 4.

Part 2 Climate

2.1 Climatological conditions

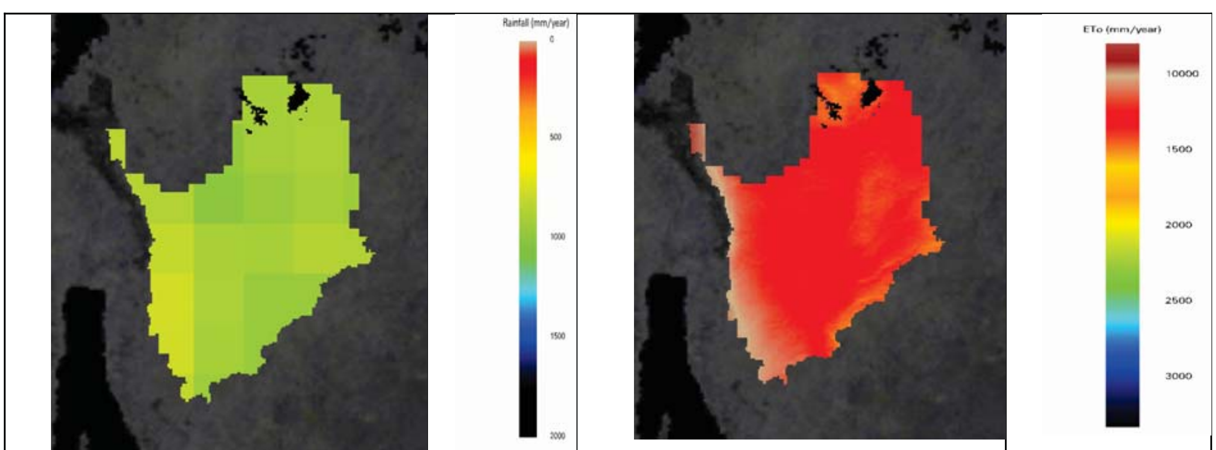
Burundi receives a significant amount of rainfall. The rainfall season is continuous and long, running from September to May. June, July and August are dry, and this is the period that irrigation is typically needed. According to the Ministry of Territorial Development and Environment (2001) and to FAO (AQUASTAT,2005) the water balance for a normal year is as follows:

- Average annual rainfall: 1274 mm
- Average evapotranspiration (ET): 872 mm

Table 40 shows the monthly values for rainfall and reference evapotranspiration (ET_0). The rainfall is based on TRMM satellite data. The ETo is computed with the standardized Penman-Monteith equation specified in FAO56.

Table 40 Monthly values for rainfall and ET_0.

Month	Rainfall (in mm)	ET_0 (in mm)	Aridity (P/ET_0)
January	97	105	0.92
February	106	101	1.05
March	131	108	1.21
April	181	95	1.91
May	91	99	0.92
June	8	107	0.07
July	1	122	0.01
August	17	132	0.13
September	59	125	0.47
October	97	122	0.80
November	146	102	1.43
December	106	99	1.07
TOTAL	1040	1317	



Annual rainfall | Annual reference ET

Figure 50 Spatial variation of rainfall (left) and ET_0 (right) for the part of Burundi that is located in the Nile Basin.

ET_0 exceeds rainfall during seven months and this shows the need of irrigation systems. The monthly water shortage occurs in June to September when the aridity index is lower than 0.5. The highest ET_0 rates occur in the plain area at the east side near Tanzania. Due to the long rainfall season, Burundi is more commonly known as a rainfed agricultural country, rather than an irrigation country.

2.2. Climatic zones

The current study aims to provide information for improved irrigation practices in the Nile Basin and covers various climate zones. This hampers a comparison between countries and among schemes. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities. Unexpected rainfall can for instance reduce the irrigation efficiency, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences on the basis of diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

The irrigation schemes of Burundi are located in climate zone 4 (humid tropics).

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on the data send by the LSI representatives of Burundi. The first step was to compute all the indicators per pixel. All the RO and PO indicators have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. These annual accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

Sustainability indicators were obtained by investigating the last five year's trends of vegetation index (from the SPOT-Vegetation satellite) and soil moisture (from the AMSR-E satellite). It indicates the slope of the trend line over these past years.

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined. A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 6).

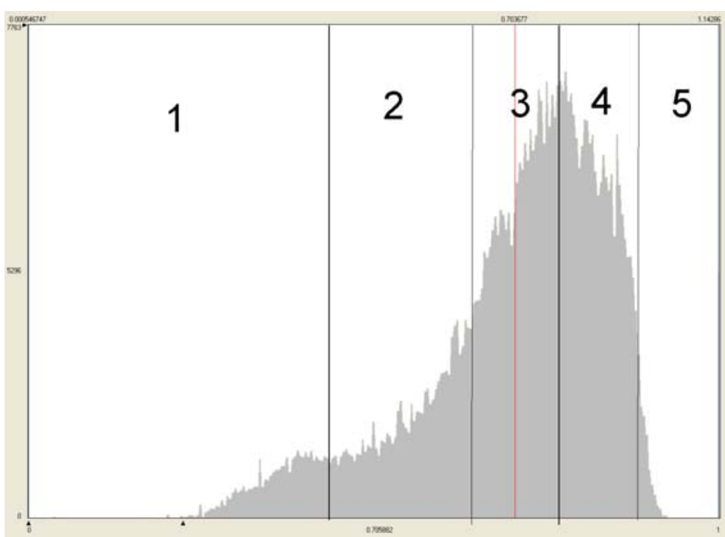


Figure 51 Distribution of the values of one indicator over 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems included in different climatic zone, different benchmark values are considered to avoid any climatic bias in the allocation of the score. Burundi is located in climatic zone 4.

Table 41 Benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
Bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
Cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
Cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
Bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
Ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
Un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
Rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
Spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
Amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, district average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at Country level

As displayed in Figure 7, the average score considering all the indicators together for all the 14,625 ha of irrigated land is 3.6, which is an above average score (the average score being 3). It shows that the irrigation systems in Burundi are sound. This average is translated into scores for each individual indicator. The aspects that Burundi should provide more attention to are those with a relative low score.

The scores of 2.8 for land productivity and 2.9 for water productivities are lower than average but still reasonable.

Concerning the PO indicators, more attention should be given to beneficial fraction. A low beneficial fraction shows a significant amount of non-beneficial ET losses. The lower than expected performance of this last indicator might explain the wide range of the land and biomass water productivity. Because the crop water consumption is quite high and the beneficial fraction low, it leads to relatively low biomass water productivity. On the other hand, there is good performance in terms of reliability, uniformity, and crop water deficit. Because irrigation water supply is continuous in time (as mentioned in 1.3), farmers are not restricted in their application of water; so the crop water deficit is low (it gets a high score). Similarly, they can rely on timely availability of water; so reliability is high.

The sustainability of irrigation practices in Burundi seems to be very good. Compared to the previous years, irrigated land is becoming greener (as the score for the land sustainability is higher than 3), hence the irrigation systems are healthy and continuous. The soils are gradually getting wetter (water sustainability gets the maximum score of 5).

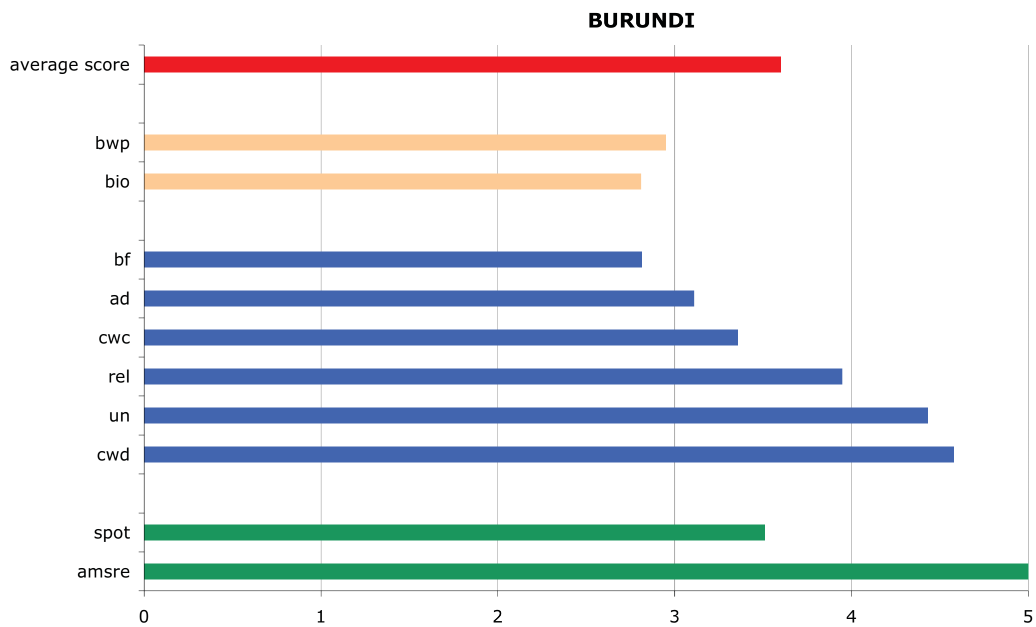


Figure 52 Representation of the average score for each indicator in Burundi.

3.3 Results at district level

3.3.1. Average per district

In Burundi, seven districts[11] have more than 187.5 ha of irrigated land (more than 30 pixels of 6.25 ha). In Figure 8 the average scores for all indicators per district are compared. It can be noticed that all the districts have a good and uniform performance on average, ranking from 3.6 and 3.8, the best district being Buziga and the poorest performing one Bugendana (see Figure 9 for their location). The equal performance per district results in an excellent score for the country level.

[11] According to the LSI representatives, there are more than 7 districts with more than 187, 5 ha of irrigated land. There are for example 349, 35 ha in the district of Buhiga (province of Karuzi) and Gitaramuka in the province of Karuzi with 293 ha.

