Assessment of the Irrigation Potential in Burundi, Eastern DRC, Kenya, Rwanda, South Sudan, Tanzania and Uganda

Final Report
Appendix South Sudan

July 2012

Client
Nile Basin Initiative
NELSAP Regional Agricultural Trade and Productivity Project

Report FutureWater: 114

FutureWater
Costerweg 1V
6702 AA Wageningen
The Netherlands

+31 (0)317 460050

info@futurewater.nl

www.futurewater.nl

PREFACE

The Nile Basin Initiative (NBI), under the Nile Equatorial Lakes Subsidiary Action Program (NELSAP) and the project Regional Agricultural Trade and Productivity Project (RATP) announced a Request for Proposals (RFP) entitled “Assessment of the Irrigation Potential in Burundi, Eastern DRC, Kenya, Rwanda, Southern Sudan, Tanzania and Uganda” in July 2010 (RATP/CONSULTANCY/04/2010). The study was categorized as “preparation for a development program” and has therefore a strategic perspective.

FutureWater, in association with WaterWatch, submitted a proposal in response to this RFP. Based on an independent Technical and Financial evaluation FutureWater, in association with WaterWatch, has been selected to undertake the study.

The consulting services contract was signed between the “Nile Basin Initiative / The Regional Agricultural Trade and Productivity Project” and “FutureWater in association with WaterWatch” entitled “Consulting Services for Assessment of the Irrigation Potential in Burundi, Eastern DRC, Kenya, Rwanda, Southern Sudan, Tanzania and Uganda”. This contract was dated 5-Feb-2011 and total project duration is 16 months. The Contract Reference Number is: NELSAP CU/RATP2/2011/01. Tangible outputs of this study area:

- Inception report
- Phase 1 report
- Seven country reports phase 2
- Final report

The Consultants wish to acknowledge the support, fruitful discussions and useful comments from all NBI-RATP staff and stakeholders in the countries. In particular Dr. Innocent Ntabana and Dr. Gabriel Ndikumana are acknowledged for starting this initiative and their support and advice on the study.

Various people and institutions have contributed to this specific country/focal area report: Mary Loki (NLO), Jal Fnom (Field assessor/NLO), Makuac Deng (Field assessor/NLO), Isaac Liabwel C. Yol, amongst others. Their contribution is highly appreciated.

Authors of this report are:

- Dr. Peter Droogers[1] (Project Leader / Water Resources Specialist)
- Prof. Dr. Pascal Nkurunziza[1] (Assistant Team Leader)
- Prof. Dr. Wim Bastiaanssen[2] (Senior Irrigation Specialist)
- Dr. Walter Immerzeel[1] (Senior Water Modeler)
- MSc. Wilco Terink[1] (Data Analyst, Hydrologist)
- MSc. Johannes Hunink[1] (Data Analyst, Hydrologist)
- Dr. Wouter Meijninger[2] (Remote Sensing Specialist)
- Prof. Dr. Petra Hellegers[3] (Water Economist)
- MSc. Simon Chevalking[4] (Environmental Expert)
- Dr. Frank Steenbergen[4] (Social Geographer)
- BSc. Jaïrus Brandsma[1] (Data and GIS Analyst)

[1]FutureWater, [2]WaterWatch, [3]LEI, [4]MetaMeta

Contact: Peter Droogers; p.droogers@futurewater.nl; +31 317 460050; www.futurewater.nl

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1 Introduction

1.1 Background

South Sudan (Figure 1) is the newest country in Africa with an area more than 64 million hectares and a population of around 8 million. It occupies an important area within the Nile basin.

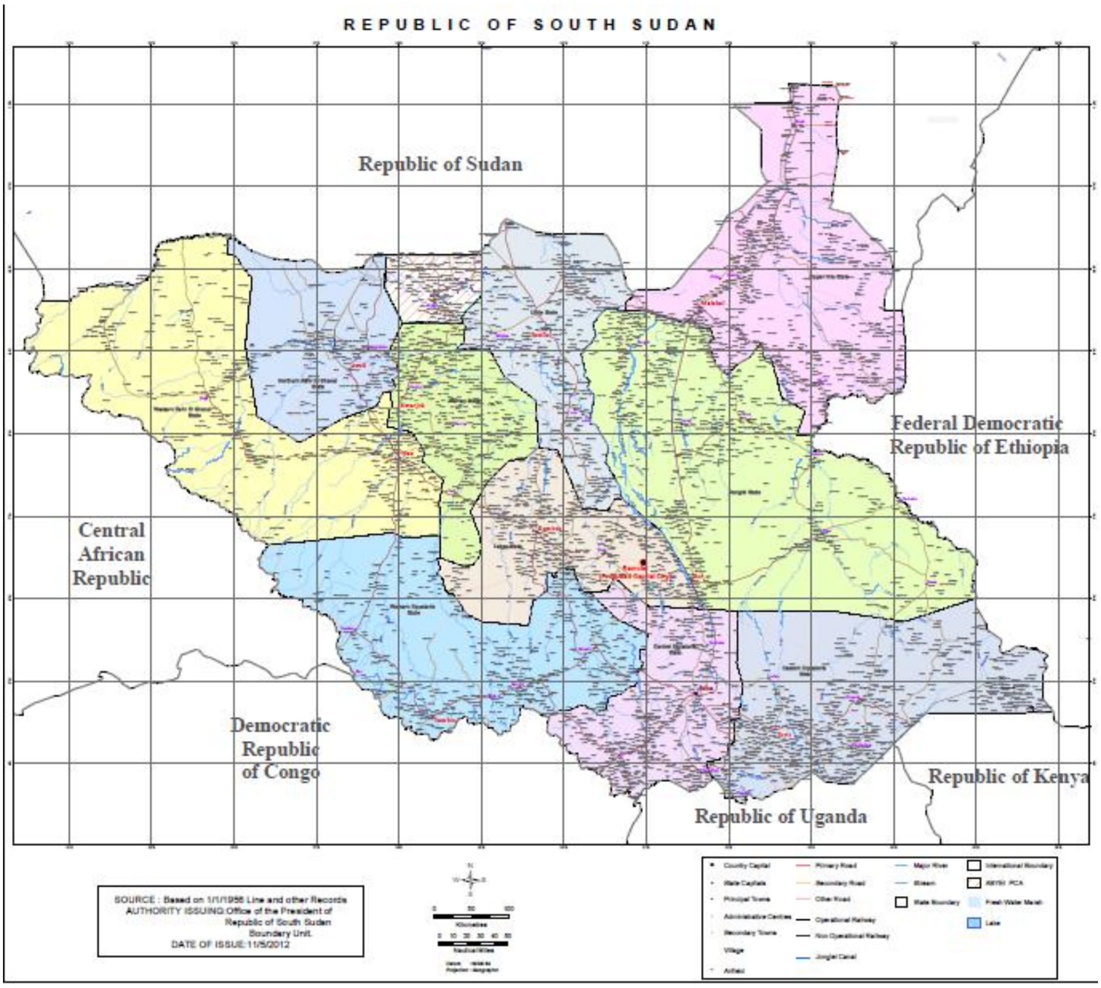


Figure 1: Map of South Sudan (source: Office of the President of The Republic of South Sudan).

The sum of the internal and external water resources available to South Sudan will depend on some projections on future changes in water demands and the availability of water resources. Predicting this future is by definition a delicate matter with lots of uncertainties that might be involved. This is especially the case for South Sudan, a country still recovering from decades of conflict and as a result is anticipating changes and developments while at the same time still lacking well worked-out long term strategic plans for development of agriculture, industries, etc.

The major water consumers currently in South Sudan are domestic and agriculture. The current water *demand* is higher than the actual consumption, taking into account the fact that for a substantial number of inhabitants the water consumption is below the basic human needs. Actual figures on water usage by irrigated agriculture in South Sudan are not available. Industrial water use is very marginal in South Sudan, as the only industries are some oil refineries, some envisaged sugar cane factories and one brewery. No figures on the industrial water consumption are available. A number of dams are planned to be built in South Sudan and the estimated total annual evaporation from their lakes is considered negligible. Other water demands come from sectors that are "non-consumptive", i.e. fisheries, navigation and environment sectors.

South Sudan is almost entirely situated within the White Nile basin, and it is where its main tributaries of Bahr el-Ghazal, Bahr el-Jebel and the Sobat River meet. When high river discharges coincide with the peak of rainfall, water spills over the banks of rivers; spreading into large areas, which are relatively flat and lower than banks of the rivers, creating wetlands whose area is approximately 0.03×10^6 km^2 (3 million ha) of which 1.4 million is seasonal and the rest of 1.6 million is permanent. Therefore, only part of river discharges entering the area flow out, hence the region was termed Sudd (barrier/blockage in Arabic Language). Table 1 below shows an overview of average annual flow volumes in the White Nile basin (Sutcliffe and Parks, 1999).

Table 1: Overview of average annual volumes in the White Nile basin (in BCM)

Basin	runoff	flow to wetlands	remaining
Bahr el-Jebel	33	17	16
Bahr el Ghazal	11.3	11	0.3
Sobat	17.5	4	13.5
Total	61.8	32	29.8

Geological formations in South Sudan consist mainly of sedimentary/alluvial deposits known as Umrwaba, including the Baggara and the Sudd groundwater basins; in addition to crystalline rock formation known as basement complex, where water occurs in fractures/faults and weathered zones. Table 2 below shows the estimated storage volume, annual recharge and annual abstraction (in million cubic meters, BCM) of the Sudd and the Baggara aquifers from three different sources. Differences in numbers between the sources are striking, especially with respect to annual recharge. Therefore, in South Sudan, the substantial mutual differences in numbers between the different sources demonstrate a lack of understanding of groundwater recharge and abstraction. But, despite this huge knowledge gap, groundwater is the primary source of drinking water for the majority of people.

Table 2: Storage, Annual recharge and annual abstraction of the Sudd and Baggara aquifers in billion cubic meters (BCM)

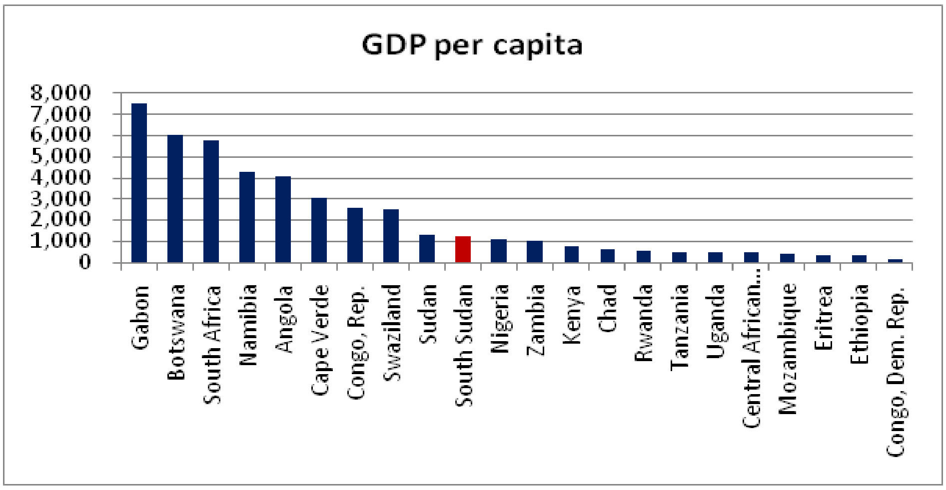
Source	Sudd			Baggara		
	Stor.	Rech.	Abstr.	Stor.	Rech.	Abstr.
Yousif and Abdalla [2010]	1.8	0.034	0.003	1.7	0.030	0.028
Medani [2009]	4.5	0.080	-	5.4	0.040	-
Omer [2008]	-	0.341	0.0018	-	0.155	0.012

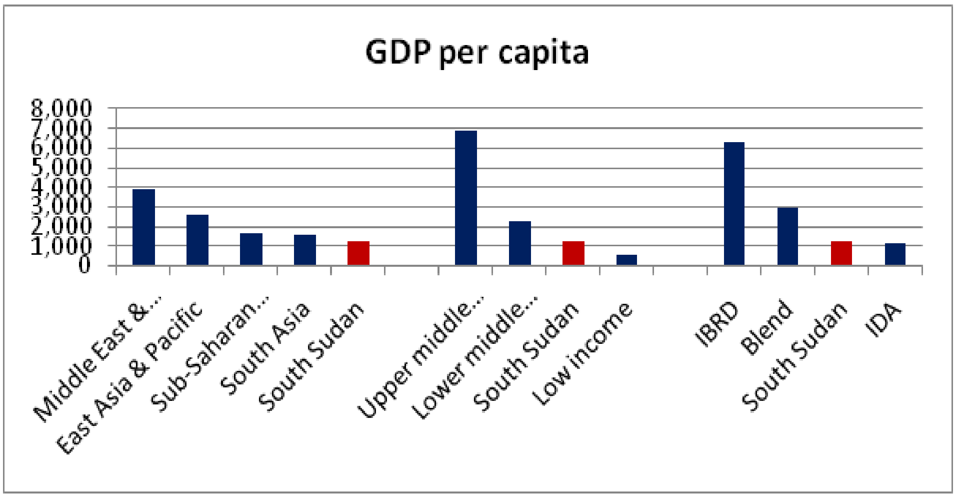
At present there is no exact figure about how much groundwater is abstracted from the different basins in South Sudan. However, from the limited information available, there is large groundwater potential and current abstraction is only a small fraction of the resources available.

1.1.1 Socio-economy

Years of conflict and neglect have left South Sudan one of the most underdeveloped regions in the world, despite its rich resource base. Poverty is widespread, and is especially acute in rural areas and the more remote corners of the Country. Poverty in South Sudan has many dimensions, including low levels of consumption, and poor health and education. The legacy of the prolonged war in South Sudan makes the fight against poverty more demanding and challenging. SSCCSE carried out the National Baseline Household Survey (NBHS) in 2009 that gave the first precise estimates of consumption in South Sudan. The survey provided the basic information for the poverty estimates in SSDP. South Sudan has experienced very low levels of investment or development in basic services or infrastructure over the past five decades since the independence of Sudan. The average household is still agricultural, with 78% of households depending on crop farming or animal husbandry as their primary source of livelihood. There is no national labour market; job seeking is localised with most relying on the informal sector. 53% of the working population in South Sudan work as unpaid family workers and only 12% as paid employees. According to provisional SSCCSE estimates, nominal GDP of South Sudan in 2009 was 24.95 billion Sudanese pounds (SSP), or SSP2,967 per capita. With an average exchange rate in 2009 of 2.31 pounds per US dollar, this is $1,285 per capita. GDP is dominated by the oil sector; in 2009, oil exports were 66% of the value of GDP. GDP per capita of South Sudan is shown against comparator countries in Figure 2. Gross National Income (GNI) is equal to GDP plus income from South Sudanese citizens earned abroad minus income of foreigners earned in South Sudan. The GNI for South Sudan is $888 per capita, making South Sudan a low -income country.

Figure 2: GDP per capita in South Sudan and comparators





1.1.2 *Demographic context*

South Sudan has a population of 8.3 million according to the 5th Sudan Population and Housing Census (2008, Table 3), of which 1.4 million live in urban areas, compared with 6.9 million in rural areas. The population is therefore currently predominantly rural (83%) and dependent on subsistence agriculture. South Sudan is a young country with half (51%) the population under the age of 18 and 72% under the age of 30.

Table 3: Selected demographic indicators by place of residence

	South Sudan	Urban	Rural
Total population	8,260,490	1,405,186	6,855,304
Male	4,287,300	754,086	3,533,214
Female	3,973,190	651,100	3,322,090
Average household size	7	9	7
Dependency ratio (%) (<14 +>55)/14-55 population	88	75	91

Source: 5th Sudan Population and Housing Census (2008).

1.1.3 Millennium Development Goals, current status

Incidence and depth of poverty

51% of the population lives below the national consumption poverty line. There is no direct internationally comparator because Purchasing Power Parity (PPP) data are not available for South Sudan. However, data on infant mortality; maternal mortality; the ratio of the proportion of births attended by skilled health personnel; measles immunisation coverage; the proportion of the population below minimum level of dietary consumption; net enrolment and completions rates in primary education, and literacy rates suggest that the incidence of poverty in South Sudan is actually greater than this. Infant mortality is the ninth worst in the world and South Sudan is in the bottom five countries for 11 of the 22 Millennium Development Goal (MDG) indicators for which there are data.

The poverty gap is 24%. This measure is an estimate of the average shortfall in consumption relative to the poverty line. The poverty gap in the population as a whole is 24% (see Table 4). Table 4 summarises the two different poverty measures according to three criteria: by urban and rural areas, by greater region and by state. Table 5 looks at poverty incidence by household head characteristics; namely sex and education.

South Sudan has a high degree of food insecurity with 47% of the population being undernourished. Inadequate food consumption is one of the key signs of poverty. The level of food insecurity in South Sudan is significant given between one third and one half of the population was either severely or moderately food insecure over the past three years. The food security situation is relatively better in Western Equatoria State (WES), Central Equatoria (CES) and Unity, where less than a quarter of their population was insecure. On the other hand, food insecurity was highest in Eastern Equatoria State (EES), Warrap and NBS where close to half their population was food insecure (Table 5).

Table 4: South Sudan poverty estimates

	Incidence (%)	Poverty gap	Share of population (%)	Share of national poverty (%)
South Sudan	51	23.7	100	100
Urban	24	8.8	15.6	7.5
Rural	55	26.5	84.4	92.5
Greater Upper Nile	44	19.9	33.3	28.8
Greater Bahr el Ghazal	62	30.5	35.8	43.6
Greater Equatoria	45	19.9	30.9	27.7
Upper Nile State (UNS)	26	9.8	12.6	6.4
Jonglei State (JS)	48	22.2	14.3	13.7
Unity State	68	34.6	6.4	8.7
Warrap State (WS)	64	34.1	14.2	18
Northern Bahr el Ghazal (NBS)	76	36.8	9.7	14.5
Western Bahr el Ghazal State (WBS)	43	17.6	3.7	3.2
Lakes	49	22.6	8.1	7.9
Western Equatoria State (WES)	42	15.5	7.6	6.3
Central Equatoria State (CES)	44	22.5	13.1	11.3
Eastern Equatoria State (EES)	50	19.8	10.2	10.1

Source: SSCCSE (2010) Poverty in Southern Sudan: Estimates from NBHS 2009.

Table 5: Level of food insecurity by states, 2010

States	Projected population (2011)	Severely food insecure		Moderately food insecure		Food secure	
	Number	Number	%	Number	%	Number	%
EES	986,000	143,000	14.5	337,000	34	506,000	51
JS	1,478,000	219,000	14.8	351,000	24	908,000	61
Lakes	807,000	106,000	13.2	224,000	28	477,000	59
NBS	848,000	58,000	6.9	309,000	36	481,000	57
UNS	1,037,000	73,000	7.0	319,000	31	645,000	62
WS	1,071,000	154,000	14.4	367,000	34	550,000	51
WBS	368,000	24,000	6.5	72,000	20	272,000	74
WES	676,000	18,000	2.7	123,000	18	535,000	79
CES	1,224,000	51,000	4.2	211,000	17	962,000	79
Unity State	664,000	40,000	6.0	97,000	15	527,000	79
Total	9,157,745	886,000	9.7	2,410,000	26.3	5,863,000	64

Source: compiled from WFP, 2011 'Annual Needs and Livelihood Analysis'.

The Food and Agriculture Organisation (FAO)/World Food Programme (WFP) estimated cereal production in South Sudan to have been 695,000 tonnes in 2010 (28.5% higher than in 2000), but this still falls short of domestic consumption needs by 291,000 tonnes. Domestic production would have to be 42 % above 2010 levels to meet the shortfall. FAO/WFP estimates that food assistance requirements will remain high with a monthly average of 816,000 beneficiaries of food aid. This is expected to rise during the lean season to 2.7 million food aid beneficiaries per month. This reflects that a significant proportion of the population (as high as 33% in the lean season) will continue to depend on food aid to ensure a minimum level of nutritional intake.

1.1.4 Social development

Poverty is a multi-dimensional phenomenon that affects populations through reduced access to healthcare, education and economic opportunities. There has been almost no development in the form of basic services over the past five decades since independence. This is clearly seen in the poor levels of various social indicators like literacy levels, infant mortality rates and access to water and sanitation. Two decades of conflict have resulted in many not having access to schools, hospitals or safe sources of drinking water. The terrain of South Sudan and the geographical constraints that reduce access to large regions further increases the difficulty of improving social indicators. Infrastructure investments planned under the SSDP seek to address directly the issue of accessibility.

Education status

South Sudan is a young nation with over 4 million children (below the age of 18) in 2008. In 2010 it was estimated that there were over 2 million children of primary school-going age but only 900,000 were actually attending school. The second MDG is to universal primary education. As can be seen in the following indicators, South Sudan still has a long way to go to achieve this. Only 40% of the population between 15-24 is literate. The literacy rate for males in this age group is 55% compared with 28% for females. In Kenya, the figure for adult literacy (15 and above) is 87% compared with 27% in South Sudan. Among the primary school age children less than half are in schools. The net primary school enrolment rate in 2010 was 44%, the fourth lowest in the world. Moreover, there is significant variation between genders with the enrolment rate for males being 51% compared to 37% for females. This is far lower than the average for the region. Kenya has an enrolment rate of 86% and Uganda has an almost universal enrolment rate at 97%. Only 37% of the population above the age of six has ever attended school in South Sudan. Amongst these, 68% are attending school now, reflecting the near absence of formal education in earlier years.

Health status

The infant mortality rate in South Sudan in 2006 was 102 per 1000 live births which is the ninth highest in the world. In the same year, the maternal mortality rate was 2054 per 100,000 live births, rated the highest in the world. Nutritional intake remains a challenge with 33% of the children under the age of five moderately or severely underweight and 34% suffering from moderate or severe stunting.

Table 6: Selected social indicators

Region	Ever attended school*	Literacy rate (15+)*	Maternal mortality rate per 100,000[2]	Children 12-23 months fully immunised, %[2]	Access to improved drinking water, %[1]	Phone+	Bicycle+
Southern Sudan	37%	27%	2054	17	55	15	25
Upper Nile	50%	45%	2094	29	35	30	13
Jonglei	27%	16%	1861	12	67	5	7
Unity	32%	26%	1732	24	54	27	9
Warrap	22%	16%	2173	12	52	9	21
N. Bahr El Ghazal	28%	21%	2182	6	66	7	32
W. Bahr El Ghazal	40%	34%	2216	6	45	25	44
Lakes	26%	18%	2243	7	71	13	40
Western Equatoria	58%	33%	2327	8	40	11	56
Central Equatoria	58%	44%	1867	44	51	28	36
Eastern Equatoria	27%	19%	1844	14	63	8	12

* As a percentage of population six years and over.
+ Percentage of households that own a phone/bicycle.
Sources: 1 NBHS (2009) 2 SHHS (2006).

Large sections of the population do not have access to a modern health service with only 44% of settlements lying within a 5km radius of a primary healthcare unit. User rates are estimated to be as low as 0.2 outpatient contacts per person per year.
While preventable diseases are major sources of morbidity and mortality, only 17% of children aged 12-23 months were fully immunised in 2006.

HIV/AIDS has not yet reached epidemic proportions in South Sudan with incidence currently at 3%, which is lower than in neighbouring countries. However, knowledge of the disease and contraceptive use remain low, which makes it a potential danger in the coming years. 45% of women have heard of AIDS and only 4% use any form of contraception, the second lowest rate in the world.

Lack of access to safe drinking water and sanitation facilities is another cause of disease. Currently only 55% of the population has access to improved sources of drinking water according to World Health Organisation (WHO) definitions. Sanitation remains a challenge with 80% of the population not having access to any toilet facilities.

These all are important indicators to track, especially given the MDGs commitment to reducing child mortality, improving maternal health, combating HIV/AIDS and ensuring environmental sustainability (Goals 4, 5, 6 and 7).

Institutions

Ministry of Water Resources and Irrigation (MWRI) leads the development of policies, strategies, guidelines, regulations and standards; in addition to coordination of other regional, national, bilateral and donor group projects such as NBI, UNICEF, FAO, ect. MWRI is to ensure coordinated development and management of water resources (including irrigation development) on the one hand, and provision and sustainability of water and sanitation services on the other hand. Overall, the responsibility for operating and managing the facilities and delivering of services lies with the state and county levels of the government. MWRI therefore is the central policy making, regulating and coordinating body in the water sector of South Sudan.

There is currently a Water Sector Steering Committee (WSSC), chaired by MWRI that guides the policy, institutional and legal framework process.There is an ongoing organized inclusive multi-stakeholder driven consultation, to identify key building blocks for water sector legislations that: Cater for the establishment of appropriate institutions (government, community, civil society, etc) with clearly separated mandates, roles and responsibilities pertaining to regulating water aspects such as extraction, use, pollution control, conservation, safe water and improved sanitation service delivery. This will lead to formalization of the present ad-hoc water licensing systems, including payment of water fees for abstraction (by the Directorate of Water Resources Management); issuing of drilling permits (by the Directorate of Rural Water Supply and Sanitation), payment for irrigation system water use (by the Directorate of Irrigation and Drainage), etc. Therefore, the institutional framework for irrigation and water resources development is still evolving. Main policies are the South Sudan Water Policy of 2007; the South Sudan Development Plan (SSDP) and the WASH Strategic Framework of 2011; Draft Agricultural Policy Framework of 2011; Land Act of 2009; etc.

The South Sudan Water Sector Strategic Framework, concluded in 2011 provides direction for *Water* Resources Management (WRM) and the overall Water Sector governance and development. This Strategic Framework is developed in order to implement the Water Policy in a systematic approach; move from ad-hoc emergency interventions to a holistic, government-led planning and implementation of well-targeted development programs; and to attract investment towards achieving water and sanitation MDG targets; and contributing to a diversified and sustainable economic development.

SOUTH SUDAN – INSTITUTIONAL	
Main guiding policies, act and ordinances	• *South Sudan Water Policy 2007, reflects the vision for water sector, and establishes basic principles and objectives to guide future water sector development, in prioritizing user needs. T includes vision for the agricultural and forest sector (MWRI, 2010)* • *SPLM Policy Framework for the Government of South Sudan (GOSS) 2010, Work Draft* • *UNICEF is guiding together with DRWS MWRI and the Directorate of Rural Water Supply and Sanitation) development of the water sector.* • *Water, Sanitation and Hygiene (WASH) Sector Strategic Frame work of 2011.*

Institutional mandate irrigation development (groudwater development, Meghani, M. et al. 2007 and BMB Mott MacDonald, 200X)	• *Although OLS (Operation Lifeline Sudan) was ended in 2003, UNICEF is still regarded the leading agency in the water sector (the "sector lead") in South Sudan. However, the*
	• *Ministry of Irrigation and Water Resources has already taken over a responsibilities:*
	  ○ *Dir. of Water Resources Management and Coordination*
	  ○ *Dir. of Hydrology and Survey*
	  ○ *Dir. of Irrigation and Drainage*

Water Permit System – Drillers (Armstrong, T.; 200X)	○ *In South Sudan all drillers are required to register with the nascent Ministry of Water and Irrigation, but authorisations to drill boreholes are not required.* ○ *UNICEF, in concert with the Directorate of Rural Water and Sanitation (DRWS) has prepared standardised borehole completion logs that all organisations providing boreholes should complete and submit.*
Land tenure	*Guided by the 2009 South Sudan Land Act, supervised by the South Sudan Land Commission (SSLC)*
Government Effectiveness (percentile rank 0-100) (World Bank, 2009)	*7.1*
Rule of Law (-2.5 – 2.5, in which high values represent effective enforcement of law (World Bank, 2009)	*-1,34*

2 Countrywide irrigation potential

2.1 Terrain and soil

2.1.1 Relief, climate, and hydrography

South Sudan expands on clay plains, with gradual extend of uphill slopes to the mountains on the Uganda frontier. At this frontier the mountains series of the Imatong, Didinga, and Dongotono rise to more than 3,000 meters. It also expands in the west from water divide along borders with Central African Republic and DR Congo eastward, passing through low lands of the White Nile Valley and the Sudd wetlands to the Ethiopian highlands (NEPAD/FAO, 2005). The average annual rainfall approximately ranges from 500-600 mm/year to more than 1500 mm in the south western part of the Country. On the other hand, potential evaporation decreases from a maximum annual value of 2400 mm to a minimum annual value of less than 1400 mm in the south-western part of the Country. Another important observation is that rainfall in Southern Sudan suffers noticeable decreasing trend accorded to climate change though it is relatively less in comparison to northern part of the country [Yousra & Magdoleen, 2009]

Based on climatic and soils attributes of the African continent, among the Africa's six divisions, South Sudan has wide range of geographical differences that entail location specific solutions.

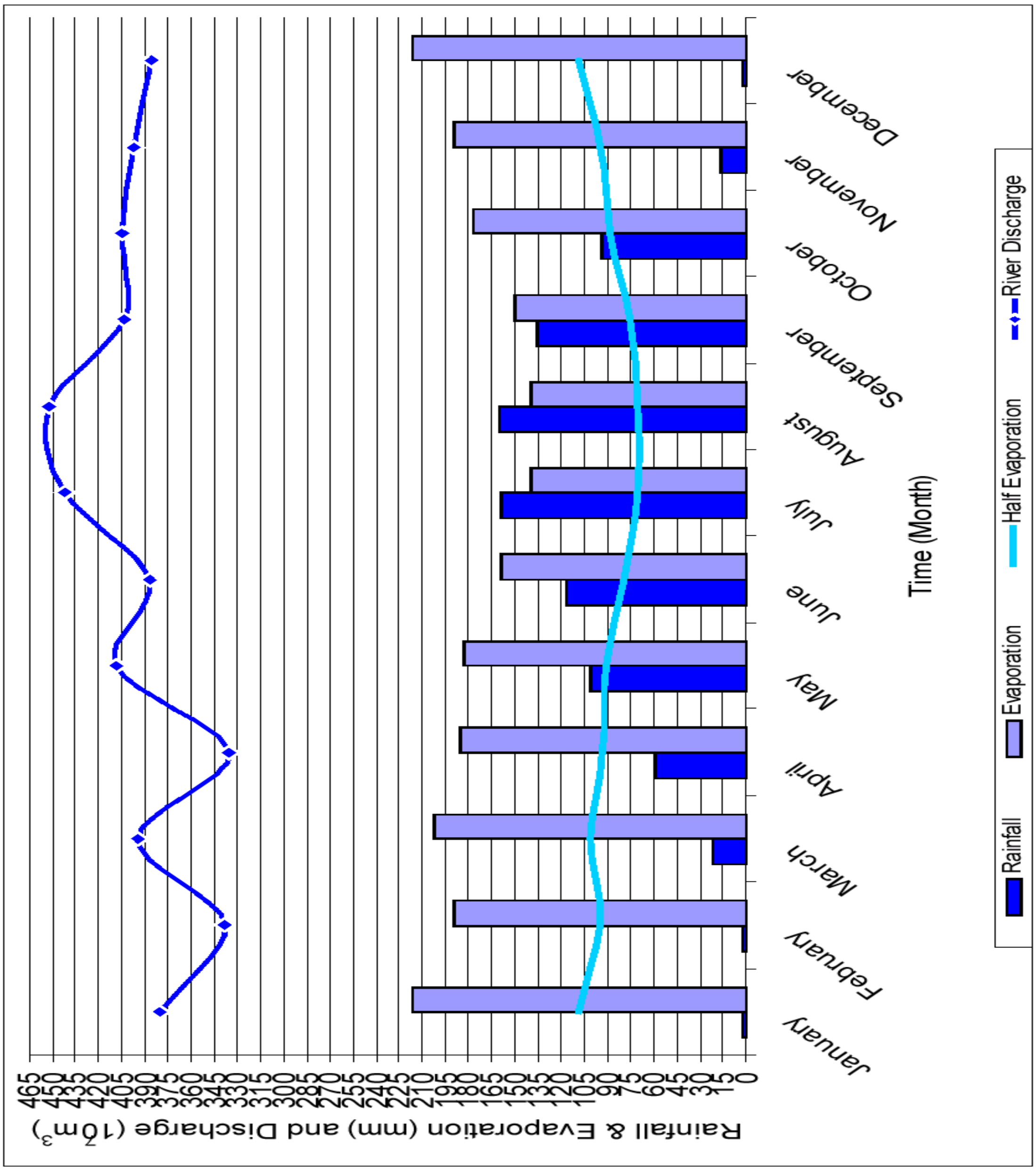
The *northern parts of Southern Sudan;* fall under Sudano-Sahelian Region, within its predominantly dry sub-humid and semiarid, with extensive grazing. From the averages for 1930 to 1960[1] (25 years), annual rainfall of this zone has declined. Hence, this zone is characterised by occurrence of dry spells, especially in the first months of the rainy season. Also, in the 2nd half of the season, the zone is characterised by heavy and stormy rains of short duration, hence the rate of precipitation greatly exceeds infiltration rate into its flatlands. In addition, these heavy rains coincide with high river inflows, resulting in an extensive flooding for long periods[2].

The *southeast and eastern parts;* fall under dry sub-humid and semiarid mountainous East Africa, with potential for tropical rain-fed annual crops.

The *southwest and western areas with good drainage conditions;* fall under the Humid Central Africa, within its predominantly moist sub-humid and humid of wide range of perennial tropical crops and extensive areas under forest.

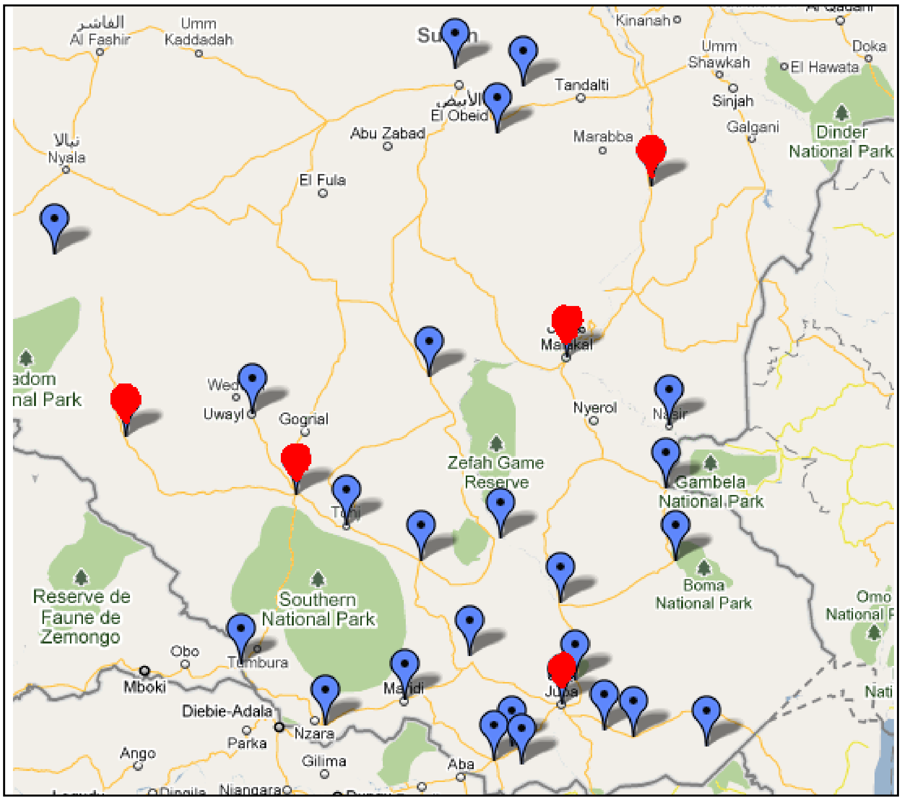
The *climate of the South in general* is seasonal with considerable annual variations, and its mean temperature is greater than 25 ^{o}C, hence generally a warm thermal zone[3]. It is characterised by single rainfall season, therefore a pattern of one growing period that becomes shorter northwards. As a result, in the semiarid and dry sub-humid zones, precipitation exceeds half the potential (or open water) evaporation for six months (see exemplary chart below), which allows for a maximum growing period of around 180 days. And in the moist sub-humid zone, precipitation exceeds half the potential evaporation for nine months, allowing for a growing period of about 270 days. But, latter reports assert that growing season in South Sudan ranges from 150 days in around the wetland plains northwards with a maximum of 850-mm/annum rainfall to 240 days in the green belt zone southwards with 1,800-mm/annum rainfall (FAO, special report on South Sudan, November, 16, 1998). Hence, a trend towards shorter single rainfall seasons that continues from the South to the North.

[1] African Agriculture in the Next 25 Years: Annex IV, Irrigation and Water Control, FAO, 1986.
[2] The zone in question mostly lies below the latitude passing through Mangalla.
[3] Harry van Velthuizen, Luc Verelst and Paolo Santacroce, Crop Production System Zones of the IGADD Sub-region, FAO Agrometeorology Working Paper Series 10, 1995.



Chart[1] of Rainfall & Evaporation over and River Discharges into Swamps and Marshes of South Sudan

[1] This chart is based on 1941-1970 average rainfall (mm), derived from monthly rainfall records at 8 stations between Mangalla and Malakal; 1963 open water evaporation (mm), estimated from records of mean monthly and annual meteorological data at Bor; and 1980 Bahr el-Jebel discharges at Mongalla.



Working Gauges	Abandon Gauges

Fig.2.1: Rain Gauging Stations with the Five Operating Stations

The main source of metrological data is the Civil Aviation, which is under the Ministry of Transport. Until the late seventies, there used to be a meteorological network across the country well distributed all over South Sudan. Unfortunately, the network has suffered great deterioration over the past few decades and the number of working stations in the whole country is now not more than 5 stations. Indeed, the number of stations in was 29 but most of them have stopped functioning during the eighties, and only five of these stations are currently working (Fig.2.1). The stations that are currently working and have up to data information in digital format are given in the table 2.1 below.

Table 2.1: Meteorological Stations with up to-date Data

Station	Starting year
Wau	1921
Malakal	1937
Juba	1925
Renk	1937
Raja	1928

The parameters that are measured are rainfall, evaporation, temperature, relative humidity, soil moisture, sunshine hours and wind speed and direction.

2.1.2 Terrain suitability

The terrain slope is a key characteristic for assessing the irrigation potential. Steeper slopes evidently are less suitable for irrigation. Different types of irrigation also have different associated slope suitability. Three different irrigation types are included in the suitability analysis: border/furrow, sprinkler irrigation, drip irrigation, and hill-side irrigation (see main report). The base of this analysis is the digital elevation model of the 90-meters SRTM. This DEM was used to derive slopes and to undertake the suitability analysis.

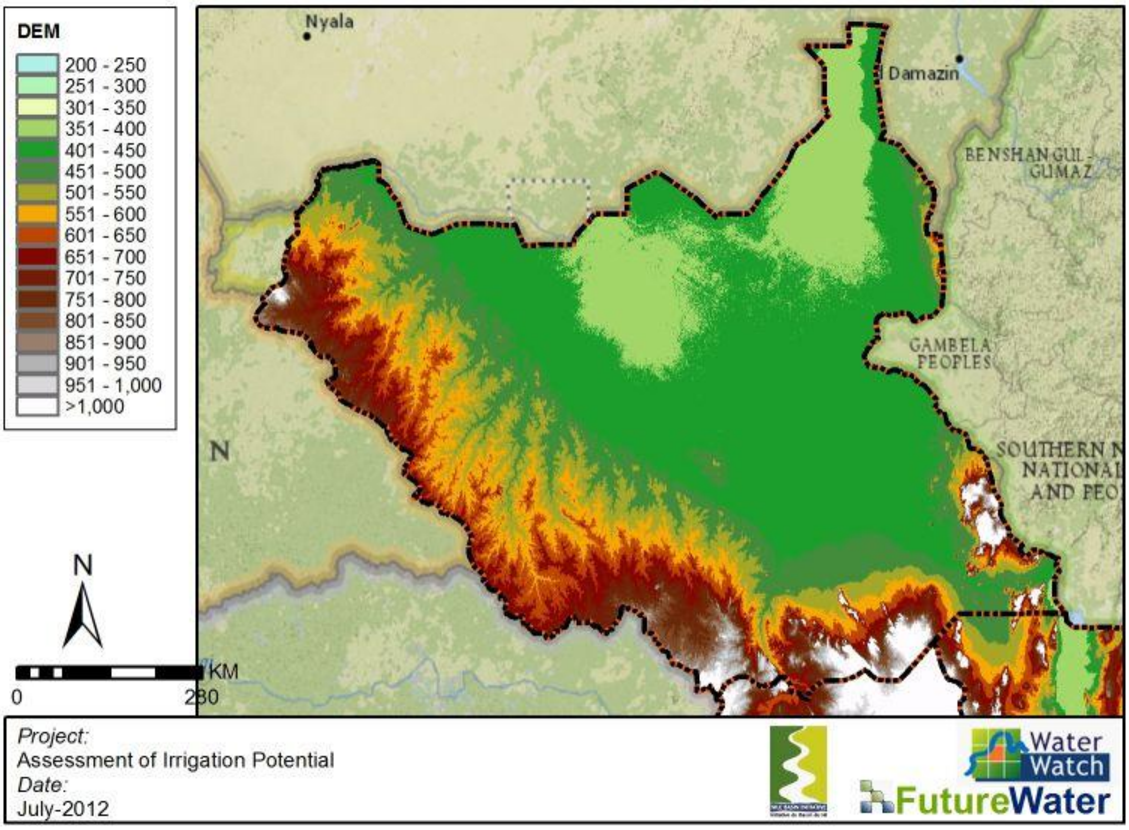
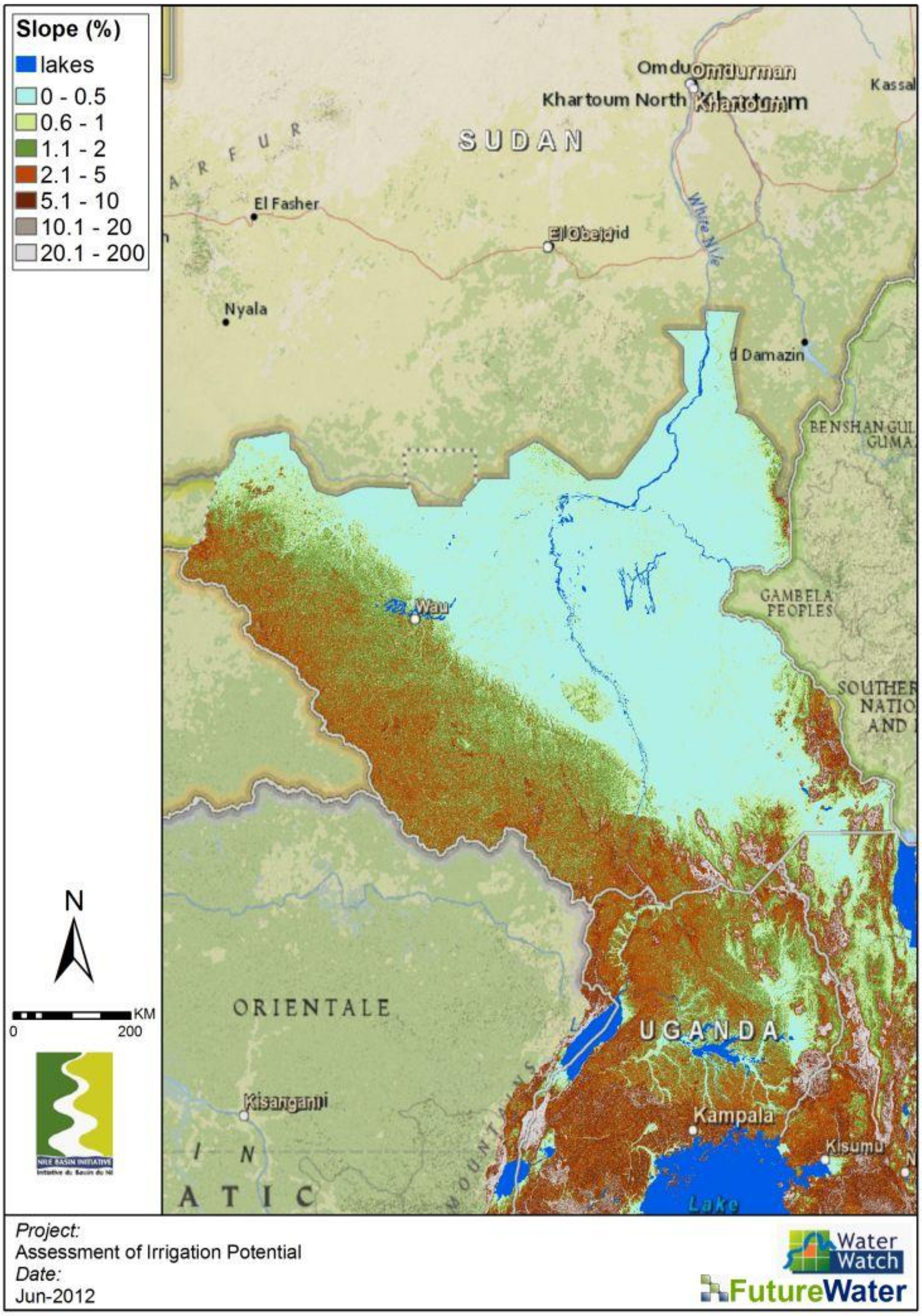
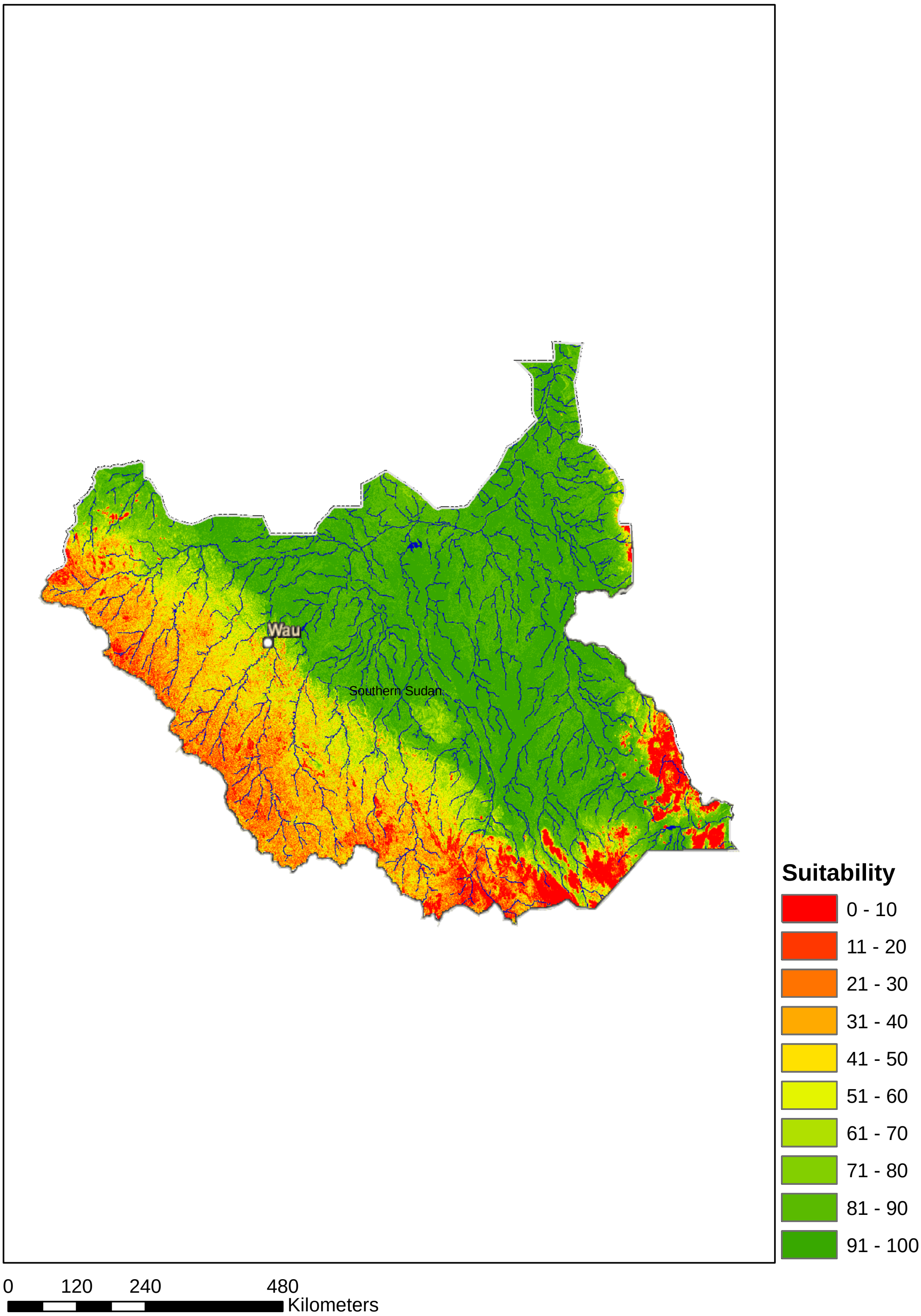


Figure 2.2: Digital Elevation Model of South Sudan. (Source: ASTER)

In Figure 2.2 the DEM for South Sudan is shown. The country is characterized by quite extensive flatlands with some hills and mountains (south-west and south-east), resulting in lower elevations in the eastern, central and northern parts. Associated slopes can be seen in Figure . Based on these slope classes for each of the three irrigation types, suitability for irrigation has been determined. It is clear that because of the mild slopes, most type of irrigation can be applied across the country.


Slope (%)
lakes
0 - 0.5
0.6 - 1
1.1 - 2
2.1 - 5
5.1 - 10
10.1 - 20
20.1 - 200
N
KM
0
200
SUDAN
Omdurman
Khartoum North
Khartoum
Kassal
El Fasher
El Obeid
Nyala
White Nile
Damazin
BENSHANGUL GUMA
Wau
GAMBELA PEOPLES
SOUTHER NATIO AND
ORIENTALE
UGANDA
Kisangani
Kampala
Kisumu
Lake
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater



Wau
Southern Sudan
Suitability
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
0
120
240
480
Kilometers

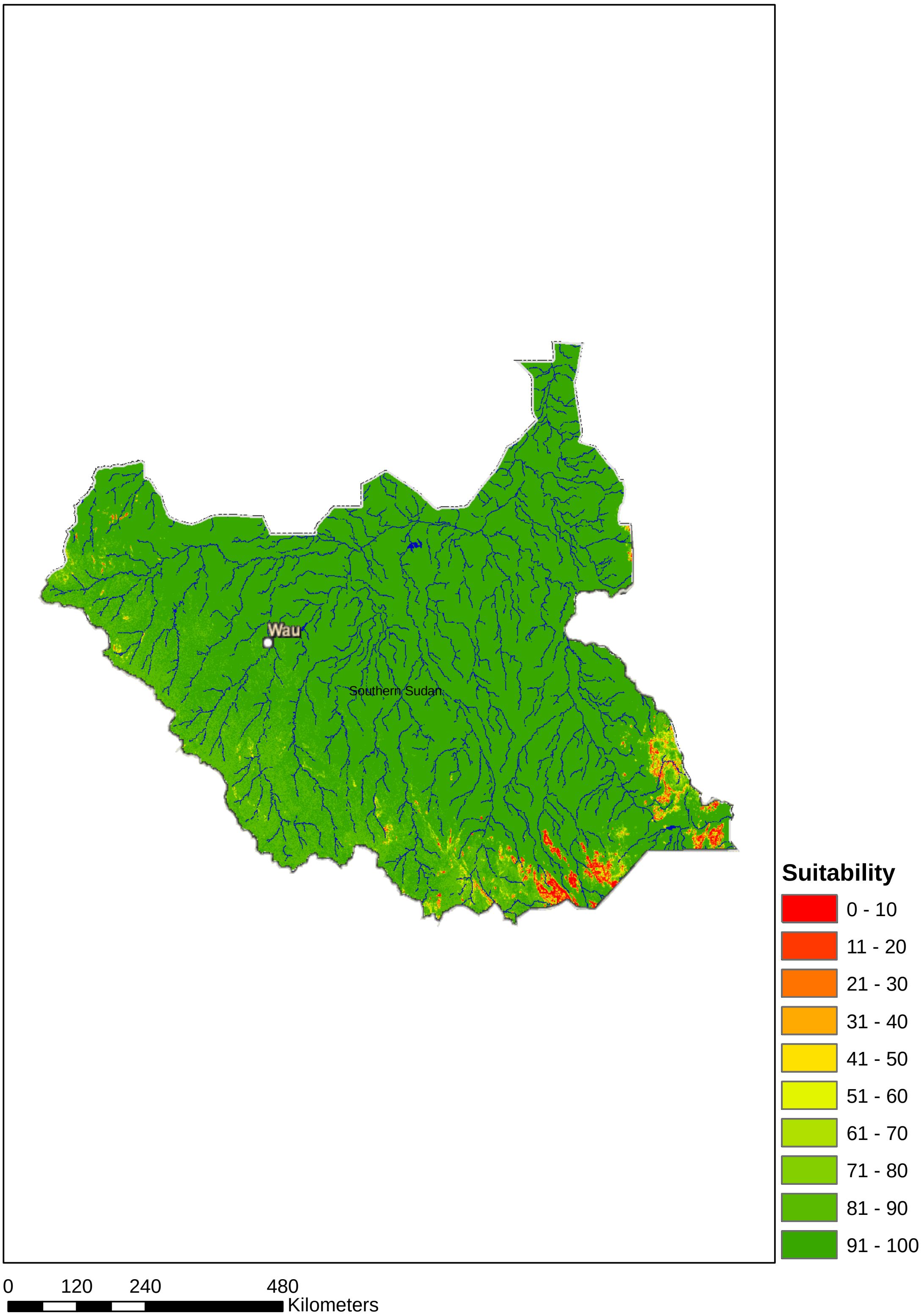


Figure 3: Terrain slope as percentage (top), surface irrigation (middle), and drip irrigation (bottom).

2.1.3 Soil Suitability

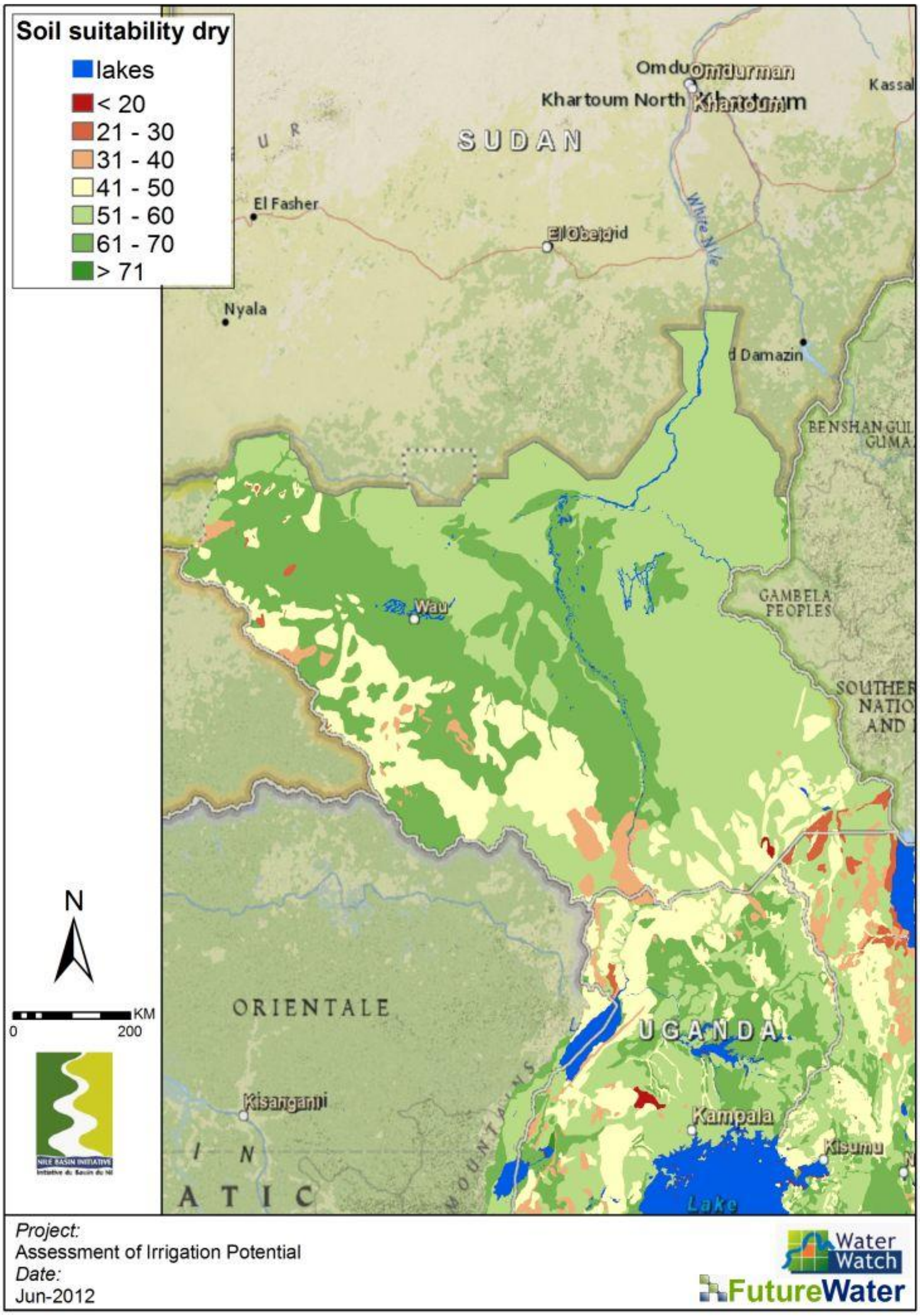
Based on local soil maps as combined in the Harmonized World Soil Database (HWSD) soil suitability for irrigation has been assessed based on the FAO methodology (for details, see main report). The following characteristics are included in the soil suitability assessment:
(i) organic carbon, (ii) soil water holding capacity, (iii) drainage capacity, (iv) soil texture, (v) pH, and (vi) soil salinity. Given the quite different characteristics for rice crops, two suitability maps were created.

The soils of the southern Sudan fall into two major groups; the soils of the alluvial clay plains and the soils of the lateritic zone.

In the former group alkaline clays and heavy loams predominate. The soil depth is never a limiting factor and erosion is practically absent. The nutrient status of these soils is high and signs of nutrient deficiency are uncommon. The full agricultural potential of these soils cannot, however, be utilized without control of moisture conditions. In the Central Rainlands lack of moisture is the main limiting factor, and without irrigation optimal yields cannot be expected. In the Flood Region both lack and excess of moisture limit the agricultural potential of clay soils. Here drainage as well as irrigation is essential in order to utilize fully their inherent fertility. The sandy soils which occur in isolated patches on the plains are in general less fertile, but are often intensively cultivated because their tillage is much easier, and in the Flood Region they are less liable to waterlogging.

In the areas where lateritic soils occur the rainfall is higher and better distributed, the topography is more undulating, and soils are generally lighter and characterized by free drainage. Their moisture regime is therefore more favourable for crops, though on sandy loams with low moisture-retention capacity plants often suffer from drought conditions. The nutrient status of these soils is definitely inferior to that of the alluvial clays. The nutrients tend to accumulate under the natural vegetation in the surface soil and are quickly lost under cultivation by leaching and erosion. In many parts of the Equatorial Region erosion is serious and results in shallow 'truncated' soils of very low fertility.

Source: Natural Resources and Development potential in South Sudan, 1954



Soil suitability dry
lakes
< 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
> 71
SUDAN
Khartoum North
El Fasher
Nyala
Wau
GAMBELA PEOPLES
ORIENTALE
UGANDA
Kisangani
Kampala
Kisumu
N
KM
0
200
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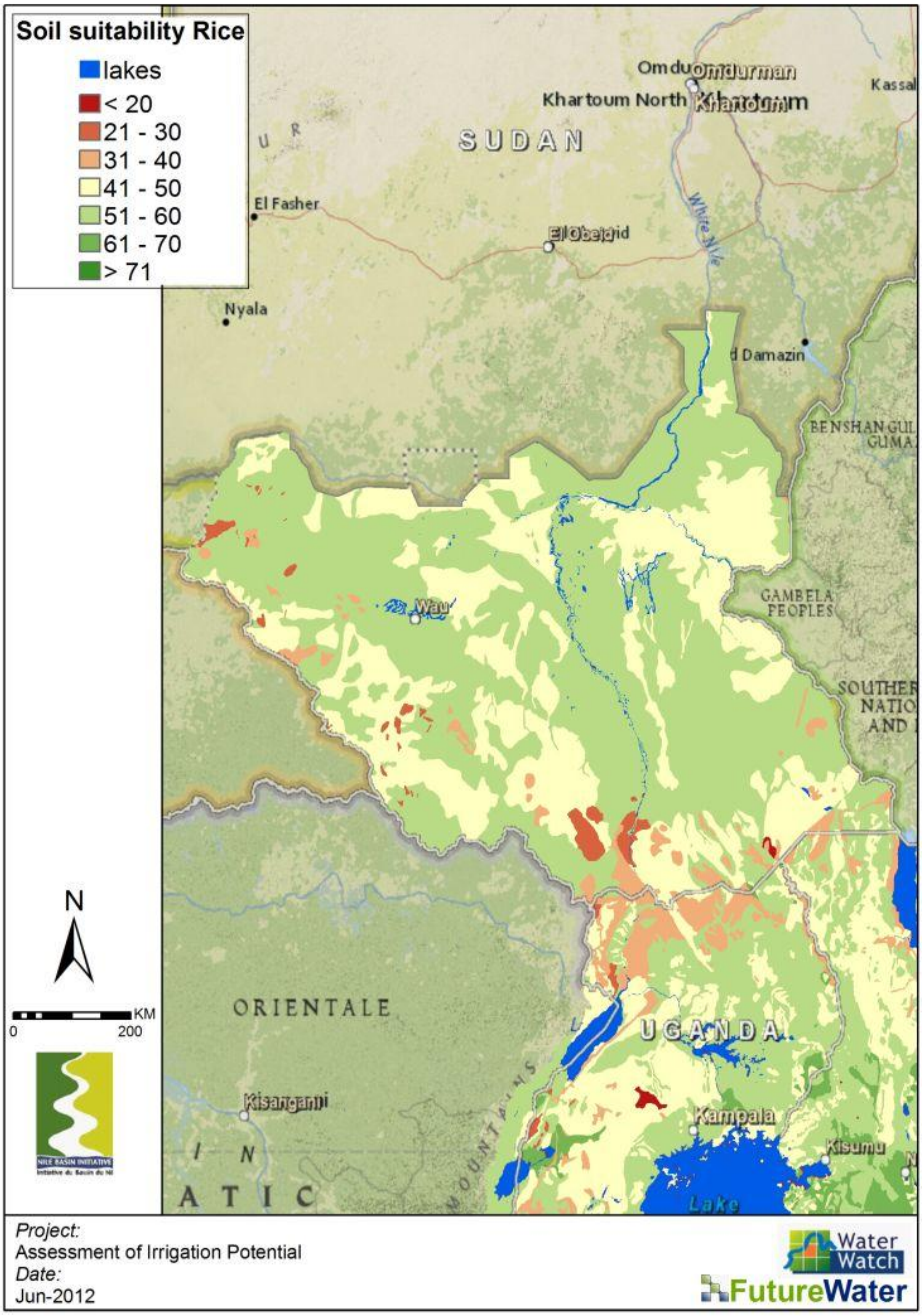


Figure.3: Soil suitability for dry crops (top) and rice/paddy (bottom)

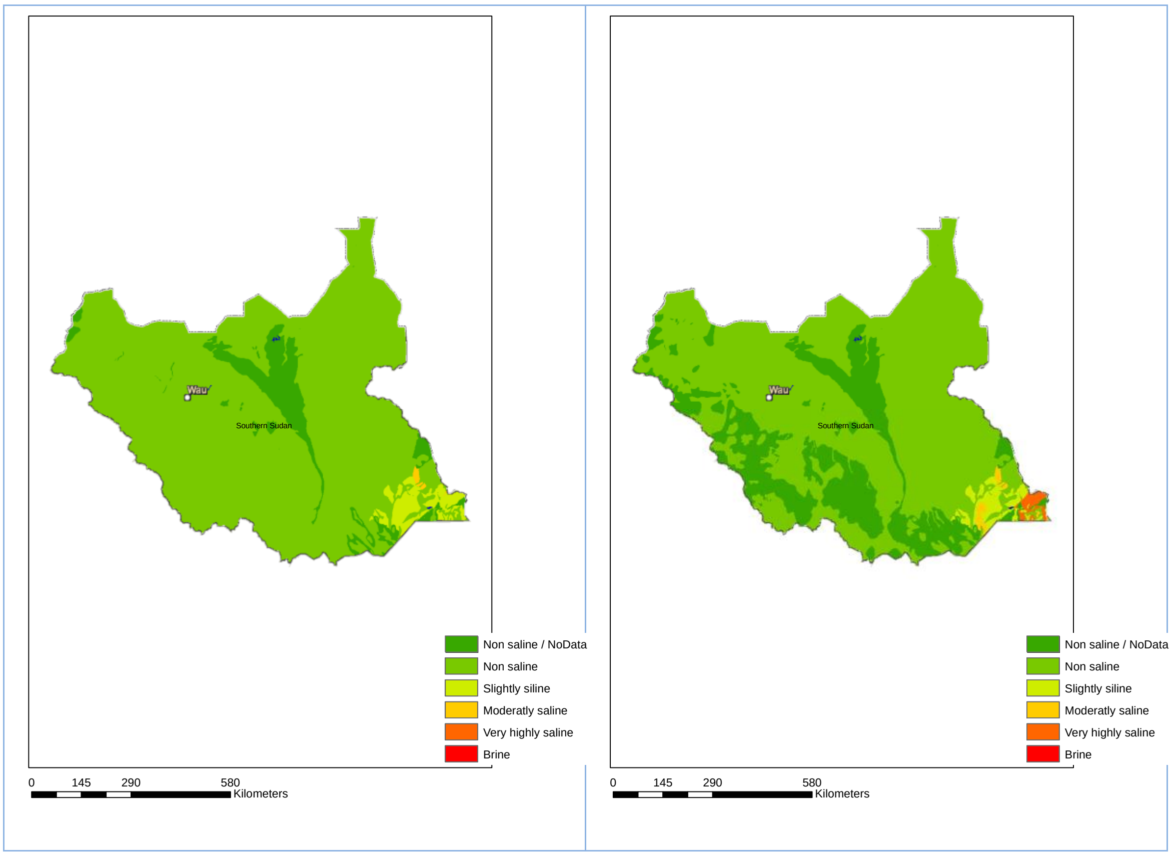


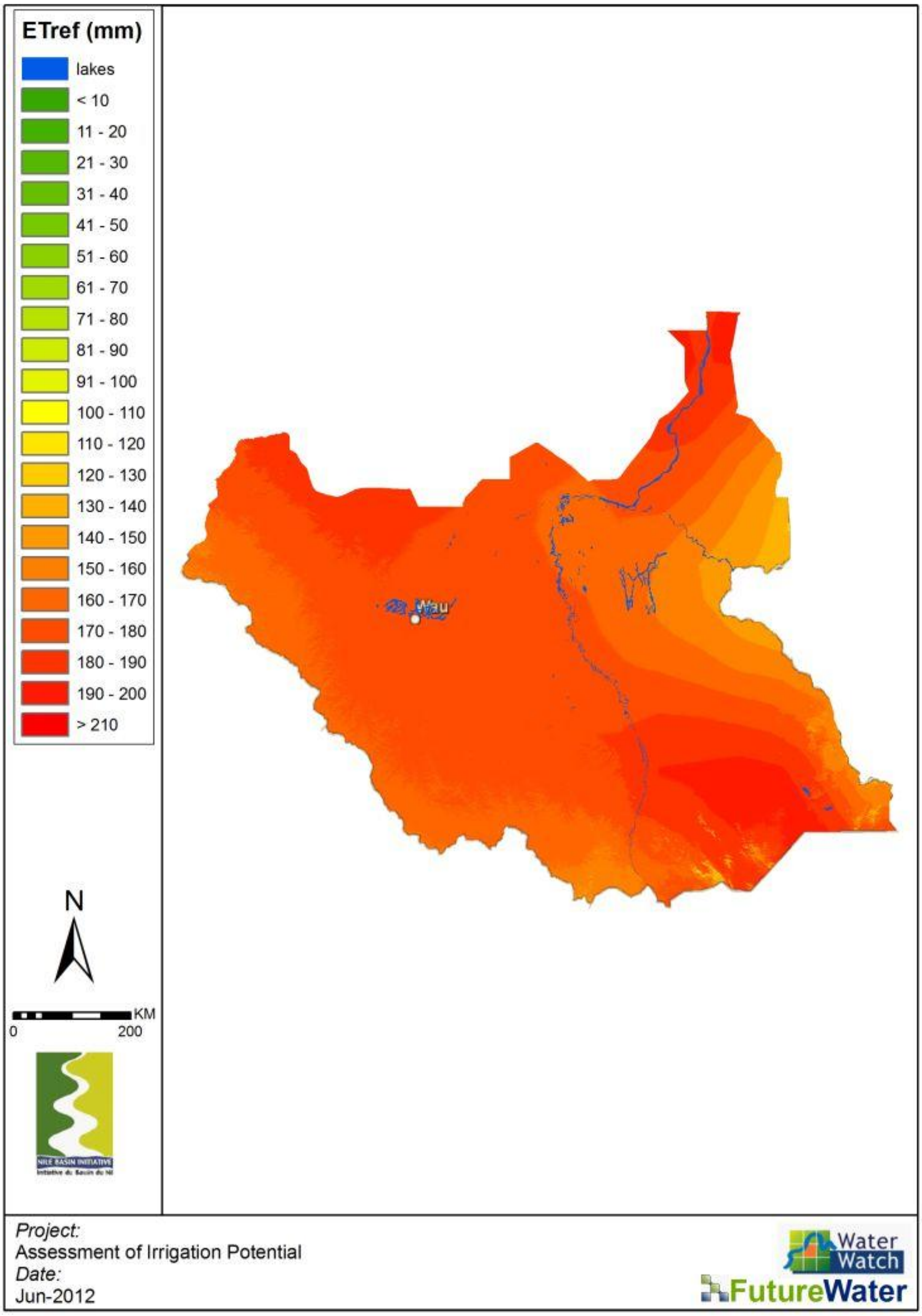
Figure 4: Salinity, top-soil (left) and sub-soil (right)

2.2 Water

2.2.1 Irrigation water requirements

The amount of water needed during a growing season depends on the crop, yield goal, soil, temperature, solar radiation, and other bio-physical factors. The amount of water required for irrigation is also a function of rainfall and irrigation efficiencies. During Phase 1 of this study the irrigation water requirements are based on an innovative method using satellite information (see main report for details). The following maps provide for each month the reference evapotranspiration (= evaporative demand of the atmosphere), the actual evapotranspiration under current conditions and the final irrigation water requirements.

