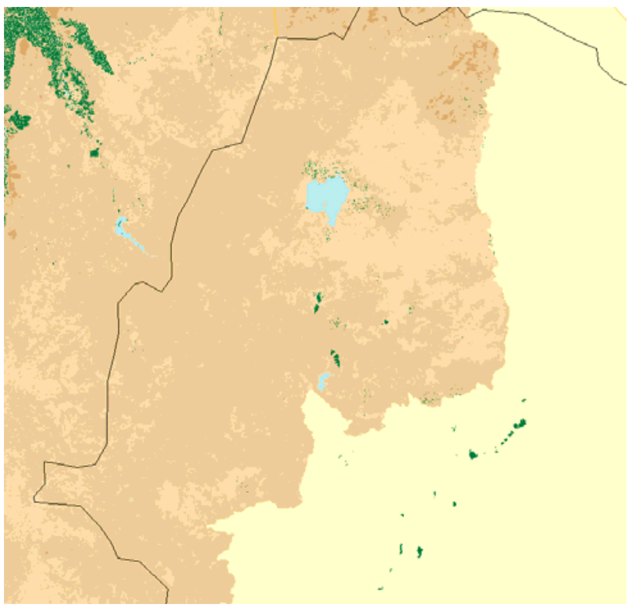
Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Ethiopia



Appendix F

January 2009

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Purpose of this report:

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

Part 1 Location of irrigated areas

1.1 Location of the irrigated areas

Ethiopia is located in the transition zone between the vast irrigation schemes of Egypt and Sudan towards the downstream end of the basin, and the small holder irrigation in the upstream Nile Basin. The Nile Basin in Ethiopia is one of four major drainage systems: (i) Nile basin; (ii) The Rift Valley; (iii) Shebelle–Juba basin (iv) north-east Coast. It represents 32% of the total area of about 1.13 million km^2 and comprises the Abbay, Tekeze and Baro-Akobo rivers. Both the Blue and White Nile drain from Ethiopia (part of the White Nile also drains from Uganda) and together they provide almost 70% of the annual runoff (122 BCMs m^3) of the country. There are several lakes in the country (covering about 7,000 km^2), but only Lake Tana, the source of Abbay River is within the Nile Basin.

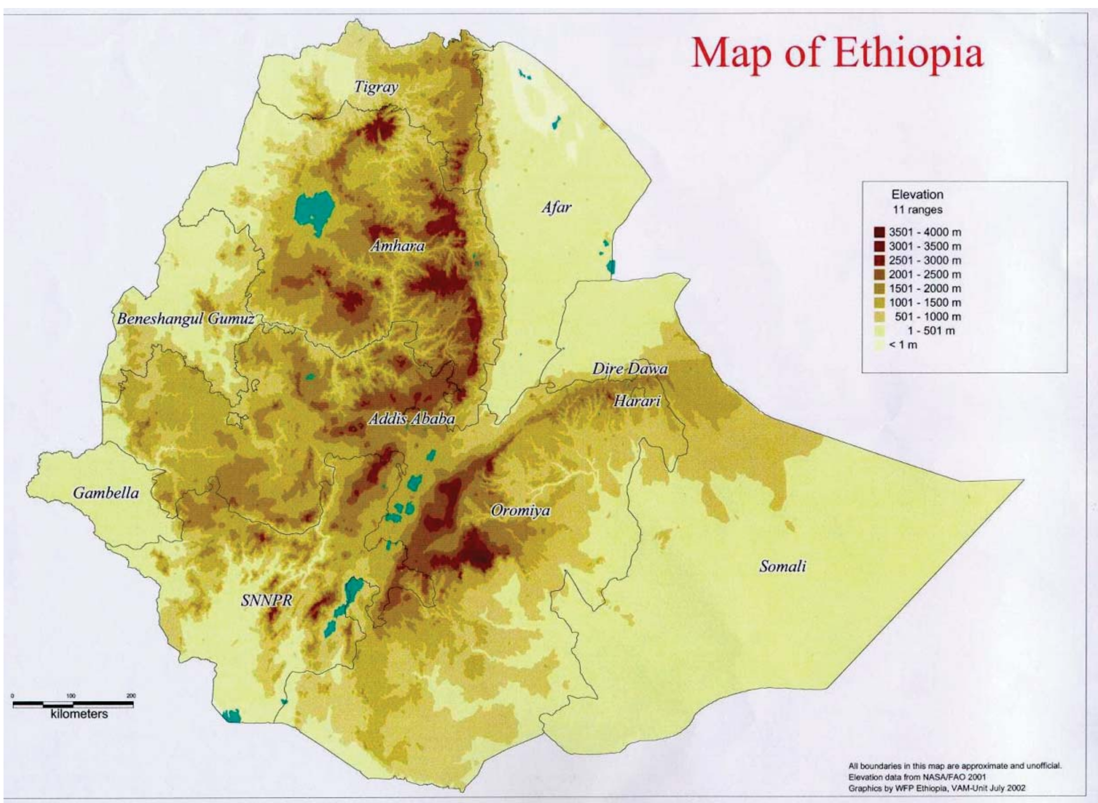
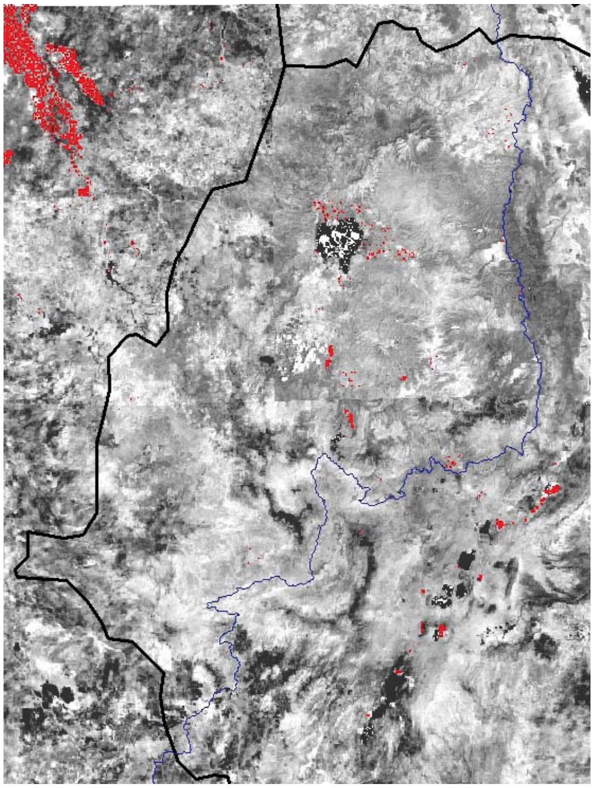


Figure 68 Topographical map of Ethiopia

The alluvial soils in the vicinity of streams and rivers and lakes are used for irrigation (see Figure 69). Irrigation in Ethiopia dates back several centuries, if not millennia, while "modern" irrigation was started by the commercial irrigated sugar estate established in the early 1950s.



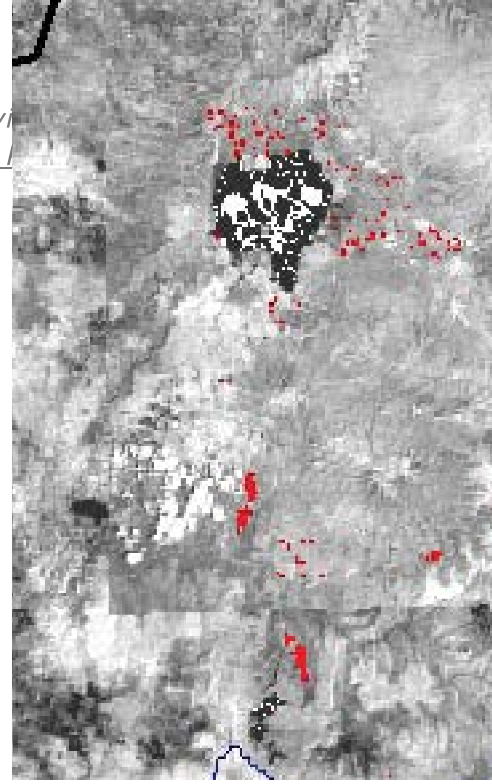


Figure 69 Distribution of the irrigated areas within the Nile Basin according to the FAO-GMIA product, and being refined within the current study. The red dots represent the irrigated areas.

Table 48 shows that 90,769 ha of irrigated land is present in the Nile Basin component of Ethiopia. It also suggests that there is much more irrigation outside the Nile Basin region, which is true. Several irrigation schemes are located in the Awash river basin and the Central Rift Valley. Awulachew et al. (2007) report an amount of 107,265 ha of irrigated land in Ethiopia.

Table 48 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Ethiopia	184,239
IWMI – GIAM	Entire Ethiopia	160,785
Current study	Nile Basin component of Ethiopia	90,769

Irrigation potential has been estimated at about 2.7 million ha, considering the availability of water and land resources, technology and finance (AQUASTAT, 2005). According to the LSI representative, the total gross irrigation potential estimate of the country is even higher : 3.7 million ha. The surface water resource potential of the country is indeed impressive, but little has been developed so far. Since recently, Ethiopia has embarked on an irrigation master development plan in the Nile basin ("the Nile irrigation and drainage project"), and it is expected that the irrigated areas will be expanded in the future. The combined Tana-Beles river basin has for instance is foreseen to expand by 240,000 ha.

1.2 Description of LSI

Four categories of irrigation schemes can be distinguished:

(i) Traditional irrigation schemes (1-100 ha) developed by the farmers themselves and covering about 155,014 ha with about 639,031 farmers involved. They are mainly used for the production of vegetables for the local market and experience problems with faulty irrigation systems stemming from lack of technology and knowledge.

(ii) Modern small-scale irrigation schemes: (up to 200 ha) constructed by the government/NGOs with farmer participation. They are generally based on direct river diversions. About 51,198 ha was equipped for irrigation in 2004 involving about 198,393 farmers. The operation and maintenance of the schemes are the responsibility of the water users, supported by the regional authorities/bureaus in charge of irrigation development and management.

(iii) Modern private irrigation: Private investment in irrigation has recently re-emerged with the adoption of a market-based economic policy in the early 1980s. Virtually all irrigated state farms were privately owned farms until nationalization of the private property in the mid 1970s. At the end of 2000, private investors had developed about 5,500 ha of irrigated farms.

(iv) Public irrigation schemes: comprise medium/large-scale irrigation schemes (>200 ha) covering about 97,700 ha. They are constructed, owned and operated by public enterprises along the Awash River and were built in the 1960s–70s as either private farms or joint ventures.

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

1.3 Agricultural conditions

Agriculture is a very important sector for the Ethiopian national economy as it involves 74% of the active population and represents 57% of the GDP. It is mainly rainfed agriculture and is dominated by subsistence small holder farms. Irrigation accounts for about 5 %. Export crops such as coffee, oilseed and pulses are mostly rainfed but industrial crops such as sugar cane, cotton and fruit are irrigated. Other irrigated crops include vegetables, fruit trees, maize, wheat, potatoes, sweet potatoes and bananas (Figure 70). The cropping seasons are represented in Table 49.

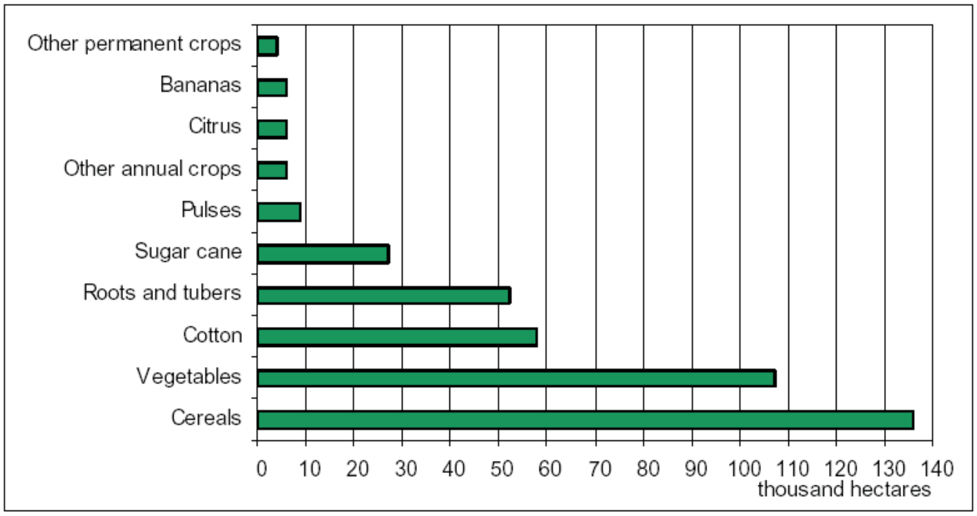


Figure 70 Irrigated crops in Ethiopia (FAO, AQUASTAT, 2005)

Table 49 Cropping calendar in Ethiopia (FAO, AQUASTAT, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
ETHIOPIA													
Maize	23						14	14	14	14	14		
Sorghum	20						12	12	12	12	12		
Sugarcane	17	11	11	11	11	11	11	11	11	11	11	11	11
Pulses	2	1	1	1								1	1
Vegetables	70	43	43	43								43	43
Bananas	1	1	1	1	1	1	1	1	1	1	1	1	1
Citrus	3	2	2	2	2	2	2	2	2	2	2	2	2
Soybean	4	2	2	2								2	2
Tobacco	4	2	2	2								2	2
Cotton	43				27	27	27	27	27	27	27		
All irrigated crops	187	63	63	63	40	40	66	66	66	66	66	63	63
Equipped for irrigation	161												
Cropping intensity	116												

Part 2 Climate

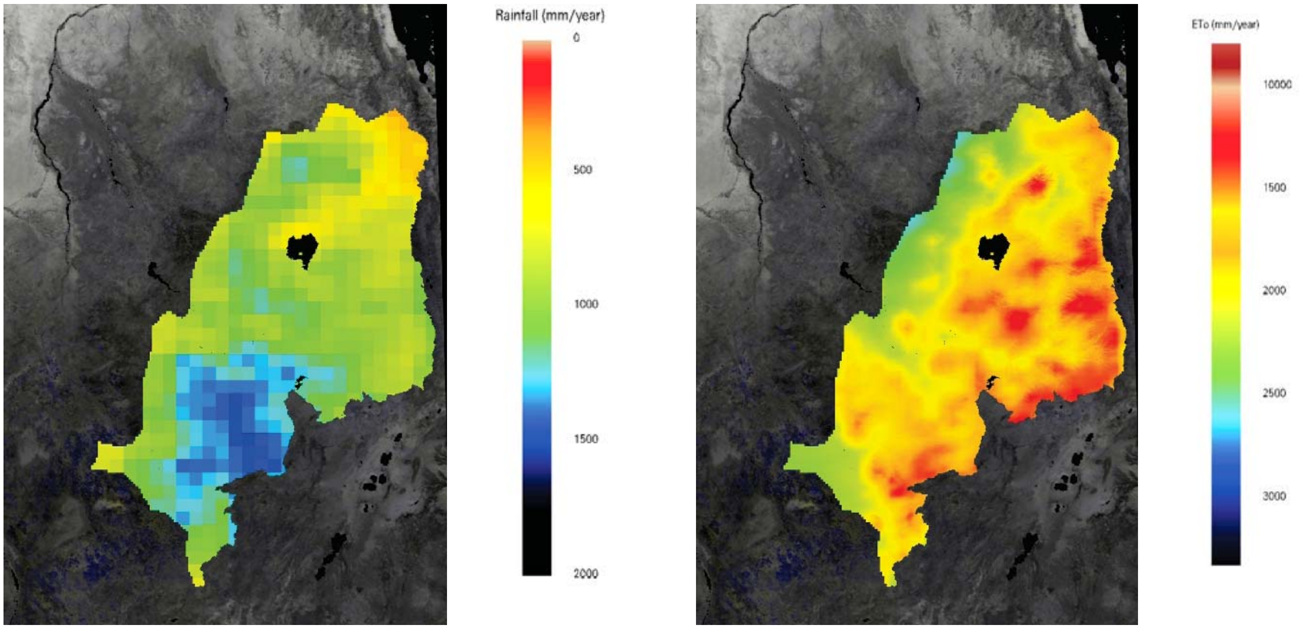
2.1 Climatological conditions

Ethiopia has a tropical monsoon climate with wide topographic-induced variations. Three climatic zones are identified: a cool zone consisting of the central parts of the western and eastern section of the high plateaus, a temperate zone between 1,500 m and 2,400 m above sea level, and the hot lowlands below 1,500 m. Mean annual temperature varies from less than 7−12ºC in the cool zone to over 25 ºC in the hot lowlands. Mean annual potential evapotranspiration varies between 1,700−2,600 mm in arid and semi-arid areas and 1,600−2,100 mm in dry sub-humid areas. Average annual rainfall is 848 mm, varying from about 2,000 mm over some parts of south-west Ethiopia to less than 100 mm over the Afar Lowlands in the north-east.

In this study, the reference evapotranspiration (ET_0) is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007. Table 50 shows that the winter months November to March have hardly any rainfall. ET_0 exceeds rainfall during ten months. Therefore irrigation systems are needed for maintenance of soil moisture of cropland. Only the monsoon rains in July and August induce an aridity index that exceeds 1.0. As Figure 71 shows, the highest rainfall occurs in the south-western part of Ethiopia due to the south-west monsoon that hits the highlands upstream of Gambella plain i.e. orographically induced rainfall. The highest reference ET occurs near the border of Sudan in the lower part of the Beles basin.

Table 50 Monthly values for rainfall and ET0 for the year 2007.

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	0	162	0
February	0	166	0
March	8	196	0.04
April	23	190	0.12
May	74	177	0.42
June	137	152	0.90
July	324	121	2.68
August	298	117	2.55
September	118	131	0.90
October	45	141	0.32
November	11	138	0.08
December	2	146	0.01
TOTAL	1040	1837	



Annual rainfall

Annual reference ET

Figure 71 Spatial variation of rainfall and ET0.

2.2 Climatic zones

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

The irrigation schemes across Ethiopia are included in three climatic zones: semi-arid climate (zone 2), arid climate (zone 3) and the humid climate (zone 4) (see Figure 72). Very few areas are located in climate zone 3.

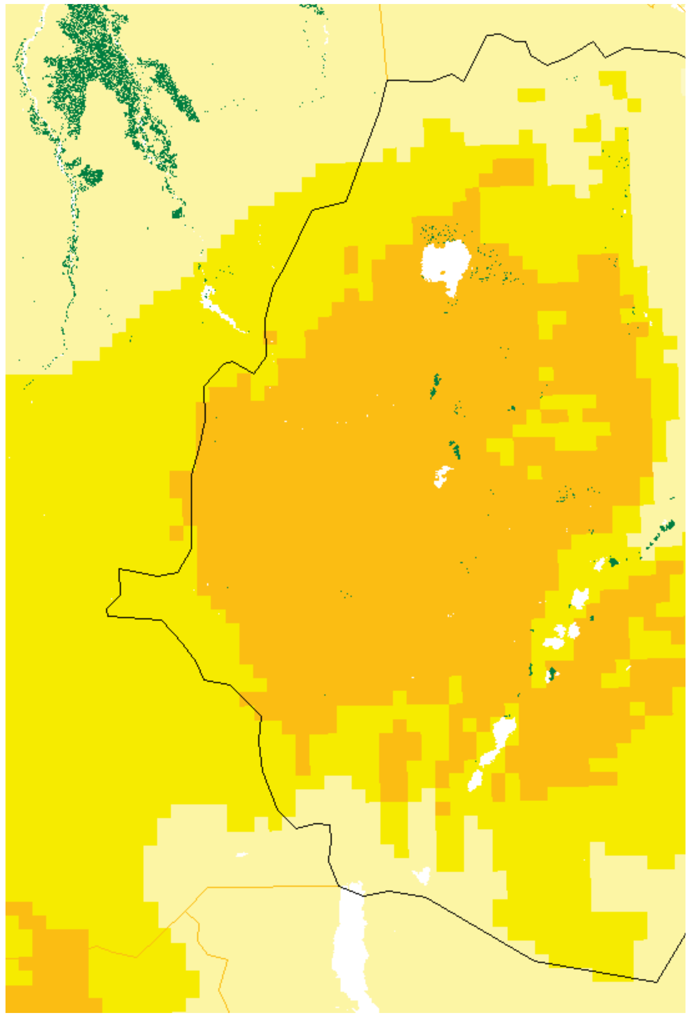


Figure 72 Climate zones distinguished for the mapping of best irrigation practices. The irrigated areas of Ethiopia are located in all the three climate zones identified (light yellow: arid; yellow: semi-arid; orange: humid tropics)

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

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

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

The sustainability indicators have been obtained by investigating the last five year's trends in the vegetation index (from the SPOT-Vegetation satellite) and the soil moisture (from the AMSR-E satellite).

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, 4 different benchmark values were defined. A score between 1 and 5 has been given to each pixel; 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 73).

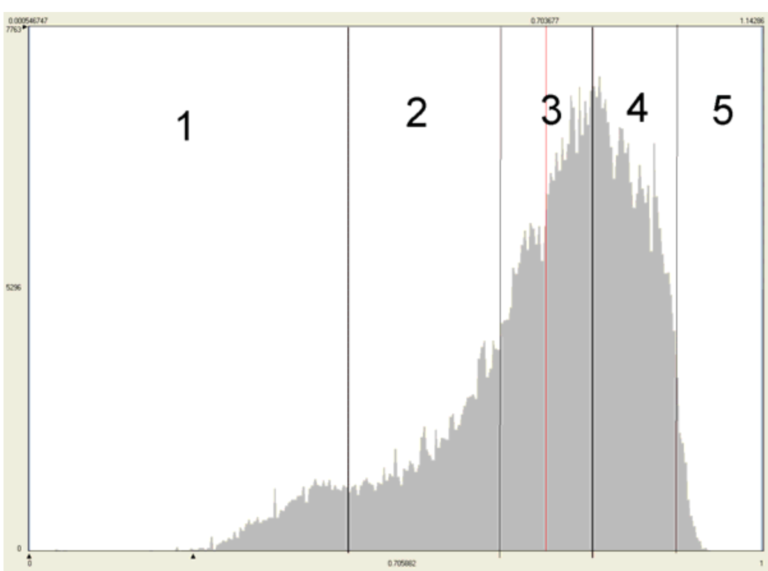


Figure 73 Distribution of the values of one indicator in 5 classes

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

If the country has irrigation systems included in different climatic zones, different benchmark values are considered to avoid any climatic bias in the allocation of the score (Table 51, Table 52, Table 53). Ethiopia, it is located in climatic zone 2, 3 and 4. The benchmark values for each climatic zone will be displayed in the tables below. The benchmarks for Tigray are based on what is physically feasible in the semi-arid zone, which is more comparable to the climate of Sudan, than to the humid tropics of Gambella plain.

Table 51 benchmark values for pixel located in climatic zone 2

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<3,300	<4,400 and >3.300	<7,800 and >4,400	<10,000 and >7,800	>10,000
bwp	Kg/ m3	<0.7	<1 and >0.7	<1.5 and >1	<2.3 and >1.5	>2.3
cwc	M3/ha/year	>11,600	<11,600 and >7,600	<7,600 and >4,400	<4,400 and >2,000	<2,000
cwd	M3/ha/year	<390 and >280	>500	<500 and >390	<280 and >168	<168
bf	-	<0.47	<0.62 and >0.47	<0.75 and >0.62	<0.86 and >0.75	>0.86
ad	-	<0.40	<0.47 and >0.4	<0.58 and >0.47	<0.7 and >0.58	> 0.7
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.56	<0.72 and >0.56	<0.80 and >0.72	<0.90 and >0.8	>0.90
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Table 52 benchmark values for pixel located in climatic zone 3

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5

bio	Kg/ha/year	<7,000	<10,500 and >7,000	<13,500 and >10,500	<15,000 and >13,500	>15,000
bwp	Kg/ m3	<1.3	<2.2 and >1.3	<2.5 and >2.2	<3 and >2.5	>3
cwc	M3/ha/year	>10,200	<10,200 and >7,000	<7,000 and >5,300	<5,300 and >4,000	<4,000
cwd	M3/ha/year	<110	<175 and >110	<310 and >220	>310	<220 and >175
bf	-	<0.5	<0.7 and >0.5	<0.83 and >0.7	<0.88 and >0.83	>0.88
ad	-	<0.56	<0.63 and >0.56	<0.70 and >0.63	<0.78 and >0.70	> 0.78
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.74	<0.8 and >0.74	<0.86 and >0.8	<0.92 and >0.86	>0.92
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Table 53 benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80

bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

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

3.2 Results at country level

The average score considering all the indicators together for all the irrigated land is 2.9, which is a relatively poor score. Figure 74 shows the country average for each indicator. The elements with a relative low score are the ones that Ethiopia should provide more attention to.

The score of 3.1 for biomass water productivity is about average. The score of 2.4 for land productivity tends to indicate poor practices.

Concerning the PO indicators, there is very good performance in terms of uniformity, and average performance in terms of crop water deficit and crop water consumption and reliability. The weakest aspect of Ethiopian irrigation seems to be adequacy and, to a lesser extent, the beneficial fraction.

The land sustainability of irrigation practices seems to be under control. From the last years, the irrigated land have remained relatively constant in terms of soil moisture and greenness (as the score for the land and water sustainability is around 3), hence the irrigation systems are quite healthy and continuous. The soils are being relatively well maintained. Hence, the irrigation system in Ethiopia is relatively sound but special attention should be given to avoid water sustainability to get worse.

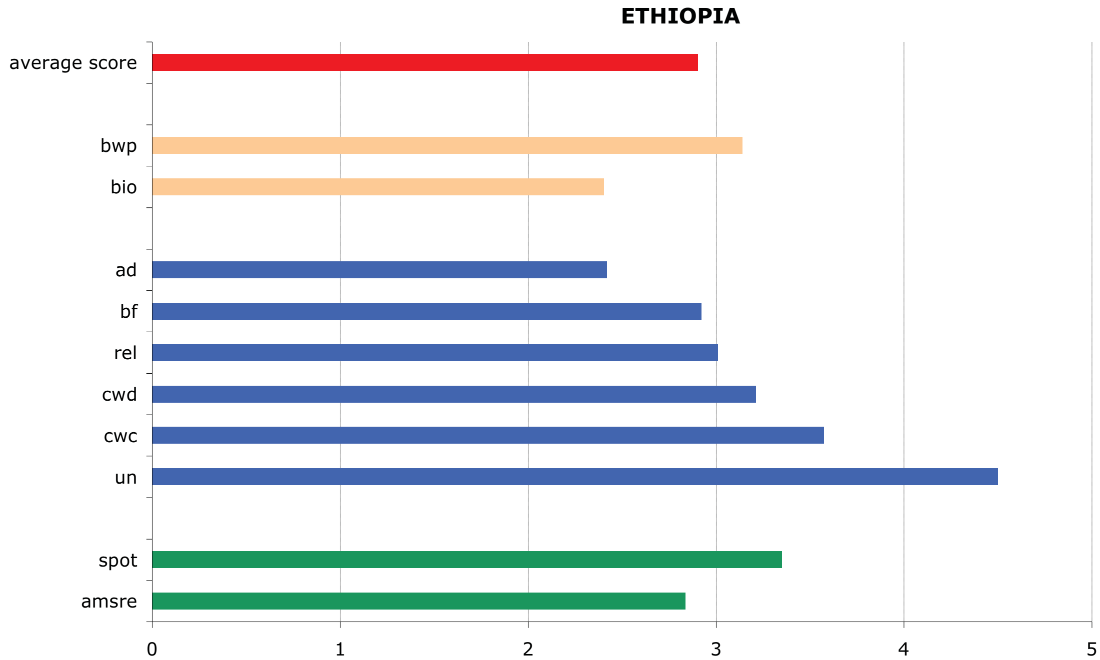


Figure 74 Representation of the average score for each indicator in Ethiopia.

3.3 Results at district level

3.3.1 Average per district

In Figure 75 the average score for all the indicators per district are compared. In Ethiopia, 42 districts with more than 30 pixels of 6.25 ha have been identified.

In terms of total average score, the best irrigation district is Adwa, with an average of 3.9. The district that has the lowest average is Chilga, with an average of 2.6 (see Figure 76 for their locations). Hence, there is a significant variability in the irrigation practices in Ethiopia. This shows that local solutions and management practices can make a difference.

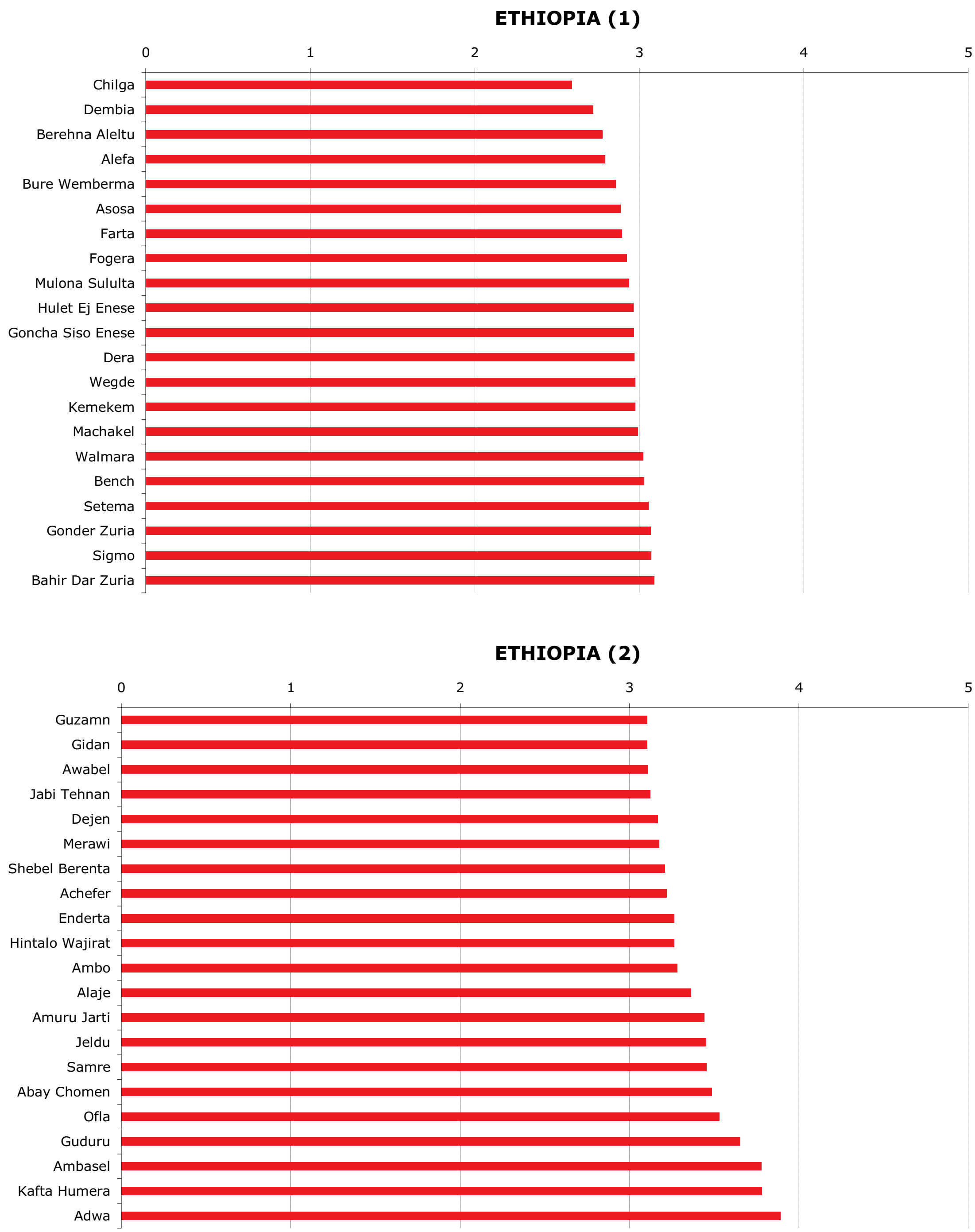


Figure 75 Representation for the average total score for Ethiopia for each district.