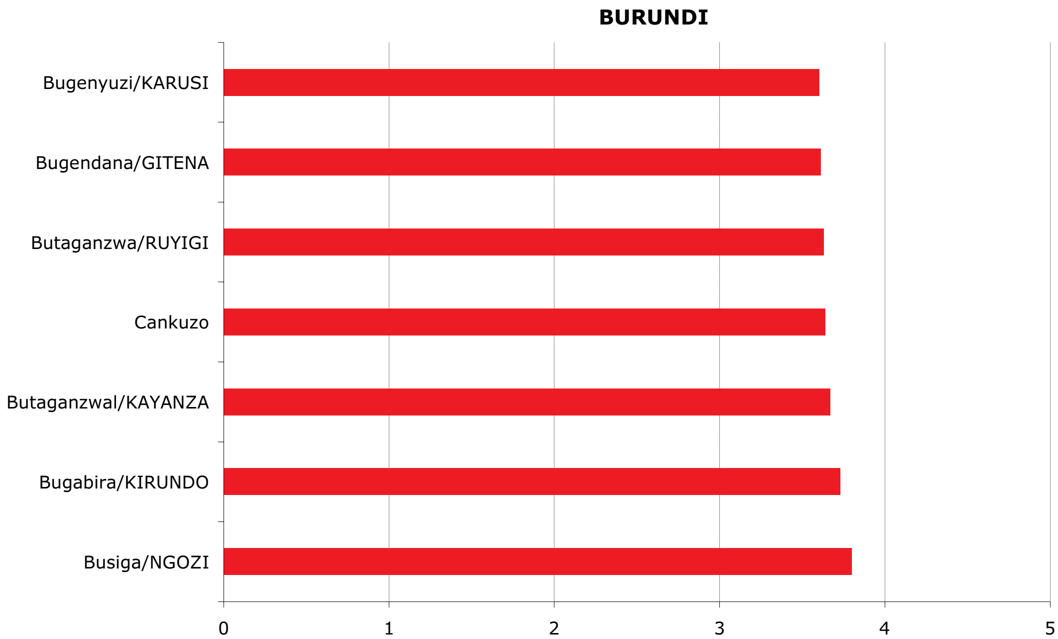


Figure 53 Representation of the total score for Burundi for each district.

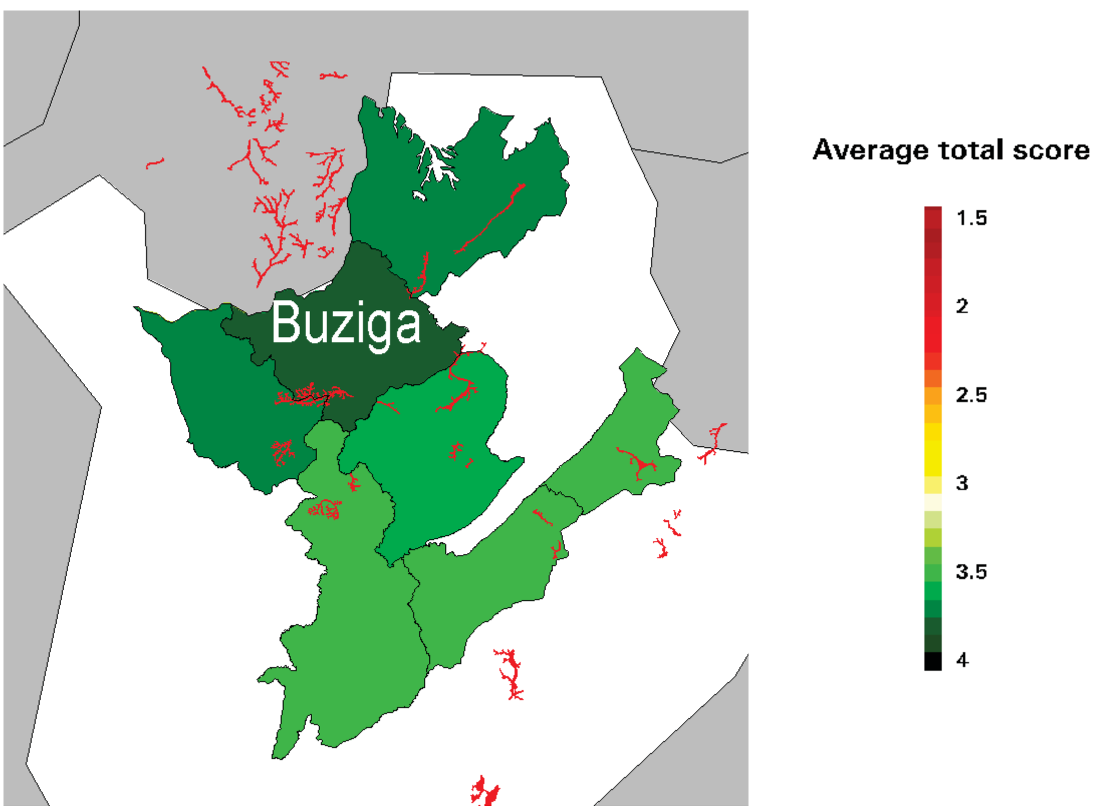


Figure 54 Map showing the total score per irrigated district.

3.3.2. Breaking down the total score into RO indicators, PO and sustainability indicators.

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 10 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance and enables ranking of the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

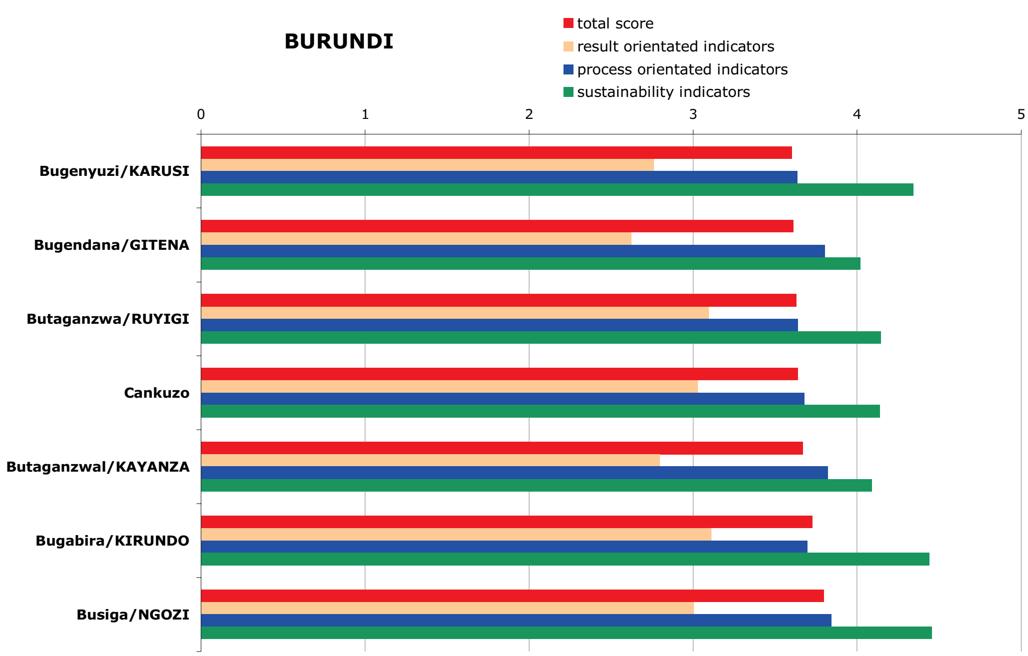


Figure 55 Breaking down the total score per indicator

The first aspect that draws attention is that each of the 7 districts of Burundi presents more or less the same score for each category of indicators, which in turn is linked to the uniform conditions encountered at country level. This could be ascribed to the relative small size of the country and the uniform climate.

As far as the RO indicators are concerned, the average of the water and land productivity is quite low (between 2.6 and 3.1). Hence, irrigation should become more output orientated.

Concerning the PO indicators, the seven districts of Burundi get a good and homogeneous score, ranking from 3.6 to 3.8. These high scores make it difficult to draw improvement recommendations relating to the functioning of the irrigation systems.

Regarding the land and water sustainability, it is really good. The score for all the districts are comprise between 4 and 4.4.

3.4 Analysis per pixel for an irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the neighboring districts of Butaganzwal/KAYANZA and Buziga/NGOZI, which are the two best districts in terms of performance. The 6th PO indicator uniformity cannot be displayed as it is an indicator at district level. This example demonstrates that at certain places, crop water consumption and beneficial fraction should be managed better (Figure 11).