January


ETref (mm)
lakes
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11 - 20
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31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
100 - 110
110 - 120
120 - 130
130 - 140
140 - 150
150 - 160
160 - 170
170 - 180
180 - 190
190 - 200
> 210
Wau
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KM
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200
Project:
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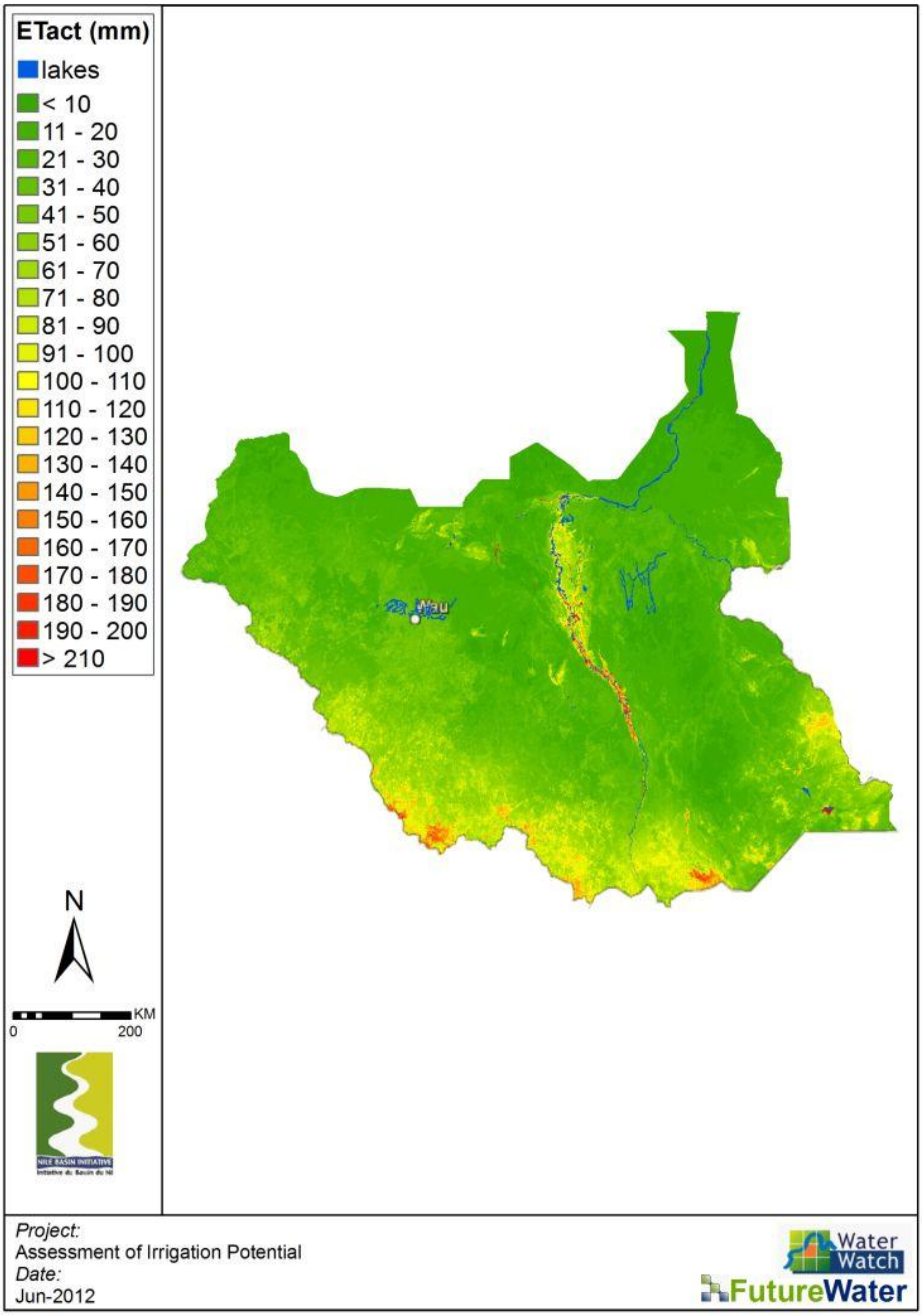
FutureWater


ETact (mm)
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31 - 40
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81 - 90
91 - 100
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110 - 120
120 - 130
130 - 140
140 - 150
150 - 160
160 - 170
170 - 180
180 - 190
190 - 200
> 210
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200
Project:
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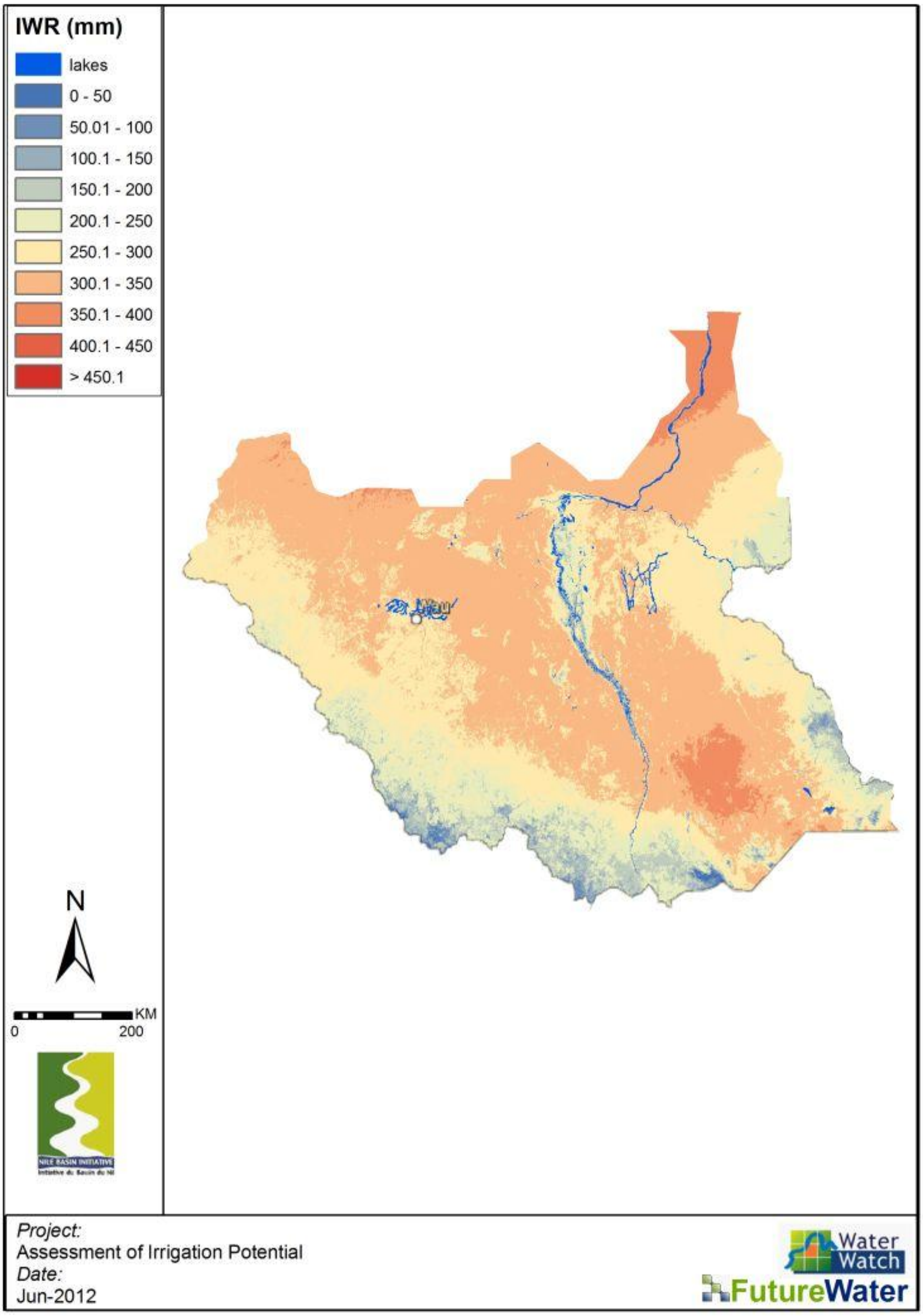
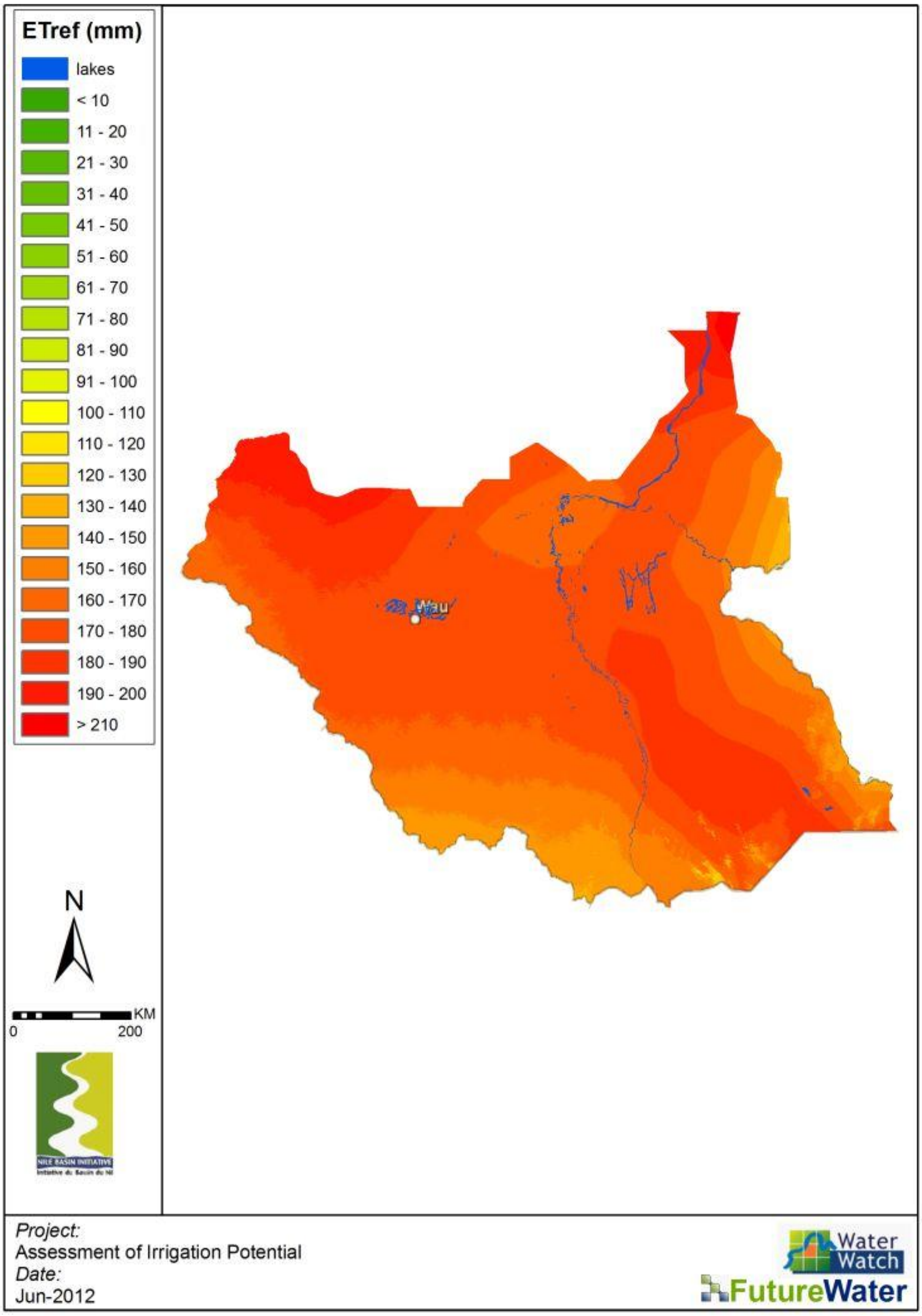


Figure 5: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). for January (Average 2001-2010). (Source: study analysis).

February



ETref (mm)
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Project:
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Jun-2012
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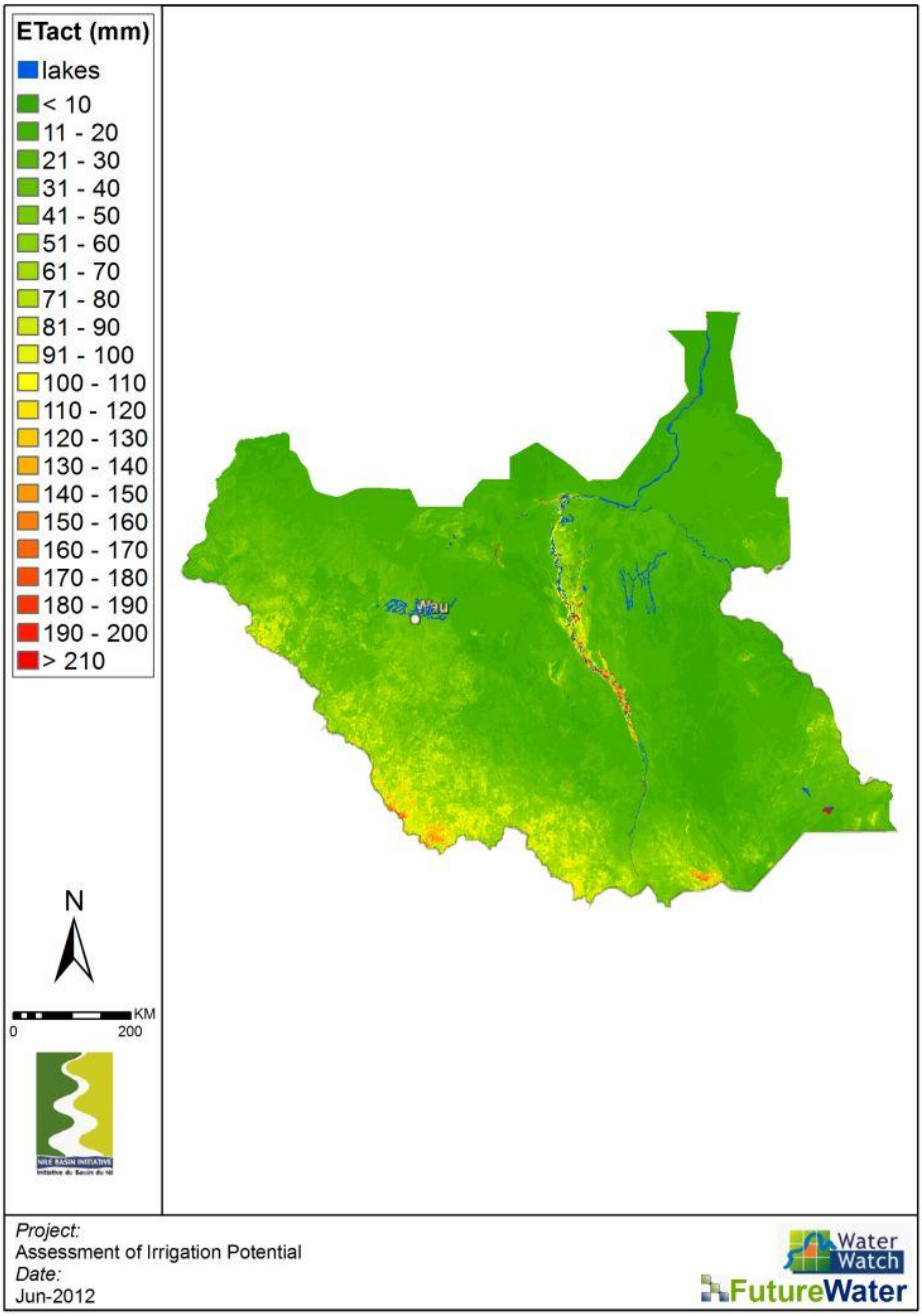
FutureWater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Assessment of Irrigation Potential
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FutureWater

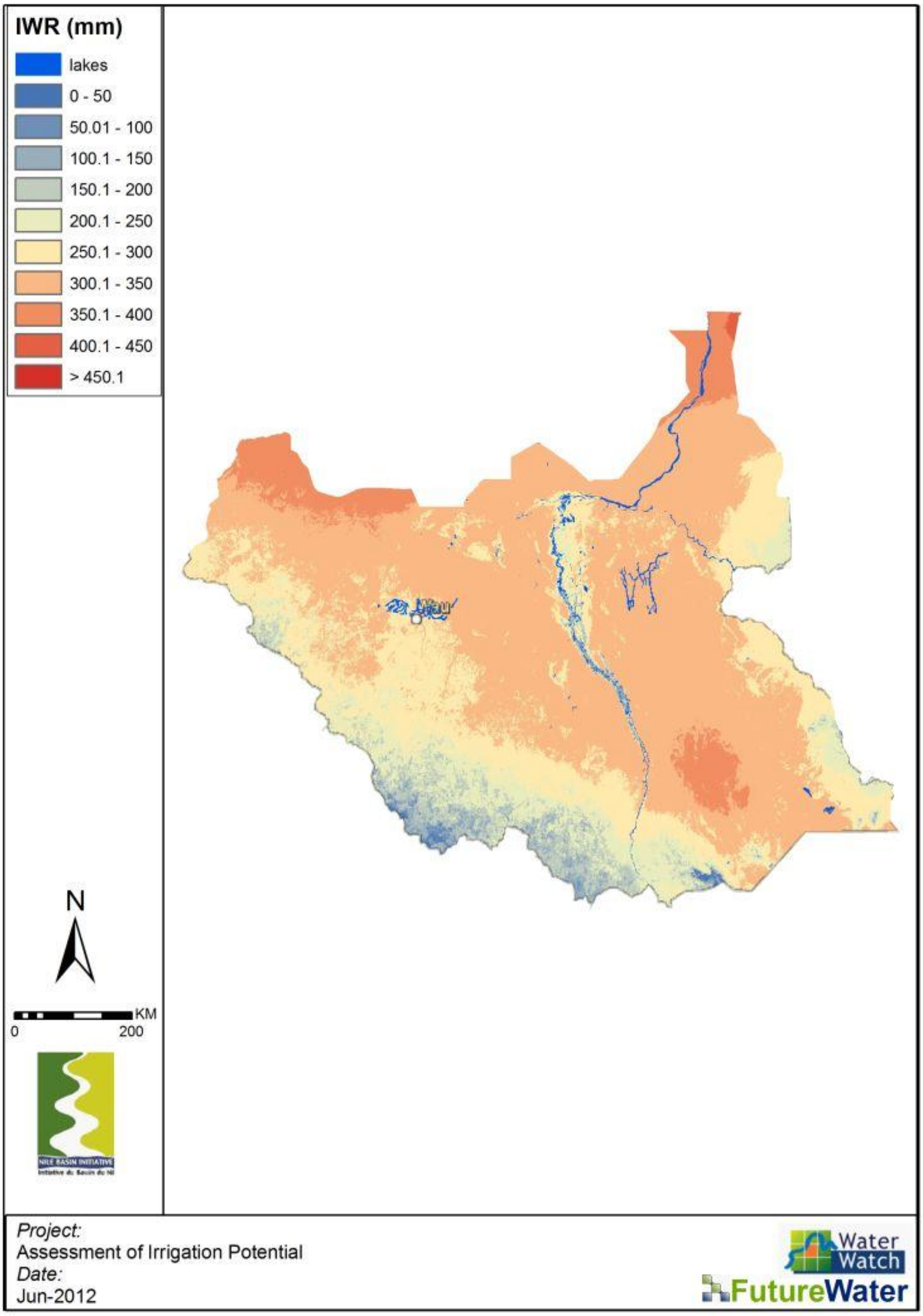
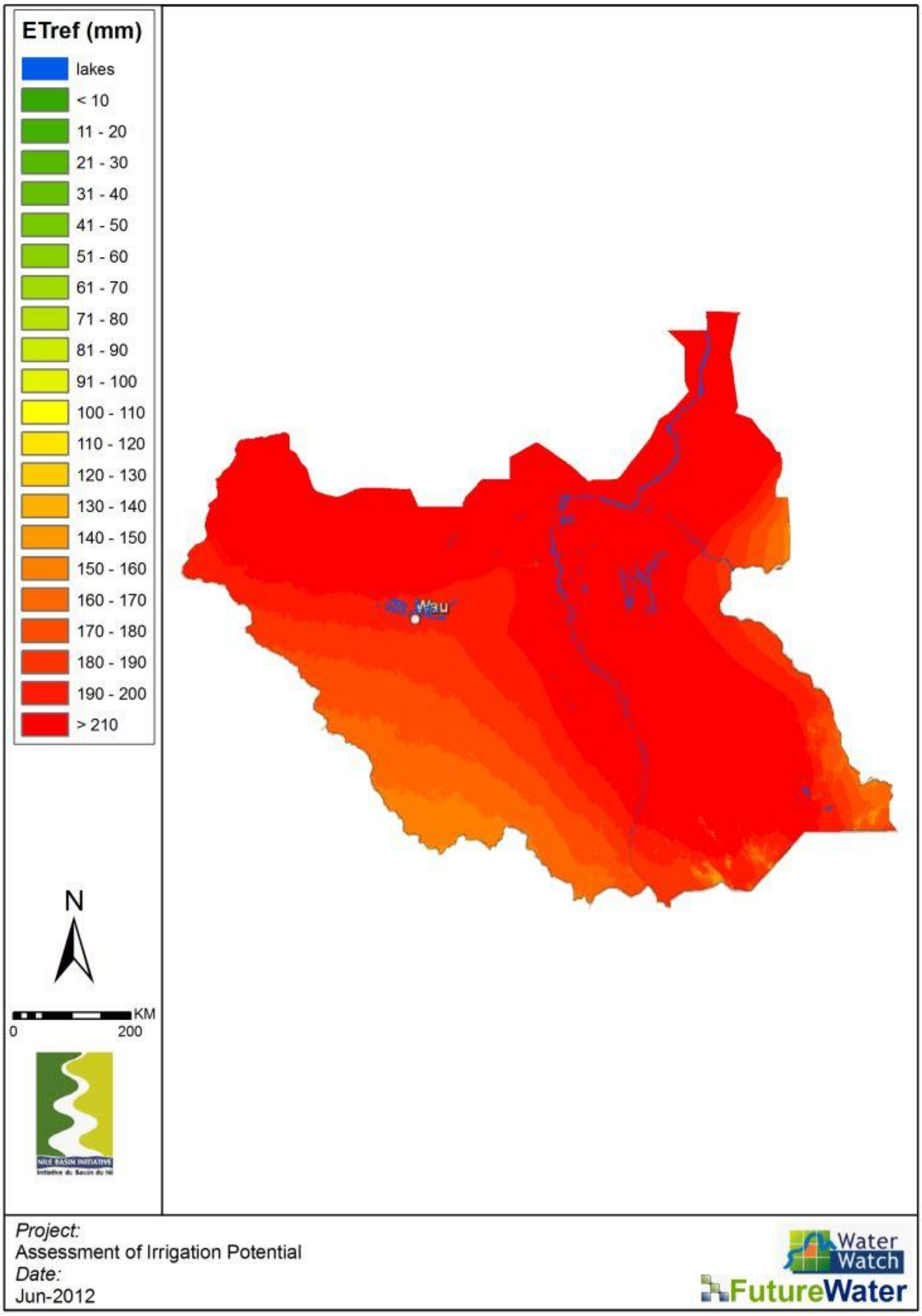


Figure 6: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). for February (Average 2001-2010). (Source: study analysis).

March



ETref (mm)
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Assessment of Irrigation Potential
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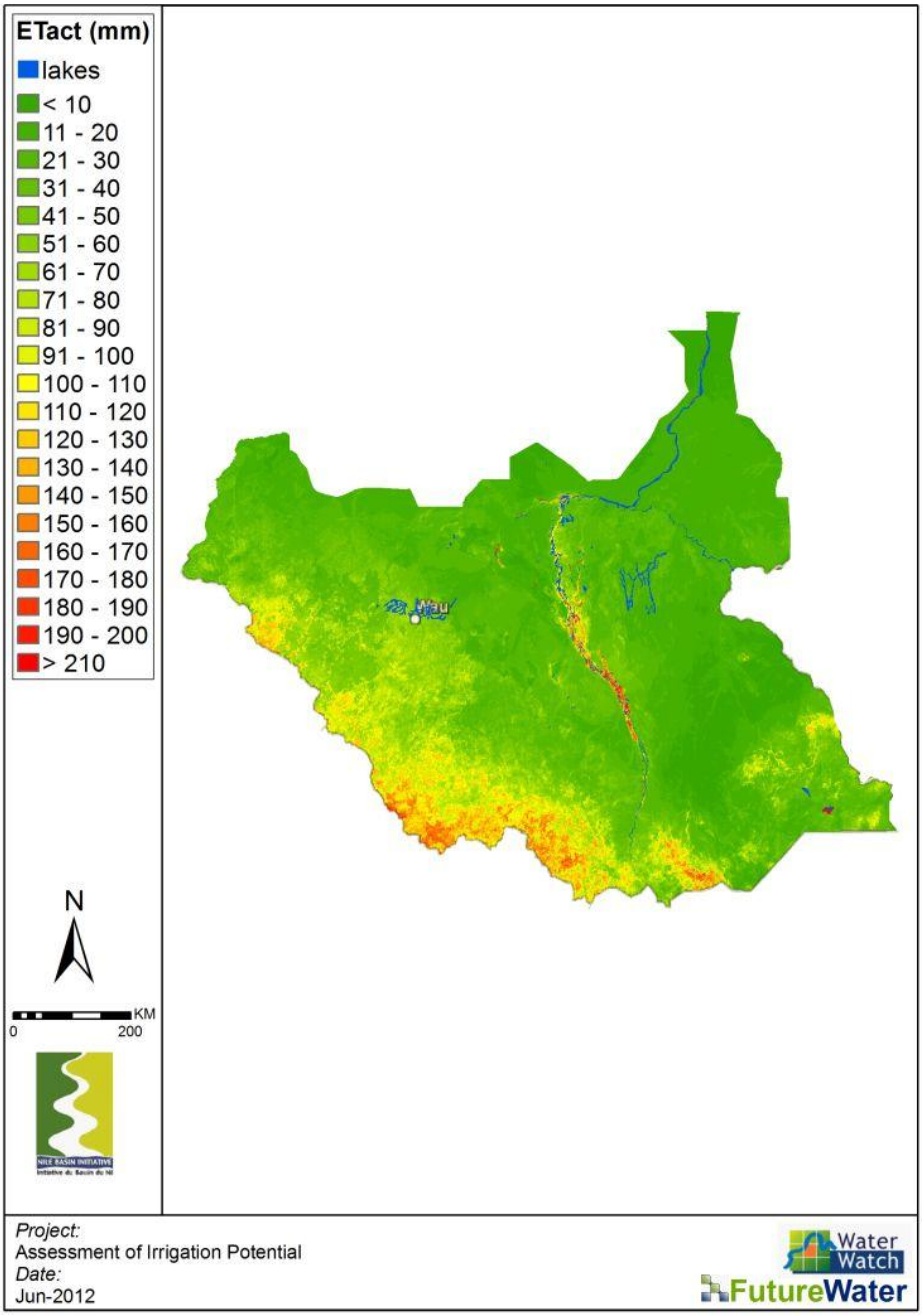
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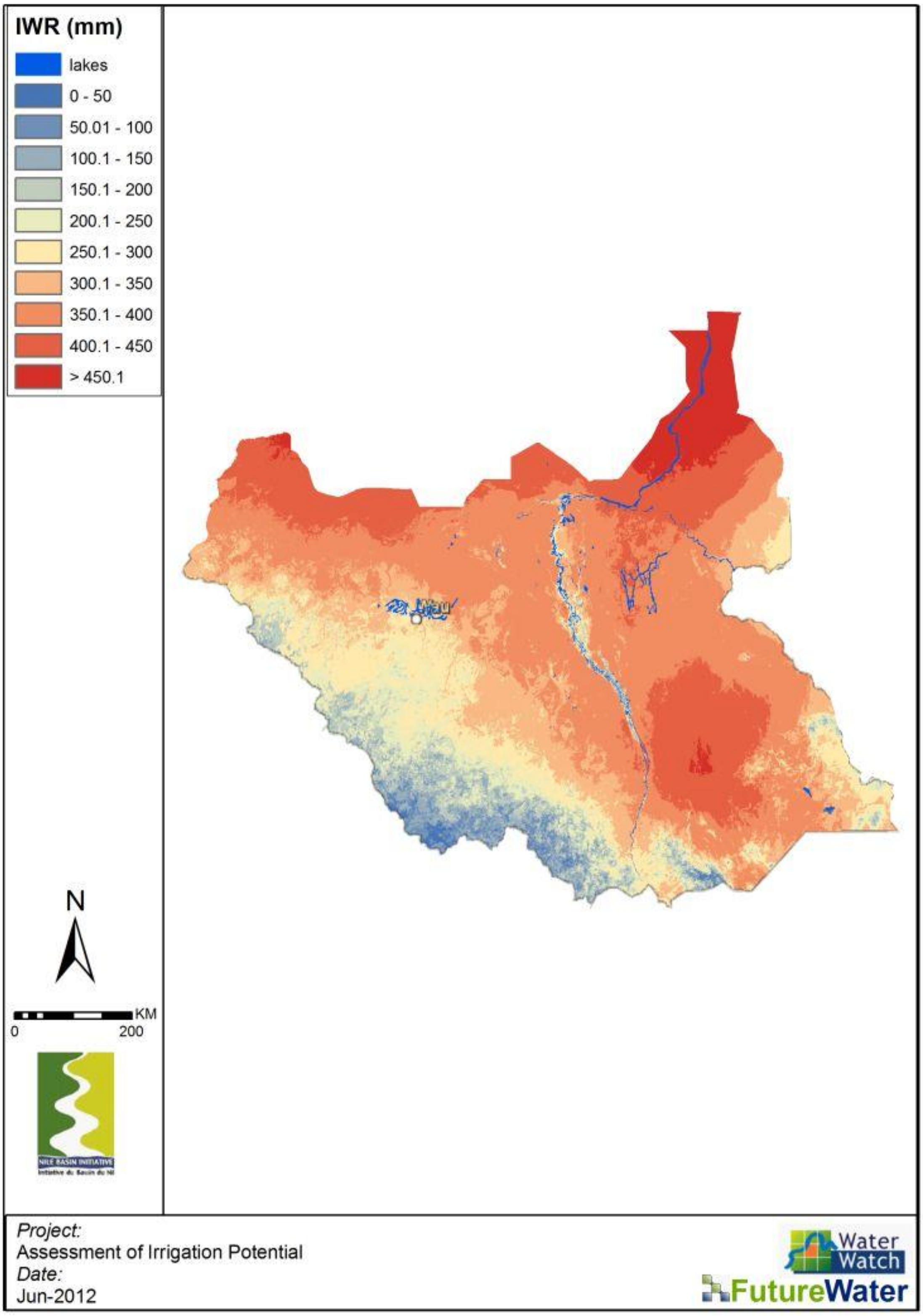
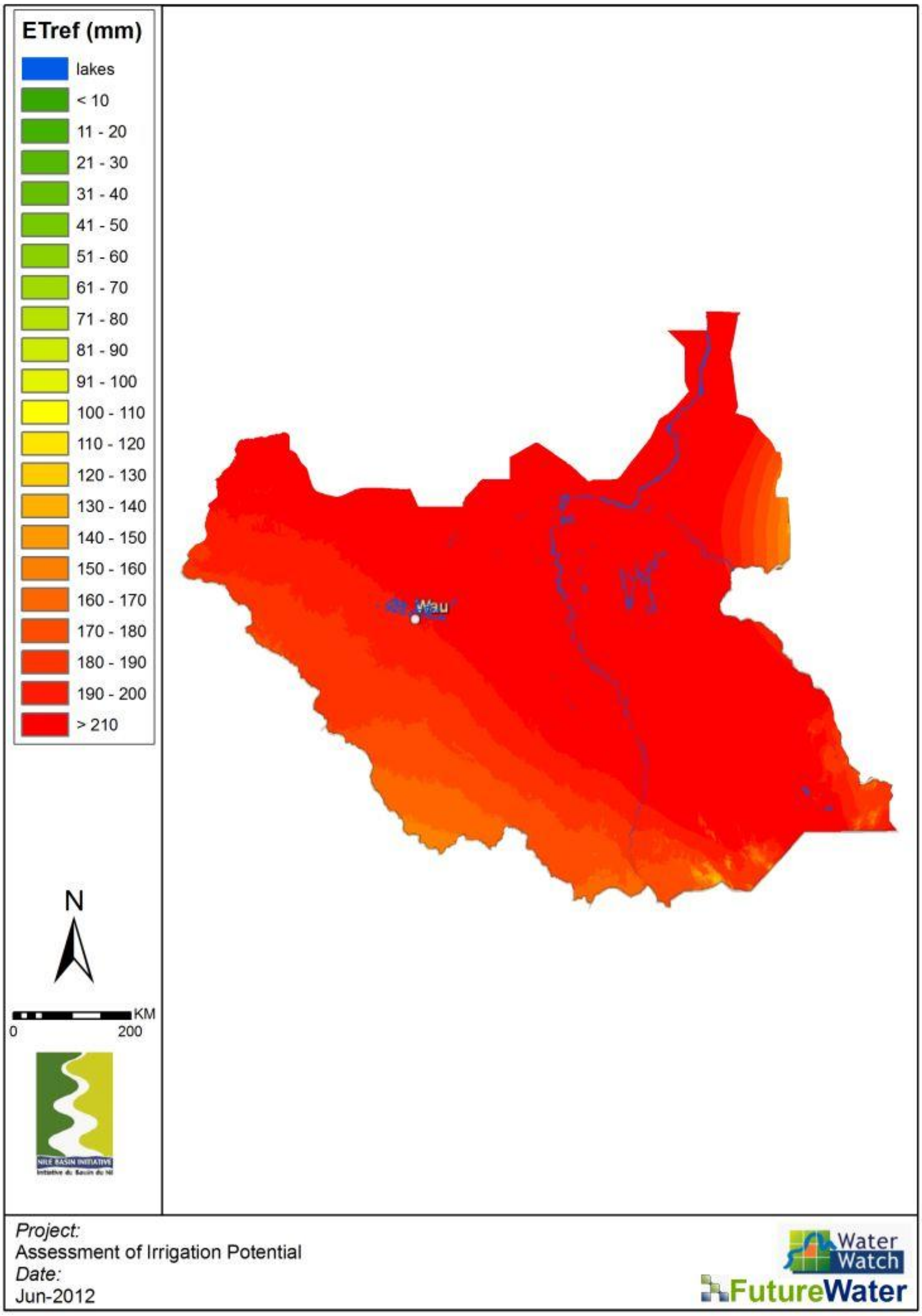


Figure 7: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). for March (Average 2001-2010). (Source: study analysis).

April



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Assessment of Irrigation Potential
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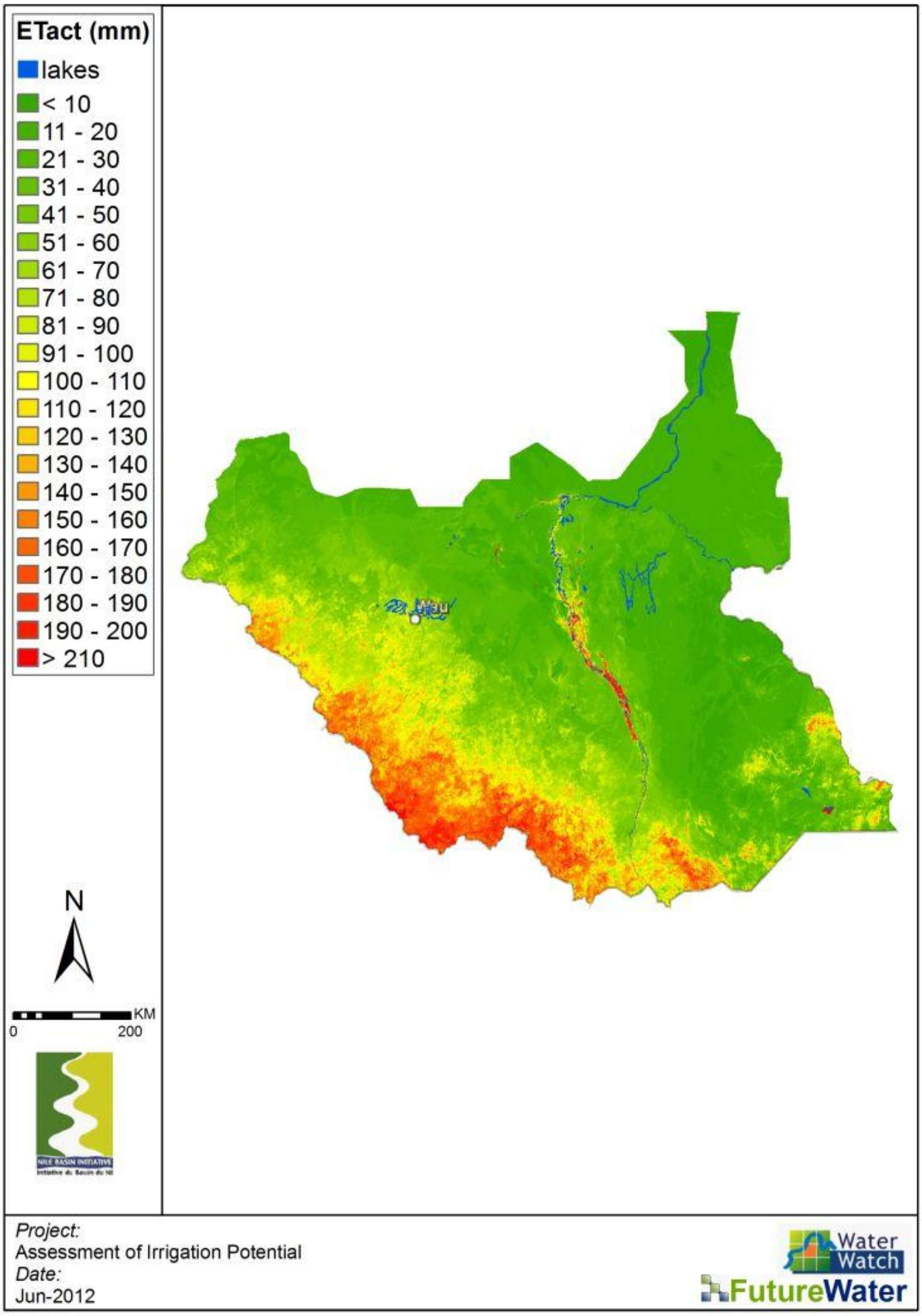
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Assessment of Irrigation Potential
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Jun-2012
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FutureWater

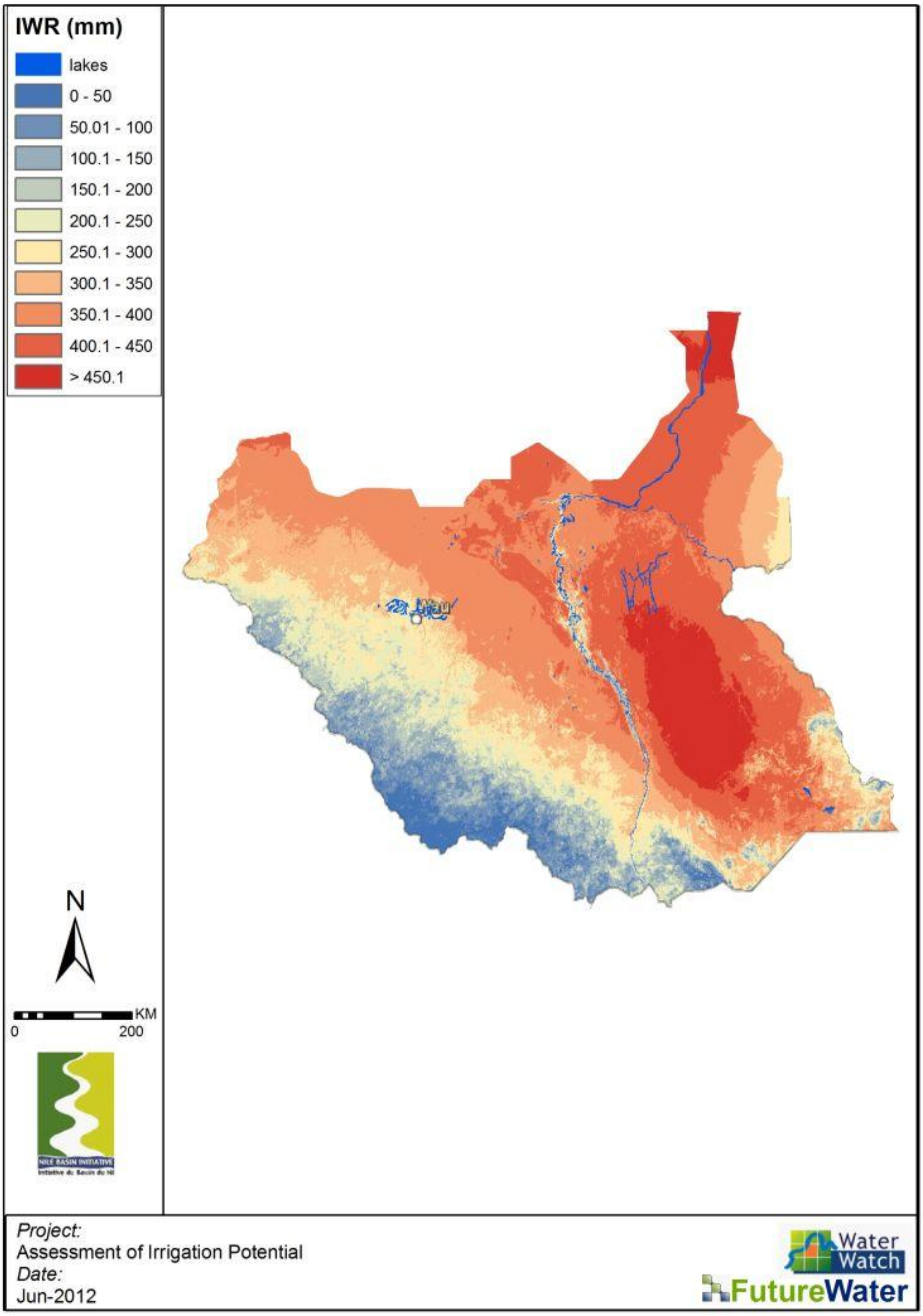
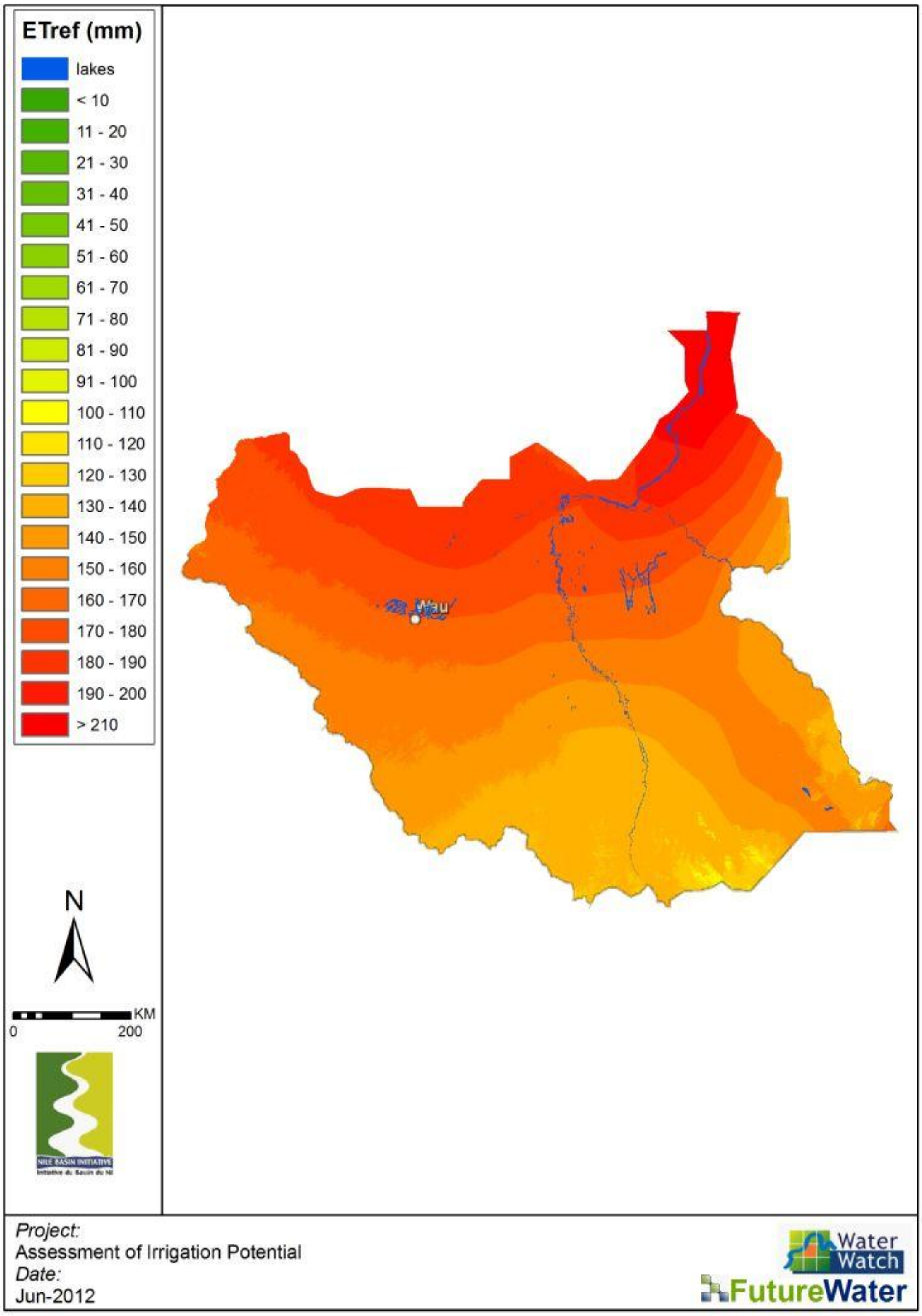


Figure 8: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). for April (Average 2001-2010). (Source: study analysis).

May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Project:
Assessment of Irrigation Potential
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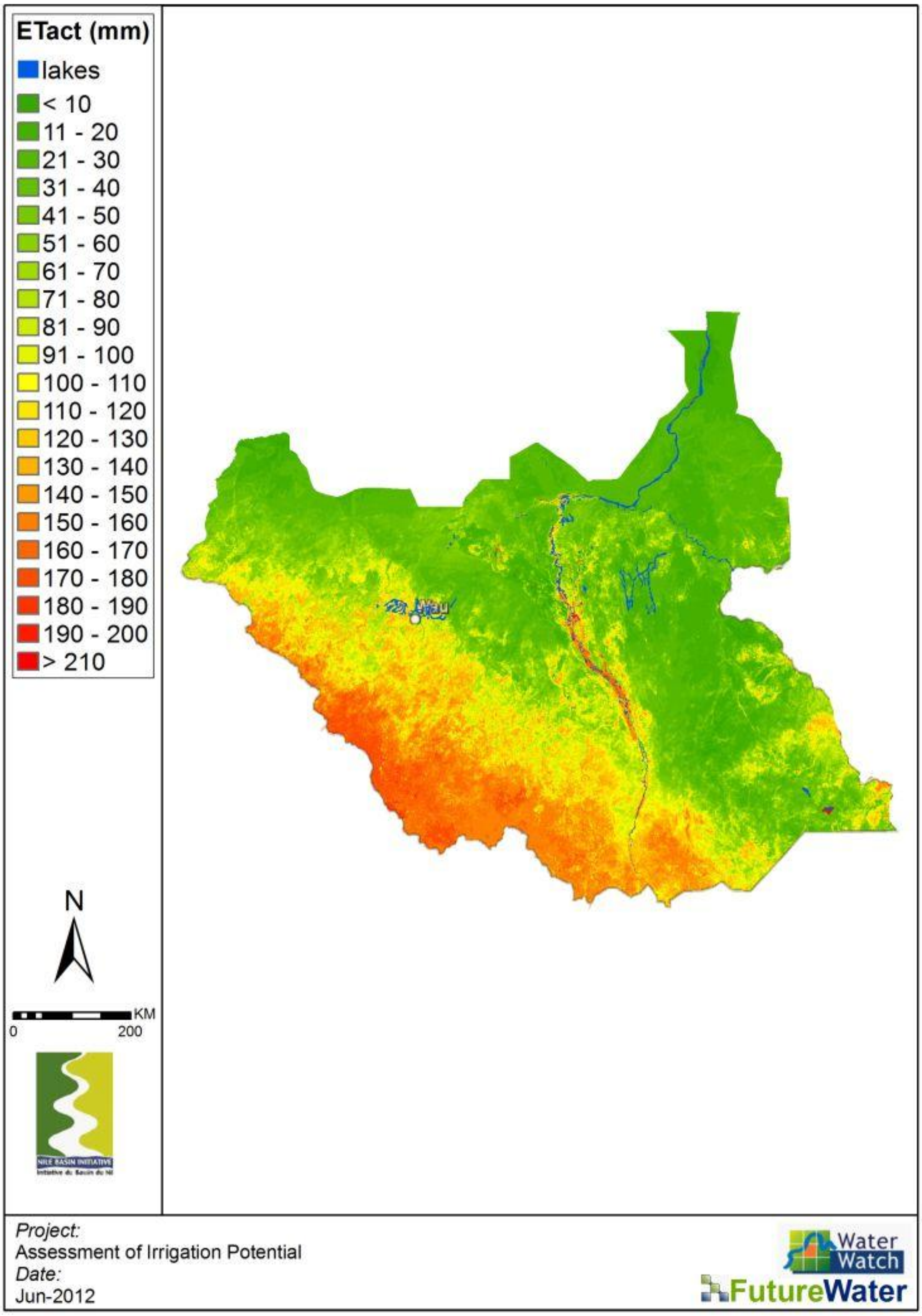
FutureWater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Assessment of Irrigation Potential
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Jun-2012
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FutureWater

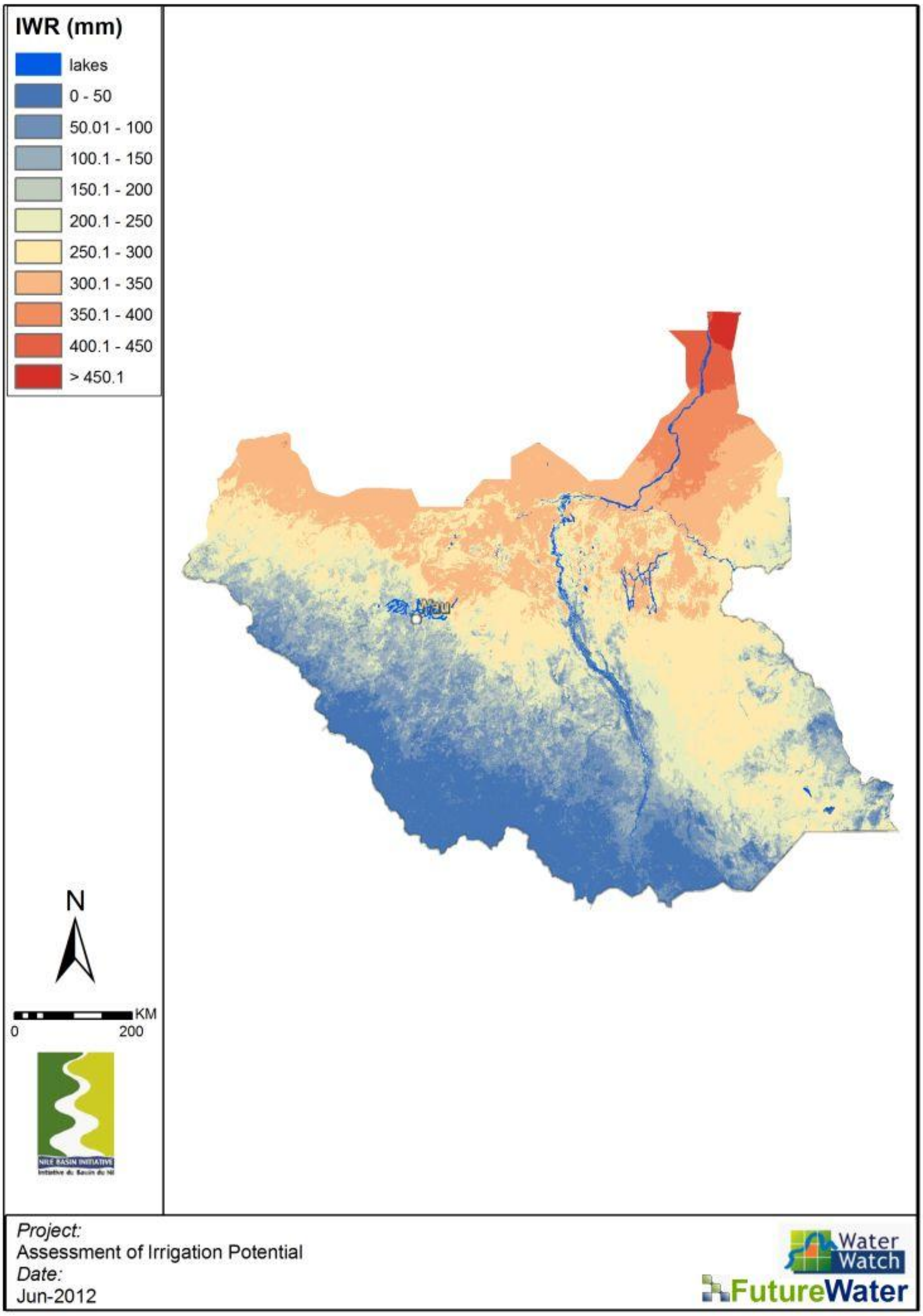
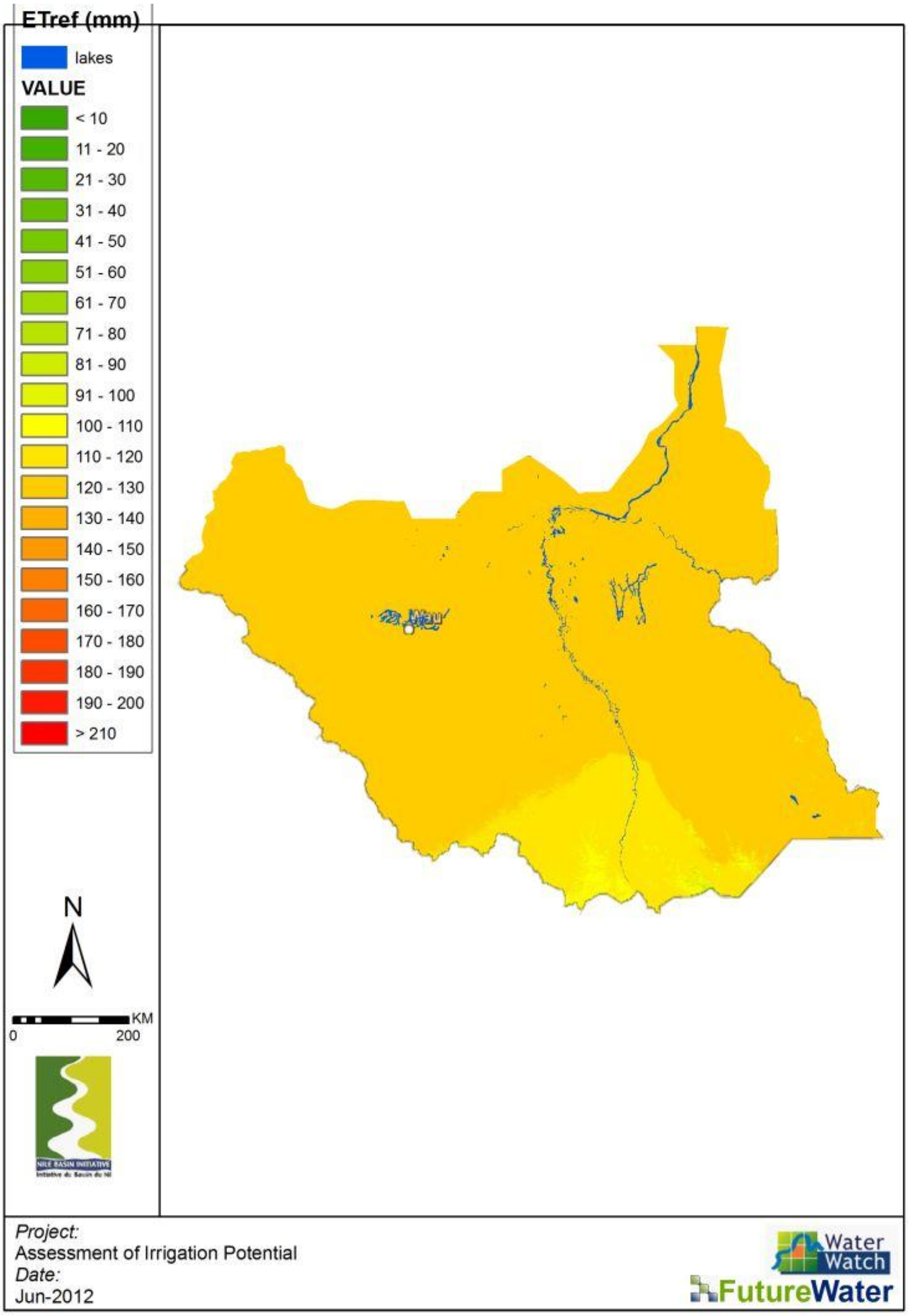


Figure9: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for May (Average 2001-2010). (Source: study analysis).

June


ETref (mm)
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Assessment of Irrigation Potential
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Jun-2012
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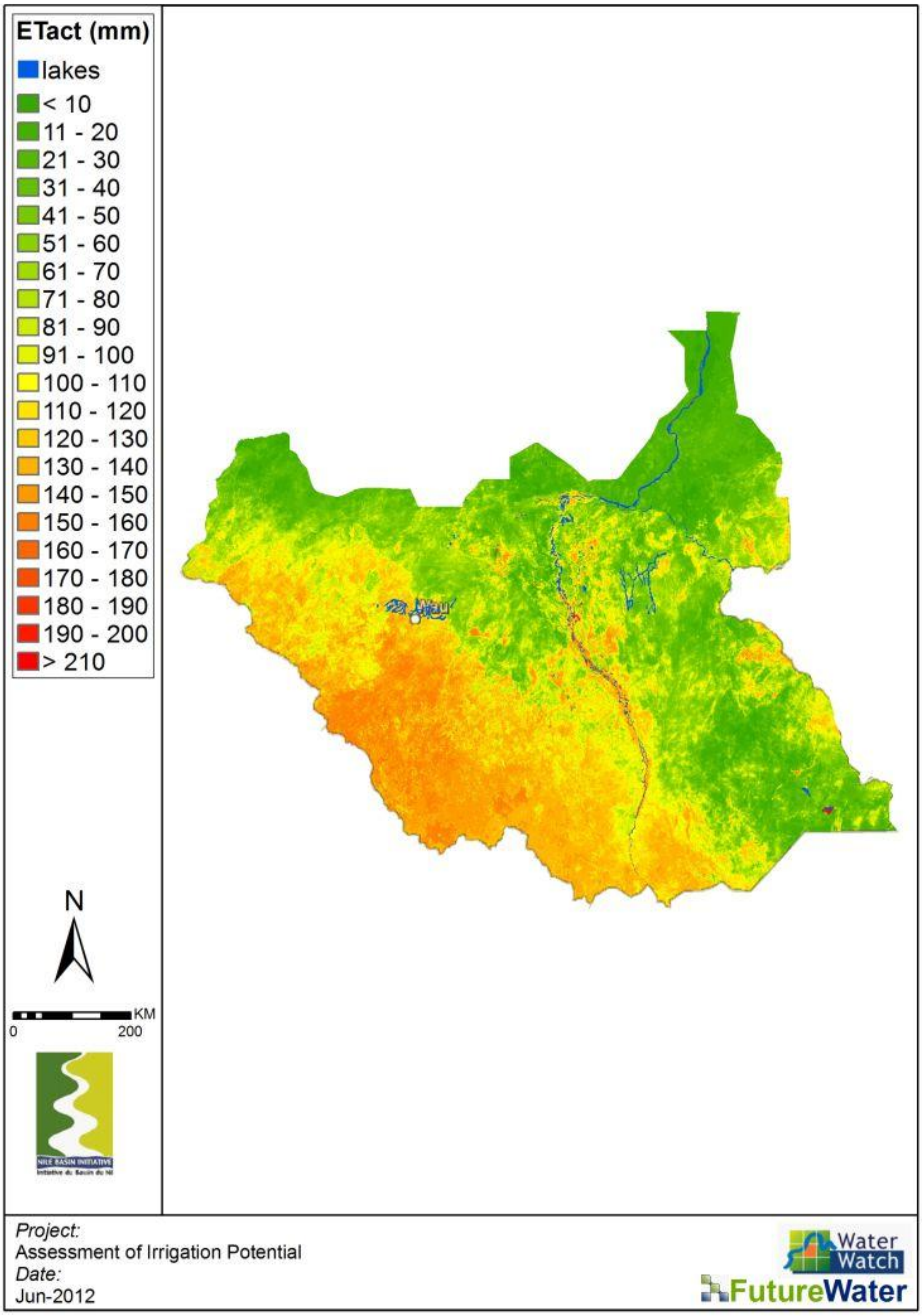
FutureWater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190 - 200
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Jun-2012
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FutureWater

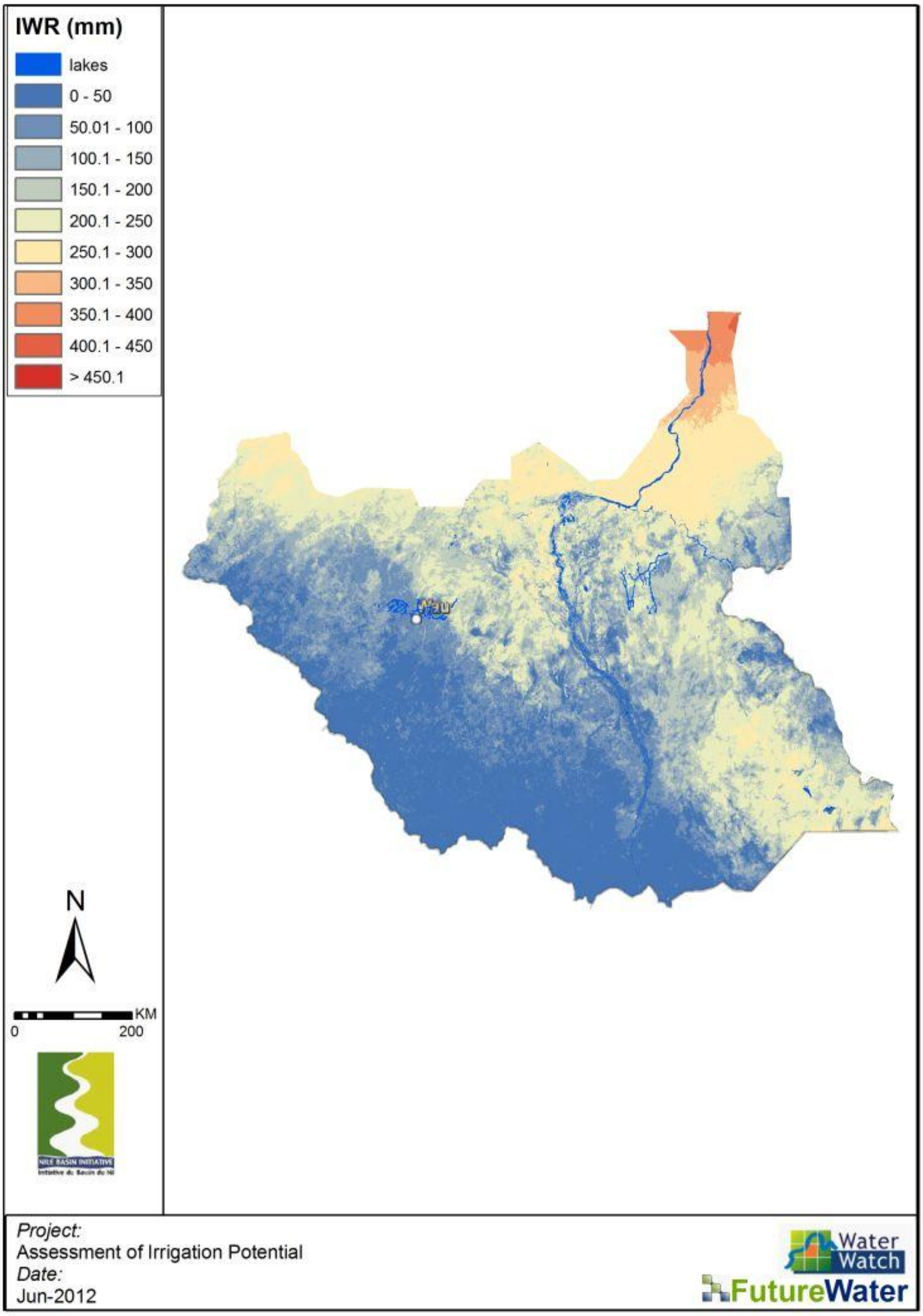
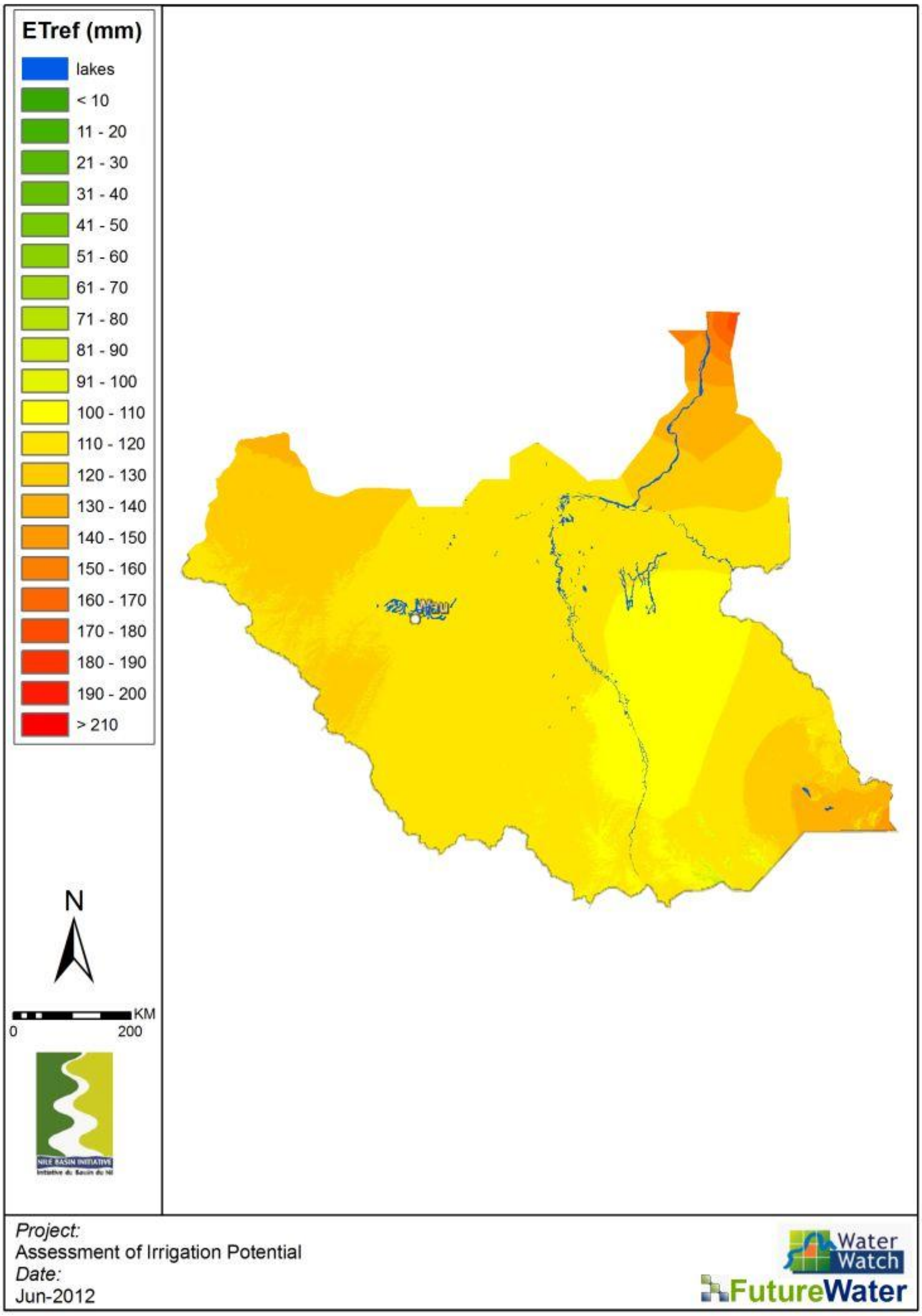


Figure 10: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). For June (Average 2001-2010). (Source: study analysis).