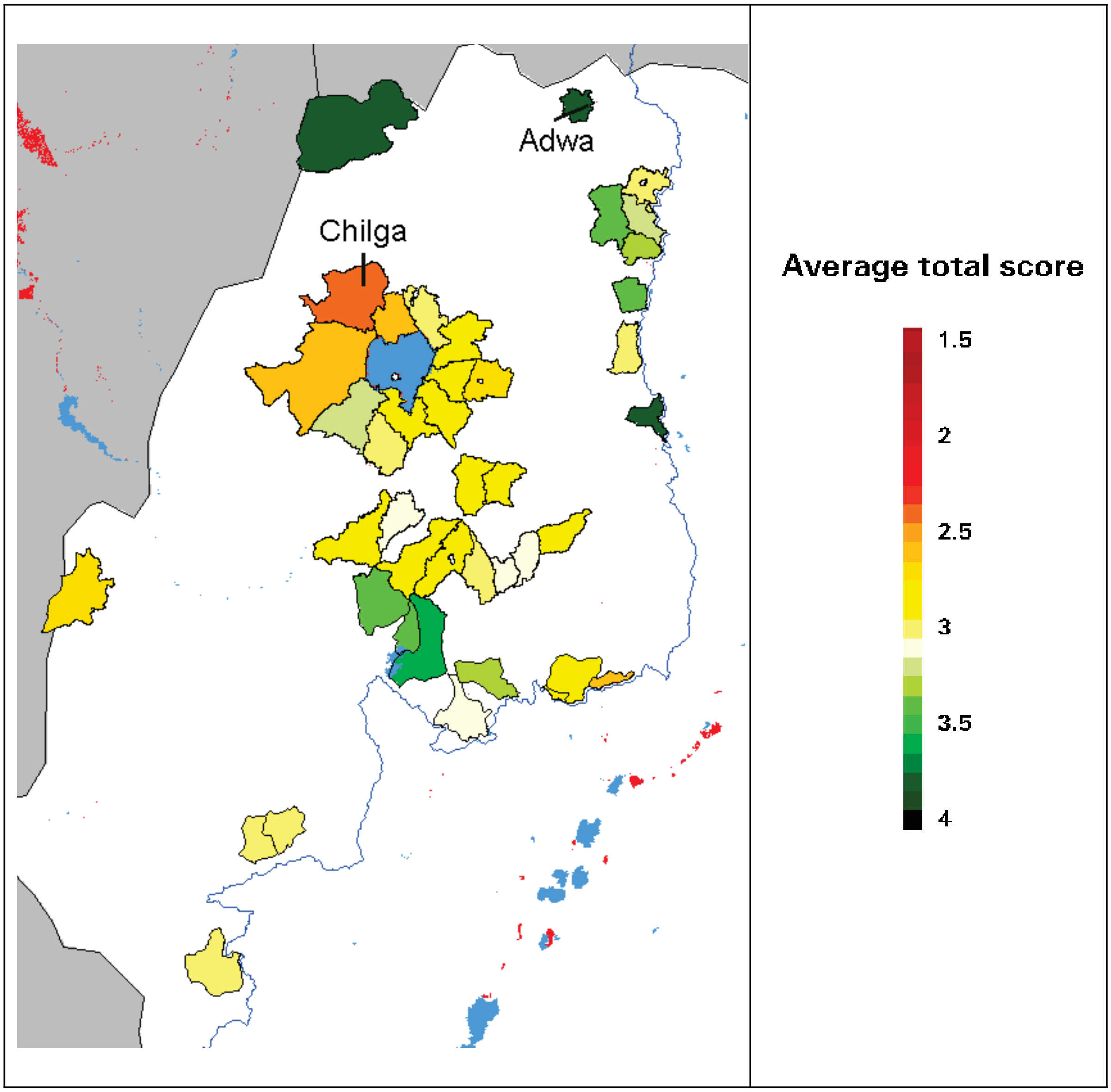
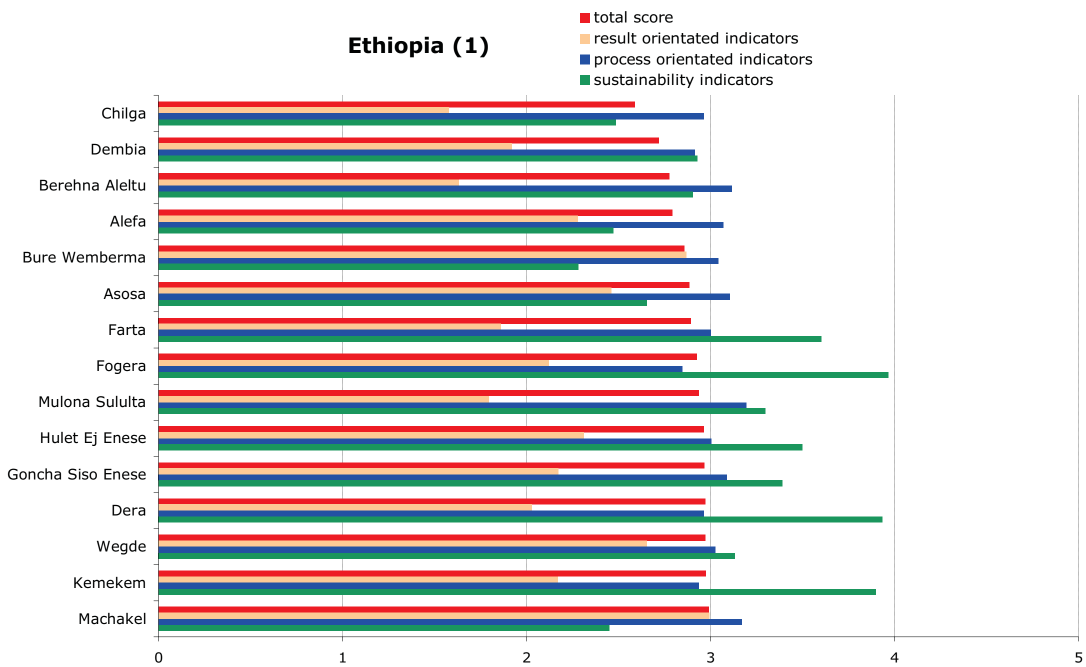


Figure 76 Map showing the total score per irrigated district.

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

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 77 provides the average score per group of indicators. Considering the total score or the average for all indicators for each district gives an idea of the total performance. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.


Ethiopia (1)
total score
result orientated indicators
process orientated indicators
sustainability indicators
Chilga
Dembia
Berehna Aleltu
Alefa
Bure Wemberma
Asosa
Farta
Fogera
Mulona Sululta
Hulet Ej Enese
Goncha Siso Enese
Dera
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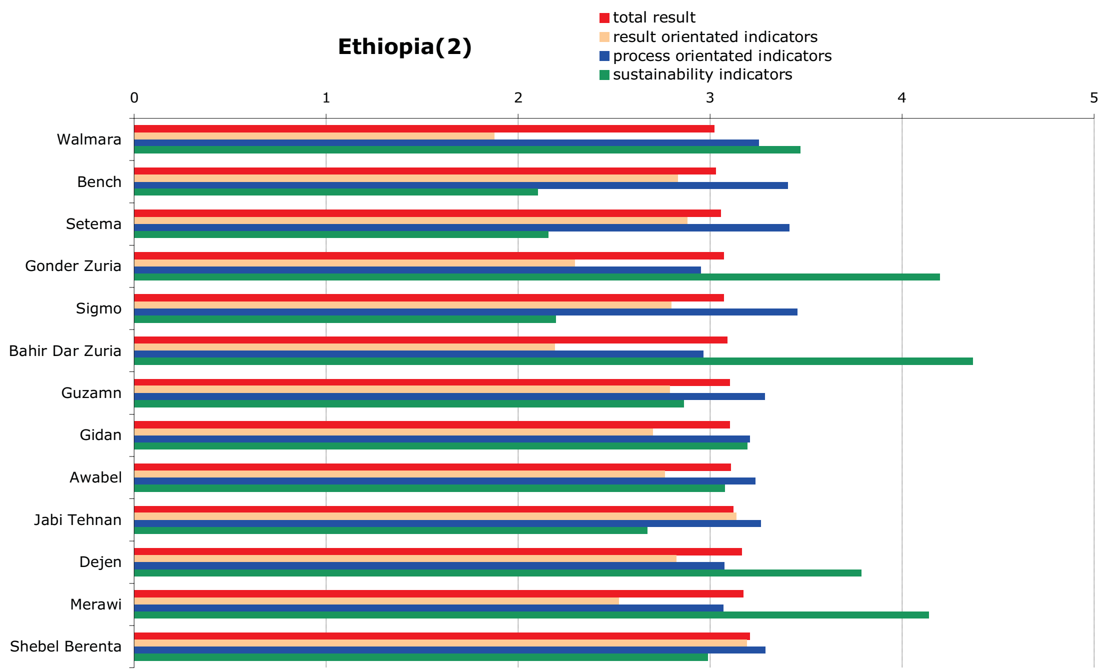
0
1
2
3
4
5


Ethiopia(2)
total result
result orientated indicators
process orientated indicators
sustainability indicators
0
1
2
3
4
5
Walmara
Bench
Setema
Gonder Zuria
Sigmo
Bahir Dar Zuria
Guzamn
Gidan
Awabel
Jabi Tehnan
Dejen
Merawi
Shebel Berenta

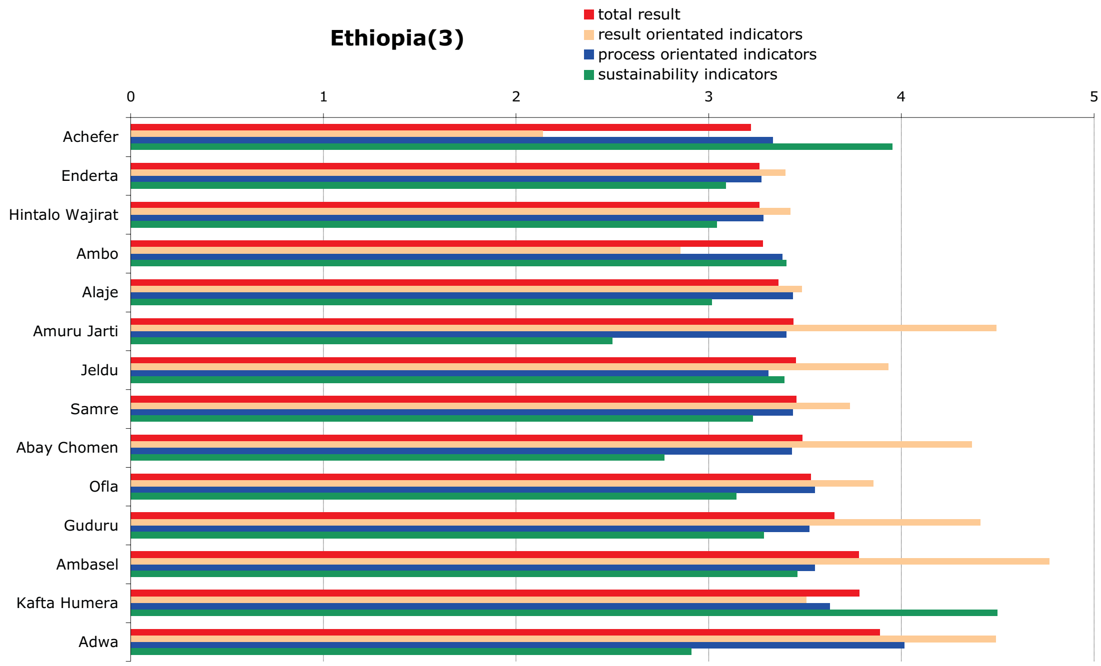


Figure 77 Breaking down the total score per indicator

A good total score does not always mean a good performance for the three categories of indicators: RO, PO and sustainability. Indeed, if one looks at the average score for the RO indicators, Bahir Dar Zuria is fourth best in terms of total score whilst it has a low score in terms of land and biomass water productivity. This is due to the fact that its score for land and water sustainability is really good. Hence, a favourable total performance does not mean a sustainable system. In fact, considering the score for the sustainability indicators, there is no obvious difference between the good performing and the bad performing districts. This shows once again the relevance of breaking the irrigation performance down into different types of indicators.

The upper third best performing districts have a good to very good score in terms of RO indicators. On the contrary, the other districts have a better score in terms of the PO indicators average score than in terms of RO indicators. It means that even though the management of the irrigation systems seems quite good, other factors are limiting the land and water productivity. These factors might be linked to agricultural practices such as crop types or application of fertilizers. Relevant improvement recommendations should be made district per district by looking at the different scores of every single indicator.

3.4 Analysis per pixel for an irrigation system

Looking at what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators are displayed for the irrigated pixel in the district of Jabi

Tehnan, which is an average district in terms of performance. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. This example demonstrates that reliability and adequacy need to be managed better (Figure 78).

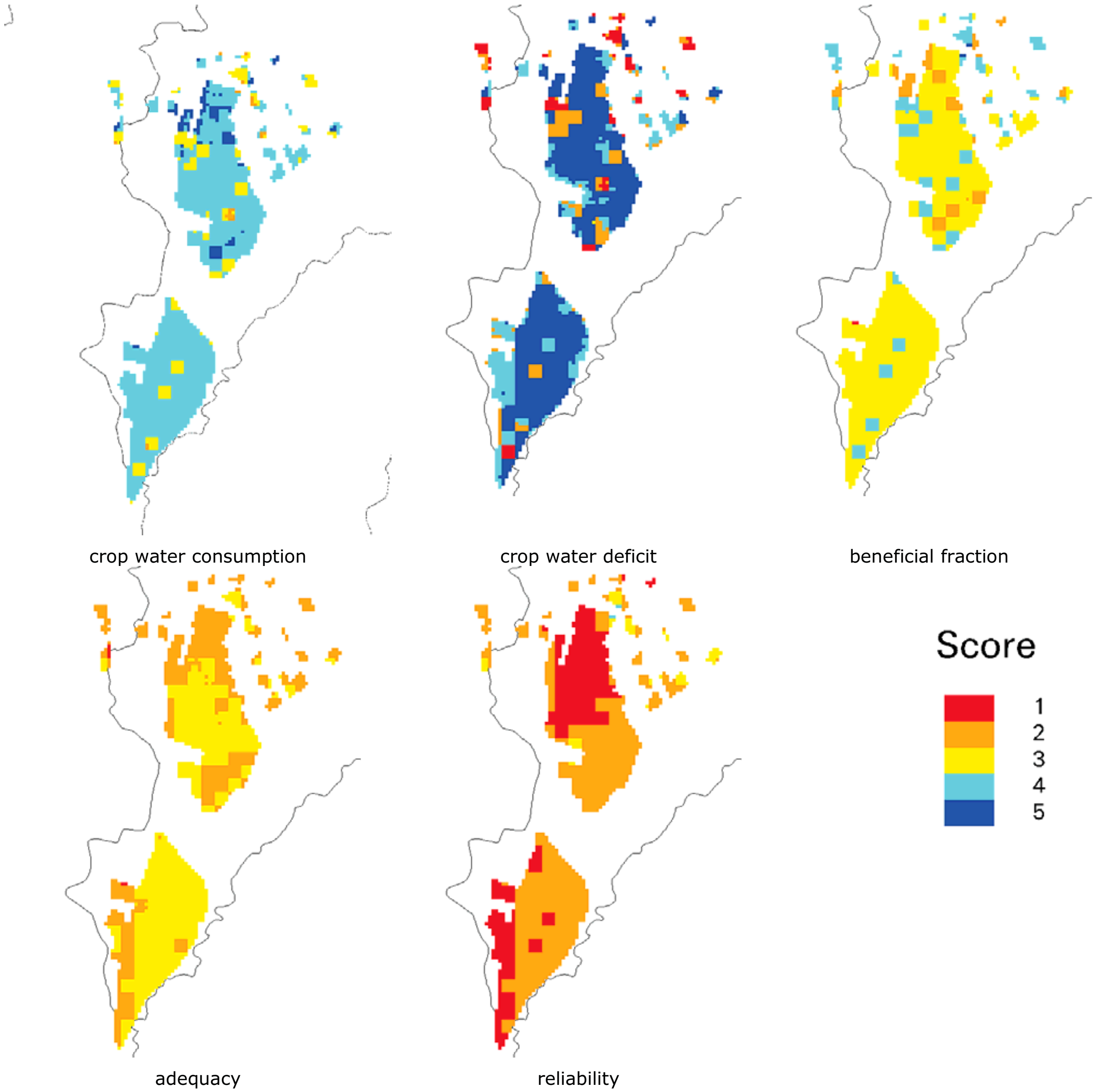


Figure 78 Spatial distribution of each indicator for the districts of Jabi Tehnan

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators and the sustainability indicators influence the RO indicators mostly. A regression analysis was performed with the values for all indicators of the 42 districts. It showed that crop water consumption, reliability, and adequacy are the three main explanatory factors for biomass production. Hence the timely delivery of adequate irrigation amounts should get more attention in Ethiopia.

Besides, an increase in beneficial fraction leads to an increase in biomass production and biomass water productivity. An increase in crop water consumption leads to an increase in biomass production but a decrease in biomass water productivity. It seems that the lower the crop water consumption and the higher the beneficial fraction, the better the biomass water productivity. But none of the relationships depicted is clear. It is thus better to focus on increasing biomass production rather than biomass water productivity.

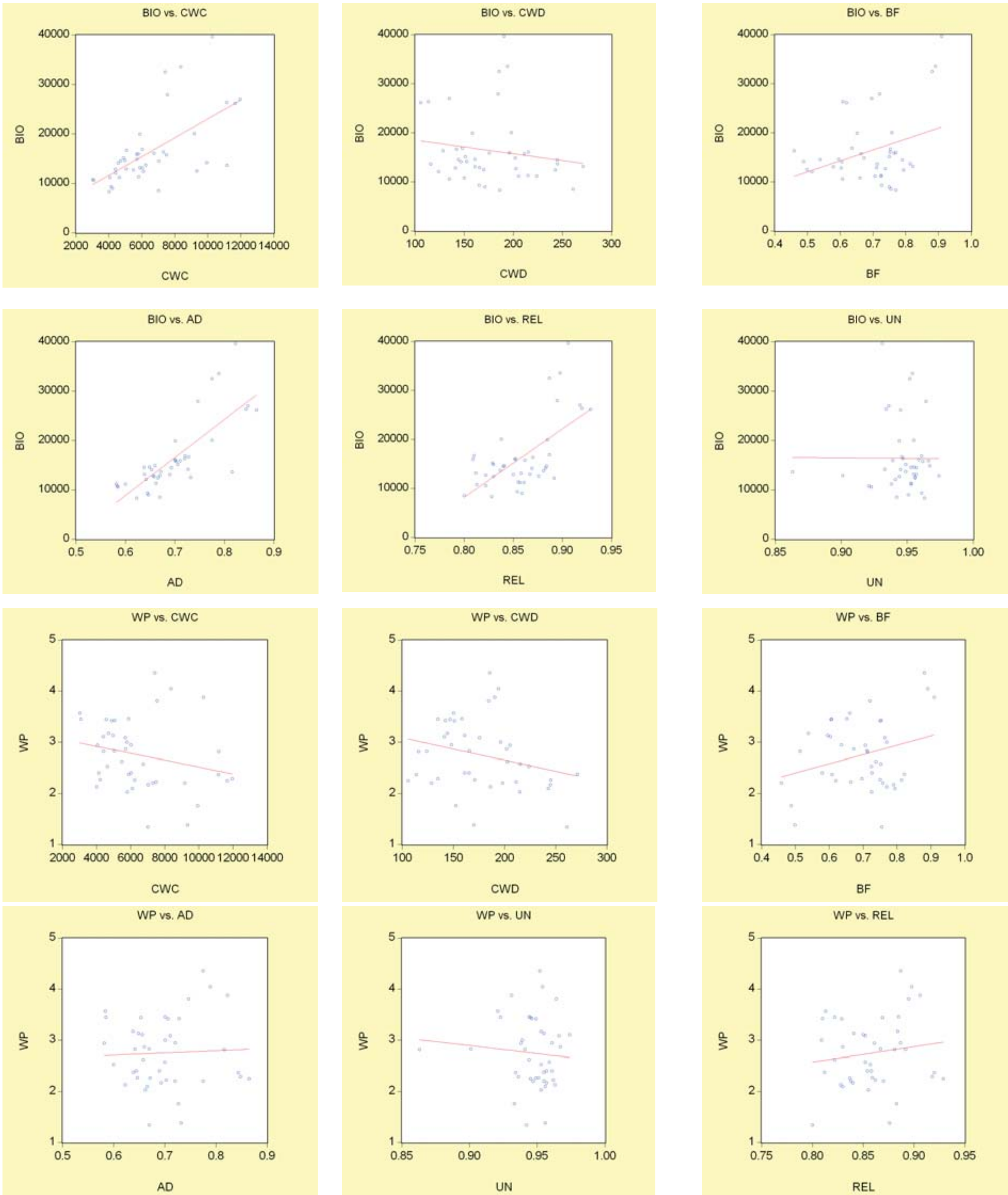


Figure 79 Relationships between RO indicators and PO indicators

4.2 Weak and strong aspects per district

In Table 54, the best and poorest indicators are presented. This helps to identify which elements of irrigation performance need improvement.

Adequacy, beneficial fraction, and reliability seem to be the main problem factors for the majority of the districts. On the other side of the scale, crop water deficit and uniformity are often mentioned as being the best indicators.

Table 54 best and poorest PO irrigation indicator per district

district	lowest score		2nd lowest		2nd best		best	
Chilga	ad	1.55	bf	1.67	cwd	3.42	un	5.00
Dembia	bf	1.65	rel	2.63	cwd	3.77	un	4.00
Berehna Aleltu	ad	1.79	rel	2.03	cwc	4.13	un	5.00
Alefa	bf	1.49	ad	2.30	un	4.00	cwd	4.16
Bure Wemberma	rel	1.74	ad	2.57	cwc	3.77	un	4.00
Asosa	ad	1.93	rel	2.01	bf	3.01	un	5.00
Farta	rel	2.10	cwd	2.30	cwc	3.84	un	5.00
Fogera	cwd	1.80	ad	1.88	cwc	3.70	un	4.00
Mulona Sululta	ad	2.02	rel	2.10	cwc	4.19	un	5.00
Hulet Ej Enese	rel	2.13	ad	2.31	cwc	3.17	un	5.00
Goncha Siso Enese	ad	1.77	rel	2.09	cwc	3.56	un	5.00
Dera	cwd	1.85	rel	1.92	cwc	3.78	un	5.00
Wegde	ad	1.96	rel	1.96	cwc	3.62	un	5.00
Kemekem	rel	1.64	cwd	1.68	cwc	3.85	un	5.00
Machakel	rel	1.85	ad	1.87	cwc	3.98	un	4.00
Walmara	rel	2.01	ad	2.05	cwc	4.20	un	5.00
Bench	ad	2.00	cwc	2.20	un	4.00	cwd	4.26
Setema	ad	1.87	cwc	2.28	un	4.00	cwd	4.59
Gonder Zuria	rel	1.83	ad	2.32	un	4.00	cwc	4.06
Sigmo	ad	1.94	cwc	2.07	un	4.00	cwd	4.27
Bahir Dar Zuria	cwd	1.92	rel	2.03	cwc	3.36	un	5.00
Guzamn	rel	2.03	ad	2.30	cwc	3.81	un	5.00
Gidan	bf	1.73	ad	2.92	cwd	4.08	cwc	4.22
Awabel	ad	1.81	rel	2.00	cwc	4.08	un	5.00
Jabi Tehnan	rel	1.70	ad	2.16	un	4.00	cwd	4.29
Dejen	ad	2.22	bf	2.30	un	4.00	cwc	4.09
Merawi	rel	2.10	ad	2.22	cwc	3.44	un	5.00
Shebel Berenta	bf	2.22	rel	2.40	cwd	4.06	un	5.00
Achefer	rel	2.78	bf	2.87	ad	3.69	cwd	4.71
Enderta	bf	2.47	rel	3.11	un	4.00	cwc	4.65
Hintalo Wajirat	bf	2.16	rel	3.38	un	4.00	cwc	4.73
Ambo	bf	2.47	rel	2.72	cwd	3.94	un	5.00
Alaje	ad	2.54	bf	2.87	cwc	3.68	un	4.00
Amuru Jarti	cwc	2.34	cwd	2.86	ad	4.00	bf	4.53
Jeldu	ad	2.77	rel	2.83	cwc	3.40	un	5.00
Samre	ad	2.82	bf	2.89	un	4.00	cwc	4.06
Abay Chomen	cwd	2.39	cwc	2.97	bf	4.13	un	5.00

Ofla	bf	1.71	ad	3.45	cwc	4.10	un	5.00
Guduru	rel	2.82	cwd	2.83	bf	4.12	un	5.00
Ambasel	bf	2.19	ad	3.31	un	4.00	cwd	4.58
Kafta Humera	cwc	2.68	bf	3.53	cwd	3.81	un	4.00
Adwa	cwc	3.41	bf	3.44	cwd	4.43	un	5.00

4.3 Recommendation countrywide

With a growing population, food security is becoming a major concern in Ethiopia even though it has a high agricultural potential (the total arable land is estimated to be 55 million ha according to FAO). However, improvements in rainfed agriculture will fail to make up the deficits and keep pace with the increasing demand resulting from population growth. Since 1991, a combination of the positive effects of policy initiatives and good rains allowed the country to achieve food self-sufficiency and food exports in 1996/97. But bad weather – a combination of rainfall deficits during the growing season and excess rainfall during the ripening and harvest season – has reversed that situation in 1997/98, demonstrating the dependence of agriculture on climatic factors. Even in good years Ethiopia cannot meet its large food deficit through rainfed production. Improving the productivity of irrigated land should be on the agenda. The fact that on average, the performance of the LSI is quite low offers the greatest possibilities for improved productivity and for meeting the demand for food within the country.

The weakest aspect is more on the agronomical side than on the irrigation side.
As the population is growing fast, food deficit is getting bigger and bigger.
If the country is to address its serious problems of poverty and food deficits due to the fast growing population, it is important to increase the productivity of existing irrigation systems. Biomass production can be increased if sufficient irrigation water (adequacy) is applied at the right time (reliability). To do so, investments should be made to improve agronomical research and extension services: more qualified and equipped staff able to advice on application of fertilizers.

According to an IWMI study, the limitation in the availability of water in semi arid areas (like Ethiopia) is not caused by low rainfall but lack of capacity for sustainable management and use of the available water. Neither the farmers nor the extension services are attempting to generate/implement practices that can retain the temporary excess rain water for use during dry spells. The agronomical research has an important role to play to find crop varieties and practices that could tolerate the temporary water logging problems and the sporadic dry spells.

The institutional context does not seem to favour the cooperative management of the irrigation systems, such measures because of its lack of organization, different institution involved, and its instability (in the irrigation sector).

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m3	Bio/ETact	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M3/ha/year	ETact	Saving of water resources
	Crop water deficit	cwd	M3/ha/year	ETpot-ETact	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	Tact/ETpot	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	Tact/Tpot	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	1-CV(Tact/Tpot)(x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	1-CV(Tact/Tpot)(t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
					Indication of changes of water resources availability
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 General information on irrigation conditions in Ethiopia (Aquastat, 2005)

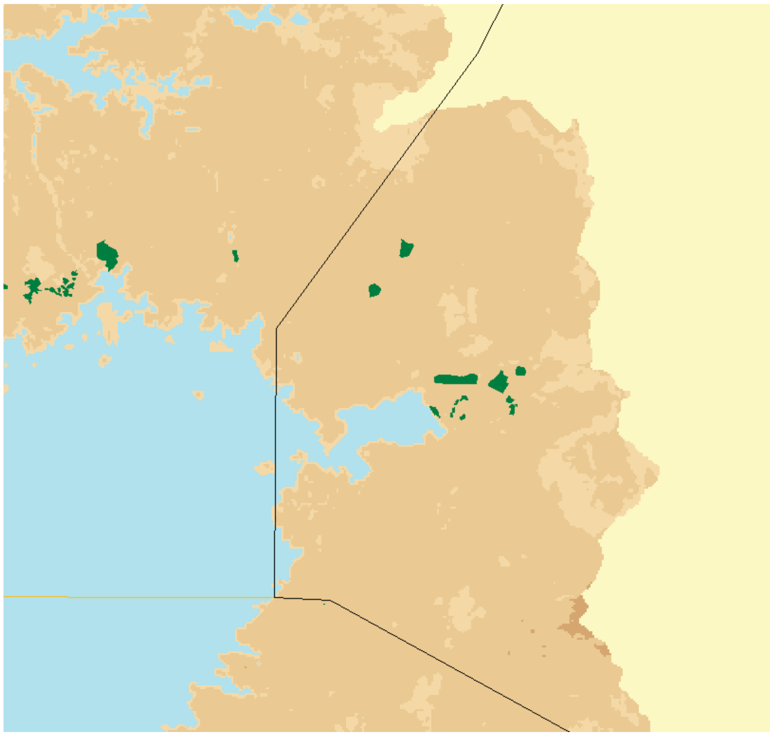
Irrigation and drainage

Irrigation potential			2 700 000	ha
Water management				
1. Full or partial control irrigation: equipped area		2001	289 530	ha
- surface irrigation		2001	283 163	ha
- sprinkler irrigation		2001	6 355	ha
- localized irrigation		2001	12	ha
• % of area irrigated from groundwater			-	%
• % of area irrigated from surface water			-	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)			-	ha
3. Spate irrigation			-	ha
Total area equipped for irrigation (1+2+3)		2001	289 530	ha
• as % of cultivated area		2001	2.5	%
• average increase per year over the last 7 years		1994-2001	6.2	%
• power irrigated area as % of total area equipped			-	%
• % of total area equipped actually irrigated			-	%
4. Non-equipped cultivated wetlands and inland valley bottoms			-	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		2001	289 530	ha
• as % of cultivated area			2.5	%
Full or partial control irrigation schemes	Criteria			
Small-scale schemes	< 200 ha	2001	191 827	ha
Medium-scale schemes		2001	0	ha
Large-scale schemes	> 200 ha	2001	97 703	ha
Total number of households in irrigation			-	
Irrigated crops in full or partial control irrigation schemes				
Total irrigated grain production		2002	238 138	tonnes
• as % of total grain production		2002	2.6	%
Total harvested irrigated cropped area		2002	410 557	ha
• Annual crops: total		2002	395 016	ha
- maize		2002	86 859	ha
- wheat		2002	23 162	ha
- other cereals (sorghum, barley, teff, other)		2002	26 058	ha
- vegetables		2002	107 126	ha
- sugarcane		2002	27 197	ha
- cotton		2002	57 906	ha
- roots and tubers		2002	52 231	ha
- pulses		2002	8 686	ha
- other annual crops		2002	5 791	ha
• Permanent crops: total		2002	15 541	ha
- citrus		2002	5 828	ha
- bananas		2002	5 828	ha
- other permanent crops		2002	3 885	ha
Irrigated cropping intensity		2002	142	%
Drainage - Environment				
Total drained area			-	ha
- part of the area equipped for irrigation drained			-	ha
- other drained area (non-irrigated)			-	ha
• drained area as % of cultivated area			-	%
Flood-protected areas			-	ha
Area salinized by irrigation			-	ha
Population affected by water-related diseases			-	inhabitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Kenya



Report G

January 2009

NILE BASIN INITIATIVE
Initiative du Bassin du Nil

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 Kenya and will become an integral component of the final LSI report that will combine results from all countries.

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

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

The Nile Basin in Kenya covers only 8.5% of the total area of the country but contains over 50% of the national freshwater resources with seven major rivers (Nzoia, Yala, Nyando and Sondu Miriu, Kuja-Migori, Mara and Sio-Malaba) draining directly in to Lake Victoria. While the western part of Kenya is endowed with a high amount of total rainfall, the irregular character of rainfall motivates the stakeholders to invest in irrigation systems. Figure 80 shows the location of the main irrigation systems according to this study. Figure 81 shows the area with potential irrigation.