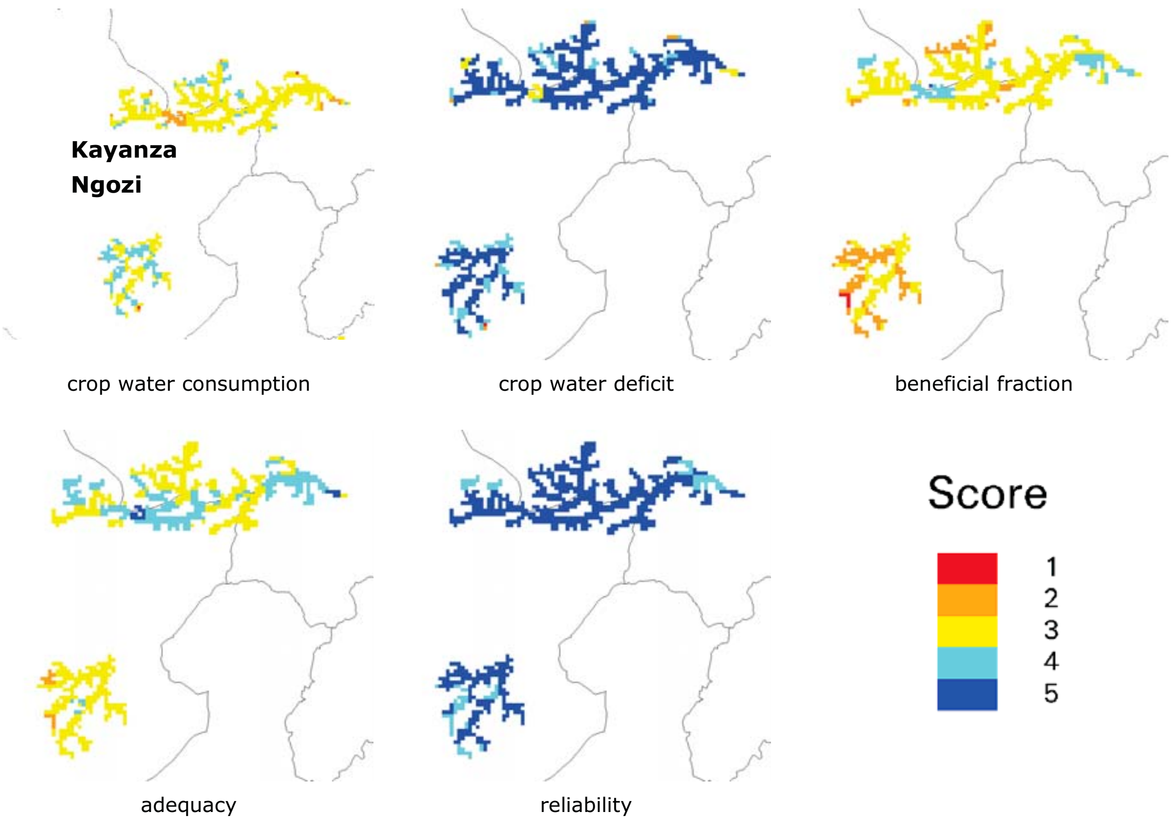


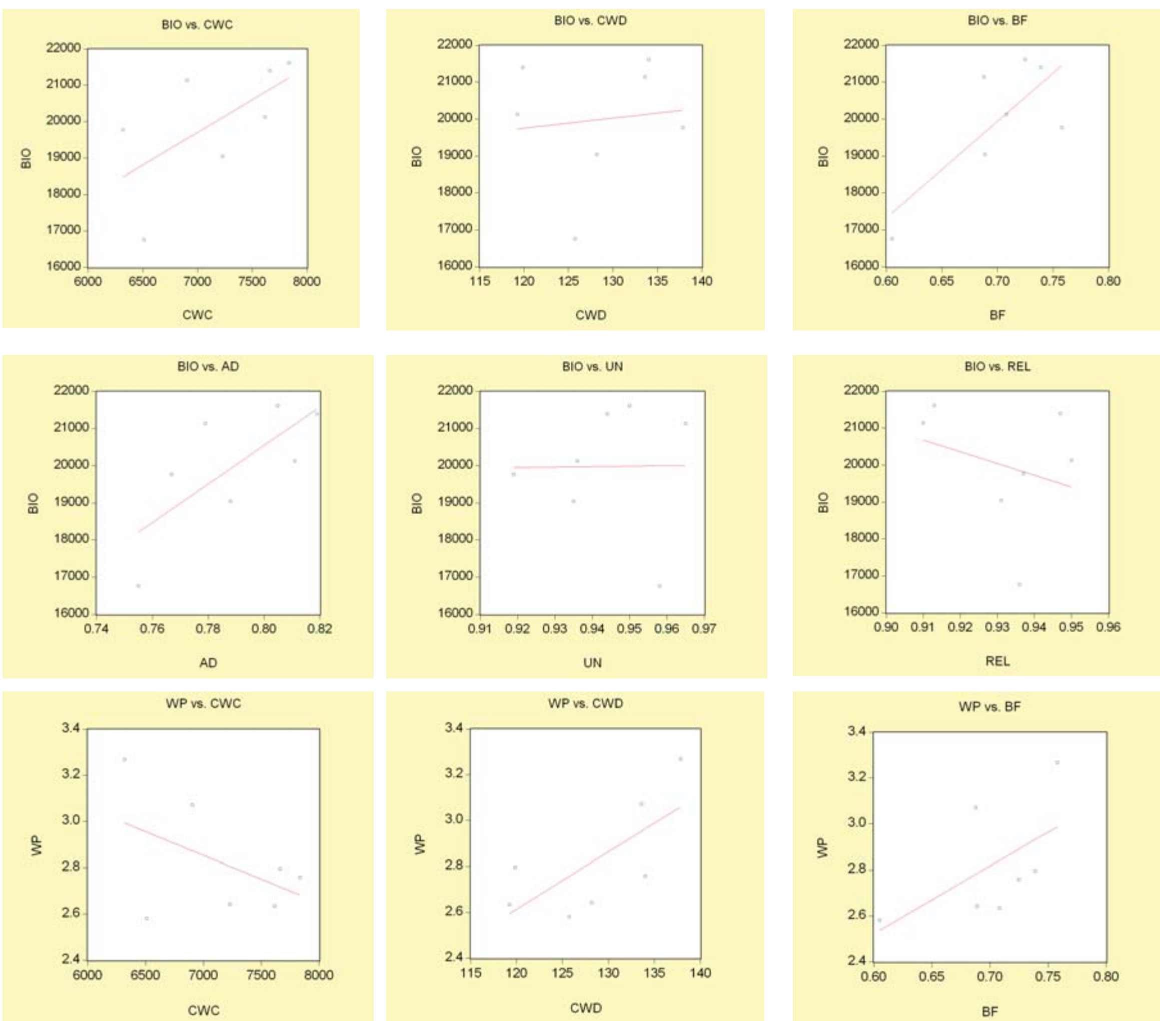
Figure 56 Spatial distribution of each indicator for the districts of Butaganzwal/KAYANZA and Busiga/NGOZI

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the seven districts. It showed that beneficial and crop water consumption are the two main explanatory factors for biomass water productivity and biomass production. An increase in beneficial fraction leads to an increase in biomass production and biomass water productivity. An increase in crop water consumption leads to an increase in biomass production but a decrease in biomass water productivity. No clear relationships could be identified for the other indicators.

This shows that methods should be investigated to convert non-beneficial evaporation into transpiration. This can be achieved with intercropping and other measures that increase Leaf Area Index.



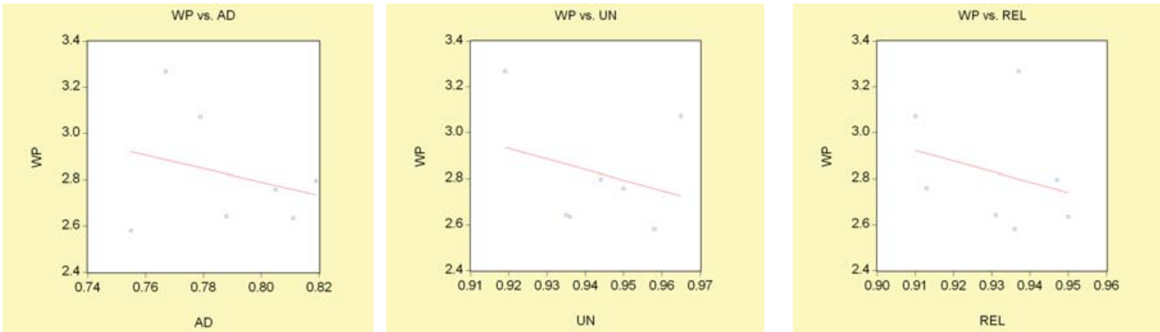


Figure 57 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationships between the indicators are better understood, the next step is to identify the weakest elements per districts. In Table 42, the best and poorest indicators are presented.

It appeared that all irrigation districts function relatively similarly. Beneficial fraction and adequacy are the main problems (it is the worse indicator for almost all districts), as well as the low biomass production and the low beneficial fraction. On the other side of the scale crop water deficit, reliability and uniformity always appear to be the best indicators. These results typically apply to a humid country with high rainfall rates.

Table 42 Best and poorest PO irrigation indicator per district

District	Lowest		2nd lowest		2nd best		Best	
Bugenyuzi/KARUSI	bf	2.79	ad	3.06	rel	4.05	cwd	4.59
Bugendana/GITENA	bf	2.18	ad	3.06	cwd	4.76	un	5.00
Butaganzwa/RUYIGI	bf	2.79	ad	2.95	cwd	4.69	un	5.00
Cankuzo	bf	2.90	ad	2.92	cwd	4.59	un	5.00
Butaganzwal/KAYANZA	bf	2.80	ad	3.15	cwd	4.76	rel	4.86
Bugabira/KIRUNDO	bf	3.17	ad	3.32	cwd	4.04	rel	4.39
Buziga/NGOZI	bf	2.99	cwc	3.16	rel	4.77	cwd	4.77

4.3 Recommendation countrywide

According to the LSI country participants, the purpose of LSI systems in Burundi is to ensure food security, increase rural incomes, and create jobs. However, it has also been mentioned in different reports that food production is relatively unstable and is unable to keep pace with the rise in population (after Rwanda, Burundi is the second biggest country in terms of population density: ranging from 254 persons/km^2 to 400-500 persons/km^2). Ensuring food security should definitely be high on the agenda.

The results of this study are confirming that fact. It has shown than one of the weakest aspects of irrigated agriculture in Burundi is the land productivity. Expanding the irrigated surface could enable higher food production, but it is probably better to in the first place invest on improving the performance of the existing irrigation systems. The idea is to increase land productivity for the existing irrigated areas without increasing crop water consumption, because it is already too high. Thus, special attention should be given to introduce or develop agronomic extension services that could advise on the use of fertilizer or improved seeds stock.

According to LSI country participants there are no water quotas for LSI systems. Specifying water rights (absolute volumes, proportions, guaranteed minimum) to major users could help to decrease water consumption. Also, priorities are not specified for water allocation amongst the sectors (domestic, agriculture, industry, etc.). Implementing an irrigation policy in the future could also help with allocating the water more evenly between the sectors.

Reducing erosion and loss of soil fertility is also one major aspect to focus on according to different reports. The fact that soils are degrading is not coming out of our results as Land sustainability gets a score higher than 3, but it may be because of the short period covered by our report (our analysis only reflects the trend over the past 5 years).

According to LSI country participants, government departments are responsible for planning, design, construction, operation and in some cases maintenance, of LSI schemes, if not delegated to water user associations. The government could also invest in modernizing the irrigation infrastructures. Irrigation systems are outdated and insensitive to climatic variations. Investing in storage of rainfall could also improve the reliability, even though it is already very good. If farmers know that they can rely on the supply of water, they might use it more efficiently and apply irrigation at more appropriated times, which would also help to increase biomass water productivity as well as the beneficial fraction.

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Ministère de l'aménagement du territoire et de l'environnement, 2001. «La politique nationale de gestion des ressources en eau et plan d'actions».