July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Project:
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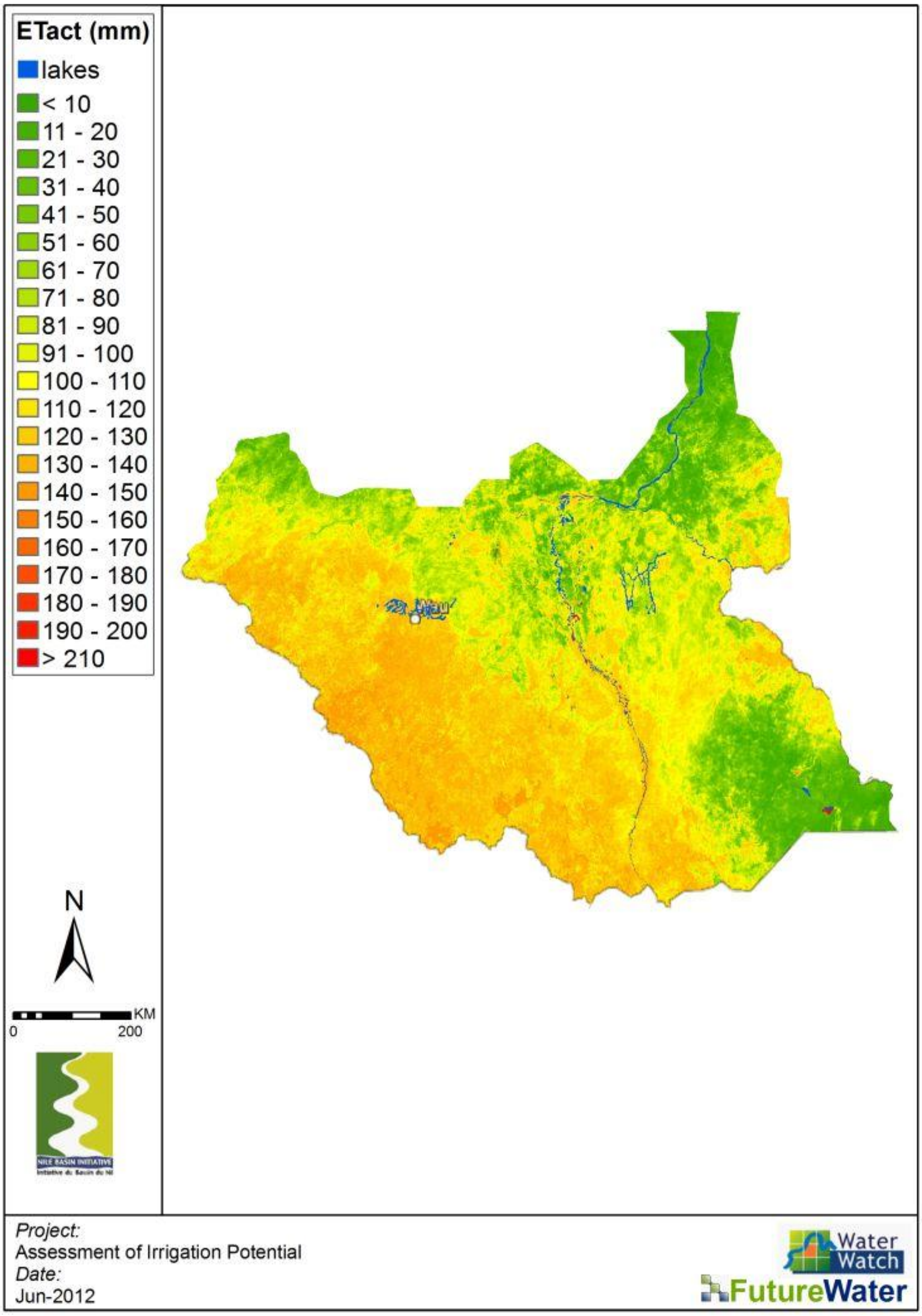
ETact (mm)
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160 - 170
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FutureWater

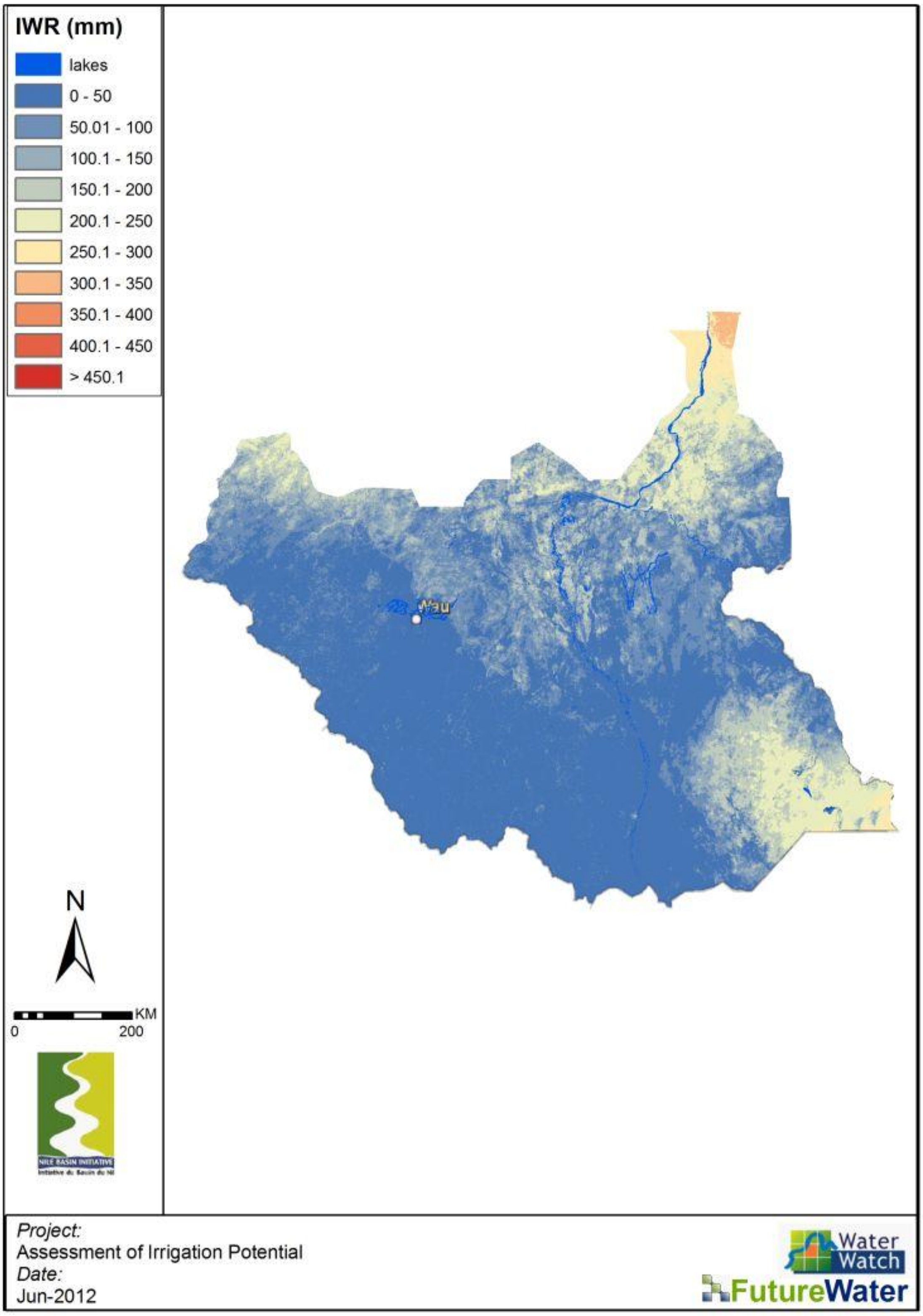
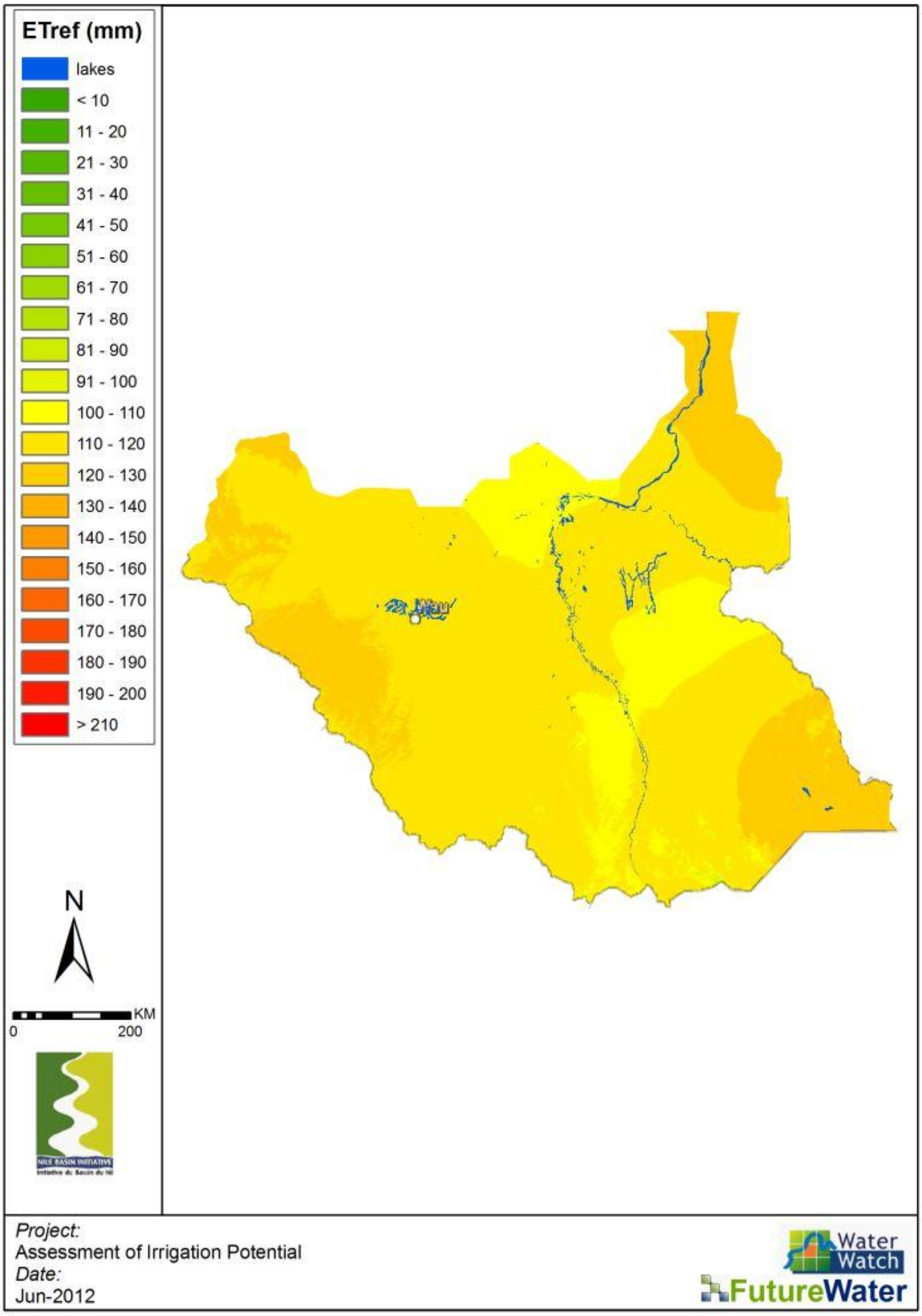


Figure 11: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for July (Average 2001-2010). (Source: study analysis).

August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Project:
Assessment of Irrigation Potential
Date:
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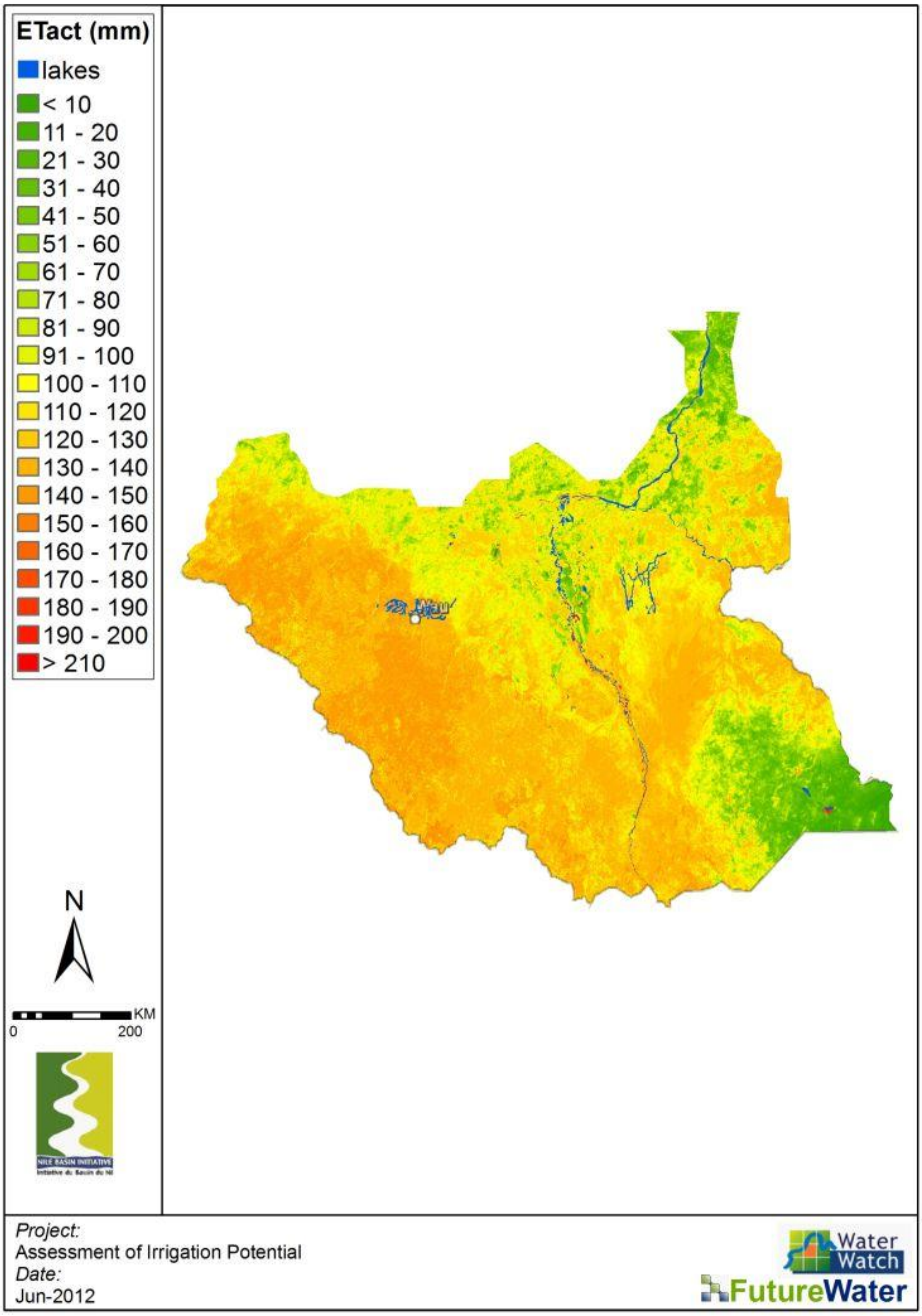
ETact (mm)
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Project:
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Date:
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Water Watch
FutureWater

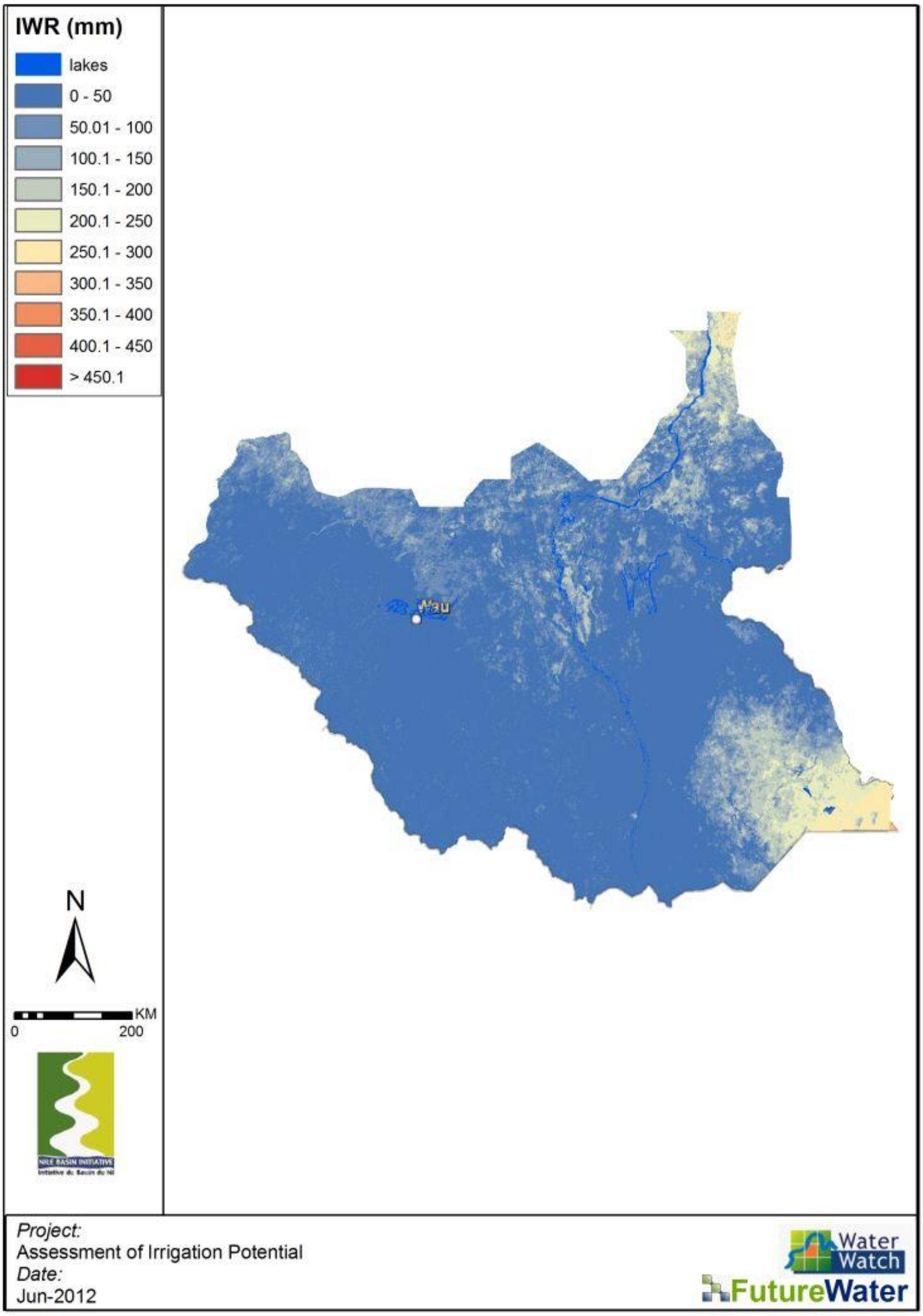
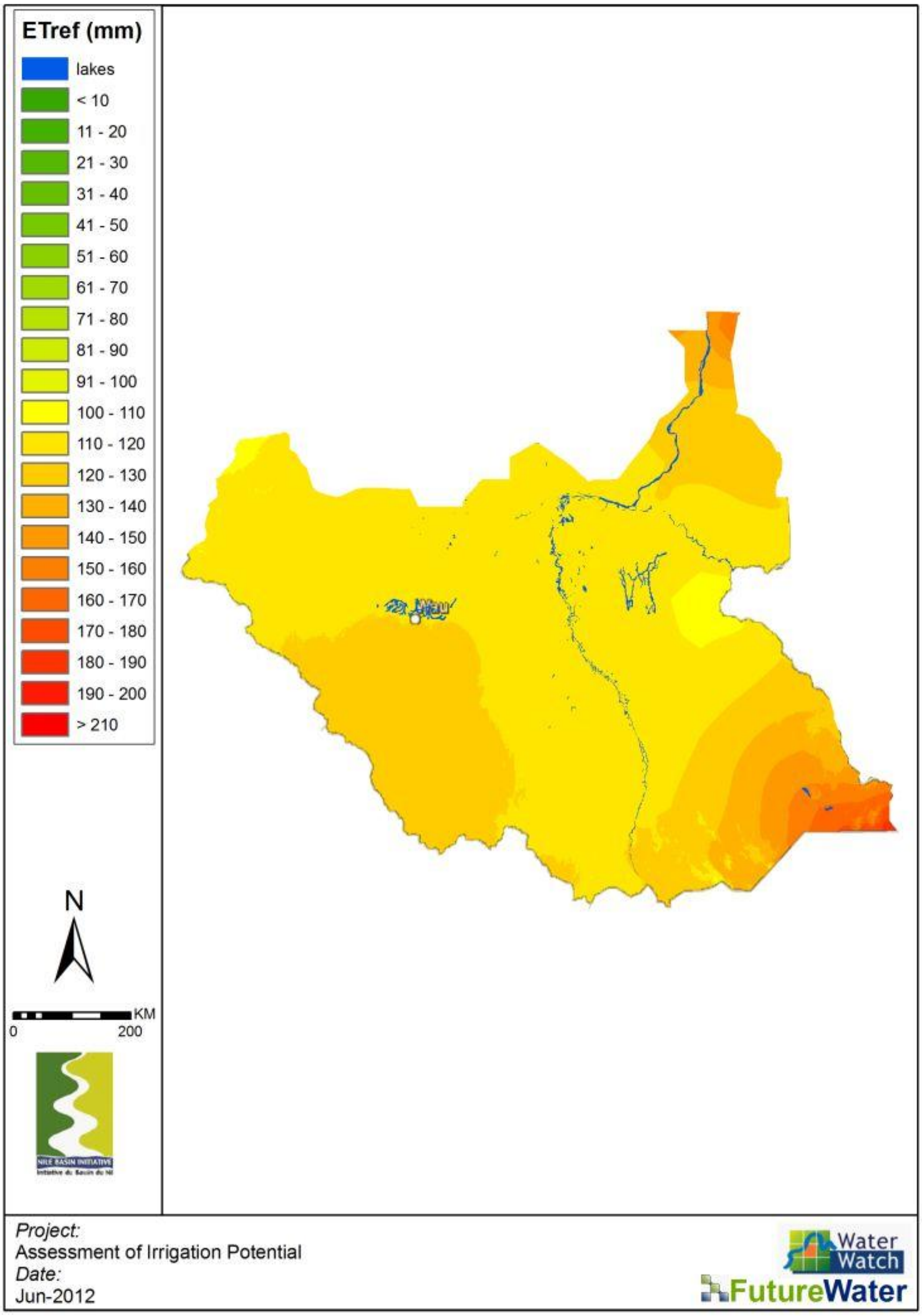


Figure 12: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for August (Average 2001-2010). (Source: study analysis).

September


ETref (mm)
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Project:
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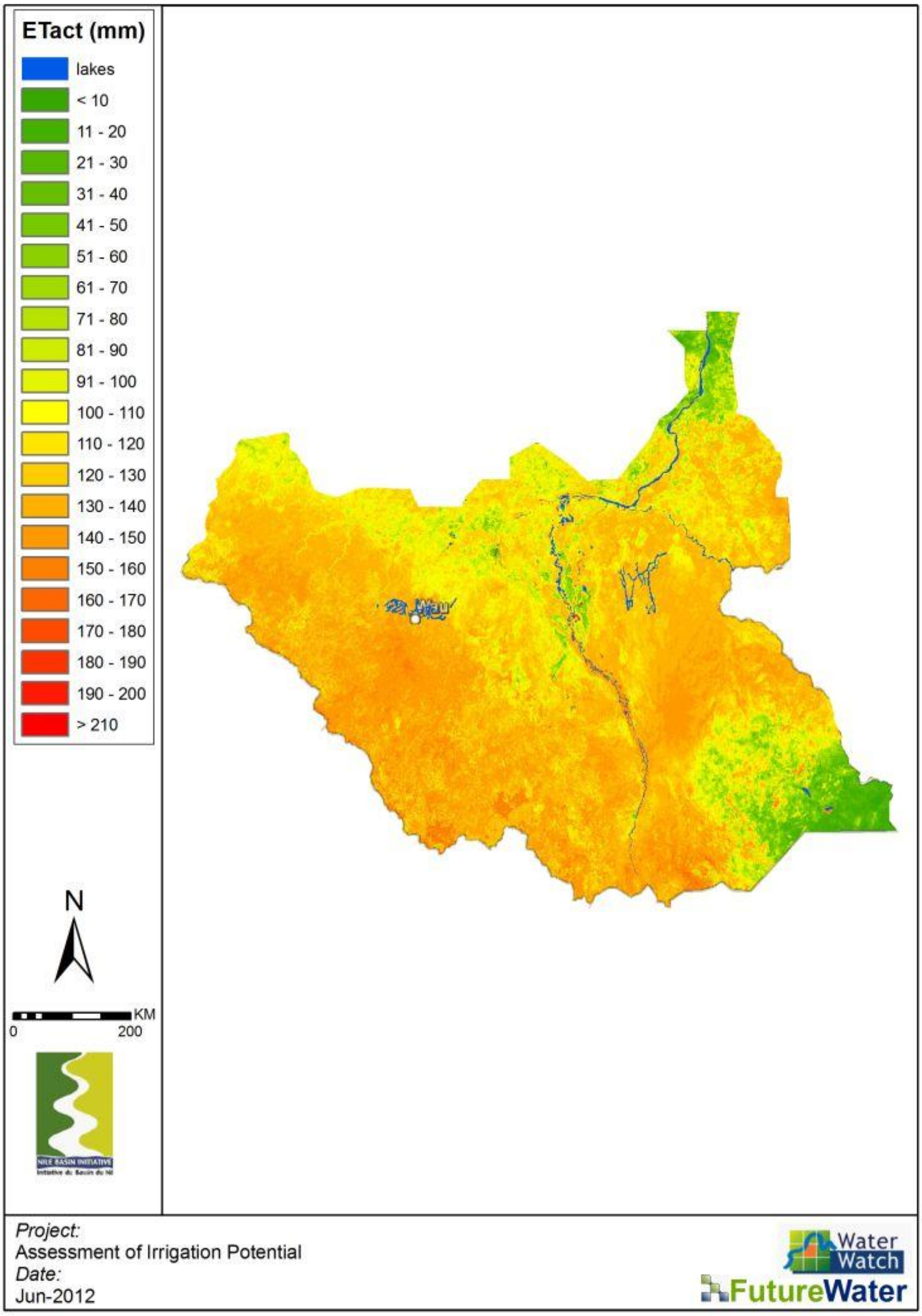
FutureWater


ETact (mm)
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180 - 190
190 - 200
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NILE BASIN INITIATIVE
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

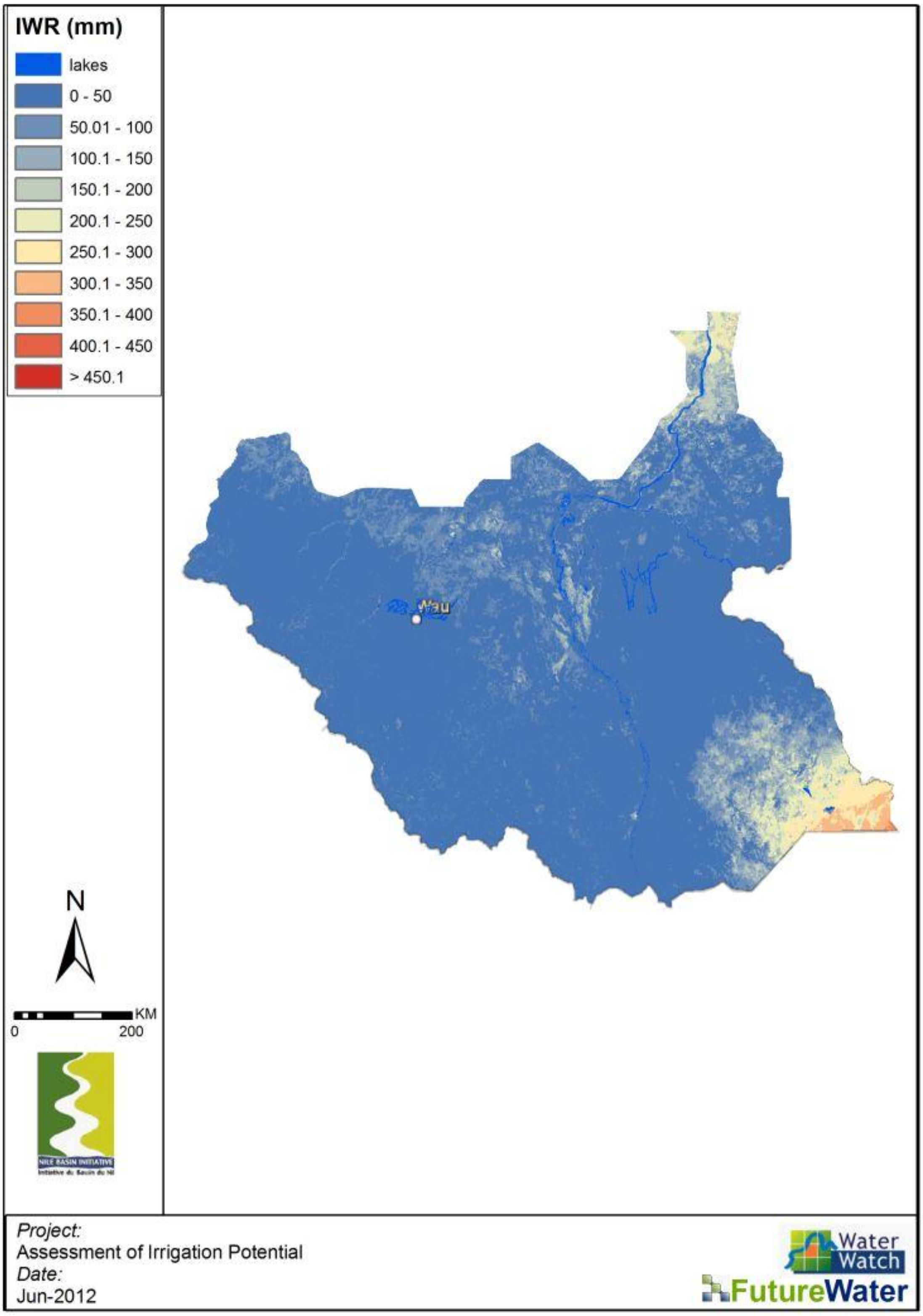
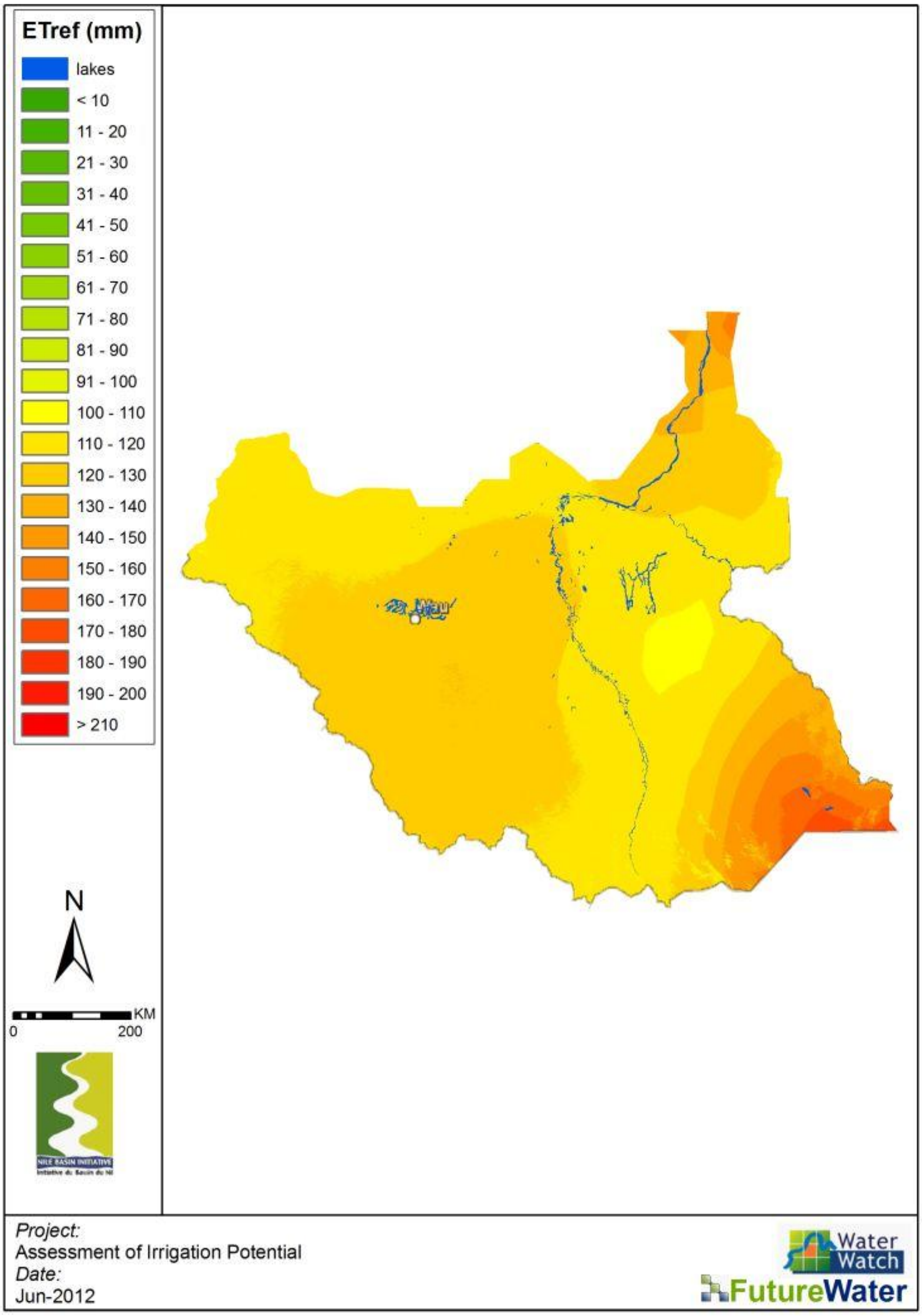


Figure 13: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for September (Average 2001-2010). (Source: study analysis).

October



ETref (mm)
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Project:
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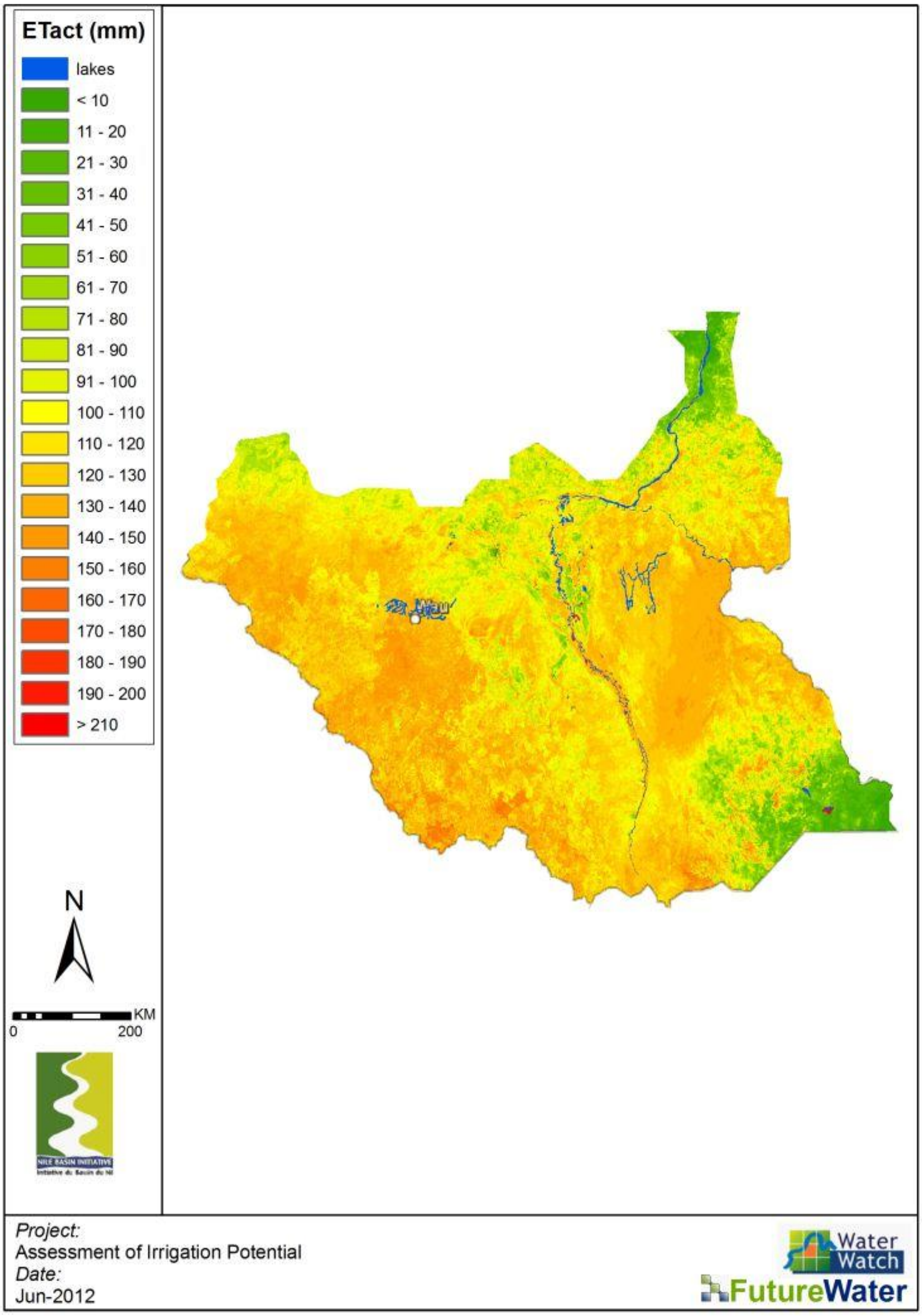
Jun-2012


ETact (mm)
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Project:
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Water Watch
FutureWater

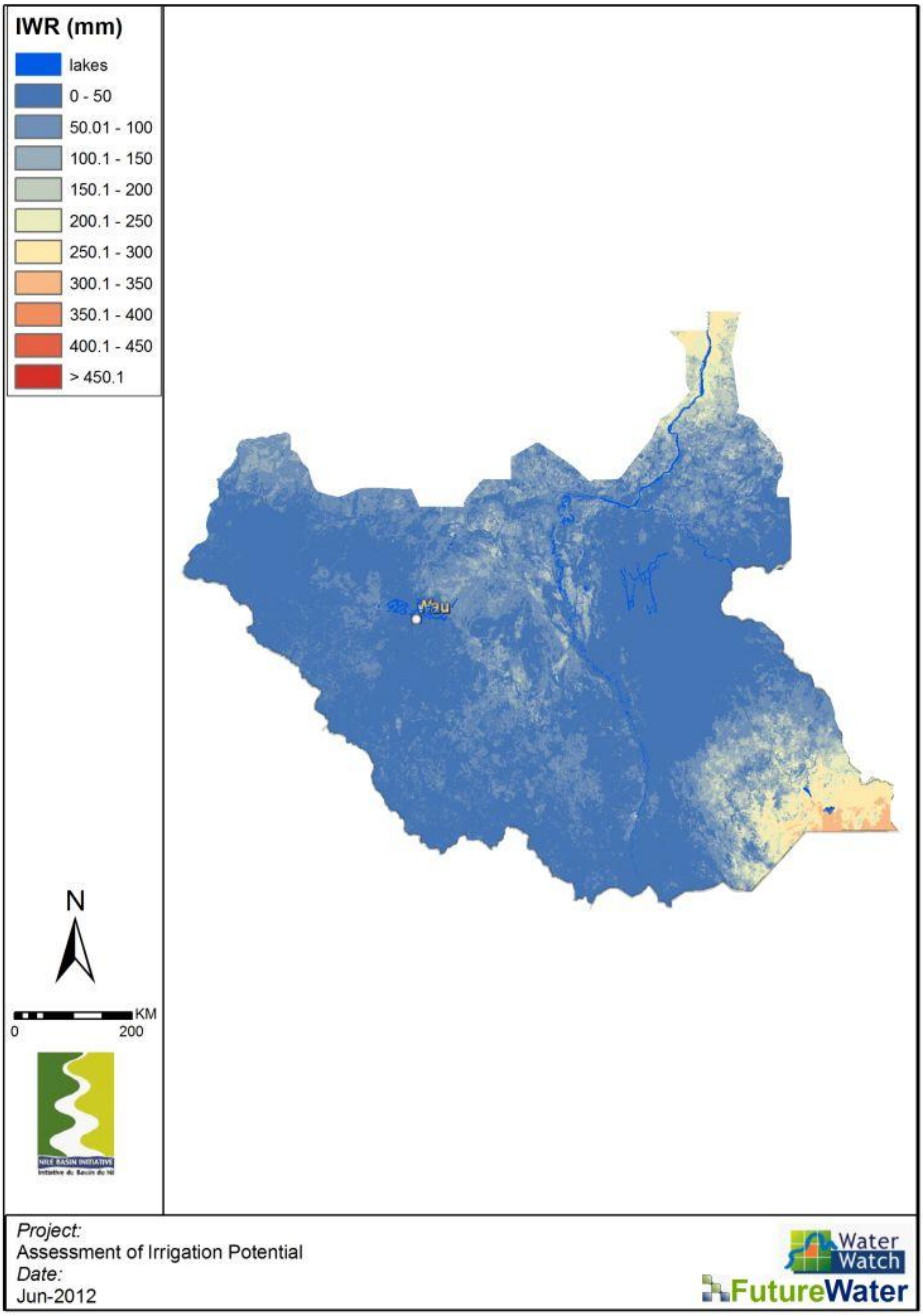
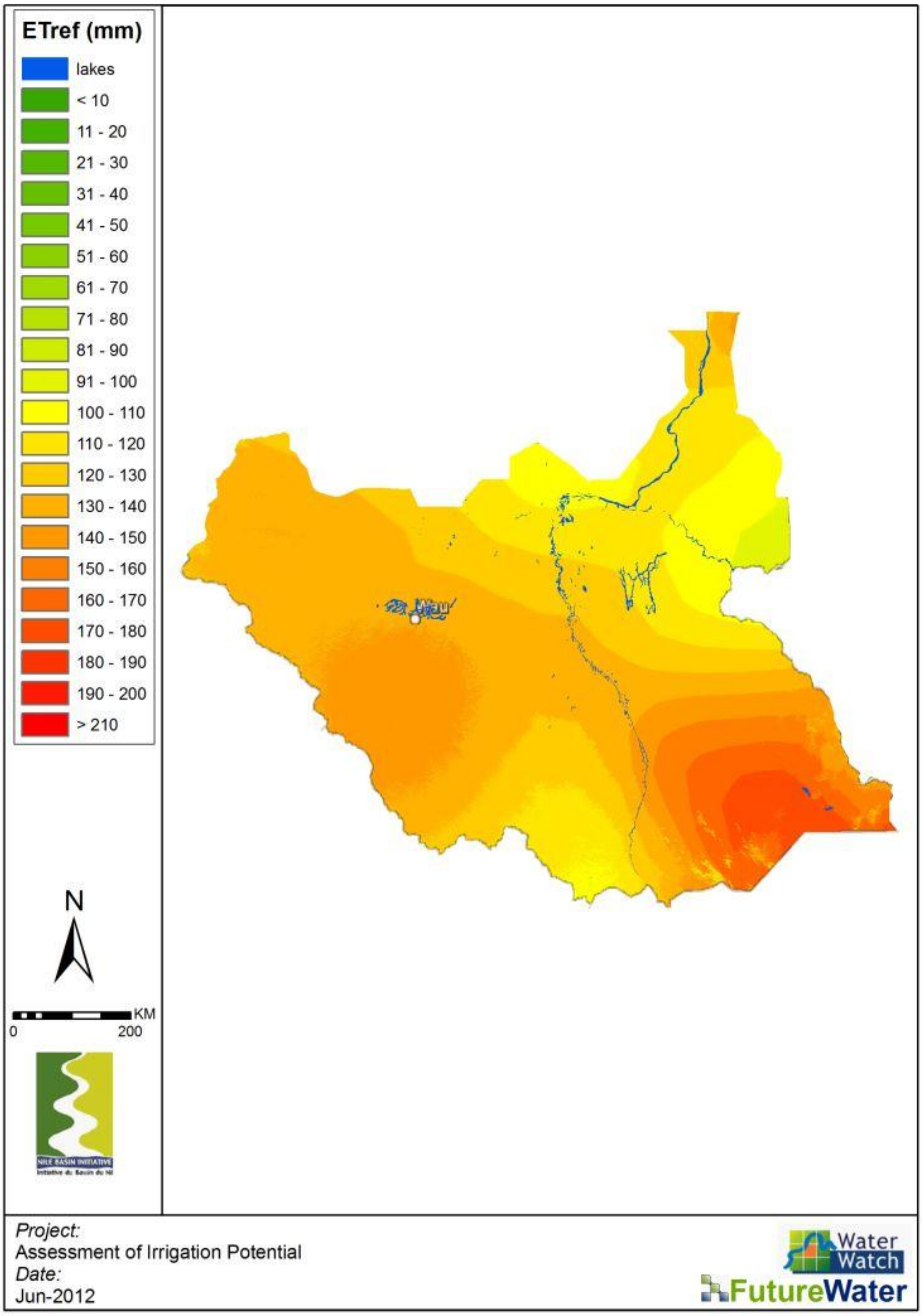
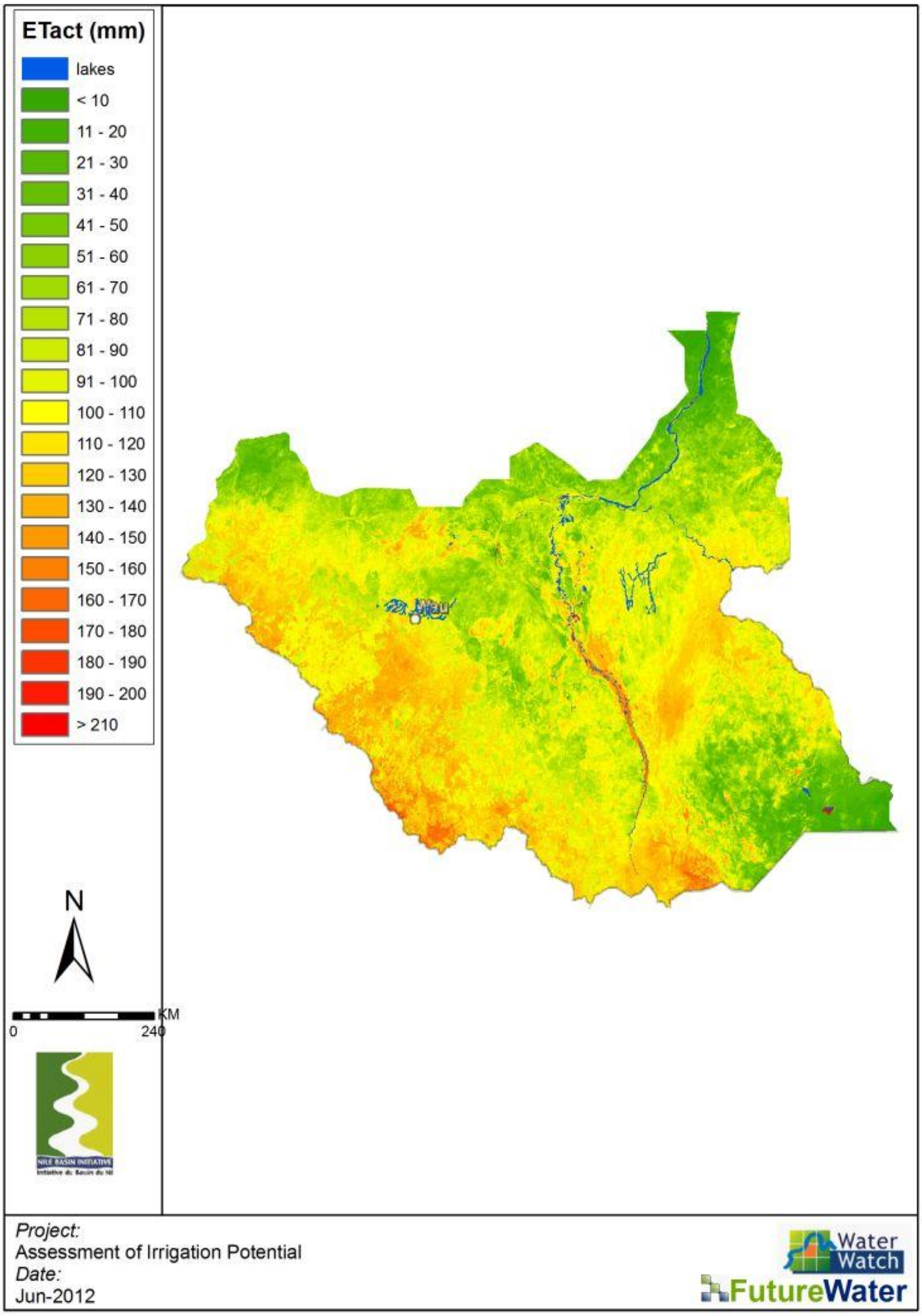


Figure 14: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for October (Average 2001-2010). (Source: study analysis).

November


ETref (mm)
lakes
< 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
100 - 110
110 - 120
120 - 130
130 - 140
140 - 150
150 - 160
160 - 170
170 - 180
180 - 190
190 - 200
> 210
N
KM
0
200
NILE BASIN INITIATIVE
Initiative du Bassin du Nil
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater



ETact (mm)
lakes
< 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
100 - 110
110 - 120
120 - 130
130 - 140
140 - 150
150 - 160
160 - 170
170 - 180
180 - 190
190 - 200
> 210
N
KM
0
240
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

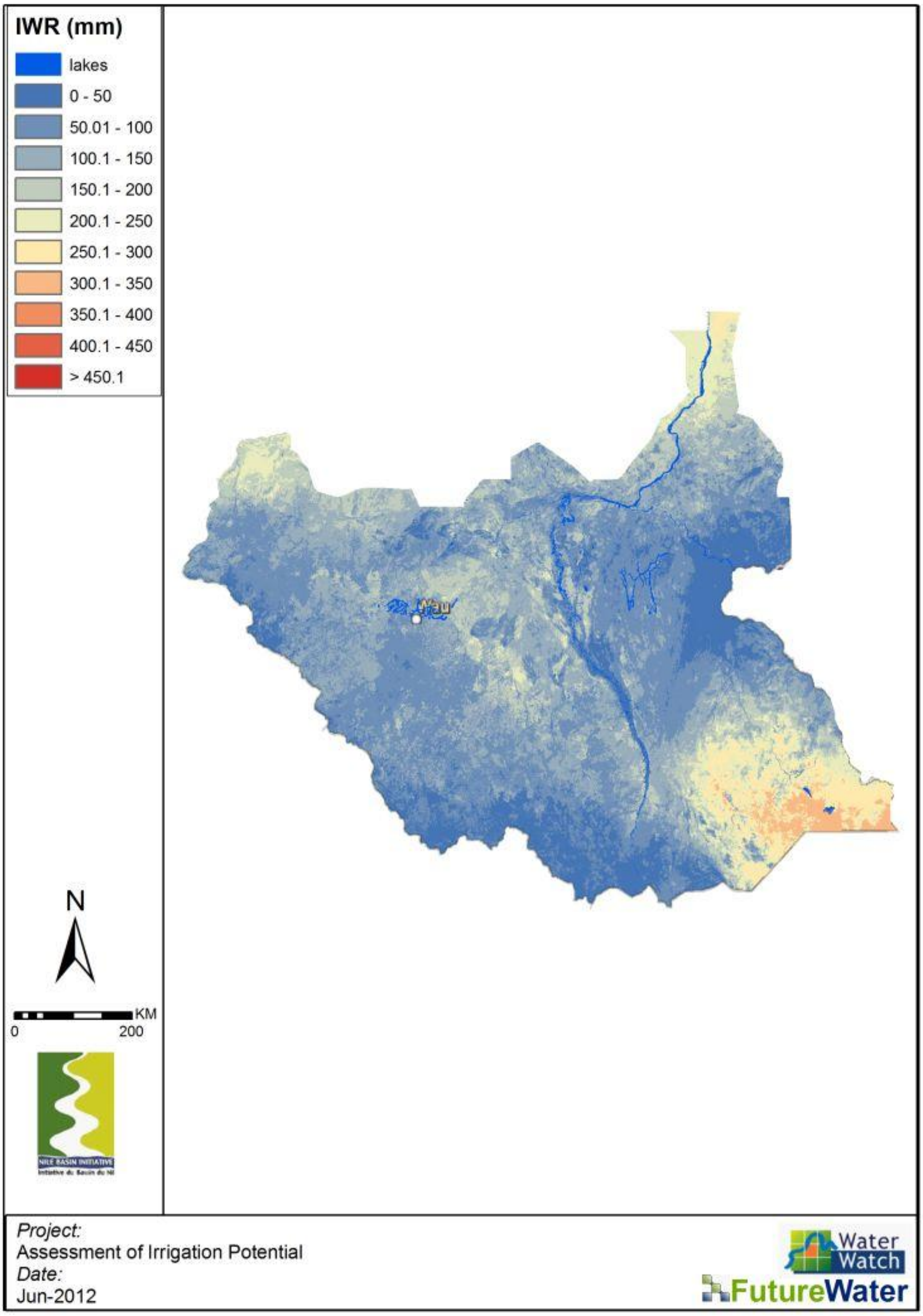
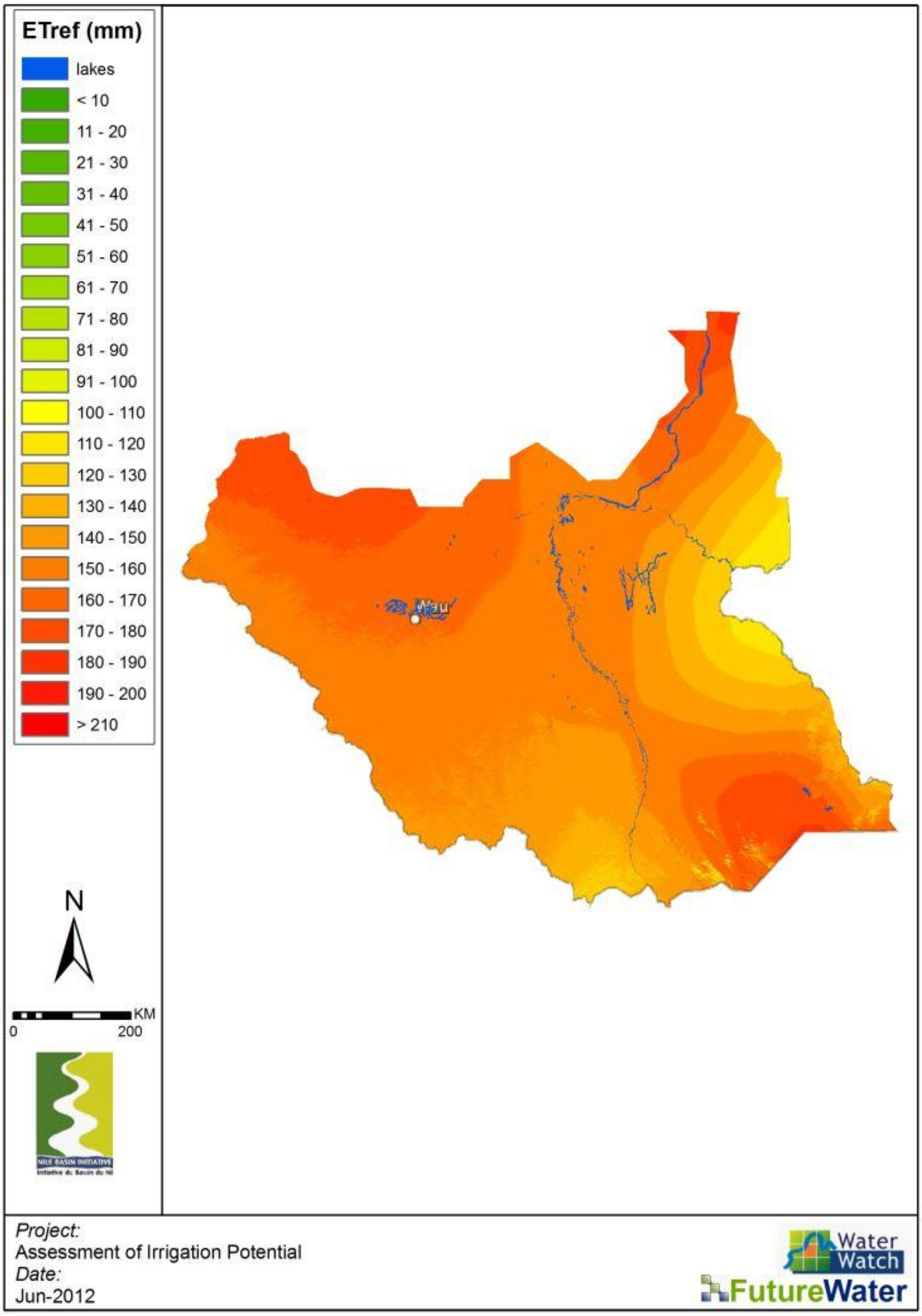
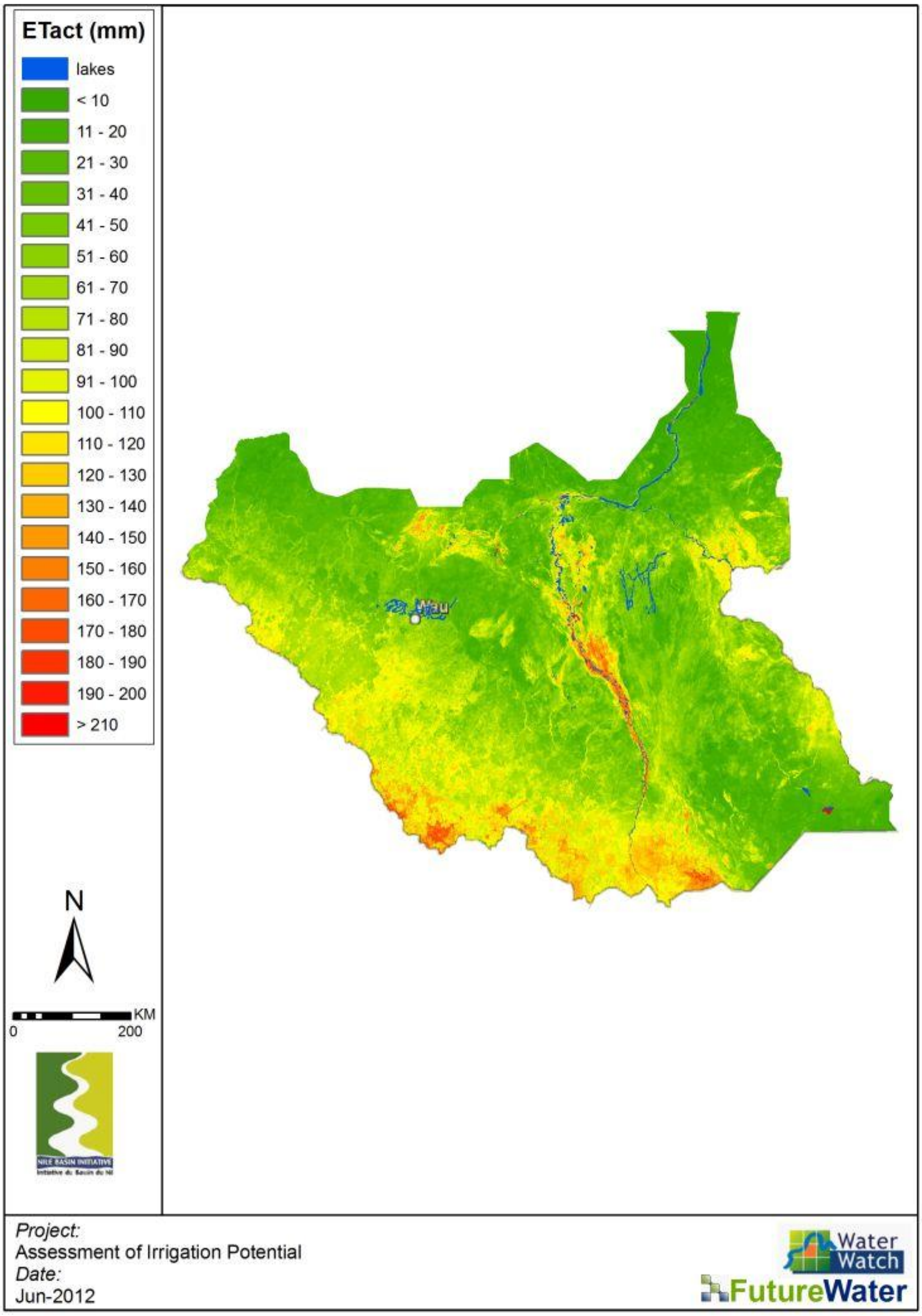


Figure 15: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for November (Average 2001-2010). (Source: study analysis).