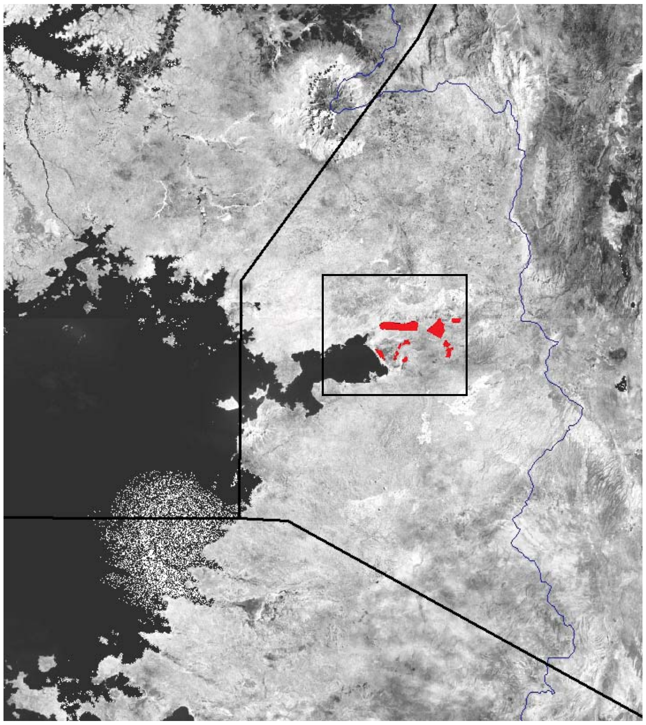


Figure 80 Map with the distribution of irrigated areas within the Nile Basin according to this study. The red dots represent the irrigated areas

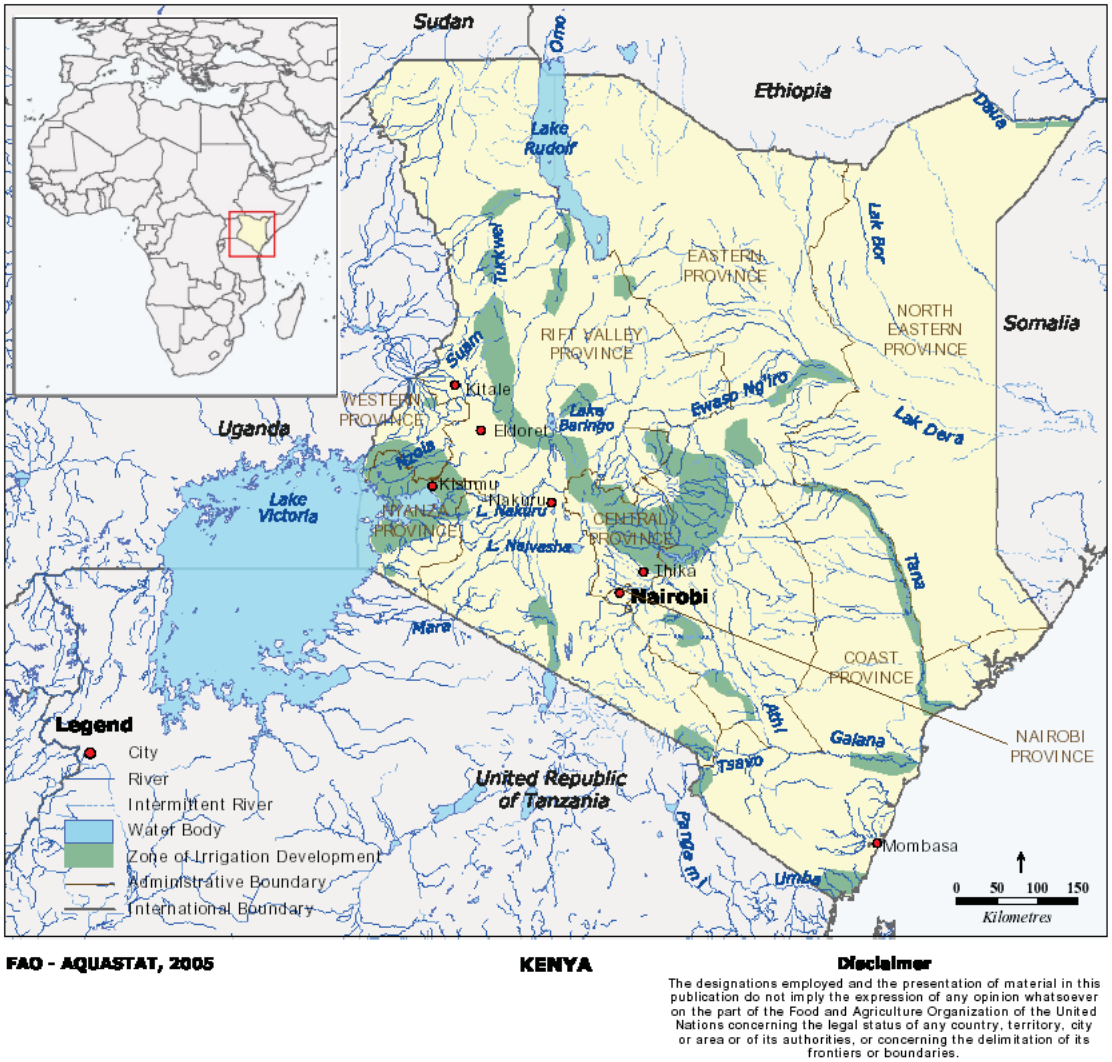


Figure 81 Map of the potential irrigation systems in Kenya

According to this study, a total of 34,154 ha of land is irrigated in the Nile basin component of Kenya (Table 55).

Table 55 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Kenya	66,610
IWMI – GIAM	Entire Kenya	85,401
Current study	Nile Basin component of Kenya	34,156

1.2 Description of LSI

Kenya has an irrigation potential of 539,000 ha out of which 105,800 ha (or 20%) have been developed. 50% of this has been achieved over the last 20 years. Private, public and smallholder categories account for 42,800 ha (40%), 16,000 ha (15%)

and 47,000 ha (44%) of the total respectively. In the lake Victoria basin, an irrigation potential of 200,000 ha has been estimated which is 37% of the national potential.

Public and private irrigation schemes in the Kenyan Nile basin include West Kano, Ahero and Bunyala irrigation schemes. Almost all irrigation is achieved through developments using river water, but about 4,100 water pans and small dams and 15 large dams have also been built. The former being located in the arid areas and the latter in the medium potential zones. Basin, furrow and flood irrigation methods are used in most community irrigation schemes with sprinkler and drip schemes being used on some private farms especially for the cultivation of flowers and horticultural crops. Table 56 displays the main characteristics of some irrigation scheme located in the district of the Nile Basin.

Table 56 Summary of some key data of Kenyan irrigation schemes that are located in the Nile Basin (source: National Kenya Irrigation Board)

Scheme name	Location (Town/district/ Basin)	Irrigation area (ha)	Main Crop	Crop yield (ton/ha)	Water abstraction Method	Abstraction
1 Ahero	Ahero/Nyando*/Lake Victoria	960	Rice	3.5	Pumped – River Nyando	4 pumps each 600l/s
2 West Kano	Kabonyo/Kisumu/Lake Victoria	900	Rice	3.5	Pumped – Lake Victoria	2 pumps each 750 l/s

* Nyando district is a fairly new district in Kenya which broke away from Kissumu district in Nyanza province in 1998. In this study, we worked with an older district distribution. The irrigation districts of Nyando are included in the district of Kisumu in the report.

More detailed information concerning irrigation in Kenya can be found in Annex 2. There are other water user association irrigated schemes within the Nile Basin region; these could command approximately 3,000 ha inclusive of the privately owned Yala swamp which is about 500 ha.

1.3 Agricultural conditions

Large scale agriculture accounts for 30% of marketed produce comprising tea, coffee, horticultural produce, maize and wheat (see Figure 82 for the national number). The cropping calendar is represented in Table 57.

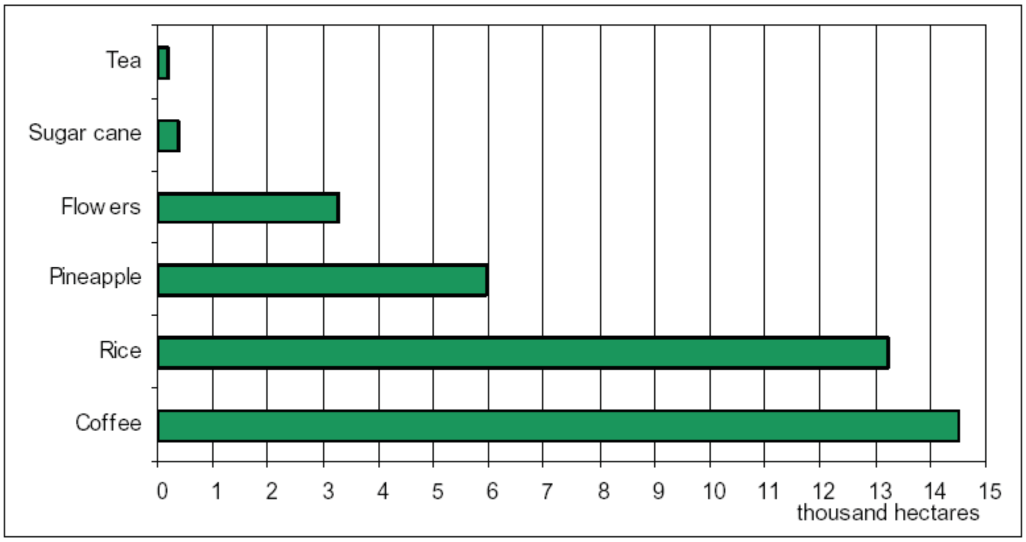


Figure 82 Main irrigated crops in Kenya in 2003 (Aquastat, 2005)

Table 57 Cropping calendar in Kenya in 2003 (Aquastat, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
KENYA													
Rice	18				26	26	26	26	26				
Maize	4				6	6	6	6	6				
Sugarcane	2	3	3	3	3	3	3	3	3	3	3	3	3
Vegetables	26	38	38								38	38	38
Bananas	1	1	1	1	1	1	1	1	1	1	1	1	1
Citrus	5	7	7	7	7	7	7	7	7	7	7	7	7
Coffee	18	26	26	26	26	26	26	26	26	26	26	26	26
Cotton	3	4	4	4						4	4	4	4
All irrigated crops	77	81	81	43	71	71	71	71	71	43	81	81	81
Equipped for irrigation	68												
Cropping intensity	113												

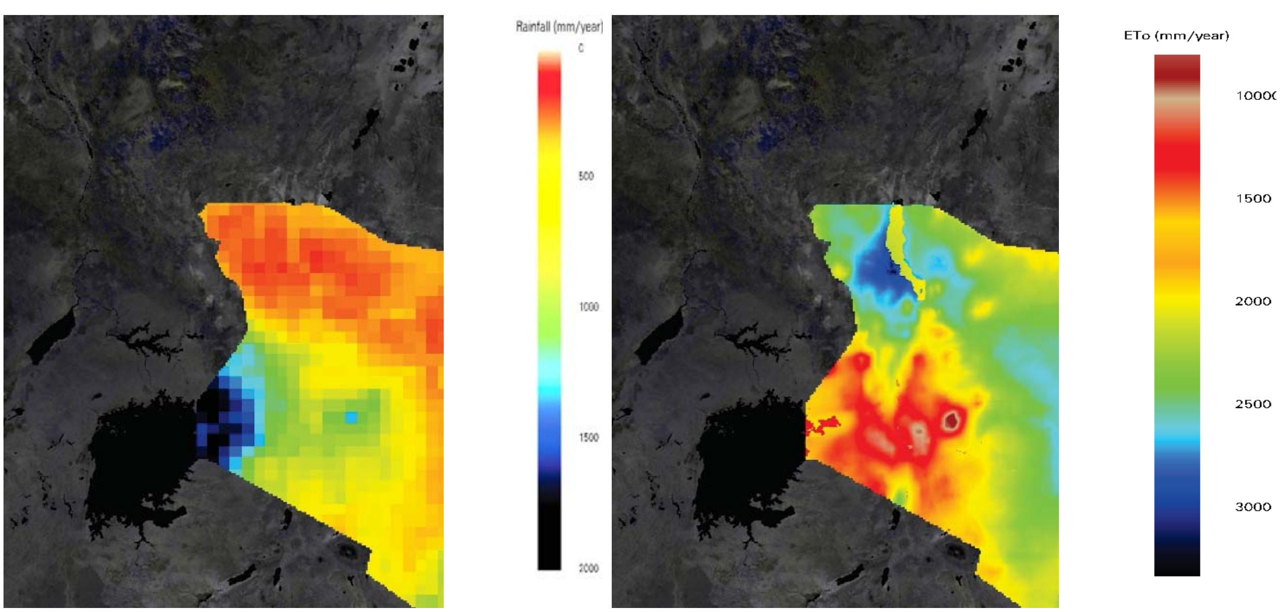
Part 2 Climate

2.1 Climatological conditions

In this study, the reference evapotranspiration (ET_0)is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007. According to this study (Table 58), the rainy season starts in May and continues up to November. Only the winter months are dry, with monthly aridity values of approximately 0.3. Figure 83 shows that the western part of Kenya receives a significant amount of rainfall (1155 mm/yr).

Table 58 Monthly values for rainfall and reference ET_0

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	58	169	0.34
February	47	156	0.30
March	13	168	0.08
April	34	138	0.25
May	178	133	1.29
June	113	124	0.91
July	137	124	1.10
August	141	134	1.05
September	108	142	0.76
October	150	152	0.99
November	119	141	0.84
December	54	156	0.35
TOTAL	1155		



Annual rainfall Annual reference ET

Figure 83 Spatial variation of rainfall and ET_0

2.2 Climatic zones

The current study, aimed at providing information for improved irrigation practices in the Nile basin, covers various climate zones. Rainfall and temperatures specifically need to be analyzed, because they have a large impact on attainable land and water productivities, as well as the irrigation efficiencies. Unexpected rainfall can for instance reduce the irrigation efficiency, and also induce more variations in soil moisture conditions than in a situation where the crop moisture depends solely on irrigation water supply. To make corrections for these climatic influences on the basis of diagnosis of the irrigation systems, and to define climate dependent target values of irrigation management, four different climate zones have been identified for the Nile Basin. The zones have been made contiguous where possible. Insertion of more zones would result into scattered appearances of the zones. All Kenyan irrigation schemes located in the Nile basin are included in climate zone 4 (humid tropics).

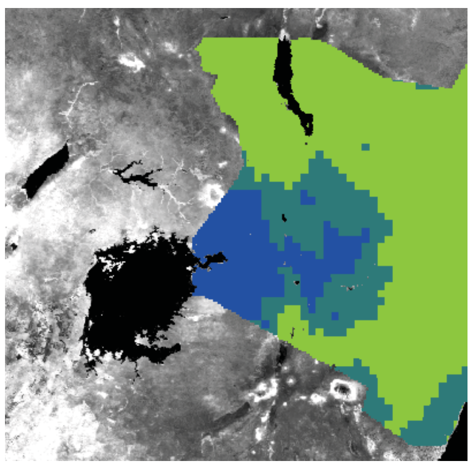


Figure 84 Climate zones distinguished for the irrigation performance mapping in Kenya. The irrigated areas are only located in the climate zone humid tropics, displayed in blue.

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on manual digitization of visually recognizable irrigated systems using existing irrigation reports, Google earth and Landsat images.

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

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

Table 59 Definition of the performance indicators selected to describe the LSI for each Nile Basin country. A more detailed description is given in Appendix 2.

Indicator	Acronym	Unit	Formula
Biomass productivity	bio	Kg/ha/year	Bio
Biomass water productivity	bwp	Kg/m3	Bio/ET_{act}
Crop Water Consumption	cwc	M3/ha/year	ET_{act}
Crop water deficit	Cwd	M3/ha/year	$ET_{pot}-ET_{act}$
Beneficial fraction	Bf	-	T_{act}/ET_{pot}
Adequacy (Crop Water stress)	Ad	-	T_{act}/T_{pot}
Uniformity	Un	-	$1-CV(T_{act}/T_{pot})(x,y)$
Reliability	Rel	-	$1-CV(T_{act}/T_{pot})(t)$
Land sustainability	spot	1/year	Slope ndvi spot
Water sustainability	amsre	1/year	Slope soil moisture

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined as displayed in Table 60. A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 85).

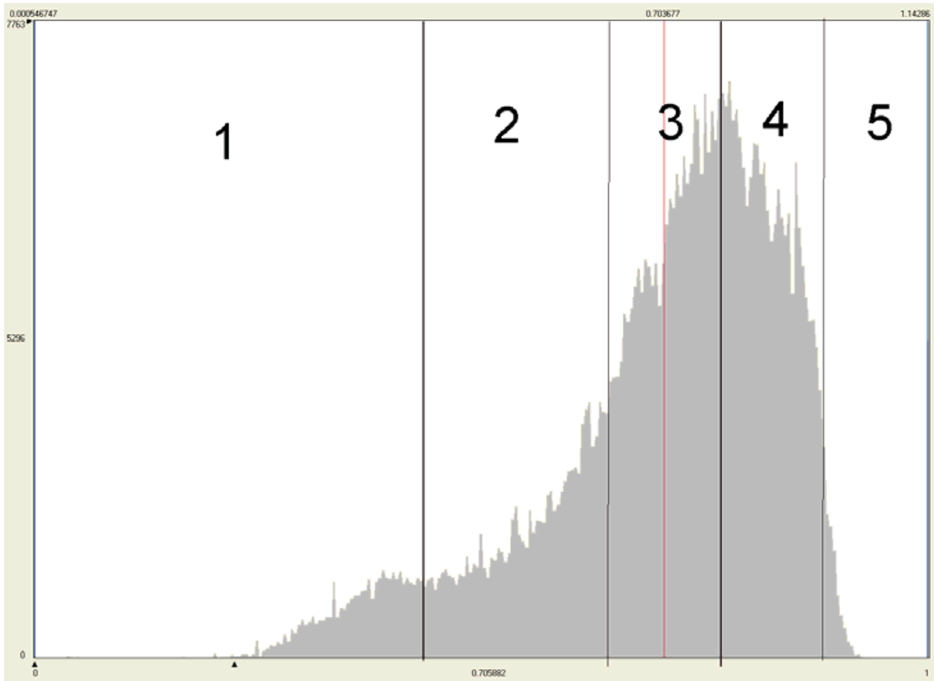


Figure 85 Distribution of the values of one indicator over 5 classes

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

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

Table 60 Benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91

ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

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

3.2 Analysis at Country level

Figure 86 shows the country average for each indicator. The average score considering all the indicators together for all the 34,156 ha of irrigated land is 3.7, which is a good score. The country average is calculated on a pixel base. . The elements with a relative low score are the ones that Kenya should provide more attention to.

The first comment to make is that, except for crop water consumption, all the indicators are above average, which shows the good global performance of irrigated system in Kenya.

The scores of 3.6 for land productivity and 3.5 for water productivity are good.

The PO indicators show very good performance in terms of beneficial fraction, uniformity, and reliability. Crop water deficit and adequacy are also good. Crop water consumption seems to be the weakest point, with an average score of 2.5. Hence the crop consumptive use is very high and need to be reduced.

Water sustainability seems to be under control. From the last years, the irrigated land is becoming wetter (as the score for the water sustainability is higher than 4.6). The land sustainability seems to be stagnant, with an average score of 3. The latter implies that irrigation intensity is constant in most irrigated land.

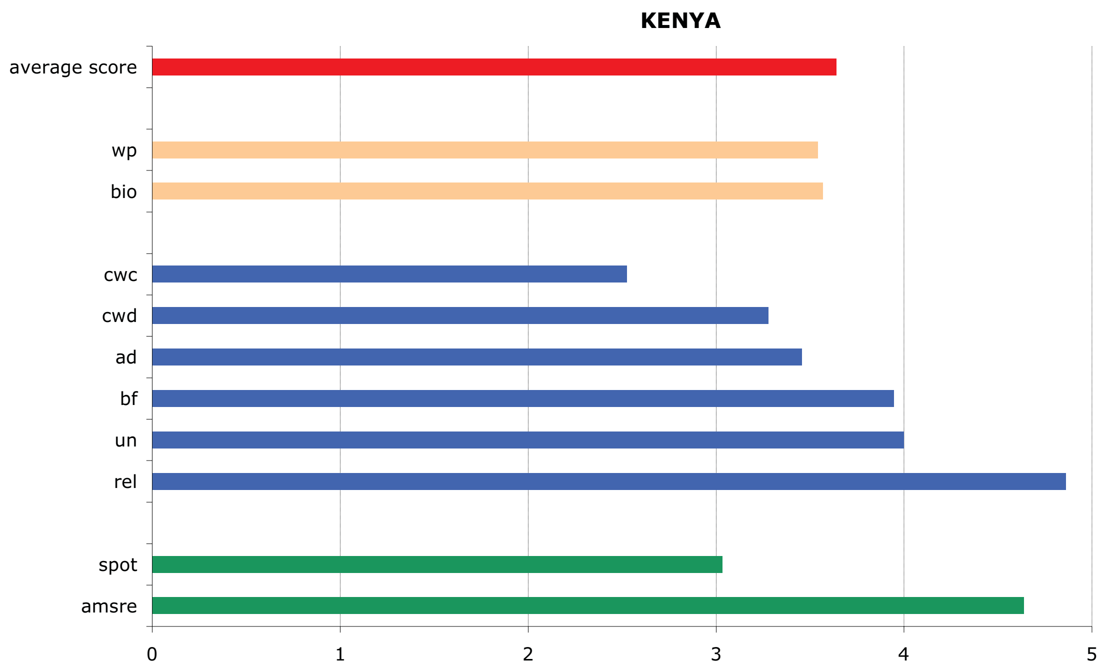


Figure 86 Representation of the average score for each indicator in Kenya.

3.3 Analysis at district level

3.3.1. Average per district

In Figure 87 the average score for all the indicators per district is compared. In Kenya, five districts having more than 30 pixels with 6.25 ha have been identified.

In terms of total average score, the best irrigation districts are Butere Mumais and Kericho, with an average of 3.9. The district that has the lowest average is Kisumu, with an average of 3.6 (see Figure 88 for their location). The average score for these 5 districts is high to very high, which already indicates the good performance of irrigation in Kenya. This good performance was already reflected in the country scale analysis.

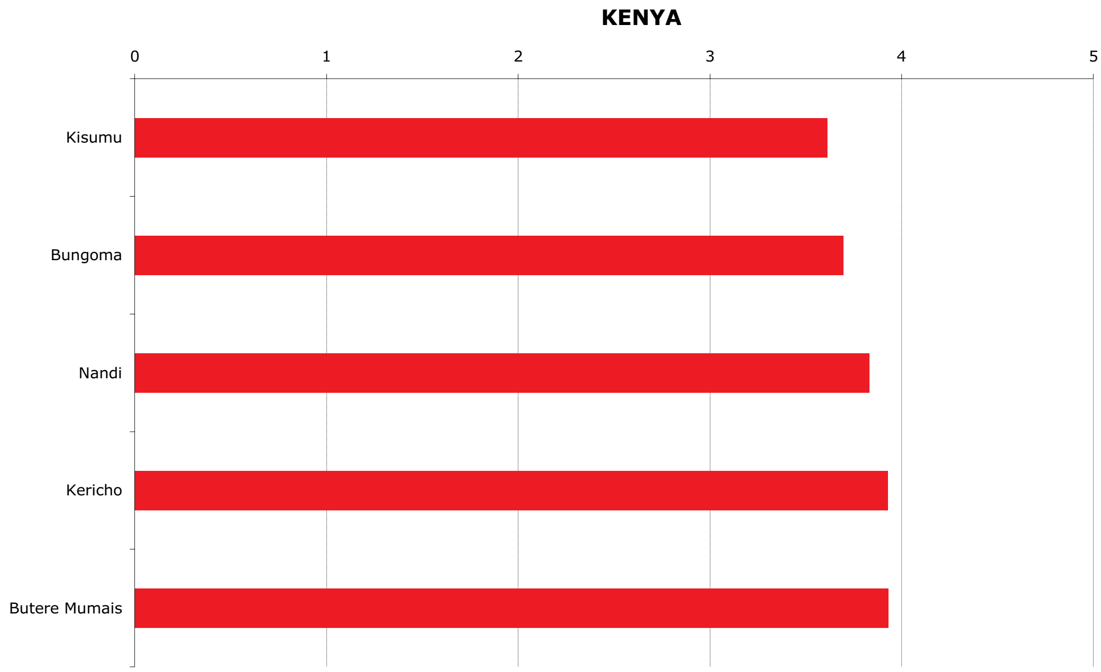


Figure 87 Total scores for Kenya for each district

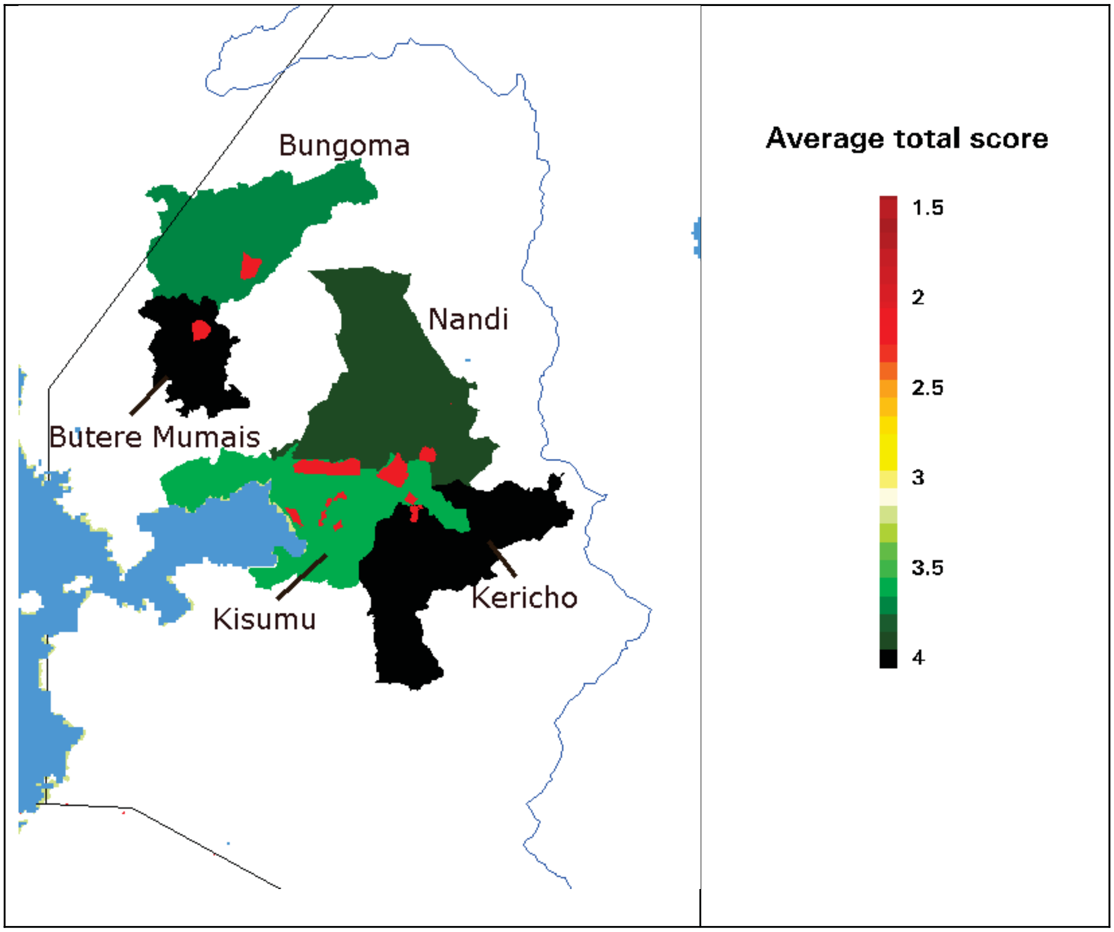


Figure 88 Map showing the average total score per irrigated district in the Nile basin component of Kenya

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

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 89 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators (see Figure 85). Considering the total average score for all indicators for each district gives an idea of the total performance and enables to rank the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

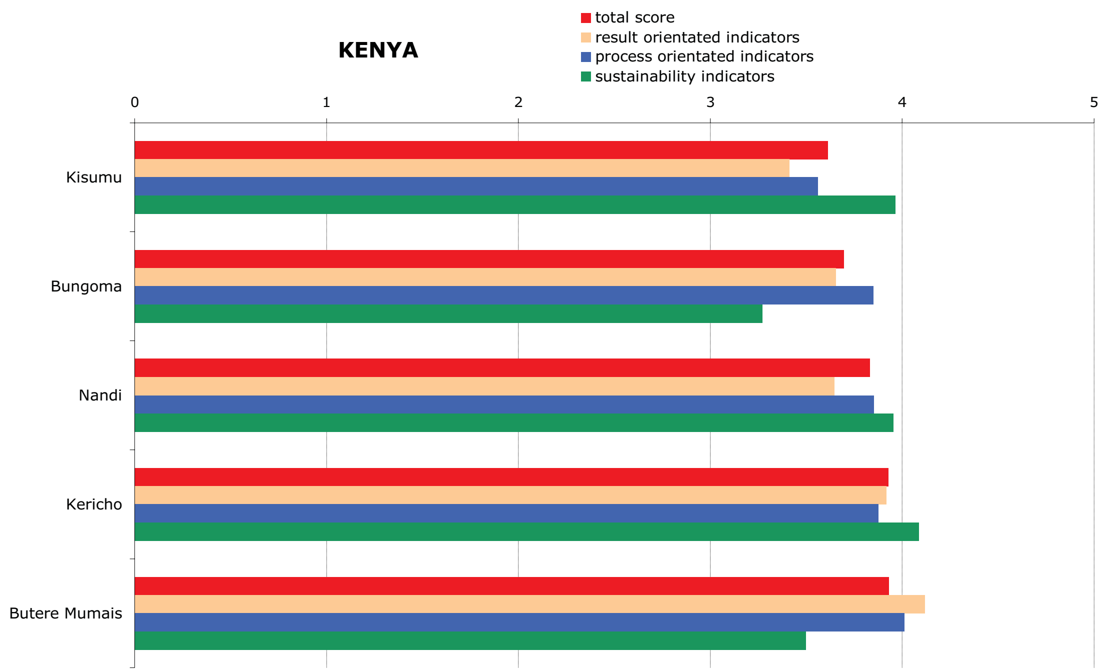


Figure 89 Representation of the average score for the irrigated districts in Kenya.

The first aspect that draws attention is that there is little variation between the districts in the total score. This total score is also broken down into the three indicators. The RO indicators vary only between the good score of 3.4 and 4.1; the PO indicators vary between 3.6 and 4 and the sustainability indicators vary only between 3.3 and 4.1. This is linked to the fact that the uniformity is very good overall in the country, as shown previously.

These good scores indicate generally good management of irrigation systems in Kenya, which makes recommendations for improvements on a country level unnecessary. Relevant improvement should be made on district level by considering different scores of every single indicator for each district.

3.4 Analysis per pixel for the best irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the neighbouring districts of Bungoma and Butere Mumais. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. This example displayed in Figure 90 demonstrates that crop water consumption is probably the weakest aspect at district level but also at pixel level. However, the crop water consumption is not homogeneous. Such an analysis helps to indentify where exactly crop water consumption is too high.

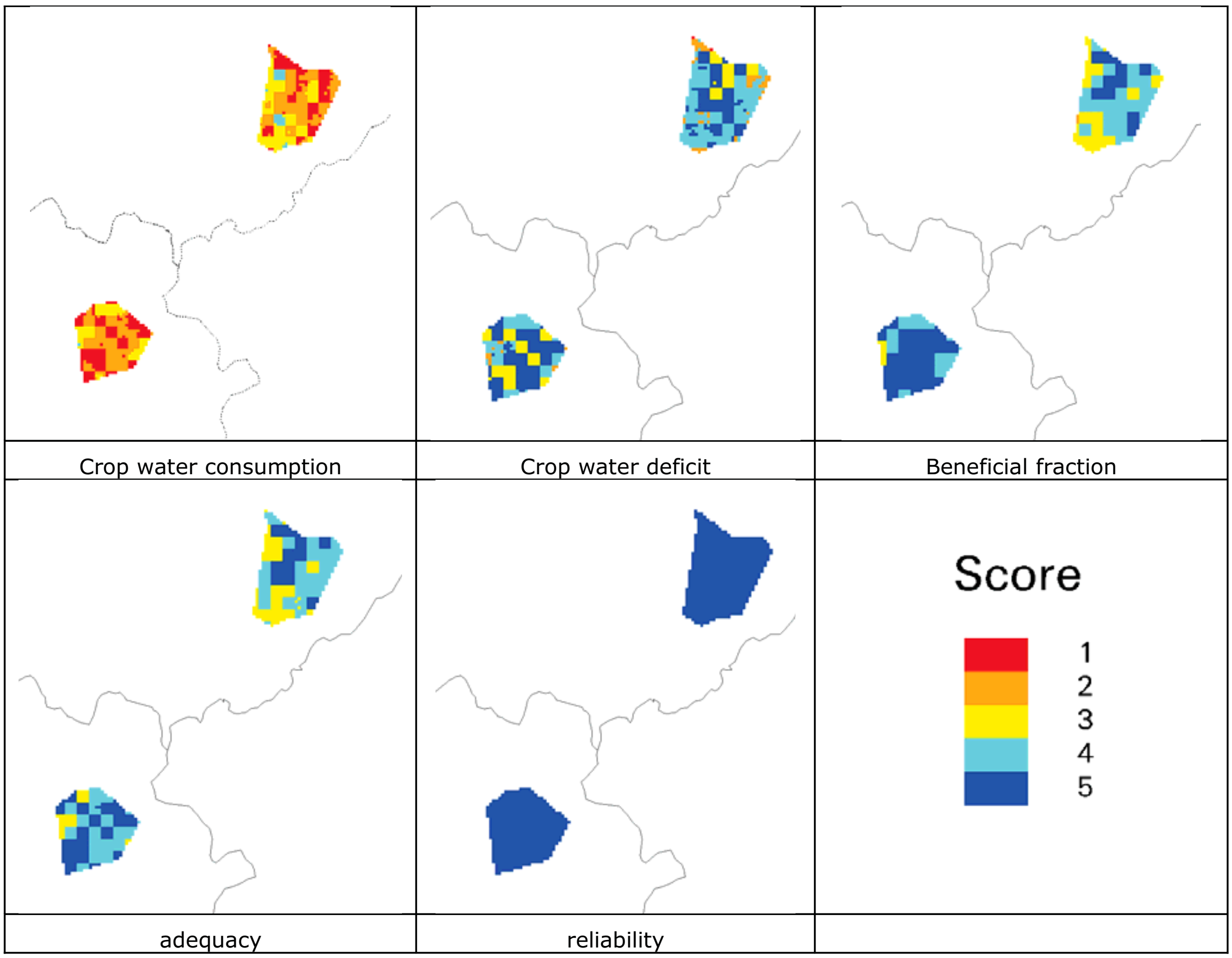


Figure 90 Spatial distribution of each indicator for the district of Bungoma and Butere Mumais.

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the 5 districts. It showed that the higher the beneficial fraction, crop water consumption, reliability and adequacy, the higher the biomass production. The correlation with crop water deficit is negative. Concerning the biomass water productivity, the links are less clear (Figure 91).