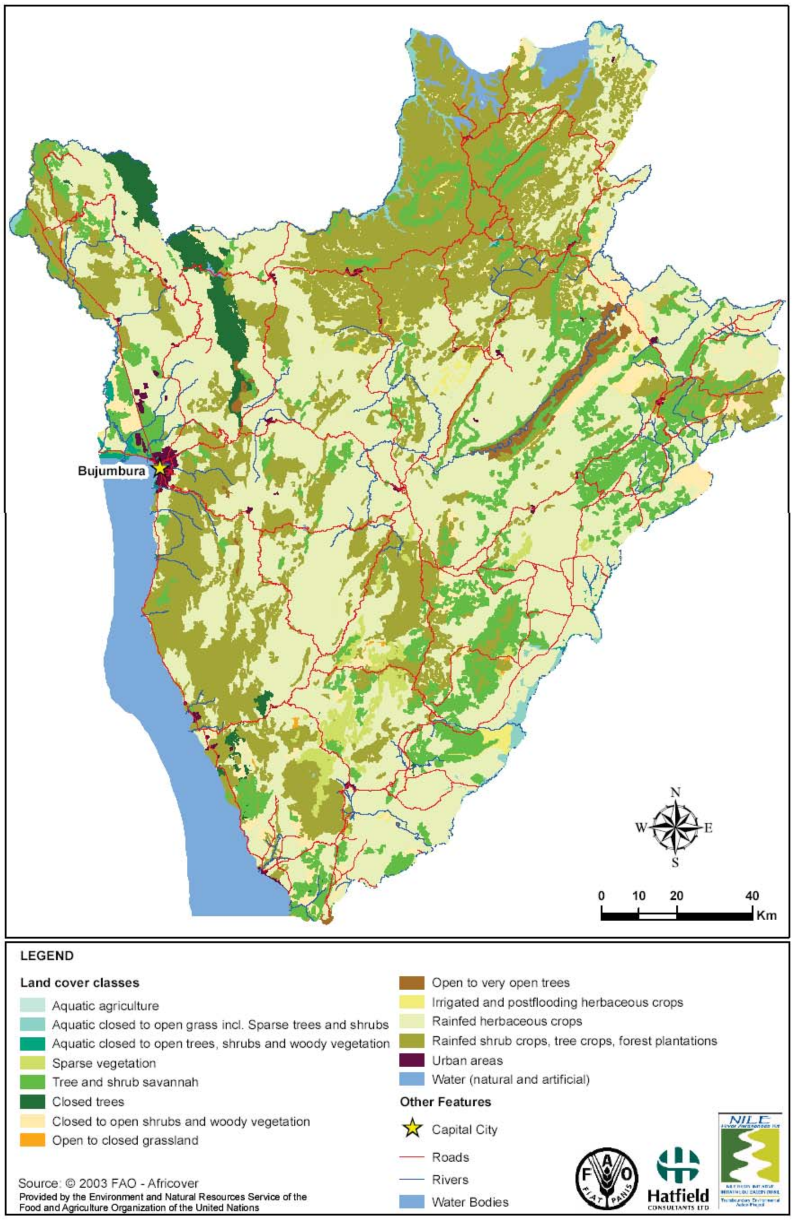
Ntamavukiro, A. 2007. Projet «Utilisation efficace de l'eau pour la production agricole». Initiative du Bassin du Nil. Etat des lieux sur l'utilisation de l'eau pour la production agricole. Cas du Burundi. Bujumbura, août 2007

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m^3	Bio/ET_{act}	High return from total water used by a crop
PO	Crop Water Consumption	cwc	$M^3/ha/year$	ET_{act}	Saving of water resources
	Crop water deficit	cwd	$M^3/ha/year$	$ET_{pot}-ET_{act}$	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	T_{act}/ET_{pot}	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	T_{act}/T_{pot}	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	$1-CV(T_{act}/T_{pot})(x,y)$	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	$1-CV(T_{act}/T_{pot})(t)$	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 Burundi Land cover (FAO, 2003)

Generalized Land Cover Map of Burundi



Disclaimer - The boundaries, colors, denominations and any other information does not imply, on the part of the NBI, any judgement or legal status of any territory, or any endorsement or acceptance of such boundaries.

Annex 3 General information on irrigation conditions in Burundi (FAO, 2005)

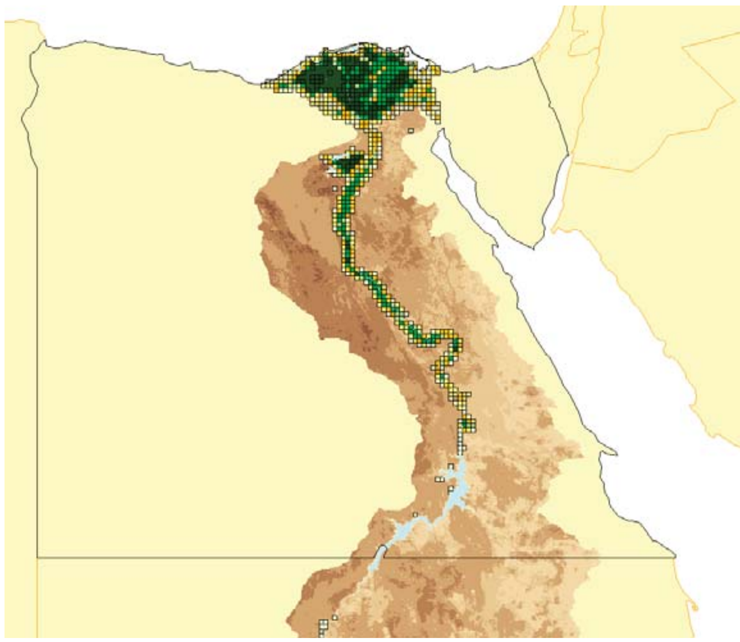
Irrigation et drainage

Potentiel d'irrigation			215 000	ha
Contrôle de l'eau				
1. Irrigation, maîtrise totale/partielle: superficie équipée		2000	6 960	ha
- irrigation de surface		2000	6 960	ha
- irrigation par aspersion			-	ha
- irrigation localisée			-	ha
• partie irriguée à partir des eaux souterraines			-	%
• partie irriguée à partir des eaux de surface			-	%
2. Zones basses équipées (marais, bas-fonds, plaines, mangroves)		2000	14 470	ha
3. Irrigation par épandage de crues			-	ha
Superficie totale équipée pour l'irrigation (1+2+3)		2000	21 430	**ha**
• en % de la superficie cultivée		2000	1.6	%
• augmentation moyenne par an sur les 15 dernières années		1985-2000	2.7	%
• superficie irriguée par pompage en % de la superficie équipée			-	%
• partie de la superficie équipée réellement irriguée			-	%
4. Marais et bas-fonds cultivés non équipés		1999	83 000	ha
5. Superficie en cultures de décrue non équipée			-	ha
Superficie totale avec contrôle de l'eau (1+2+3+4+5)		**2000**	**104 430**	**ha**
• en % de la superficie cultivée		2000	7.9	%
Périmètres en maîtrise totale/partielle	**Critère**			
Périmètres d'irrigation de petite taille	< 50 ha	2000	800	ha
Périmètres d'irrigation de taille moyenne	> 50 ha et < 100 ha	2000	500	ha
Périmètres d'irrigation de grande taille	> 100 ha	2000	5 660	ha
Nombre total de ménages en irrigation			-	
Cultures irriguées dans les périmètres en maîtrise totale/partielle				
Production totale de céréales irriguées		2000	25 260	tonnes
• en % de la production totale de céréales			10	%
Superficie totale en cultures irriguées récoltées			-	ha
• Cultures annuelles/temporaires: superficie totale			-	ha
- riz		2000	4 210	ha
- canne à sucre		2003	1 450	ha
- légumes		2003	800	ha
- café		1997	500	ha
- Cultures permanentes: superficie totale			-	ha
Intensité culturale des cultures irriguées			-	%
Drainage - Environnement				
Superficie totale drainée			-	ha
- partie de la superficie équipée pour l'irrigation drainée			-	ha
- autres surfaces drainées (non irriguées)			-	ha
• superficie drainée en % de la superficie cultivée			-	%
Superficie protégée contre les inondations			-	ha
Superficie salinisée par l'irrigation			-	ha
Population touchée par les maladies hydriques liées à l'eau			-	habitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Egypt



Appendix E

January 2009

Table of contents

Purpose of this report:

This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Egypt and will become an integral component of the final LSI report that will combine results from all countries

Disclaimer: National and district boundaries in this report are based on data from various internet sources of different years, and do not reflect current political reality. Modern country names and boundaries have not always been added and their omission does not indicate support or non-support of any nation.

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

Figure 58 Map of Egypt and its districts

Egypt has a history of 6000 years of irrigation. The uncertain and erratic flow of the Nile river, and the need for water supply throughout the entire year has inspired the Egyptians and the British imperial rulers to construct large storage reservoirs in the Nile such as at Aswan. The high Aswan dam was constructed in 1964 and can store 169 BCM water. The presence of huge storage facilities has inspired the development of double and even triple cropping systems. The soils of the delta – and also in the river valley – have rich sediments, and are extremely suitable for irrigation practices. Figure 58 displays the different districts in Lower Egypt that will be used as units of analysis in this study.

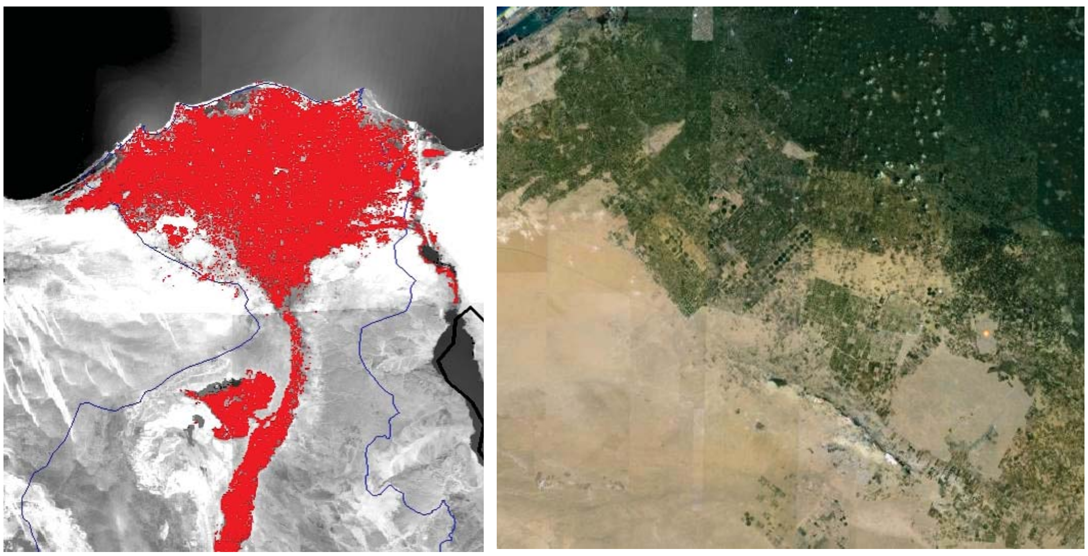


Figure 59 Map showing the distribution of irrigated areas in Lower Egypt according to the FAO-GMIA product, and being refined in the current study. The red dots on the left hand side represent irrigated land

This study estimates the irrigated area to be 3 million ha, of which 85% is in the Nile Valley and Delta. The total irrigated area is 7, 2 million feddan (one feddan is 0.42 ha). Our estimate is larger than the IWMI estimates (2.1 million ha) and smaller than the FAO estimates (3.2 million ha). The irrigated area in Egypt is approximately 60% of all irrigated land present in the Nile Basin.

Table 43 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Egypt	3,245,650
IWMI – GIAM	Entire Egypt	2,144,099
Current study	Nile Basin component of Egypt	2,963,581

1.2 Description of LSI

Around 3 million ha is intensively cultivated annually and 85% of this is in the Nile Valley and Delta. The irrigation system in the old land of the Nile Valley is a combined gravity and water lifting system (lift: about 0.5-1.5 m). The irrigation system in the new lands (reclaimed areas) is based on a cascade of pumping stations from the main canals to the fields, with a total lift of up to 50 m. Surface irrigation is banned by law in the new reclaimed areas, which are located at the end of the systems, and are more at risk of water shortage. Farmers have to use sprinkler or drip irrigation, which are more suitable for the mostly sandy soil of those areas.