December


ETref (mm)
lakes
< 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
100 - 110
110 - 120
120 - 130
130 - 140
140 - 150
150 - 160
160 - 170
170 - 180
180 - 190
190 - 200
> 210
N
KM
0
200
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater


ETact (mm)
lakes
< 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
100 - 110
110 - 120
120 - 130
130 - 140
140 - 150
150 - 160
160 - 170
170 - 180
180 - 190
190 - 200
> 210
N
KM
0
200
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

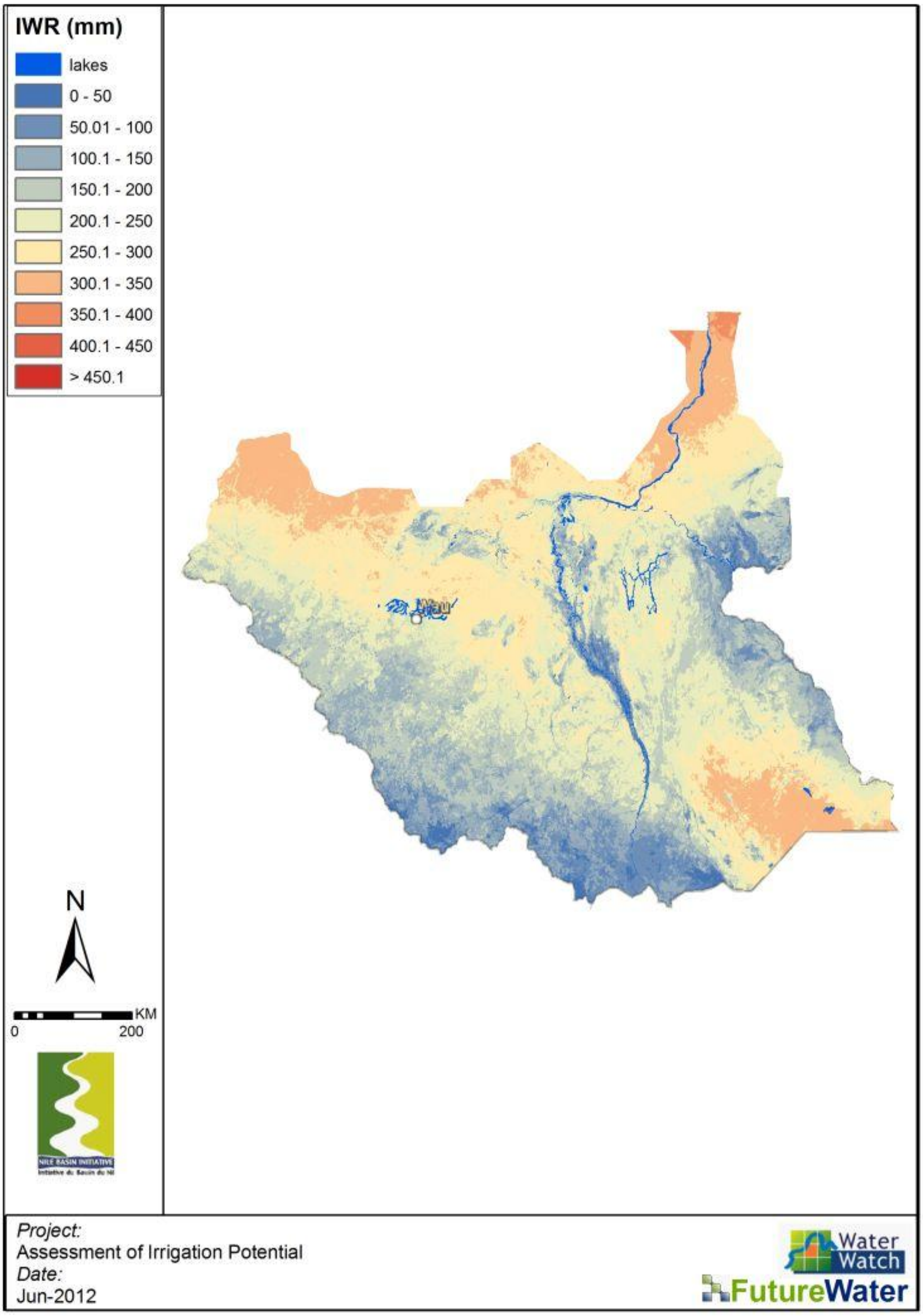


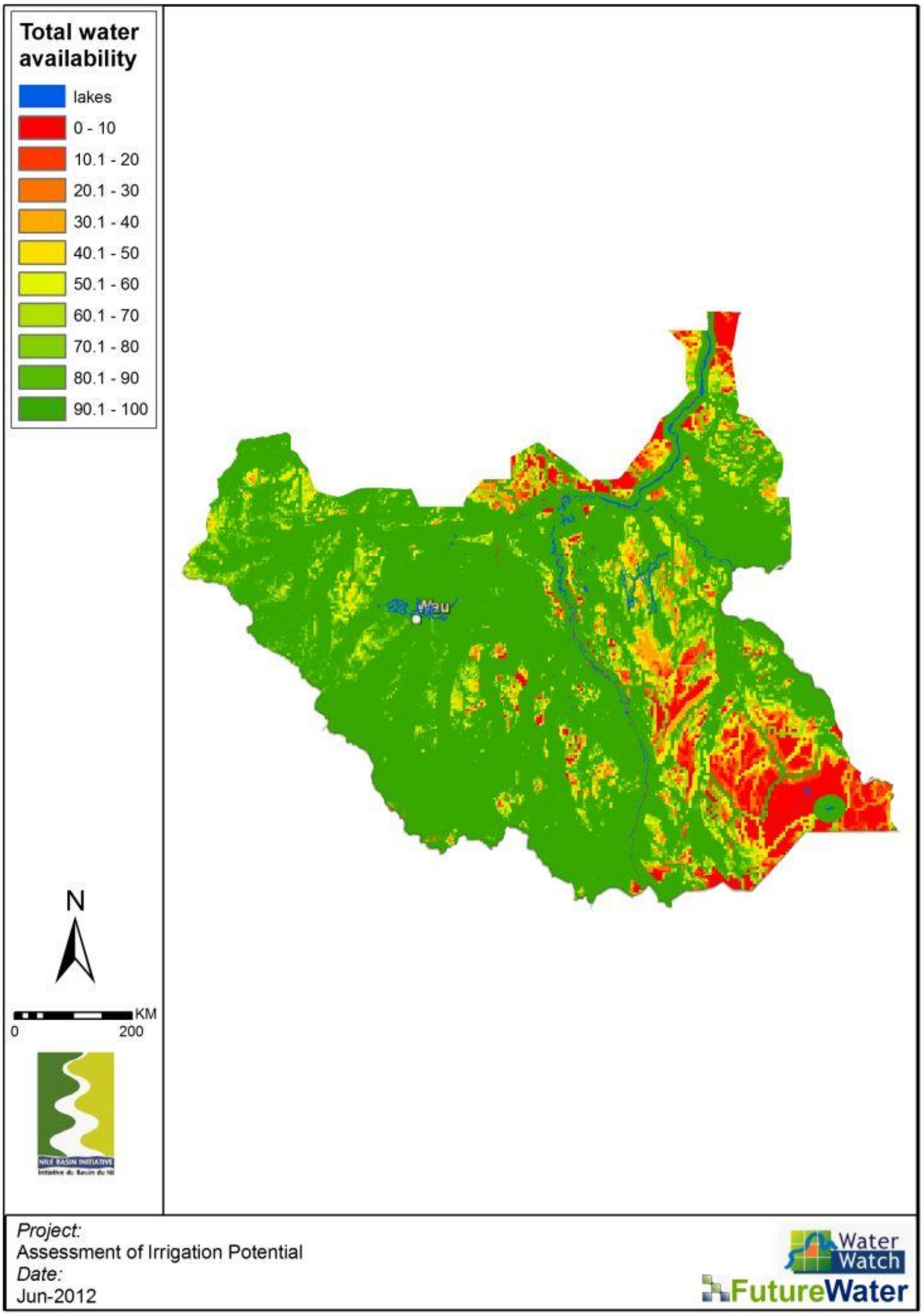
Figure 16: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for December (Average 2001-2010). (Source: study analysis).

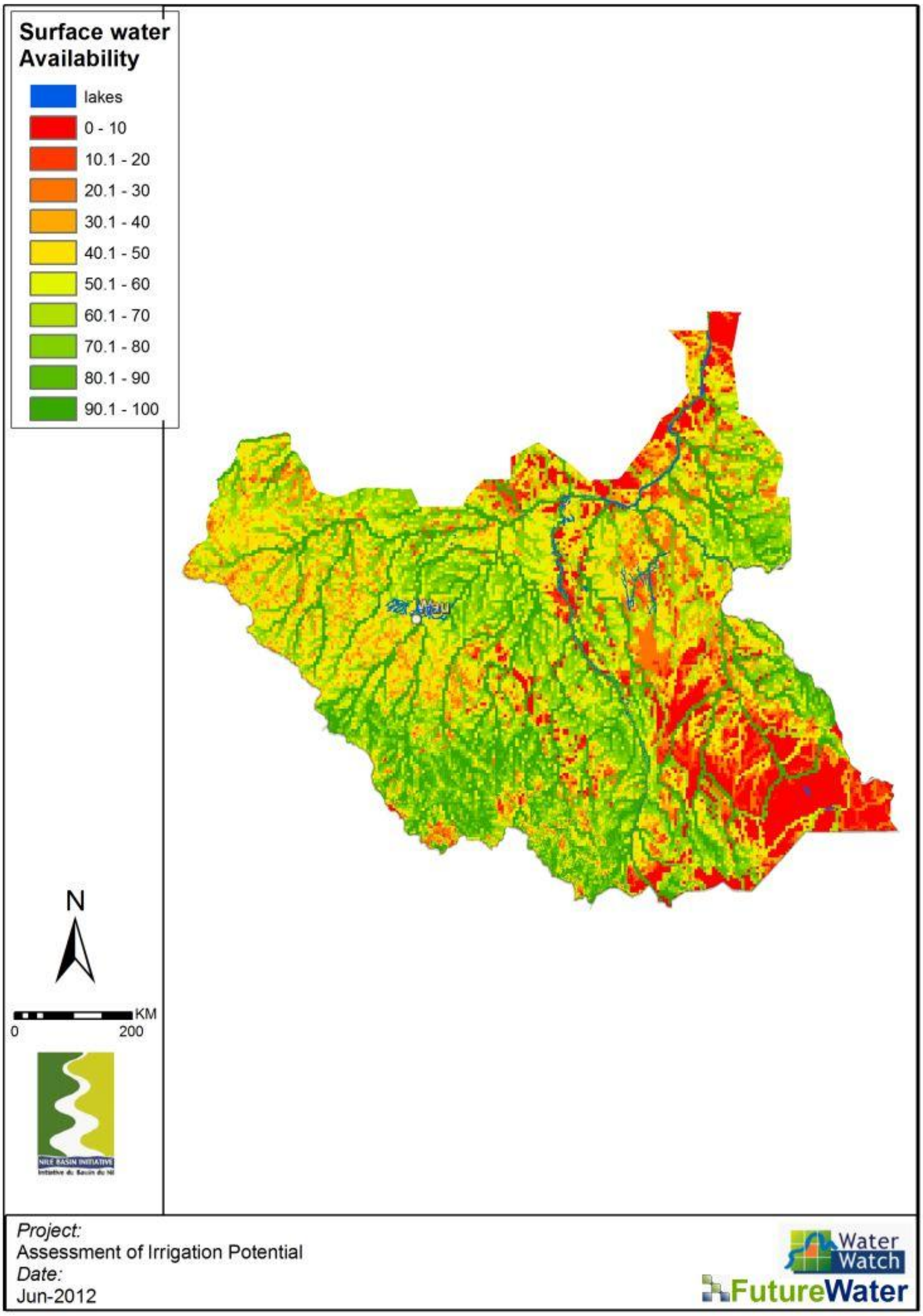
2.2.2 Water availability for irrigation

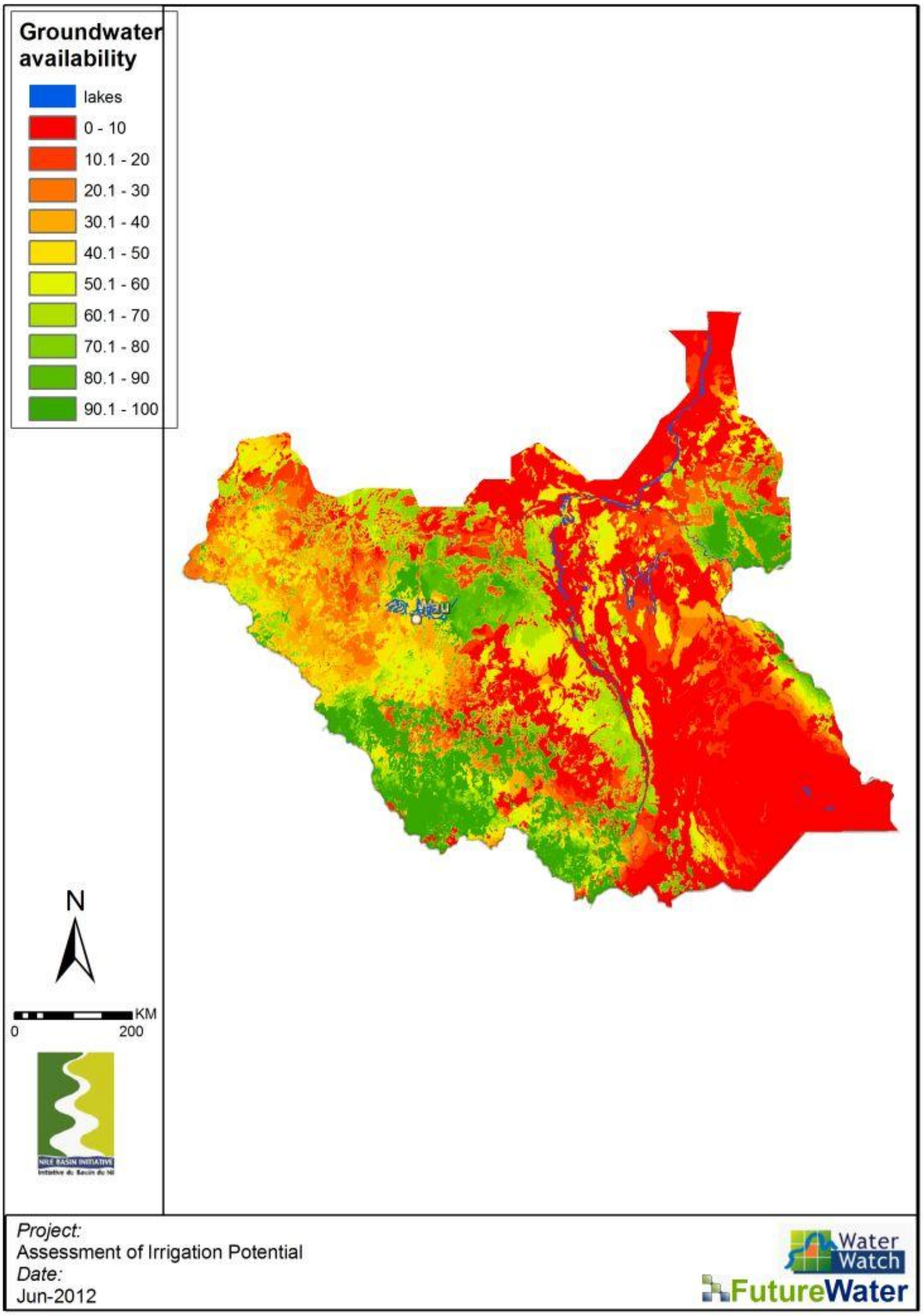
2.2.2.1 NELmod

Water for irrigation can originate from three main sources: surface water, groundwater, and reservoirs. Based on the water availability (NELmod results), and irrigation demands (ETLook/SEBAL results) coverage of irrigation water requirements has been made (for details see main report). As explained in detail in the main report this water availability reflects only the need for irrigation, e.g. if rainfall occurs the irrigation water requirement is lower. Also the assumption that reservoir water can be used is based on the long-term annual flow rather than on restrictions for construction of a reservoir.

Results indicate that water availability for irrigation in the region is somewhat limited, except for regions close to streams if reservoirs could be constructed.


Total water availability
lakes
0 - 10
10.1 - 20
20.1 - 30
30.1 - 40
40.1 - 50
50.1 - 60
60.1 - 70
70.1 - 80
80.1 - 90
90.1 - 100
Wau
N
KM
0
200
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater


Surface water Availability
lakes
0 - 10
10.1 - 20
20.1 - 30
30.1 - 40
40.1 - 50
50.1 - 60
60.1 - 70
70.1 - 80
80.1 - 90
90.1 - 100
N
KM
0
200
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater


Groundwater availability
lakes
0 - 10
10.1 - 20
20.1 - 30
30.1 - 40
40.1 - 50
50.1 - 60
60.1 - 70
70.1 - 80
80.1 - 90
90.1 - 100
N
KM
0
200
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

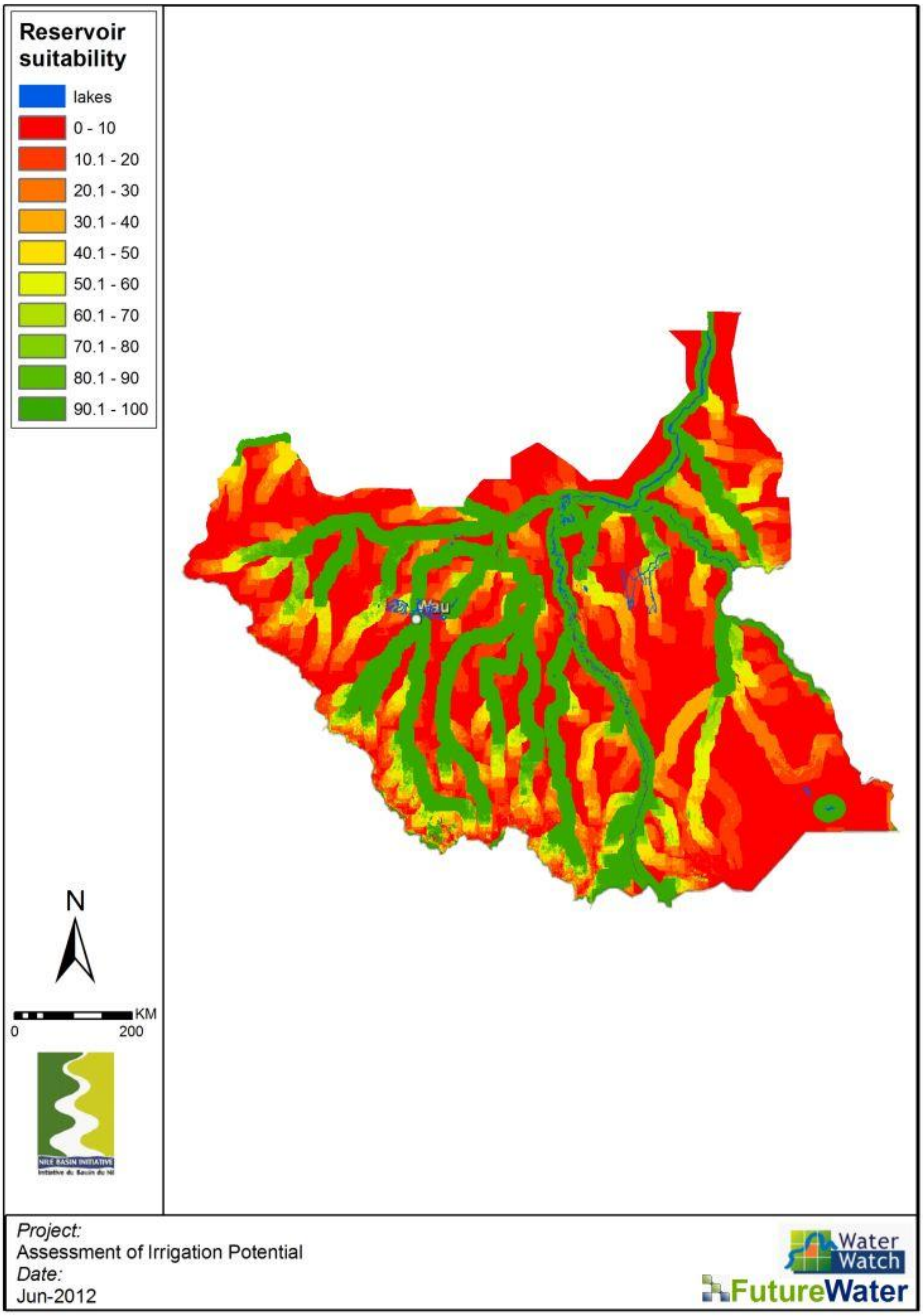


Figure 17. Water availability for irrigation. Total coverage (top), coverage from surface water (second), coverage from ground water (third), and from potential reservoirs (bottom). (Source: study analysis).

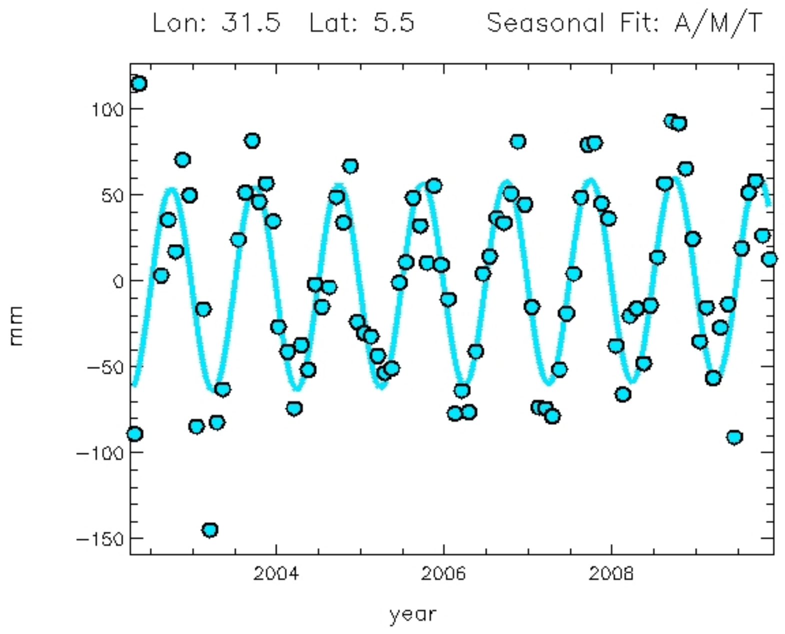


Figure 18: Annual groundwater storage trends for South Sudan, based on GRACE satellite observations (Source: UoC, 2011).

2.2.2.2 Groundwater Trends

Large scale groundwater trends can also be observed from the GRACE satellite. This twin-satellite detects on a monthly base groundwater fluctuations over rather large areas (for details see main report). Long term groundwater trends based on GRACE can be seen in Figure 18. It is clear that the overall trend is groundwater levels are more or less stable over the last 10 years. Groundwater recharge based on NELmod is presented in Figure 19. Overall groundwater recharge is quite limit except for areas around the Nile.

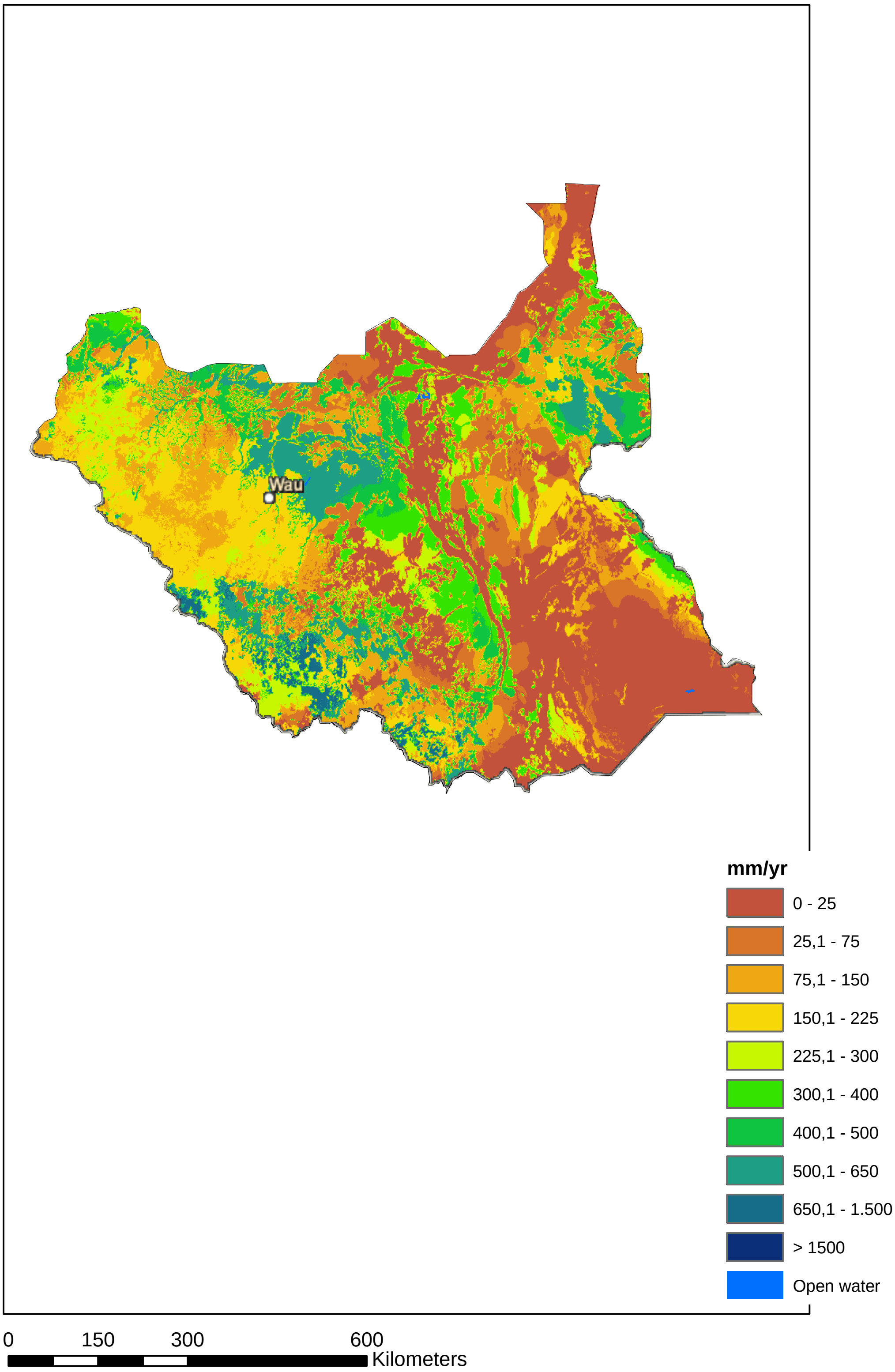
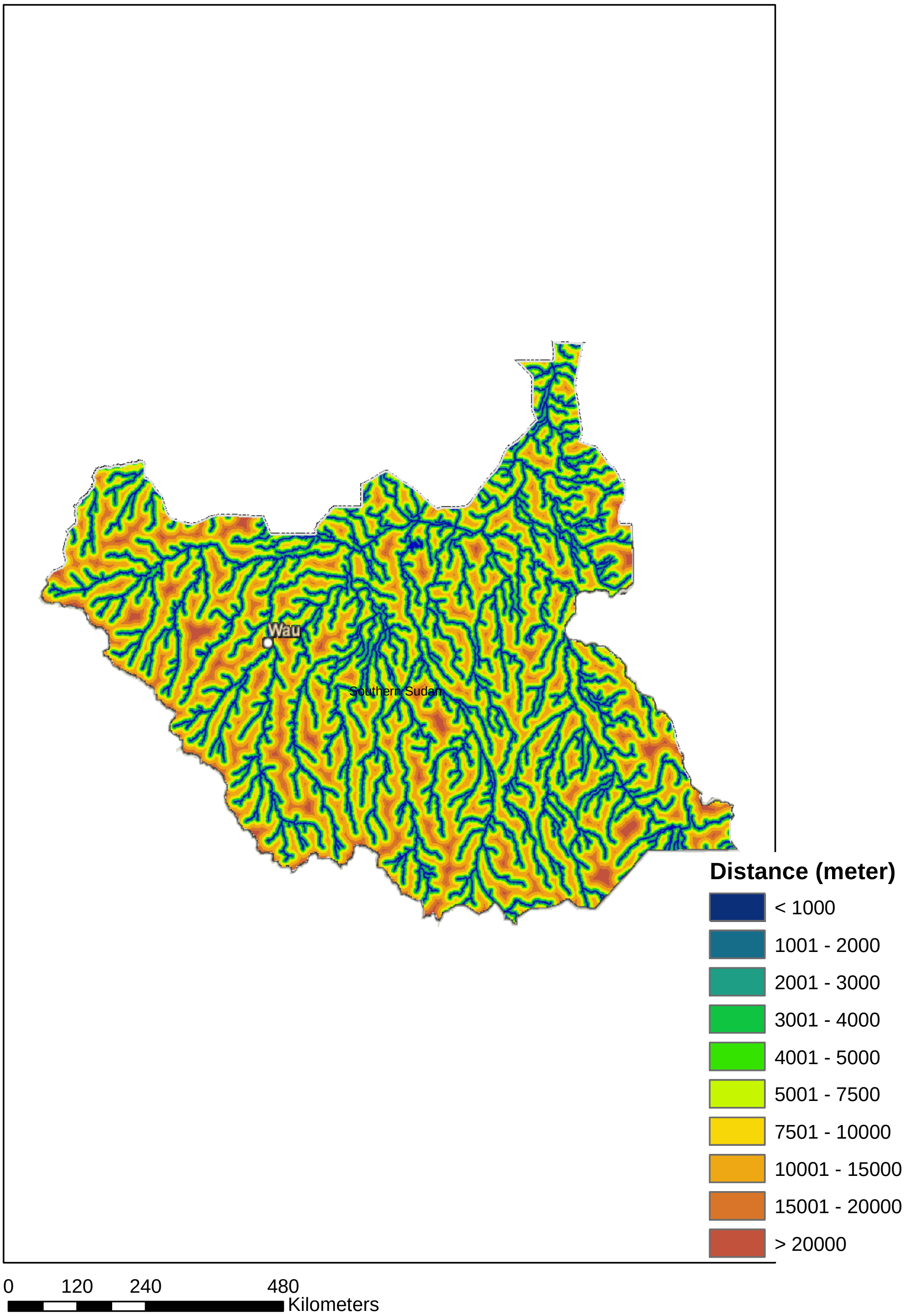
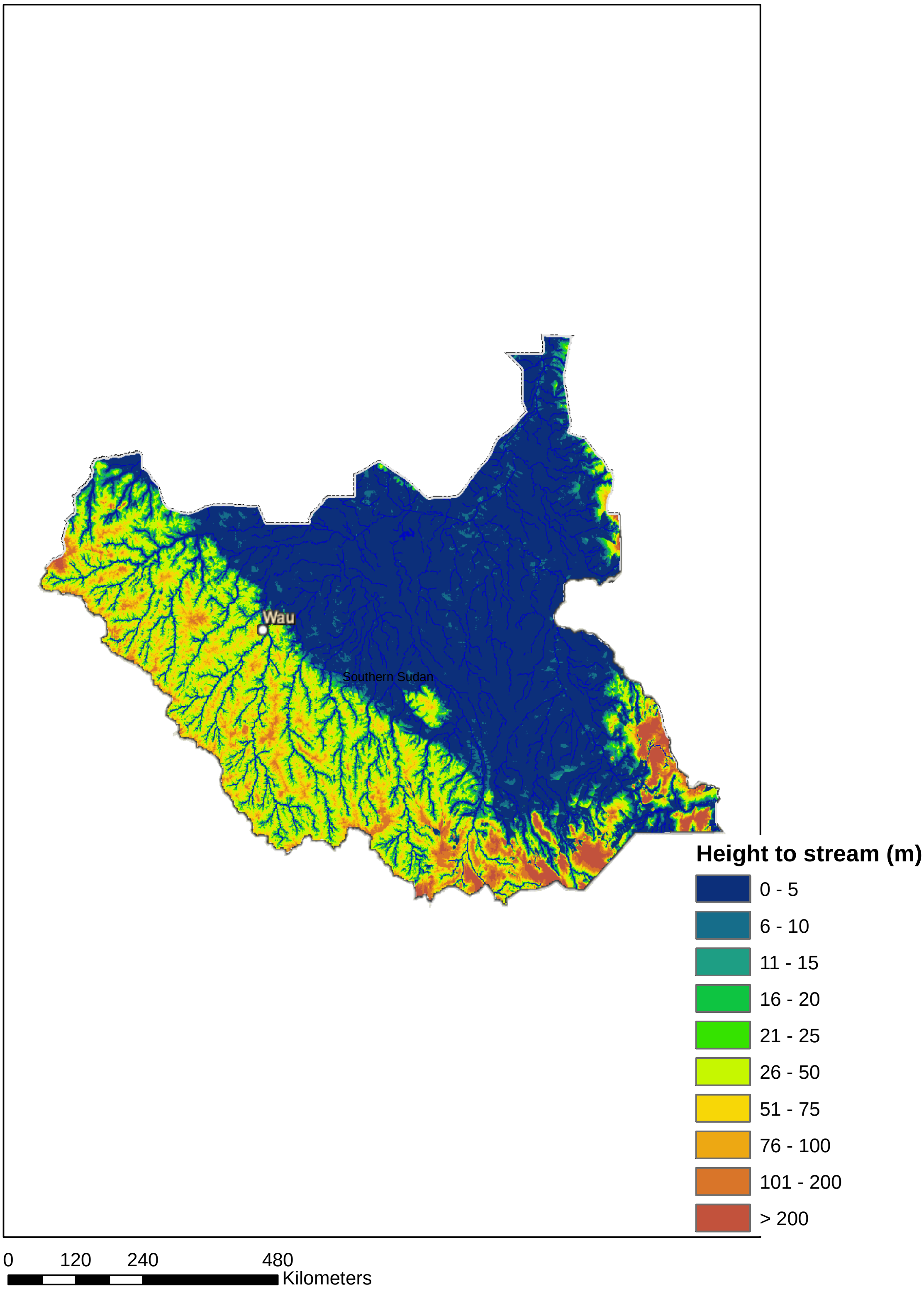


Figure 19: Annual groundwater recharge based on NELmod.

2.2.3 Access to a potential water source

A crucial component in assessing the potential for irrigation is the distance from the potential irrigation scheme to natural course of a river, stream or lake or to an existing reservoir. Based on various distance classes and elevation, this suitability in terms of access to a potential water source is defined (for details see main report). Access to a potential water source is quite limited for most areas in the country, especially since land is often high above streams.





Wau
Southern Sudan
Height to stream (m)
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 50
51 - 75
76 - 100
101 - 200
> 200
0
120
240
480
Kilometers

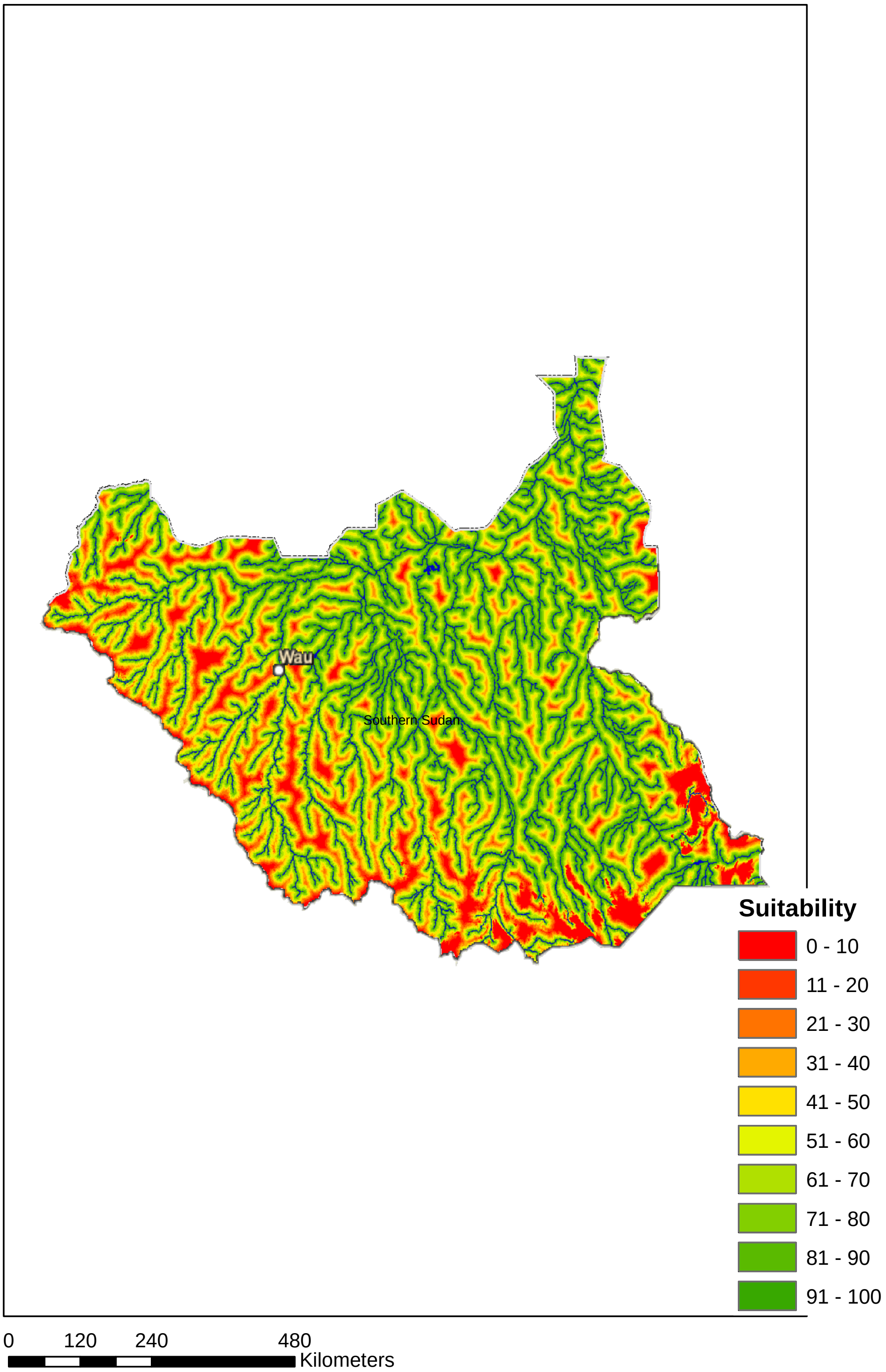


Figure20: Average distance to a natural stream, lake or reservoir (top left), elevation above natural stream, lake or reservoir (top right), and access to water suitability score (bottom).

2.3 Land use

2.3.1 Current land use

Actual land cover based on AfriCover is shown in Figure 21. Distribution of irrigated and rainfed crops are shown in Figure 22. Specific maps for 26 crops are included in the database attached to the report.

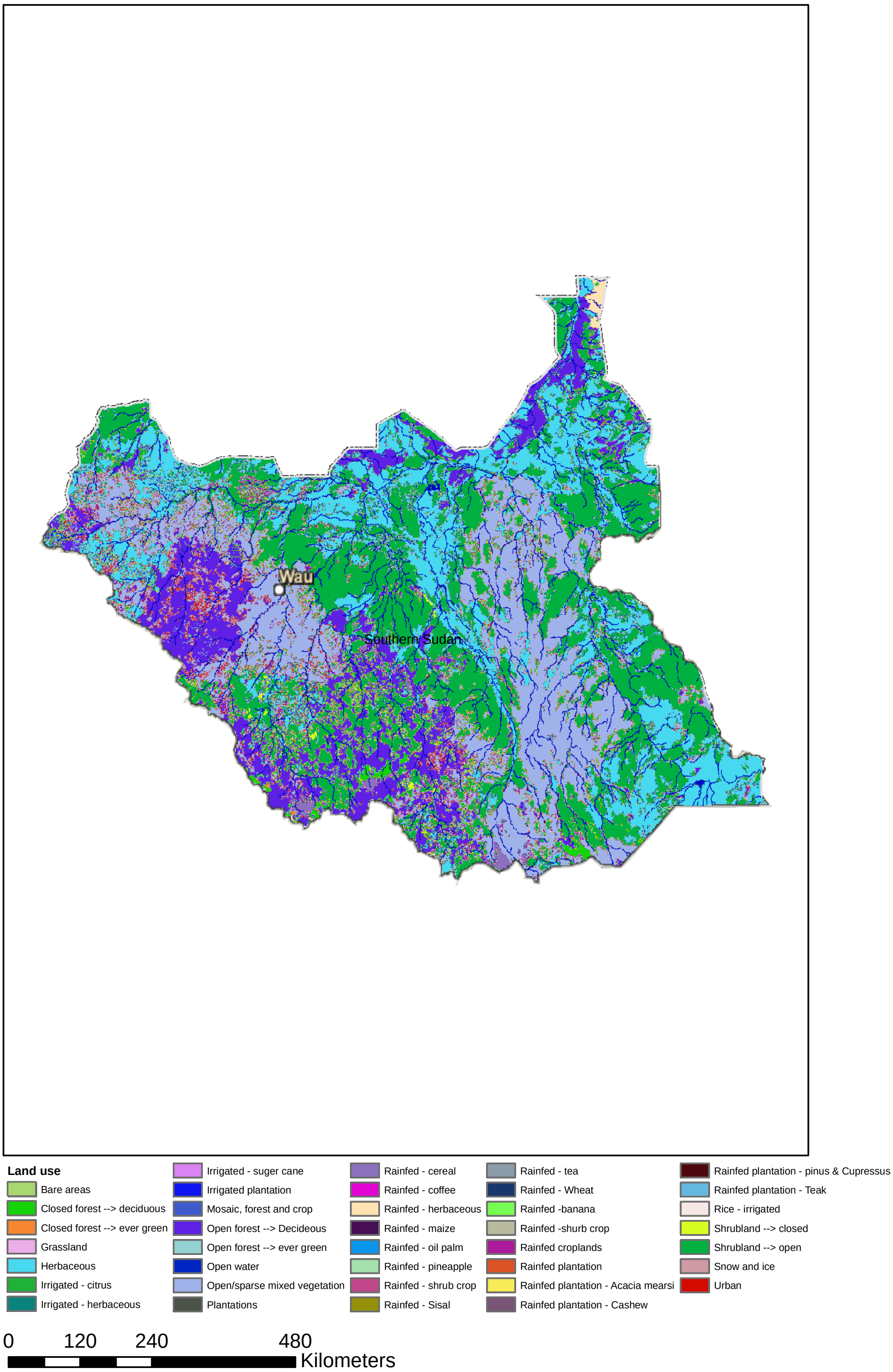
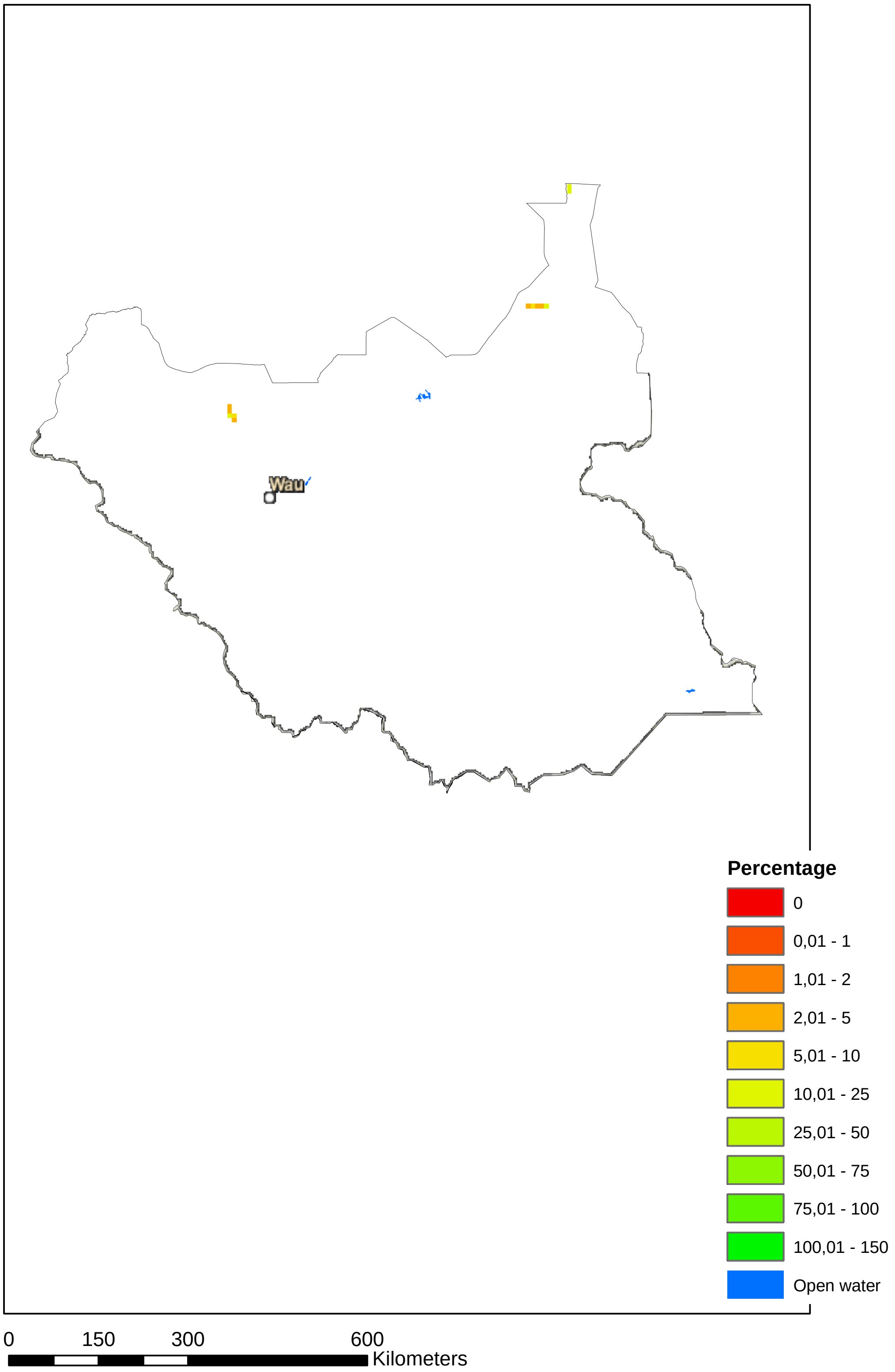


Figure 21: Land use in South Sudan, based on AfriCover.


Wau
Percentage
0
0,01 - 1
1,01 - 2
2,01 - 5
5,01 - 10
10,01 - 25
25,01 - 50
50,01 - 75
75,01 - 100
100,01 - 150
Open water
0
150
300
600
Kilometers

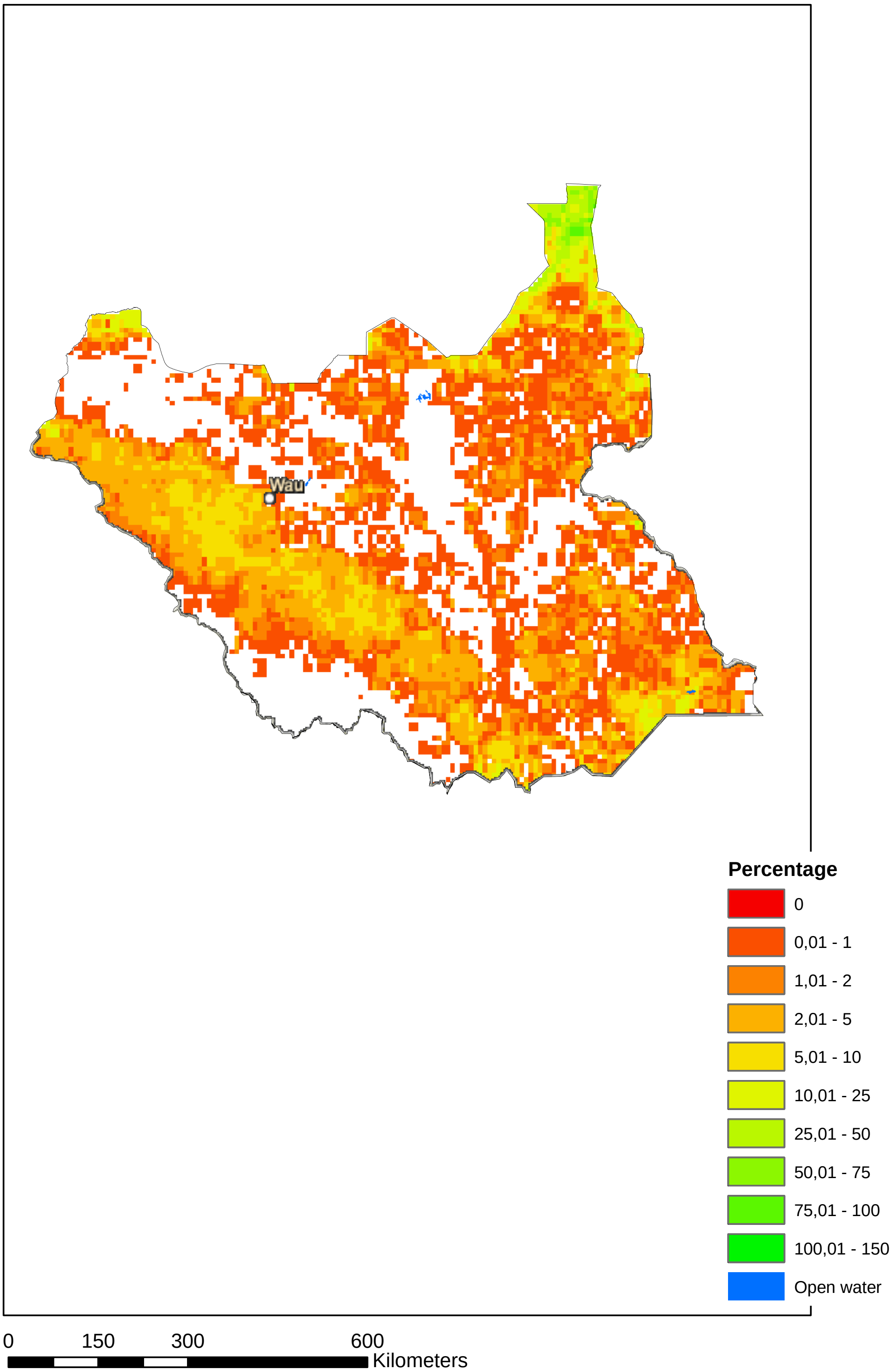
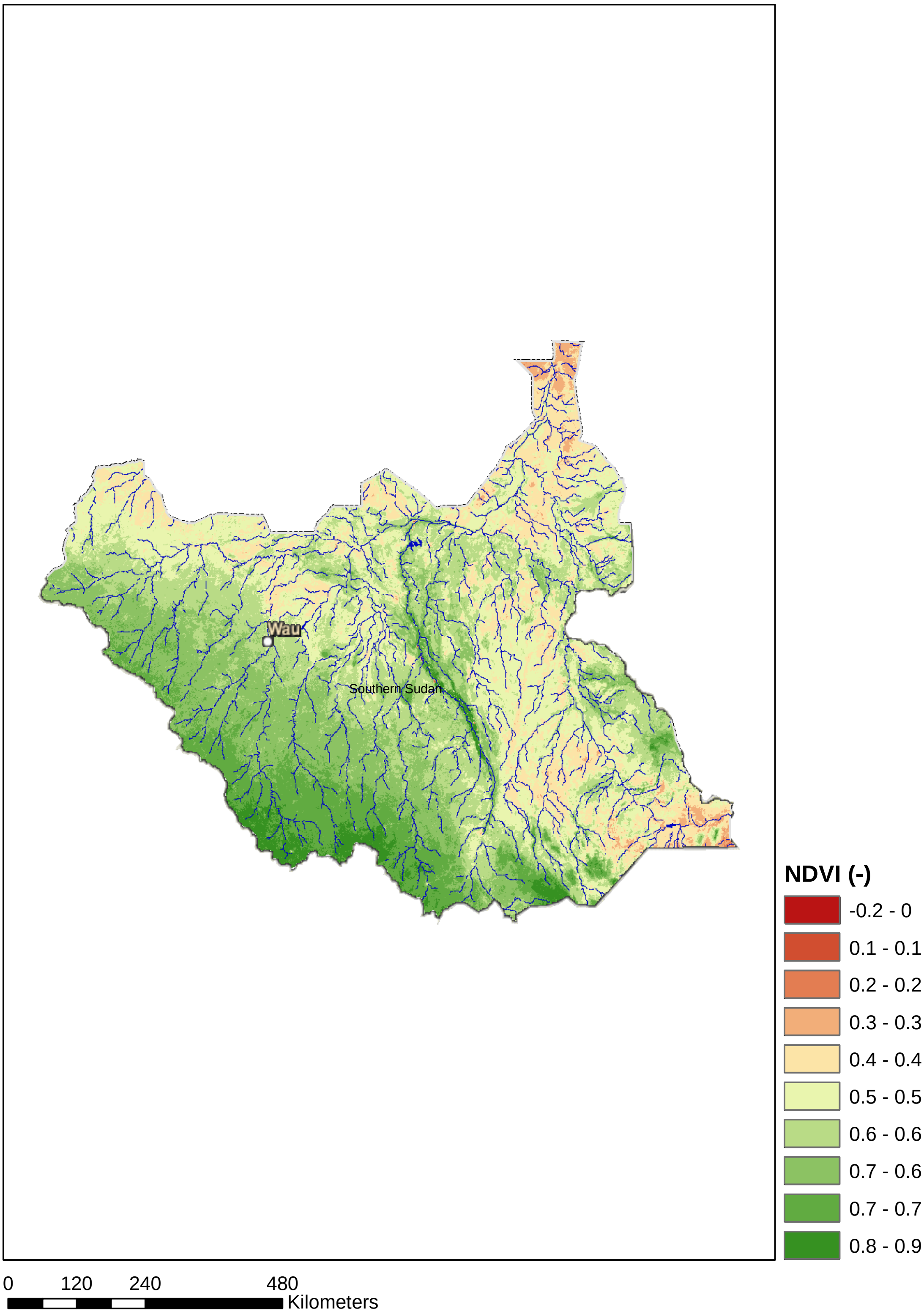


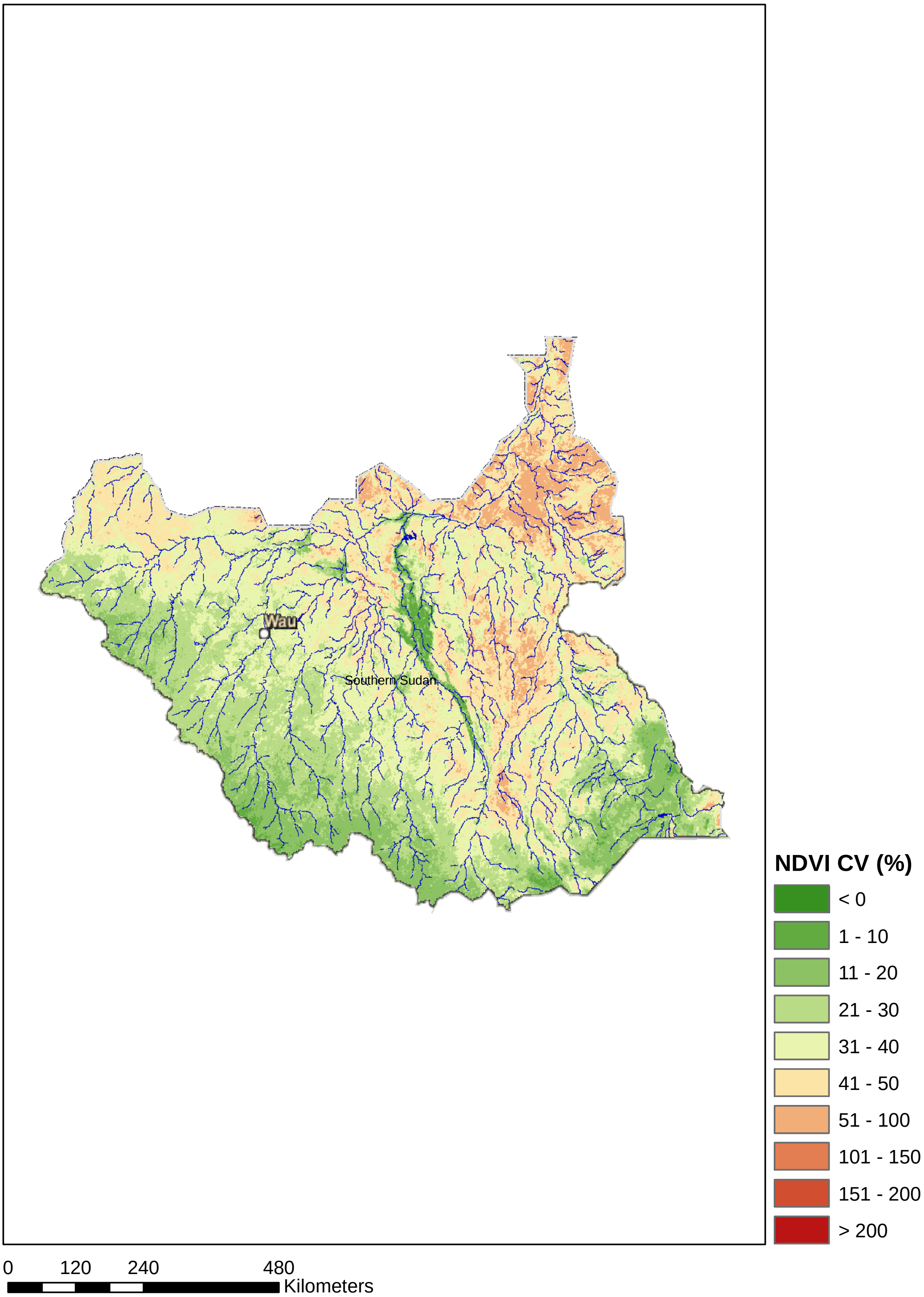
Figure 22. Irrigated (left) and rainfed cropping intensities[1] (right) as percentage of cells of about 10 x 10 km (Source: Mirca2000).

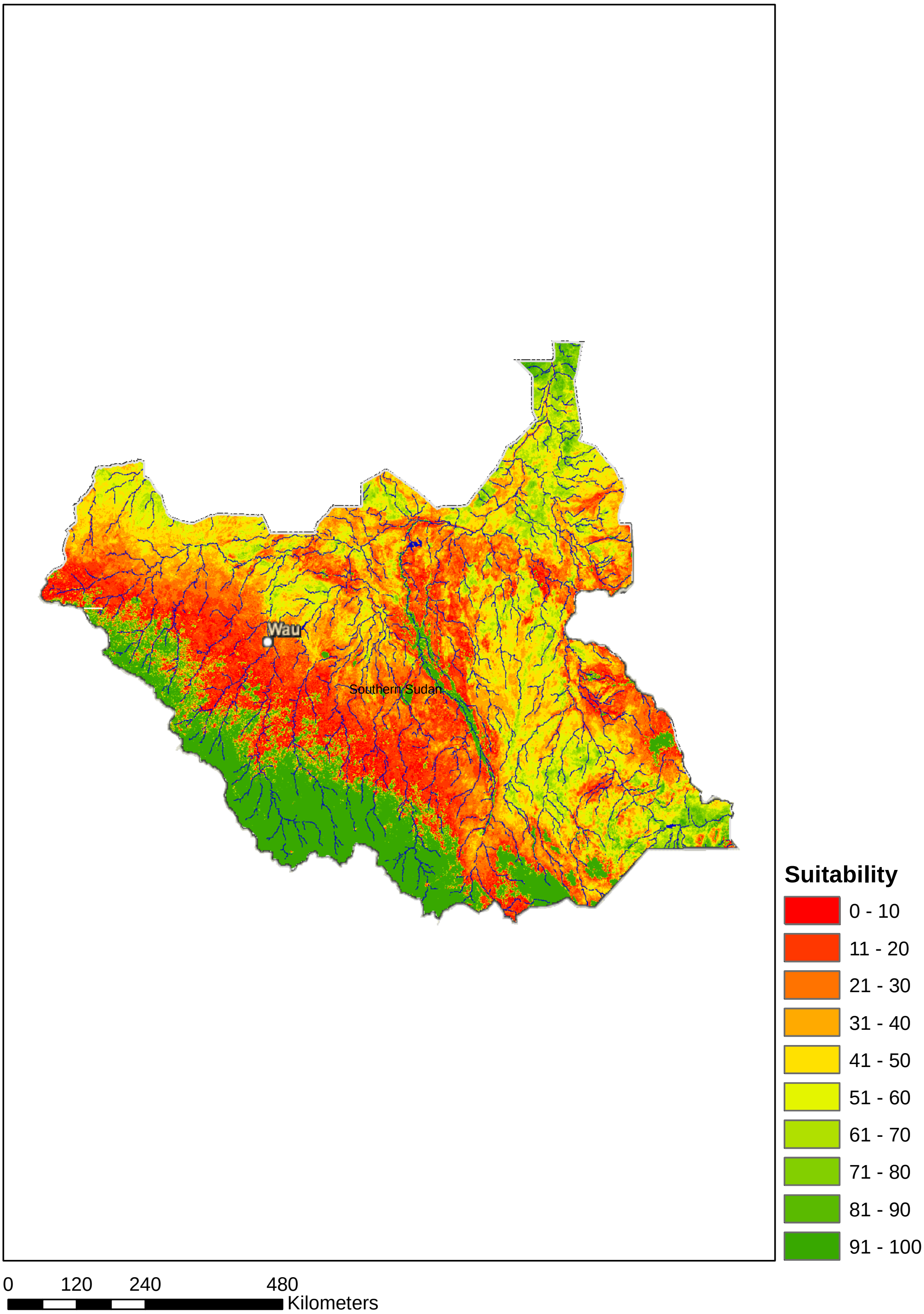
[1] Percentages can be above 100% as multiple cropping season might exist in one year.

2.3.2 Current land productivity (NDVI)

Current land productivity is assessed based on satellite information and is a good proxy of all integrated features like soils, slopes, management, vegetation, etc. Current land productivity in the country is very low and monthly variation is high.




Wau
Southern Sudan
NDVI CV (%)
< 0
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 100
101 - 150
151 - 200
> 200
0
120
240
480
Kilometers


Wau
Southern Sudan
Suitability
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
0
120
240
480
Kilometers

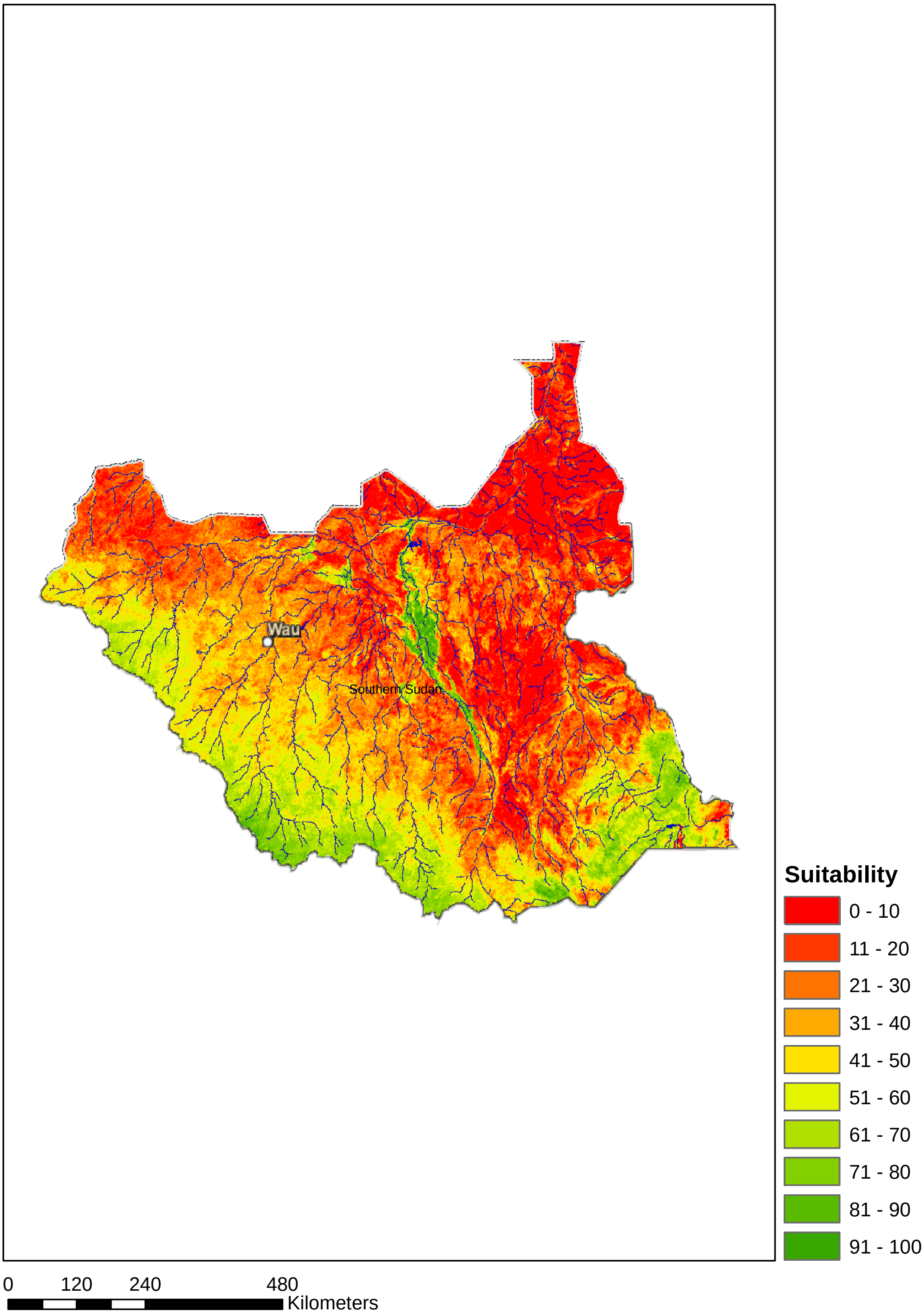


Figure 23: Current land productivity based on NDVI. Average NDVI (top), average monthly coefficient of variation (second), and the land productivity scores based on average NDVI (third) and monthly coefficient of variation (bottom). (Source: study analysis).

2.4 Agriculture

2.4.1 Backgound

With almost all of South Sudan's agricultural production being rain-fed, rainfall variability is a major factor in determining crop performance. There can be considerable variation in rainfall from year to year and also from location to location within the same year. In many lowland areas, flooding is a common occurrence, while many areas, especially those towards the north of the country, are susceptible to prolonged dry periods. Most crop production is carried out on small, hand-cultivated areas. Despite the abundant availability of land, the area cultivated by households is severely limited by labour shortages. Nationally, the average size of cropped area per household is estimated at about 0.75 hectares in 2011. Farmers commonly use their own seed saved from the previous year's harvest, and virtually no commercial fertilizers, pesticides or herbicides are used. Sorghum is the main crop cultivated in South Sudan; there is a very large number of local landraces and varieties ranging from short-season to very long-season (more than 220 days) and from short stature to very tall (more than 5 metres). Local diet also includes maize flour (largely imported from Uganda) and cassava (mainly produced in the Green Belt). Sorghum is often intercropped with sesame and millet. Maize is normally cultivated in limited areas close to homesteads and is often consumed green. Minor cereal crops such as bulrush millet, finger millet and upland rice are also cultivated in certain locations. Groundnut is cultivated on sandy soils in most locations and makes an important contribution to household diet; it is the main cash crop contributing to farming households' income at certain periods of the year. Sweet potato, yam, coffee, mango and papaya are commonly grown. Okra, cowpea, green-gram, pumpkin, bambara nut and tobacco are also widely grown around homesteads. Vegetables such as onions or tomatoes are not commonly grown in rural areas, but are increasingly cultivated near cities to supply urban markets.

Relatively long dry spells can occur, leading to crop losses and reduced yields (Howel et al, 1988). **Error! Reference source not found.** shows clearly, yields fluctuate from year to year, but are on average equal to about 0.9.