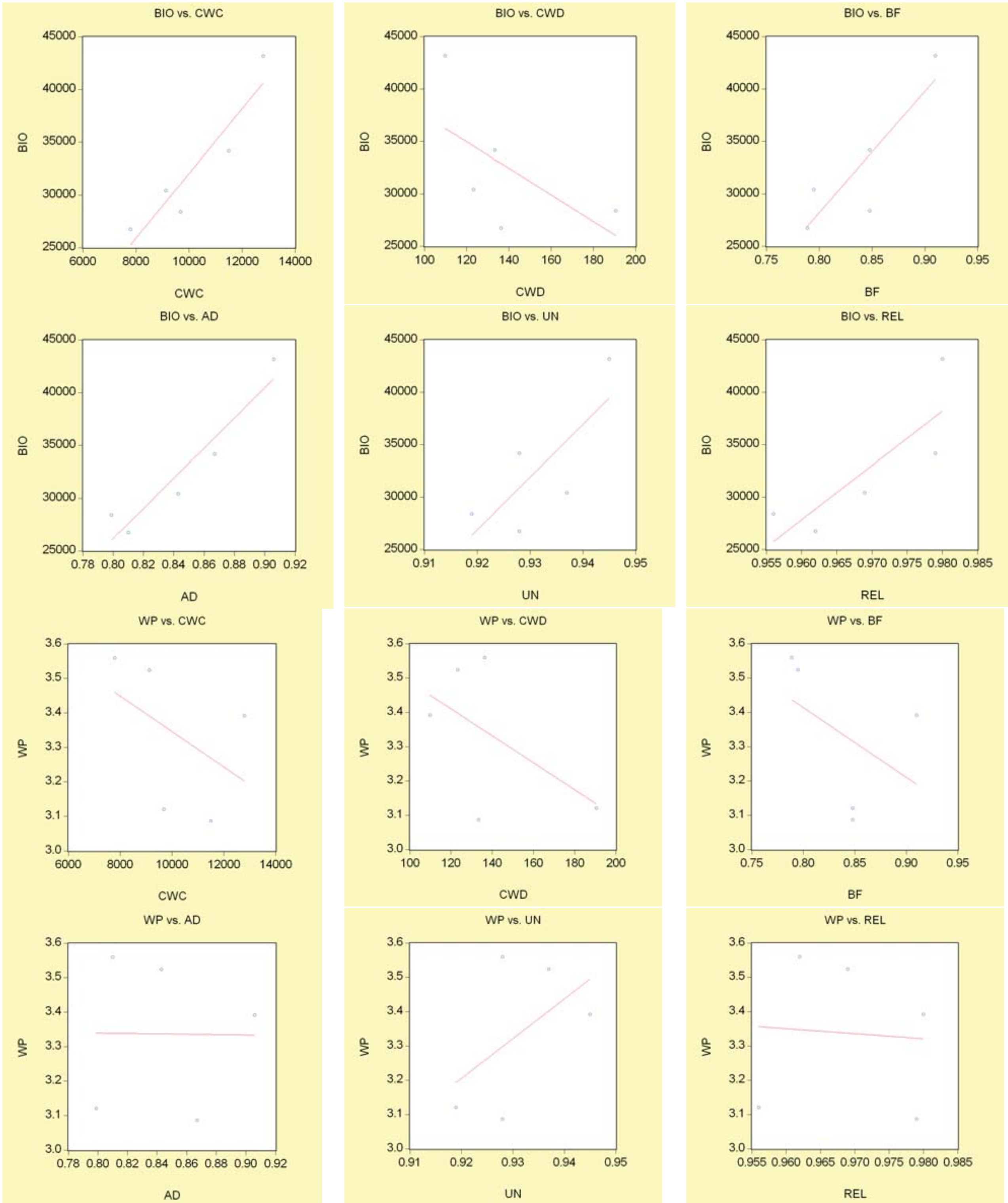


Figure 91 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationship between the indicators is better understood, the next step is to identify the weakest elements per district. In Table 61, the best and poorest indicators are presented.

Table 61 Best and poorest PO irrigation indicator per district

District	Lowest		2nd lowest		2nd best		Best	
Kisumu	cwc	2.62	cwd	2.81	un	4.00	rel	4.79
Bungoma	cwc	2.14	ad	3.34	cwd	4.04	rel	5.00
Nandi	cwc	3.18	bf	3.37	cwd	4.22	rel	5.00
Kericho	cwc	2.74	bf	3.44	cwd	4.41	rel	5.00
Butere Mumais	cwc	1.82	un	4.00	bf	4.68	rel	5.00

It appears once again that the irrigation districts function relatively similarly. Crop water consumption seems to be the main problem for all the districts. Reliability is the best indicator in all districts. Crop water deficit is cited three times as the second best indicator.

4.3 Recommendation countrywide

The LSI schemes considered in this study are performing well. However, special attention should be given to saving water. If Kenya is planning to develop irrigation to achieve its target towards improving food and income security for the local people, abundant water consumption should be avoided.

The following recommendations apply:

- Introduce water saving plans during the main cropping season and limit crop water use to approximately 3000 m^3/ha
- Only irrigate when crop water stress (T_{act}/T_{pot}) and ET deficit ($ET_{pot}-ET_{act}$) exceed a certain threshold value. Otherwise pumping from rivers and lakes is not needed.
- Focus more on non-uniformity. Although it is good at country level, it could push up the biomass water productivity.
- Advise farmers and water utilization agencies regarding best practices and to become familiar with the optimum quantities of water to be used for their needs.
- The government should invest in modernizing of irrigation infrastructures.
- Give attention to land sustainability.

In Kenya, the irrigated areas have been digitalized manually based on Landsat images and Google Earth. After the emission of the report first draft, the LSI representatives indicated that there is no irrigation systems in the provinces of Butere Mumais and Bungoma. Upon double checking with the Landsat images, irrigated areas appear to be really present. We advice the Kenyan delegates to visit the areas with following center coordinates : 0°33' N, 34°40 E and 0°22' N, 34°32' E. The LSI representatives also mentioned that only Kisumu has irrigation whilst the districts of Nandi and Kericho are displayed as having irrigation in the present analysis. This is due to the lack of accuracy of the shape file used for the districts limits.

Annex 1 Definition of irrigation performance indicators

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

Annex 2 General information on irrigation conditions in Kenya (Aquastat, 2005)

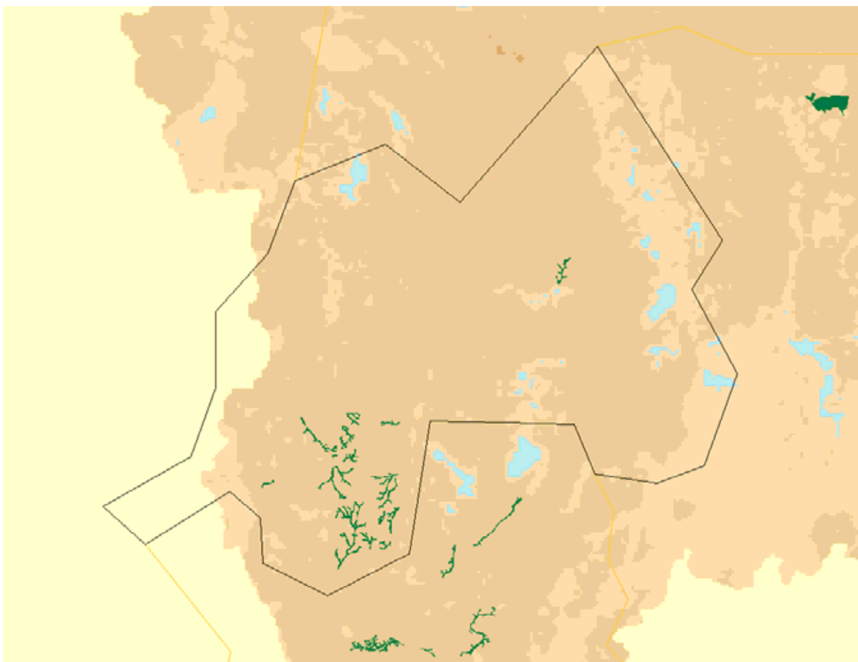
Irrigation and drainage

Irrigation potential			353 060	ha
Water management				
1. Full or partial control irrigation: equipped area		2003	103 203	ha
- surface irrigation		2003	39 217	ha
- sprinkler irrigation		2003	61 986	ha
- localized irrigation		2003	2 000	ha
• % of area irrigated from groundwater		1992	1	%
• % of area irrigated from surface water		1992	99	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)			-	ha
3. Spate irrigation			-	ha
Total area equipped for irrigation (1+2+3)		**2003**	**103 203**	**ha**
• as % of cultivated area		2003	2.0	%
• average increase per year over the last 11 years		1992-2003	4.1	%
• power irrigated area as % of total area equipped		2003	46	%
• % of total area equipped actually irrigated		2003	94	%
4. Non-equipped cultivated wetlands and inland valley bottoms		1992	6 415	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		**2003**	**109 618**	**ha**
• as % of cultivated area		2003	2.1	%
Full or partial control irrigation schemes	**Criteria**			
Small-scale schemes (smallholder)	5 -1 000 ha	2003	48 048	ha
Medium-scale schemes (private/commercial)	0.5 - 5 950 ha	2003	42 700	ha
Large-scale schemes (NIB)	213 - 6 200 ha	2003	12 458	ha
Total number of households in irrigation			-	
Irrigated crops in full or partial control irrigation schemes				
Total irrigated grain production			-	tonnes
• as % of total grain production			-	%
Total harvested irrigated cropped area			-	ha
• Annual crops: total			-	ha
- rice		2003	13 229	ha
- coffee		2003	14 533	ha
- tea		2003	172	ha
- sugar cane		2003	350	ha
- flowers		2003	3 262	ha
- pineapple		2003	5 950	ha
• Permanent crops: total			-	ha
Irrigated cropping intensity			-	%
Drainage - Environment				
Total drained area		2003	18 639	ha
- part of the area equipped for irrigation drained			-	ha
- other drained area (non-irrigated)			-	ha
• drained area as % of cultivated area			-	%
Flood-protected areas			-	ha
Area salinized by irrigation		1999	30 000	ha
Population affected by water-related diseases			-	inhabitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Rwanda



Report H

January 2009

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 Rwanda and will become an integral component of the final LSI report that will combine results from all countries.

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

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

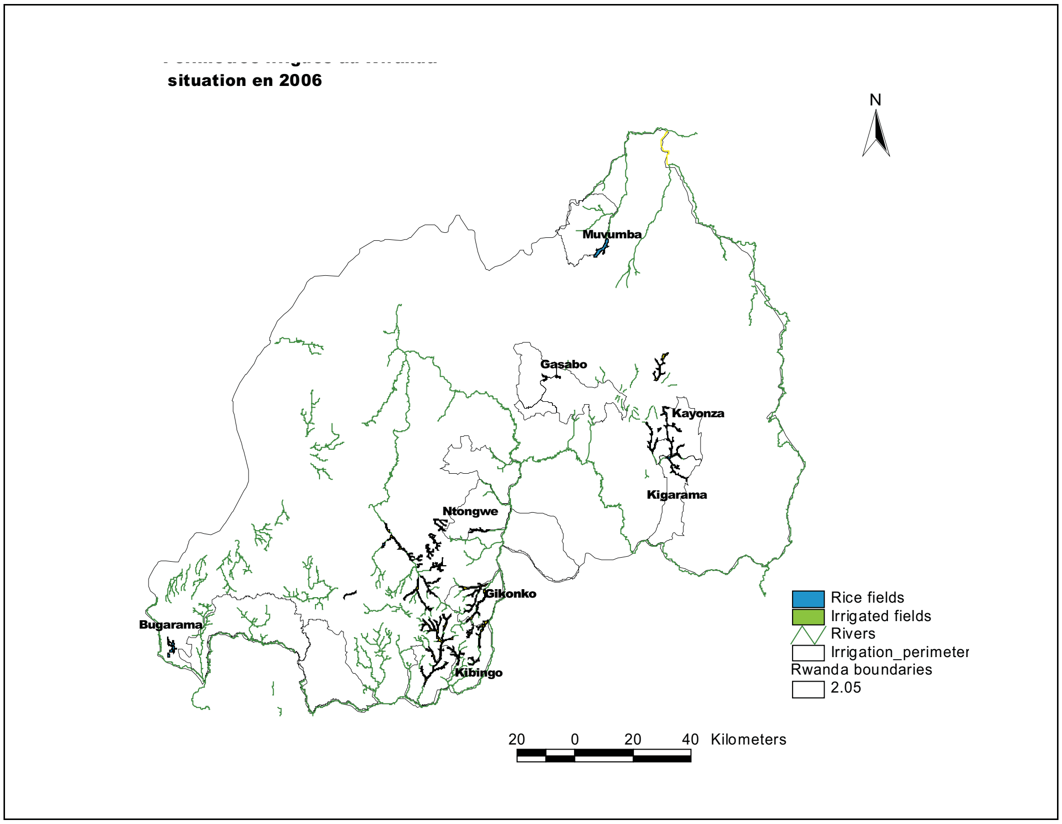


Figure 92 Irrigated areas in Rwanda in 2006 according to the LSI participants

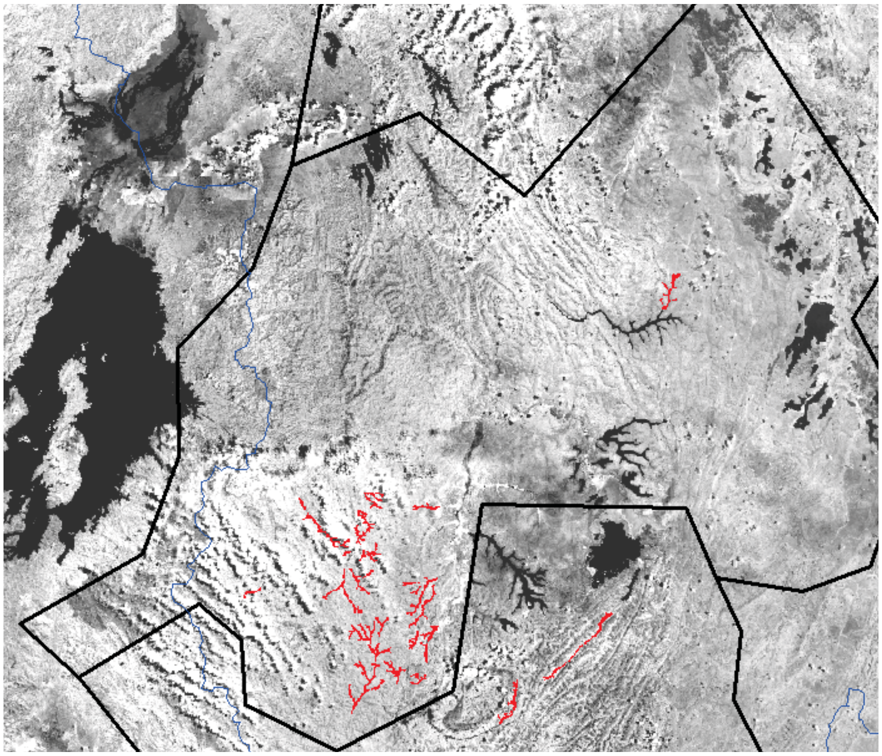


Figure 93 Map with the distribution of the irrigated areas in Rwanda within the Nile Basin according to the LSI participants.

Rwanda is one of the smallest of the Nile Basin countries with most of the country in the Nile Basin (83%) and the remainder in the Congo basin. More than 90% of the national water resources drain to the Nile Basin through the two main rivers of the Nyabarongo and Kagera. Arable land covers 1,385,000 ha, (52% of the country). The cultivated area is 852,000 ha (62% of arable land; 31% of the total area of the country). Agriculture is the principal water consuming activity (68% of the total water resources). Figure 93 shows that irrigation most of the time takes place in alluvial soils with streams and wetlands. An area of 17,638 ha of irrigated land in Rwanda is located in the Nile Basin according to this study (Table 62).

Table 62 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Rwanda	4,000
IWMI – GIAM	Entire Rwanda	80,067
Current study	Nile Basin component of Rwanda	17,638

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

1.2 Agricultural conditions

Farming is the principal economic activity and is carried out by more than 1.4 million households. Forty five percent of the land area is classified as arable. The main irrigated crops are rice and vegetables. Table 63 displays the cropping calendar with the surface per crop in Rwanda.

Table 63 Cropping calendar in Rwanda (Aquastat, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
RWANDA													
Rice	2		50	50	50	50	50						
Vegetables	2												
Vegetables-one		17	17	17	17								
Vegetables-two						17	17	17	17				
Vegetables-three										17	17	17	17
All irrigated crops	4	17	67	67	67	67	67	17	17	17	17	17	17
Equipped for irrigation	4												
Cropping intensity	100												

Part 2 Climate

2.1 Climatological conditions

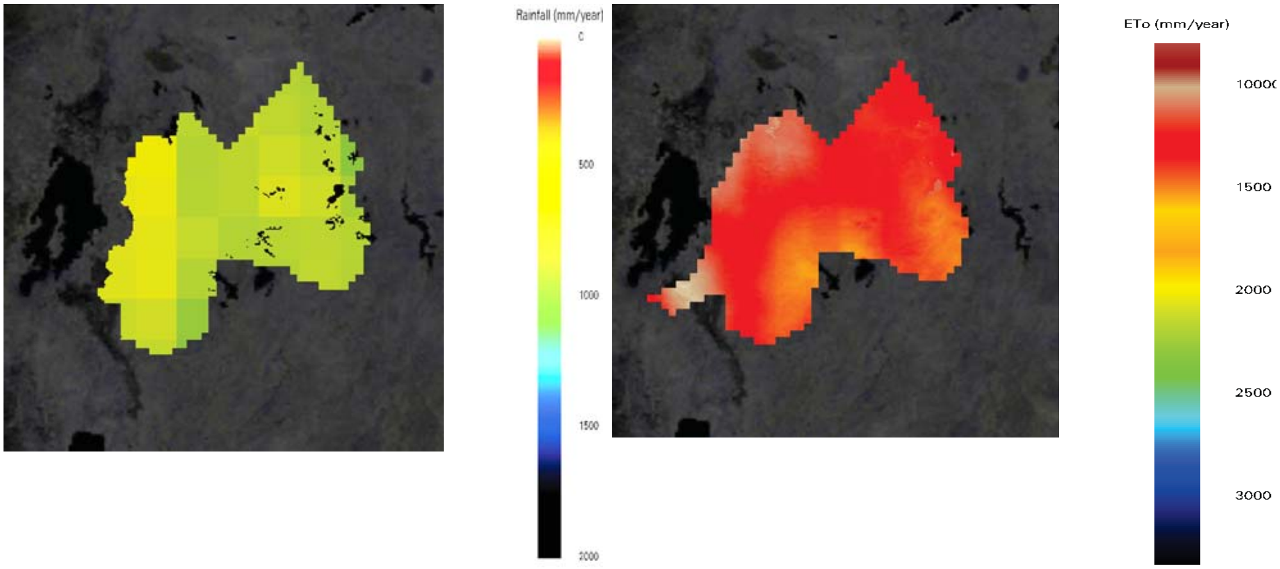
In this study, the reference evapotranspiration (ET_0) is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007.

Rwanda receives a significant amount of rainfall (997 mm/yr). The rainfall season is from September to May. June, July and August are dry, and this is the period that irrigation is typically needed.

According to Table 64, ET_0 exceeds rainfall during seven months. The monthly water shortage occurs in June to September when the aridity index is lower than 0.5. The highest rainfall (± 950 mm/yr) and ET_0 rates occur in the southern side near Burundi (± 1500 m/yr) (Figure 94). For this relative long period with sufficient water to meet ET_0, Rwanda is more commonly known as a rainfed agricultural country rather than an irrigation country.

Table 64 Monthly values for rainfall and reference ET_0.

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	86	106	0.81
February	101	101	1.00
March	115	108	1.06
April	180	97	1.86
May	98	97	1.01
June	10	107	0.09
July	1	121	0.01
August	21	128	0.16
September	65	120	0.54
October	93	119	0.78
November	133	103	1.29
December	94	103	0.91
TOTAL	997	1310	



Annual rainfall Annual reference ET

Figure 94 Spatial variation of rainfall (left) and ET_0 (right).

2.2 Climatic zones

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

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

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on the data send by the LSI representatives of Rwanda.

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

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

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined (Table 65). A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 95).

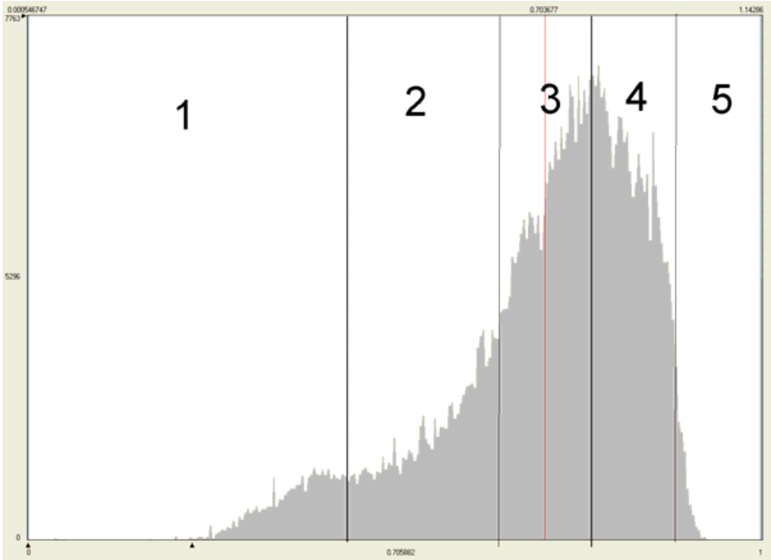


Figure 95 Distribution of the values of one indicator over 5 classes

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

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

Table 65 benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

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

3.2 Results at country level

As displayed in Figure 96, the average score considering all the indicators together for all 17,638 ha of irrigated land in the Nile Basin component of Rwanda is 3.6, which is above average (the average score being 3). This average is translated into scores for each individual indicator, as demonstrated in Figure 96. The aspects that Rwanda should provide more attention to are the elements with a relative low score (bf, ad, cwc).

The score of 2.9 for land productivity and 3 for water productivities are slightly lower than average but still reasonable.

Concerning the PO indicators, more attention should be given to beneficial fraction. The relatively low performance of this indicator might explain the wide range of the land and biomass water productivity. Because the crop water consumption is quite high (between 6,700 m^3/ha/year) and the beneficial fraction low, it leads to relatively high non-beneficial soil evaporation and low biomass water productivity. On the other hand, there is a good performance in terms of reliability, crop water deficit, and uniformity. Because irrigation water supply is continuous in time (as reliability gets a score of 4.8), farmers are not restricted in their application of water. Crop water deficit is therefore low (so it gets a high score of 4.6).

The sustainability of irrigation practices in Rwanda seems to be under control. Compared to the last years, the irrigated land is becoming greener (as the score for the land sustainability is higher than 3), showing that the irrigation systems are healthy and continuous. The soils are gradually getting wetter (water sustainability gets the high score of 4.3).

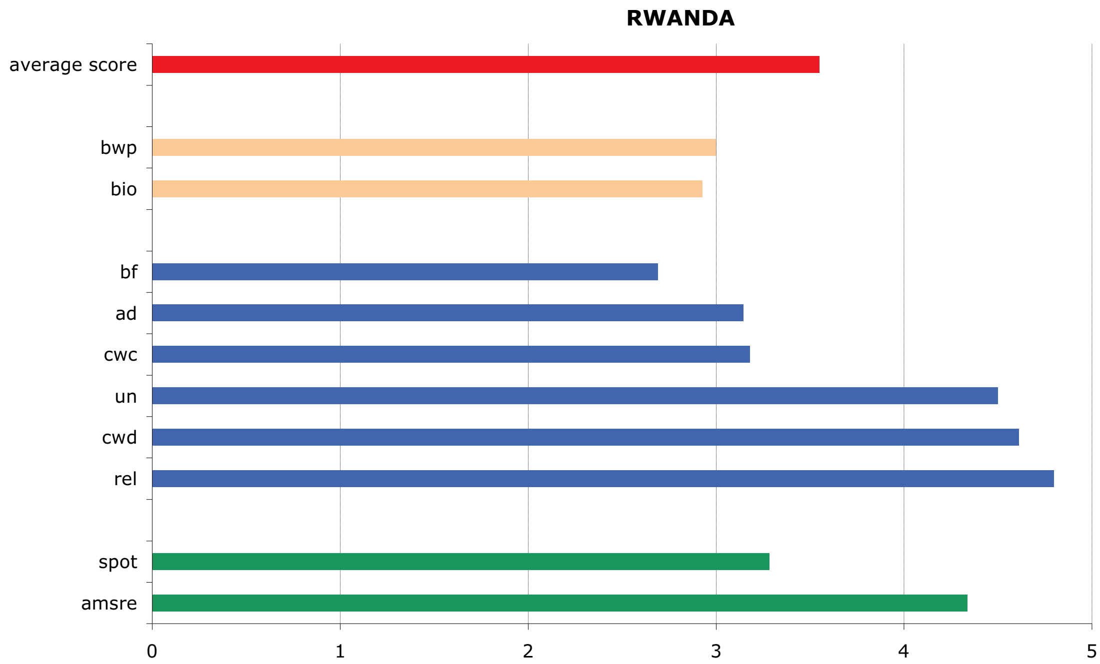


Figure 96 Representation of the average score for each indicator in Rwanda.

3.3 Results at district level

3.3.1 Average per district

In Rwanda, eight districts have more than 187.5 ha of irrigated land (more than 30 pixels of 6.25 ha). In Figure 97 the average score for all indicators per district is compared. All the districts have a good and uniform performance on average, ranking from 3.4 and 3.8, the best district being Nyanza and the poorest performing Nyaruguru (see Figure 98 for their locations). The equal performance per district gives an excellent score for uniformity at country level.

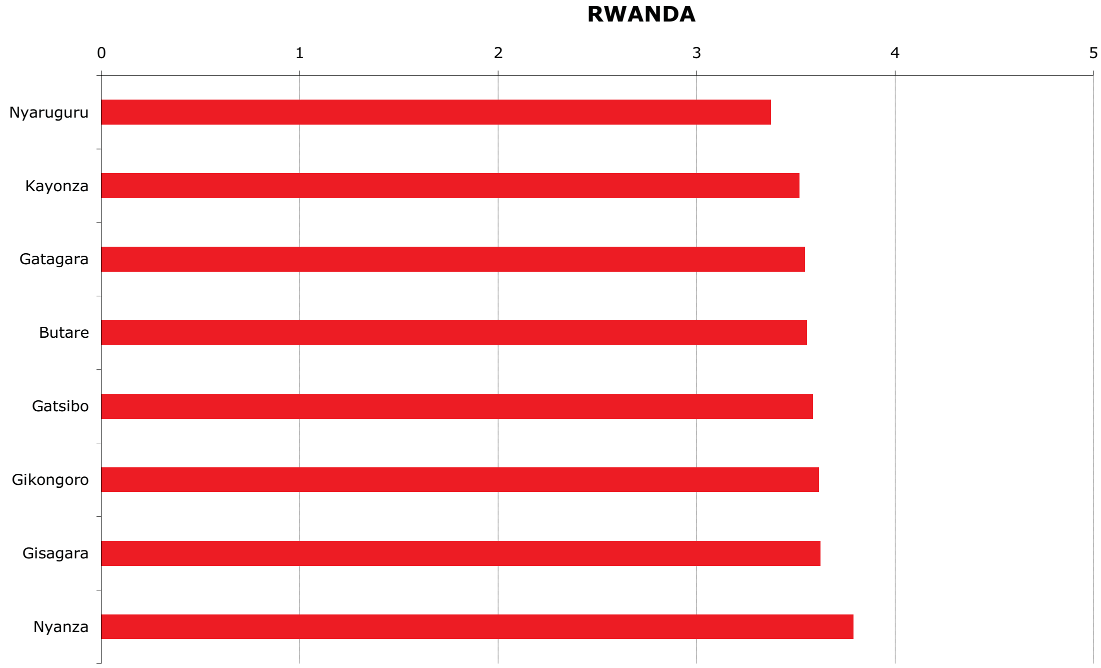
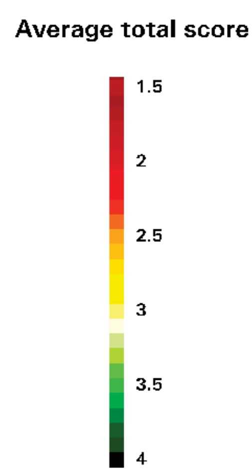


Figure 97 Representation for the total average score for each district in Rwanda.



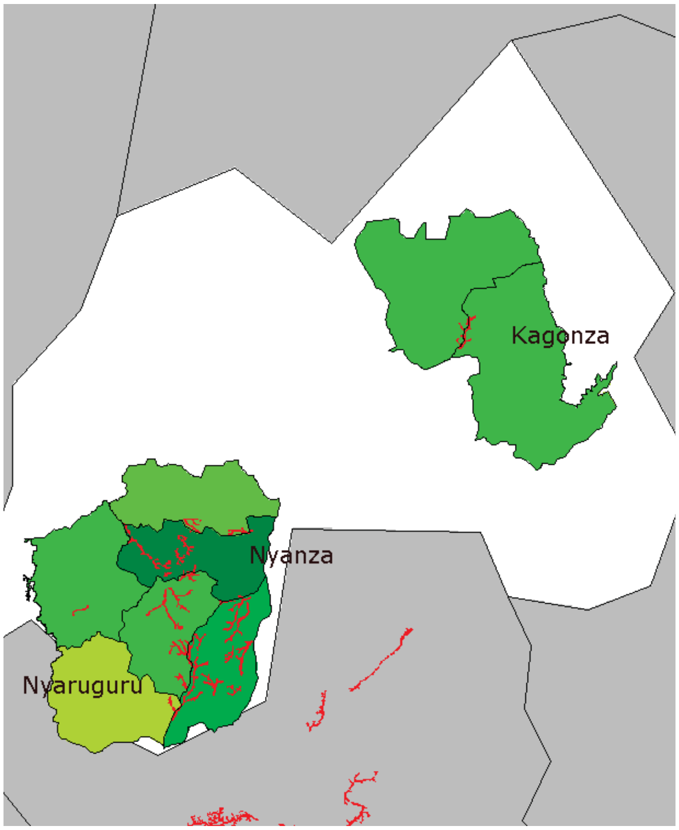


Figure 98 Map showing the total average score per irrigated district

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

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 99 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance and enables to rank the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

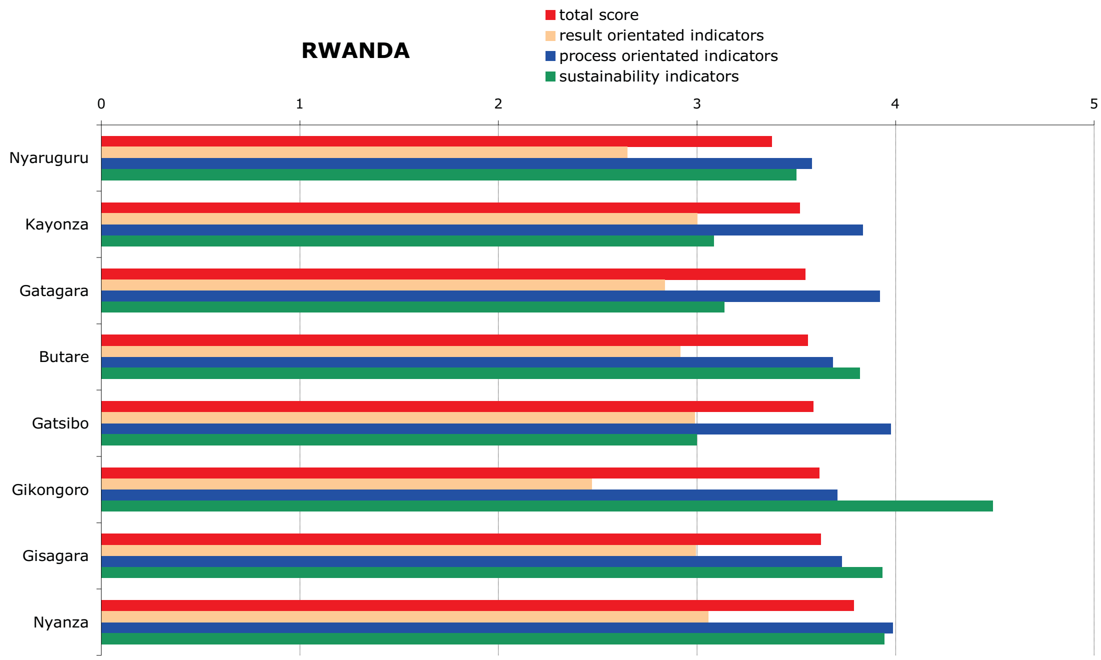


Figure 99 Total score per indicator per irrigated district in Rwanda

The first aspect that draws attention in the breaking down of the total performance score is that each of the eight districts of Rwanda has more or less the same score for each category of indicators, which once again is linked to the uniform conditions encountered at country level. This could be ascribed to the relative small size of the country and the uniform climate.

As far as the RO indicators are concerned, the average of the water and land productivity is quite low (between 2.7 and 3.1). Hence, irrigation should become more output orientated.

Concerning the PO indicators, the eight districts of Rwanda get a good and homogeneous score, ranking from 3.6 to 4. These high scores make it difficult to draw improvement recommendations relating to the functioning of the irrigation systems. It is remarkable to see that PO indicators are good and RO indicators are adequate only. The breakdown in Part 4 provides more insights.

Land and water sustainability is good. The score for all the districts are between 3.1 and 4.5.