Egypt's irrigation system extends over 1,200 km, from Aswan to the Mediterranean Sea and includes 2 storage dams at Aswan, and 7 major barrages on the Nile that divert river water into an extensive network of irrigation canals. This includes 13,000 km of main public canals, 19,000 km of secondary public (Branch), and 100,000 km of tertiary private watercourses (mesqas). The mesqa systems are owned, operated and maintained by farmers. They form the main water distribution system to farmer's fields. Complimentary drainage networks cover about 272,000 km with 17,500 km of main drains, 4,500 km of open secondary drains, and 250,000 km of covered secondary & tile drains. While the traditional irrigation systems are all government operated and exists of small land holdings, new settlements in the Western Desert along the Cairo – Alexandria road arose through private investments and full blown commercial agro-business operations. These systems also occur along the Ismailaya Road. These new estates use micro-irrigation technologies on light textured soils, as opposed to surface irrigation methods on heavy textured soils in the Delta and Valley.

In the case of Egypt, the following classification is used to differentiate the irrigation systems according to their scale (according to the LSI participants from Egypt):

- 450 ha is considered a small scale irrigation scheme;
- Between 450 and 4,500 ha, it is considered a medium size irrigation system
- 4,500 ha is considered a large scale irrigation scheme.

Private owners most of the time have irrigation schemes of between 0.2 and 10,000 ha and the private firms have irrigation schemes between 10 and 450 ha.

More detailed information concerning irrigation in Egypt can be found in Annex 2.

1.3 Agricultural conditions

The agriculture year is divided into three separate seasons: winter (October to February), summer (March to June), and Nili (July to September) as displayed in Table 44. Most crops are grown both in the Delta and in the Valley, with the exception of rice (Delta mainly) and sugarcane (Valley). The main winter crops are wheat and fodder or Berseem (Trifolium alexandrinum). Berseem is grown either over 3 months with 2 cuts as feeds and a soil improver (short Berseem) usually preceding cotton, or over 6-7 months either with 4-5 cuts as a fodder crop or grazed by tethered cattle (long Berseem). Minor winter crops are, amongst others, pulses, barley and sugar beet. The main summer crops are maize, rice and cotton, the latter being the most important Egyptian export crop. In 2002, yields were 6.4 ton/ha for wheat, 8.1 ton/ha for maize, 9.4 ton/ha for rice and 2.6 ton/ha for cotton. Figure 60 shows the different crops per hectare according to the FAO-

AQUASTAT. More detailed information concerning irrigation in Egypt can be found in Annex 2.

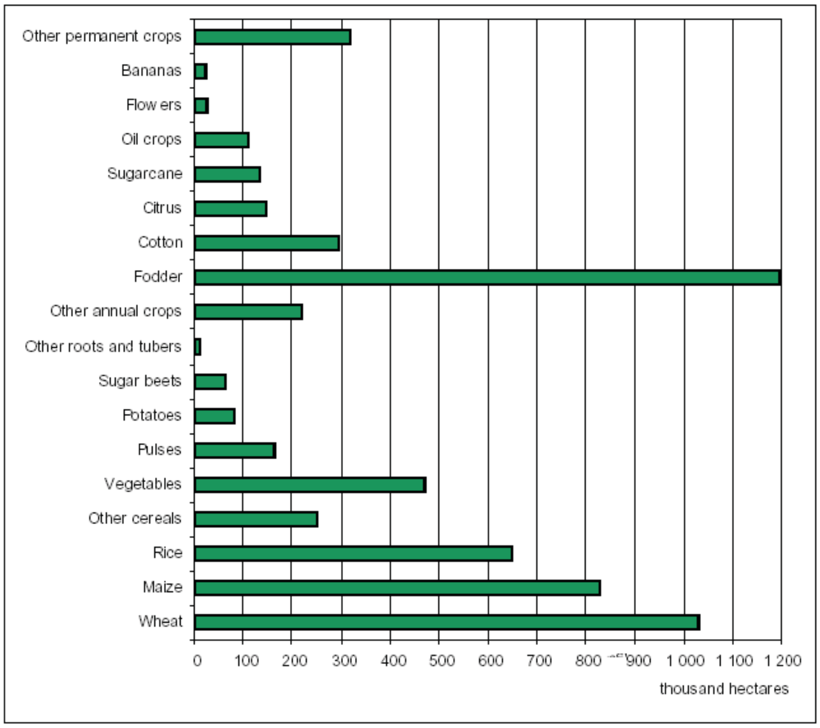


Figure 60 Irrigated crops in Egypt (source: FAO-AQUASTAT, 2005)

Table 44 Cropping seasons (source: FAO-AQUASTAT, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
EGYPT													
Wheat	1021	31	31	31	31	31						31	31
Rice	607						19	19	19	19	19		
Maize	795						24	24	24	24	24		
Barley	58	2	2	2								2	2
Sorghum	158	5	5	5								5	5
Potatoes	85		3	3	3	3	3						
Sugarbeet	41					1	1	1	1	1	1		
Sugarcane	124	4	4	4	4	4	4	4	4	4	4	4	4
Pulses	178				5	5	5	5	5				
Vegetables	421												
Vegetables-one				6	6	6	6						
Vegetables-two								6	6	6	6		
Citrus	132	4	4	4	4	4	4	4	4	4	4	4	4
Fruits	311	10	10	10	10	10	10	10	10	10	10	10	10
Oil crops	20	1	1	1	1	1	1	1	1	1	1	1	1
Groundnut	49					2	2	2	2	2			
Cotton	321	10						10	10	10	10	10	10
Fodder	1098	34	34	34	34							34	34
All irrigated crops	5419	100	93	99	98	67	79	86	86	80	79	100	100
Equipped for irrigation	3246												
Cropping intensity	167												

Part 2 Climate

2.1 Climatological conditions

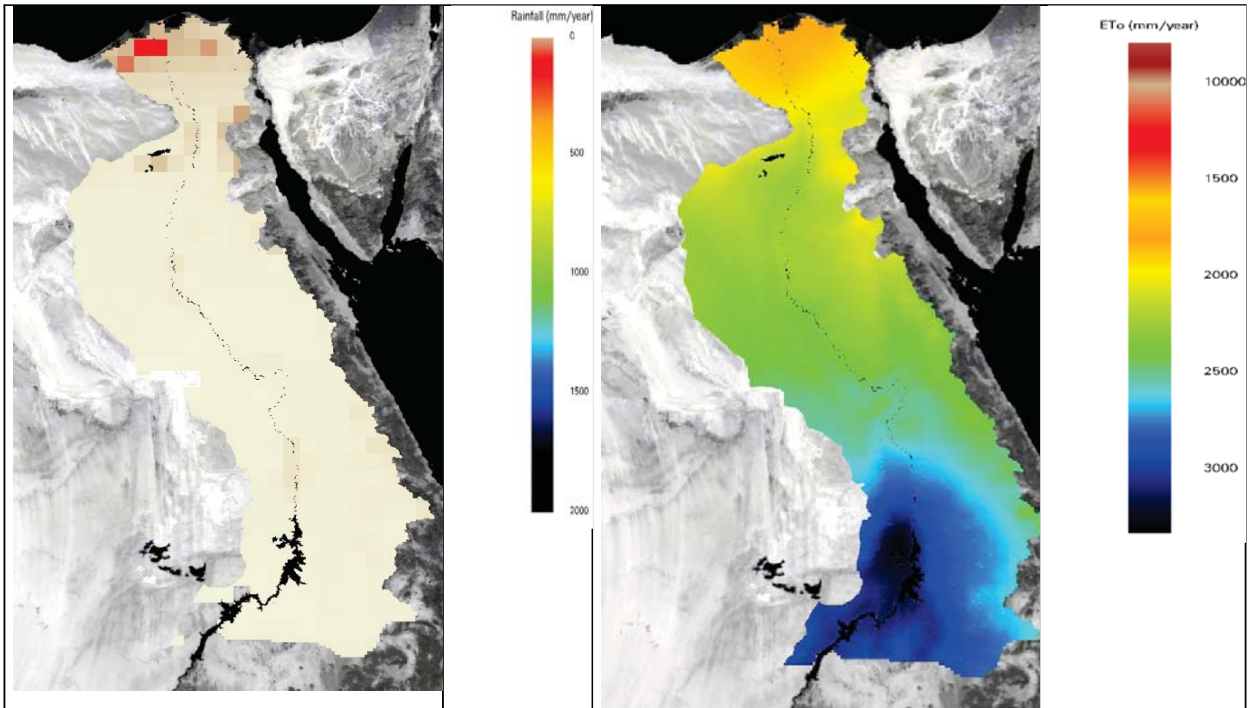
In this study, the reference evapotranspiration (ET_0) is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007. Table 45 shows the monthly values for rainfall and ET_0.

Egypt is a typical desert country. There is some rainfall along the shore line of the Mediterranean Sea, but a hundred kilometer inland this rainfall reduces to virtually nothing. The average rainfall for Egypt is only approximately 10 mm/yr. Agriculture is thus not feasible without irrigation. The uncertain rainfall factor can be ignored in the planning of water resources. This makes it easier to operate the canals and plan the on-farm irrigation practices.

The temperatures are cool in the winter and hot during the summer. ET_0 varies from 3.5 to 9 mm/d. This is related to the dry and hot desert climate. The winters are mild, and very well suited for various crops. The summer crops must be heat tolerant; hence rice, cotton and sugarcane (grown in Upper-Egypt) are common.

Table 45 Monthly values for rainfall and reference evapotranspiration (ET0).

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	3	80	0.01
February	2	98	0.01
March	1	146	0.01
April	0	190	0
May	0	239	0
June	0	250	0
July	0	232	0
August	0	210	0
September	0	179	0
October	0	152	0
November	1	100	0.01
December	2	81	0.01
TOTAL	9	1957	



Annual rainfall	Annual reference ET

Figure 61 Spatial variation of rainfall (left) and ET0 (right).

2.2 Climatic zones

The current study, aimed at providing information for improved irrigation practices in the Nile basin, covers various climatic zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as on percolation rates and irrigation efficiencies. Unexpected rainfall can for instance reduce the fraction of beneficial transpiration, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences based on the diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climatic zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones.

Part **3** Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on (i) the data sent by the LSI representatives of Egypt, (ii) the FAO irrigated areas, and (iii) manual digitization of visually recognizable irrigated system using Google earth and Landsat images.