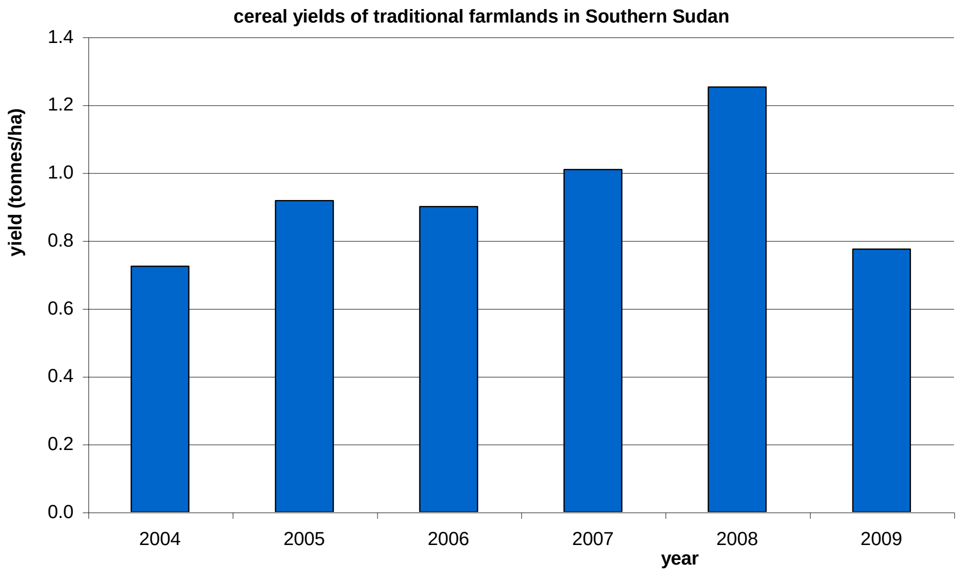


Figure 24: Cereal yields of traditional farmlands in South Sudan

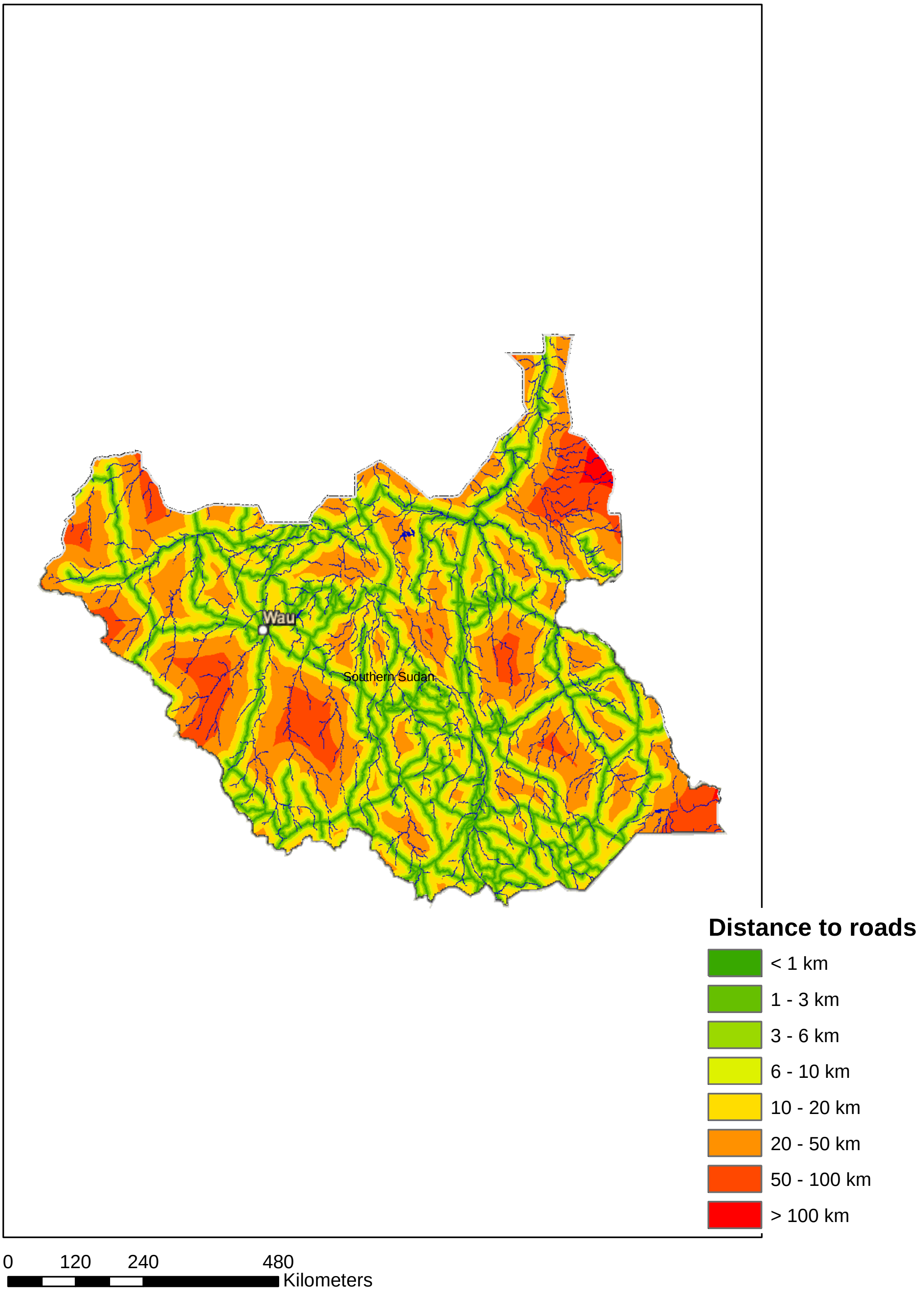
2.4.2 Potential crop yield assessment

Potential crop yield assessment is based on the so-called yield-gap analysis. Yield-gap is defined as the difference between the actual yield and the maximum obtainable yield. The yield-gap analysis is essential to show what might be an obtainable yield if all factors are optimal. Instead of using a so-called theoretical yield assuming that no restrictions exist, yield-gap analysis are based on realistic and attainable yields (details see main report). The analysis will therefore compare all countries involved in this study as well as the average of the continent and the highest value obtained somewhere in the world. Moreover, a trend analysis per country will indicate whether improvements can still being made.

2.5 Infrastructure

2.5.1 Access to transportation

Access to transportation is an important factor to be considered for irrigation development. Harvested products should be transported to markets and also supply of seeds, fertilizer and machinery require close distances to transportation means. Distances to roads, railways and/or waterways are taken as input to determine the suitability in this respect (for details see main report). Overall most part of the country has limited access to transportation.


Wau
Southern Sudan
Distance to roads
< 1 km
1 - 3 km
3 - 6 km
6 - 10 km
10 - 20 km
20 - 50 km
50 - 100 km
> 100 km
0
120
240
480
Kilometers

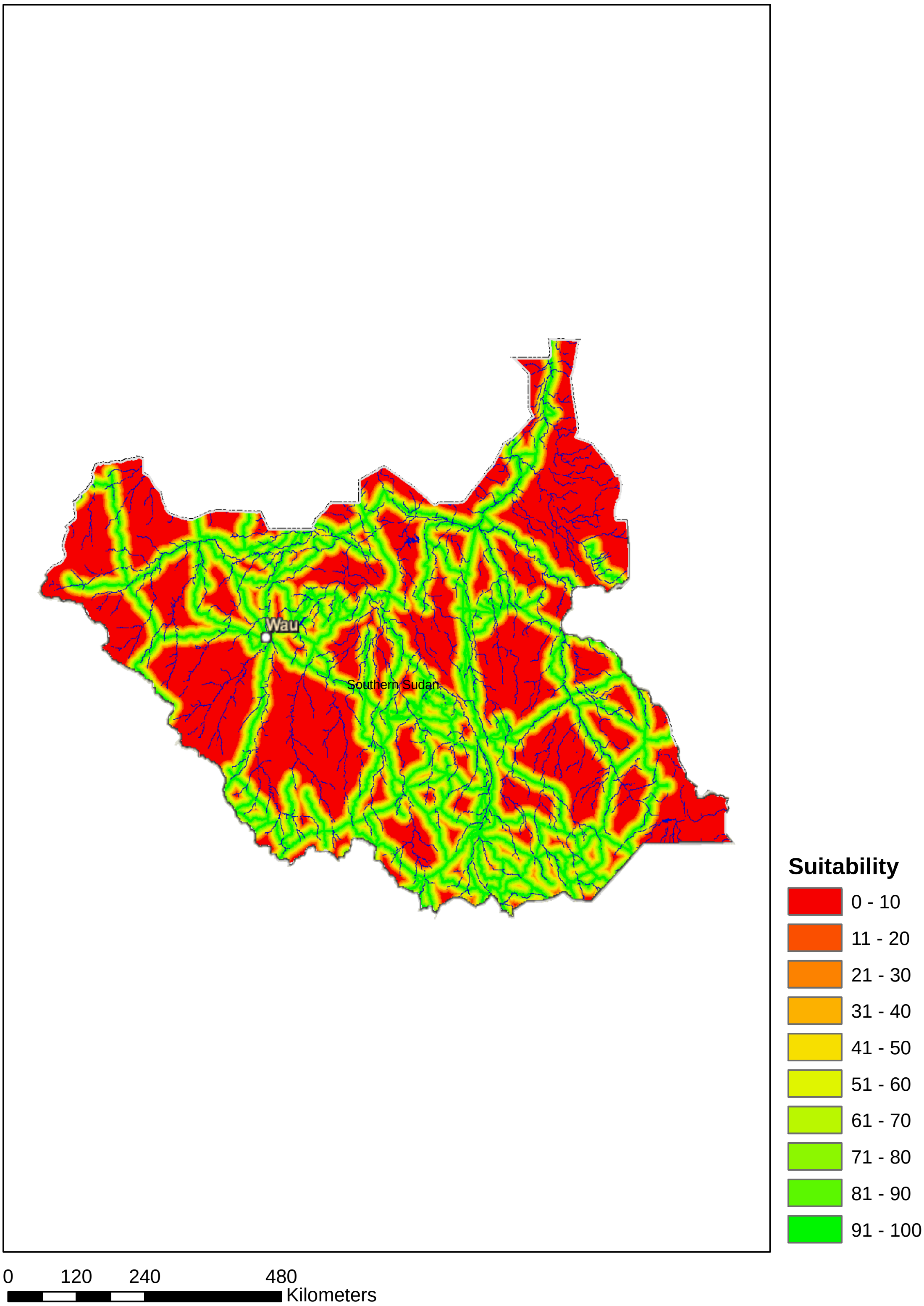
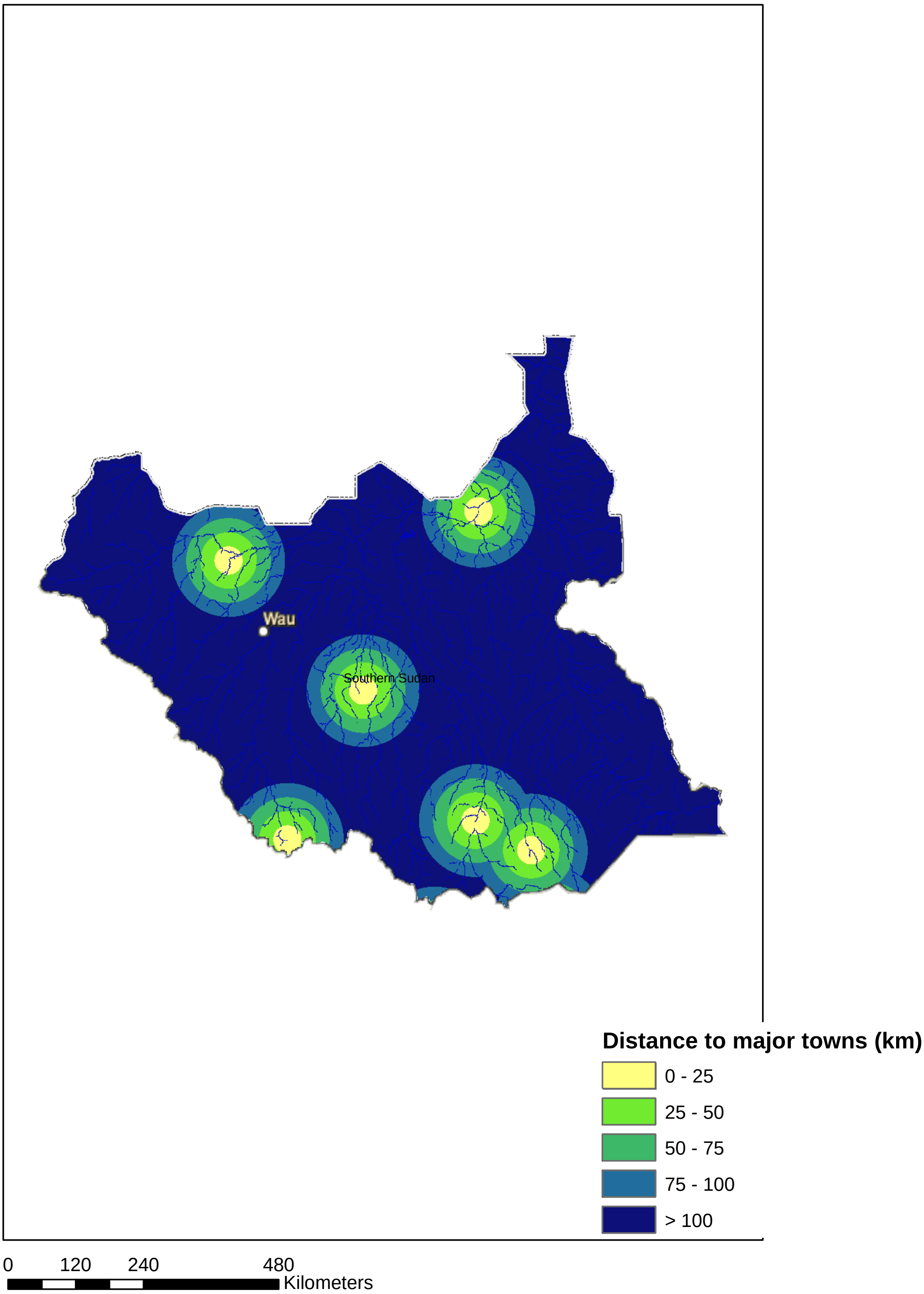
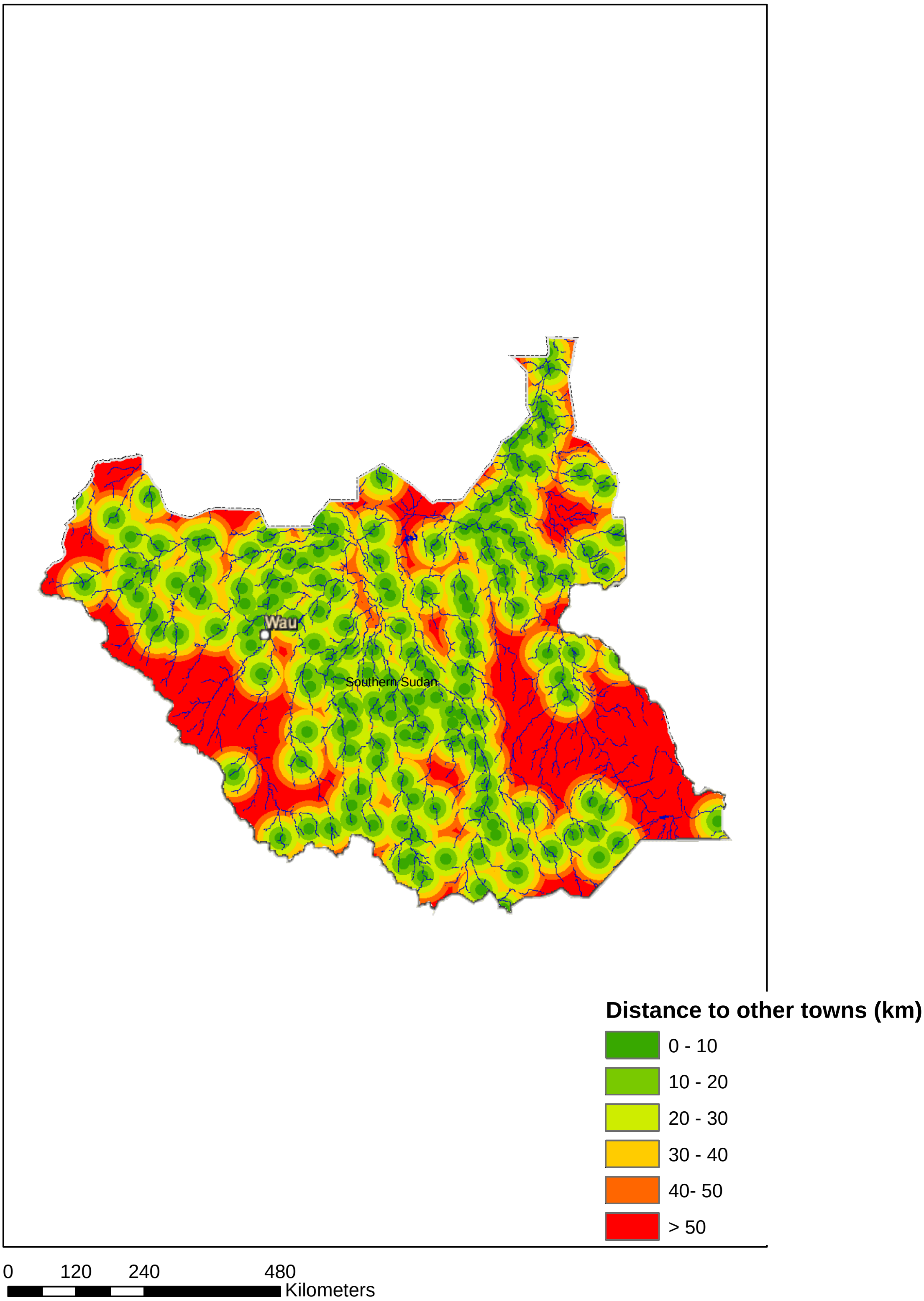


Figure 25: Distance to transportation (top), and suitability (bottom). (Source: study analysis).

2.5.2 Access to markets

Access to markets is an important factor if irrigated agriculture would be developed. Harvested products should be sold to the local, regional, national or world market. Distance to nearest markets is therefore an important factor to determine suitability for irrigated agriculture. Analysis is based on the distances to the nearest smaller cities and larger towns (see for details main report).




Wau
Southern Sudan
Distance to other towns (km)
0 - 10
10 - 20
20 - 30
30 - 40
40- 50
> 50
0
120
240
480
Kilometers

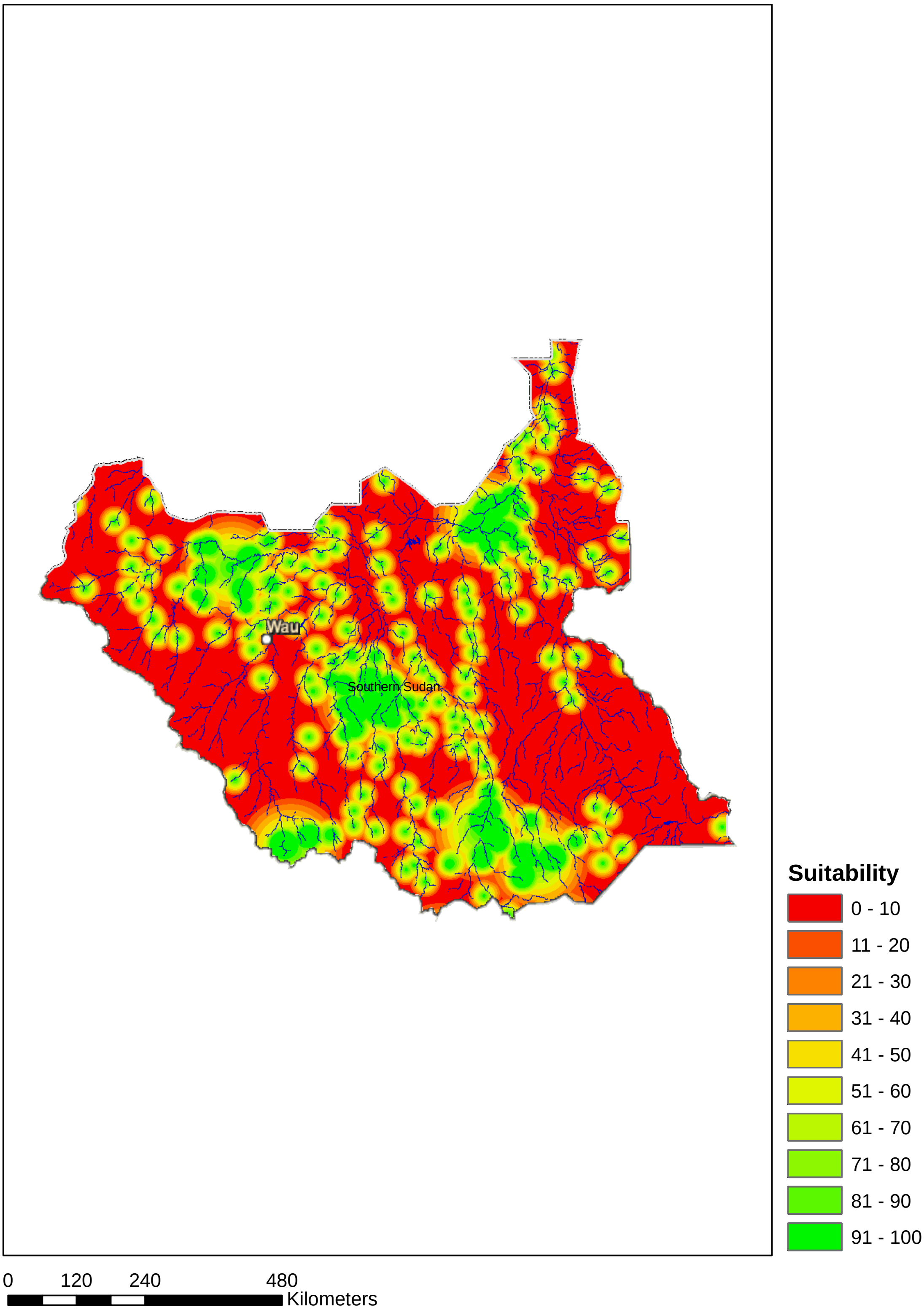


Figure 26: Distance to major towns (top), distance to other towns (middle), and combined suitability index (bottom). (Source: study analysis).

2.6 Population density

Population density should be considered in the context of irrigation. Highly-dens populated areas are not suitable for irrigation. On the contrary, areas where hardly anybody lives might face difficulties in terms of labor and markets. Total population of South Sudan is just over 8 million which is quite well distributed over the country with some regional differences. Population density can be observed in Figure 27.

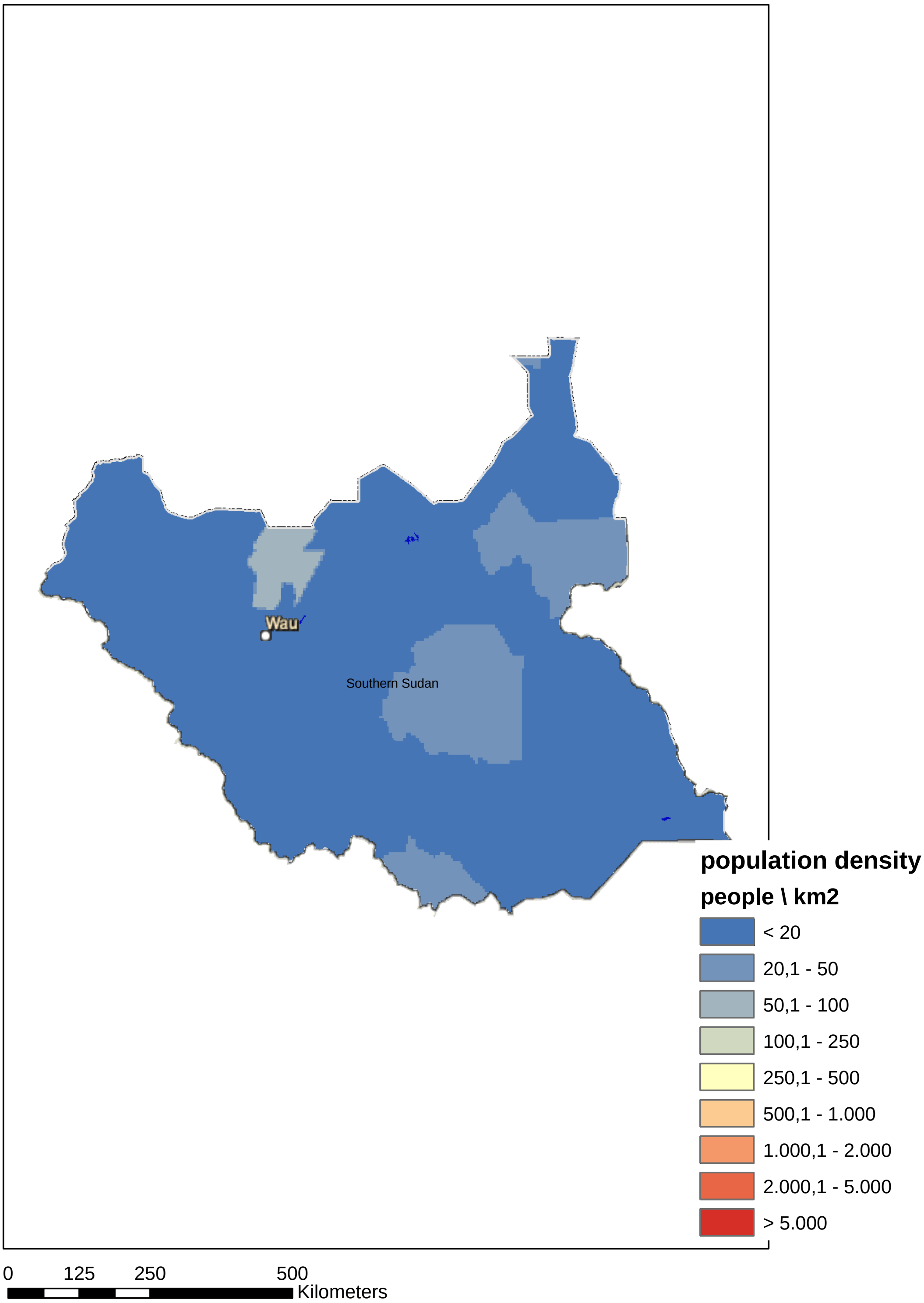


Figure 27: Population density distribution (source: CIESIN)

2.7 Institutional and legal framework

2.7.1 Water treaty agreements

Within the GOSS, the Ministry of Water Resources and Irrigation (MWRI) has overall leadership in the water sector. The Ministry has the responsibility for drafting and overseeing the implementation of policies, guidelines, master plans and regulations for water resources development, conservation, and management in South Sudan; encouraging scientific research into the development of water resources in South Sudan; overseeing the operation of the Water Corporation of South Sudan (WCSS); overseeing the design, construction, and management of dams and other surface water storage infrastructure for irrigation, human and animal consumption and hydroelectricity generation; setting tariffs; creating policy on rural and urban water resource development and management; making provisions for local community management and maintenance of constructed water supplies until state and local governments have the capacity to undertake such functions; initiating irrigation development and management schemes; protecting the Sudd and other wetlands from pollution; and advising and supporting the states and local governments in their responsibilities for water supply and building their capacity to assume all functions vested by the Constitution and GOSS policy.

The South Sudan Urban Water Corporation (SSUWC) was established to operate urban water facilities, improve their sustainability and expand the service coverage.

In December 2007, the GOSS passed the South Sudan Water Policy. The policy provides that access to sufficient water of an acceptable quality to meet basic human needs is a human right. The policy provides that the right to water shall be given the highest priority in the development of water resources; rural communities shall participate in the development and management of water schemes; and the involvement of NGOs and the private sector in water projects shall be encouraged. The policy also provides for the establishment of institutions at the central, state and county level, development of sub-sector strategies for rural water supply, urban water supply and water resources management, establishment of Budget Sector Working Groups, and creation of sector coordination mechanisms.

South Sudan is a member of the Nile Basin Initiative (NBI), a cooperative institution formed by 10 riparian countries in 1999. The purpose of the NBI is to achieve sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile basin water resources. The NBI has grant-funded Shared Vision Program supporting activities that build an enabling environment for investment, and a Subsidiary Actions Program for specific investments, such as irrigation and hydropower. The initiative also seeks to reverse land degradation and improve environmental management.

2.7.2 Land ownership rights[1]

Land has played an important role in the long lasting civil war and the associated civil, social, economic and political disorder. There is a great need for a stable policy and institutions securing property rights, which will contribute to peace and security in the region, and enhance economic, social and political development.

A land policy has been developed between 2006 and 2011. The goal of this policy is to strengthen land tenure security for all citizens.

[1] Based on the 2011 South Sudan land policy

The Land Act 2009, Section 7 recognizes three types of land tenure in South Sudan: public, community, and private land. Most land in rural areas is held under community tenure and rights are administered by traditional authorities. Most land in urban areas is held under public and private tenure, and is administered by statutory authorities. The Land Act 2009 and this Land Policy accord all three systems of tenure - community land, public land and private land--equal status before the law. This Land Policy endorses in general terms the existing patterns of land tenure as they relate to land use, that is:

- Community tenure will be the principal form of tenure in areas that are predominantly rural;
- Public and freehold tenure will be the principal forms of tenure in areas that are gazette officially as urban areas, under the Town and Country Planning Act;
- Public land also includes land over which no private ownership including customary ownership is established; roads and other public transportation thoroughfares; watercourses over which community ownership cannot be established; and forest and wildlife areas formally gazette as national reserves or parks;
- Peri-urban areas may be administered under community, public or private tenure, subject to principles of good land administration and planning and the comparative capacities of alternative tenure systems to administer land rights in given areas efficiently;
- It is the government’s intention to offer freehold title to the original holders of customary rights on community land converted to state land for purposes of urban expansion.

2.8 Irrigation potential

Based on information as presented in the previous sections, suitability for irrigated agriculture can be determined. Some information is more qualitative and presented as general reference to support decision making. Other information is quantitative and will be used to create maps to be used to support decisions to select areas that can be studied more in-depth

Results of the analysis are used to create an overall map of "suitability for irrigation". These maps (determining factors) are all scaled between values of 0 (not suitable) to 100 (very suitable). Note that many of these individual maps are composed by combining various other sources. By combining this information a total suitability map per country is produced. The following maps are used to this end:

- Terrain suitability
- Soil suitability
- Water availability
- Distance to water source
- Accessibility to transportation

Based on these maps, the final score indicating suitable for irrigation can be observed in **Error! Reference source not found.** and Table 5. Scores above 60% can be considered as potential suitable for irrigation, while scores above 70% can be considered as very suitable with only minor limitations. The overall suitability for the country is determined at about 24 Million hectare. In order to assess what limitations are in a certain areas, information from the previous sections can be used.

The suitability map as presented should be considered as the final map for irrigation potential. This map reflects the situation for surface irrigation and non-rice crops. The database attached to the report includes the digital version of these maps allowing zooming in. Moreover, this database includes also the maps with the determining layers that can be used to explore the limitations for a specific area.

It is important to realize that the suitability map has to be considered using other (non-determining) information and maps. Moreover, other factors like expert knowledge, existing policies etc. should play an integrated role as well.

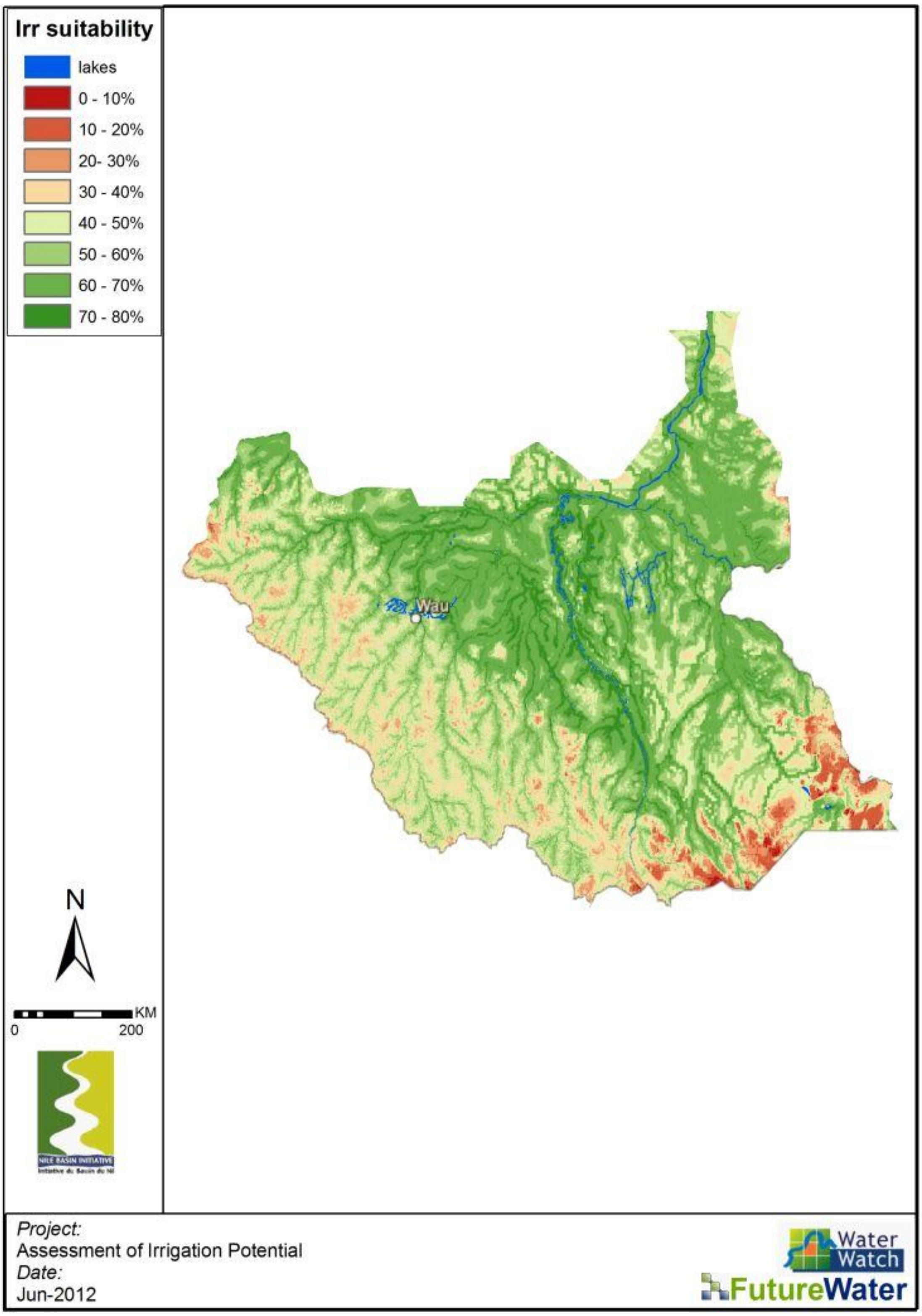


Figure 28: Irrigation suitability score

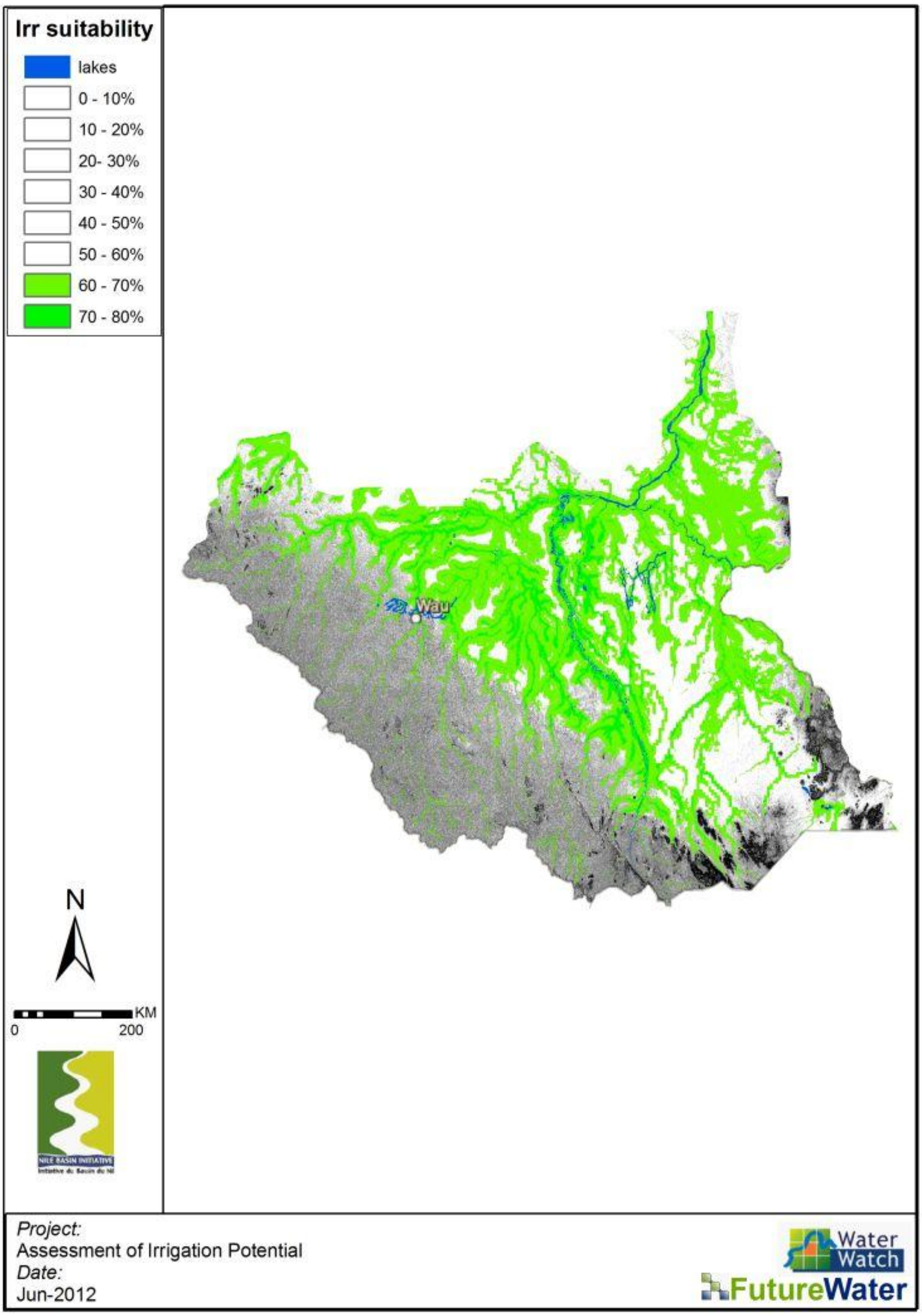


Figure 29: Final map indicating areas suitability for irrigation.

Table 1. Suitability classes.

Suitability	Irrigation potential (ha)
0 - 10%	81,494
10 - 20%	1,023,394
20 - 30%	1,856,750
30 - 40%	6,372,481
40 - 50%	13,773,494
50 - 60%	15,836,800
60 - 70%	20,320,056
70 - 80%	3,825,288
80 - 90%	0
90 - 100%	0
Total >60%	24,145,344

2.8.1 Focal areas

Based on the results from the first phase of the irrigation potential study and the local available expert knowledge and political considerations five focal areas have been delineated on which the second phase will focus. In the following chapters these focal areas will be studied on a more detailed level, and the possibilities for irrigation development will be described. In Table 2 the names and areas are given, and in Figure 30 a map is supplied on which the focal areas are shown.

Table 2: Focal areas South Sudan

	Jebel Lado	Pagarau	Aweil	Renk	Wau
Area in ha	3159	13832	17876	10231	5077

Figure 30: Overview focal areas South Sudan

3 Jebel Lado focal area

3.1 Introduction

This chapter will describe the current state of the Jebel Lado focal area, concerning land and water resources, and will discuss the potential to develop irrigation in the area. This irrigation potential will be based on the land and water resources, the irrigation requirements, the potential crop yields and will also involve the socio-economic considerations and institutional frameworks. Based on these aspects the potential for irrigation will be described, and cost for irrigation development calculated. In Figure 32 a detailed map of the area is given. Total area is 3160 ha.

Selection of this specific focal area was based on results of Phase 1 of this study, while final selection was the responsibility of the relevant country representatives. Results presented hereafter have been obtained from a broad range of sources: Phase 1, previous other studies and reports, modeling results, remote sensing, expert knowledge and field visits by Jal Fnom, Makuac Deng and Mary Loki as supervisor in April and May 2012.

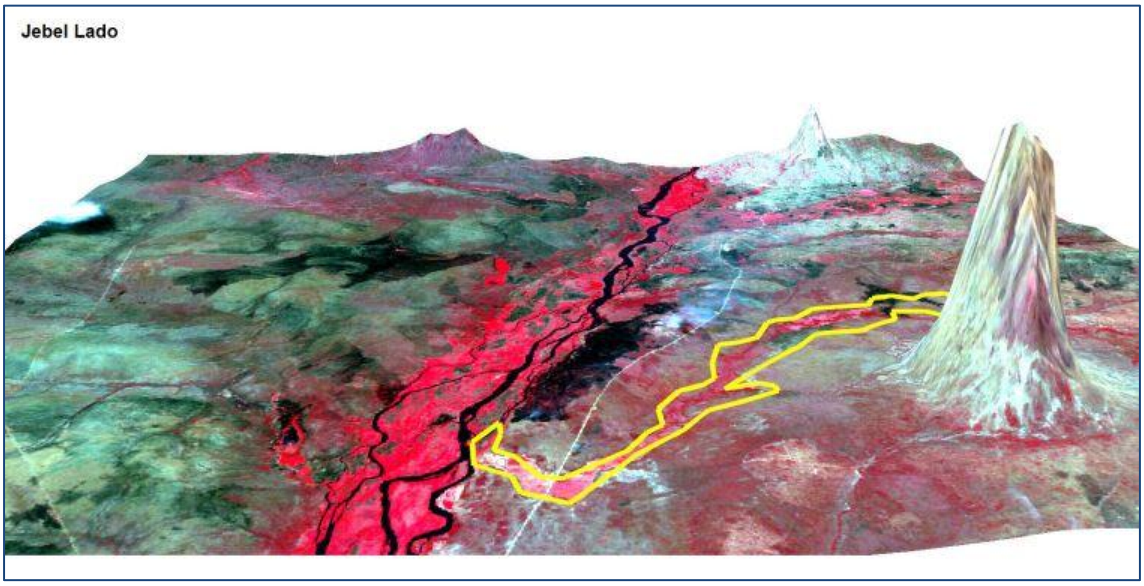


Figure 31: 3D impression of Jebel Lado focal area, South Sudan.

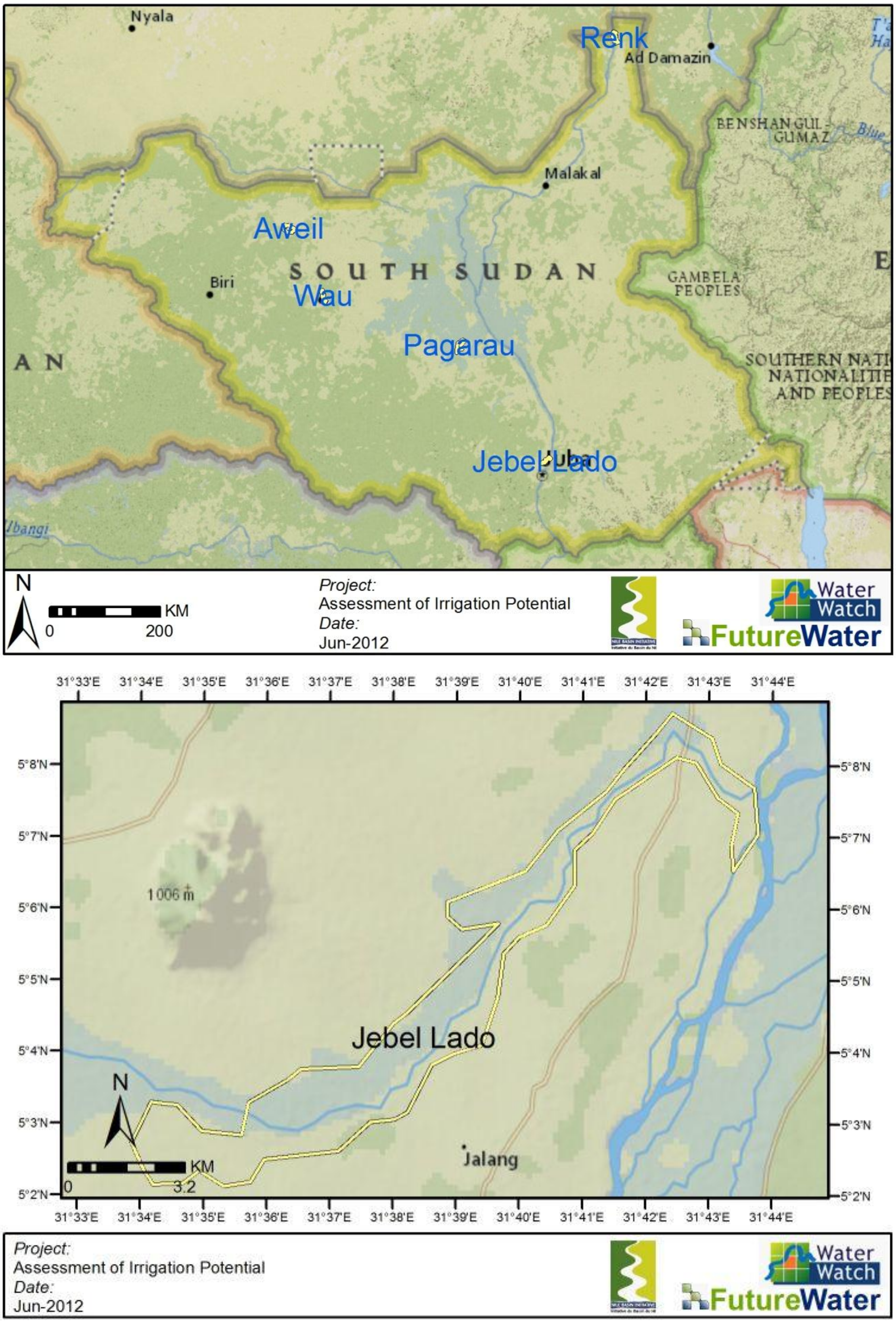


Figure 32: Jebel Lado focal area, South Sudan.

3.2 Land suitability assessment

3.2.1 Terrain

Jebel Lado focal area is situated in the South of South Sudan within the state of Central Equatoria. The focal area is wrapped around the eastern side of the mountain, and covers a stream valley. The stream valley runs from West to East, and drains in the East into the White Nile. The total surface of the focal area is 3159 ha, which mainly includes the riverbed. The land descends gradually from 470 m in the West, to 435 m at the junction with the White Nile (

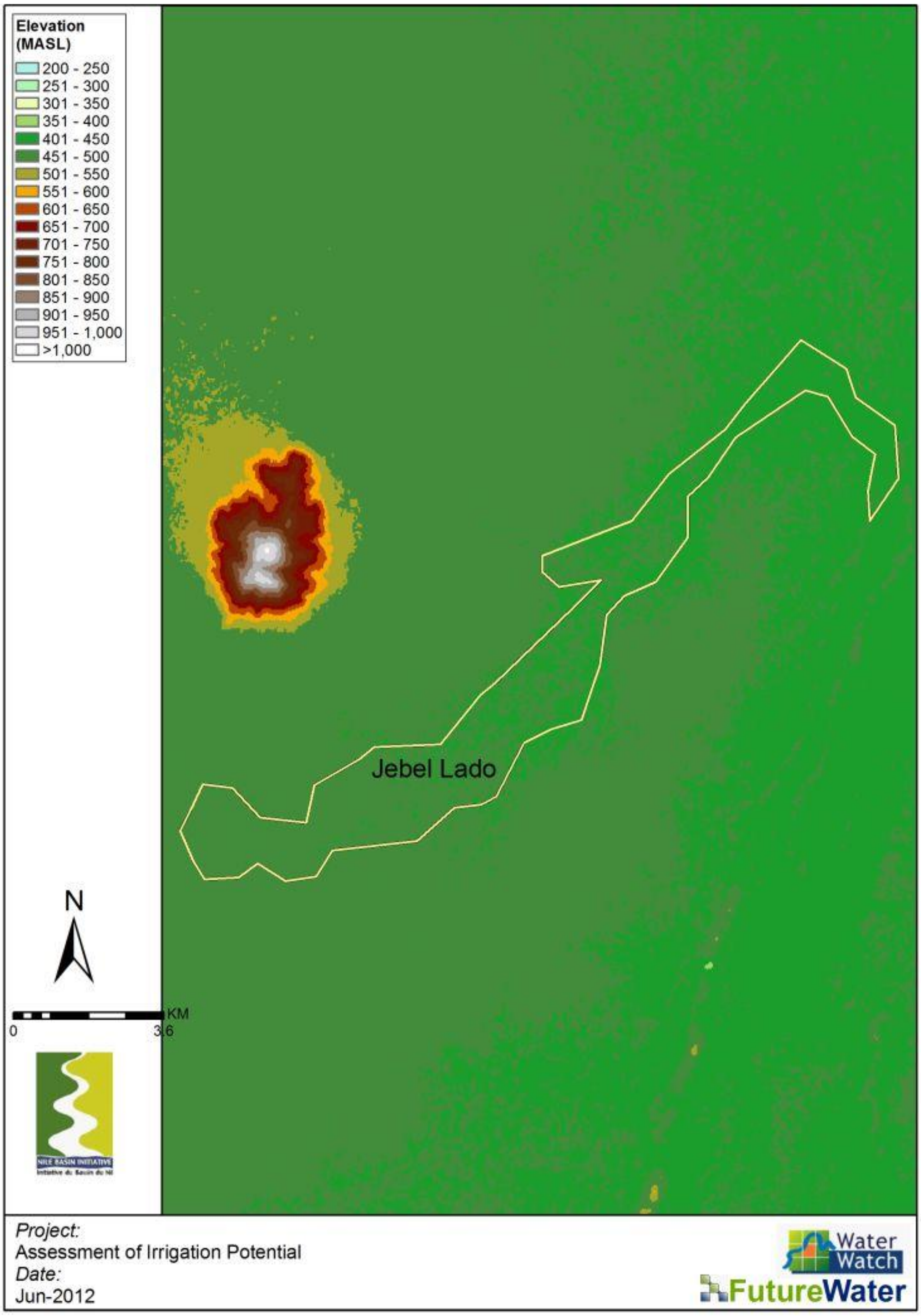


Figure 33). The slope of the focal area is very limited and mostly does not exceed 2% (Figure 34). On smaller scales, however, the slopes may reach locally up to 10%. The topography seems to be very suitable for surface irrigation.

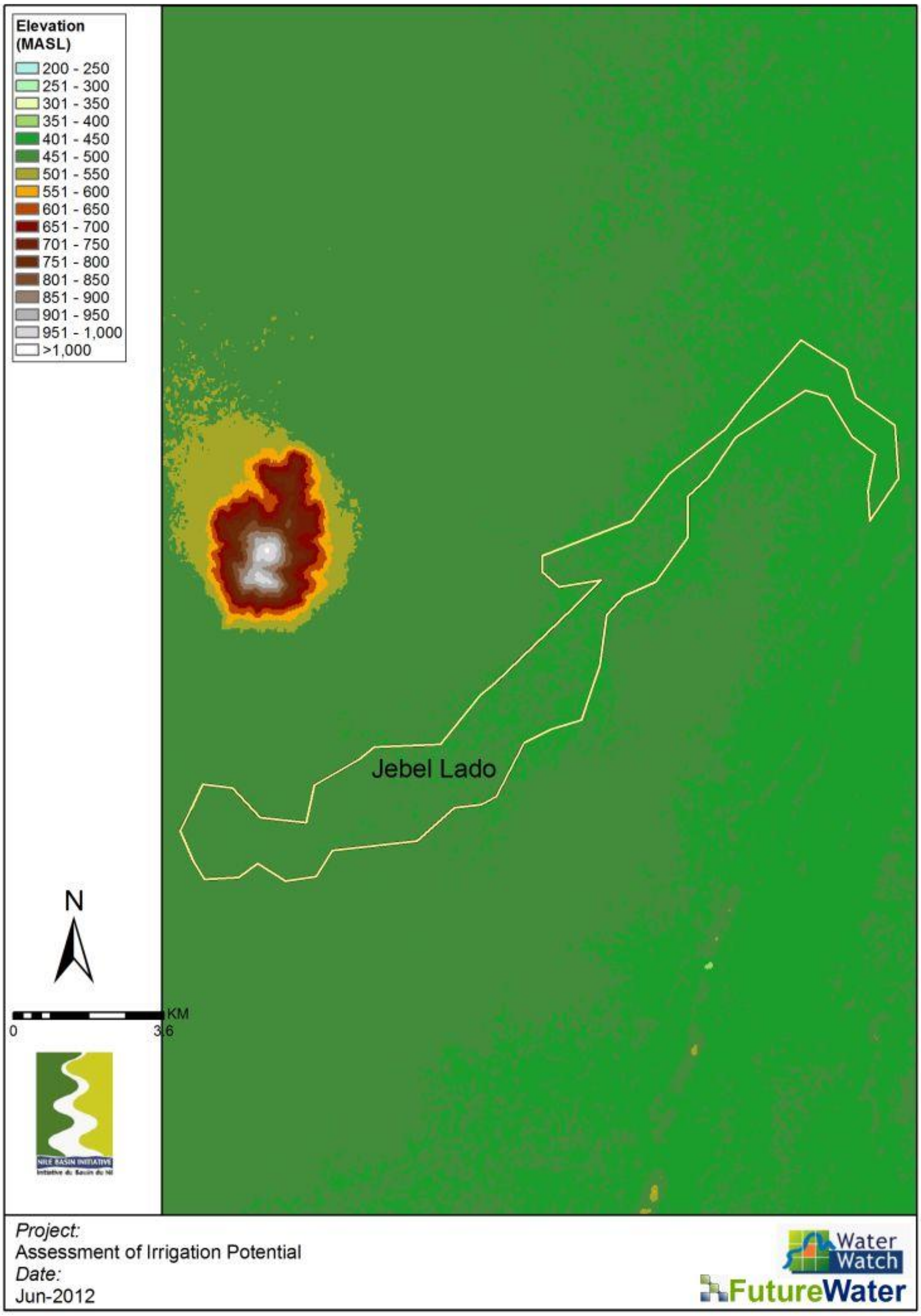


Figure 33: DEM Jebel Lado focal area. Resolution 1 arc second (+/- 30m).

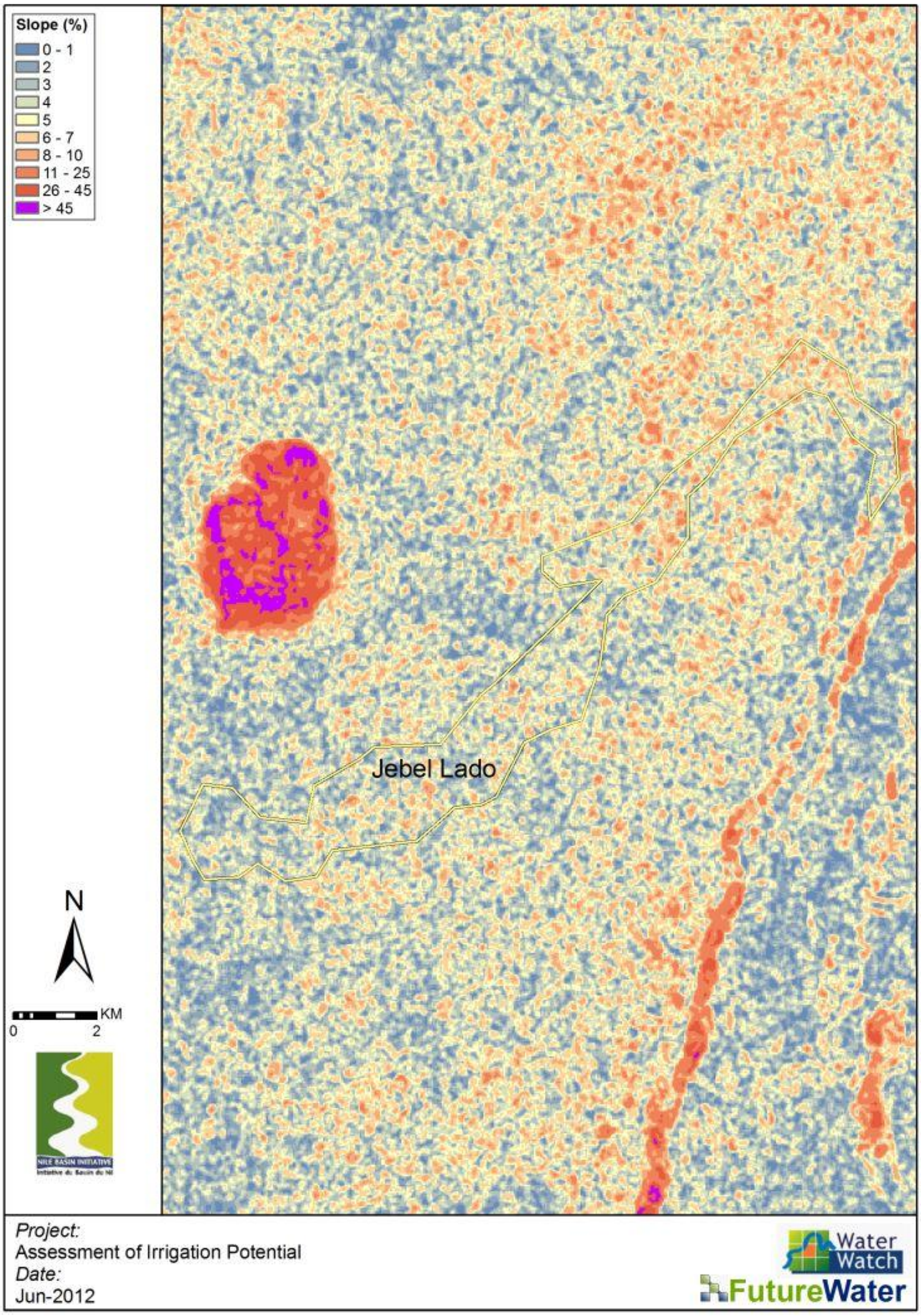


Figure 34: Slope map Jebel Lado focal area (source: ASTER).

3.2.2 Soils

The soils in the focal area are rather uniform. The soil in this river valley is formed under alluvial processes. The largest part of the area is a Fluvisol, with a smaller part having Gleysols. The soil mainly consists of sandy clay, towards loamy on some parts. Therefore, the drainage in the area is quite poor. The top soil is richer in organic carbon than the sub soil, and contains 0.6-1.2% organic carbon. The available water holding capacity is large with over 150 mm/m. Paddy rice cultivation is widespread on many tropical Fluvisols with satisfactory irrigation and drainage. Paddy land should be dry for at least a few weeks every year, in order to prevent the redox potential of the soil from becoming so low that nutritional problems (Fe or H2S) arise. A dry period also stimulates microbial activity and promotes mineralization of organic matter. Many dry land crops are grown on Fluvisols as well, normally with a certain form of water control. The main obstacle to utilization of Gleysols, is the necessity to install a drainage system to lower the groundwater table. Adequately drained Gleysols can be used for arable cropping, dairy farming and horticulture. If too wet soils are cultivated, then the soil structure will be destroyed for a long time. Therefore, Gleysols in depression areas with unsatisfactory possibilities to lower the groundwater table are best kept under a permanent grass cover or swamp forest.

Figure 35. Charateristics of Jebel Lado focal area.

3.2.3 Land productivity

The annual average land productivity (NDVI) in the five South Sudanese focal areas ranges between 0.30 and 0.60. Compared to the South Sudanese average NDVI of 0.50, the Jebel Lado focal area has an above average land productivity of 0.54 (Figure 37). The Bahr el Jebel river valley, together with the Nile river valley, has the highest land productivity. Within the focal area, the NDVI is highest in the stream valley with values over 0.6. Land productivity is decreasing further away from the river to values of 0.45. This is due to the changing soil type and water regime. The variation in land productivity over the year is quite large. Near to the Bahr al Jebel River, the variation in NDVI is lowest, and the variation increases nearly linear with the distance to the river.

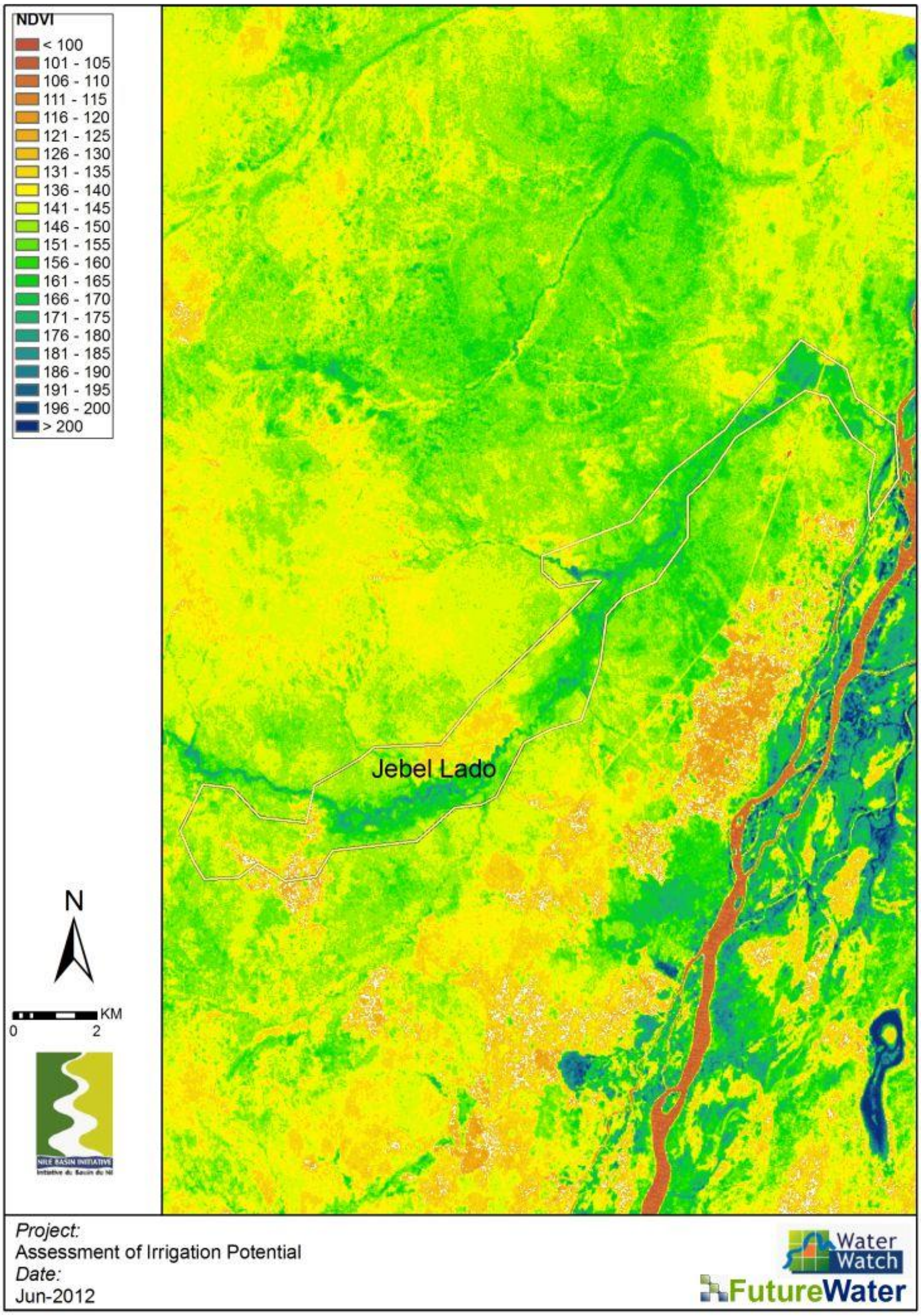


Figure 36: High resolution NDVI for Jebel Lado

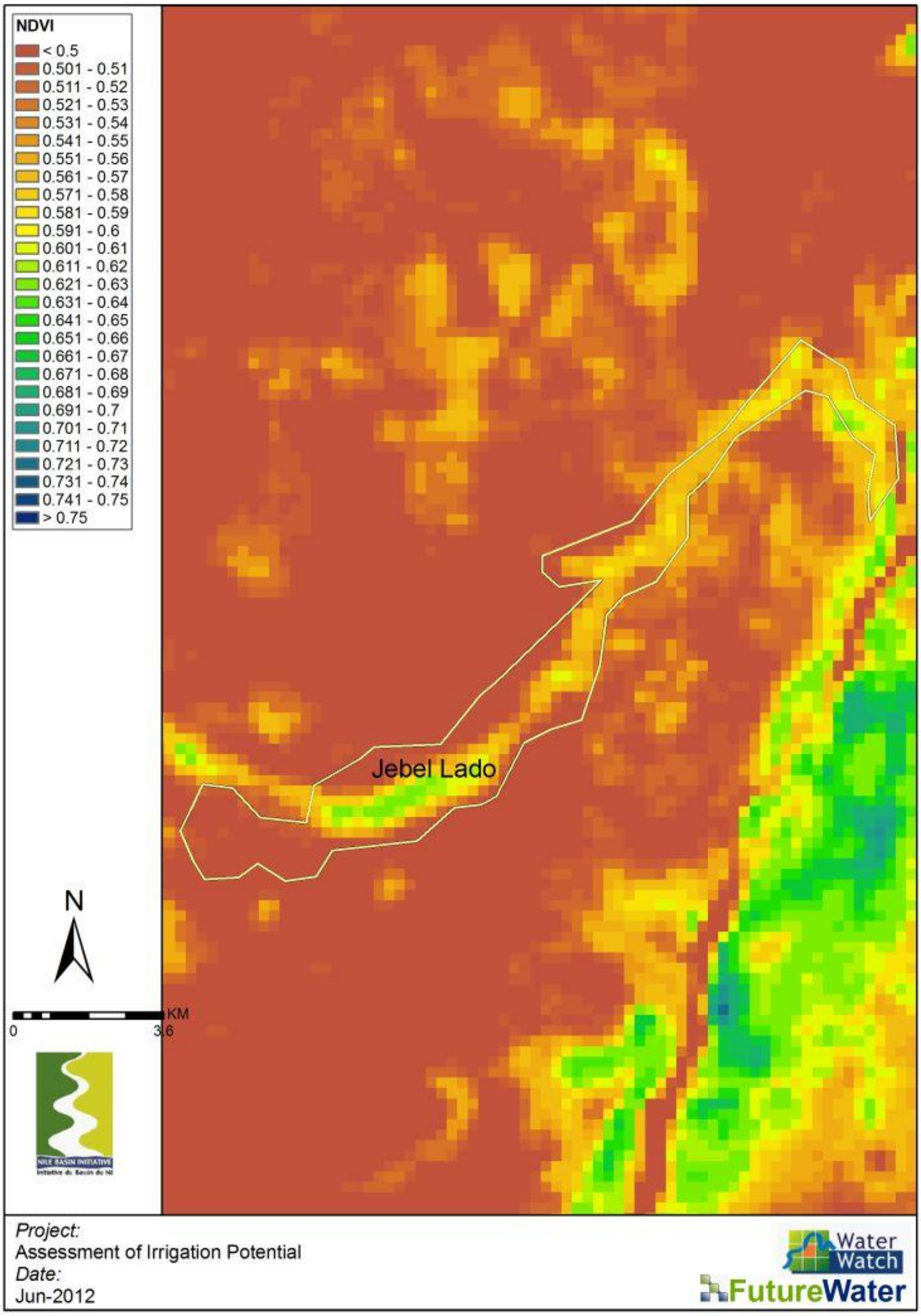


Figure 37: Yearly average NDVI values for Jebel Lado.

3.2.4 Potential cropping patterns

Currently, agriculture is practiced in a small part (10%) of the focal area. The remaining land consists mainly of sparse mixed vegetation and scrubland. Crops which are currently grown in the area include maize, sorghum, cassava and millet. They are all grown rain-fed, which incorporates that they are grown in one growing cycle per year within the raining season. When an irrigation scheme is developed, it is advised to focus partially on staple crops, such as paddy, maize, cassava, millet and vegetables and partially, with an eye on the future on cash crops, which could diversify the economy. However, the focus should be on crops that reduce hunger as first priority, and as second priority poverty, so that the economic situation of the rural area can be strengthened. If an irrigated part of the focal area can be used in two growing cycles per year, then food security increases and poverty decreases.

Figure 38. Charateristics of Jebel lado focal area.

3.3 Water resource assessment

3.3.1 Climate

Average climate conditions for the area are shown in the figure below. Precipitation is based on an advanced calibration/validation algorithm using satellite derived precipitation and calibrated using local observations. Details can be found in the Phase 1 Report. Reference evapo-transpiration (ETref) is calculated using the well-known Penman-Monteith approach. Input data for ETref is based on local observations and an advanced spatial downscaling algorithm.

The climate of the area can be characterized as warm with temperatures during the year ranging from about 24^{o}C to 36^{o}C. Annual average precipitation is 952 mm and reference evapotranspiration 1851 mm per year.

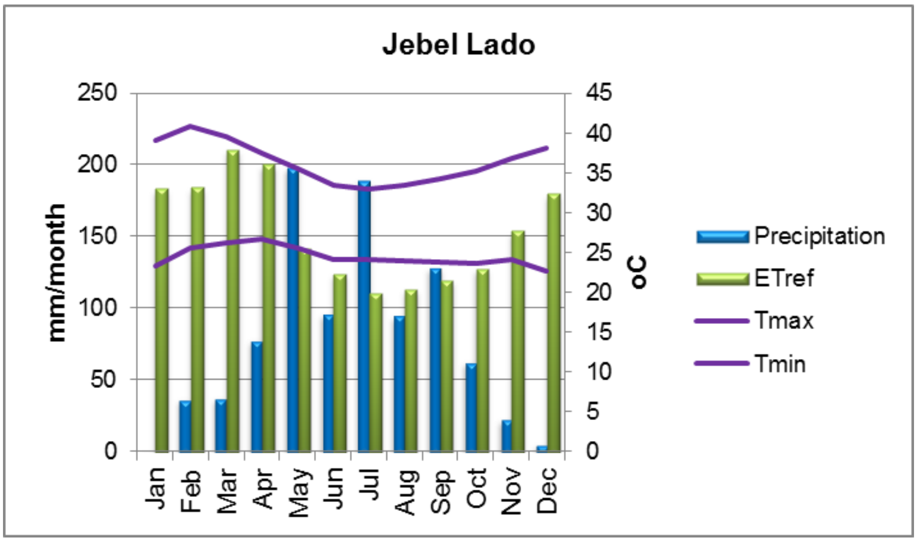


Figure 39: Average climate conditions Jebel Lado the focal area.