3.4 Analysis per pixel for one irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the neighbouring districts of Gatsibo and Kayonza. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. Figure 100 demonstrates that at certain places, adequacy and beneficial fraction should be managed better. This suggests that the crop is stressed and does not receive sufficient irrigation water. A large part of the irrigation water is not used beneficially and this is probably the reason why the biomass production is below average.

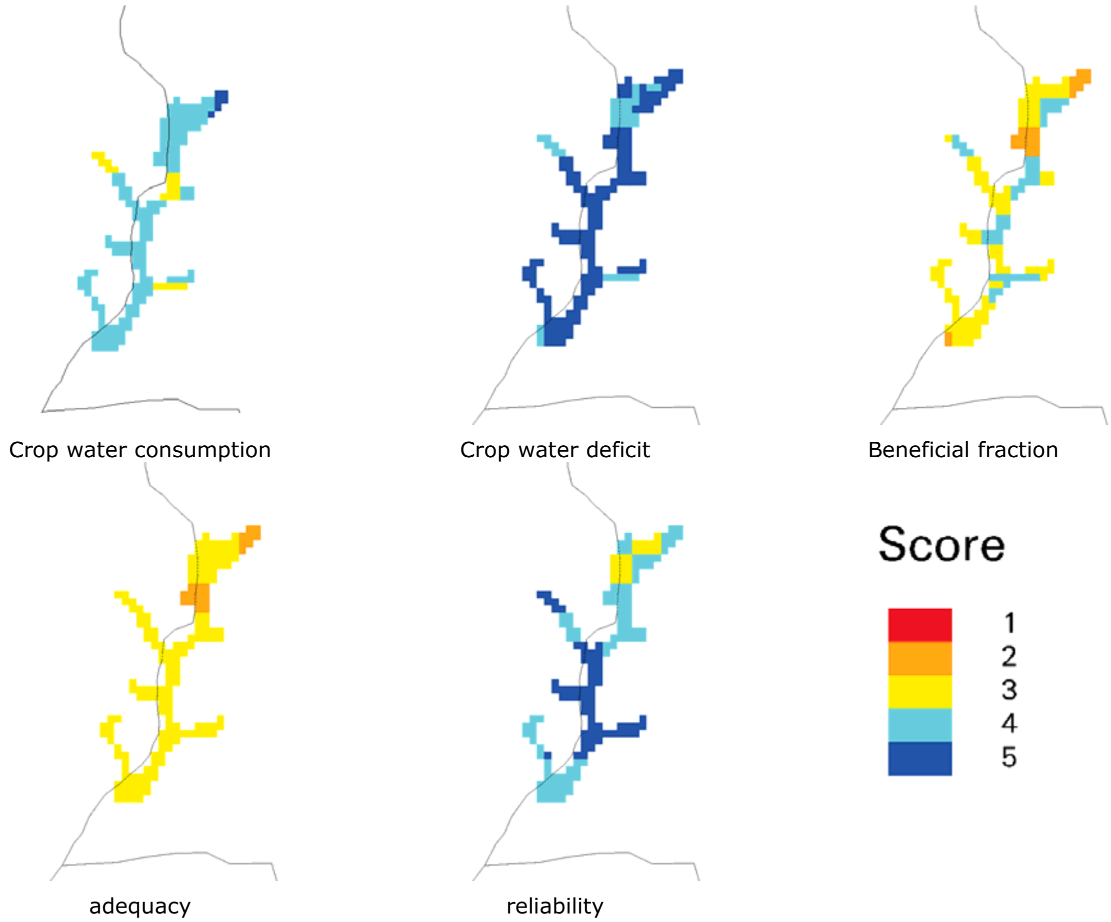


Figure 100 Spatial distribution of each indicator for the districts of Gatsibo and Kayonza

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the eight districts. Figure 101 shows that crop water consumption, reliability and adequacy are the main explanatory factors for biomass production. An increase in beneficial fraction or a decrease in crop water consumption leads to an increase in biomass water productivity. There are no clear trends for the other indicators.

Practically this relates to the following advice:

- More irrigation water should be converted to crop transpiration (T). The field practices on irrigation should be critically evaluated.
- More irrigation water should be applied directly to the crop so that adequacy is increased.

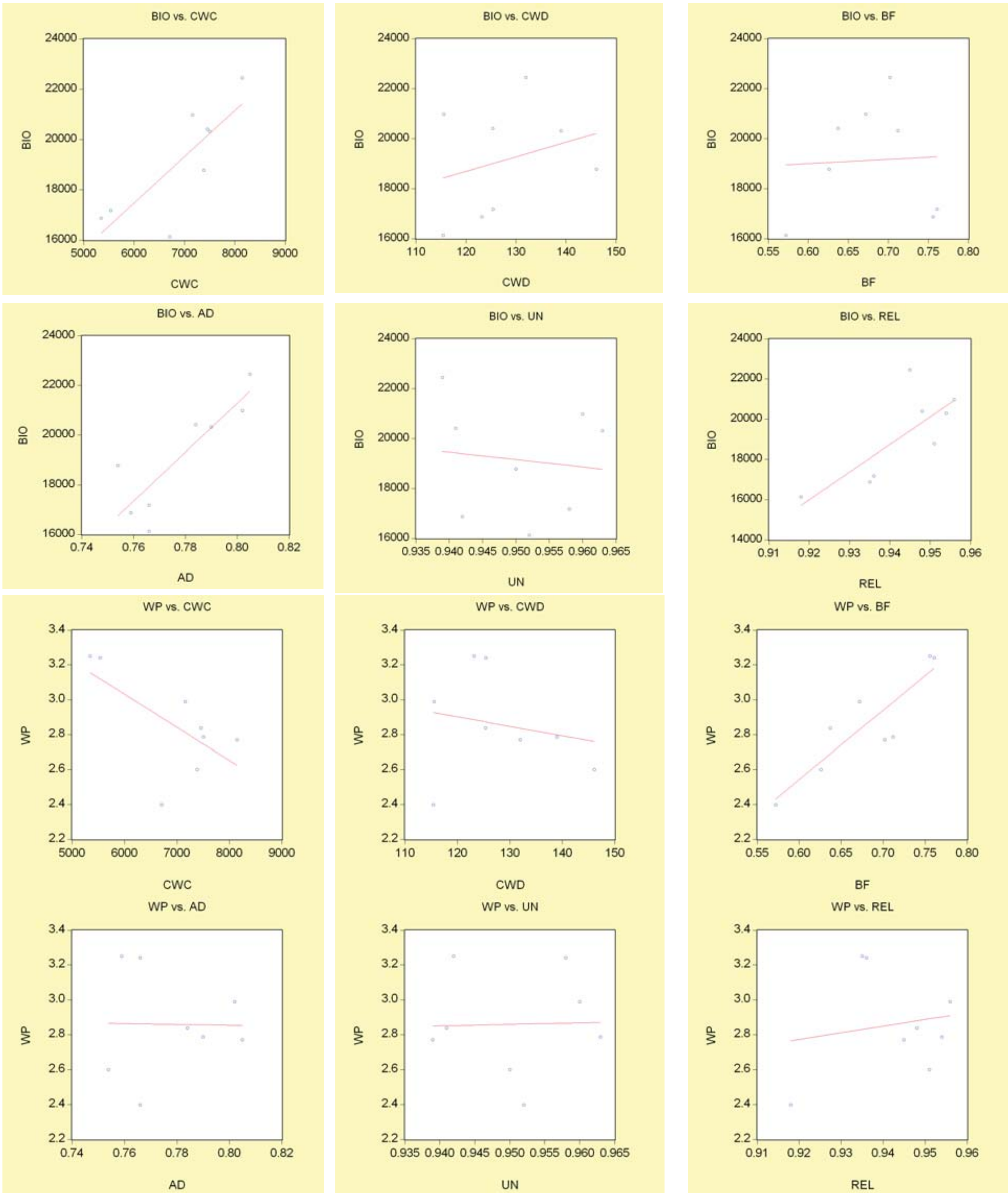


Figure 101 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationship between the indicators is better understood, the next step is to identify the weakest elements per district. In Table 66, the best and poorest indicators are presented.

Each irrigation district appears to function relatively similarly. The beneficial fraction and adequacy seem to be the main problems. On the other side of the scale crop water deficit and uniformity are always the best indicators.

Table 66 Best and poorest PO irrigation indicator per irrigated district in Rwanda

District	Lowest		2nd lowest		2nd best		Best	
Nyarugur u	bf	2.26	ad	2.88	cwd	4.28	rel	5.00
Kayonza	ad	2.74	bf	3.17	rel	4.21	cwd	4.82
Gatagara	bf	2.87	ad	2.89	rel	4.99	un	5.00
Butare	bf	2.42	ad	2.94	cwd	4.55	rel	4.88
Gatsibo	bf	3.04	ad	3.08	cwd	4.78	un	5.00
Gikongoro	bf	2.25	ad	3.08	cwd	4.75	un	5.00
Gisagara	bf	2.83	cwc	3.00	cwd	4.55	rel	4.76

4.3 Recommendations countrywide

The increase in food production is relatively unstable and is unable to keep pace with the rise in population (Rwanda is the biggest country in terms of population density : 343 inhabitants/km^3). Ensuring food security should definitely be high on the agenda. The purpose of the LSI should then be to ensure food security, increase rural incomes and create jobs.

The results of this study confirmed that fact. It showed than one of the weakest aspects of irrigated agriculture in Rwanda is the land productivity. Expanding the irrigated area could help to provide more food for the country, but it is probably better to invest in improved performance of the existing irrigation systems. The idea is to increase land productivity of the existing irrigated areas without increasing crop water consumption, because cwc is already too high. Thus, special attention should be given to introduce or develop agronomic extension services that could advise on the use of fertilizer or improved seed stocks.

The following recommendations apply:

- Introduce or develop agronomic extension services that could advise on the use of fertilizers or improved seed stocks.
- Launch an educational program jointly with agronomists and irrigation engineers to define the timing of irrigation water supply. This should result in an improvement of the biomass production and biomass water productivity.
- Improve the local organization of on-farm water management practices. This could be achieved through the establishment of irrigation study clubs or water user associations that visit other plots to understand minor differences in management that cause local differences in the irrigation reports.

- Start irrigation when crop water stress (T_{act}/T_{pot}) exceeds a certain threshold value. This would improve the adequacy. It also saves power and reduces the return flow from the irrigated plots.
- Visit the farmers in the vicinity from the district of Nyanza and get exposure to their good water conservation practices. The farmers from Gikongoro should be invited to visit Nyanza.

Annex 1 Definition of irrigation performance indicators

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

Annex 2 General information on irrigation conditions in Rwanda (Aquastat, 2005)

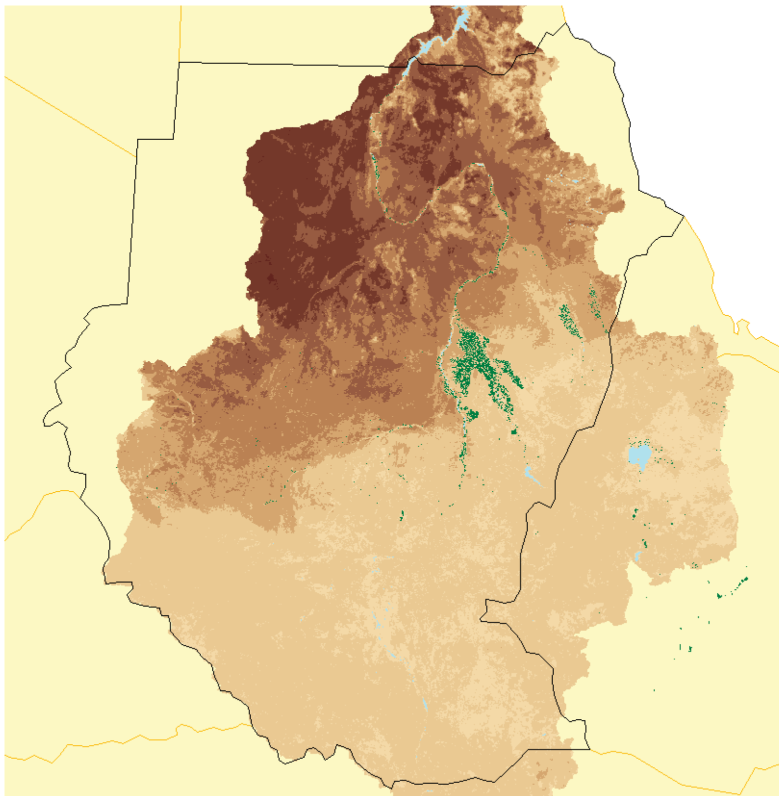
Irrigation et drainage

Potentiel d'irrigation			165 000	ha
Contrôle de l'eau				
1. Irrigation, maîtrise totale/partielle: superficie équipée		1996	3 500	ha
- irrigation de surface		1996	3 500	ha
- irrigation par aspersion			-	ha
- irrigation localisée			-	ha
• partie irriguée à partir des eaux souterraines			-	%
• partie irriguée à partir des eaux de surface			-	%
2. Zones basses équipées (marais, bas-fonds, plaines, mangroves)		2000	5 000	ha
3. Irrigation par épandage de crues			-	ha
Superficie totale équipée pour l'irrigation (1+2+3)		**2000**	**8 500**	**ha**
• en % de la superficie cultivée		2000	0.7	%
• augmentation moyenne par an sur les … dernières années			-	%
• superficie irriguée par pompage en % de la superficie équipée			-	%
• partie de la superficie équipée réellement irriguée			-	%
4. Marais et bas-fonds cultivés non équipés		2000	94 000	ha
5. Superficie en cultures de décrue non équipée			-	ha
Superficie totale avec contrôle de l'eau (1+2+3+4+5)		**2000**	**102 500**	**ha**
• en % de la superficie cultivée		2000	8.9	%
Périmètres en maîtrise totale/partielle	**Critère**			
Périmètres d'irrigation de petite taille	< ha		-	ha
Périmètres d'irrigation de taille moyenne	> ha et < ha		-	ha
Périmètres d'irrigation de grande taille	> ha		-	ha
Nombre total de ménages en irrigation			-	
Cultures irriguées dans les périmètres en maîtrise totale/partielle				
Production totale de céréales irriguées			-	tonnes
• en % de la production totale de céréales			-	%
Superficie totale en cultures irriguées récoltées			-	ha
• Cultures annuelles/temporaires: superficie totale			-	ha
• Cultures permanentes: superficie totale			-	ha
Intensité culturale des cultures irriguées			-	%
Drainage - Environnement				
Superficie totale drainée			-	ha
- partie de la superficie équipée pour l'irrigation drainée			-	ha
- autres surfaces drainées (non irriguées)			-	ha
• superficie drainée en % de la superficie cultivée			-	%
Superficie protégée contre les inondations			-	ha
Superficie salinisée par l'irrigation			-	ha
Population touchée par les maladies hydriques liées à l'eau			-	habitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Sudan



Report I

January 2009

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

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

Part 1 Overview of irrigated areas

1.1 Location of the irrigated areas

Sudan is the largest country in Africa with a total area of about 2.5 million km2. It has a special geopolitical location connecting the Arab world to Africa south of the Sahara and shares common borders with nine countries. It has an estimated population of 40 million people. Protracted civil strife and poor economy has meant that poverty is widespread and predominantly a rural phenomenon with over 2/3 estimated to live on less than US$ 1/day.

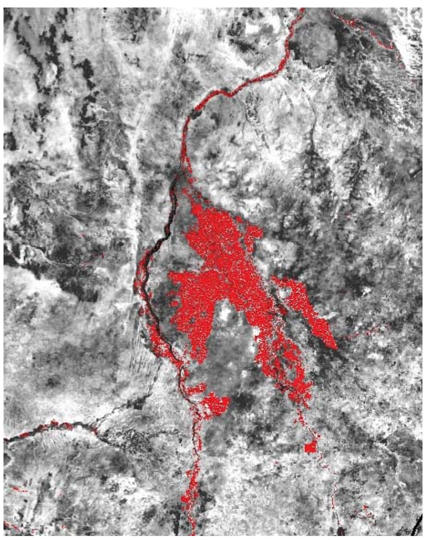


Figure 102 Map showing the distribution of the irrigated areas within the Nile Basin according to FAO-GMIA product, and being refined in the current study

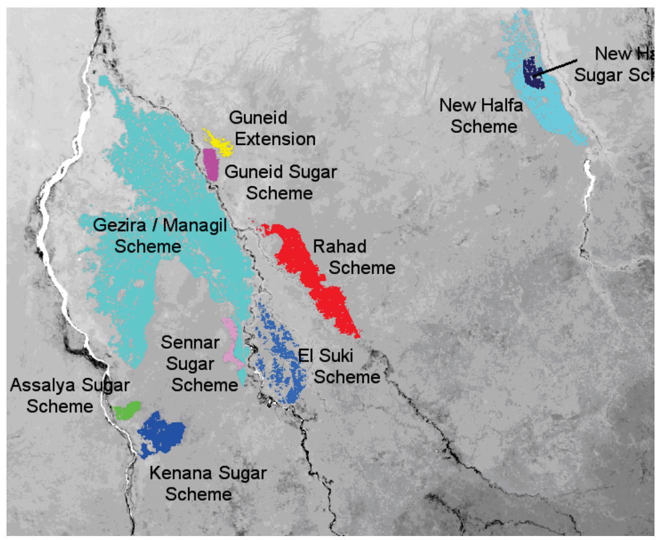


Figure 103 The main irrigation schemes in Sudan

Sudan is endowed with many large scale irrigation systems. It has the largest irrigated area in sub-Saharan Africa and the second largest in all Africa, after Egypt. Indeed, the arid climate of Sudan in conjunction with the manifold rivers that are flowing from the highlands of Ethiopia towards the Nile river system creates good opportunity to introduce irrigated agriculture. These rivers are the Sobat, Blue Nile and Atbara, besides several smaller rivers. According to this study (see Table 67), there is approximately 1.7 million hectare of irrigated land in Sudan. This land is essentially irrigated during the summer period when erratic monsoon rains occur. The irrigation capacity during the winter period is limited, partially because of sediments in reservoirs and in the main canal conveyance system.

Table 67 Different sources for the irrigation statistics for Sudan

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Sudan	1,946,200
IWMI – GIAM	Entire Sudan	1,737,188
Current study	Nile Basin component of Sudan	1,749,300

1.2 Description of LSI

During the colonial era, the Britons developed LSI schemes of which the Gezira Scheme, located south of Khartoum between the Blue and White Nile, is by far the largest. After independence in 1956, the command area of the Gezira Scheme was doubled when the Managil extension was completed. The Gezira scheme is one of the largest irrigation systems of the African continent.

Other new schemes that were established were the New Halfa Scheme and the Rahad Scheme on the right bank of the Blue Nile. Most of the LSI schemes are located inside the Nile basin watershed. Table 68 gives the main characteristics of the major LSIs. In addition to the traditional irrigation practices, several sugarcane estates have emerged during the last years. Among them is the large Kenana farm that is privately managed.

Table 68 LSI schemes in Sudan and their characteristics

Scheme	Source	Major crops	Gross irrigated area*
Assalaya Sugar Scheme	White Nile	sugar	16,613 ha
El Suki Scheme	Blue Nile	Cotton/sorghum	75,375 ha
Gezira/Managil Scheme	Blue Nile	sorghum/cotton/wheat	982,063 ha
Guneid Sugar Scheme	Blue Nile	sugar	20,688 ha
Guneid Extension	Blue Nile	unknown	13,875 ha
Kenana Sugar Scheme	White Nile	sugar	63,531 ha
New Halfa Scheme	Atbara	Cotton/wheat/groundnuts	146,138 ha
New Halfa Sugar Scheme	Atbara	sugar	22,569 ha
Rahad Scheme	Rahad & Blue Nile	sorghum/cotton/groundnuts	153,756 ha
Sennar Sugar Scheme	Blue Nile	sugar	18,925 ha

Source: WaterWatch (2006)

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

1.3 Agricultural conditions

Agriculture still remains the major source of income for most of the country's population and the irrigated sub-sector contributes more than half of the total volume of the agricultural production although the irrigated area constitutes only about 11% of the total cultivated land. It has become more and more important over the past few decades as a result of drought and rainfall variability and uncertainty. The irrigated sector produces 95% of the long stable high quality cotton produced, 100% of sugar production, 36% of sorghum and 32% of groundnuts. Other main irrigated crops are fodder, wheat and vegetables with other crops comprising maize, sunflower, potatoes, roots and tubers and rice. Although (gravity) irrigated agriculture started as early as 100 years ago by Shadoufand Sagia, water productivity is very low. This is attributed to water not delivered at the right time in the right quantity due to poor canal condition (silting, aquatic weeds) and poor management of irrigation water at the field level.

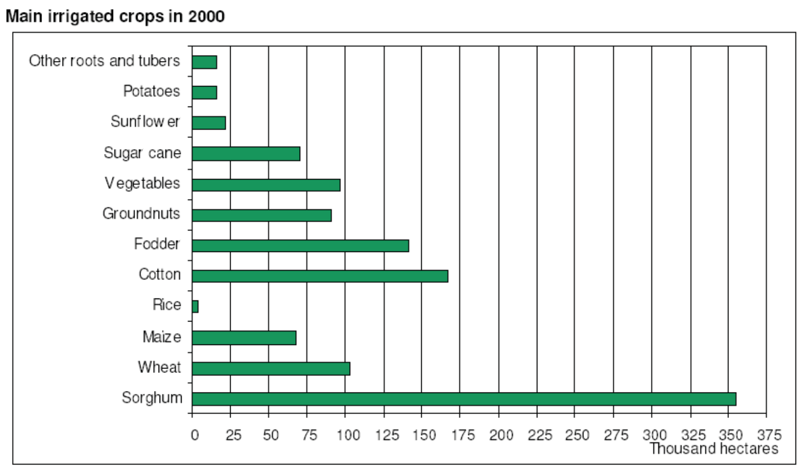


Figure 104 Main crops in Sudan (Aquastat, 2005)

Table 69 displays the cropping calendar in Sudan. The first season is the main irrigation season. This period starts at the end of April, before the rainy season begins. This is a long season and typically reflects the cotton growing season. The crops are thus planted and harvested in dry periods and capture the rains in the middle of their growing season. The second cropping season in Sudan largely overlaps with the first crop. The sowing in July is done typically during the rainy period. Only a low percentage of irrigated land has two irrigation seasons. Hence, in the dry winter period not much irrigation takes place, and it seems that this situation deviates significantly from the design principles to have double crops.

Various reasons are given for this development ranging from sediments, soil salinity, to low market prices.

Table 69 Cropping calendar in Sudan (Aquastat, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
SUDAN													
Wheat	249	13	13	13	13	13						13	13
Maize	33						2	2	2	2	2		
Sorghum	394						20	20	20	20	20		
Sugarcane	72	4	4	4	4	4	4	4	4	4	4	4	4
Pulses	46	2	2	2								2	2
Vegetables	80	4	4	4								4	4
Citrus	12	1	1	1	1	1	1	1	1	1	1	1	1
Fruits	95	5	5	5	5	5	5	5	5	5	5	5	5
Groundnut	384	20	20	20								20	20
Cotton	332				17	17	17	17	17	17	17		
All irrigated crops	1697	48	48	48	39	39	48	48	48	48	48	48	48
Equipped for irrigation	1946												
Cropping intensity	87												

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

Part 2 Climate

2.1 Climatological conditions

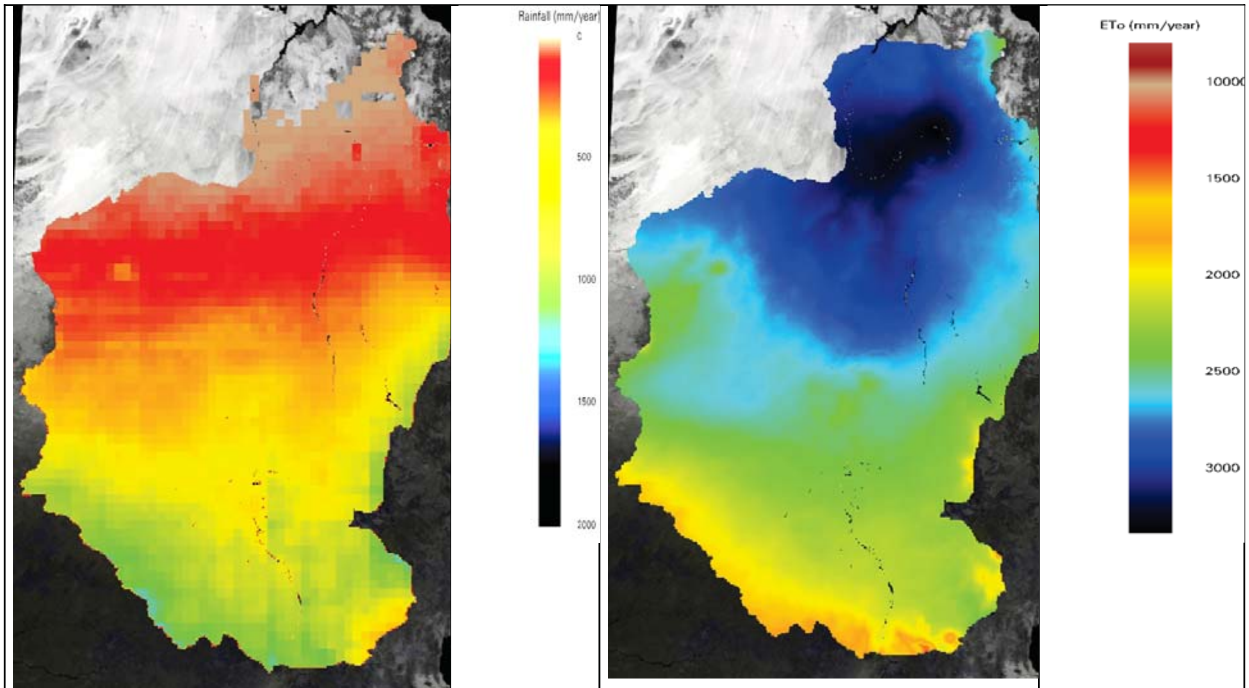
Sudan is located in the transition zone between the wet Equatorial Lake region and the Saharan desert. While the southern part of Sudan has a humid and semi-arid character, the alluvial plain south of Khartoum with all the irrigation system has a clear arid zone.

In this study, the reference evapotranspiration (ET0) is computed with the standardized Penman-Monteith equation specified in FAO56 and the rainfall is based on TRMM satellite data for the year 2007. As Table 70 shows, the annual rainfall is 200 mm/yr, and this can increase towards the south up to values of 500 mm/yr (see Figure 105). The rainfall season is short, and takes place in July, August and September. The remaining part of the year is very dry in Sudan with – in essence – no rainfall events. Hence, irrigation is the only option to grow crops.

The (ET0) exceeds rainfall during the entire year. The daily ET0 rates are 6.5 mm/d in December to 10 mm/d in May. This is related to the desert climate with extreme high temperatures and dry air masses with air humidity dropping below 20 and 10%. The highest rainfall (± 1200 mm/yr) occurs at the border with Uganda. The highest ET0 rates were observed in northern Sudan where the Nile flows through the desert. Aridity therefore increases towards the north. This harsh climate is not attractive for agricultural cropping, as crops experience thermal stress under these circumstances. There are thus natural limitations to favourable crop production.

Table 70 Monthly values for rainfall and ET_0.

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	0	206	0
February	0	223	0
March	0	285	0
April	0	290	0
May	1	304	0.01
June	12	281	0.04
July	68	231	0.29
August	88	199	0.44
September	29	201	0.14
October	2	210	0.01
November	0	217	0
December	0	201	0
TOTAL	198	2848	



Annual rainfall	Annual reference ET

Figure 105 Spatial variation of rainfall (left) and ET_0 (right) of the Nile Basin component of Sudan.

2.2 Climatic zones

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

The Sudanese climatic division is displayed in Figure 106. The vast majority of the irrigation schemes are located in climate zone 2 (arid). Irrigation in the Nile valley in the northern part of the country occurs in climate zone 1 (hyper-arid). The semi-arid climate in the vicinity of the Roseirres reservoir also hosts some irrigation activities which fall under climate zone 3. Irrigated land in southern Sudan (El Byeara) falls in climate zone 3. Hence, three different zones will be considered.

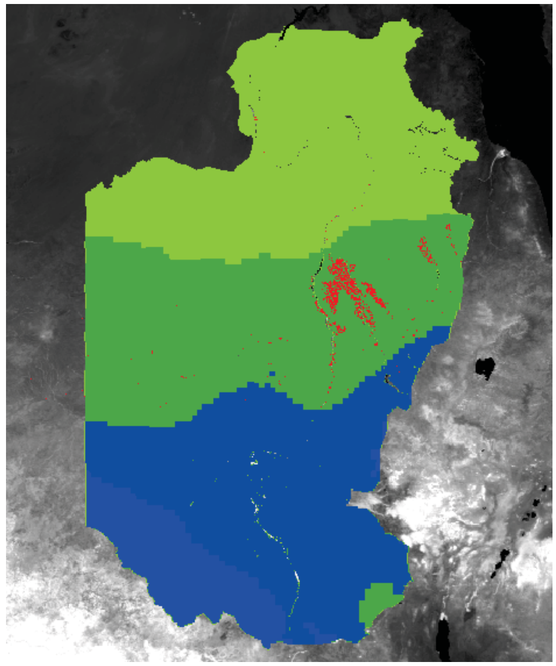


Figure 106 Climate zones identified for the mapping of best irrigation practices. The Sudanese irrigated areas are located in three climatic zones, with the majority in the arid zone (dark green). The locations of the irrigated areas are depicted by the red pixels.

Part 3 Raster and vector-based irrigation performance analysis

3.1 Methodology

In this study, the irrigated areas have been identified at a resolution of 250m based on the FAO irrigated area map, previous WaterWatch studies and manual digitization of visually recognizable irrigated systems, using Google earth and Landsat images.

The first step was to compute all the indicators per pixel. All the RO and PO indicators described in Table 71 have been computed based on the annual accumulated values of biomass production (Bio), Actual Evapotranspiration (ET_{act}), Potential Evapotranspiration (ET_{pot}), Actual Tranpiration (T_{act}), Potential Transpiration (T_{pot}). This was done for the year 2007. These annual accumulated values are the result of a land surface energy balance algorithm that was run for the whole Nile basin, based on data from Terra and Aqua satellites. The Modis and AMSR-E sensor data were used.

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

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined (Table 72, Table 73 and Table 74). A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 107).

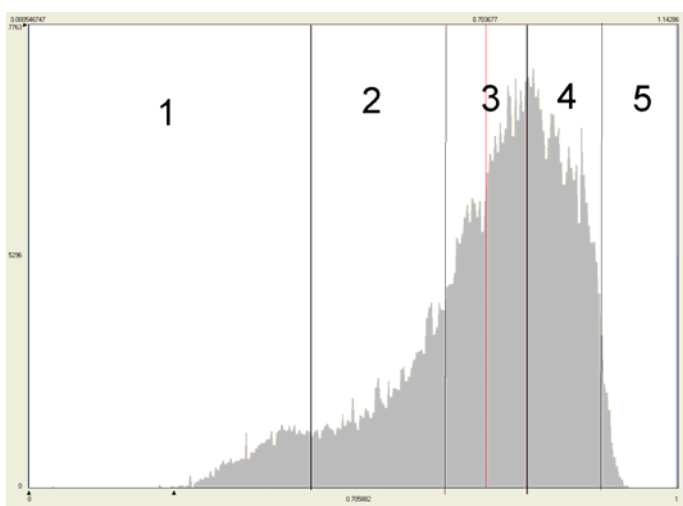


Figure 107 Distribution of the values of one indicator over 5 classes

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

If the country has irrigation systems included in different climatic zone, different benchmark values are considered to avoid any climatic bias in the allocation of the score. In the case of Sudan, it is located in climatic zone 1, 2 and 3.

Table 71 benchmark values for pixel located in climatic zone 1 (hyper-arid)

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

Table 72 benchmark values for pixel located in climatic zone 2 (arid)

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<3,300	<4,400 and >3.300	<7,800 and >4,400	<10,000 and >7,800	>10,000
bwp	Kg/ m3	<0.7	<1 and >0.7	<1.5 and >1	<2.3 and >1.5	>2.3
cwc	M3/ha/year	>11,600	<11,600 and >7,600	<7,600 and >4,400	<4,400 and >2,000	<2,000

cwd	M3/ha/year	<390 and >280	>500	<500 and >390	<280 and >168	<168
bf	-	<0.47	<0.62 and >0.47	<0.75 and >0.62	<0.86 and >0.75	>0.86
ad	-	<0.40	<0.47 and >0.4	<0.58 and >0.47	<0.7 and >0.58	> 0.7
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.56	<0.72 and >0.56	<0.80 and >0.72	<0.90 and >0.8	>0.90
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

Table 73 benchmark values for pixel located in climatic zone 3 (semi-arid)

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
Bio	Kg/ha/year	<7,000	<10,500 and >7,000	<13,500 and >10,500	<15,000 and >13,500	>15,000
bwp	Kg/ m3	<1.3	<2.2 and >1.3	<2.5 and >2.2	<3 and >2.5	>3
cwc	M3/ha/year	>10,200	<10,200 and >7,000	<7,000 and >5,300	<5,300 and >4,000	<4,000
cwd	M3/ha/year	<110	<175 and >110	<310 and >220	>310	<220 and >175
bf	-	<0.5	<0.7 and >0.5	<0.83 and >0.7	<0.88 and >0.83	>0.88
ad	-	<0.56	<0.63 and >0.56	<0.70 and >0.63	<0.78 and >0.70	> 0.78
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.74	<0.8 and >0.74	<0.86 and >0.8	<0.92 and >0.86	>0.92
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3

amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

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

3.2 Results at Country level

As displayed in Figure 108, the average score considering all the indicators together for all the 1.7 million ha of irrigated land is 3.2, which is an average score. The graph underneath shows the country averages for each indicator. The aspects that Sudan should provide more attention to are the ones with relative low scores.