The first step was to compute all the indicators per pixel. All the RO and PO indicators described have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), the Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. The annually accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

The sustainability indicators have been obtained by investigating the last five year's trends in the vegetation index (from the SPOT-Vegetation satellite) and the soil moisture (from the AMSR-E satellite).
The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, 4 different benchmark values were defined. A score between 1 and 5 has been given to each pixel; 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 62).

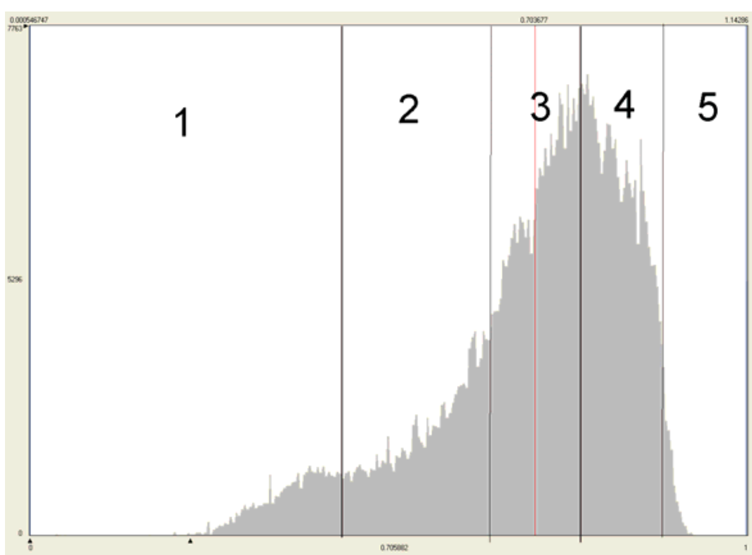


Figure 62 distribution of the values of one indicator in 5 classes

An average score of 3 for all pixels per climatic zone will indicate good benchmarking.

If the country has irrigation systems in different climatic zones, different benchmark values are considered to avoid climatic bias in scoring. In the case of Egypt, irrigation systems are located in climatic zone 1 (Table 46).

Table 46 benchmark values for pixel located in climatic zone 1

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<7,000	<16,000 and >7,000	<28,000 and >16,000	<32,000 and 28,000	>32,000
bwp	Kg/ m3	<1.5	<2.3 and >1.5	<2.8 and >2.3	<3.3 and >2.8	>3.3
cwc	M3/ha/year	>12,500	<12,500 and >9,000	<9,000 and >5.700	<5,700 and >1,000	<1,000
cwd	M3/ha/year	<340 and >250	>500	<500 and >340	<250 and >130	<130
bf	-	<0.7	<0.9 and >0.7	<0.94 and >0.9	<0.97 and >0.94	>0.97
ad	-	<0.45	<0.64 and >0.45	<0.74 and >0.64	<0.86 and >0.74	> 0.86
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.75	<0.82 and >0.75	<0.88 and >0.82	<0.95 and >0.88	>0.95
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Once each indicator gets a score per pixel, districts average and country average values can be calculated. The indicators are averaged per type: RO indicators, PO indicators, and sustainability indicators, to simplify understanding of processes and results.

3.2 Results at Country level

The average score considering all the indicators together for all the 3 million ha of irrigated land is 3.1. Figure 63 shows the country average for each indicator. The elements with a relative low score are the ones that Egypt should provide more attention to.

Values of 3.0 and 2.9 for land and water productivity respectively, are considered average.

Values of 2.8 and 2.6 respectively for PO indicators, crop water consumption and uniformity are below average. This shows that the access to water resources is not equal everywhere in the Egyptian irrigation systems. This is likely related to the large areas and differences between crop physical systems in upper, middle and lower Egypt. Adequacy and the reliability are slightly above average. Crop water deficit and the beneficial fraction are on the other side of the scale and appear very good at country level.

Sustainability of the land resources does not seem to be fully under control. The irrigated land is constantly green, and there is no clear signal that the system is deteriorating. However, the soil moisture levels show a decline over the last 5 years. This is an interesting issue, because Egypt is expanding its land horizontally, and more irrigation water is now brought from the traditional areas in the valley and delta to the desert. This is occurring already in Sinai and plans exist to convey Nile water resources to the Western Desert to supplement groundwater resources. Although no firm conclusion can be drawn from this finding, decreasing soil moisture values should be treated with caution. The preservation of land wetness definitely needs to get special attention during the monitoring of the irrigation systems.

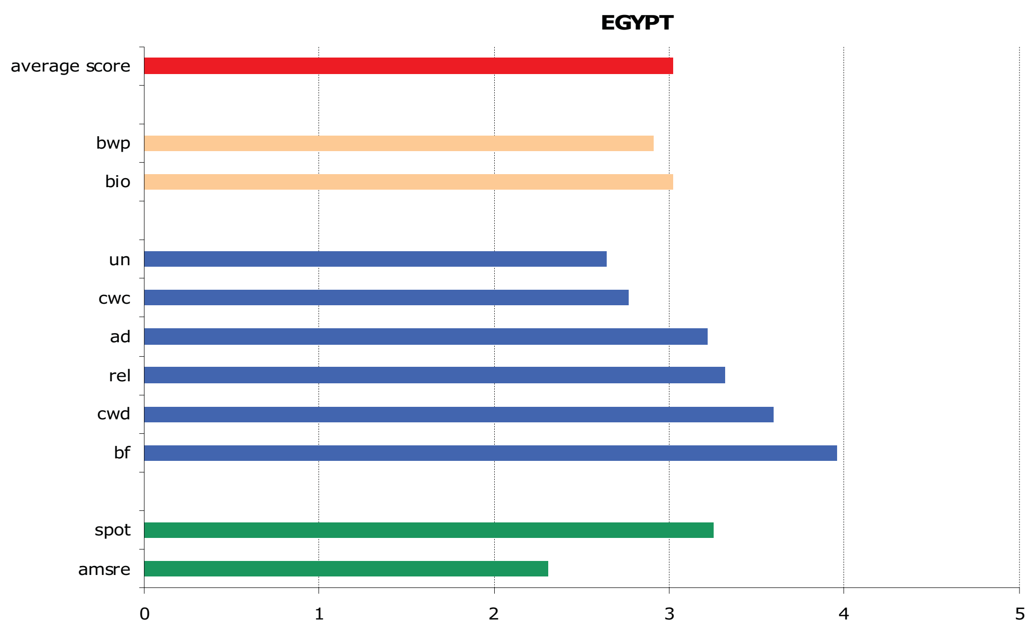


Figure 63 The average score for each indicator in Egypt.

3.3 Results at district level

3.3.1 Average per district

In Figure 64 the average score for all the indicators per district are compared. The western Delta appears to have the best score. Twenty two districts having more than 30 pixels of 6.25 ha have been identified. In terms of total average score, the best irrigation district is Dumyat, with an average of 3.6. The district that has the lowest average is Al Jizah, with an average of 2.5 (see Figure 64 for their locations).

Dumyat is based in the Delta (Lower Egypt) and Al Jizah on the fringes of the Nile valley (Upper Egypt). The soil in Al Jizah is sandy and this could be an explanation for the low performance.

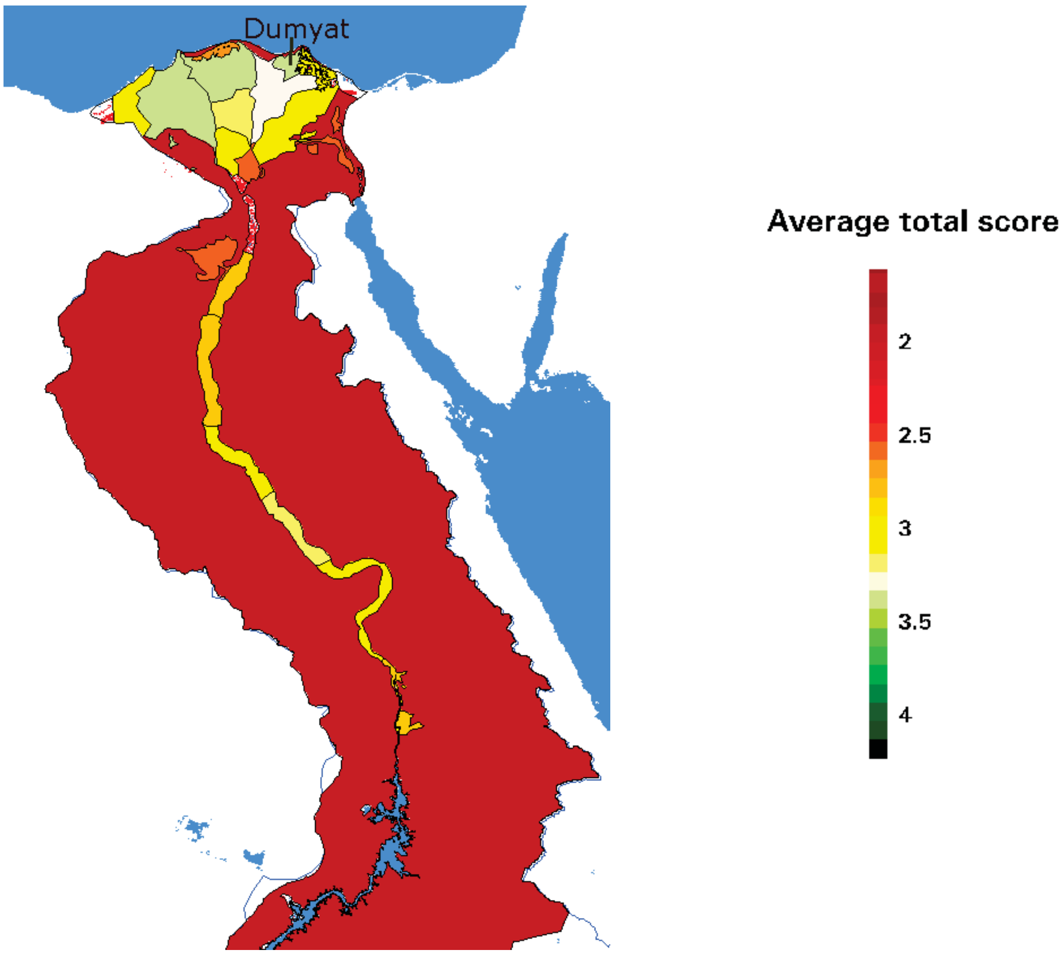


Figure 64 Map of Egypt showing the total score per irrigated district

3.3.2 Breaking down the total score into RO, PO and sustainability indicators

By breaking down the total score into 3 types of indicators (RO, PO and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 65 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance and enables ranking of districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