3.3.2 Water balance

A very detailed high resolution model was built for NEL countries (NELmod). For a detailed description see Phase 1 report. Results from NELmod were extracted for this specific focal area and are shown below. It is clear that during November till April the water demand by crops cannot be met by rainfall. It is also clear that quite some groundwater recharge occurs in the region, opening the venue to develop groundwater based irrigation.

The focal area is located in the state Central Equatoria. Already quite some existing boreholes and water points can be found in the region (Figure 40).

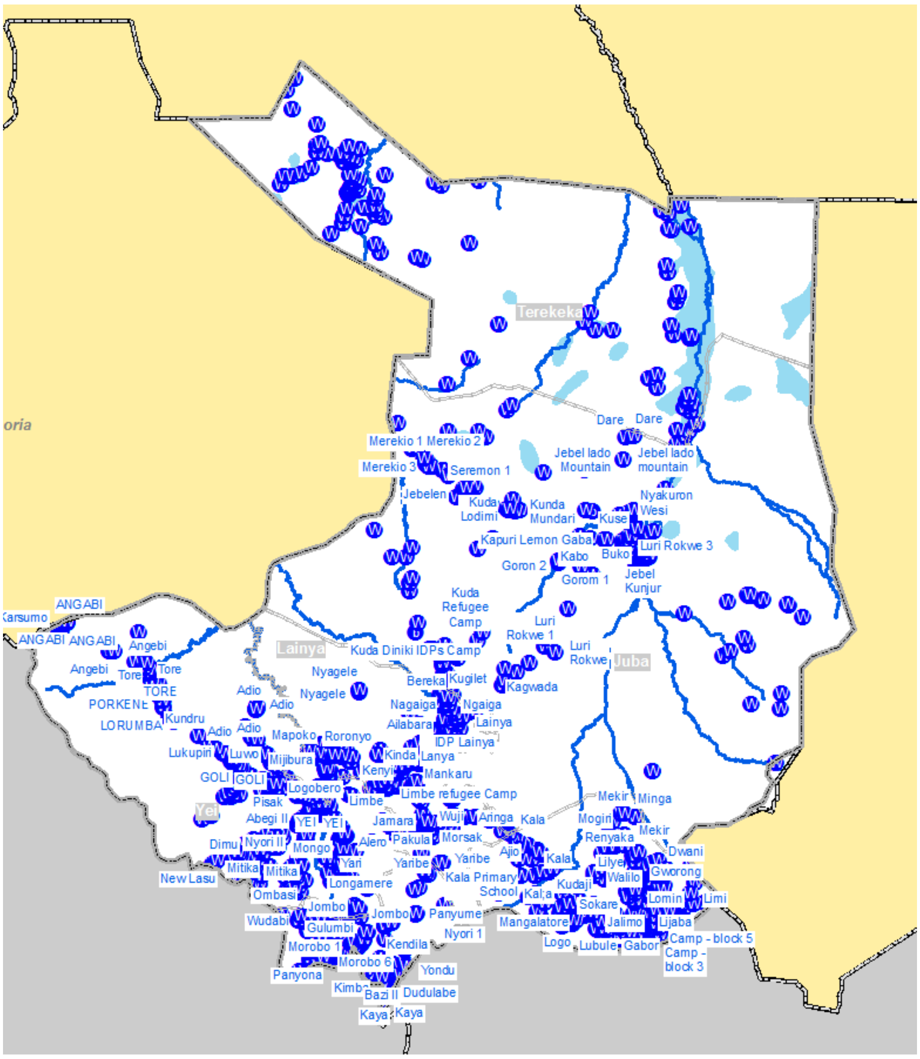


Figure 40. Boreholes (B) and Waterpoints (W) in Central Equatoria province in South Sudan (source: South Sudan Information Management Working Group).

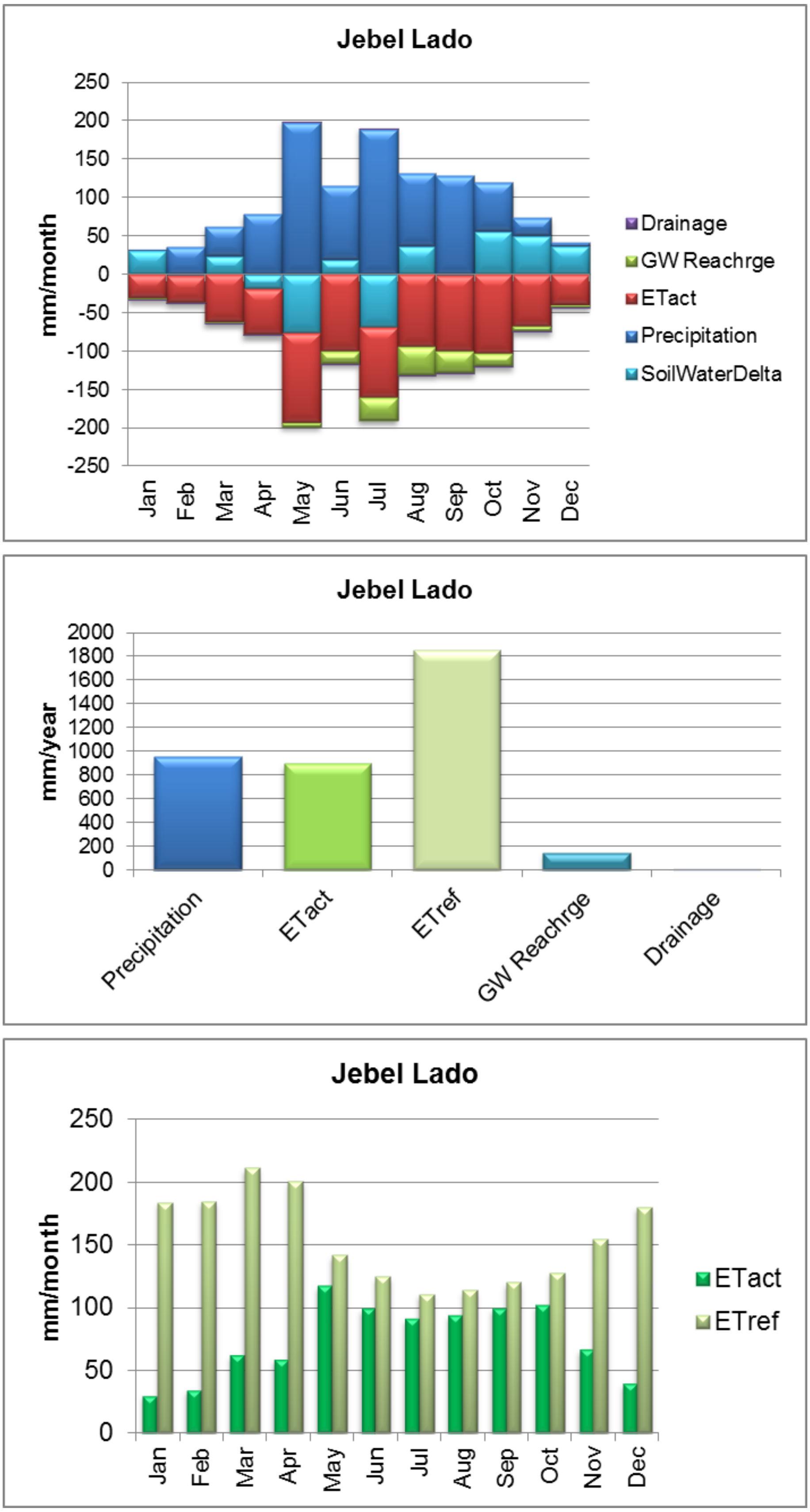
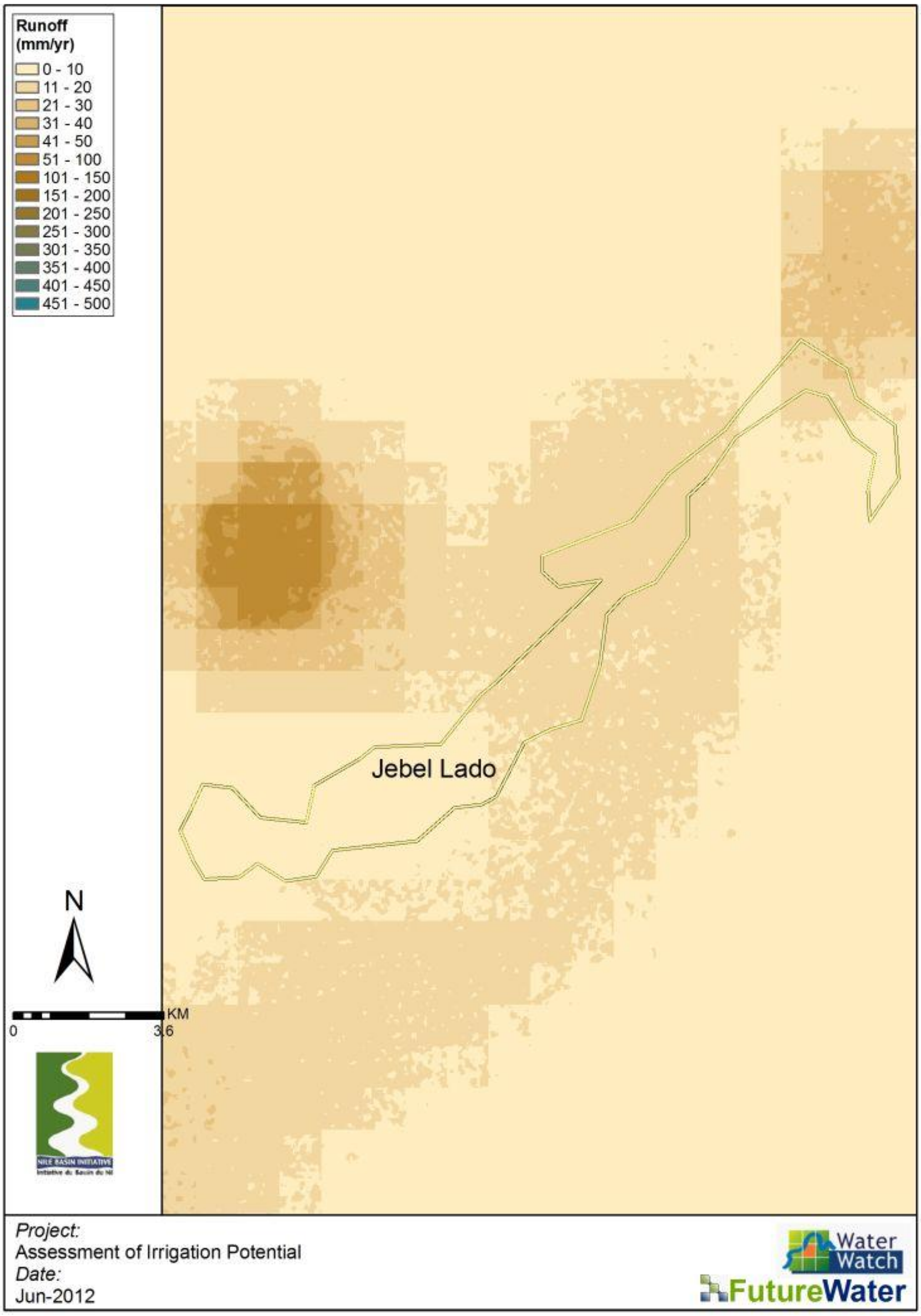
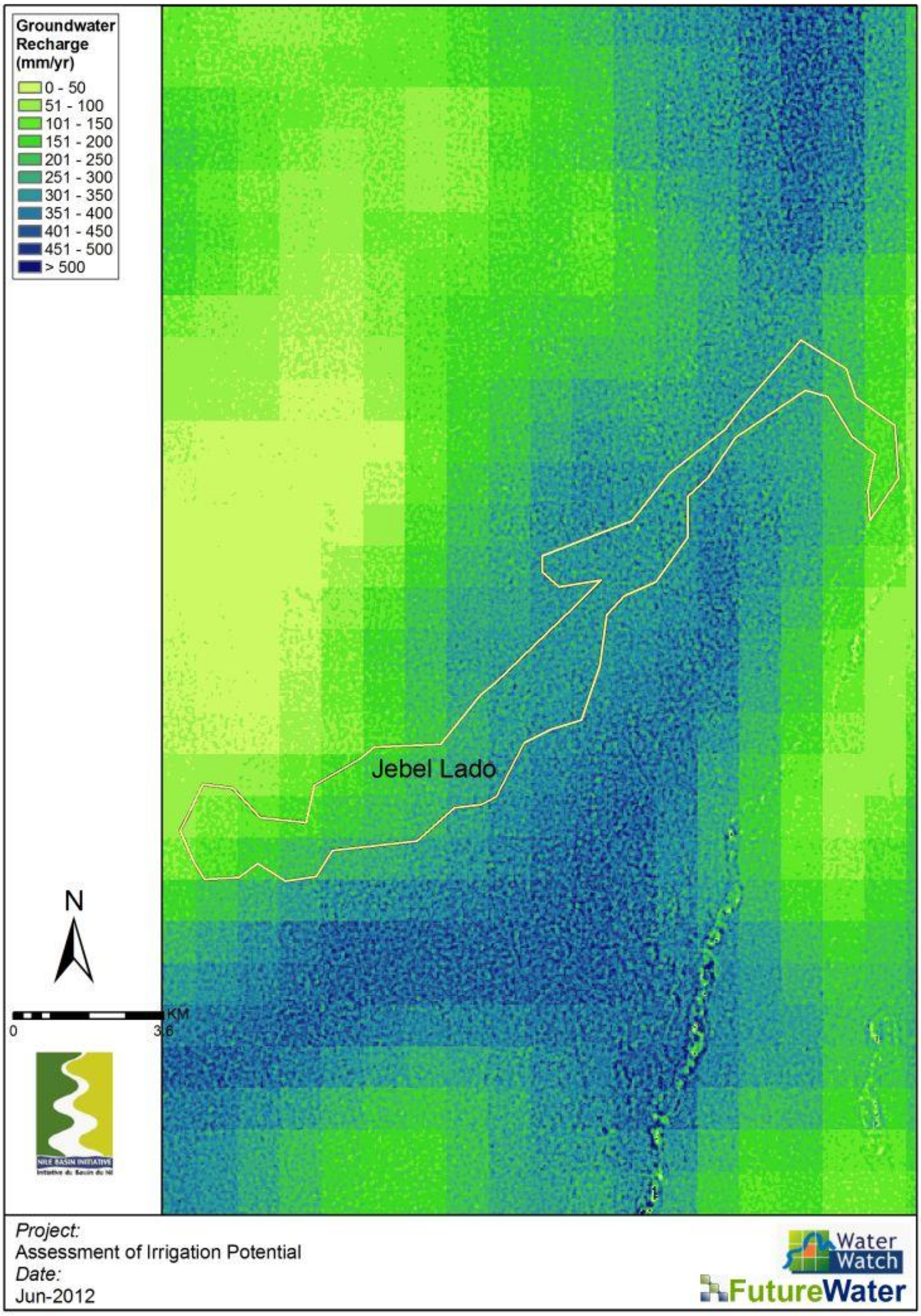


Figure 41: Water balances for the area based on the high resolution data and modeling approach for Jebel Lado focal area.


Runoff
(mm/yr)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
451 - 500
Jebel Lado
N
KM
0
3.6
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater


Groundwater Recharge (mm/yr)
0 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
451 - 500
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Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

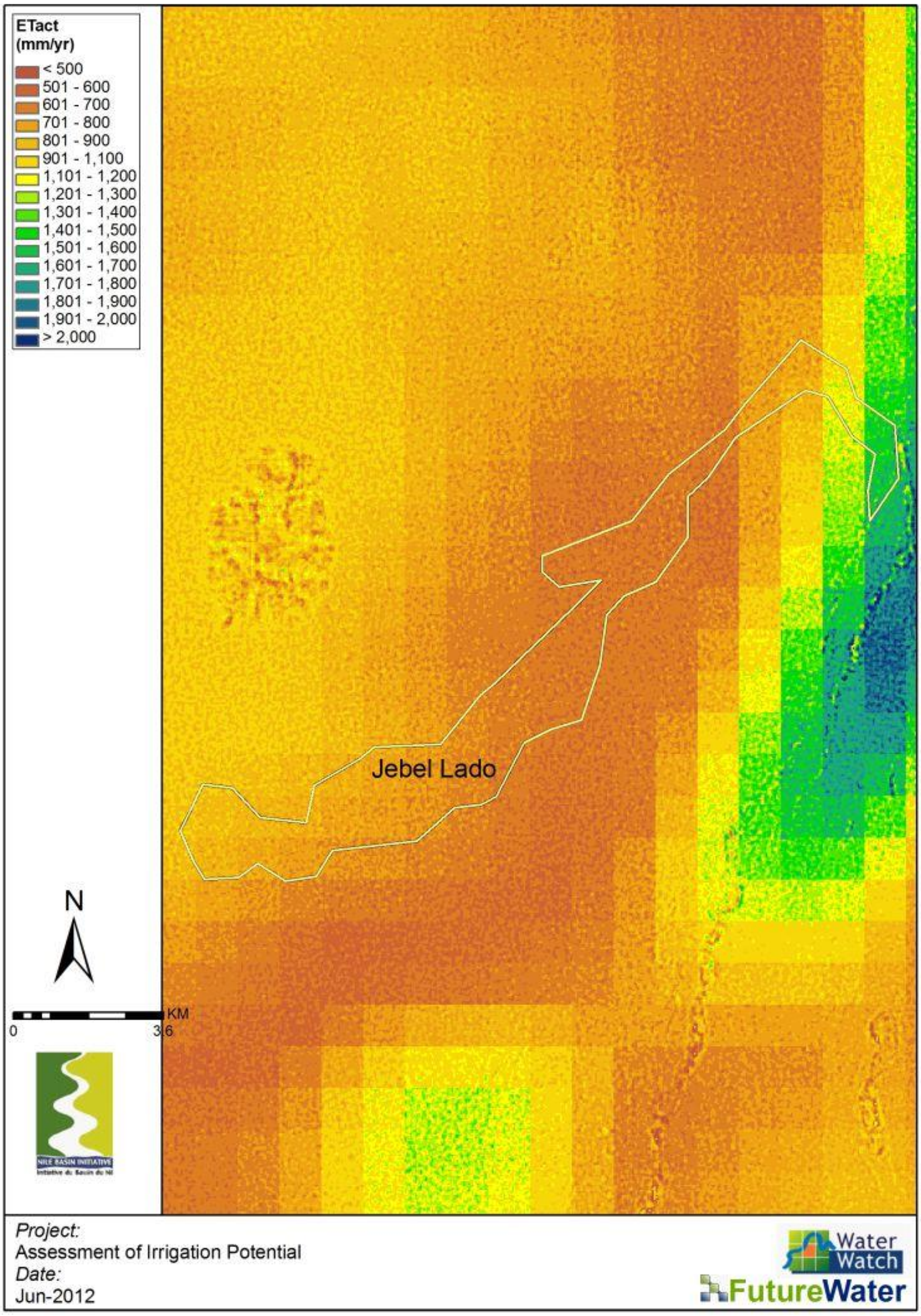


Figure 42: Water balances for the area based on the high resolution data and modeling approach for Jebel Lado focal area.

Figure 43. Charateristics of Jebel Lado focal area.

3.4 Assessment of irrigation water requirements

3.4.1 Irrigation water requirements

Irrigation water requirements depend on many factors such as: climatic conditions, crop, growing season, irrigation practices etc. A first estimate of irrigation requirements could be based on the difference between rainfall and reference evapotranspiration. It was however selected for this pre-feasibility assessment to provide a first estimate of irrigation needs based on the most promising crops. To this end, FAO's AquaCrop, the successor of CropWat was setup for local and crop specific conditions.

In the table below the irrigation water requirements for each selected crop are provided based on AquaCrop calculations. All units are provided in mm per growing season for the specific crops. Note that for various crops, like vegetables and similar crops, multiple croppings per years might occur.

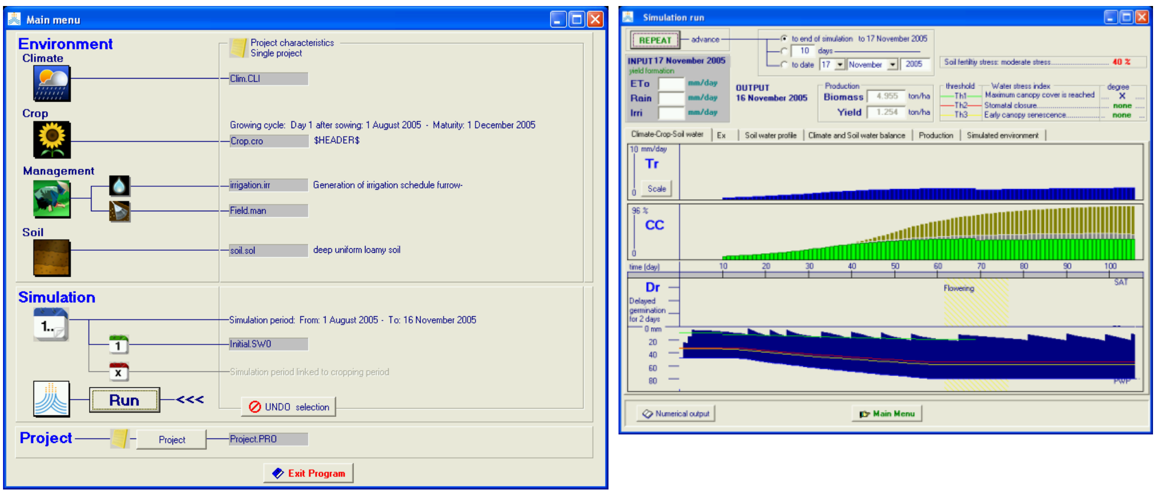


Figure 44: Typical example of AquaCrop input and output screens.

Table 3: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season.

Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year	===	== (day of year) ==		======== growing season =======			
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Maize	952	1851	121	238	560	130	469	433
Cassava	952	1851	121	350	791	120	981	505
Millet	952	1851	121	243	577	120	492	454

3.4.2 Irrigation systems and irrigations efficiencies

The Bahr el Jebel River that flows through the focal area drains an approximate area of 1300 km^2. The river water is enough to irrigate the entire area, but some water storage is needed as water levels in the dry season may run low. The topography of the focal area is very suitable for gravity surface irrigation, as the area descends very gradually towards the East. For rice production border irrigation is recommended, and then preferably as close to the river as possible. The efficiency of border irrigation is low, but on the other hand investment costs are much lower as for sprinkler or drip irrigation. Sprinkler and drip irrigation use the available water twice to three times as efficient and these systems may be considered to be used a little bit more up slope, where gravity irrigation will not be possible. Due to the low population density, the human resources are a serious topic to consider when opting for one irrigation technique. In the areas where gravity irrigation is possible, furrow irrigation can be considered to irrigate maize, vegetables or cassava.

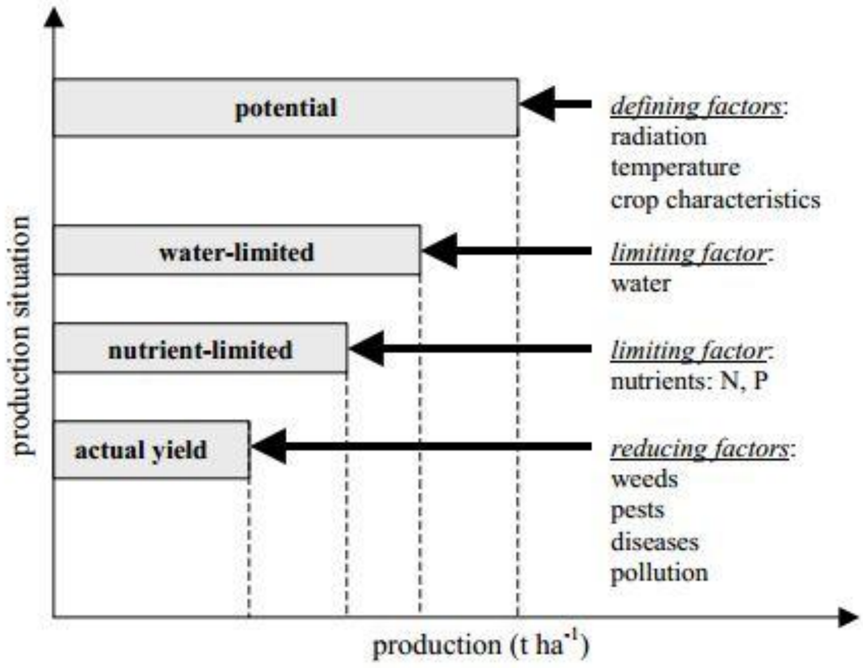
3.4.3 Water source

The Bahr el Jebel River flows through the area, and will be the main water source for irrigation. The river drains an approximate area just under the 1300 km^2 and the river has an average flow of 5 m^3/s, which will be sufficient to irrigate an area of 5000 ha. However, the seasonal variation in flow is large as precipitation is close to 0 mm/month from November to March. Therefore, and to control the flow, it is recommended to build a reservoir, or a series of small reservoirs upstream. These reservoirs can also be used as an intake for a primary canal, following the contour lines to keep the water on elevation for gravity irrigation. If water is limited, there is always an option to use the Nile water to irrigate the eastern part of the focal area. This will require pumping, which increases the conveyance costs, requires some control of the river Nile, which may be problematic. Therefore this will not be the preferred option.

3.5 Potential crop yield assessment

The yield gap describes the difference between the current yield, and the maximum possible yield. Mostly the maximum possible yield is defined as the highest yield in the world, but it can also be assessed against a regional background which makes the yield gap more realistic and the maximum yield possible to achieve under the given circumstances.

The gap between the actual yield and the potential yield can be caused by several processes. Factors which may cause that the maximum possible yield is not reached can be the water availability, the soil and the available nutrients, or yield reducing factors like diseases, weeds or pollution.



3.5.1 Yield gap analysis potential dominant crops[1]

Yields in Sudan are relatively high compared to surrounding countries. There is, however, a large differentiation between crops. Sudan has extremely high yields for dry beans, bananas, sugar cane, sweet potatoes and potatoes. For paddy and cotton seeds, Sudan performs better than the world's average yields. Most probably this finds its origin in the intensification and irrigation programs, which have been introduced in the past to increase food production and to meet the demand. In Figure 45, the yield gap is shown relatively to the highest obtainable yield in the world, to the world's average, and to Africa's average. Within Jebel Lado focal area the yields are slightly higher than Sudanese average yields. For Cassava the yield gap is large as Sudan get yields at 25% of the East African average. With irrigation, the yields for Cassava can at least reach towards this East African average, which would mean a fourfold production. Production of maize and rice can increase under irrigation. Maize can double and reach towards the world's average, and rice is expected to surpass the world's average, and increase towards 60-70% of the world's highest yield. Irrigation will not only increase yields due to proper water management, but also enable for a second growing cycle per year, which enhances productivity.

[1] This section is bases on FAOSTAT with yields from former Sudan.

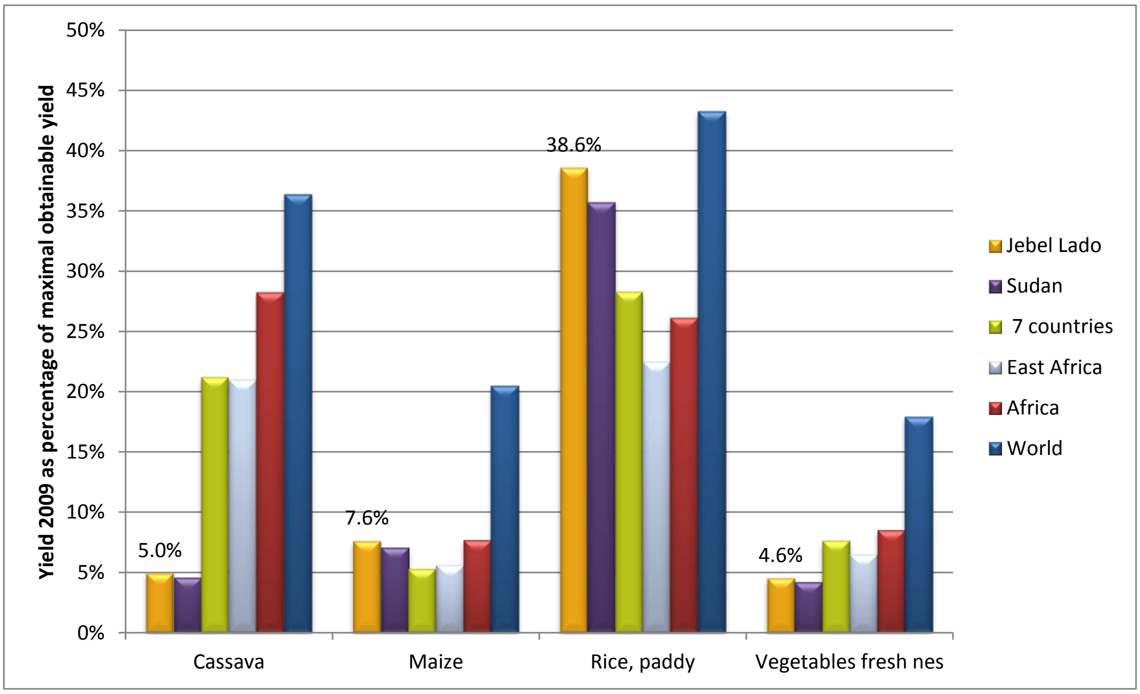


Figure 45: Yield gap Jebel Lado (source: FAOSTAT, 2010).

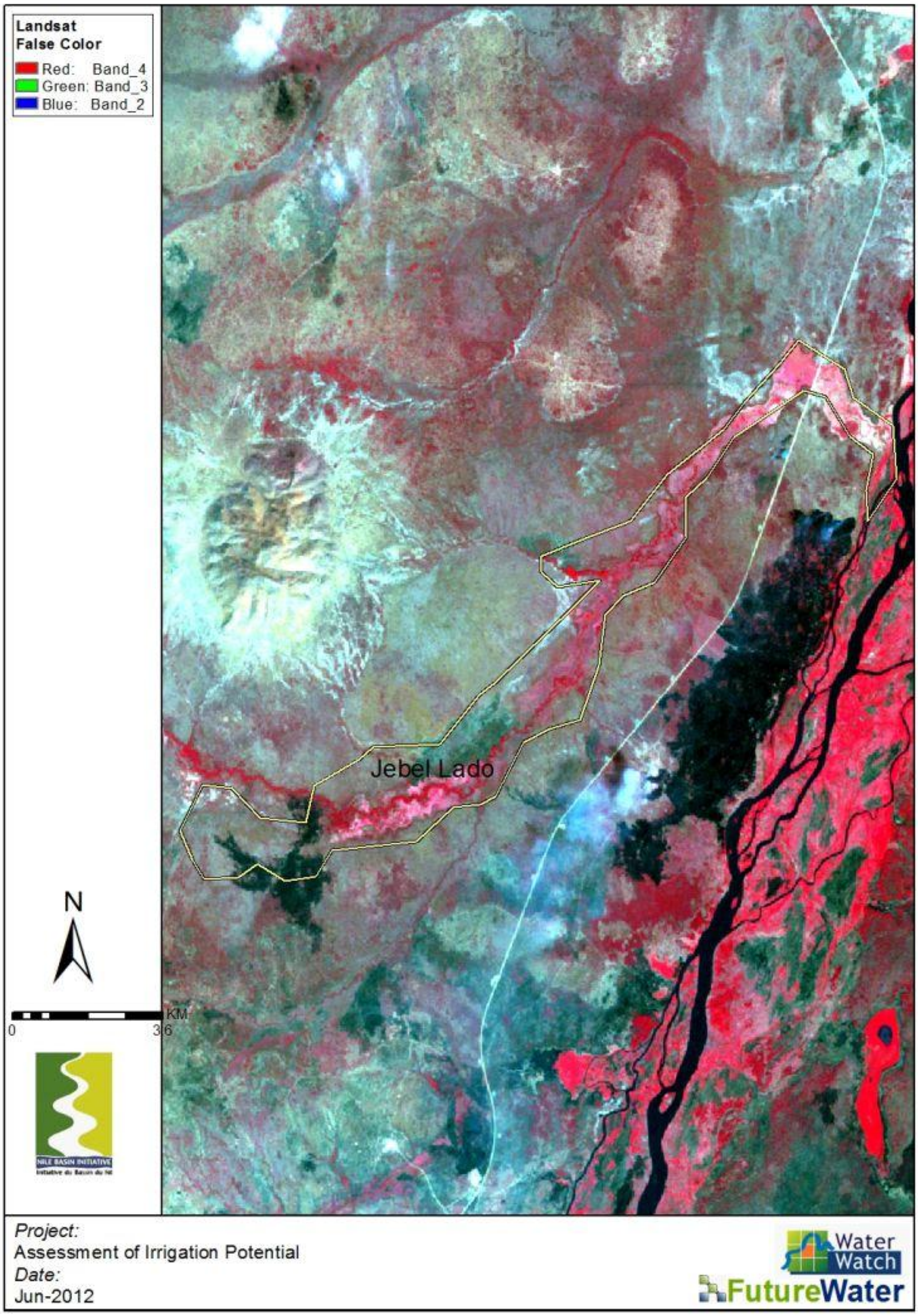


Figure 46: Landsat False Color Composite indicating current productivity of Jebel Lado focal area.

3.6 Environmental and socio-economic considerations

3.6.1 Population displacements

In the Jebel Lado focal area there are some small communities, which live together. There are not many houses scattered around the area. Especially in the part of the focal area within the river valley the population density is extremely low due to flood risks. Therefore, population displacements are probably not needed when developing irrigation systems. With the design of any irrigation scheme, it is advised to limit any population displacement. The exact numbers of effected houses can only be known after designing the scheme, which is beyond the scope of this pre-feasibility study.

3.6.2 Social

Population density in Central Equatoria state is relatively high compared to the South Sudanese average. The population density is approximately 40 people/km^2 compared to the South Sudanese average of 13 people/km^2. This country wide population density is among the lowest in the African sub-tropical countries. (CIESIN) In 2008 it is estimated that half of the population is below the age of 18 years. Within South Sudan 51% of the population is living below the national consumption poverty line (SSDP). Within Central Equatorial this percentage is slightly lower with 44%. However, in rural areas this may be higher since people depend more on local agriculture for their living. The productions of cereals within Central Equatoria state, although increasing in recent years, is still below half of the demand. (FAO, 2012) Within the state 44% of the population is literate. (SSNBS) From the total population 65% is rural, and 58% of the households depend on crop farming or animal husbandry as primary source of their livelihood. The enrollment rate for the primary school is approximately 50%. (SSNBS) Concerning agriculture, the agricultural knowledge is average, which means that for irrigation training will be needed. The accessibility is quite good, but should be improved when developing irrigation. Nearby markets include Juba (25 km away). The area is inhabited by the Bari community.

3.6.3 Upstream downstream consideration

Currently, there are not many up-downstream related problems. The area is not steep and flow velocity is not large enough to cause erosion. When developing an irrigation scheme it is advised to pay attention to river flow control, and anti-salinization measures. This may result in measures that enable the water to drain quickly. But to enhance the environmental aspects upstream, within the focal area and downstream, it is advised to search for measures which first retain the precipitation water, and try to store it upstream. This will enhance the upstream ecosystem, and groundwater levels. On a larger scale the groundwater is recharged, which can become available downstream, and evaporation enhances the water cycle and the precipitation in the area.

3.6.4 Protected areas

Within the focal area no protected areas are reported.

3.7 Benefit-cost Analysis

A simplified benefit-cost analysis is undertaken for the area. Information for this is based on various sources such as FAO publications, IFPRI publications, local expertise and data. A full benefit-costs analysis has to be undertaken in a sub-sequent feasibility study for the area.

From the total area as selected it can be expected that about 1500 ha is actual suitable to develop irrigation. Note that this is a first-order benefit-cost analysis. A feasibility study can provide a more rigorous benefit-cost analysis, which is required before taking any implementation planning. However, the following table shows that based on this first-order analysis, investments in irrigation can have a small financial benefit with a internal rate of return of about 6%.

Main assumptions for the benefit-costs analysis include:

- Irrigated land based on GIS and local experts for boundaries
- Number of farmers based on average land tenure area
- Irrigation infrastructure based on irrigation type and source
- Social infrastructure based on local expert judgment on farmers' trainings need
- Accessibility infrastructure based on generalized road conditions
- Internal Rate of Return based on 25 years
- Crop revenues based on local crop potentials and local market prices (crop, kg/ha, $/kg):
    - Maize: 2,000 kg/ha, 0.22 $/kg
    - Cassava: 3,500 kg/ha, 0.28 $/kg
    - Millet: 3,000 kg/ha, 0.55 $/kg

Based on expert knowledge on the suitability to develop irrigation in the area scores between 1 (negative: low suitability or expensive) to 10 (positive: high suitability or low investments) have been marked. The filled radar plot below indicates the options for the focal area. Overall, the weak part of the site lies under farmers capacity, accessibility to roads, to markets and the initial investment cost.This in-turn affects access to market as farmers cannot transport their yield easily and more importantly may not fetch golden prices. However, soil suitability and water availability is a great deal for the area that will foster an increase yields.

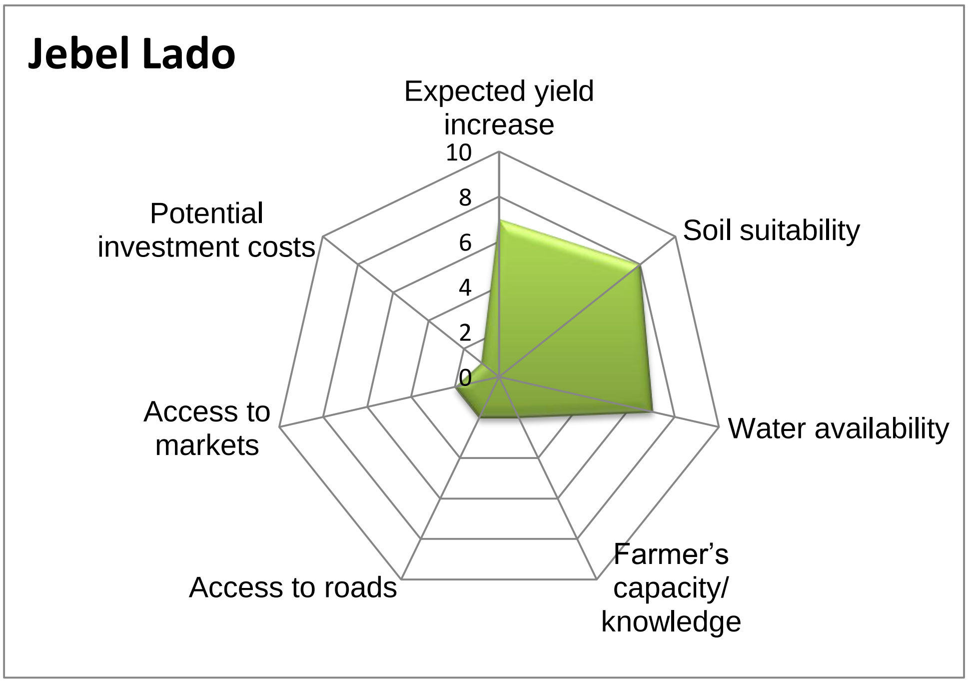


Figure 47: Filled radar plot indicating expert knowledge score to develop irrigation in the Jebel Lado focal area (1 = negative, 10 = positive). (Source: local experts and study analysis).

Table 4: Benefit-cost analysis for Jebel Lado area.

Characteristics	
Irrigated land (ha)	1,500
Farmers	1,500
Investment Costs	
Irrigation infrastructure (US$/ha)	5,000
Social infrastructure (US$/farmer)	500
Accessibility infrastructure (million US$)	2.0
Operational Costs	
O&M irrigation (US$/ha/yr)	60
Extension service (US$/farmer)	10
O&M roads (US$/yr)	40,000
Summary	
Initial investments (million US$)	10.3
O&M costs (million US$/yr)	0.145
Net benefits per year (million US$/yr)	0.921
IRR (Internal Rate of Return)	6.3%

4 Pagarau focal area

4.1 Introduction

This chapter will describe the current state of the Pagarau focal area, concerning land and water resources, and will discuss the potential to develop irrigation in the area. This irrigation potential will be based on the land and water resources, the irrigation requirements, the potential crop yields and will also involve the socio-economic considerations and institutional frameworks. Based on these aspects the potential for irrigation will be described, and cost for irrigation development calculated. In Figure 49 a detailed map of the area is given. Total area is 13,830 ha.

Selection of this specific focal area was based on results of Phase 1 of this study, while final selection was the responsibility of the relevant country representatives. Results presented hereafter have been obtained from a broad range of sources: Phase 1, previous other studies and reports, modeling results, remote sensing, expert knowledge and field visits by Jal Fnom, Makuac Deng and Mary Loki as supervisor in April and May 2012.

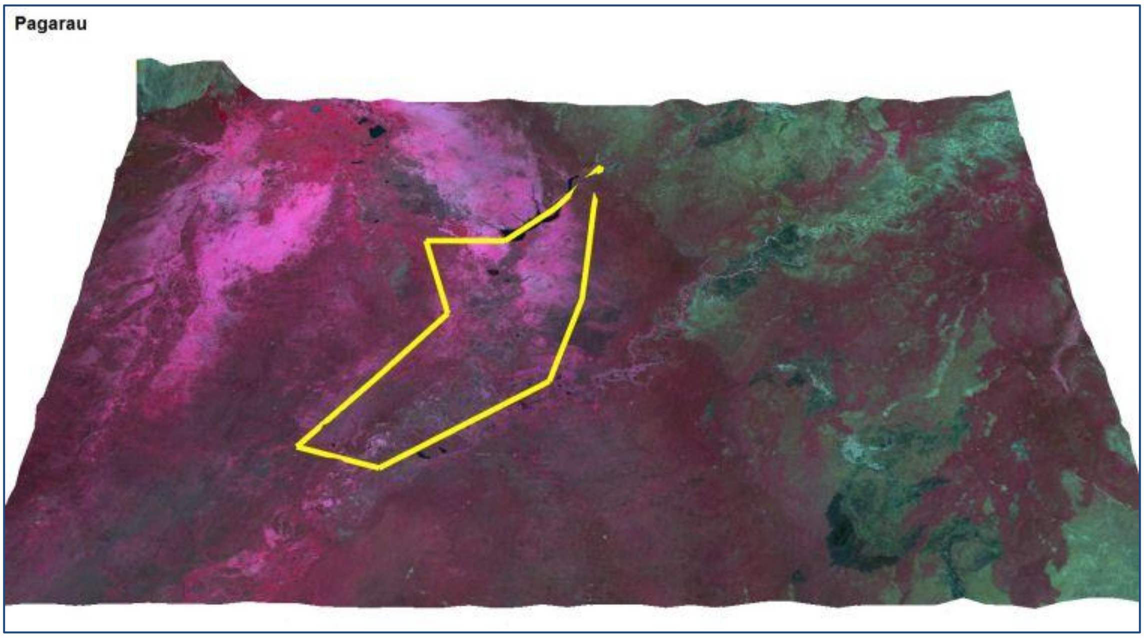


Figure 48. 3D impression of Pagarau focal area, South Sudan.

4.2 Land suitability assessment

4.2.1 Terrain

Pagarau focal area is located in the Lakes state, in central South Sudan. The area (13,832 ha) is the second largest of the five focal areas in South Sudan. The area is rather flat and descends slightly from South (420 m) to North (415 m) (Figure 50). A large river runs through the area, which can serve as an irrigation water source. The river finally drains into the White Nile, which is approximately 60 km north of the focal area. A small lake borders the focal area on the Southern tip. Based on the 250 m resolution slope map, the slopes do not exceed 1%. On a smaller scale (30 m), slopes are more significant; staying under 3% in most of the area, and reaching towards 10% on some places in the North (Figure 51).

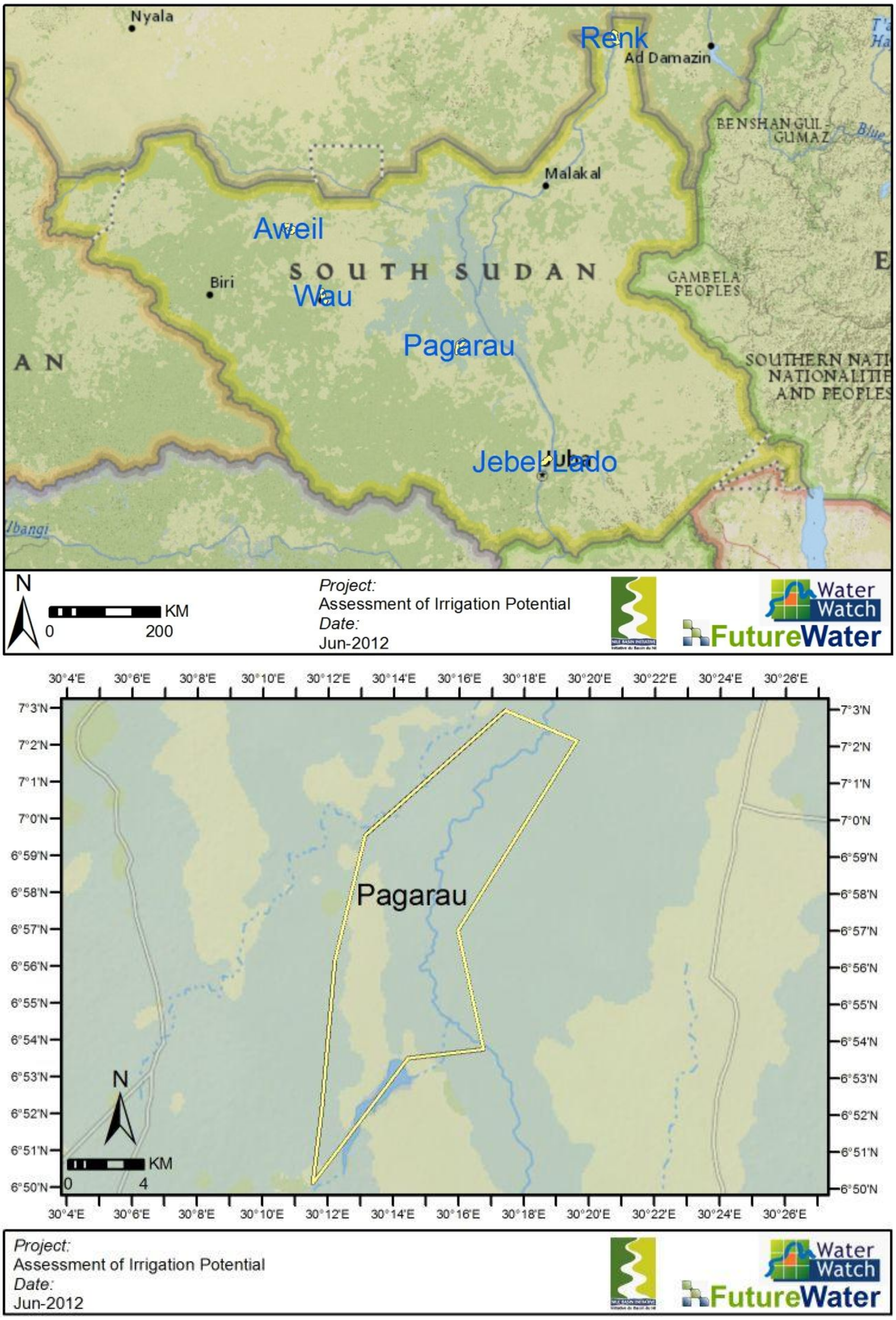


Figure 49: Pagarau focal area, South Sudan

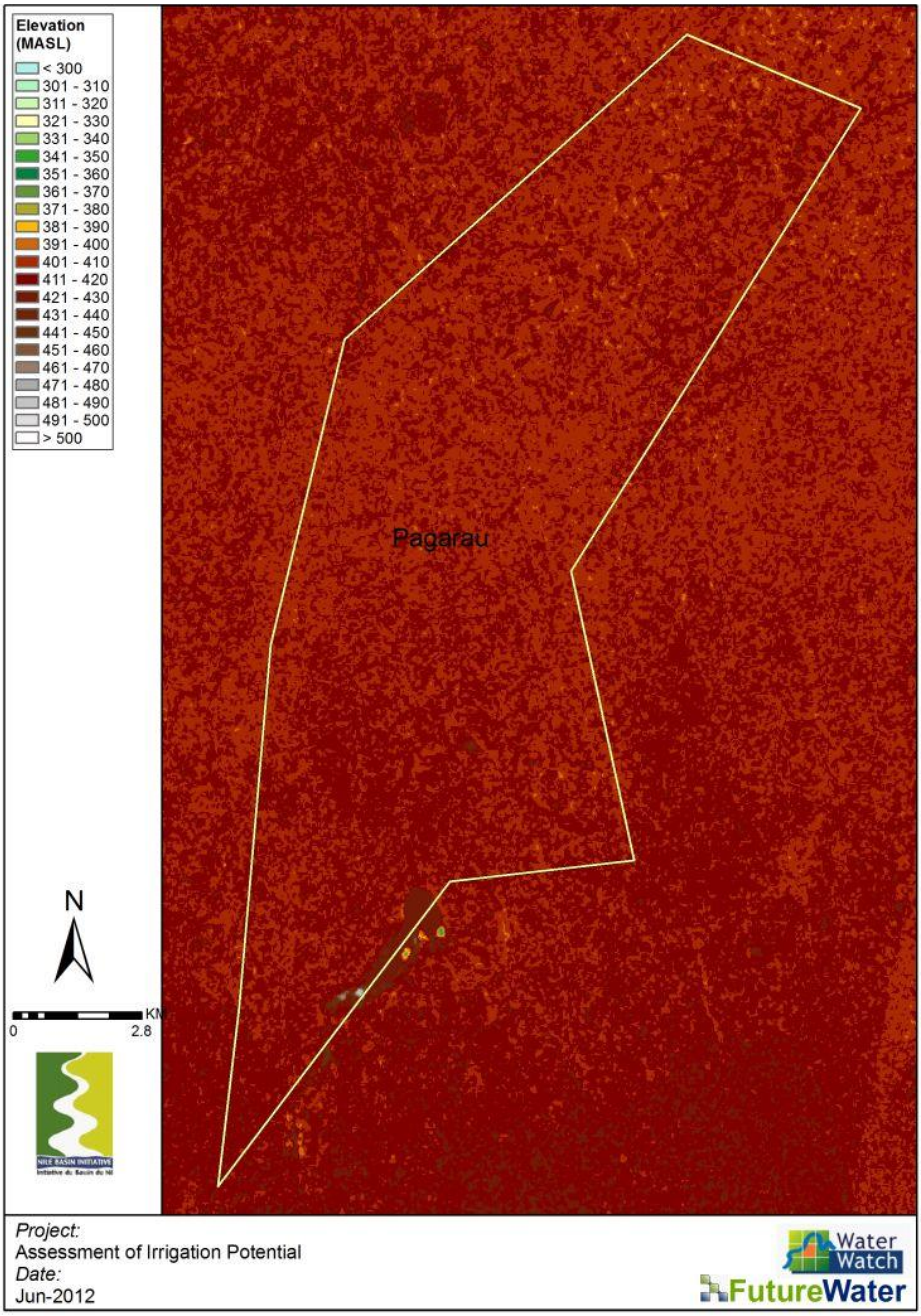


Figure 50: DEM Pagarau focal area. Resolution 1 arc second (+/- 30m).

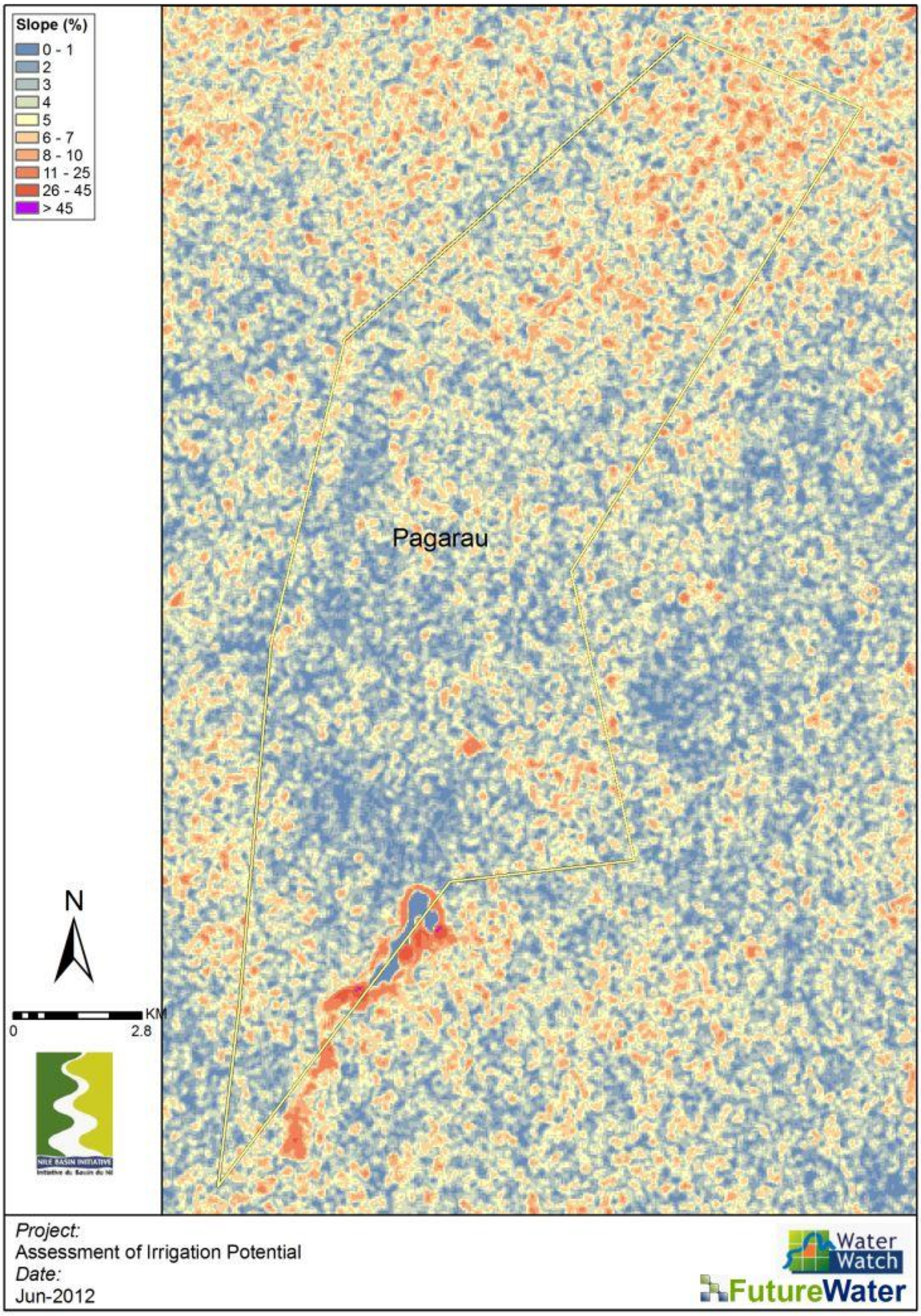


Figure 51: Slope map Pagarau focal area (source: ASTER).

4.2.2 Soil

The focal area is located on a transition between soil types. The texture in the western part is loamy, and changes towards a more clayey texture in the largest eastern part. The western part is located in a soil which is formed under strong fluvial processes, and the eastern part, which contains Gleysols and Histosols, is partially formed under fluvial processes. Due to poor drainage and high groundwater levels peat has been developed. Therefore, the available water holding capacity in the whole area is large with over 150 mm/m. Organic carbon in the eastern part is extremely high (15%), compared to 1% in the west. Management of the eastern part with Gleysols and Histosols is characterized by the necessity to install a drainage system to lower the groundwater table. Adequately drained Gleysols can be used for arable cropping, dairy farming and horticulture. If too wet soils are cultivated, then the soil structure will be destroyed for a long time. Therefore, Gleysols in depression areas with unsatisfactory possibilities to lower the groundwater table are best kept under a permanent grass cover or swamp forest. Concerning Histosols in the tropics, an increasing numbers of landless farmers venture onto the peat lands, where they clear the forest and cause raging peat fires in the process. Many of them abandon their land again after only a few years; the few that succeed are on shallow, topogenous peat. In recent decades, increasing areas of tropical peat land have been planted for oil-palm and pulp wood tree species, such as Acacia mangium, Acacia crassicarpa and Eucalyptus. This practice may be less than ideal, but it is far less destructive than arable subsistence farming.

4.2.3 Land productivity

The annual average land productivity (NDVI) in the five South Sudanese focal areas ranges between 0.30 and 0.60. Compared to the South Sudanese average NDVI of 0.50, the Pagarau focal area has an above average land productivity of 0.60 (Figure 54). The annual average land productivity is quite uniform over the whole area. The variation over the year is much lower around the river, and increases on places where the NDVI is slightly higher. These are mainly the peat soils.

Figure 52. Charateristics of Pagarau focal area.

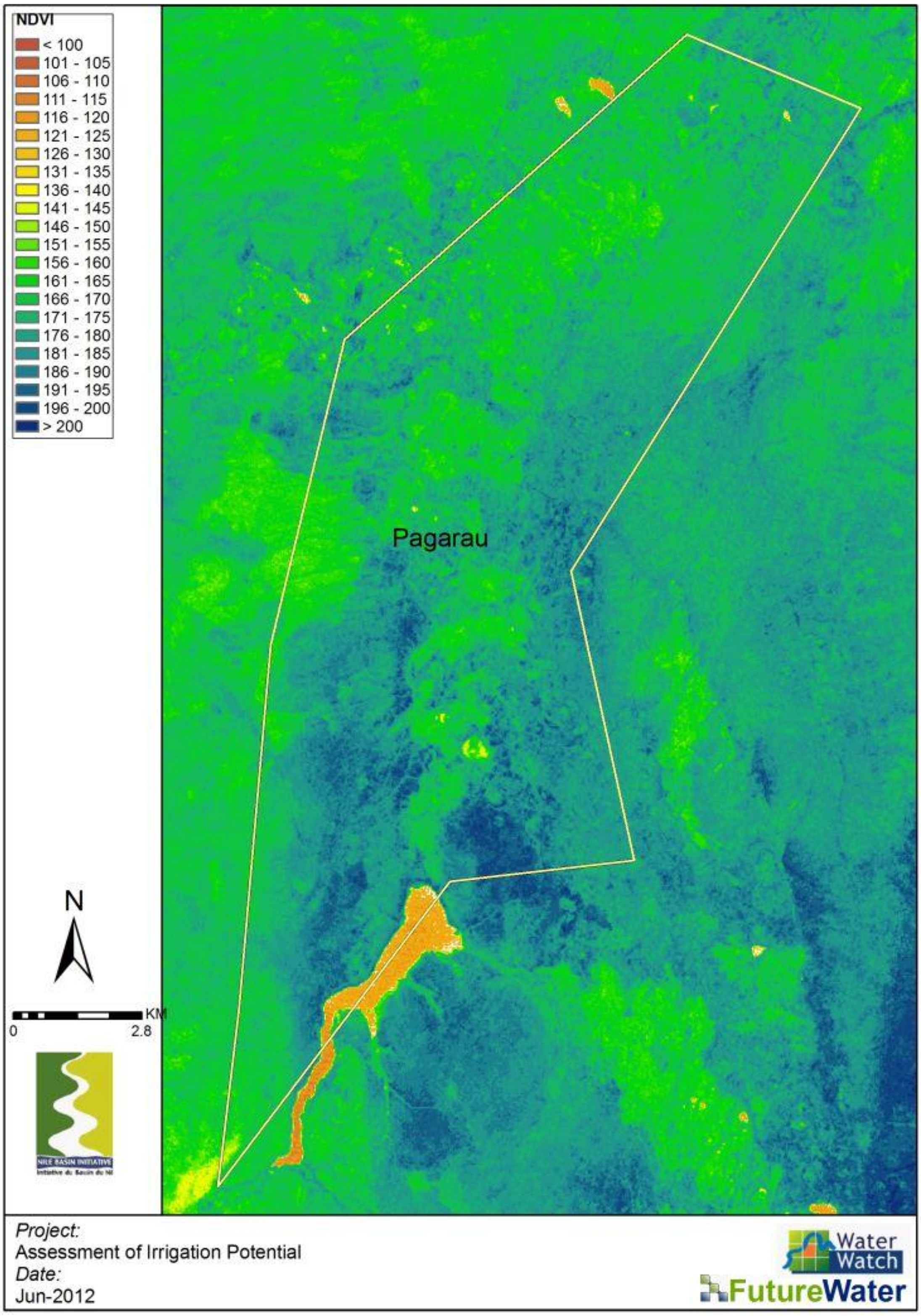


Figure 53: High resolution NDVI for PAGARAU focal area

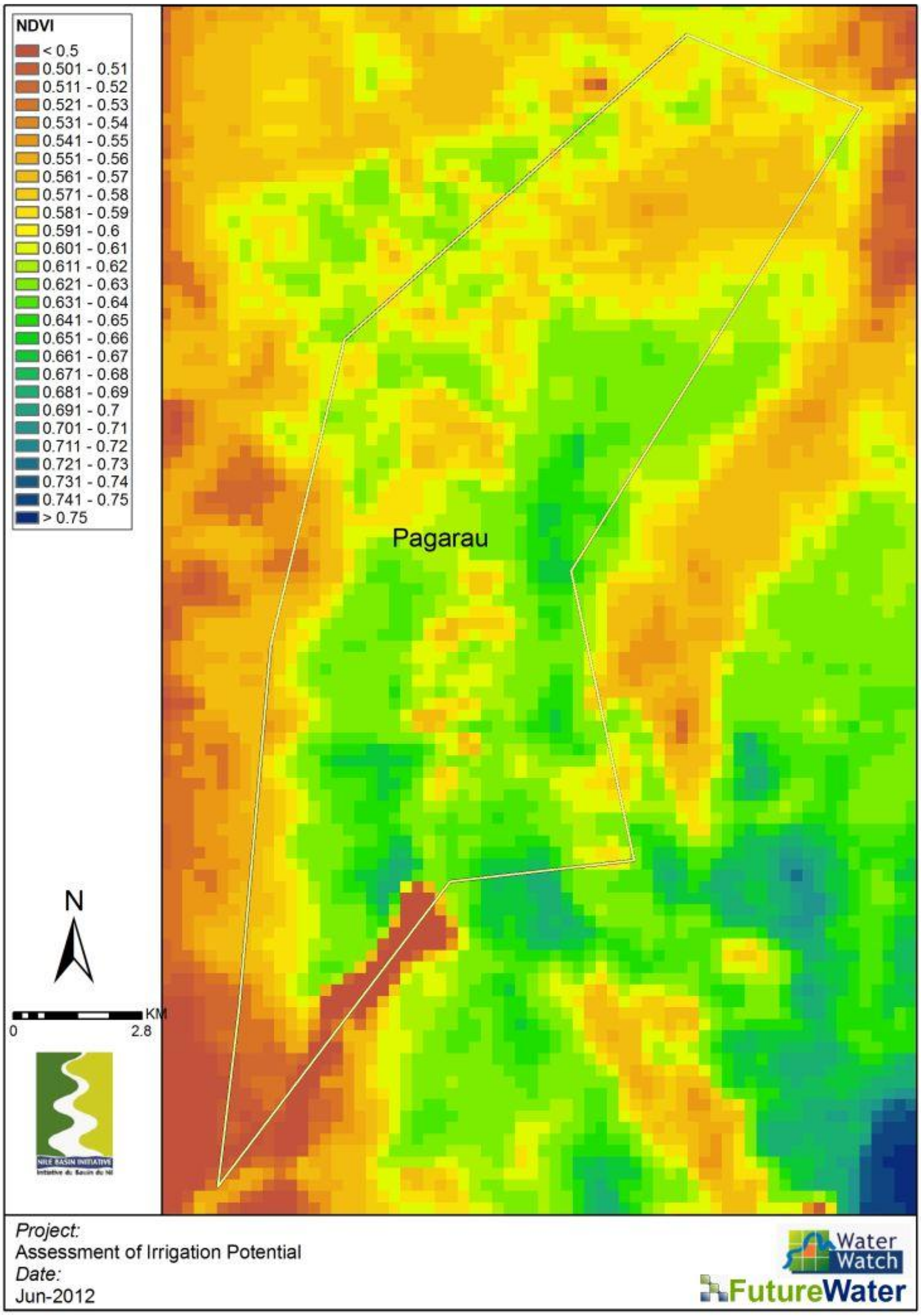


Figure 54: Yearly average NDVI values for Pagarau focal area.

4.2.4 Potential cropping patterns

Currently, agriculture in the focal area in not taking up a large part of the area (<10% of the focal area). The western part of the area is mainly covered with herbaceous plants, and the eastern part with open forest. Crops that are currently grown in the area include maize, sorghum, rice and groundnuts. They are all grown rain fed, which incorporates that they are grown in one growing cycle per year during the raining season. When developing an irrigation scheme, it is advised to focus partially on staple crops, such as paddy, maize, sorghum and vegetables and partially, with an eye on the future on cash crops, such as sugar cane, which could diversify the economy. However, the first priority should be crops that reduce hunger, and as second priority poverty, so that the economic situation of the rural area can be strengthened. If irrigated, then a part of the focal area can be used during two growing cycles per year, which increases food security and reduces poverty.

4.3 Water resource assessment

4.3.1 Climate

Average climate conditions for the area are shown in the figure below. Precipitation is based on an advanced calibration/validation algorithm using satellite derived precipitation and calibrated using local observations. Details can be found in the Phase 1 Report. Reference evapo-transpiration (ETref) is calculated using the well-known Penman-Monteith approach. Input data for ETref is based on local observations and an advanced spatial downscaling algorithm.

The climate of the area can be characterized as warm with temperatures during the year ranging from about 25°C to 36°C. Annual average precipitation is 736 mm and reference evapotranspiration 1892 mm per year.

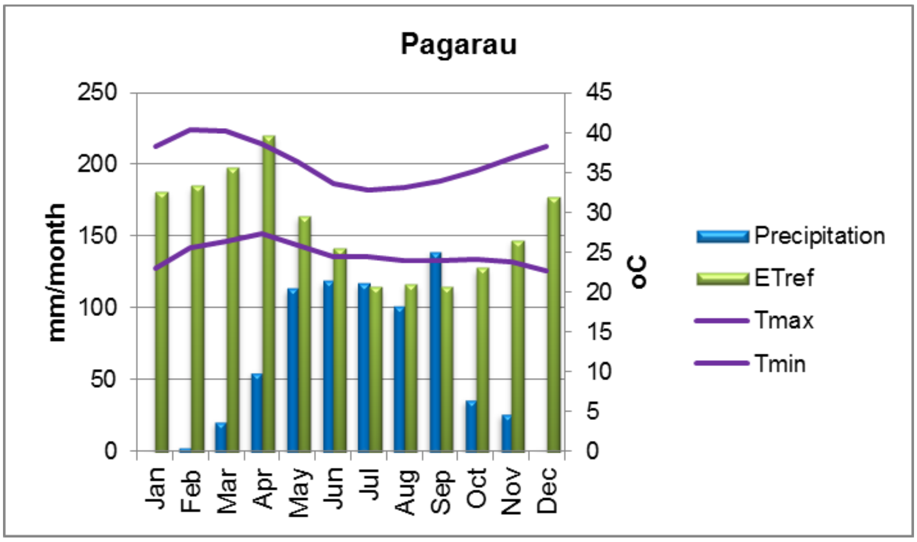


Figure 55: Average climate conditions forPagarau focal area.