The scores of 3.0 for land productivity and 2.7 for water productivities are reasonable but could be improved, in particular the biomass water productivity.

Concerning the PO indicators, reliability and crop water deficit show good performances. Adequacy, beneficial fraction, and crop water consumption are average. The uniformity seems to be the weakest aspect with an average score of 2.6.

The sustainability of irrigation practices seems to be under control. Compared to the last years, the irrigated land is becoming greener (as the score for the land sustainability is higher than 3), hence the irrigation systems are healthy and continuous. The soils are gradually getting wetter, so there seems to be ample water resources available.

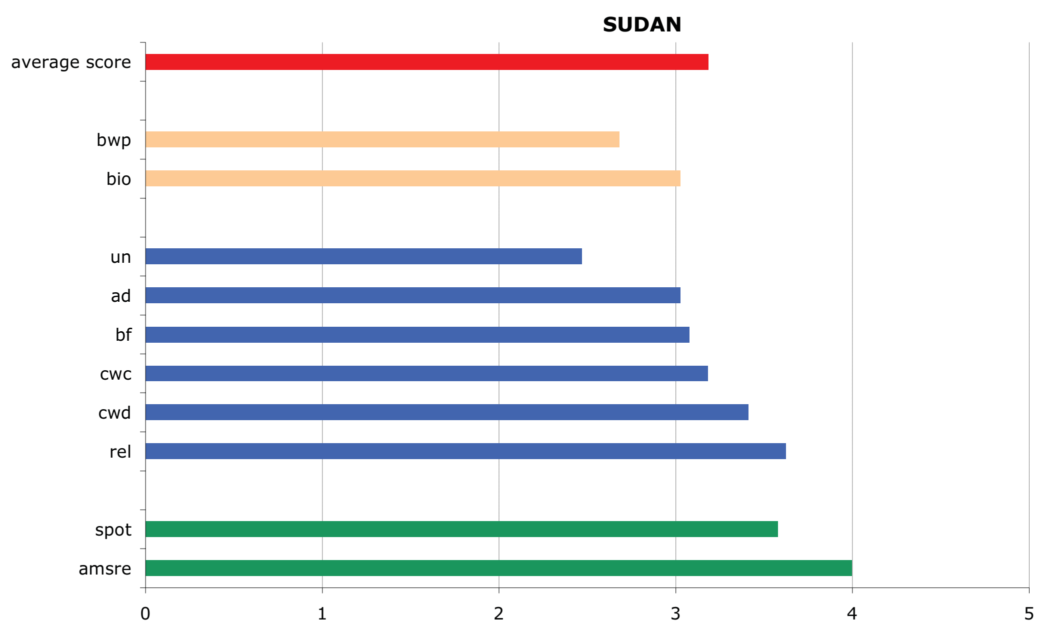


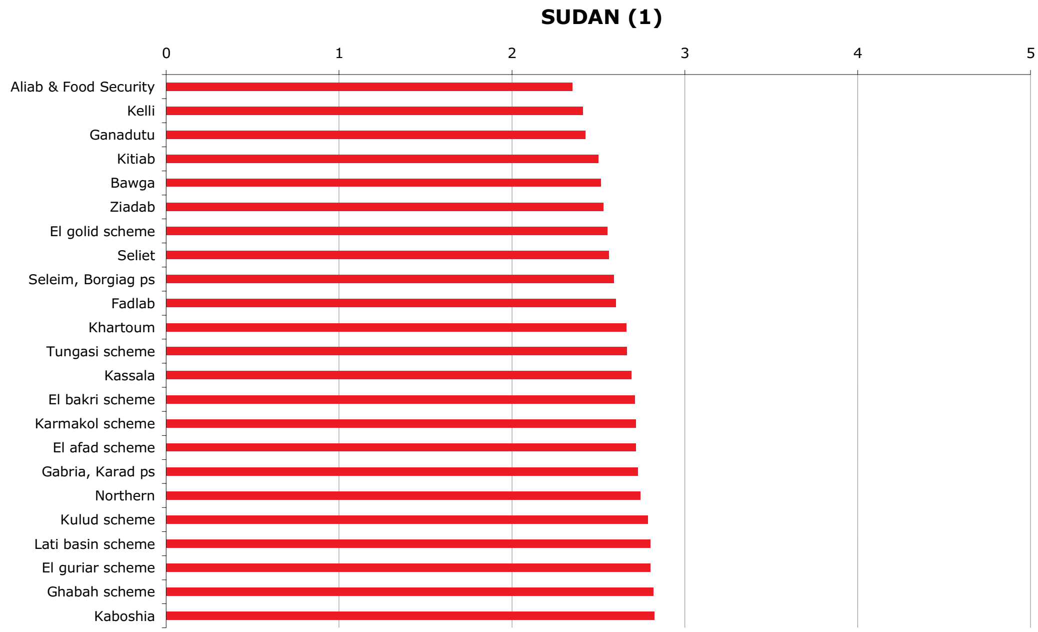
Figure 108 Average scores for Sudan for each indicator.

3.3 Results at district level

3.3.1 Average per district

In Figure 109 the average scores for all the indicators per district is compared. In Sudan, 47 districts having more than 30 pixels of 6.25 ha have been identified.

In terms of total average score, the best irrigation district is Suki, with an average of 3.6. The district that has the lowest average is Aliab & Food Security with an average of 2.3 (see Figure 110 for their locations). The average scores per district show quite a variation between the best district and the lowest district. That explains the below average score for the indicator uniformity at country level. This implies that there is considerable scope for improvement. Sudan is thus a country suitable for irrigation improvement projects.



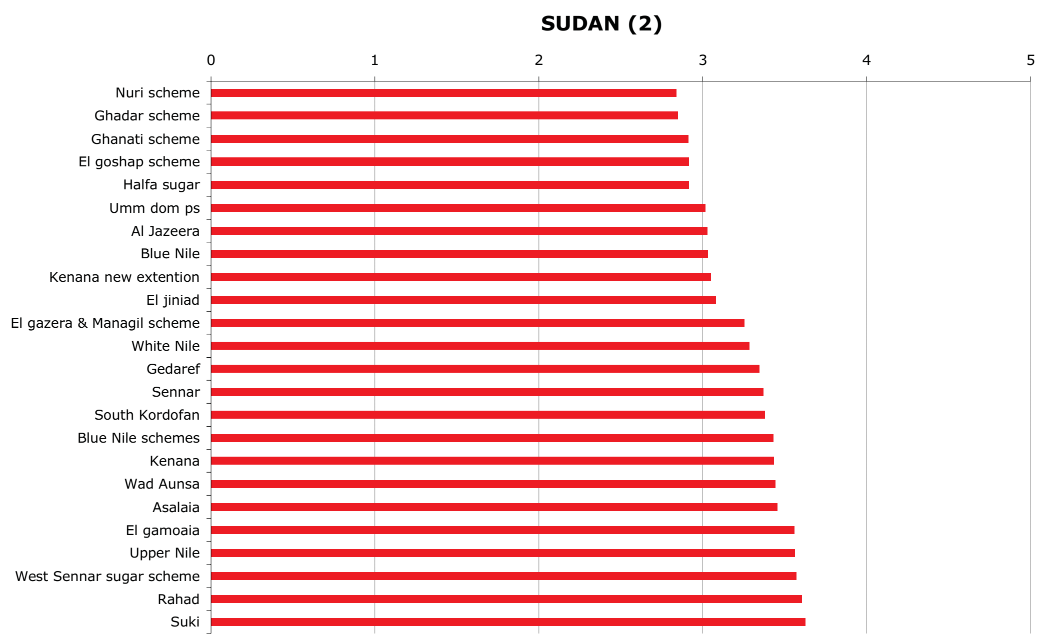


Figure 109 Total score for Sudan for each indicator

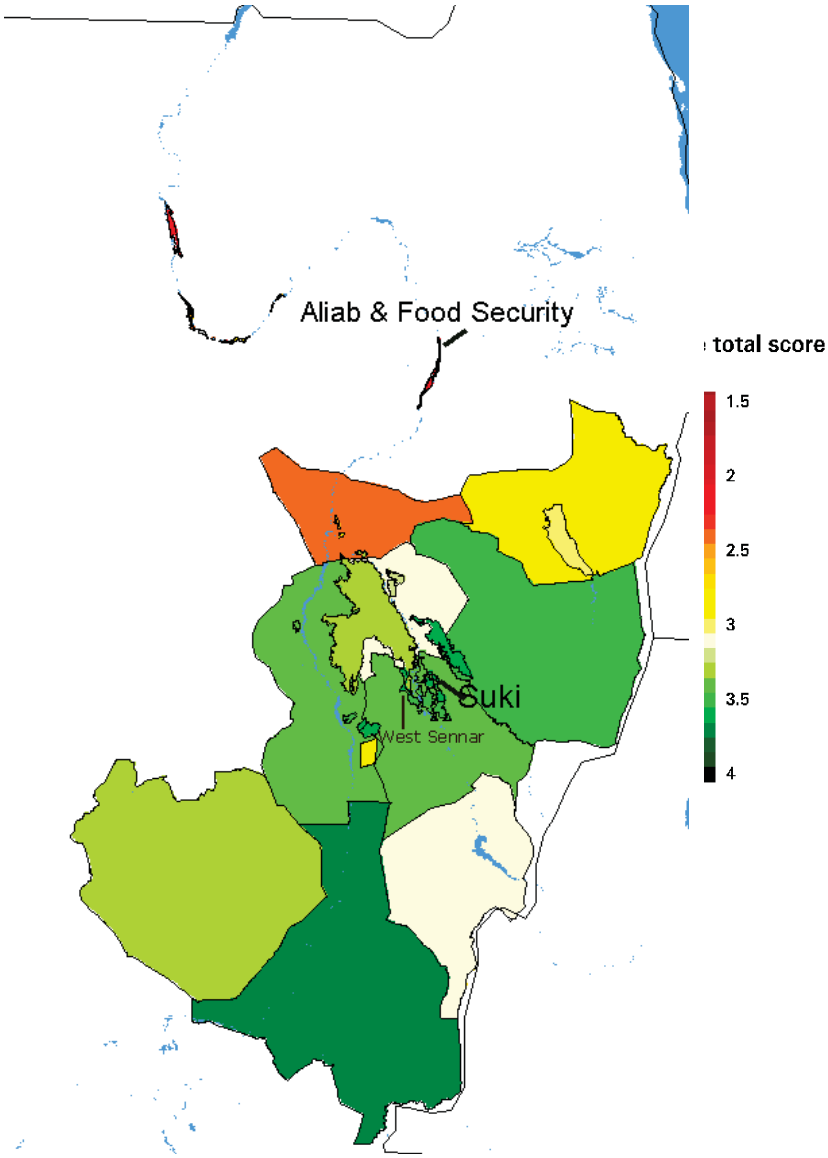
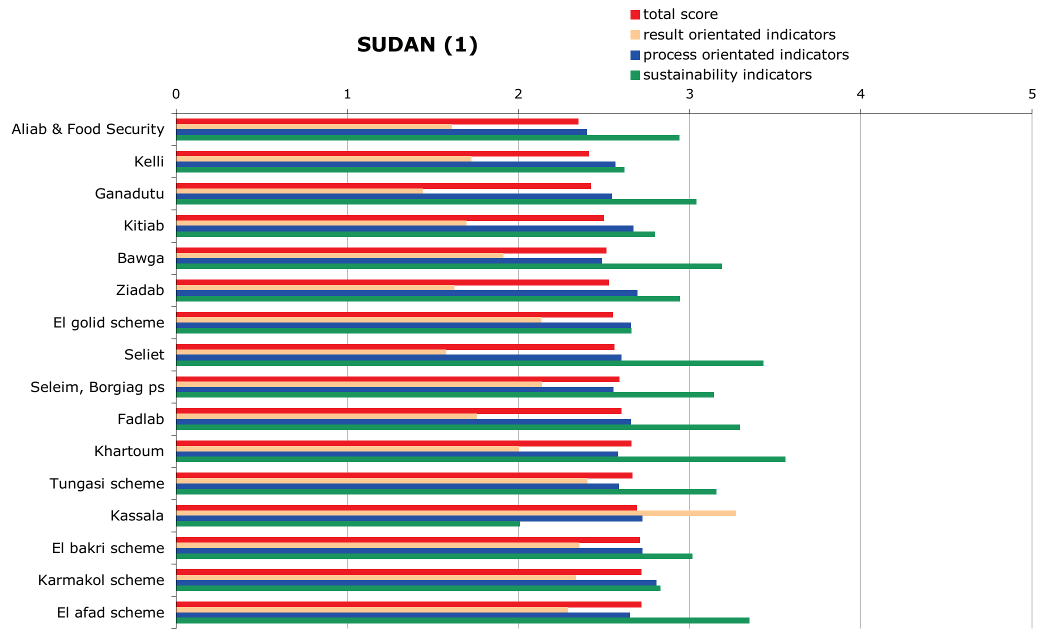


Figure 110 Map showing the total score per irrigated district of Sudan.

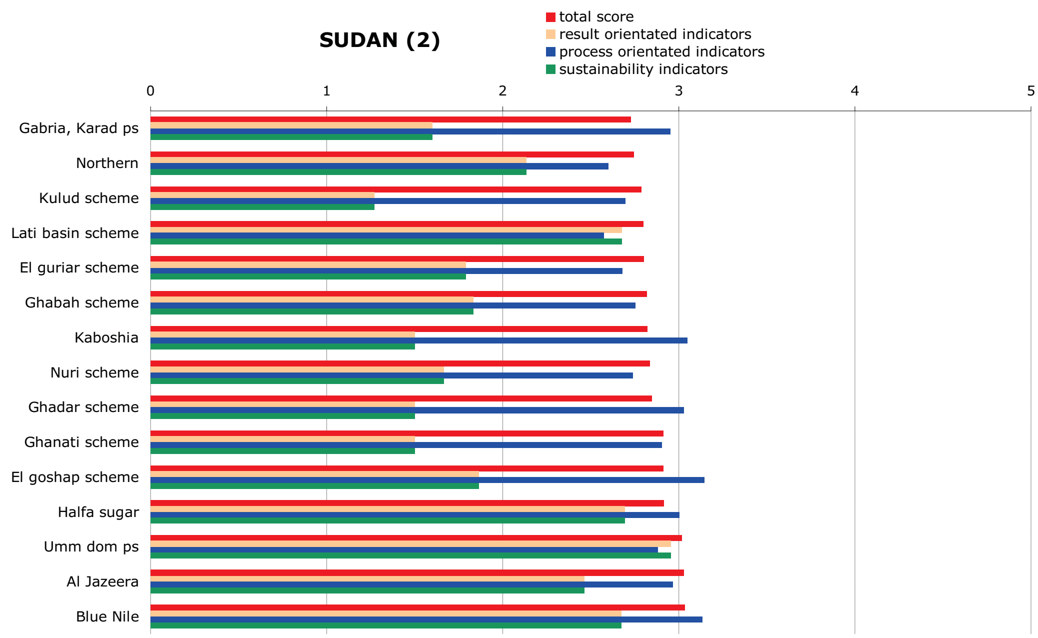
3.3.2 Breaking down the total score into RO indicators, PO, and sustainability indicators.

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 111 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. The total average score for all indicators for each district gives an idea of the total performance and enables ranking of the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

SUDAN (1)



SUDAN (2)



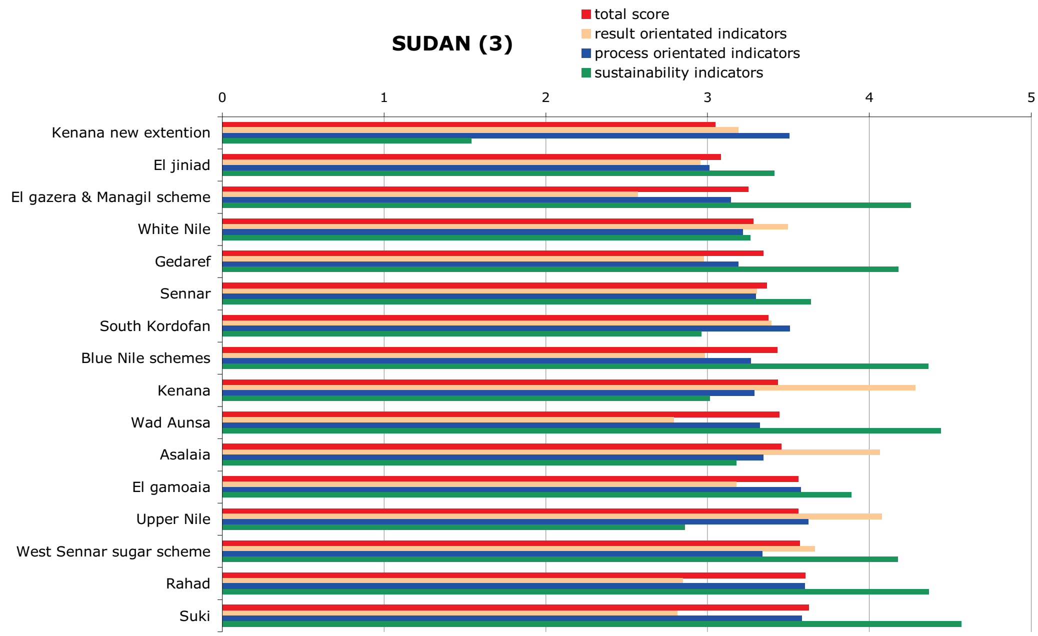


Figure 111 breaking down the total score per indicator for Sudan

The first aspect that draws attention in the breaking down of the total performance score is that a good total score does not always mean a good performance in terms of results.

For example, the district Kassala has a low total average (2.7) which could mean that the irrigation district is not performing well. However, it does perform well in terms of results (the average of the RO indicators in 3.3). The low global average that leads to ranking Kassala amongst the districts with the poorest irrigation performance is explained by the lower than average score obtained in terms of PO indicators (2.7) and sustainability indicators (2). In another case (Suki district) the RO score is low (2.8) but the sustainability is good (4.1) as well as the PO indicators (3.6).

Similarly, a good functioning system does not mean it is a sustainable system. The new Kenana district extension is a good example. It is quite a good irrigation district if we look at the total average of all the indicators together (3), or in terms of result (3.2). However, it is not a sustainable system, as indicated by its low score (total average of 1.5) for sustainability indicators. This example shows once again the relevance of breaking irrigation performance down into different types of indicators.

3.4 Analysis per pixel for an irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five indicators is displayed for the irrigated pixels in the district of West Sennar sugar scheme, which is the third best district in terms of performance. The 6th PO indicator uniformity cannot be displayed as it is an indicator at district level. Figure 112 demonstrates that the management of the district is not really homogeneous and that special attention should be given to crop water deficit and crop water consumption at certain places.

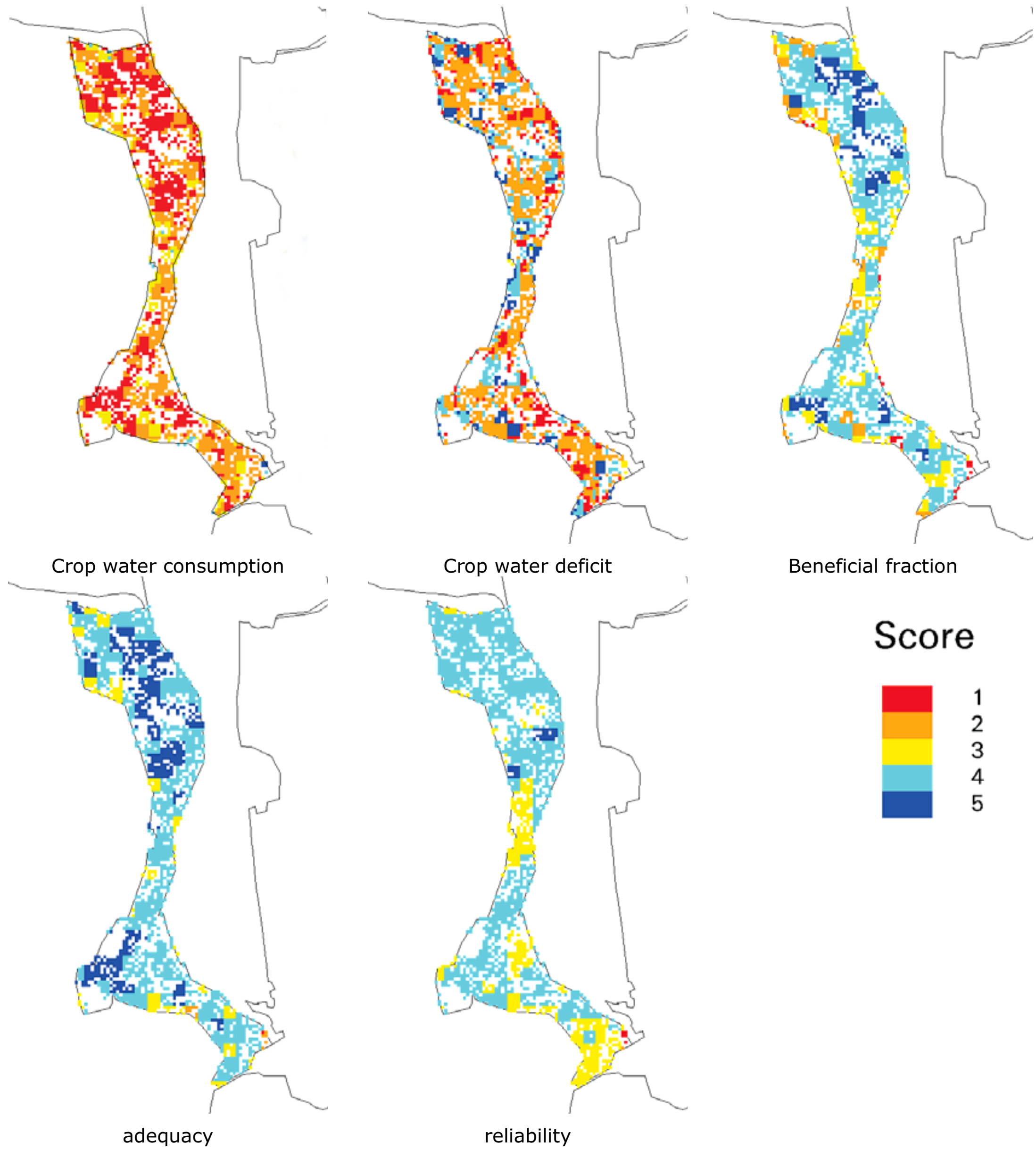


Figure 112 Spatial variation of PO indicators within the West Sennar sugar scheme.

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the 47 districts. Biomass production appears to be well correlated to adequacy and the beneficial fraction (Figure 113). Adequacy should be more than 0.7 to achieve a good yield. A beneficial fraction of at least 0.8 is desirable. It can be achieved by having closed canopies (e.g. Sugar Cane), or by low rainfall, or by modernized irrigation systems. The apparent correlation between crop water deficit and biomass production is not realistic. There are no clear relationships with uniformity and reliability.

Biomass water productivity shows only a weak relationship with crop water deficit. A low crop water deficit of 100 to 150 mm/year provides the best biomass water productivity.

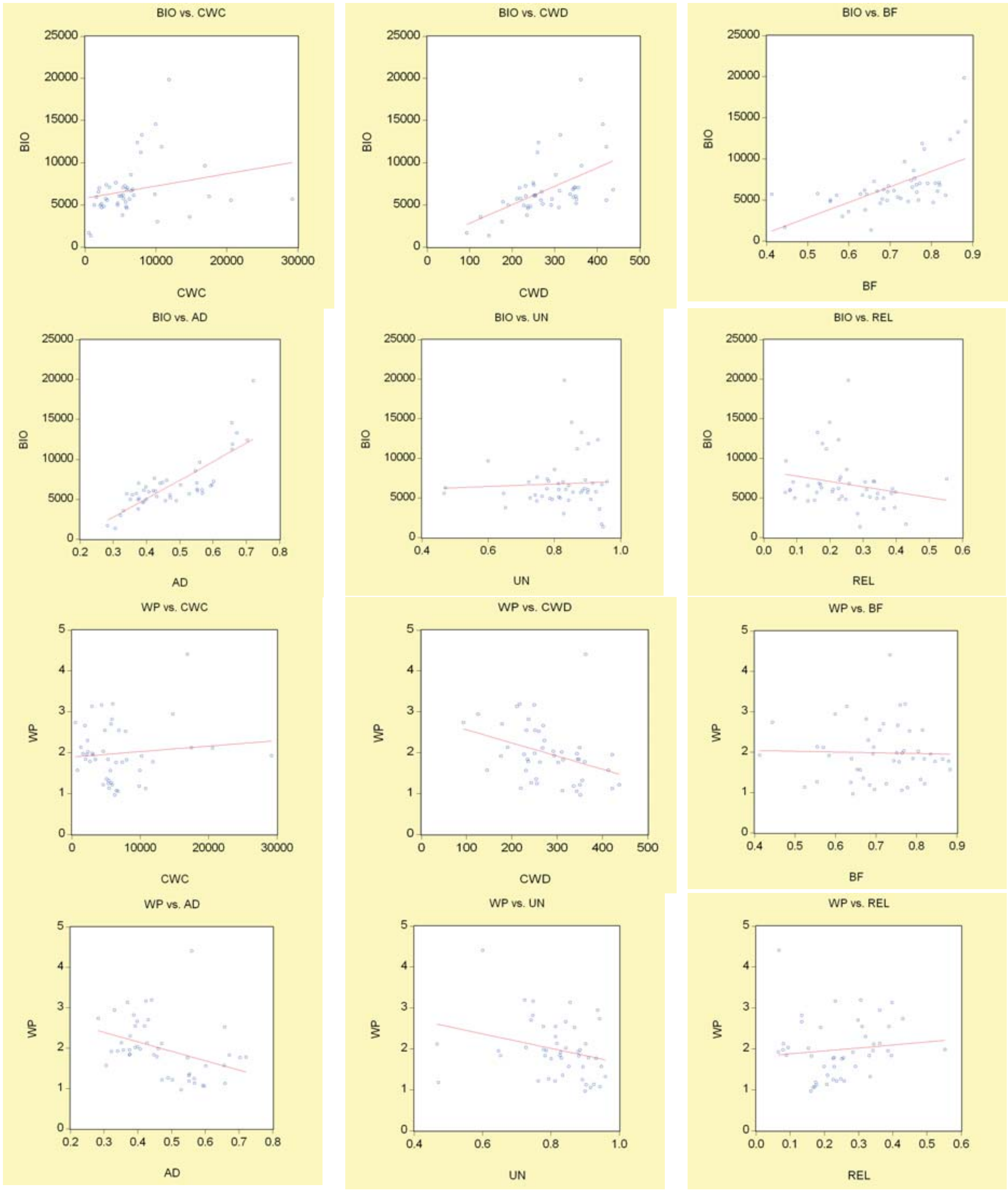


Figure 113 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationships between indicators are better understood, the next step is to identify the weakest elements per district. In Table 74, the best and poorest indicators are presented.

Uniformity and adequacy seem to be the weakest aspects for most of the districts. On the other side of the scale, crop water deficit, crop water consumption, and reliability are often the best indicators. This means that Sudan's water conservation is good.

Table 74 best and poorest PO irrigation indicator per district

district	lowest score		2nd lowest		2nd best		best	
Aliab & Food Security	un	1.00	ad	1.02	cwd	3.05	cwc	4.19
Kelli	bf	1.35	ad	1.73	cwd	3.84	cwc	4.52
Ganadutu	un	1.00	ad	1.23	rel	3.88	cwc	4.13
Kitiab	ad	1.18	un	2.00	rel	3.05	cwc	3.92
Bawga	rel	1.28	ad	1.67	cwd	3.44	cwc	4.40
Ziadab	ad	1.24	bf	1.67	cwd	3.55	cwc	4.51
El golid scheme	ad	1.30	bf	1.97	cwd	3.49	cwc	4.37
Seliet	ad	1.36	bf	1.87	cwd	3.47	cwc	4.13
Seleim, Borgiag ps	un	1.00	ad	1.56	cwd	3.99	cwc	4.41
Fadlab	un	1.00	ad	1.16	rel	3.68	cwc	4.63
Khartoum	ad	1.00	ad	1.00	cwd	3.52	cwc	4.47
Tungasi scheme	un	1.00	ad	1.35	cwd	3.60	cwc	4.18
Kassala	un	1.00	ad	1.06	cwc	4.11	bf	4.27
El bakri scheme	bf	1.00	ad	1.06	un	4.00	cwc	4.73
Karmakol scheme	ad	1.30	bf	1.89	rel	3.80	cwc	4.27
El afad scheme	ad	1.00	bf	1.59	cwd	3.16	cwc	4.65
Gabria, Karad ps	ad	1.26	bf	2.05	rel	4.00	cwc	4.49
Northern	ad	1.55	un	2.00	cwd	3.87	cwc	4.19
Kulud scheme	ad	1.00	ad	1.00	rel	3.87	cwc	3.87
Lati basin scheme	un	1.00	ad	1.31	cwc	4.18	cwd	4.21
El guriar scheme	un	1.00	ad	1.04	cwc	3.77	rel	4.16
Ghabah scheme	ad	1.06	bf	1.97	rel	3.96	cwc	4.33
Kaboshia	bf	1.00	ad	1.47	un	4.00	cwc	4.90
Nuri scheme	ad	1.00	bf	1.17	cwd	4.11	cwc	4.46
Ghadar scheme	bf	1.00	ad	2.30	cwd	4.13	cwc	4.70
Ghanati scheme	bf	1.33	ad	2.28	rel	4.00	cwc	4.69
El goshap scheme	ad	1.23	bf	2.14	rel	4.05	cwc	4.23
Halfa sugar	ad	1.39	un	2.00	bf	3.39	cwc	3.53
Umm dom ps	un	2.00	ad	2.49	cwd	3.44	cwc	4.27
Al Jazeera	un	2.00	bf	2.20	cwc	3.64	cwd	3.82
Blue Nile	rel	2.82	un	3.00	cwd	3.27	bf	3.43
Kenana new extention	rel	2.00	ad	3.16	bf	4.11	un	5.00
El jiniad	un	2.00	cwd	2.44	rel	3.56	bf	4.19
El gazera & Managil scheme	bf	2.73	cwc	2.94	cwd	3.25	rel	3.94

White Nile	un	2.00	ad	3.19	cwd	3.66	bf	3.71
Gedaref	un	2.00	bf	2.97	rel	3.64	cwd	3.92
Sennar	bf	2.91	un	3.00	ad	3.66	cwd	3.71
South Kordofan	ad	2.27	rel	2.54	un	4.00	bf	4.13
Blue Nile schemes	bf	2.76	un	3.00	ad	3.38	cwd	4.00
Kenana	cwc	1.79	un	2.00	rel	3.54	bf	4.66
Wad Aunsa	bf	1.89	cwc	3.20	un	4.00	ad	4.03
Asalaia	cwc	2.07	cwd	2.70	ad	3.68	bf	4.63
El gamoaia	rel	3.20	bf	3.52	cwd	4.22	cwc	4.25
Upper Nile	cwc	2.52	un	3.00	rel	3.80	bf	4.52
West Sennar sugar scheme	cwc	1.76	cwd	2.52	un	4.00	ad	4.18
Rahad	cwc	2.83	cwd	3.51	un	4.00	ad	4.55
Suki	cwc	2.89	bf	3.14	un	4.00	ad	4.16

4.3 Recommendations at country level

Irrigation with flood water that originates from Ethiopia is an historic phenomenon in Sudan. Water is used during the flood season to irrigate crops. The arid climate of Sudan causes a chronic shortage of water for agriculture, and for this reason 1.74 million ha of irrigation systems are in place in Sudan.

As a result of the large area of the country the irrigation performance have a wide scatter in ranking, but does not reach excellent levels. Kenana and West Sennar are modern and privately managed sugarcane estates serviced by the best irrigation systems of the Nile Basin. The Nile valley in the upstream end of the White Nile between Khartoum and the confluence with the Atbara also seems to have patches of well irrigated land.

El Gezira and some other LSI systems have a disappointing irrigation performance (an average total score around 3). A sole reason for this situation is not apparent and it is more likely to be the result of a variety of factors causing below-average operating skills. Water resources may for example be limiting because the canals are not maintained properly and have only a fraction of their design capacity due to siltation. Extreme dry and hot air during the dry season that is not very suitable for growing crops may be another causative factor. The non-flexibility of the water demand for hydropower and irrigation can also be held responsible for water delivery not being tuned with crop water requirements.

From an agronomical point of view, yields within the country are generally poor with low biomass water productivity. Extension support needs to be improved in order to realize the full irrigation potential. Information on technical packages for production and on crop management (improved seeds, fertilizer, pest control, cultural practices, harvest and post-harvest) should be provided.