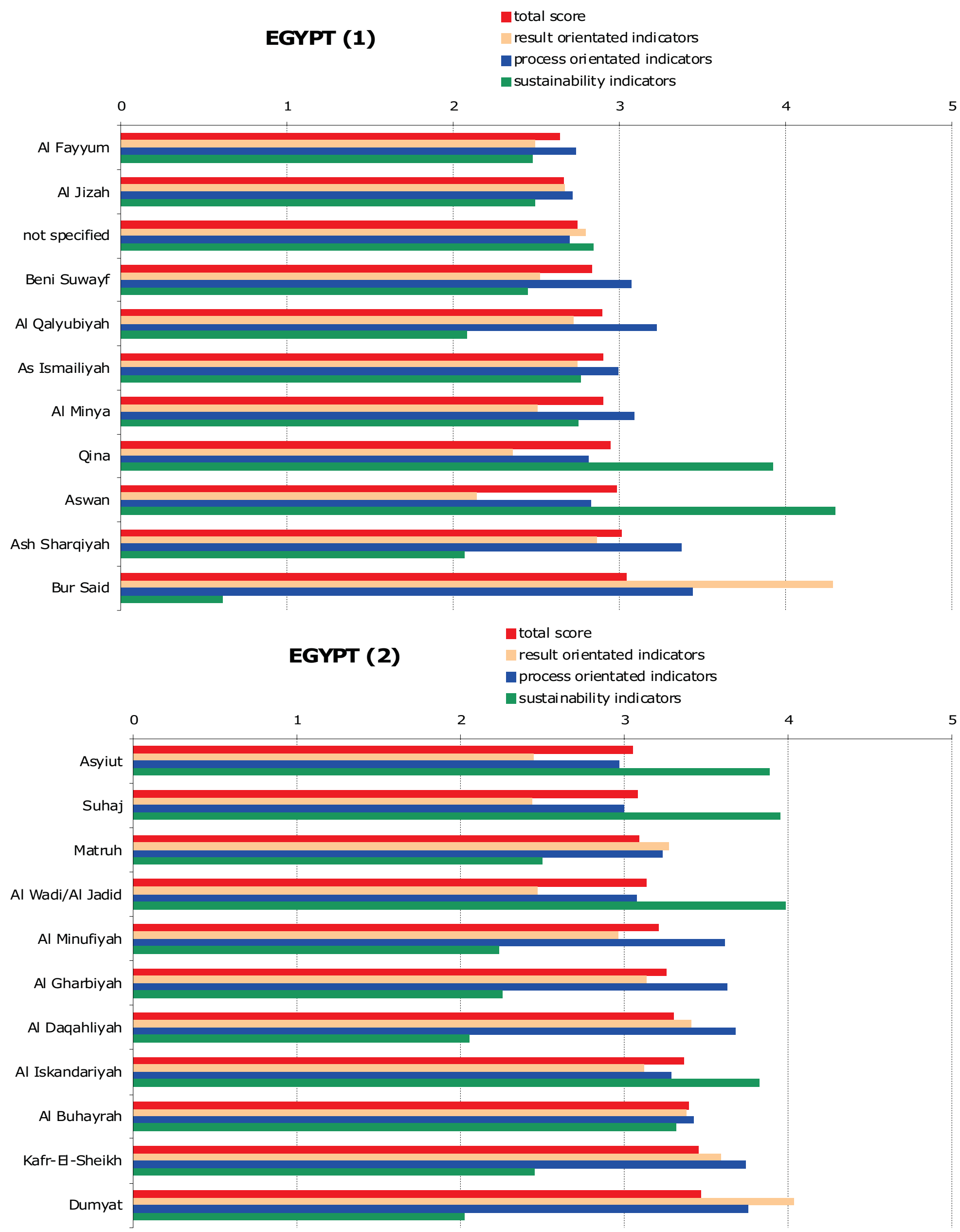


Figure 65 A breakdown of the total score per indicator per district

A good total score does not always mean a good performance in terms of results. Similarly, a poor average score does not mean that the district does not have good results.

Considering the total average score for Bur Said, it seems to be an average district. However, by looking at the average of the RO indicators, it appears to be the best performing district, with an average score of 4.3. The low global average that leads to ranking Bur Said amongst the districts with average to poorest irrigation performance is explained by the very low score obtained in terms of sustainability. The managers of Bur Said seem to over-utilize their land and water resources, resulting in unsustainable practices. A good total performance does not mean a sustainable system. This example shows once again the relevance of breaking the irrigation performance down into different types of indicators. It would be valuable to find the main reasons for this un-sustainability.

The 22 districts of Egypt have a very variable RO score, ranking from 2.1 to 4. The PO indicators vary too from one district to another, from 2.7 to 3.8. This variation complicates general improvement recommendations at a country scale. In line with the LSI assignment, relevant improvement recommendations should be made district per district by looking at the different scores of every single indicator for each district.

3.4. Analysis per pixel for the best irrigation system

Looking at what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see where which processes need more attention. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the district of Dumyat, which is the best district in terms of performance. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. Figure 66 demonstrates that crop water consumption is too high (over 12,500 m^3/ha/year) and that many precious water resources are lost by non-beneficial evaporation. Overall the system is very reliable and adequate.

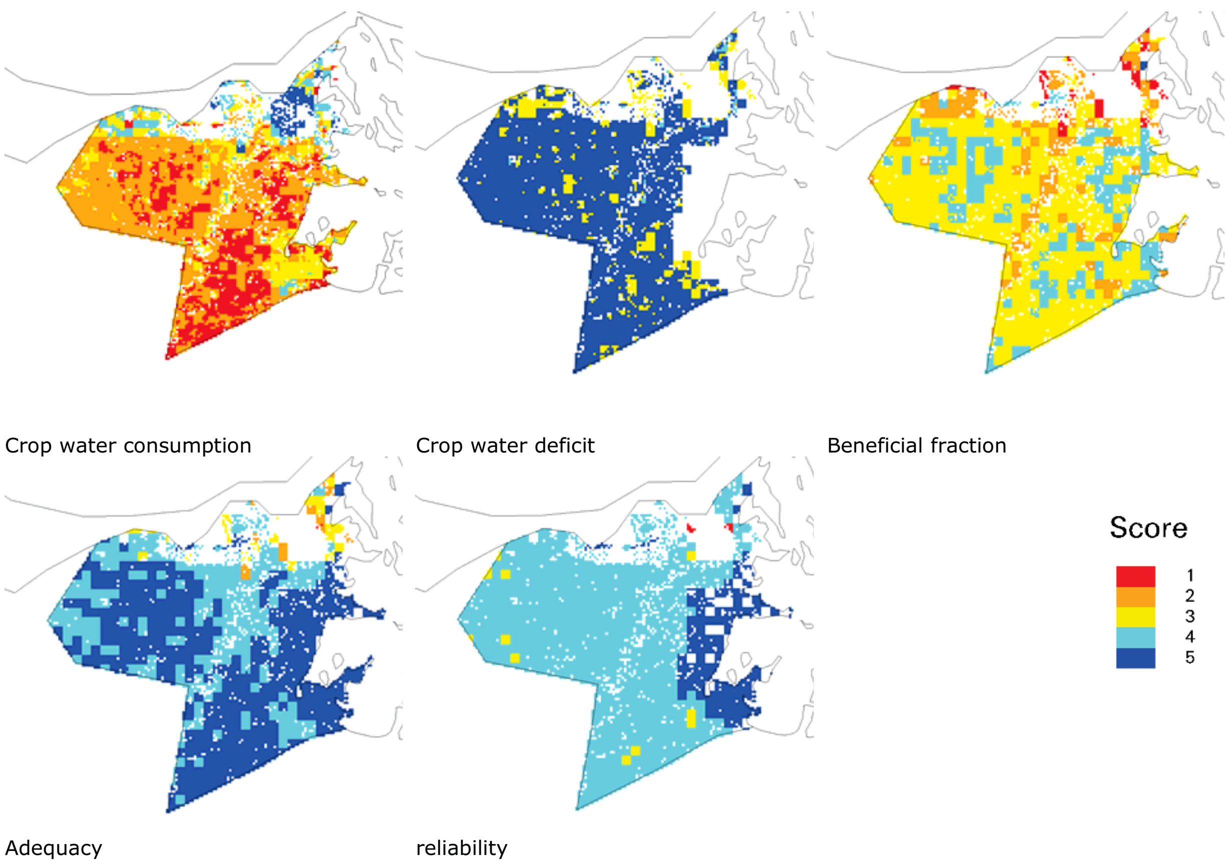


Figure 66 Spatial distribution of each indicator for the district of Dumyat

Part 4 Recommendations for improvement

4.1. Explaining the irrigation results

To be able to give appropriate recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the 7 districts. As far as the biomass production is concerned, it appears to be well correlated to adequacy and crop water consumption. The higher the crop water consumption or the adequacy, the more biomass will be produced. While this is good for crop production, it will go at the cost of a high irrigation water usage. It is positively linked to the beneficial fraction and negatively linked to the crop water deficit. No clear relationship between biomass and uniformity, or reliability is apparent.

For a high biomass water productivity, crop water consumption should be low. The highest biomass water productivity occurs when crop water consumption is low and crop water deficit is limited. This is helpful for optimizing either biomass production or biomass water productivity.