4.3.2 Water balance

A very detailed high resolution model was built for NEL countries (NELmod). For a detailed description see Phase 1 report. Results from NELmod were extracted for this specific focal area and are shown below.

The focal area is located in the state Lakes. Already quite some existing boreholes and water points can be found in the region (Figure 40)

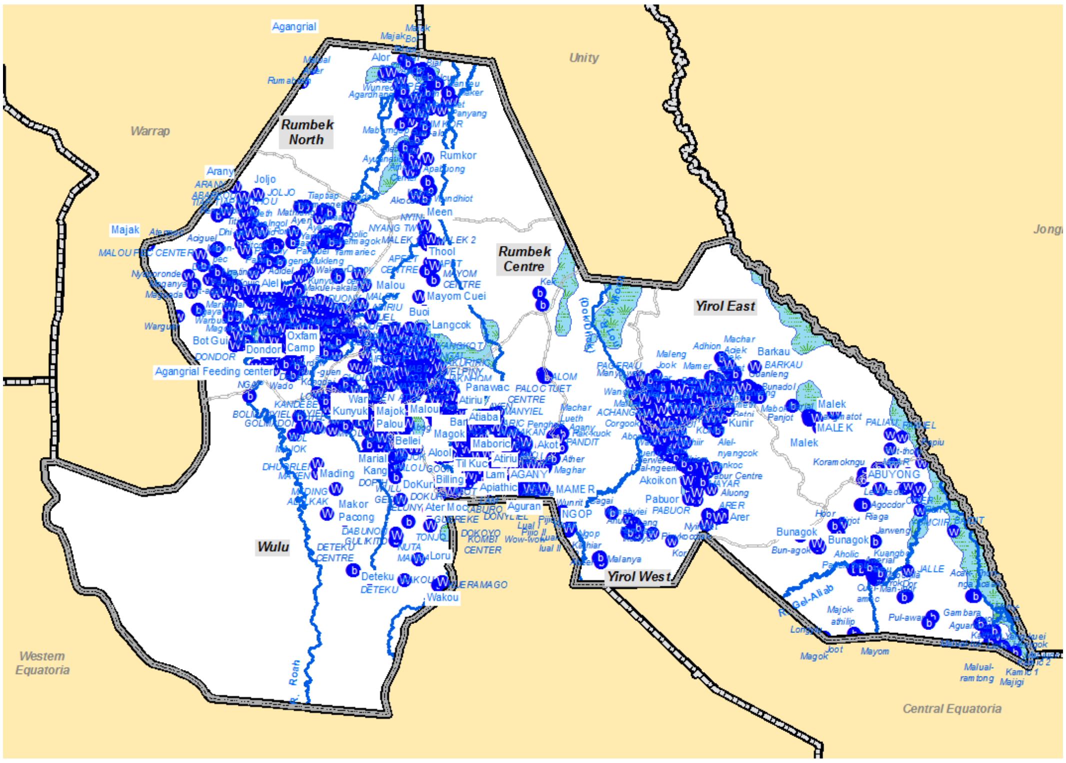


Figure 56. Boreholes (B) and Waterpoints (W) in Lakes province in South Sudan (source: South Sudan Information Management Working Group).

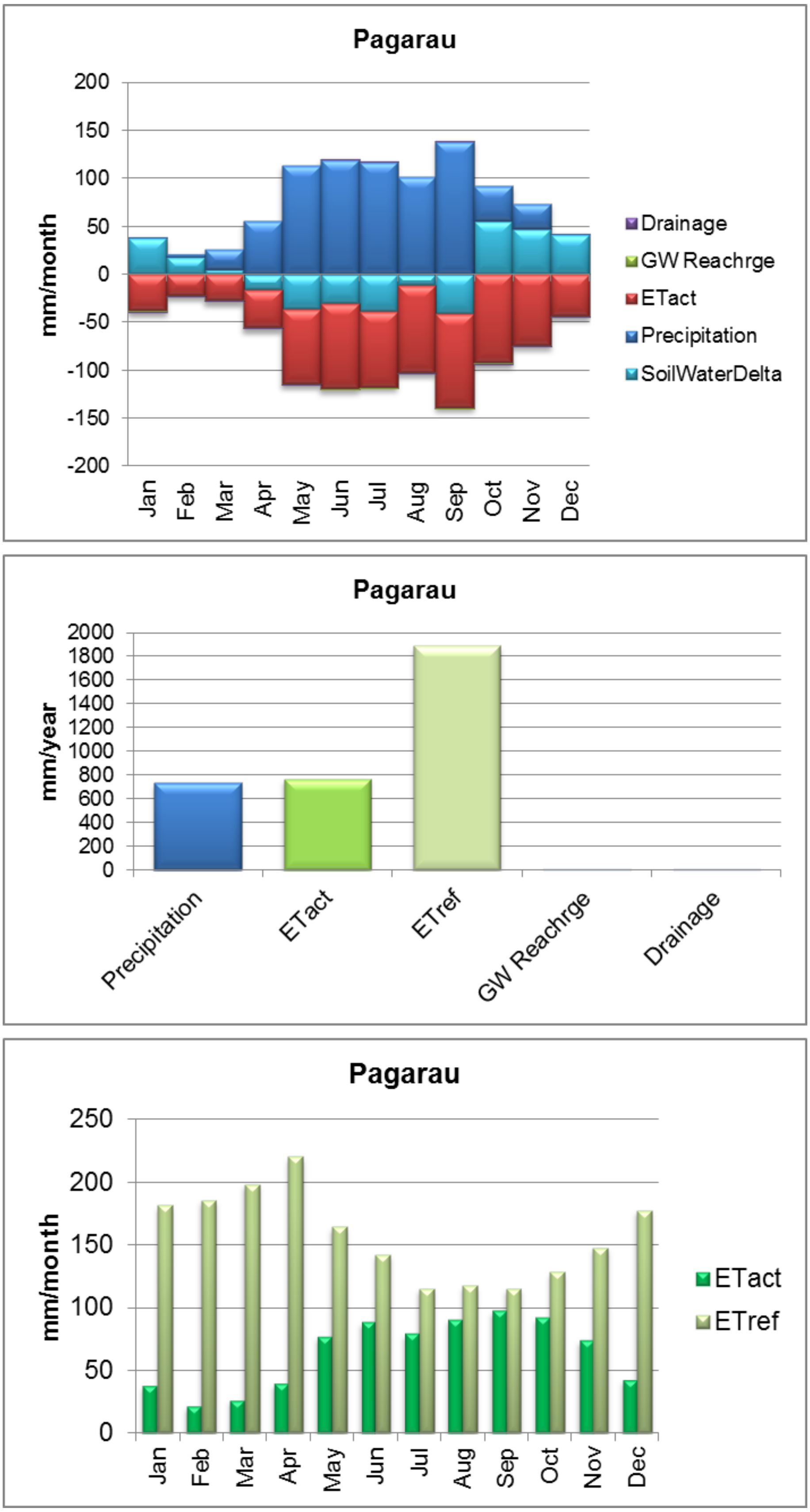
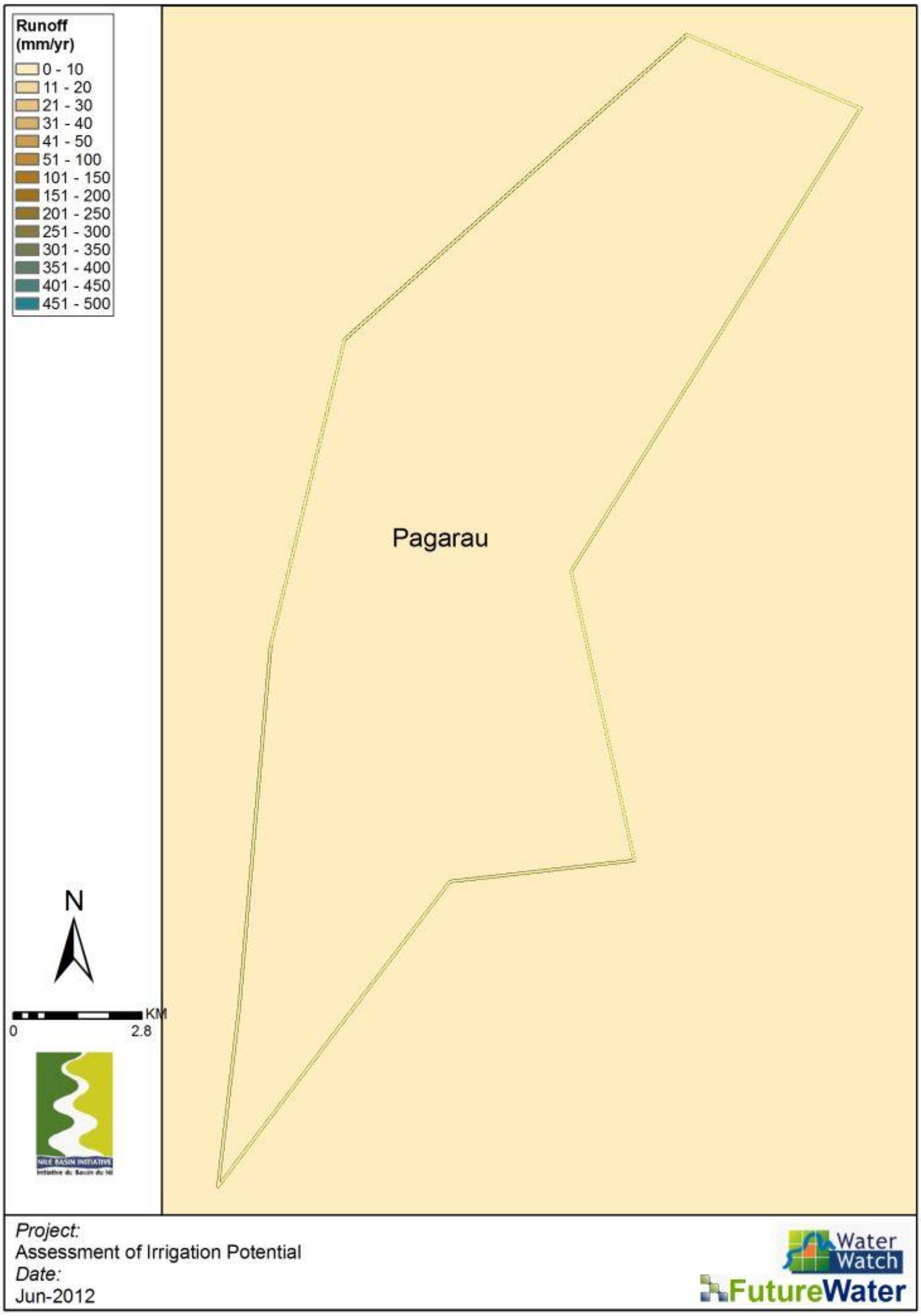


Figure 57: Water balances for the area based on the high resolution data and modeling approach for Pagarau focal area.


Runoff (mm/yr)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
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Project:
Assessment of Irrigation Potential
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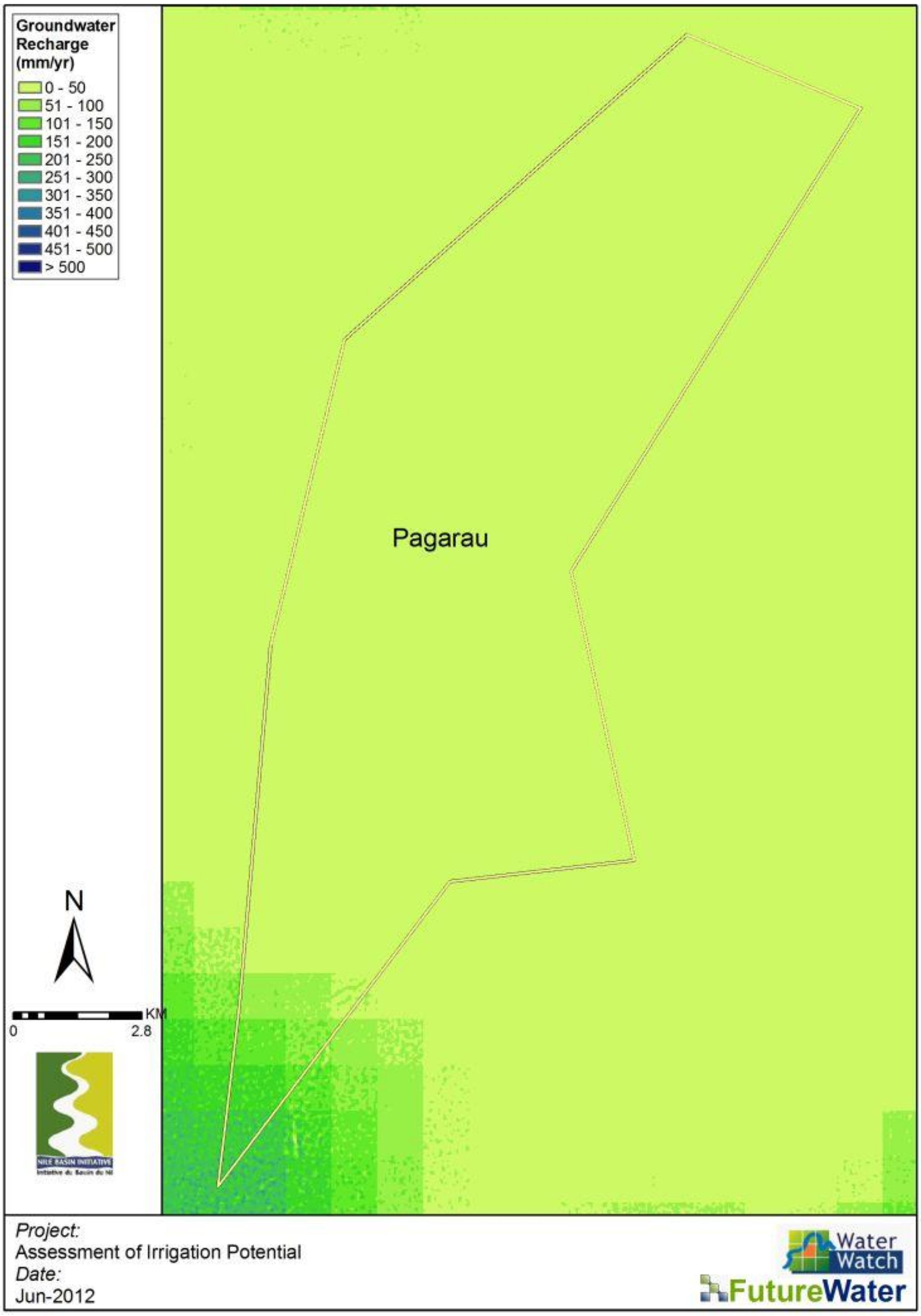
Jun-2012
Water Watch
FutureWater



Groundwater Recharge (mm/yr)
0 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
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> 500
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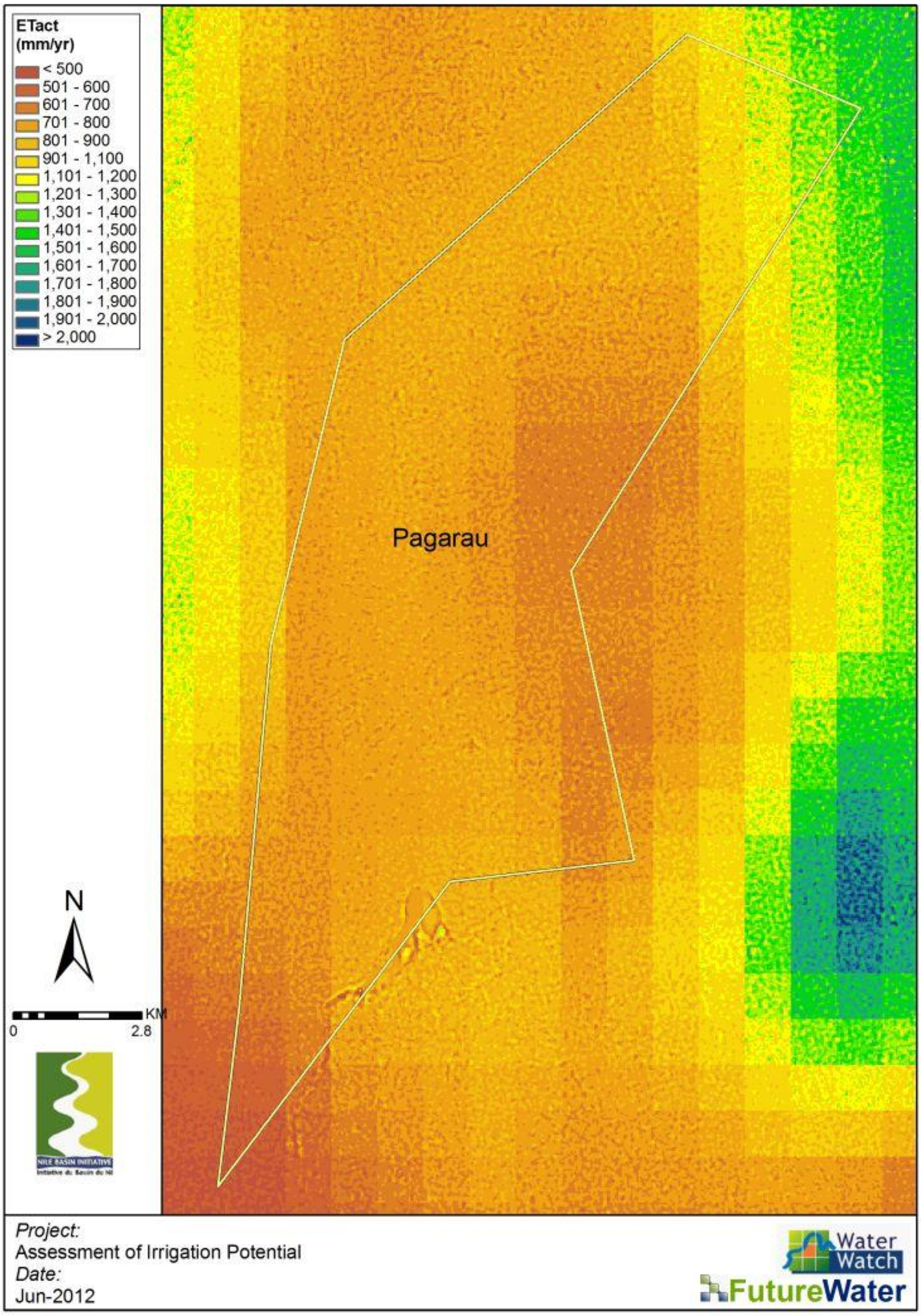


Figure 58: Water balances for the area based on the high resolution data and modeling approach for Pagarau focal area.

Figure 59. Charateristics of Pagarau focal area.

4.4 Assessment of irrigation water requirements

4.4.1 Irrigation water requirements

Irrigation water requirements depend on many factors such as: climatic conditions, crop, growing season, irrigation practices etc. A first estimate of irrigation requirements could be based on the difference between rainfall and reference evapotranspiration. It was however selected for this pre-feasibility assessment to provide a first estimate of irrigation needs based on the most promising crops. To this end, FAO's AquaCrop, the successor of CropWat was setup for local and crop specific conditions.

In the table below the irrigation water requirements for each selected crop are provided based on AquaCrop calculations. All units are provided in mm per growing season for the specific crops. Note that for various crops, like vegetables and similar crops, multiple croppings per years might occur.

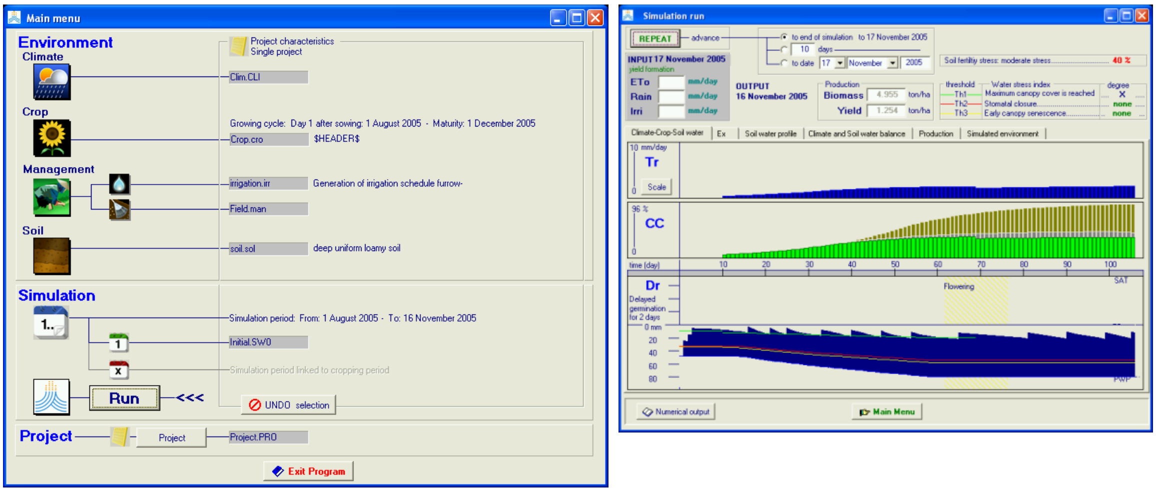


Figure 60: Typical example of AquaCrop input and output screens.

Table 5: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season.

Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year	===	== (day of year) ==		======== growing season =======			
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Rice	736	1892	213	320	294	270	437	393
Sorghum	736	1892	121	243	454	230	540	492
Maize	736	1892	121	238	433	240	517	474
Sugar cane	736	1892	1	365	737	840	1884	985

4.4.2 Irrigation systems and irrigations efficiencies

The river Yei that flows through the area drains an area of 27,000 km^2. Therefore, the water availability will be more than sufficient to irrigate the area. The area is very sparse populated, and therefore it is recommended to focus on irrigation systems that can be operate with a few human resources. This would enhance the more technical irrigation systems, such as sprinkler and drip irrigation. The installation of a good drainage system is most important to develop the area in a sustainable manner. Besides, it is advised to first focus on the clayey soils near the river, and try to avoid the peat soils, which have a high risk of degradation. The development of a paddy irrigation scheme with border irrigation will be a good option. Subsequently, sugarcane can be developed with a similar border irrigation system. Efficiency of border irrigation is low, but the water availability will not be the problem in this area. After the field assessment, furrow irrigation is advised for the irrigation of sorghum, maize, and millet. Depending on the farmers' knowledge and the possible investment, this can be changed to sprinkler irrigation to reduce water use, and make the irrigation system more efficient.

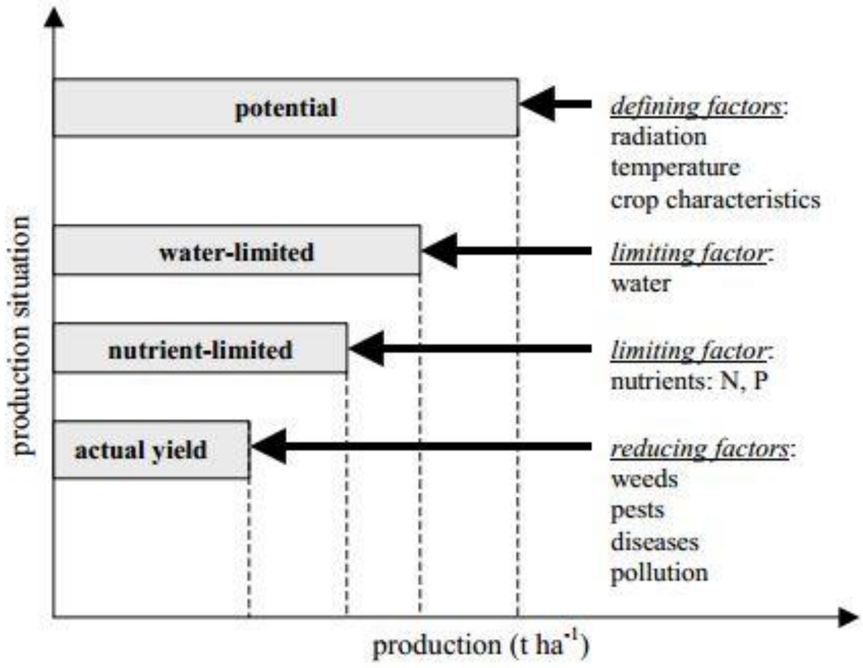
4.4.3 Water source

The water source will be Yei River. The river drains a large area of 27,000 km^2, and has an annual average flow of 33 m^3/s. On average this water will be more than sufficient to irrigate the entire area. The only constraint will be the large seasonal variety of the river flow. Therefore, stream control structures will be required, in combination with storage capacity.

4.5 Potential crop yield assessment

The yield gap describes the difference between the current yield, and the maximum possible yield. Mostly the maximum possible yield is defined as the highest yield in the world, but it can also be assessed against a regional background which makes the yield gap more realistic and the maximum yield possible to achieve under the given circumstances.

The gap between the actual yield and the potential yield can be caused by several processes. Factors which may cause that the maximum possible yield is not reached can be the water availability, the soil and the available nutrients, or yield reducing factors like diseases, weeds or pollution.



4.5.1 Yield gap analysis potential dominant crops[1]

Yields in Sudan are relatively high compared to surrounding countries. There is, however, a large differentiation between crops. Sudan has extremely high yields for dry beans, bananas, sugar cane, sweet potatoes and potatoes. For paddy and cotton seeds, Sudan performs better than the world's average yields (4300 and 2000 kg/ha respectively). Most probably this finds its origin in the intensification and irrigation programs, which have been introduced in the past to increase food production to meet the demand. In Figure 61, the yield gap is shown relatively to the highest obtainable yield in the world, to the world's average, and to Africa's average. Within the Pagarau focal area the yields are approximately 20% higher than Sudanese average yields. It is expected that the production of maize can increase threefold towards 20% of the highest obtainable. Rice is already giving yields comparable with the world's average, but with a second growing cycle the yield can double. Sugar cane is currently not much grown in the area, but the graph shows that is will be a very suitable cash crop, which will enhance poverty reduction, and may diversify exports. Irrigation will not only increase yields due to proper water management, but also enables a second growing cycle per year, which enhances productivity.

[1] This section is bases on FAOSTAT with yields from former Sudan.

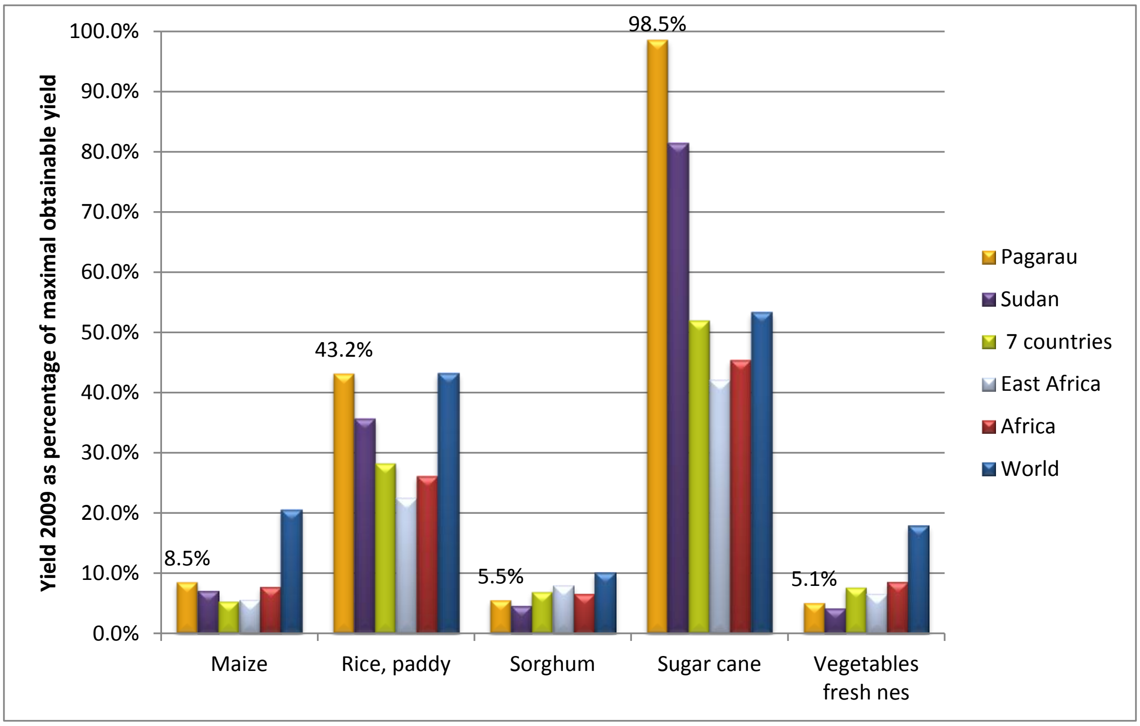


Figure 61: Yield gap Pagarau (source: FAOSTAT, 2010).

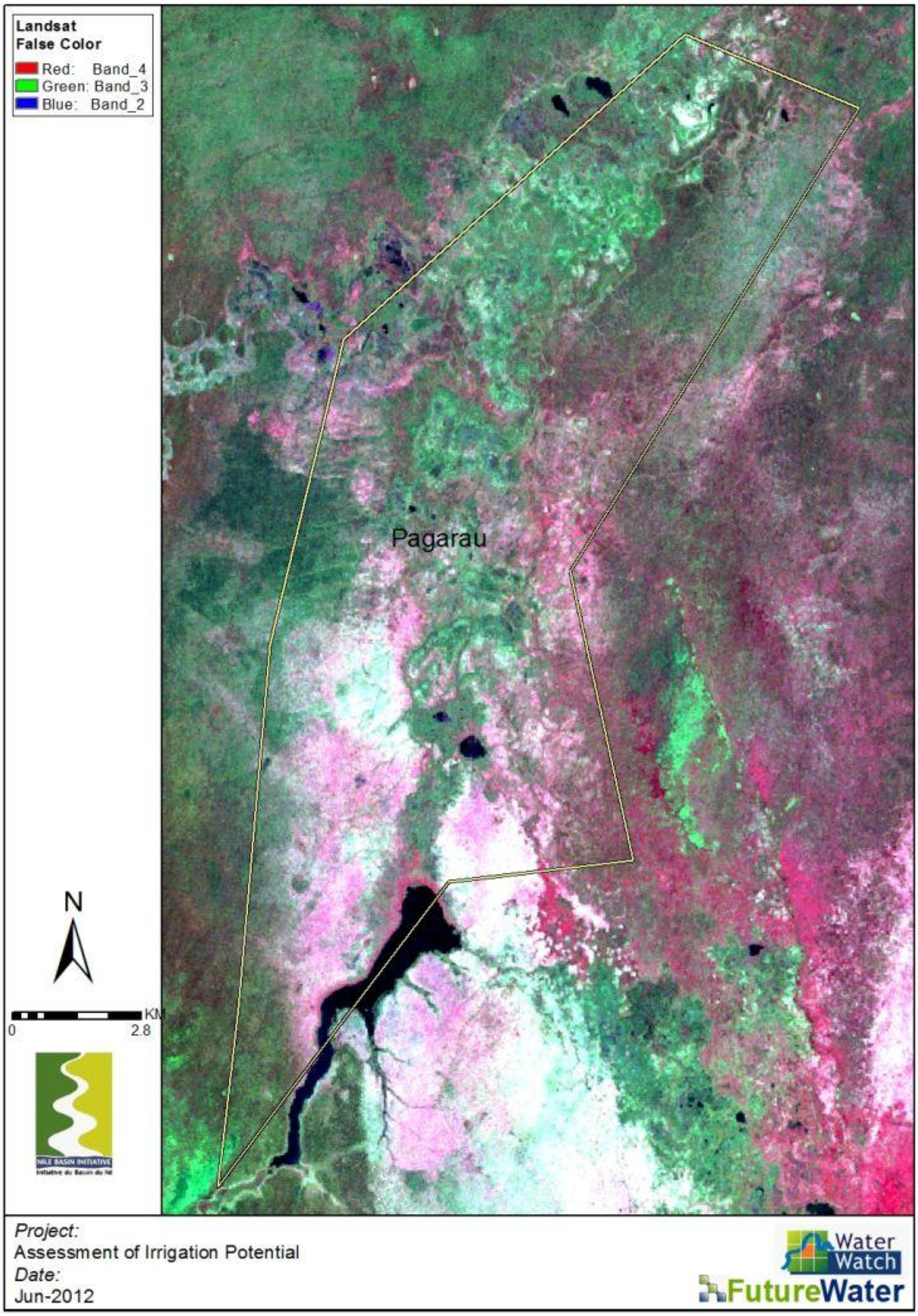


Figure 62: Landsat False Color Composite indicating current productivity of Pagarau focal area.

4.6 Environmental and socio-economic considerations

4.6.1 Population displacements

Population density in the Pagarau focal area is extremely low, and people live on the drier and somehow elevated places within the focal area. If an irrigation system is developed, it is not expected that any population displacement is needed. Especially since the population density does not allow for large scale irrigation development. With the design of any irrigation scheme, it is advised to limit any population displacement. The irrigation scheme can be developed around the existing houses. The exact numbers of effected houses can only be known after designing the scheme, which is beyond the scope of this pre-feasibility study.

4.6.2 Social

Population density in Lakes state is marginally higher compared to South Sudanese average. The population density is approximately 16 people/km^2, compared to the South Sudanese average of 13 people/km^2. This country wide population density is among the lowest in the African sub-tropical countries. (CIESIN) Within the focal area the population is estimated to be as low as 2 people/km^2. Remarkably, the ratio male to female is 1.11. In 2008 it is estimated that half of the population is below the age of 18 years. Within South Sudan, 51% of the population lives below the national consumption poverty line (SSDP). Within Central Equatorial this percentage is slightly lower (49%). In rural areas, however, in which to focal area is located this may be higher. The area is inhabited by Dinka people, which unfortunately have a very limited knowledge of agriculture, irrigation and farmers cooperatives. When developing an irrigation scheme, additional effort is needed for intensive trainings. The area is not very well accessible, with some earth roads going around the area, and the first proper roads being at Yirol town, which is at about 30 km away. Yirol town is also the primary market, after which other towns can be served. The net enrolment rate in primary school is 42% in 2009, and literacy rate among 15-24 years old is 30%, which is unevenly distributed among males and females. 91% of the population in Lake State is rural, and 89% of the population depends on crop farming or animal husbandry as their primary source of living (SSNBS).

4.6.3 Upstream downstream consideration

The upstream area for this focal area is large (27,000 km^2). Within the focal area erosion occurs on a small scale, and drainage is poor. The large variation in flow makes it necessary to develop flow regulating structures. Together with drainage in the irrigated area, this may result in measures that enable the water to drain quickly. But to enhance the environmental aspects upstream, within the focal area and downstream, it is advised to search for measures which retain the precipitation water firstly, and try to store it upstream. This will enhance the upstream ecosystem, and groundwater levels. On a larger scale the groundwater is recharged, which can become available downstream, and evaporation enhances the water cycle and the precipitation in the area. The use of fertilizer is recommended, but it is needed to use fertilizer in a responsible and well considered way. Otherwise the water quality downstream may be compromised.

4.6.4 Protected areas

Within the focal area no protected areas are reported.

4.7 Benefit-cost Analysis

A simplified benefit-cost analysis is undertaken for the area. Information for this is based on various sources such as FAO publications, IFPRI publications, local expertise and data. A full benefit-costs analysis has to be undertaken in a sub-sequent feasibility study for the area.

Note that this is a first-order benefit-cost analysis. A feasibility study can provide a more rigorous benefit-cost analysis, which is required before taking any implementation planning. However, the following table shows that based on this first-order analysis, investments in irrigation can have a positive impact.

Main assumptions for the benefit-costs analysis include:

- Irrigated land based on GIS and local experts for boundaries
- Number of farmers based on average land tenure area
- Irrigation infrastructure based on irrigation type and source
- Social infrastructure based on local expert judgment on farmers' trainings need
- Accessibility infrastructure based on generalized road conditions
- Internal Rate of Return based on 25 years
- Crop revenues based on local crop potentials and local market prices (crop, kg/ha, $/kg):
    - Rice: 4,000 kg/ha, 1.10 $/kg
    - Sorghum: 1,500 kg/ha, 0.65 $/kg
    - Maize: 1,500 kg/ha, 0.22 $/kg
    - Sugar cane: 20,000 kg/ha, 0.00 $/kg

Based on expert knowledge on the suitability to develop irrigation in the area scores between 1 (negative: low suitability or expensive) to 10 (positive: high suitability or low investments) have been marked. The filled radar plot below indicates the options for the focal area. Overall, the weak part of the site lies under farmers capacity, accessibility to roads, to markets and the initial investment cost. This in-turn affects access to market as farmers cannot transport their yield easily and more importantly may not fetch golden prices. However, soil suitability and water availability is a great deal for the area that will foster an increase yields.

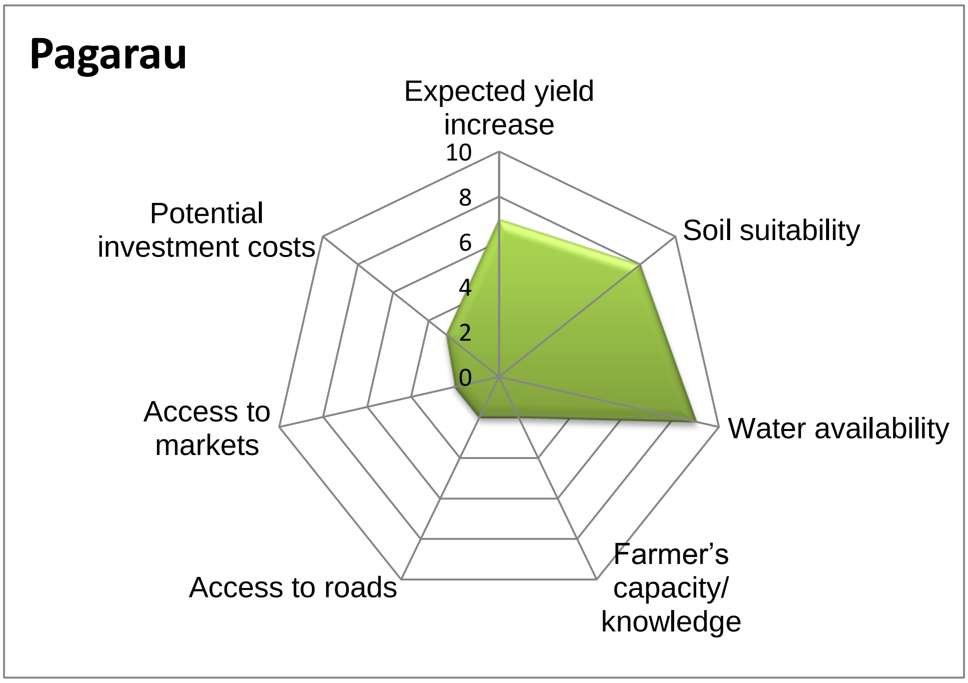


Figure 63: Filled radar plot indicating expert knowledge score to develop irrigation in the Pagarau focal area (1 = negative, 10 = positive). (Source: local experts and study analysis).

Table 6: Benefit-cost analysis for Pagarau area.

Characteristics	
Irrigated land (ha)	2,500
Farmers	3,333
Investment Costs	
Irrigation infrastructure (US$/ha)	5,000
Social infrastructure (US$/farmer)	500
Accessibility infrastructure (million US$)	5.0
Operational Costs	
O&M irrigation (US$/ha/yr)	60
Extension service (US$/farmer)	10
O&M roads (US$/yr)	100,000
Summary	
Initial investments (million US$)	19.2
O&M costs (million US$/yr)	0.283
Net benefits per year (million US$/yr)	2.139
IRR (Internal Rate of Return)	9.5%

5 Aweil focal area

5.1 Introduction

This chapter will describe the current state of the Aweil focal area, concerning land and water resources, and will discuss the potential to develop irrigation in the area. This irrigation potential will be based on the land and water resources, the irrigation requirements, the potential crop yields and will also involve the socio-economic considerations and institutional frameworks. Based on these aspects the potential for irrigation will be described, and cost for irrigation development calculated. In Figure 65 a detailed map of the area is given. Total area is 17,870 ha.

Selection of this specific focal area was based on results of Phase 1 of this study, while final selection was the responsibility of the relevant country representatives. Results presented hereafter have been obtained from a broad range of sources: Phase 1, previous other studies and reports, modeling results, remote sensing, expert knowledge and field visits by Jal Fnom, Makuac Deng and Mary Loki as supervisor in April and May 2012.

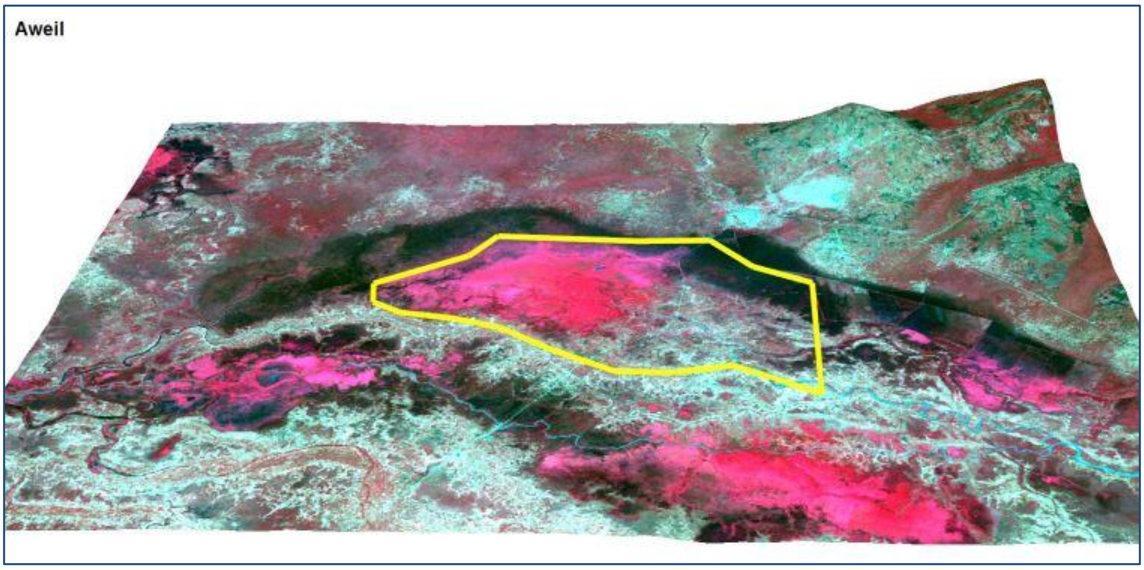


Figure 64: 3D impression of Aweil focal area, South Sudan.

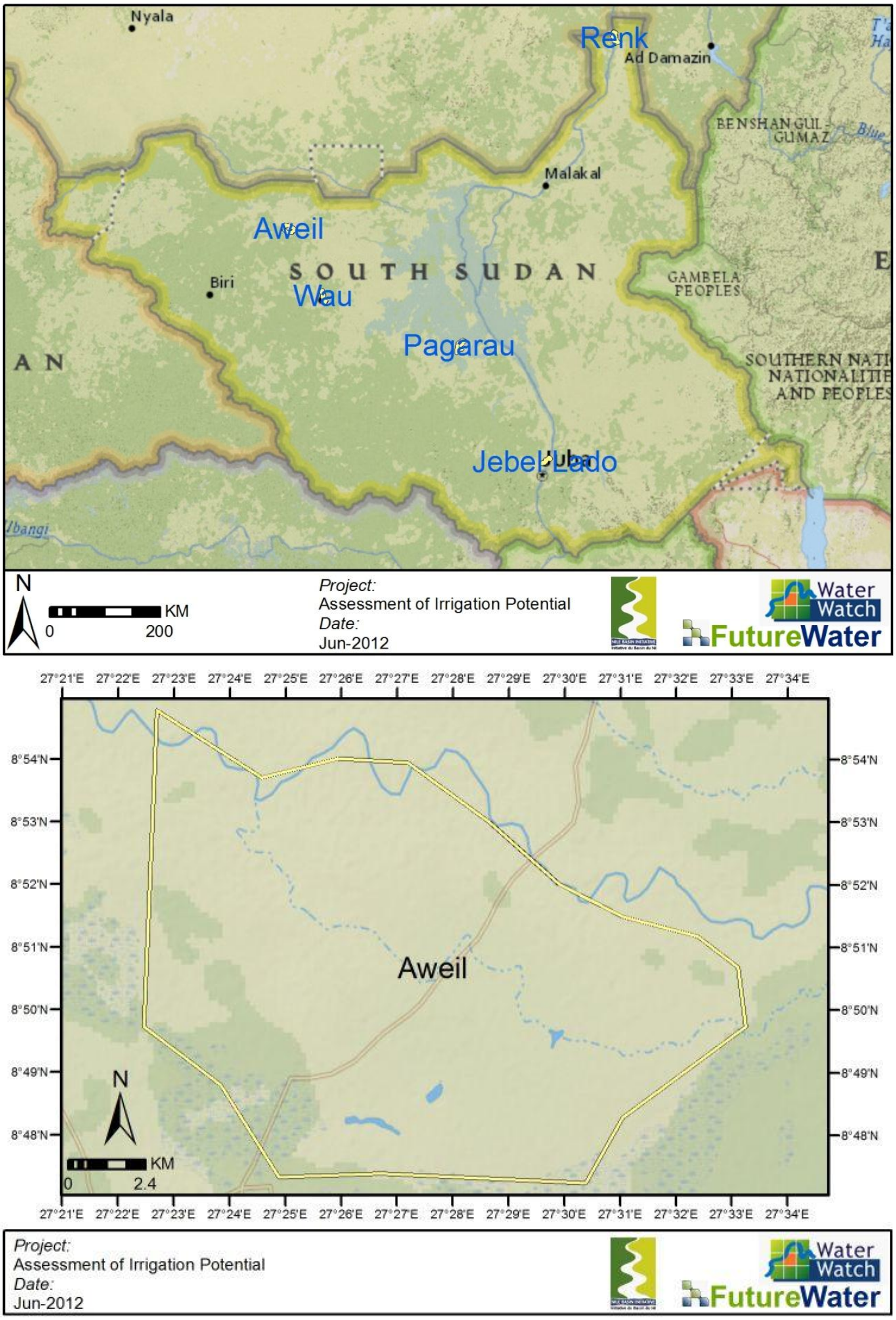


Figure 65: Aweil focal area, South Sudan.

5.2 Land suitability assessment

5.2.1 Terrain

Aweil focal area is located in the northwestern part of South Sudan, within Northern Bahr el Ghazal state. The area descends from the North West (425 m) towards the North East (415 m). One large stream passes the focal area on the northern side, and from the South a minor stream joins in. Both streams join just outside the focal area at the eastern side. The focal area (17,876 ha) is the largest of the five South Sudanese focal areas. An irrigation scheme has already been developed west of the focal area, although this irrigation scheme will need some rehabilitation. It is advised to rehabilitate that part first, before developing this focal area. Slopes in the focal area are largest in the North, reaching 2% on a 250 m resolution map. On a 30 m resolution, slopes are quite significant over the area, reaching over 10% in some small areas (Figure 67).

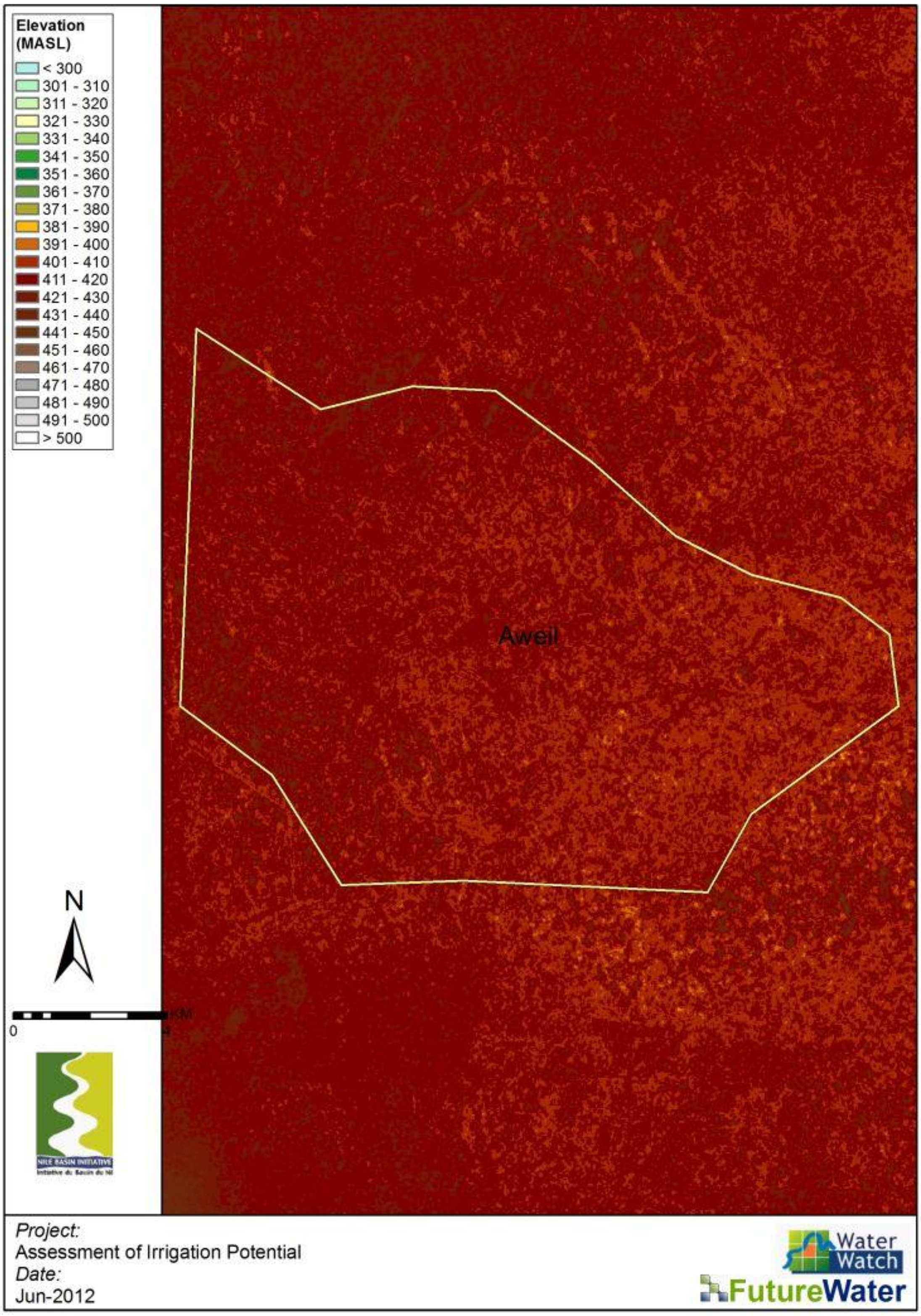


Figure 66: DEM Aweil focal area. Resolution 1 arc second (+/- 30m).

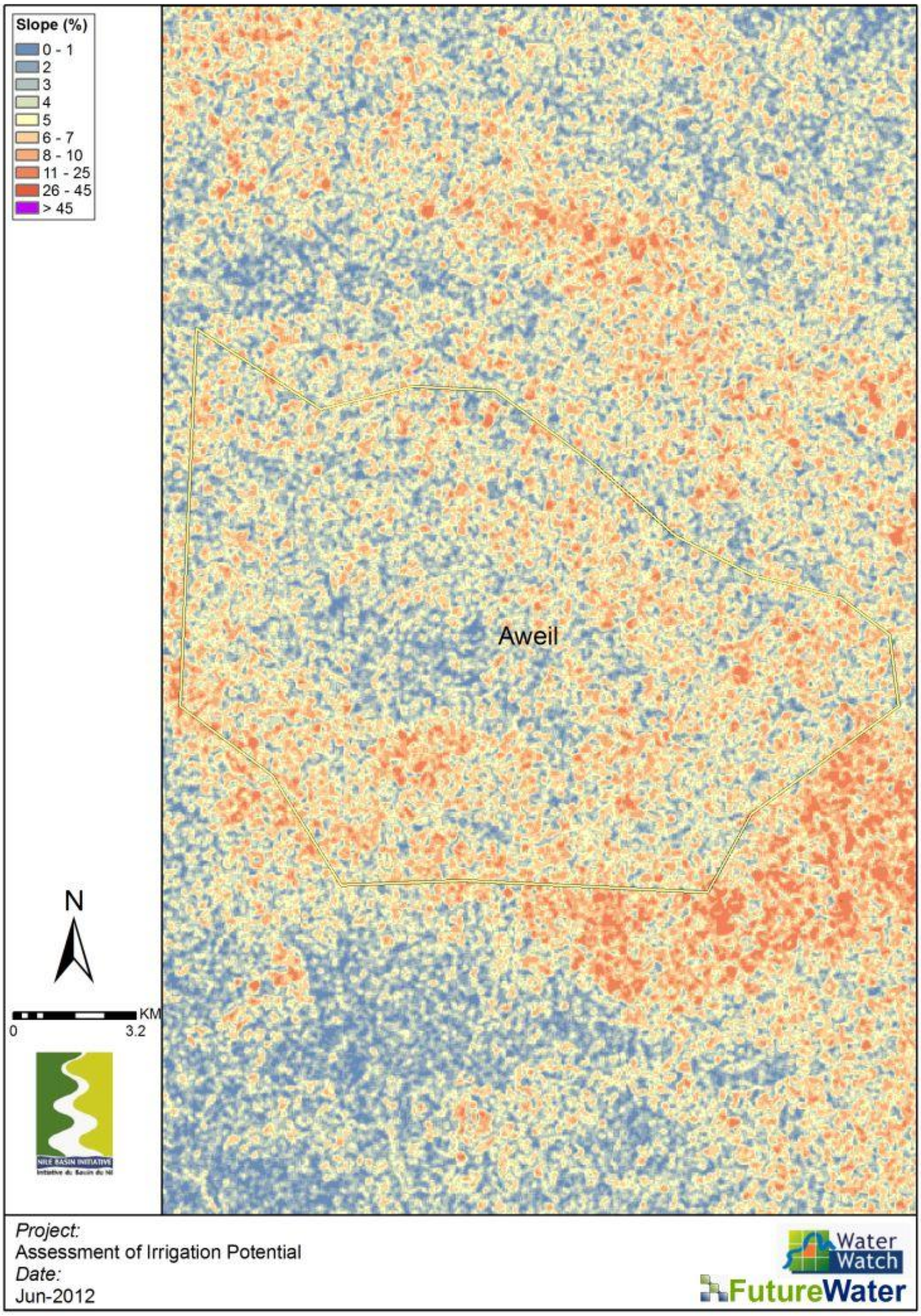


Figure 67: Slope map Aweil focal area (source: ASTER).

5.2.2 Soil

The soil in the Aweil focal area is quite uniform. Within the whole area a mixture and combination between Gleysols and Vertisols can be found. The area is well drained, and the soil has a clayey loam texture. Organic carbon in the soil is low (1%) and the available water holding capacity is between 125-150 mm/m.

The main obstacle to utilization of Gleysols is the necessity to install a drainage system to lower the groundwater table. Adequately drained Gleysols can be used for arable cropping, dairy farming and horticulture. If too wet soils are cultivated, then the soil structure will be destroyed for a long time. Therefore, Gleysols in depression areas with unsatisfactory possibilities to lower the groundwater table are best kept under a permanent grass cover or swamp forest. Gleysols can be used well for wetland rice cultivation if the climate is appropriate. Vertisols are clayey soils, with a high percentage of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. Vertisols have considerable agricultural potential, but adapted management is a precondition for sustained production. The comparatively good chemical fertility and their occurrence on extensive level plains, where reclamation and mechanical cultivation can be envisaged, are assets of Vertisols. Their physical soil characteristics and, notably, their difficult water management cause problems. Buildings and other structures on Vertisols are at risk, and engineers have to take special precautions to avoid damage. The agricultural uses of Vertisols range from very extensive (grazing, collection of fuel wood, and charcoal burning), through smallholder post-rainy season crop production (millet, sorghum, cotton and chickpeas), to small-scale (rice) and large-scale irrigated agriculture (cotton, wheat, barley, sorghum, chickpeas, flax and sugar cane). Cotton is known to perform well on Vertisols, allegedly because cotton has a vertical root system that is not damaged severely by cracking of the soil.

Figure 68. Charateristics of Aweil focal area.

5.2.3 Land productivity

The annual average land productivity (NDVI) in the five South Sudanese focal areas ranges between 0.30 and 0.60. Compared to the South Sudanese average NDVI of 0.50, the Aweil focal area has a lower than average land productivity with an NDVI of 0.46 (Figure 70). The highest land productivity can be found in the swampy area in the east of the focal area (NDVI towards 0.6). The slight ridges on the north and south of the focal area have significant lower land productivity, with values of 0.35. These areas are slightly higher and have more seasonal variation. The overall coefficient-of-variation in the focal area is very high and slightly lower around the southern border of the focal area.

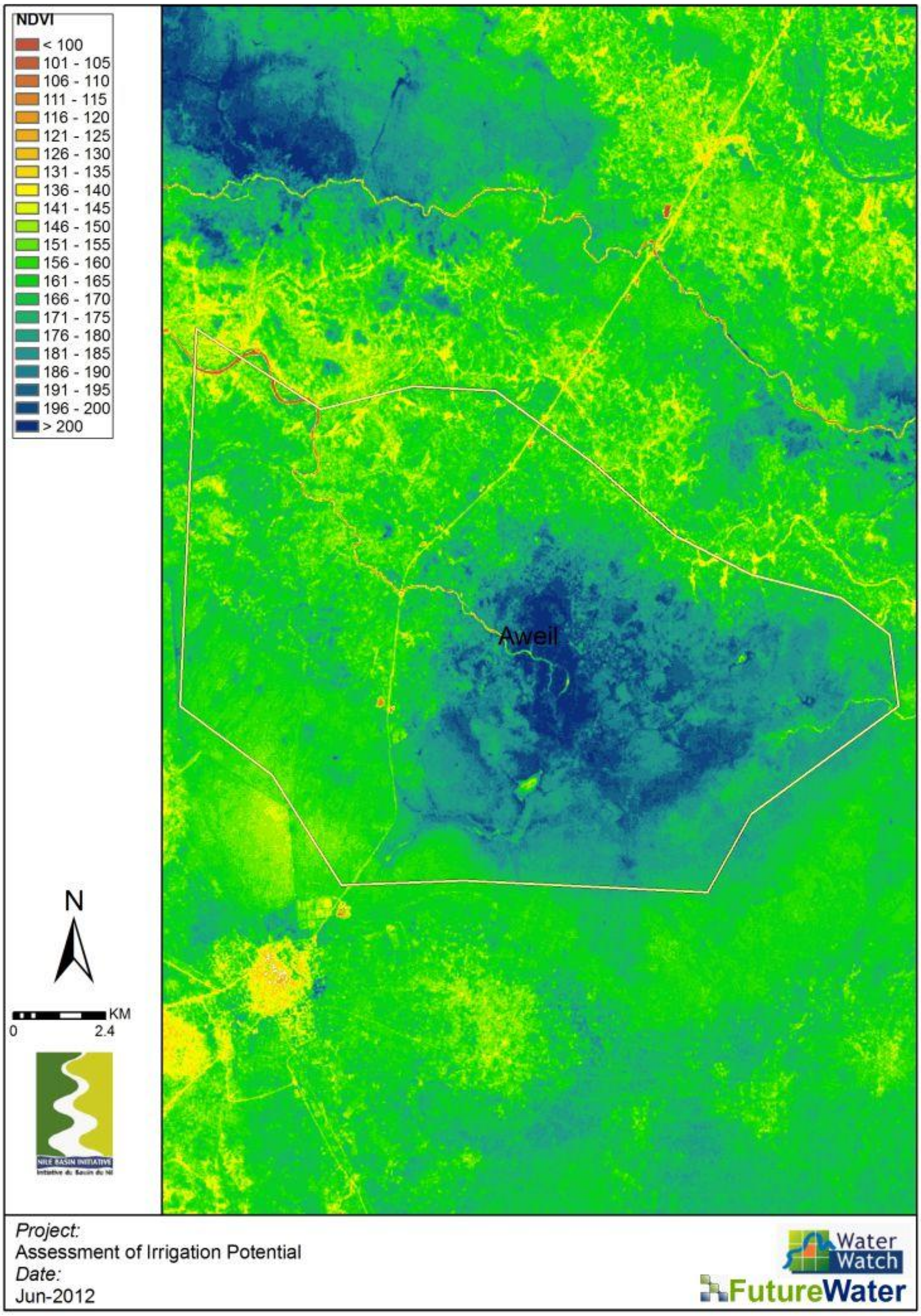


Figure 69: High resolution NDVI for Aweil focal area

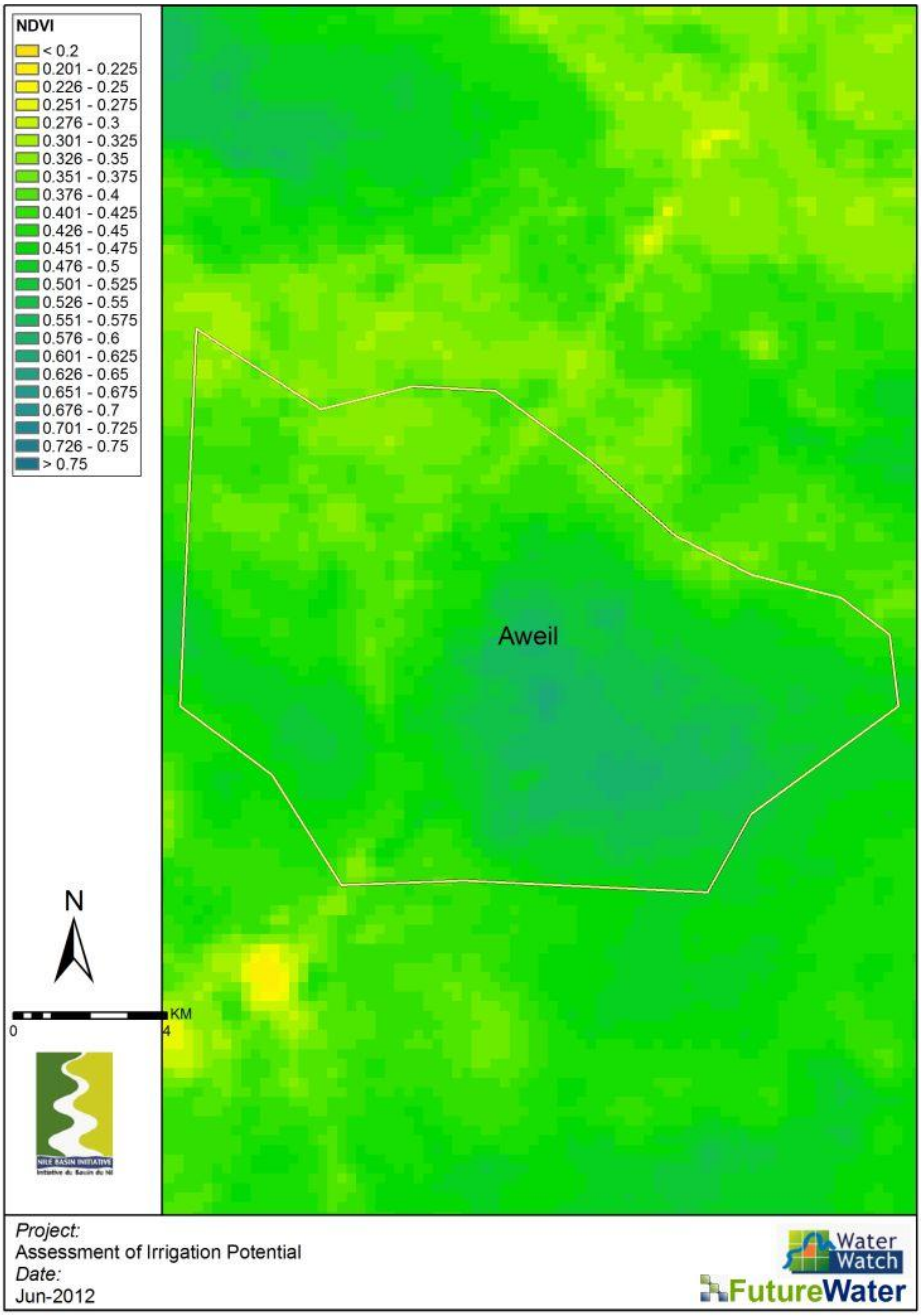


Figure 70: Yearly average NDVI values for Aweil focal area.

5.2.4 *Potential cropping patterns*

Currently, agriculture is practiced only in a small part of the focal area (4%). Furthermore, most of the land is covered with open scrubland, except for some parts towards the East, where there are herbaceous plants and a ridge along the North side of the focal area where rain fed cereals are grown. Currently, around Aweil only rice is grown, and in the North of the focal area some area is used to grow maize, sorghum and millet. Very small parts of the irrigation schemes developed around Aweil are still in use. It is advised to rehabilitate them before developing a new one. When rehabilitating the irrigation scheme it is advised to focus partially on staple crops; in this case mainly paddy and vegetables and partially, with an eye on the future, on cash crops such as sugar cane, which could diversify the economy. However, the priority should be crops that reduce hunger as first priority and poverty as second priority, such that the economic situation of the rural area can be strengthened. If irrigated, then a part of the focal area can be used during two growing cycles per year, which will create more food security and reduces poverty.

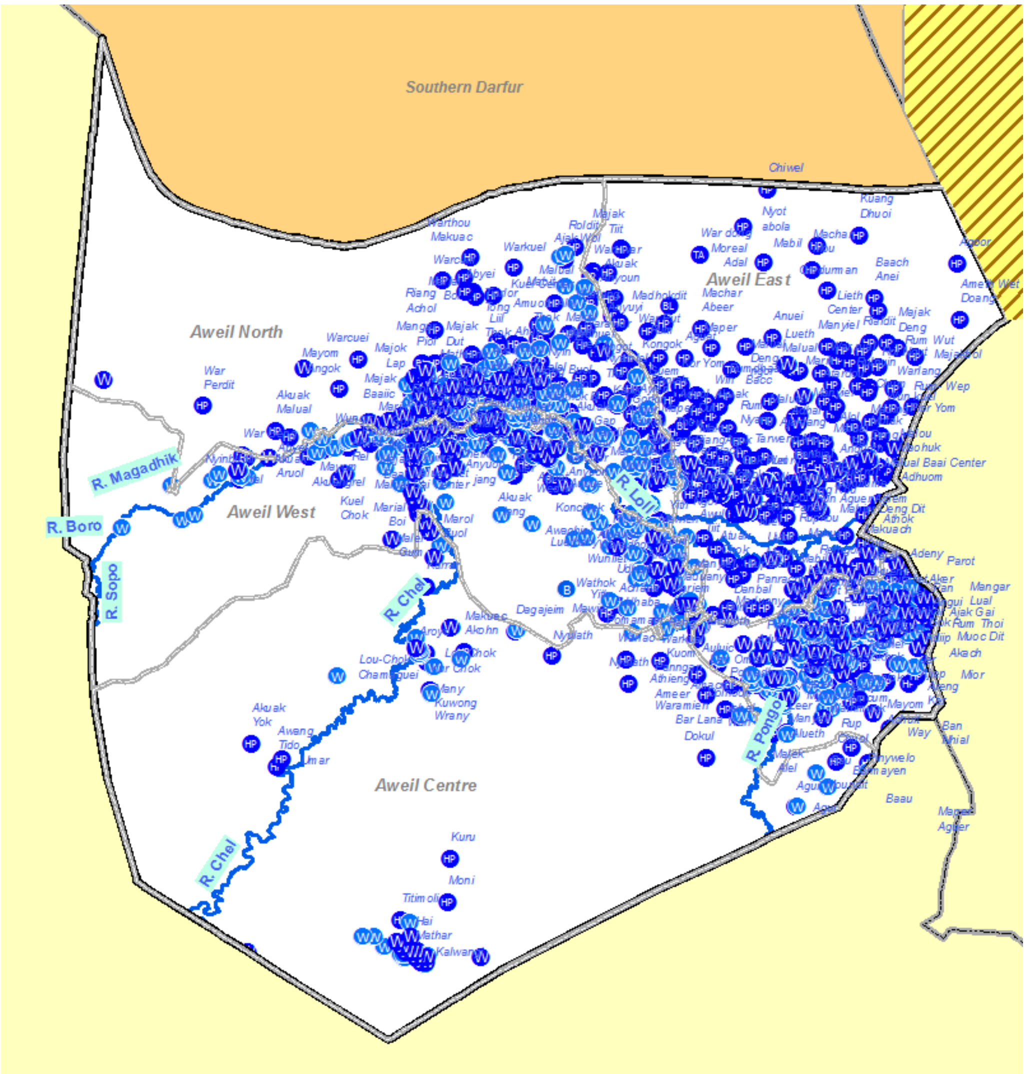


Figure 71. Boreholes (B) and Waterpoints (W) in Northern Bahr el Ghazal province in South Sudan (source: South Sudan Information Management Working Group)

5.3 Water resource assessment

5.3.1 Climate

Average climate conditions for the area are shown in the figure below. Precipitation is based on an advanced calibration/validation algorithm using satellite derived precipitation and calibrated using local observations. Details can be found in the Phase 1 Report. Reference evapo-transpiration (ETref) is calculated using the well-known Penman-Monteith approach. Input data for ETref is based on local observations and an advanced spatial downscaling algorithm.