The Government of Sudan should focus on the following aspects:

- Investigate the major underlying reasons for low crop yield and find solutions to increase production. Investigate how water productivity can be improved.

- Launch a LSI rehabilitation and maintenance program to restore the design capacity of the conveyance network.
- Determine the water allocation policies between hydropower and irrigation
- Evaluate the operational rules for water allocation and water distribution in governmental managed systems vs. privately managed systems.
- Reduce the interval between consecutive irrigation applications.
- Improve the local organization of on-farm water management practices. This could be achieved through the establishment of water user associations, or any other form of cooperative. There is indeed a need for farmers and water utilization agencies to be advised on best practices and to become familiar with the optimum quantities of water to be used.
- Involve the irrigation managers of the sugar estates in re-designing the national irrigation strategies.

Annex 1 Definition of irrigation performance indicators

Type	Indicator	Acronym	Unit	Formula	Why important ?
RO	Biomass productivity	bio	Kg/ha/year	Bio	Food security; farmer income; farm sustainability
	Biomass water productivity	bwp	Kg/m3	Bio/ETact	High return from total water used by a crop
PO	Crop Water Consumption	cwc	M3/ha/year	ETact	Saving of water resources
	Crop water deficit	cwd	M3/ha/year	ETpot-ETact	Indication of water shortage; help to evaluate deficit supply strategies
	Beneficial fraction	bf	-	Tact/ETpot	Indication of proportion of total crop water use going to production of plant (crop) matter
	Adequacy (Crop Water stress)	ad	-	Tact/Tpot	Indication of whether irrigation water reaches the roots of the crop
	Uniformity	un	-	1-CV(Tact/Tpot)(x,y)	Indication of the spatial homogeneity of the water distribution in a district
	Reliability	rel	-	1-CV(Tact/Tpot)(t)	Indication of the ability to deliver water timely, and the flexibility to cope with rainfall variations
Sustainability	Land sustainability	spot	1/year	Slope ndvi spot	Indication of farming sustainability
	Water sustainability	amsre	1/year	Slope soil moisture	Indication of changes of water resources availability

Annex 2 General information on irrigation conditions in Sudan (Aquastat, 2005)

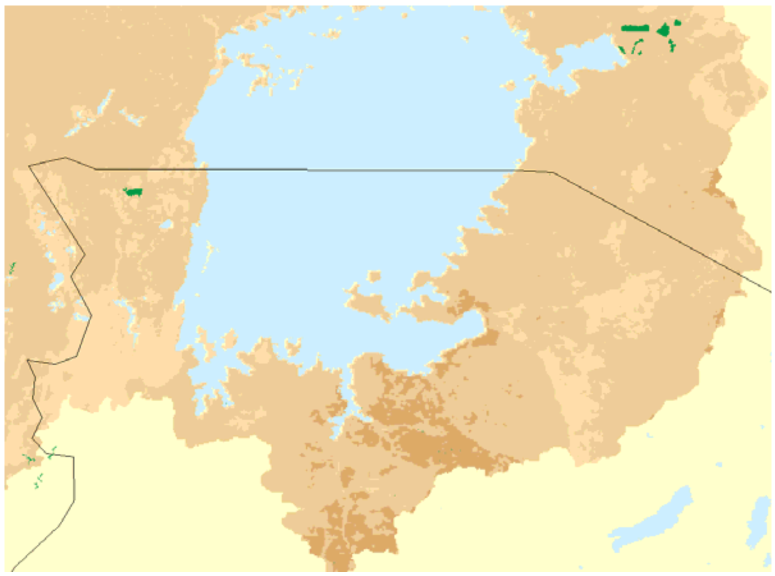
Irrigation and drainage

Irrigation potential			2 784 000	ha
Water management				
1. Full or partial control irrigation: equipped area		2000	1 730 970	ha
- surface irrigation			-	ha
- sprinkler irrigation			-	ha
- localized irrigation			-	ha
• % of area irrigated from groundwater		1995	4	%
• % of area irrigated from surface water		1995	96	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)			-	ha
3. Spate irrigation		2000	132 030	ha
Total area equipped for irrigation (1+2+3)		**2000**	**1 863 000**	**ha**
• as % of the cultivated area		2000	11	%
• average increase per year over last 5 years		1995-2000	- 0.9	%
• power irrigated area as % of total area equipped		2000	19	%
• % of total area equipped actually irrigated		2000	43	%
4. Non-equipped cultivated wetlands and inland valley bottoms			-	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		**2000**	**1 863 000**	**ha**
• as % the cultivated area		2000	11	%
Full or partial control irrigation schemes	**Criteria**			
Small-scale schemes	< 100 000 ha	2000	443 070	ha
Medium-scale schemes		2000	417 150	ha
Large-scale schemes	> 500 000 ha	2000	870 750	ha
Total number of households in irrigation		2000	200 000	
Irrigated crops in full or partial control irrigation schemes				
Total irrigated grain production			-	tonnes
• as % of total grain production			-	%
Total harvested irrigated cropped area			-	ha
• Annual crops: total			-	ha
- sorghum		1989	355 320	ha
- cotton		2000	166 900	ha
- wheat		2000	102 690	ha
- groundnuts		1989	91 140	ha
- vegetables		2000	96 820	ha
- sugar cane		2000	70 380	ha
- maize		2000	67 620	ha
- sunflower		2000	21 280	ha
- potatoes		2000	16 220	ha
- other roots and tubers		2000	16 220	ha
- rice		2000	3 620	ha
• Permanent crops: total			-	ha
- fodder		2000	141 900	ha
Irrigated cropping intensity			-	%
Drainage - Environment				
Total drained area		2000	560 000	ha
- part of the area equipped for irrigation drained			-	ha
- other drained area (non-irrigated)			-	ha
• drained area as % of the cultivated area		2000	3	%
Flood-protected areas			-	ha
Area salinized by irrigation		1999	500 000	ha
Population affected by water-related diseases			-	inhabitants

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Tanzania



Report J

January 2009

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Purpose of this report:

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

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

Figure 114 Provinces in Tanzania

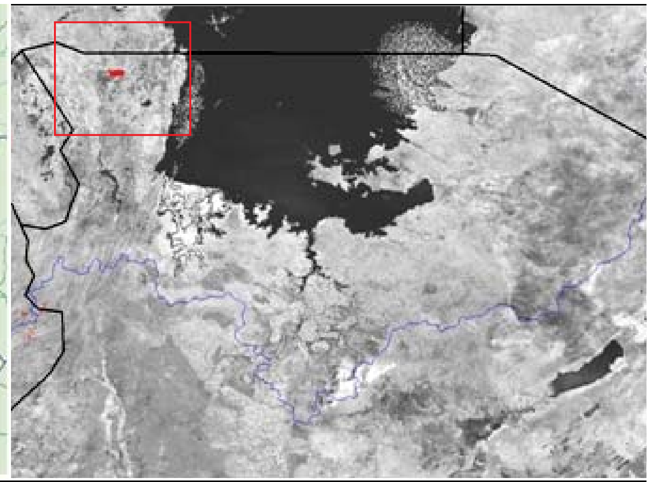


Figure 115 Map showing the only LSI scheme in Tanzania according to this study (in red)

Tanzania, with a population of 38.3 million (estimated in 2005) and a land area of 945,100 km2 is the largest country in eastern Africa and has enjoyed relative political stability since independence. Agriculture is the leading sector of the economy of Tanzania. It has linkages with the non-farm sector through agro-processing, consumption and export; provides raw materials to industries and a market for manufactured goods. About 80% of the population live in rural areas and earn their living mainly from agriculture. In spite of this reasonable growth, the livelihood of the rural population remains unchanged. This has often resulted in localized food insecurity and hunger, which has been exacerbated by the lack of access to external resources by households.

Lake Victoria Basin lies within the Nile Basin in Tanzania. It comprises the four regions of Kagera, Mara, Mwanza and Shinyanga, the last three are famous for cattle rearing and are major growers of cotton with coffee introduced in Mara quite recently (Figure 114). Kagera region is characterized by banana/coffee/horticulture systems. Other crops grown in the basin include maize, rice, sugar, tea and horticultural products. Table 75 displays the main crops grown in Tanzania and the cropping calendar. Note that the majority of these statistics occur outside the boundaries of the Nile basin.

Table 75 Cropping calendar in Tanzania (Aquastat, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
TANZANIA													
Rice	34	23	23	23								23	23
Maize	16				11	11	11	11	11				
Sugarcane	13	9	9	9	9	9	9	9	9	9	9	9	9
Vegetables	38						25	25	25	25	25		
Citrus	7	5	5	5	5	5	5	5	5	5	5	5	5
All irrigated crops	108	36	36	36	24	24	49	49	49	39	39	36	36
Equipped for irrigation	150												
Cropping intensity	72												

The National Irrigation Master Plan (NIMP) in Tanzania indicates that the irrigation potential in Tanzania is 29.4 million hectares, of which 2.3 million hectares are high potential, 4.8 million hectares are medium potential and 22.3 million hectares are low potential. This is substantially more than the current irrigation level. According to the NIMP, approximately 264,388 ha is currently under irrigation, being about 2% of the cultivated area. The latter "official" area is lower than that reported by FAO and IWMI (see Table 76). This signifies the considerable uncertainty about the real area under irrigation in Tanzania. In this study, we identified the Kagera irrigation system of 475 ha of sugar cane (see red dots in Figure 115). Other irrigation spots were found, especially in the South of Lake Victoria, but only LSI scheme are analyzed in this study.

Table 76 Different sources for the irrigation statistics for Tanzania

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Tanzania	184,330
IWMI – GIAM	Entire Tanzania	46,022
Current study	Nile Basin component of Tanzania	475

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

Part 2 Climate

2.1 Climatological conditions

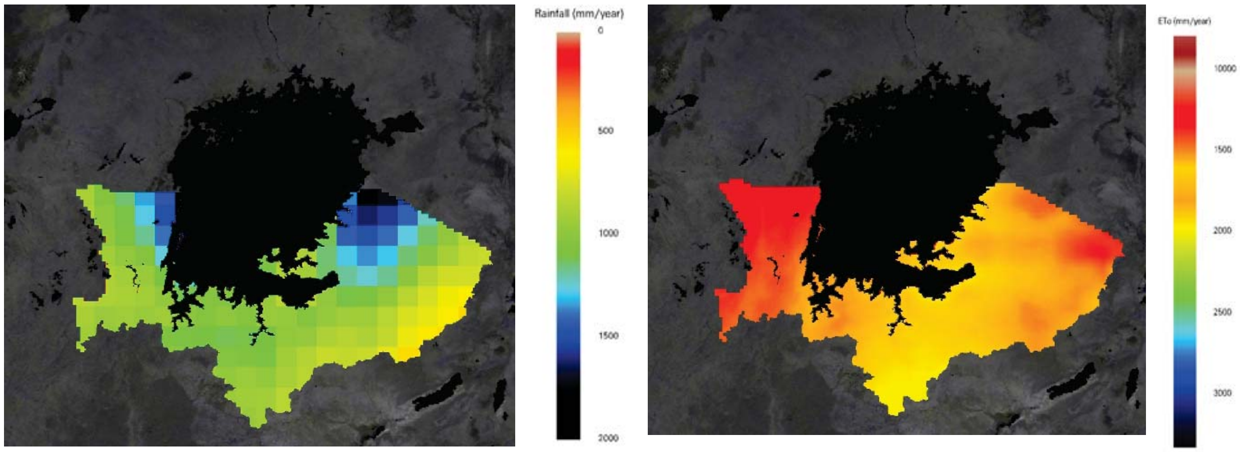
In this study, the rainfall is based on TRMM satellite data. The reference evapotranspiration (ET_0) is computed with the standardized Penman-Monteith equation specified in FAO56.

As displayed by Table 77, the monthly aridity values for June, July, August and September are approximately 0.1 to 0.35 only and without irrigation it is not feasible to grow a crop during this period. In most of the other months the aridity level exceeds 1.0, and there is thus sufficient rainfall for crop production. For this reason, Tanzania is in essence a rain-fed agricultural system. The rainfall season is continuous and long, extending from October to May. January and February are relatively dry and (ET0) exceeds rainfall during these two months. July and August are the dry months. Farmers respond to the shortage of rain water by cultivating wet river valleys and by irrigating maize and vegetables.

The northern part of Tanzania receives a significant amount of rainfall (1091 mm/yr), and the annual rainfall averaged over the whole area ranges from 700 mm to 1300 mm/yr, depending on the year considered (Figure 116). The highest rainfall (± 1600 mm/yr) occurs at the border with Kenya and Uganda.
The highest ET0 rates were observed at the most southern tip of the Nile basin in Shinyanga (± 1900 m/yr). Hence, aridity increases towards the south.

Table 77 Monthly values for rainfall and ET_0 for Tanzania

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	82	135	0.61
February	77	125	0.62
March	142	137	1.04
April	160	118	1.36
May	129	119	1.08
June	20	122	0.16
July	13	129	0.1
August	34	141	0.24
September	49	143	0.34
October	77	148	0.52
November	182	128	1.42
December	124	127	0.98
TOTAL	1091		



Annual rainfall

Annual reference ET

Figure 116 Spatial variation of rainfall (left) and ET_0 (right).

2.2 Climatic zones

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

The Tanzanian irrigation schemes are located in climate zone 4 (humid tropics), see Figure 117.

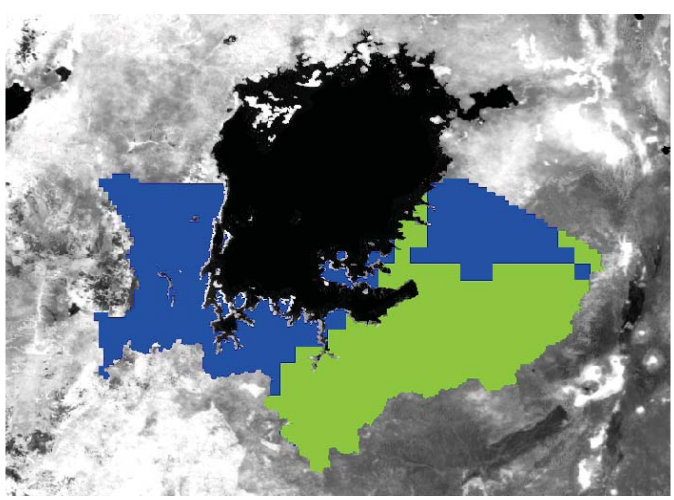


Figure 117 Climate zones identified for the mapping of best irrigation practices. Tanzanian irrigated areas are located in the humid tropics zone (blue))

Part 3 Raster and vector-based irrigation performance

3.1 Methodology

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

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

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined. A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 118).

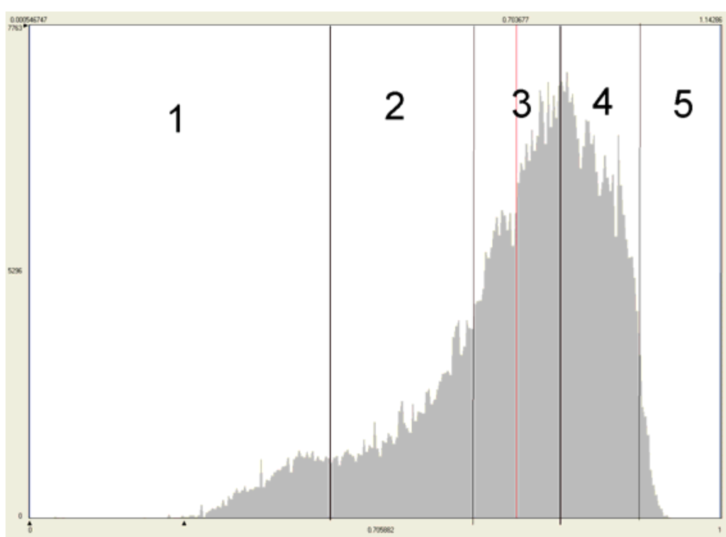


Figure 118 Distribution of the values of one indicator over 5 classes

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

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

Table 78 benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

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

3.2 Results at Country level

As displayed in Figure 119, the average score considering all the indicators together for all the 475 ha of irrigated land is 3.2, which is good (the average score being 3). This average is translated into scores for each individual indicator. The aspects that Tanzania should provide more attention to are the ones with a relative low score.

Both land and water productivity have scores of 3.1 which is reasonable.

The PO indicators show very good performance in terms of uniformity and crop water deficit. Adequacy, beneficial fraction, crop water consumption, and reliability are above average. This behaviour can be attributed to the mono-culture and single sugarcane system located in the humid tropics.

The sustainability of irrigation practices does not seem to be totally under control. Over the last years, the irrigated land became greener (as the score for the land sustainability is higher than 3) but the soils got gradually dryer.

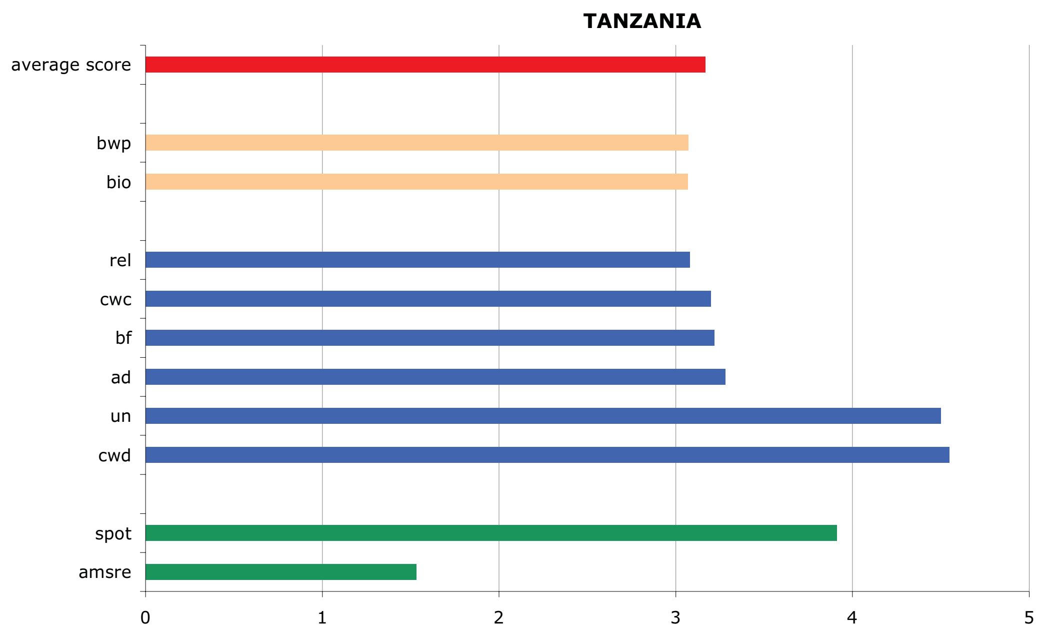


Figure 7: The average score for each indicator in Tanzania.

3.3 Results at district level

3.3.1 Average per district

In Figure 120 the average scores for all the indicators per district are compared. In Tanzania, 2 districts having more than 30 pixels of 6.25 ha have been identified: the district of Bukoba, and the district of Karagwe. But they actually share the same irrigation district. The two districts with irrigation have good total average scores of 3.3 (Bukoba) and 3.4 (Karagwe).

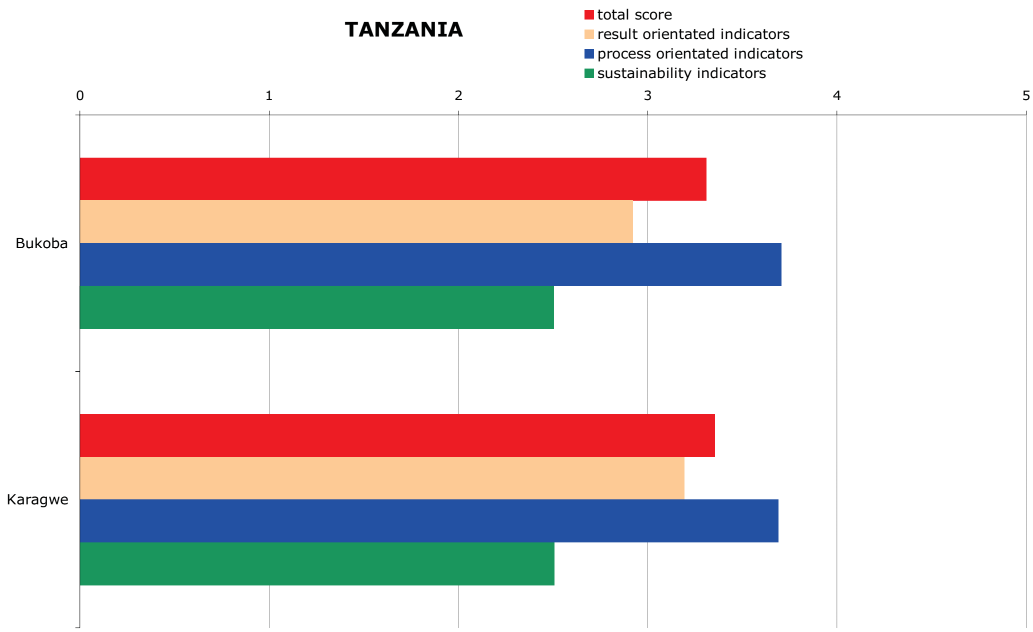


Figure 121 breaking down the total score per indicator in Tanzania

It seems that the irrigation system is well managed, as the score for the PO indicator is high (3.7). The results could be improved (The RO indicators get an average score around 3). This system is however not sustainable: the sustainability indicators have an average score of 2.5, which means that the soil moisture has decreased and the land cover has become less green with time. The Kagera sugarcane scheme thus has a problem to attend to.

3.4 Analysis per pixel for an irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the Kagera scheme. The 6th PO indicator uniformity can not be displayed as it is an indicator at district level. This example demonstrates that crop water consumption is really the weakest aspect of this irrigation system. It also helps to identify areas where it is more urgent to reduce crop water consumption (red color) (Figure 122).

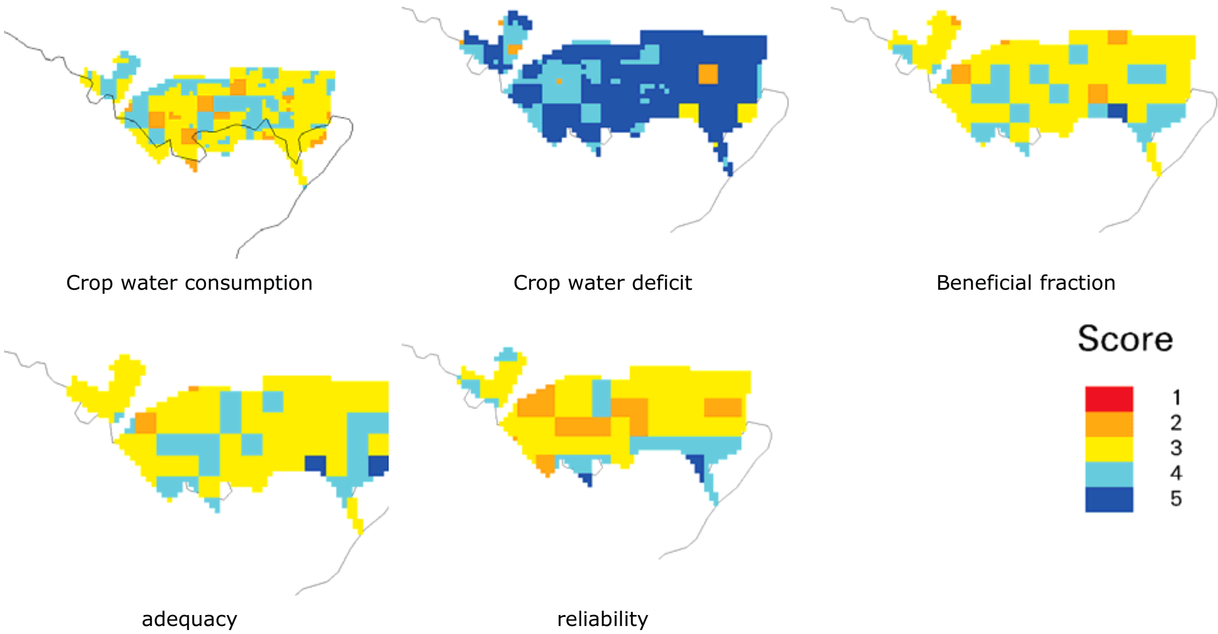


Figure 122 Spatial distribution of each indicator for the districts of Bukoba and Karagwe

Part 4 Recommendations for improvement

4.1 Weak and strong aspects per district

Once the relationships between the indicators are better understood, the next step is to identify the weakest elements per district. In Table 79, the best and poorest indicators are presented. It appears that the irrigation districts function relatively similarly. Crop water consumption and reliability seem to be the main concerns. Uniformity and crop water deficit appear to be the best characteristics of the Kagera sugar scheme.

Table 79 Best and poorest PO irrigation indicator per district

District	Lowest		2nd lowest		2nd best		Best	
Bukoba	rel	2.92	bf	3.16	cwd	4.68	un	5.00
Karagwe	cwc	3.12	bf	3.44	un	4.00	cwd	4.60

4.2 Recommendation countrywide

Irrigation practices are not well established in Tanzania, mainly because of the high rainfall which is also well distributed over the year. Irrigation is probably only useful occasionally, and supplements rainfall in some months. The dry months June, July and August are the only months that may need full irrigation supply. A first recommendation is to prepare an accurate map of the irrigation schemes in Tanzania where irrigation is actually practiced. In this study, only one main LSI was identified, therefore it makes it difficult to provide recommendations countrywide. More focus has to be given to water sustainability.

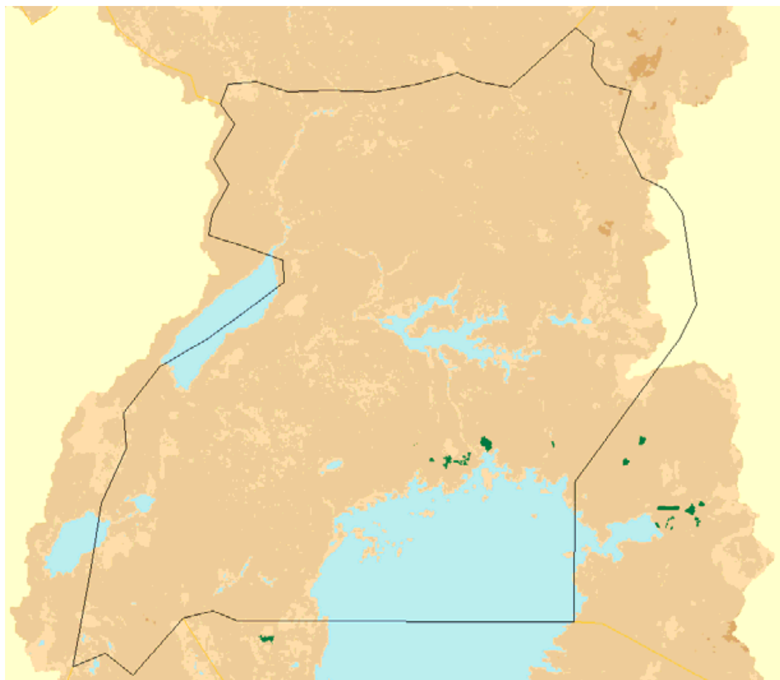
Annex 1 Definition of irrigation performance indicators

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

Large Scale Irrigation (LSI)

Nile Basin Country Irrigation Report Series

Uganda



Report K

January 2009

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Purpose of this report:

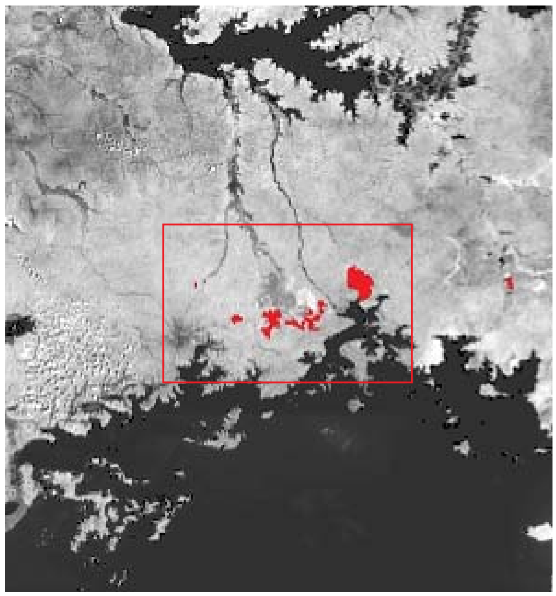
This report is one of a series of reports that will describe, and evaluate irrigation schemes in each of the Nile basin countries, and make recommendations for irrigation best practices. This report deals with Uganda and will become an integral component of the final LSI report that will combine results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

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

Part 1 Generalities on irrigated areas

1.1 Location of the irrigated areas

Uganda encompasses the northern part of Lake Victoria. Most of Uganda lies within the Nile Basin and is located on the equator, covering 241,000 km2, 18% of which is occupied by water or swamps. More than two-thirds of the country is 1,000 to 2,500 meters high.



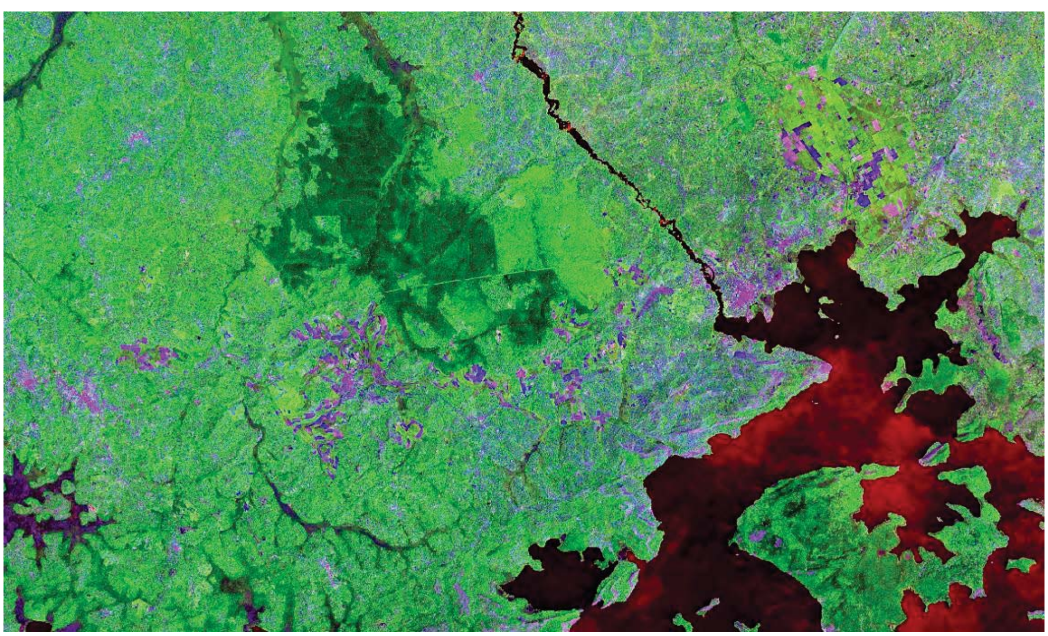


Figure 123 Map with the distribution of the irrigated areas detected within the Nile Basin according to FAO-GMIA product, and being refined within the current study. The red dots on the right hand side figure represent the irrigation schemes

According to this study, an area of 25,131 ha of irrigated land is present in Uganda (Table 80). The alluvial soils close to streams and wetlands often have some patches with irrigated land. The estimates of irrigated areas derived from the IWMI-based product of Uganda are much higher than those from FAO. It is widely known that un-official irrigation takes place over large areas in Uganda: probably up to a total of 75,000 ha. These areas can only be detected after a more detailed study.

Table 80 Different sources for the irrigation statistics

Source	Region covered	Irrigated area (ha)
FAO – GMIA	Entire Uganda	9,120
IWMI – GIAM	Entire Uganda	30,017
Current study	Nile Basin component of Uganda	25,131

1.2 Description of LSI

Irrigation has been introduced relatively recently as rainfall has been more or less sufficient in the past. Most parts of the country experience at least one long rainy season and this has been sufficient for farmers to produce at least one crop a year. In the past, irrigation was only practiced during the dry season at small-scale informal level with most of this located on the fringes of swamps. Nowadays rainfall has become less reliable and supplementary irrigation is often needed in the rain season. Many irrigation schemes have been developed by smallholders without planning and with little or no technical assistance. The technology used is basic and approaches are sometimes inappropriate. Formal irrigation developments commenced in the 1960s. Most smallholders grow rice and vegetables, with the larger commercial estates cultivating rice and sugarcane. Most irrigation developments use surface methods although the more recent developments (green house irrigated flower farms that started in 1990s) are based on drip and micro sprinklers. The main crops are displayed in Figure 124, and the cropping calendar is shown in Table 81.