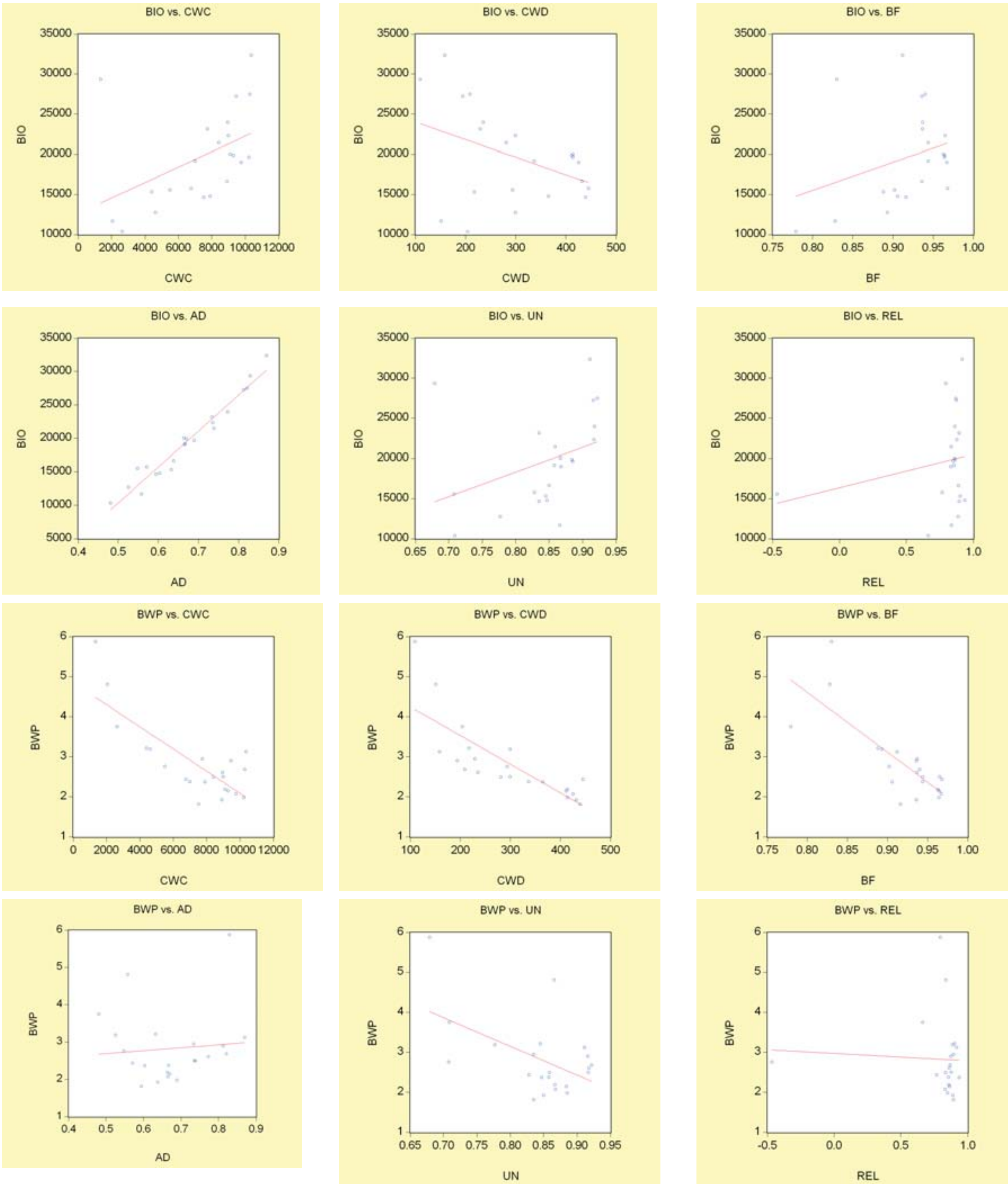


Figure 67 Relationships between RO indicators and PO/Sustainability indicators

4.2. Weak and strong aspects per district

Once the relationship between indicators is better understood, the next step is to identify the weakest elements per districts. In Table 5, the best and poorest indicators are presented.

Table 47 Best and poorest PO irrigation indicators per district

district	lowest score		2^{nd} lowest		2^{nd} best		best	
Al Fayyum	ad	1.69	cwd	1.98	cwc	3.21	bf	4.70
Al Jizah	un	1.00	ad	2.10	cwc	3.82	bf	3.95
not specified	un	1.00	ad	2.17	cwd	3.50	cwc	4.35
Beni Suwayf	cwd	2.17	cwc	2.49	ad	3.97	bf	4.68
Al Qalyubiyah	ad	1.93	cwd	2.78	rel	3.20	bf	4.38
As Ismailiyah	un	2.00	ad	2.06	rel	3.75	cwc	3.81
Al Minya	cwd	2.15	cwc	2.50	rel	3.34	bf	4.66
Qina	un	2.00	cwd	2.10	rel	3.70	bf	3.86
Aswan	un	2.00	cwd	2.03	bf	3.77	rel	3.89
Ash Sharqiyah	cwc	2.70	ad	2.87	cwd	3.89	bf	4.19
Bur Said	un	1.00	ad	2.62	rel	3.93	cwc	4.81
Asyiut	cwd	2.08	cwc	2.46	ad	3.47	bf	4.72
Suhaj	cwd	2.13	cwc	2.23	rel	3.03	bf	4.58
Matruh	bf	2.24	ad	2.83	cwd	3.96	cwc	4.33
Al Wadi/Al Jadid	un	2.00	ad	2.57	bf	3.61	rel	4.34
Al Minufiyah	cwc	2.56	ad	3.03	un	4.00	bf	4.54
Al Gharbiyah	cwc	2.54	rel	3.17	un	4.00	cwd	4.58
Al Daqahliyah	cwc	2.14	rel	3.33	un	4.00	cwd	4.79
Al Iskandariyah	un	2.00	bf	2.99	rel	3.97	cwd	4.32
Al Buhayrah	un	2.00	cwc	2.90	ad	4.16	cwd	4.57
Kafr-El-Sheikh	cwc	2.39	rel	3.42	ad	4.08	cwd	4.89
Dumyat	cwc	2.14	bf	3.03	ad	4.55	cwd	4.73

The elements with low scores indicate the aspects that each district should provide more attention to. Generally, aspects with scores lower than 3 needs to be critically considered. It seems that many districts have a problem with uniformity. The beneficial fraction as well as crop water deficit seem to be the best indicators for many districts. Beneficial fraction can be improved by soil, straw and plastic mulching. Crop water deficit can be regulated by means of shorter irrigation intervals and sufficient supplies. But once again, each district seems to function differently and therefore should be looked at independently.

4.3. Recommendation countrywide

Ancient Egyptians irrigated their land and a rich experience has been built up in agricultural water management. This is reflected in an overall good irrigation system, especially in the areas with alluvial soils at the downstream end of the Nile. Overall, the irrigation performance in upper Egypt is less favourable. The fact that the country is so large will inevitably result in a wide scatter in ranking of irrigation performance.

The most limiting resource for Egyptian agriculture is irrigation water. Management of its water resources has always been the central feature of the country's development strategies. There is indeed insufficient water to meet all demands for competing users and the potential for increasing the amount of available water is limited. Therefore, increasing water productivity should be a priority whereas it seems that all attention is given to production.

Land, next to water, is also a limiting factor. The Delta region contributes to 80% of all arable land in the country and despite the extremely limited land available for agriculture, urbanization is growing. The desert reclamation activities launched in the eighties have been quite successful, albeith the groundwater resources did not appear to be sustainably managed.

The absence of rainfall is an advantage to Egypt, because erratic rain storms can jeopardize and interfere with the irrigation planning. By absence of these events, it is easier to schedule water in the canals. While this works out quite well in the Delta, the performance in the Nile Valley is much less favourable.

The irrigation systems in the downstream end of the Rosetta and Damietta branch are among the best in the world. The national agronomical skills of Egypt and the agricultural policies could be of overriding importance in establishing this success. The short duration varieties are surely debet to that.

The Government of Egypt could focus on the following aspects:

- Provide maximum attention to a proper monitoring technology. There could be undesirable consequences for unlimited horizontal expansion. It is basically a stransfer of water from the old land to the new land
- The minimum drainage flows should be monitored for keeping the leaching fraction of the Nile basin in proper ranges
- Determine the reasons for below-average irrigation performance in certain administrative districts in Egypt.
- There are signals that the institutional capacity in Egypt is not working properly. A critical evaluation should be held by outsiders to detect where in the decision making process aspects can be improved

- Evaluate the operation and maintenance rules for irrigation water management and try to draw lessons that could be used in the arid irrigation systems of Sudan and Ethiopia.
- Continue to invest in extension services and formation of water boards. This could help in making the water distribution more uniform.

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m^3	Bio/ET_{act}	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M^3/ha/year	ET_{act}	Saving of water resources
	Crop water deficit	cwd	M^3/ha/year	ET_{pot}-ET_{act}	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	T_{act}/ET_{pot}	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	T_{act}/T_{pot}	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	1-CV(T_{act}/T_{pot}) (x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	1-CV(T_{act}/T_{pot}) (t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 General information on irrigation conditions in Egypt (AQUASTAT, 2005)

Irrigation and drainage

Irrigation potential	1997	4 420 000	ha
Irrigation:			
1. Full or partial control irrigation: equipped area	2002	3 422 178	ha
- surface irrigation	2000	3 028 853	ha
- sprinkler irrigation	2000	171 910	ha
- localized irrigation	2000	221 415	ha
- % of area irrigated from groundwater	2000	11	%
- % of area irrigated from surface water	2000	83	%
- % of area irrigated from mixed sources	2000	6	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)		-	ha
3. Spate irrigation		-	ha
Total area equipped for irrigation (1+2+3)	**2002**	**3 422 178**	**ha**
- as % of cultivated area	2002	3	%
-average increase per year over last 9 years	1993-2002	0.6	%
- power irrigated area as % of total area equipped	2002	86	%
- % of total area equipped actually irrigated	2002	100	%
4. Non-equipped cultivated wetlands and inland valley bottoms		-	ha
5. Non-equipped flood recession cropping area		-	ha
Total water-managed area (1+2+3+4+5)	**2002**	**3 422 178**	**ha**
- as % of cultivated area	2002	3	%
Full or partial control irrigation schemes: **Criteria:**			
Small-scale schemes < ha		-	ha
Medium-scale schemes		-	ha
Large-scale schemes > ha		-	ha
Total number of households in irrigation		-	
Irrigated crops:			
Total irrigated grain production	2003	19 230 797	tons
- as % of total grain production	2003	100	%
Harvested crops under irrigation (full/partial control):			
Total harvested irrigated cropped area	2002	6 027 115	ha
- Annual crops: total	2002	3 773 462	ha
. Wheat	2002	1 029 180	ha
. Rice	2002	650 026	ha
. Barley	2002	96 201	ha
. Maize	2002	827 949	ha
. Sorghum	2002	156 155	ha
. Potatoes	2002	82 588	ha
. Sweet potatoes	2002	8 388	ha
. Other roots and tubers (taro, yams, etc.)	2002	3 001	ha
. Sugar beets	2002	64 596	ha
. Pulses	2002	164 013	ha
. Vegetables	2002	472 062	ha
. Other annual crops	2002	219 303	ha
- Permanent crops: total	2002	2 253 653	ha
. Sugar cane	2002	135 815	ha
. Bananas	2002	24 165	ha
. Citrus	2002	145 421	ha
. Cotton	2002	296 693	ha
. Fodder	2002	1 195 903	ha
. Soyabeans	2002	5 914	ha
. Groundnuts	2002	59 241	ha
. Sunflower	2002	15 493	ha
. Sesame	2002	30 284	ha
. Flowers	2002	26 055	ha
. Other permanent crops	2002	318 669	ha
Irrigated cropping intensity	2002	176	%
Drainage - Environment:			
Total drained area	2003	3 024 000	ha
- part of the area equipped for irrigation drained	2003	3 024 000	ha
- other drained area (non-irrigated)		-	ha
- drained area as % of cultivated area	2002	88	%
Flood-protected areas		-	ha
Area salinized by irrigation		-	ha
Population affected by water-related diseases		-	inhabitants