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

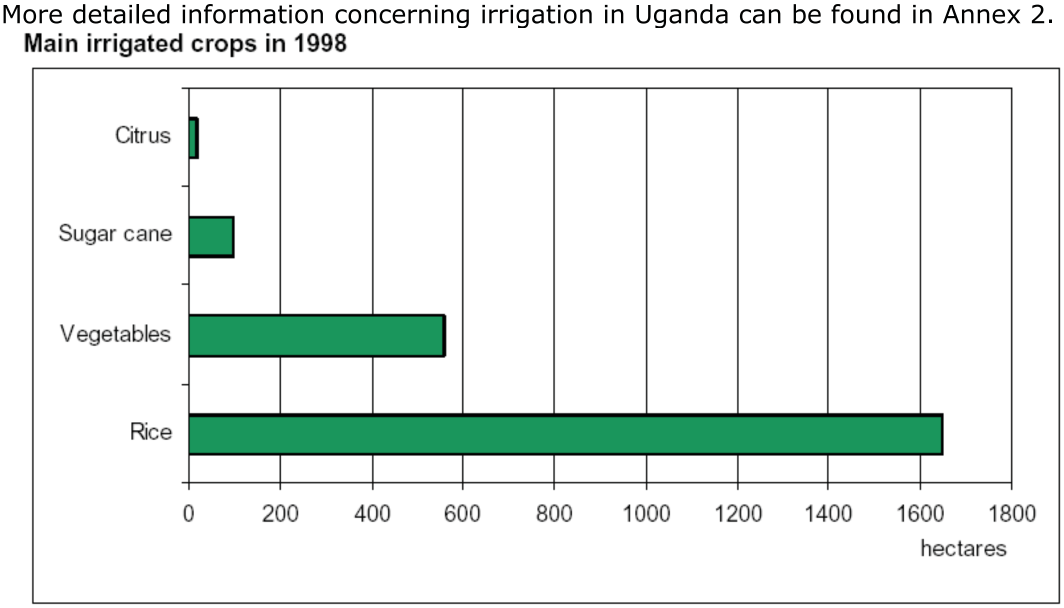


Figure 124 Main irrigated crops in Uganda (Aquastat, 2005)

Table 81 Cropping calendar for Uganda (Aquastat, 2005)

	Irrigated area (1000 ha)	Crop area as percentage of the total area equipped for irrigation by month											
		J	F	M	A	M	J	J	A	S	O	N	D
UGANDA													
Rice	5				56	56	56	56	56				
Sugarcane	4	44	44	44	44	44	44	44	44	44	44	44	44
All irrigated crops	9	44	44	44	100	100	100	100	100	44	44	44	44
Equipped for irrigation	9												
Cropping intensity	100												

Part 2 Climate

2.1 Climatological conditions

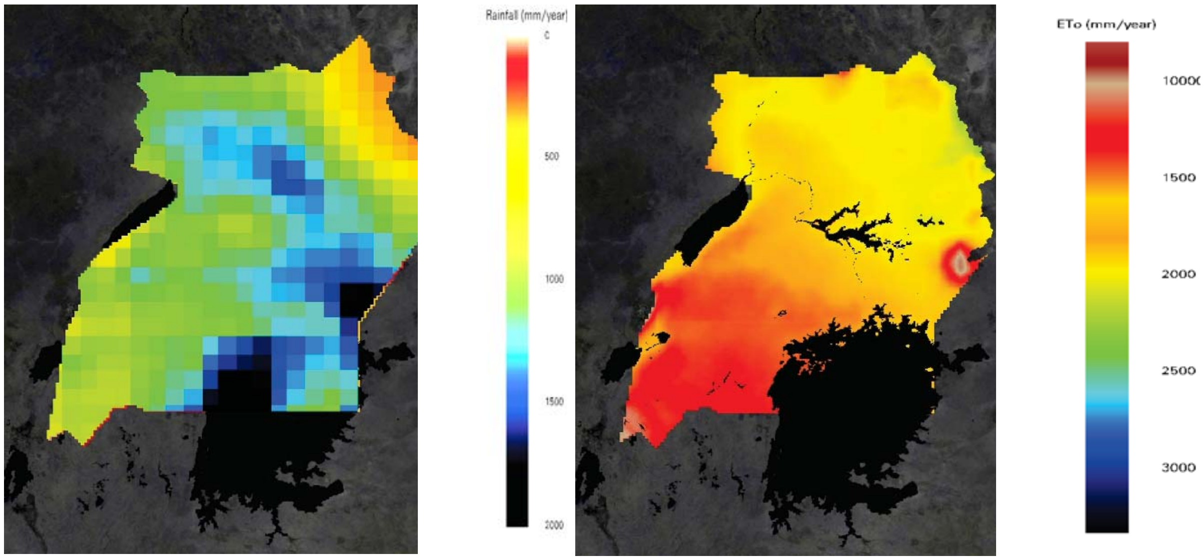
The rainfall data in this report is based on TRMM satellite data. The reference evapotranspiration (ET0) is computed with the standardized Penman-Monteith equation specified in FAO56.

According to Table 82, Uganda receives a significant amount of tropical rainfall (1300 mm/yr). The rainfall season is bi-modal. The first and major rainy season occurs from March to June. The second season is a continuation of the first season, and starts in July and continues to November. The months December, January and February are the driest, although 40 to 60 mm/month is normal. It is therefore never very dry in Uganda.

ET0 exceeds rainfall during ten months. Only the monsoon rains in April and May induce an aridity index that exceeds 1.0. This implies that supplementary irrigation is required during most of the growing season. The high ET0 can be explained by the high solar radiation and air temperatures.

Table 82 Monthly values for rainfall and ET_0.

Month	Rainfall (P)	ET_0	Aridity (P/ET_0)
January	41	157	0.26
February	63	146	0.43
March	118	156	0.76
April	206	131	1.57
May	167	126	1.33
June	96	120	0.80
July	81	122	0.66
August	108	131	0.82
September	119	135	0.88
October	130	144	0.90
November	124	133	0.93
December	58	146	0.40
TOTAL	1311	1647	



Annual rainfall   Annual reference ET

Figure 125 Spatial variation of rainfall (left) and ET_0 (right)

2.2 Climatic zones

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

The irrigation schemes of Uganda are located in climate zone 4 (humid tropics), see Figure 126.

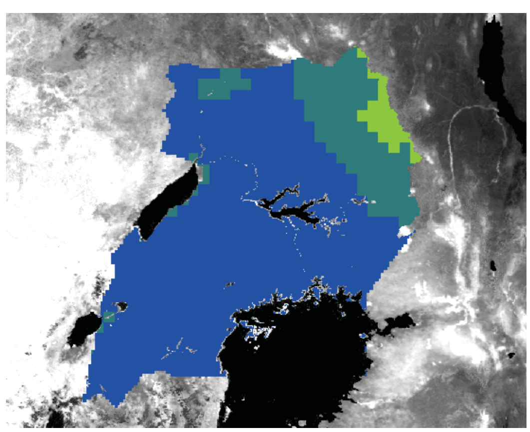


Figure 126 Climate zones distinguished for the mapping of best irrigation practices. The irrigated areas of Uganda are located in the climate zone 4: humid tropics (blue).

Part 3 Raster and vector-based irrigation performance

3.1 Methodology

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

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

The second step was to allocate a score per pixel. To do so, we studied the distribution of the values for each indicator. From that, four different benchmark values were defined. A score between 1 and 5 has been given to each pixel, 5 being the best category, depending on the value of the indicators compared to the benchmarks (Figure 127).

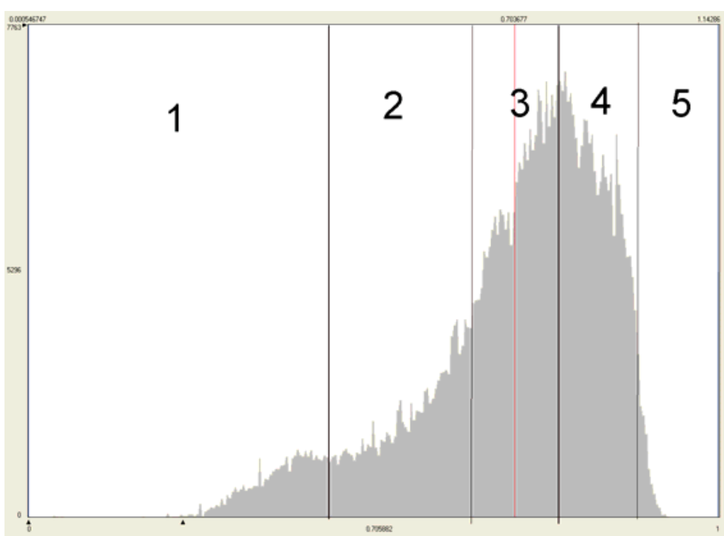


Figure 127 Distribution of the values of one indicator over 5 classes

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

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

Table 83 benchmark values for pixel located in climatic zone 4

	Unit	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5
bio	Kg/ha/year	<11,000	<17,000 and >11,000	<29,000 and >17,000	<40,000 and >29,000	>40,000
bwp	Kg/ m3	<1.5	<2.4 and >1.5	<3.3 and >2.4	<3.8 and > 3.3	>3.8
cwc	M3/ha/year	>13,300	<13,300 and > 10,000	<10,000 and >6,700	<6,700 and >3,400	<3,400
cwd	M3/ha/year	<180 and >136	>250	<250 and >180	<136 and >80	<80
bf	-	<0.45	<0.66 and >0.45	<0.82 and >0.66	<0.91 and >0.82	>0.91
ad	-	<0.62	<0.72 and >0.62	<0.83 and >0.72	<0.92 and >0.83	> 0.92
un	-	<0.75	<0.85 and >0.75	<0.9 and >0.85	<0.95 and >0.9	>0.95
rel	-	<0.8	<0.88 and >0.8	<0.92 and >0.88	<0.94 and >0.92	>0.94
spot	1/year	<-0.1	<-0.02 and >-0.1	<0.1 and >-0.02	<0.3 and >0.1	>0.3
amsre	1/year	<-0.1	<-0.05 And >-0.1	<0.05 and >-0.05	<0.15 and >0.05	>0.15

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

3.2 Results at Country level

As displayed in Figure 128, the average score considering all the indicators together for all the 25,131 ha of irrigated land is 3.45, which is good (the average score being 3). This average is translated into scores for each individual indicator. The aspects that Uganda should provide more attention to are those with a relative low score.

Land productivity has a score of 3.9 which is very good and water productivity 2.9, which is reasonable.

Concerning the PO indicators, all are above average, except for the crop water consumption with a score of 1.8. The reliability seems to be the strongest indicator as it reaches the excellent score of 4.9.

The sustainability of irrigation practices seem to be relatively under control. Compared to previous years, the irrigated land has maintained its greenness (as the score for the land sustainability is around 3). The soils are well maintained and show a constant soil moisture rate over the years. Hence, the irrigation system in Uganda is quite sound.

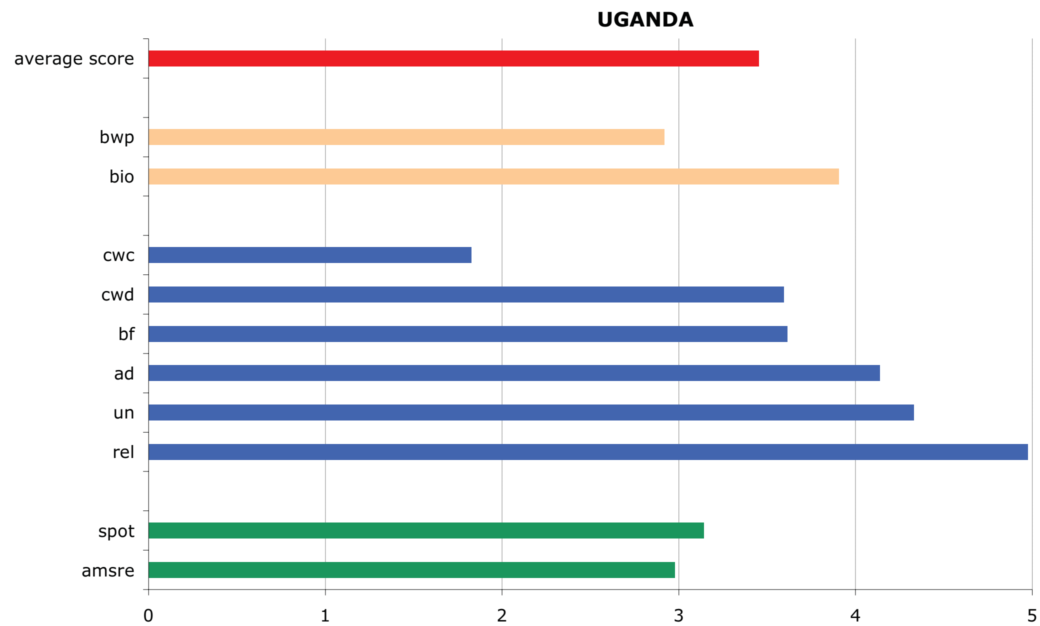


Figure 128 Representation of the average score for each indicator in Uganda.

3.3 Results at district level

3.3.1 Average per district

In Figure 129 the average scores for all the indicators per district are compared. In Uganda, six districts having more than 30 pixels with 6.25 ha have been identified. One district is called Mabira forest. It is mainly forest but because the boundaries of the districts are not very accurate, some irrigated fields that might belong to the Mukono district are included in Mabira forest in this study.

In terms of total average score, the best irrigation district is Wakiso, with an average of 3.9. The district that has the lowest average is Mukono, with an average of 3.4 (see Figure 130 for the location). The average scores for these six districts are high to very high, which already indicates the good performance of irrigation in Uganda. This good performance was already reflected in the country scale analysis.

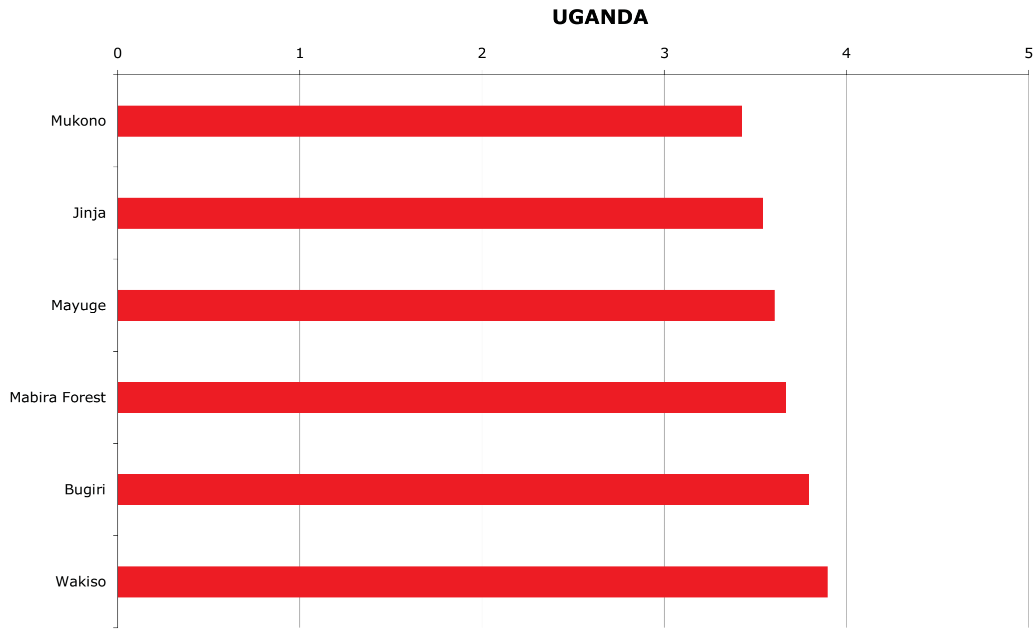


Figure 129 Total score for each district in Burundi.

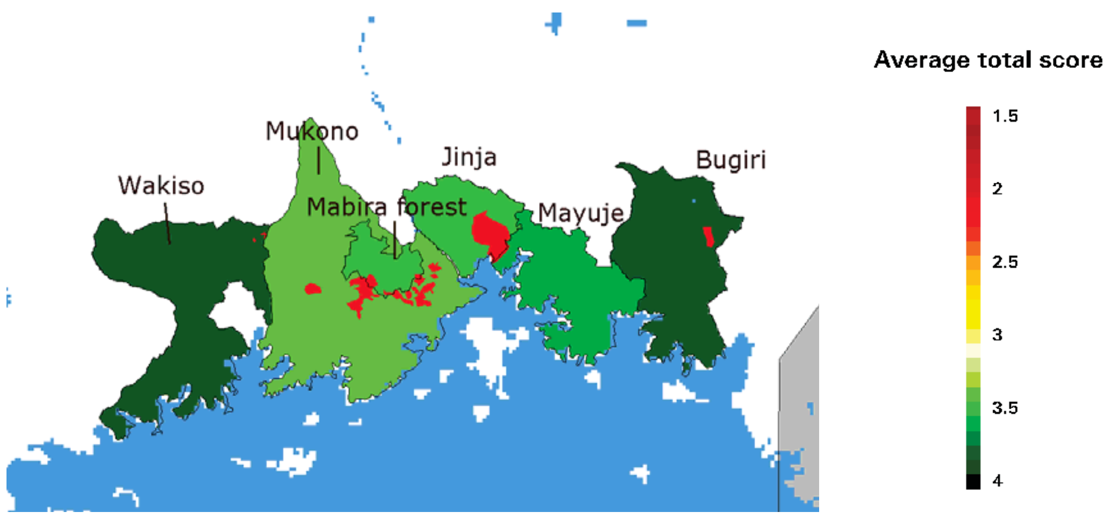


Figure 130 map showing the total score per irrigated district.

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

By breaking down the total score into 3 types of indicators (RO, PO, and sustainability), it is possible to better understand the irrigation mechanisms for each district. Figure 131 provides the average score per group of indicators. What is called 'total score' in red is the average of the 10 indicators. Looking at the total average score for all indicators for each district gives an idea of the total performance and enables ranking of the districts. A better understanding of the weak points as well as the strong points of each district will require separate analyses of each indicator group.

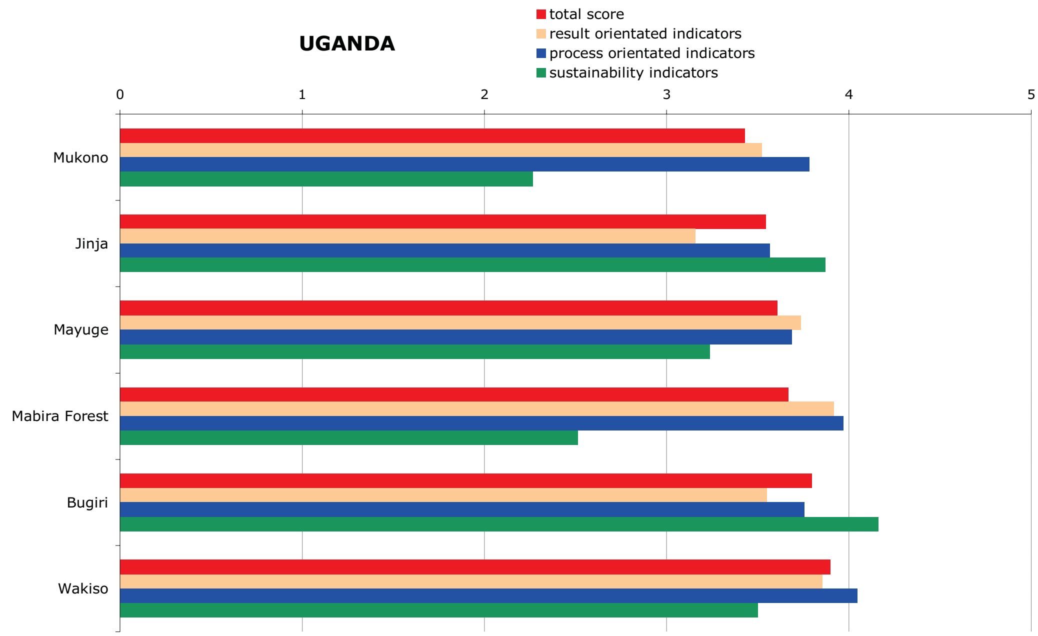


Figure 131 breaking down the total score per indicator

The first aspect that draws attention is that all the six districts of Uganda have a good average score for the RO and for the PO indicators. These high scores make it difficult to draw improvement recommendations relating to the functioning of the irrigation systems. However, good total performance does not mean a sustainable system.

Indeed, if one looks at the total average score for Mabira Forest, it seems to be a good district (total average of 3.7). However, its low score for the sustainability indicators (average score of 2.5) indicates that it is not a sustainable system.

3.4 Analysis per pixel for an irrigation system

Considering what happens within one district enables us to see the spatial distribution of the score of each indicator. In other words, it makes it possible to see whether the irrigation system is homogeneously managed. Hereafter, the spatial distribution of the five PO indicators is displayed for the irrigated pixels in the neighbouring districts of Jinja and Mukono, which are the two lower performing districts. The 6th PO indicator uniformity cannot be displayed as it is an indicator at district level. This example demonstrates that crop water consumption is really the weakest aspect of these irrigation systems. It also helps to identify areas where it is urgent to reduce crop water consumption (red color) (Figure 132).

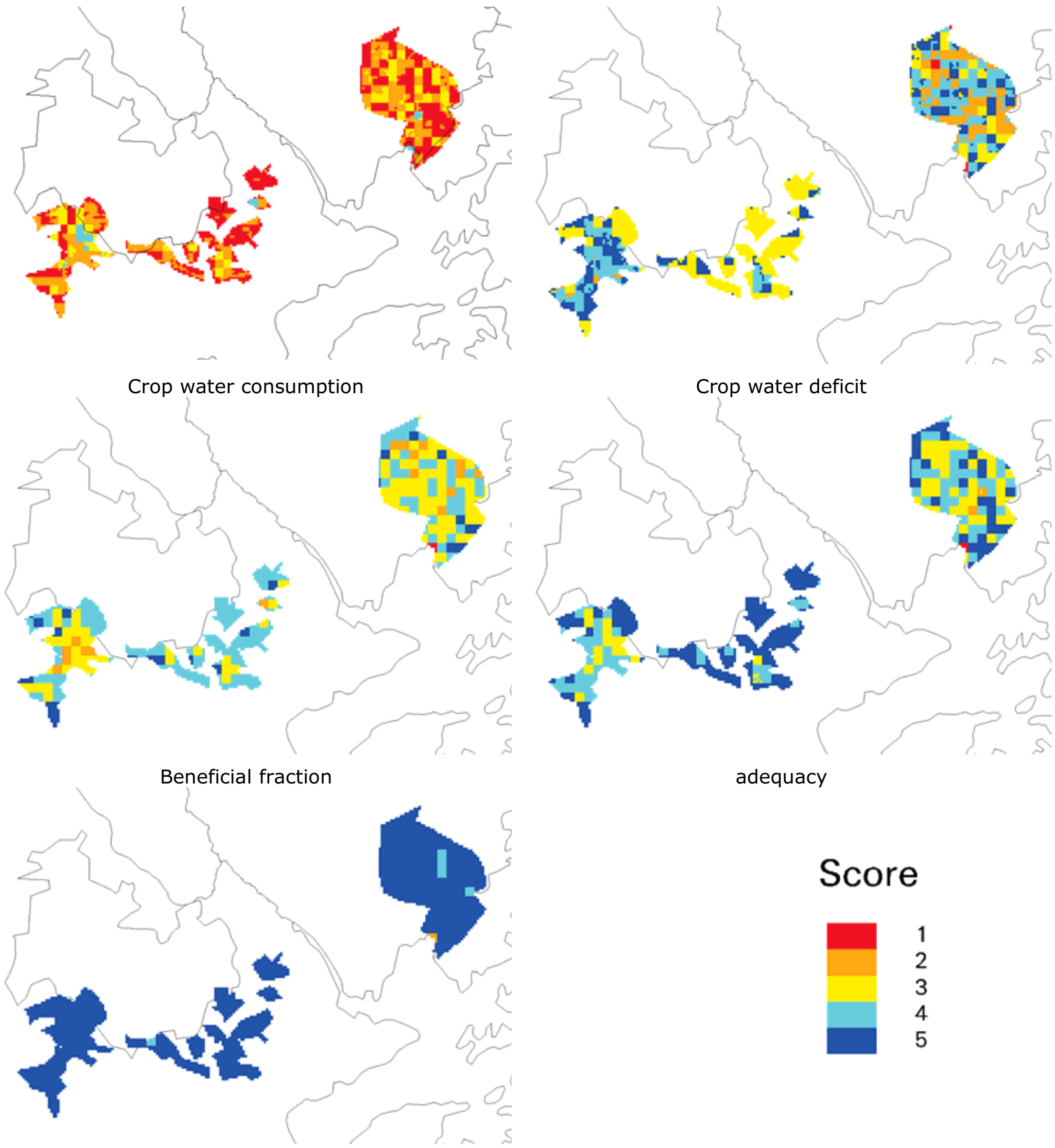


Figure 132 Spatial distribution of each indicator for the districts of Jinja and Mukono

Part 4 Recommendations for improvement

4.1 Explaining the irrigation results

To be able to give proper recommendations, it is important to understand which of the PO indicators influences the RO indicators mostly. A regression analysis was performed with the values for all indicators for the six districts. It showed that crop water consumption, reliability and adequacy are the three main explanatory factors for biomass production. Hence the timely application of adequate irrigation should get more attention in Uganda. No clear relationships with biomass water productivity are evident. It is thus better to focus on increasing biomass production rather than biomass water productivity.

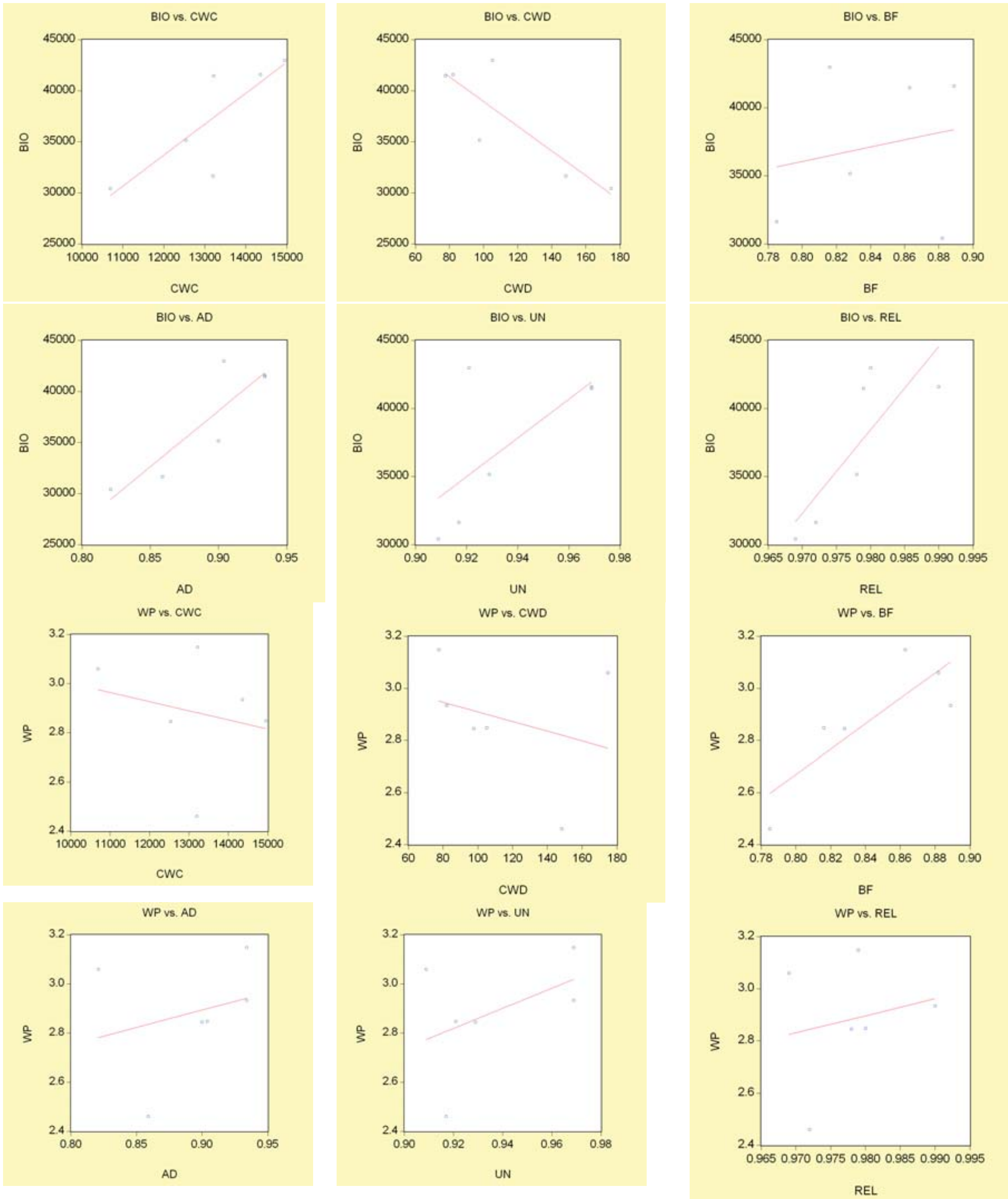


Figure 133 Relationships between RO indicators and PO/Sustainability indicators

4.2 Weak and strong aspects per district

Once the relationships between indicators are better understood, the next step is to identify the weakest elements per districts. In Table 84, the best and poorest indicators are presented.

It appears that the irrigation districts function relatively similarly. Crop water consumption seems to be the main problem for all the districts. Reliability or uniformity is the best indicator.

Table 84 best and poorest PO irrigation indicator per district

District	Lowest		2nd lowest		2nd best		Best	
Mukono	cwc	1.83	bf	3.70	ad	4.39	rel	5.00
Jinja	cwc	1.78	bf	3.36	un	4.00	rel	4.96
Mayuge	cwc	1.44	ad	3.49	un	4.00	rel	4.97
Mabira Forest	cwc	1.65	cwd	3.40	rel	4.96	un	5.00
Bugiri	cwc	2.47	cwd	3.25	ad	4.85	rel	5.00
Wakiso	cwc	1.54	cwd	3.83	un	5.00	un	5.00
Mukono	cwc	1.83	bf	3.70	ad	4.39	rel	5.00

4.3 Recommendation countrywide

Uganda has irrigation schemes in specific regions of the country. These schemes are the legal ones, and it is not unlikely that many more illegal schemes are diverting water from rivers, streams and lakes. There are organized large irrigation activities in the country.

Recent policies outline irrigation as a key intervention for food security and income generation. The land productivity is very good, but the drawback is that vast amounts of water are used due to the climatic water demand of crops. The price for a favourable agricultural production is a high crop water consumption. This leads to a below average biomass water productivity. Like in the other Equatorial Lake region, the irrigation systems are quite well managed in terms of reliability, adequacy and uniformity. If Uganda is planning to develop irrigation to achieve its target towards improving food and income security of the local people, water has to be used more efficiently.

Recommendation can be the following:

- Only irrigate when crop water stress (T_{act}/T_{pot}) and ET deficit ($ET_{pot}-ET_{act}$) exceed a certain threshold value. Otherwise pumping from rivers and lakes is not needed. This saves power and reduces the return flow from the irrigated plots.
- A reduced return flow will bring less pollutants towards the drainage systems and swamps
- Advise farmers and water utilization agencies on how to maintain yield at reduced water consumption
- Most administrative districts have a problem with the sustainability of the water and sometimes also with the land resources. More investigation is needed to find out why land is degrading, and take measures to prevent it from worsening.
- Visit the farmers in the vicinity of the district of Wakiso and get exposure to their good water conservation practices.

Annex 1 Definition of irrigation performance indicators

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

Annex 2 General information on irrigation conditions in Uganda (Aquastat, 2005)

Irrigation and drainage

Irrigation potential			90 000	ha
Water management				
1. Full or partial control irrigation: equipped area		1998	5 580	ha
- surface irrigation		1998	5 350	ha
- sprinkler irrigation		1998	230	ha
- localized irrigation			-	ha
• % of area irrigated from groundwater			-	%
• % of area irrigated from surface water			-	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)		1987	3 570	ha
3. Spate irrigation			-	ha
Total area equipped for irrigation (1+2+3)		**1998**	**9 150**	**ha**
- as % of the cultivated area		1998	0.1	%
- average increase per year over the last ... years			-	%
- power irrigated area as % of total area equipped			-	%
- % of total area equipped actually irrigated		1998	64.5	%
4. Non-equipped cultivated wetlands and inland valley bottoms		1998	49 780	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		**1998**	**58 930**	**ha**
• as % of the cultivated area		1998	0.8	%
Full or partial control irrigation schemes	**Criteria**			
Small-scale schemes	< 50 ha	1998	100	ha
Medium-scale schemes	50 – 500 ha	1998	680	ha
Large-scale schemes	> 500 ha	1998	4 800	ha
Total number of households in irrigation			-	
Irrigated crops in full or partial control irrigation schemes				
Total irrigated grain production			-	tonnes
• as % of total grain production			-	%
Total harvested irrigated cropped area			-	ha
• Annual crops: total			-	ha
- rice		1998	1 650	ha
- vegetables		1998	560	ha
- sugar cane		1998	100	ha
• Permanent crops: total			-	ha
- citrus		1998	20	ha
Irrigated cropping intensity			-	%
Drainage - Environment				
Total drained area			-	ha
- drained area in full or partial control irrigated areas			-	ha
- drained area in equipped wetland and ivb			-	ha
- other drained area			-	ha
• drained area as % of the cultivated area			-	%
• power drained area as % of total drained area			-	%
Flood-protected areas			-	ha
Area salinized by irrigation			-	ha
Population affected by water-related diseases			-	inhabitants