The climate of the area can be characterized as warm with temperatures during the year ranging from about 24°C to 36°C. Annual average precipitation is 926 mm and reference evapotranspiration 1961 mm per year.

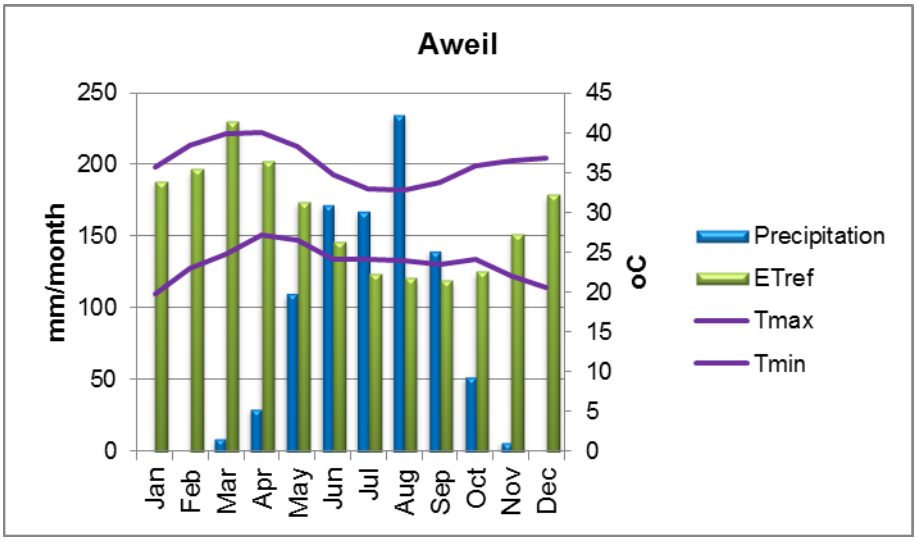


Figure 72: Average climate conditions for Aweil focal area.

5.3.2 Water balance

A very detailed high resolution model was built for NEL countries (NELmod). For a detailed description see Phase 1 report. Results from NELmod were extracted for this specific focal area and are shown below. The area is characterized by quite some groundwater recharge and might therefore be developed into a groundwater pumping system. Drainage and runoff is almost zero.

The focal area is located in the state Norther Bahr el Ghazal. Already quite some existing boreholes and water points can be found in the region (Figure 40)

Figure 73. Charateristics of Aweil focal area.

Figure 74. Charateristics of Aweil focal area.

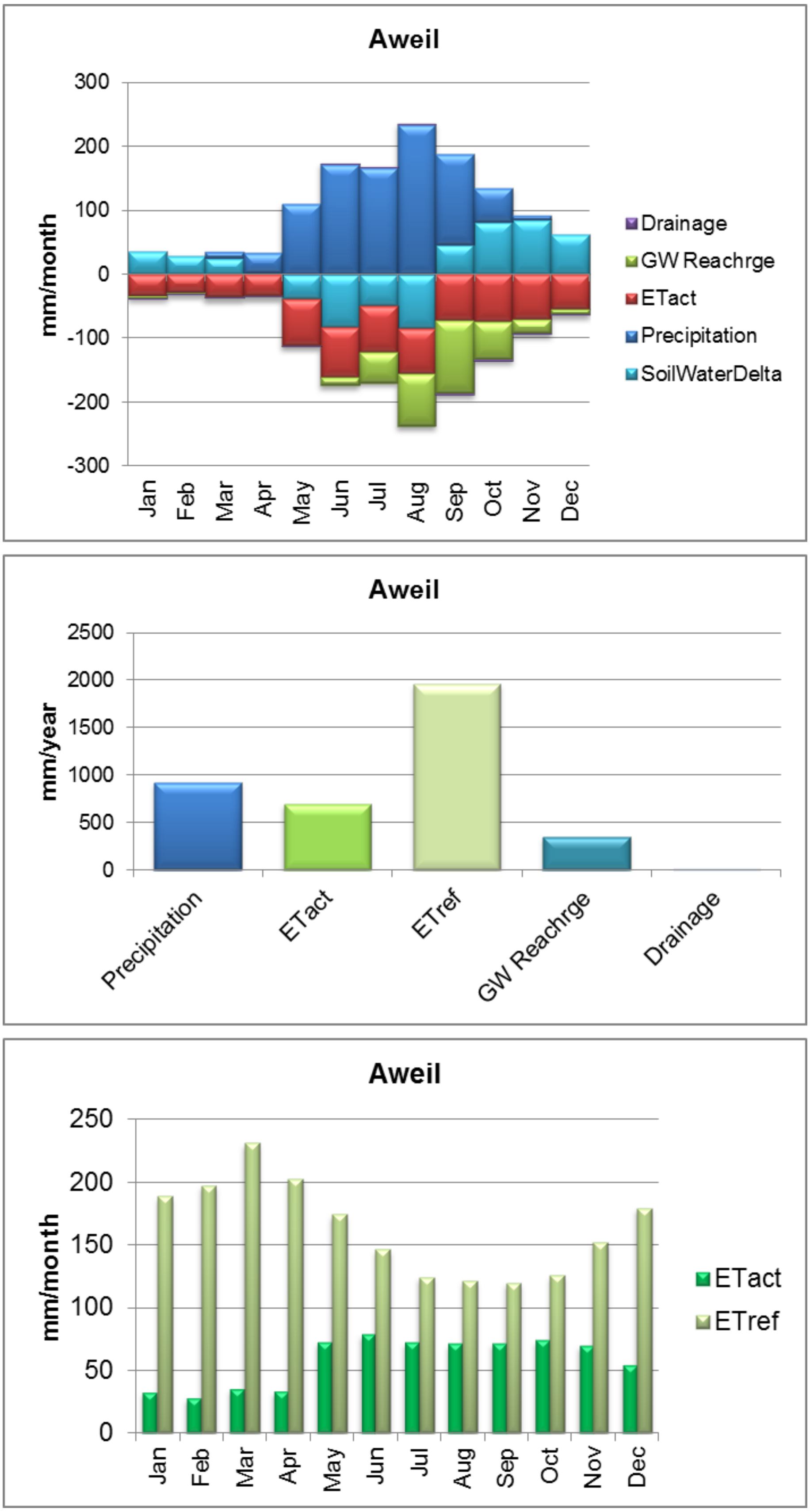
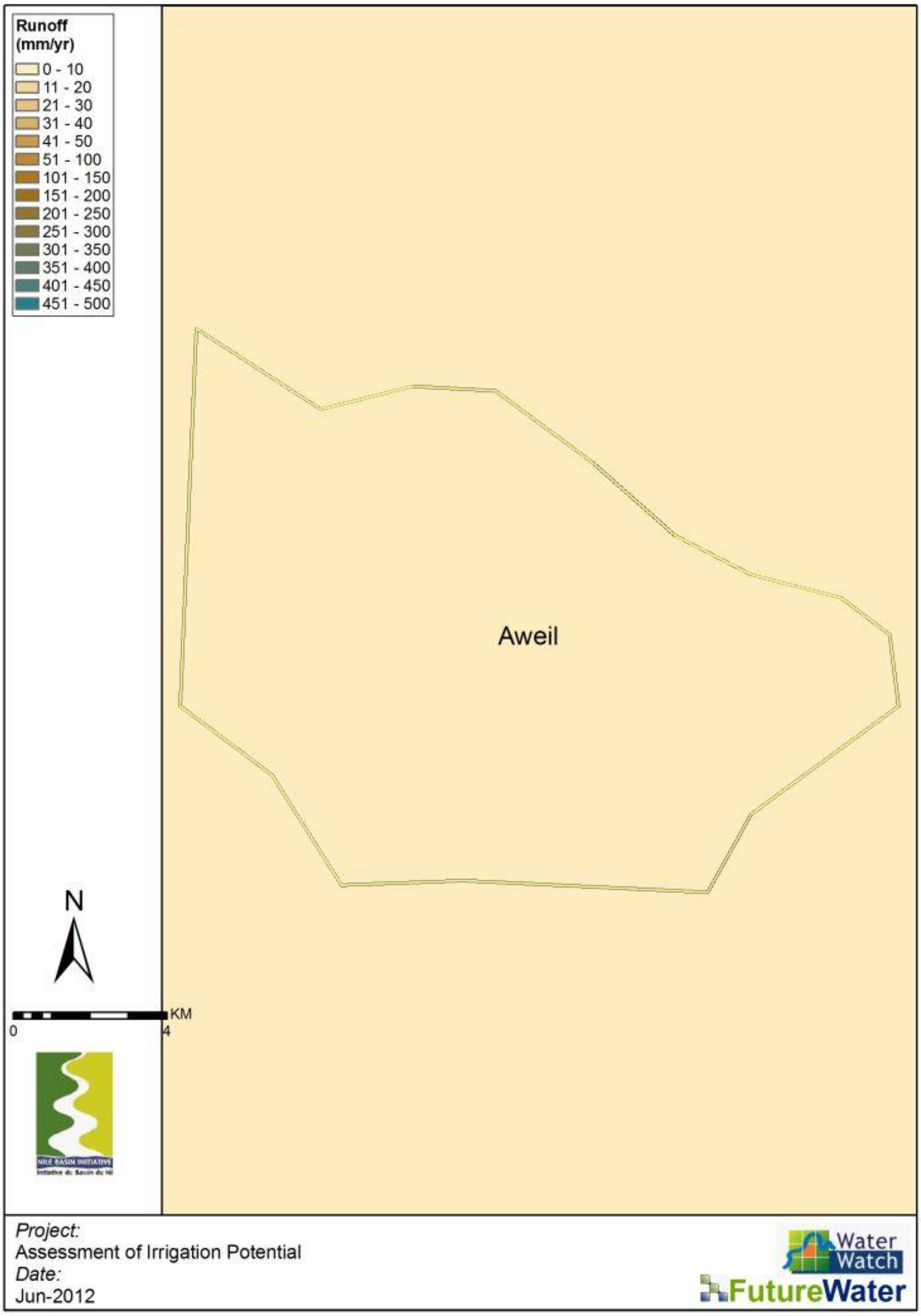


Figure 75: Water balances for the area based on the high resolution data and modeling approach for Aweil focal area.



Runoff (mm/yr)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
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Date:
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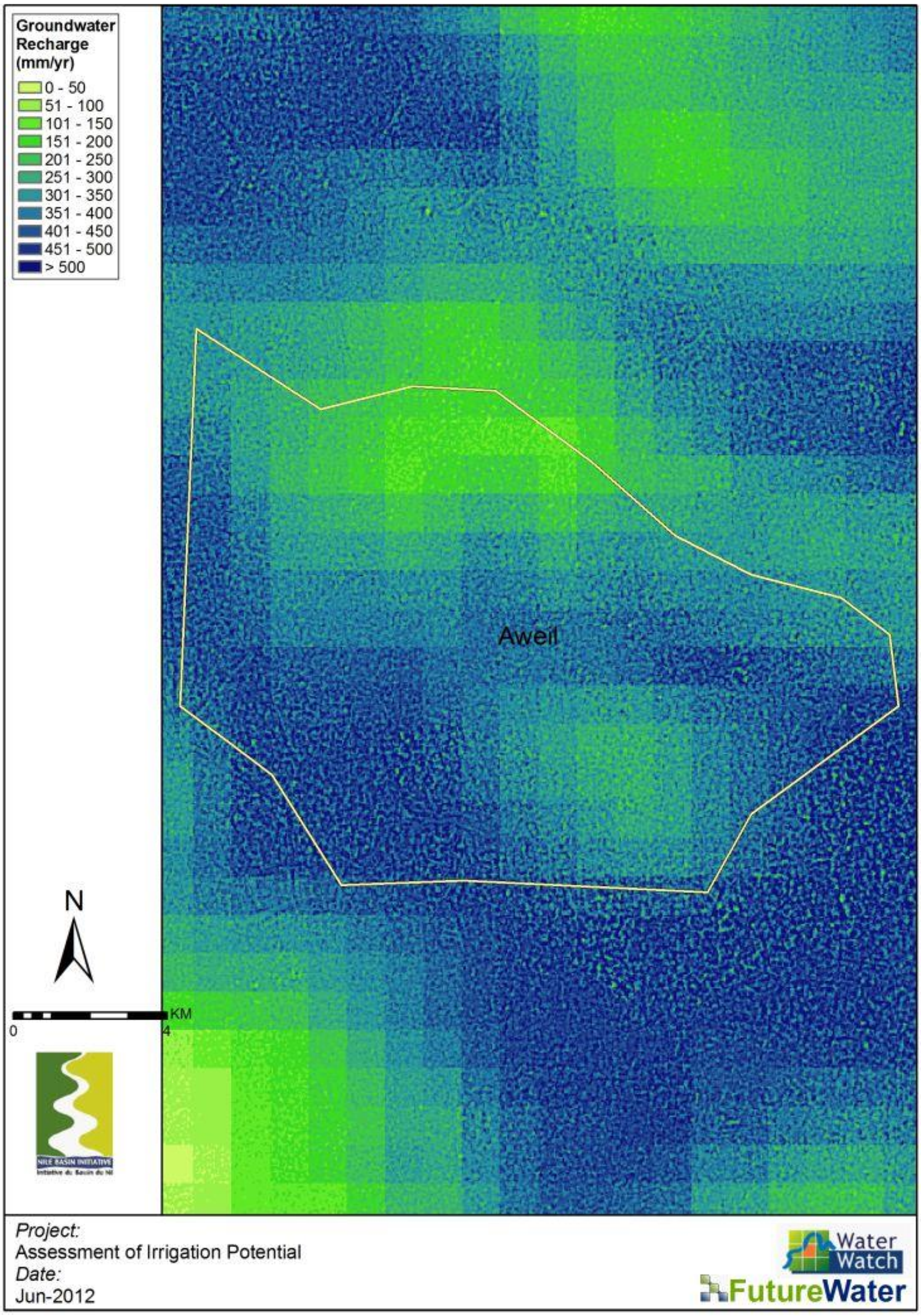

Groundwater Recharge (mm/yr)
0 - 50
51 - 100
101 - 150
151 - 200
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251 - 300
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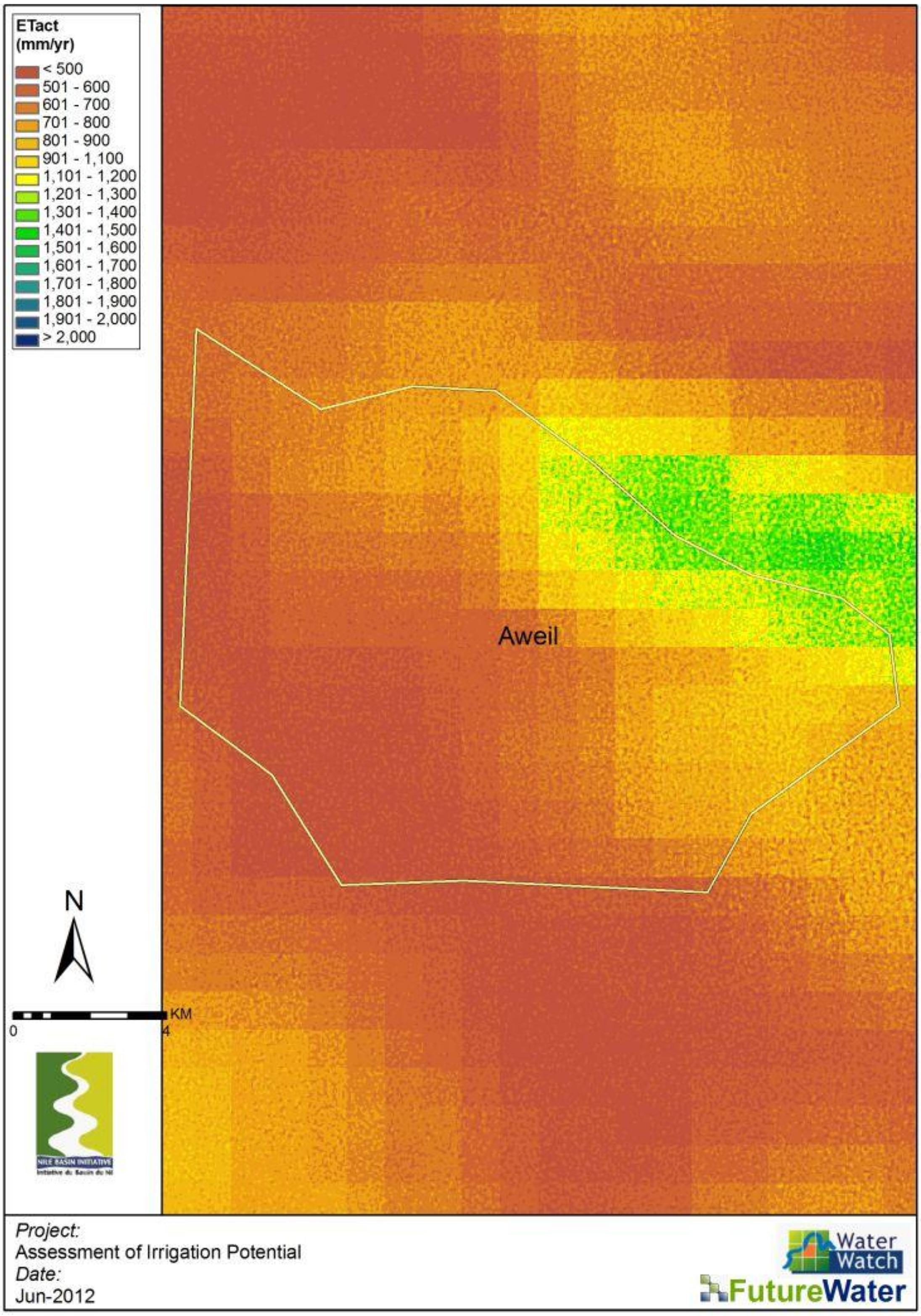


Figure 76: Water balances for the area based on the high resolution data and modeling approach for Aweil focal area.

5.4 Assessment of irrigation water requirements

5.4.1 Irrigation water requirements

Irrigation water requirements depend on many factors such as: climatic conditions, crop, growing season, irrigation practices etc. A first estimate of irrigation requirements could be based on the difference between rainfall and reference evapotranspiration. It was however selected for this pre-feasibility assessment to provide a first estimate of irrigation needs based on the most promising crops. To this end, FAO's AquaCrop, the successor of CropWat was setup for local and crop specific conditions.

In the table below the irrigation water requirements for each selected crop are provided based on AquaCrop calculations. All units are provided in mm per growing season for the specific crops. Note that for various crops, like vegetables and similar crops, multiple croppings per years might occur.

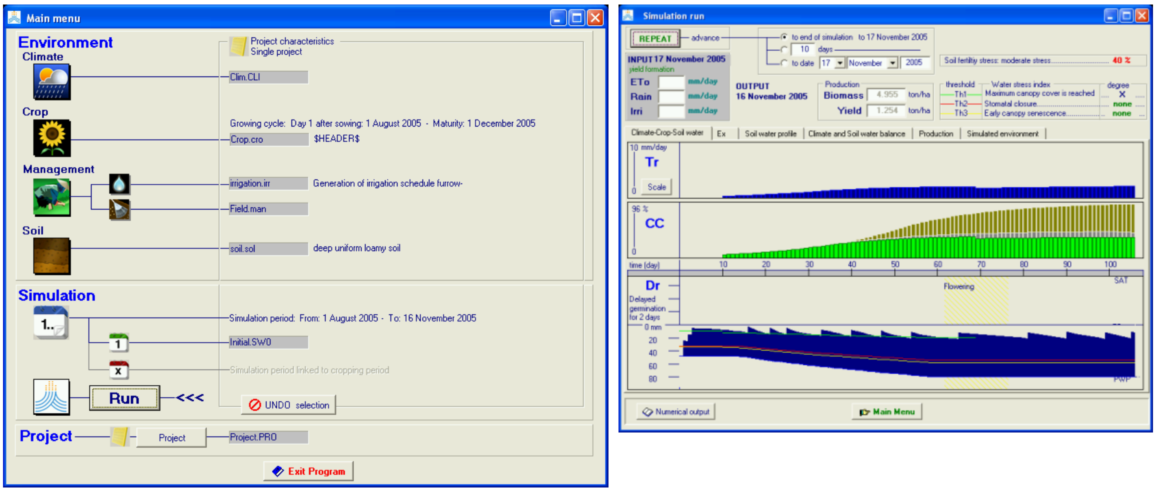


Figure 77: Typical example of AquaCrop input and output screens.

Table 7: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season.

Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year	===	== (day of year) ==		======== growing season =======			
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Rice	926	1961	213	320	435	210	445	386
Maize	926	1961	121	238	648	190	544	499
Sugar cane	926	1961	1	365	926	890	1952	1034

5.4.2 Irrigation systems and irrigations efficiencies

The topography in the Aweil focal area is very suitable for gravity surface irrigation. Since paddy rice will be the main crop in the irrigated area, border irrigation is recommended. Vegetables can be grown on small scales under furrow irrigation, and on the longer run sugar cane can be grown under border irrigation as well. Efficiencies of surface irrigation are quite low, with an average field application efficiency of 60%. The development costs for border irrigation are relatively low, and the farmer's knowledge is partially present, because an irrigation system is already present, and a large irrigation system has been operational before.

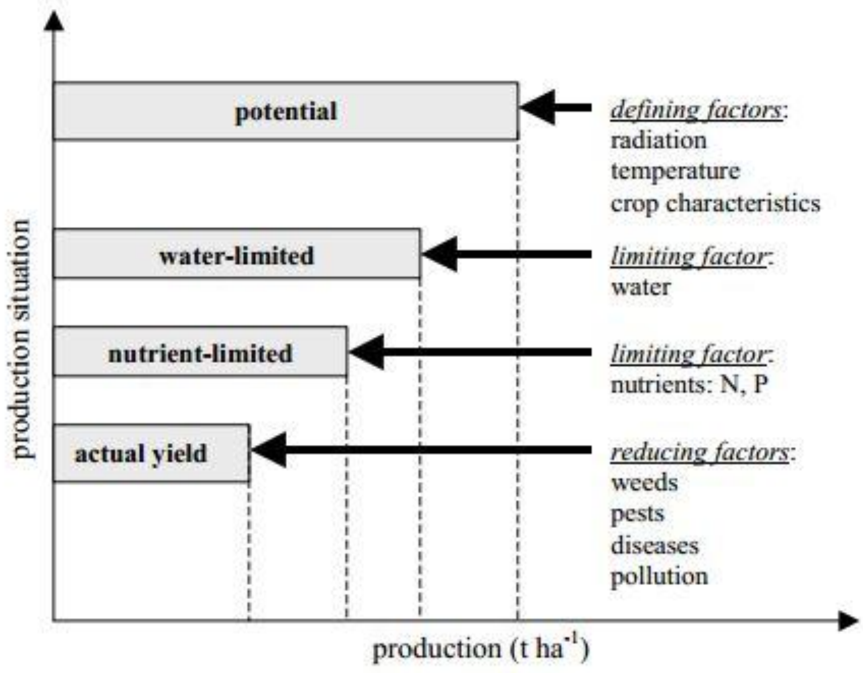
5.4.3 Water source

The river Loll passes by the focal area on the North side. This river drains an approximate area of 53,000 km^2 and sprouts from the mountains in the West. The average annual flow (50 m^3/s) is enough to irrigate the full area. The river water can be enough to irrigate the whole area, but some water storage is needed as water levels in the dry season may run low. A reservoir or a series of reservoirs upstream can control flow levels and store water to continue irrigation in the dry season from November to April. When aimed for a completely second cropping cycle on an approximate area of 5000 ha, the water storage should be around 100 million m^3.

5.5 Potential crop yield assessment

The yield gap describes the difference between the current yield, and the maximum possible yield. Mostly the maximum possible yield is defined as the highest yield in the world, but it can also be assessed against a regional background which makes the yield gap more realistic and the maximum yield possible to achieve under the given circumstances.

The gap between the actual yield and the potential yield can be caused by several processes. Factors which may cause that the maximum possible yield is not reached can be the water availability, the soil and the available nutrients, or yield reducing factors like diseases, weeds or pollution.



5.5.1 Yield gap analysis potential dominant crops[1]

Yields in Sudan are relatively high compared to surrounding countries. There is, however, a large differentiation between crops. Sudan has extremely high yields for dry beans, bananas, sugar cane, sweet potatoes and potatoes. For paddy and cotton seeds, Sudan performs better than the world's average yields. Most likely, this finds its origin in the intensification and

[1] This section is bases on FAOSTAT with yields from former Sudan.

irrigation programs, which have been introduced in the past to increase food production to meet the demand. In Figure 78, the yield gap is shown relatively to the highest obtainable yield in the world, to the world's average, and to Africa's average. Within Aweil focal area, the yields are slightly lower than Sudanese average yields. However, the current harvested area can be largely expanded, which will produce tremendously more yield. Besides, there is a real potential to increase crop production, if rice is grown in two growing cycles, and to improve the water management conditions. The use of fertilizer is recommended to push yields even further. It is expected that the yields of rice can reach around 70% of the world's highest, which would mean an increase of over 100%. Currently, sugar cane in not grown in the area, but it can be introduced later on as cash crop. The numbers show that there is a large potential to produce sugar cane, which will enhance poverty reduction and diversify the exports. Irrigation will not only increase yields due to proper water management, but also enables a second growing cycle per year, which enhances productivity.

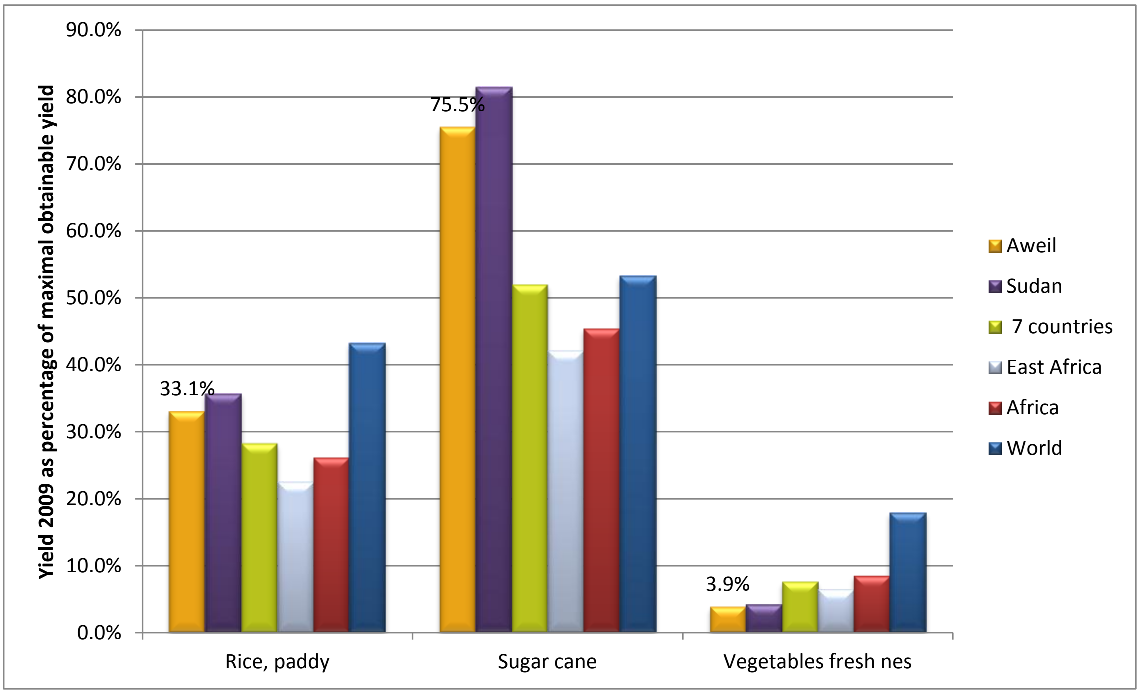


Figure 78: Yield gap Aweil (source: FAOSTAT, 2010).

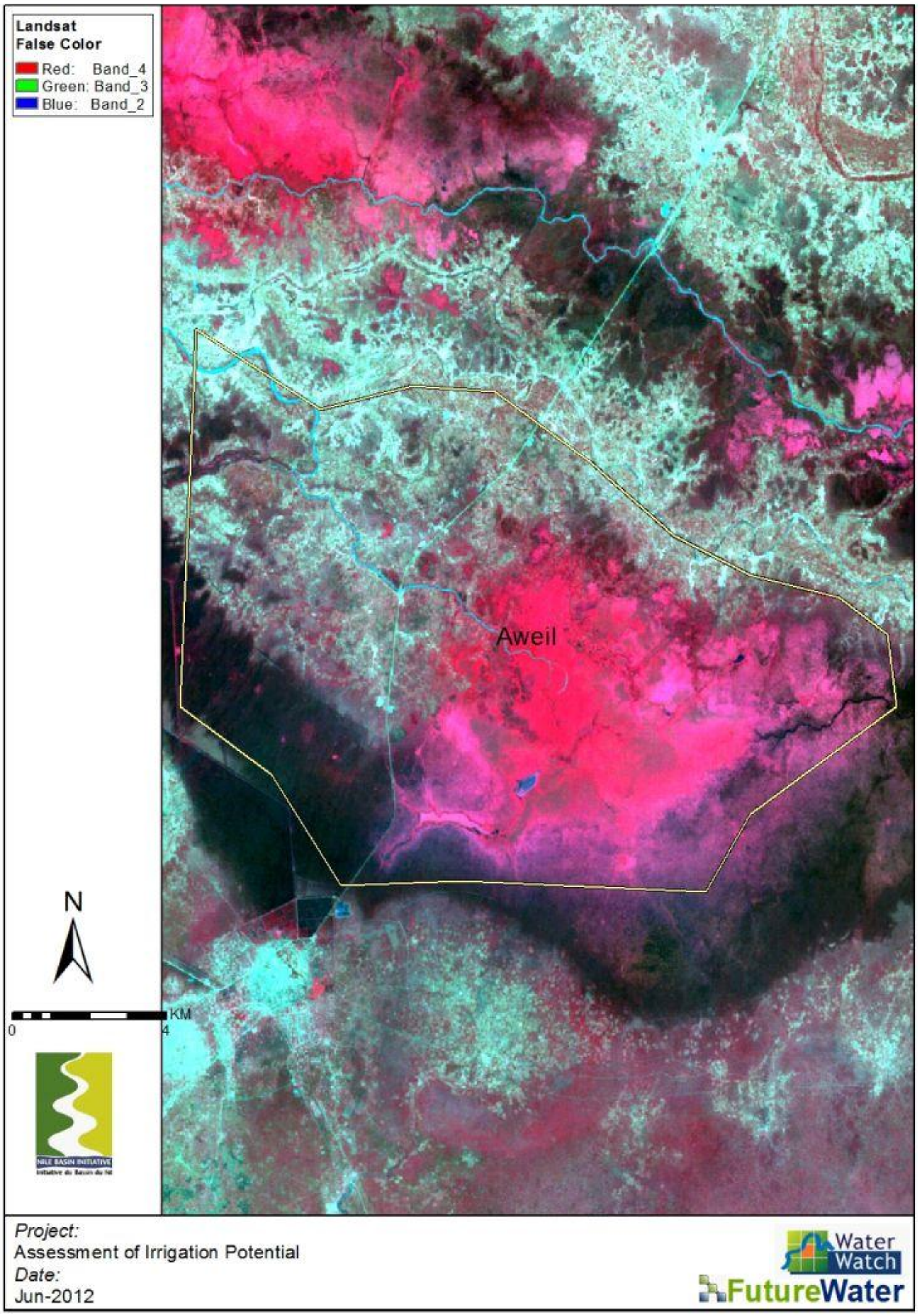


Figure 79: Landsat False Color Composite indicating current productivity of Aweil focal area.

5.6 Environmental and socio-economic considerations

5.6.1 Population displacements

Most people in the area live in Aweil town. Around the focal area and the abandoned irrigation scheme west of the focal area, there are quite some houses scattered around. However, within the focal area there are few houses and the abandoned irrigation scheme is not inhabited at all. It seems that population displacement is hardly needed, and especially when started with the rehabilitation of the old irrigation scheme. Considering the population settlement, the rehabilitation seems the best option to start with, as people are living nearby. With the design of any irrigation scheme, it is advised to limit any population displacement. The exact numbers of effected houses can only be known after designing the scheme, which is beyond the scope of this pre-feasibility study.

5.6.2 Social

Population density in the Northern Bahr el Gazal state is much higher compared to the South Sudanese average. The population density is approximately 24 people/km^2, compared to the South Sudanese average of 13 people/km^2. This country wide population density is among the lowest in the African sub-tropical countries. (CIESIN) Remarkably the ratio male to female is 0.93. In 2008, it is estimated that half (53%) of the population is below the age of 18 years. Within South Sudan 51% of the population lives below the national consumption poverty line (SSDP). Within Northern Bahr el Gazal this percentage is much higher (76%). This is the highest poverty rate in South Sudan. In rural areas, in which the focal area is located this may be higher. The area is inhabited by Dinka and Jur Chol people, which unfortunately have a very limited knowledge of agriculture, irrigation and farmers cooperatives. When developing an irrigation scheme additional effort is needed for intensive trainings. The area is not very well accessible, with some earth roads going around the area, and the first proper roads being at Aweil town, which is at about 15 km away. Aweil town is also the primary market, after which other towns can be served. The net enrolment rate in primary school is 58% in 2009, and literacy rate among 15-24 years old is 40%, which is unevenly distributed among males and females. 92% of the population in Northern Bahr el Gazal is rural, and 80% of the population depends on crop farming or animal husbandry as their primary source of living (SSNBS).

5.6.3 Upstream downstream consideration

The river that passes the Aweil focal area drains an area of 53,000 km^2. The drainage area is mainly situated in the hills towards the west. The high water availability will ensure that the water use for irrigation will hardly influence any other downstream water requirement; especially when upstream reservoirs will ensure water supply all-year-round. To enhance the environmental aspects upstream, within the focal area, and downstream, it is advised to search for measures that retain the precipitation water first, and try to store it upstream. This will enhance velocity and erosion reduction; strengthen the upstream ecosystem, and groundwater levels. On a larger scale the groundwater is recharged, which can become available downstream, and evaporation enhances the water cycle and the precipitation in the area. The use of fertilizer is recommended, but it is needed to use fertilizer in a responsible and well considered way. Otherwise the water quality downstream may be compromised.

5.6.4 Protected areas

Within the focal area no protected areas are reported.

5.7 Benefit-cost Analysis

A simplified benefit-cost analysis is undertaken for the area. Information for this is based on various sources such as FAO publications, IFPRI publications, local expertise and data. A full benefit-costs analysis has to be undertaken in a sub-sequent feasibility study for the area.

Note that this is a first-order benefit-cost analysis. A feasibility study can provide a more rigorous benefit-cost analysis, which is required before taking any implementation planning. However, the following table shows that based on this first-order analysis, investments in irrigation can have a very positive impact.

Main assumptions for the benefit-costs analysis include:

- Irrigated land based on GIS and local experts for boundaries
- Number of farmers based on average land tenure area
- Irrigation infrastructure based on irrigation type and source
- Social infrastructure based on local expert judgment on farmers' trainings need
- Accessibility infrastructure based on generalized road conditions
- Internal Rate of Return based on 25 years
- Crop revenues based on local crop potentials and local market prices (crop, kg/ha, $/kg):
    - Rice: 6,000 kg/ha, 1.10 $/kg
    - Maize: 2,000 kg/ha, 0.22 $/kg
    - Sugar cane: 20,000 kg/ha, 0.05 $/kg

Based on expert knowledge on the suitability to develop irrigation in the area scores between 1 (negative: low suitability or expensive) to 10 (positive: high suitability or low investments) have been marked. The filled radar plot below indicates the options for the focal area. Overall, the weak part of the site lies under farmers capacity, accessibility to roads, to markets and the initial investment cost. This in-turn affects access to market as farmers cannot transport their yield easily and more importantly may not fetch golden prices. However, soil suitability and water availability is a great deal for the area that will foster an increase yields.

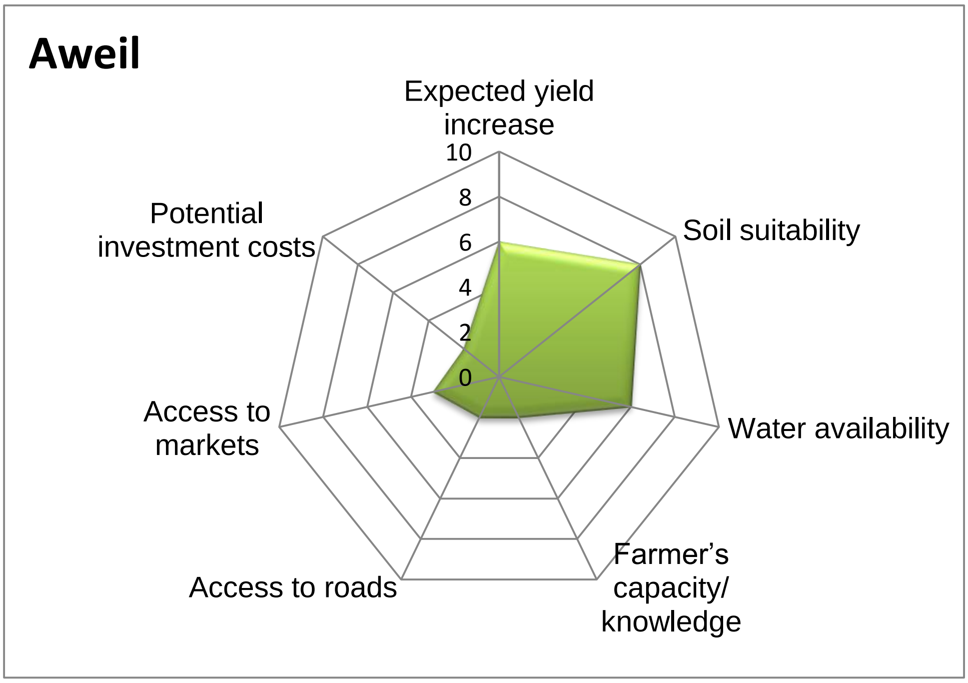


Figure 80: Filled radar plot indicating expert knowledge score to develop irrigation in the Aweil focal area (1 = negative, 10 = positive). (Source: local experts and study analysis).

Table 8: Benefit-cost analysis for Aweil area.

Characteristics	
Irrigated land (ha)	12,000
Farmers	24,000
Investment Costs	
Irrigation infrastructure (US$/ha)	3,000
Social infrastructure (US$/farmer)	500
Accessibility infrastructure (million US$)	1.0
Operational Costs	
O&M irrigation (US$/ha/yr)	60
Extension service (US$/farmer)	10
O&M roads (US$/yr)	20,000
Summary	
Initial investments (million US$)	49.0
O&M costs (million US$/yr)	0.980
Net benefits per year (million US$/yr)	19.296
IRR (Internal Rate of Return)	59.7%

6 Renk focal area

6.1 Introduction

This chapter will describe the current state of the Renk focal area, concerning land and water resources, and will discuss the potential to develop irrigation in the area. This irrigation potential will be based on the land and water resources, the irrigation requirements, the potential crop yields and will also involve the socio-economic considerations and institutional frameworks. Based on these aspects the potential for irrigation will be described, and cost for irrigation development calculated. In Figure 82 a detailed map of the area is given. Total area is 10,230 ha.

Selection of this specific focal area was based on results of Phase 1 of this study, while final selection was the responsibility of the relevant country representatives. Results presented hereafter have been obtained from a broad range of sources: Phase 1, previous other studies and reports, modeling results, remote sensing, expert knowledge and field visits by Jal Fnom, Makuac Deng and Mary Loki as supervisor in April and May 2012.

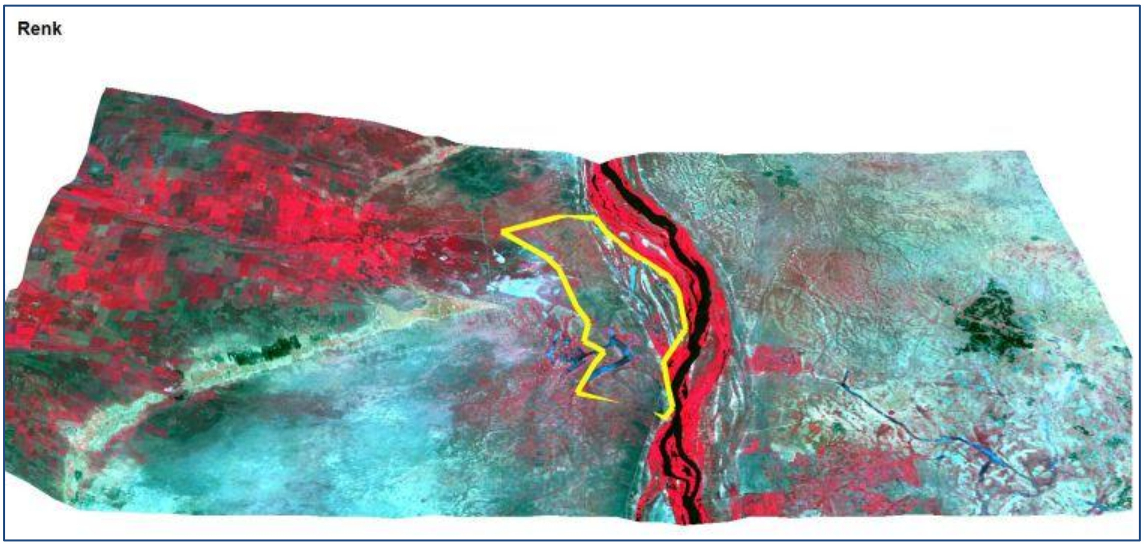


Figure 81: 3D impression of Renk focal area, South Sudan.

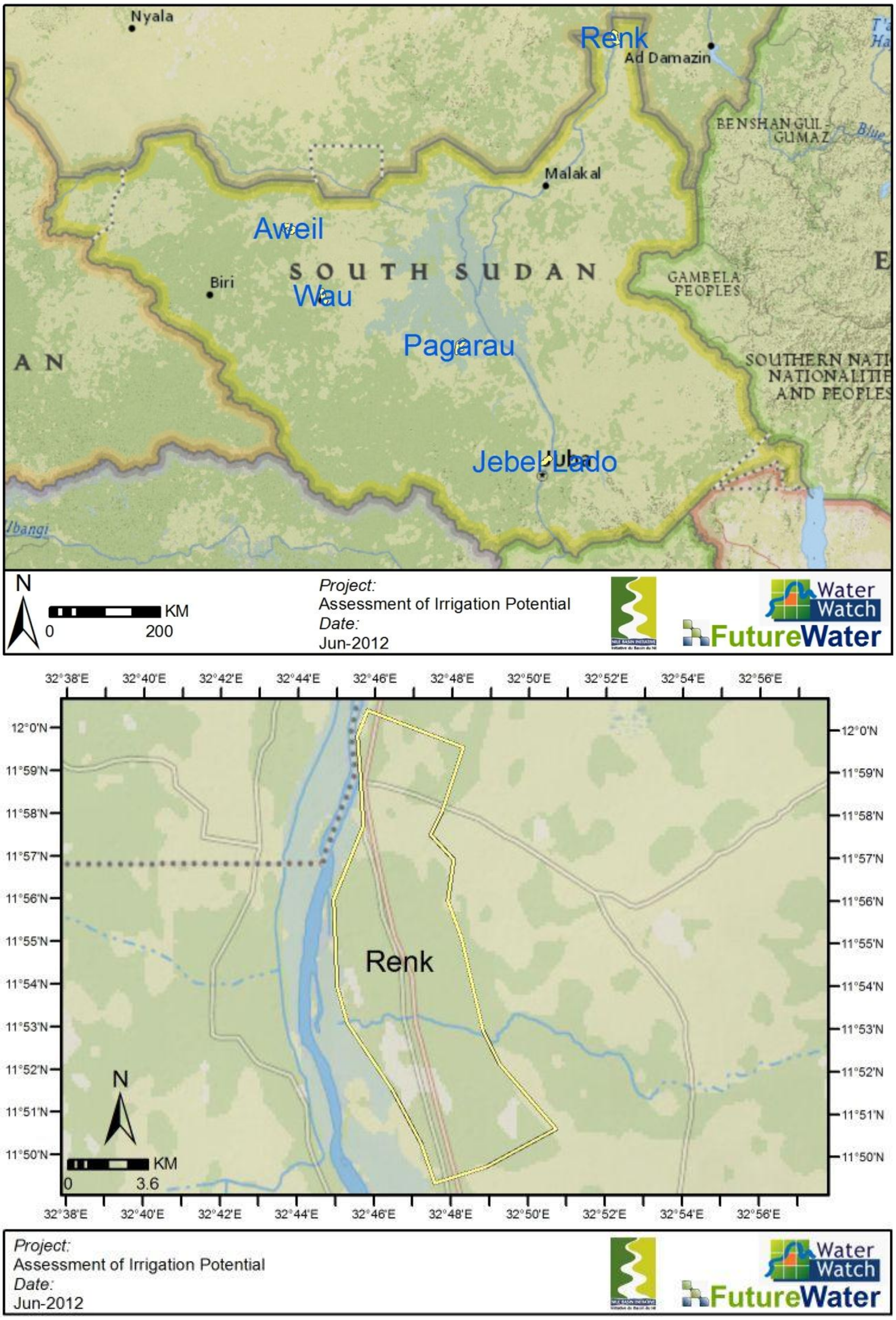


Figure 82: Renk focal area, South Sudan.

6.2 Land suitability assessment

6.2.1 Terrain

The Renk focal area is located completely in the North of South Sudan, within the Upper Nile state, and borders Sudan. The focal area includes some irrigation schemes, which are currently partially operational. The largest irrigation systems are Abu Khadra, Magara and Geigar, which spread from South to North along the Nile. The focal area (10,231 ha) covers the western banks of the White Nile, starting from Renk and going northwards. The area descends from East (390 m) to West (380 m) at Nile level (Figure 83). Two seasonal rivers pass through the area from East to West, but they are not used much for irrigation purposes. Slopes are limited. The steeper slopes can be found at a line following the road going through the area. The majority of slopes stay under 2% (Figure 84).

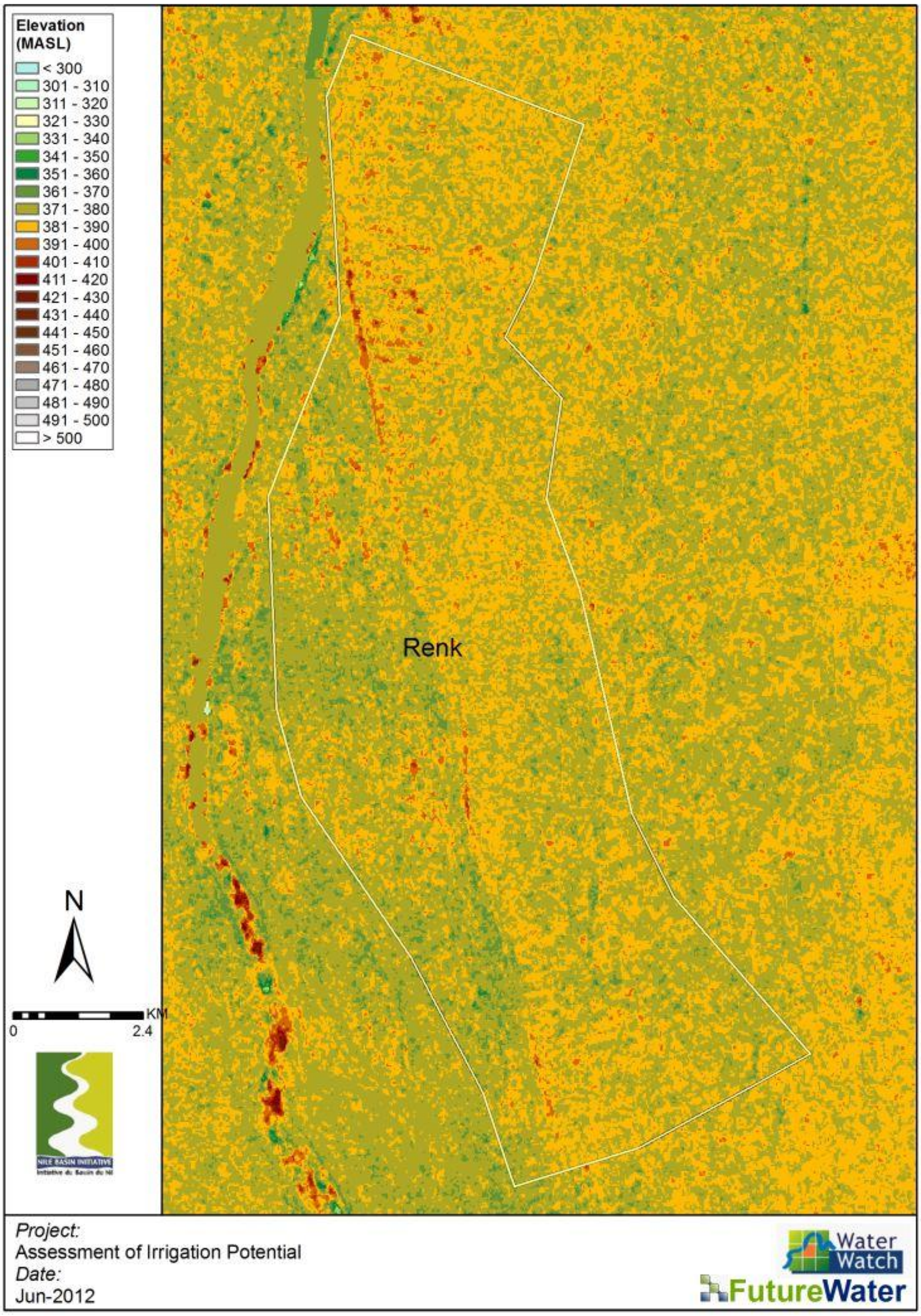


Figure 83: DEM Renk focal area. Resolution 1 arc second (+/- 30m).

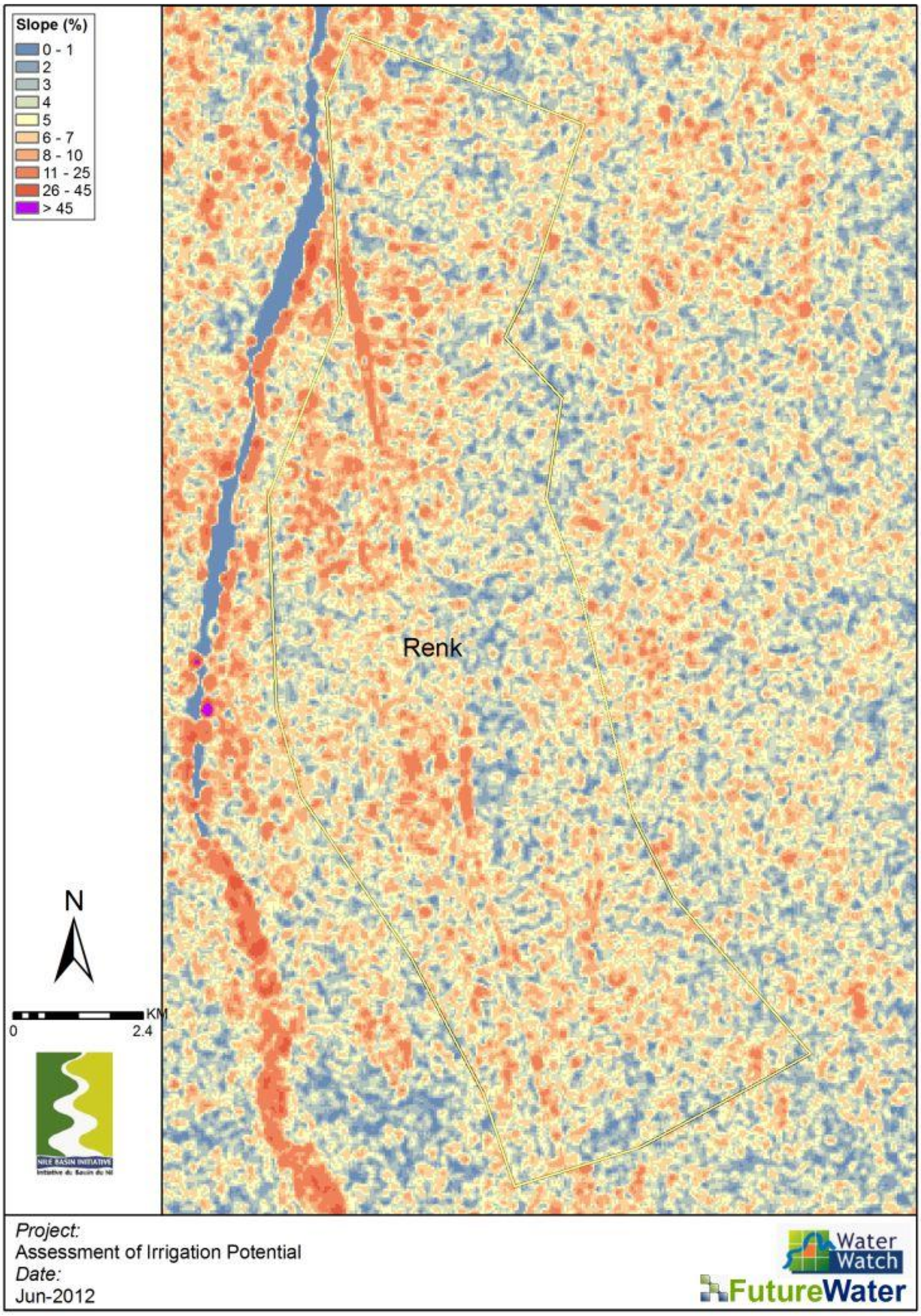


Figure 84: Slope map Renk focal area (source: ASTER).

6.2.2 Soils

The soil in Renk focal area can be defined as Eutric Vertisol. This area on the shores of the river Nile has been influenced by its regime. The texture is mainly heavy clay, which is well drained. The pH is average with a value of 7. Organic carbon in the soil is rather low (1%) and the water holding capacity is between 125-150 mm/m. The shifting swelling and shrinking of expanding clays results in deep cracks during dry season. Vertisols have considerable agricultural potential, but adapted management is a precondition for sustained production. The comparatively good chemical fertility and their occurrence on extensive level plains, where reclamation and mechanical cultivation can be envisaged, are assets of Vertisols. Their physical soil characteristics and difficult water management cause problems. Buildings and other structures on Vertisols are at risk, and engineers have to take special precautions to avoid damage. The agricultural uses of Vertisols range from very extensive (grazing, collection of fuelwood, and charcoal burning), through smallholder post-rainy season crop production (millet, sorghum, cotton and chickpeas), to small-scale (rice), and large-scale irrigated agriculture (cotton, wheat, barley, sorghum, chickpeas, flax, and sugar cane). Cotton is known to perform well on Vertisols. Management practices for crop production should be directed primarily at water control in combination with conservation or improvement of soil fertility.

Figure 85. Charateristics of Renk focal area.

6.2.3 Land productivity

The annual average land productivity (NDVI) in the five South Sudanese focal areas ranges between 0.30 and 0.60. Compared to the South Sudanese average NDVI of 0.50, Renk focal area has a lower than average land productivity with an NDVI of 0.30. This is the lowest of all focal area in South Sudan (Figure 87). Within the Nile valley the NDVI reaches values of 0.5. In the focal area, however, the NDVI values range between 0.25 and 0.33. On the part where irrigation is practiced the highest values are reached. The coefficient-of-variation is very high, which means that any land cover is very seasonal and that the land is only productive during a part of the year. Regarding the irrigation schemes, it is likely that they are not used all-year-through.

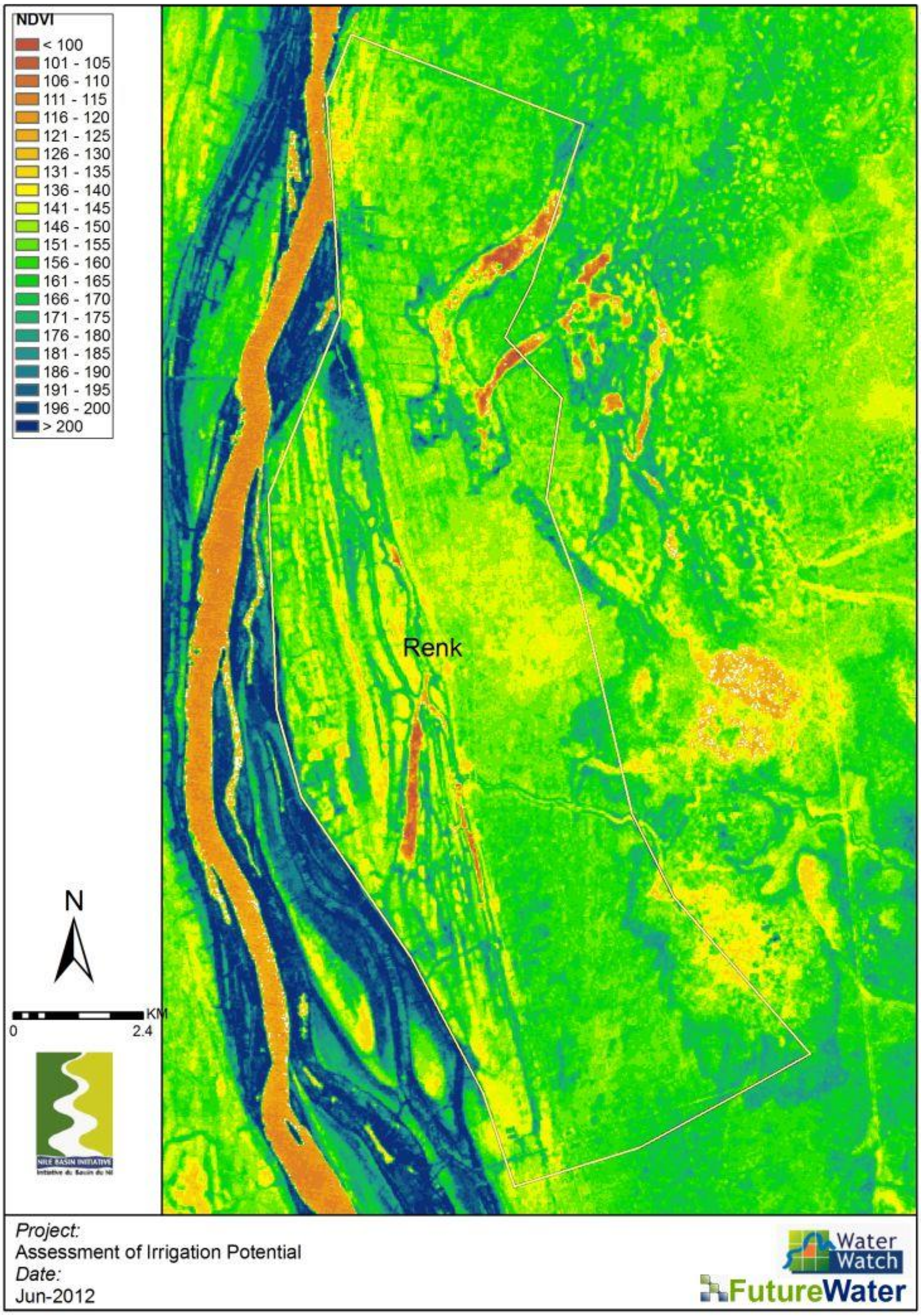


Figure 86: High resolution NDVI for Renk focal area

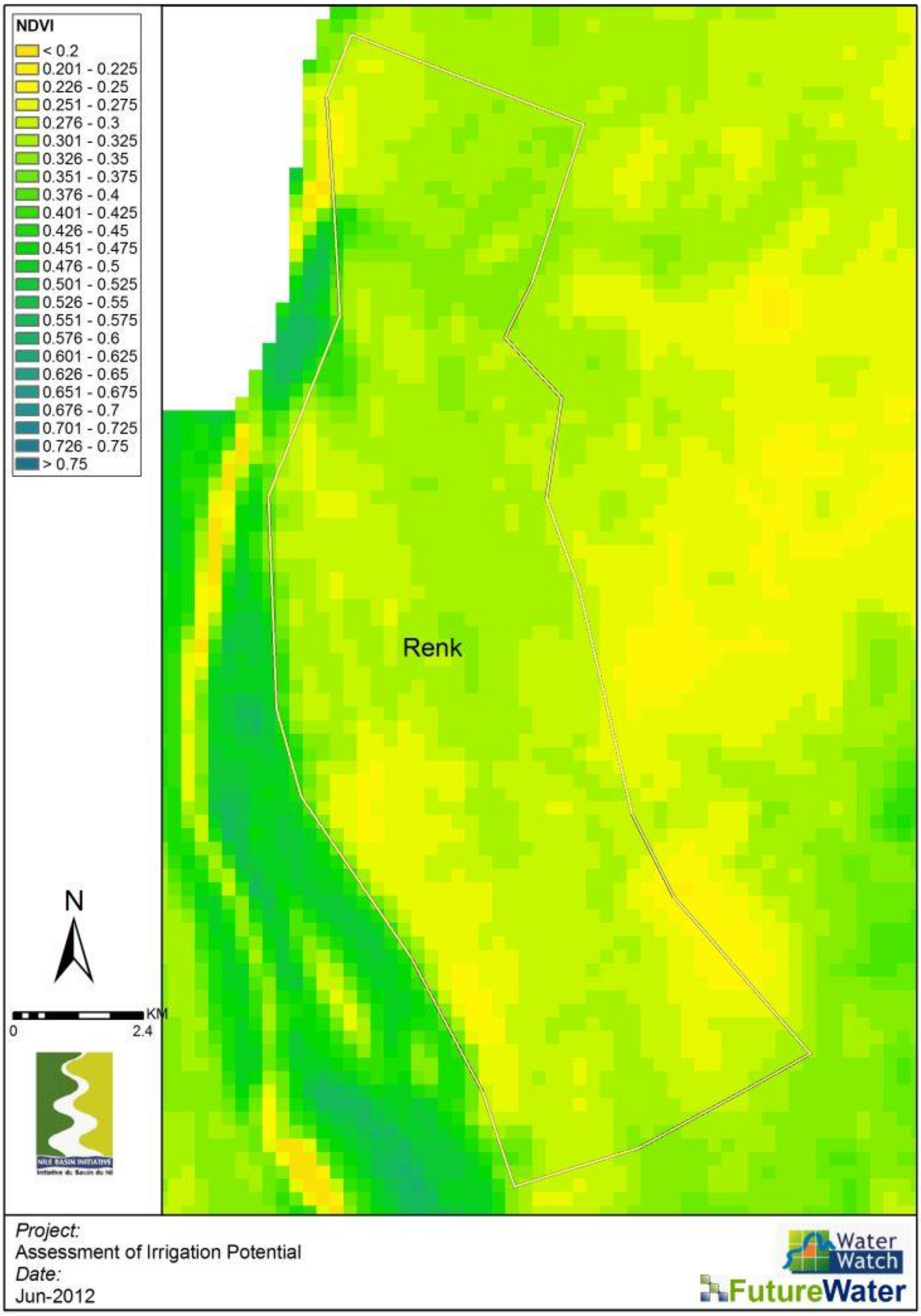


Figure 87: Yearly average NDVI values for Renk focal area.

6.2.4 *Potential cropping patterns*

Currently, agriculture is practiced only in a small part of the focal area (6%). Furthermore, most of the land near the Nile is covered with herbaceous plants, while the eastern part is covered with very open forest. Presently, around Renk Sorghum and Maize are grown. Further to the east of the focal area, large parts are used for rain fed agriculture. Very small parts of the irrigation schemes developed around Renk are still in use. It is advised to rehabilitate them before developing a new one. When rehabilitating the irrigation scheme it is advised to focus partially on staple crops; in this case mainly paddy, sorghum, maize and vegetables and partially, with an eye on the future, on cash crops, such as sugar cane, which could diversify the economy. However, the priority should be crops which reduce hunger as first priority and poverty as second priority, such that the economic situation of the rural area can be strengthened. If irrigated, then the focal area can be used during two growing cycles per year, which increases food security and reduces poverty.

6.3 Water resource assessment

6.3.1 *Climate*

Average climate conditions for the area are shown in the figure below. Precipitation is based on an advanced calibration/validation algorithm using satellite derived precipitation and calibrated using local observations. Details can be found in the Phase 1 Report. Reference evapo-transpiration (ETref) is calculated using the well-known Penman-Monteith approach. Input data for ETref is based on local observations and an advanced spatial downscaling algorithm.

The climate of the area can be characterized as warm with temperatures during the year ranging from about 22^{o}C to 36^{o}C. Annual average precipitation is 579 mm and reference evapotranspiration 2268 mm per year.

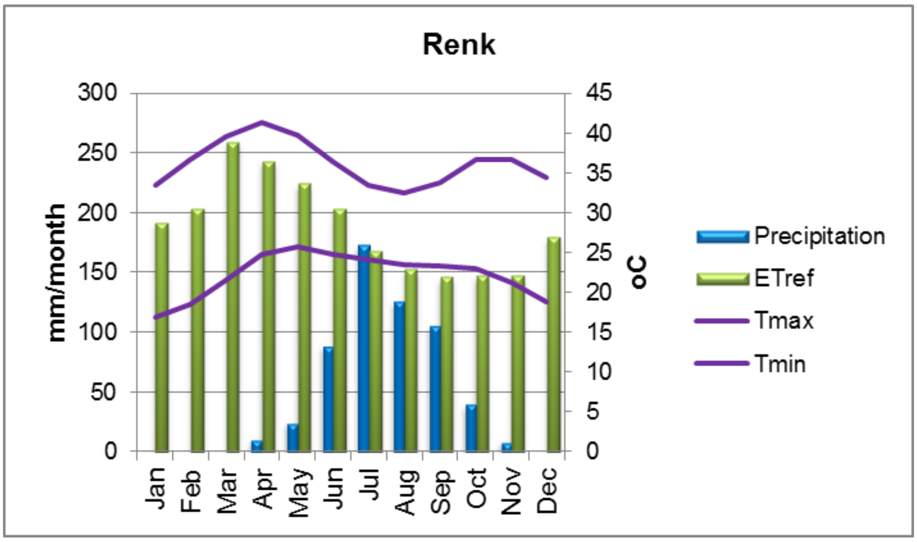


Figure 88: Average climate conditions for the focal area.

6.3.2 *Water balance*

A very detailed high resolution model was built for NEL countries (NELmod). For a detailed description see Phase 1 report. Results from NELmod were extracted for this specific focal area and are shown below.

The focal area is located in the state Upper Nile. Already quite some existing boreholes and water points can be found in the region (Figure 40).

Figure 89. Charateristics of Renk focal area.

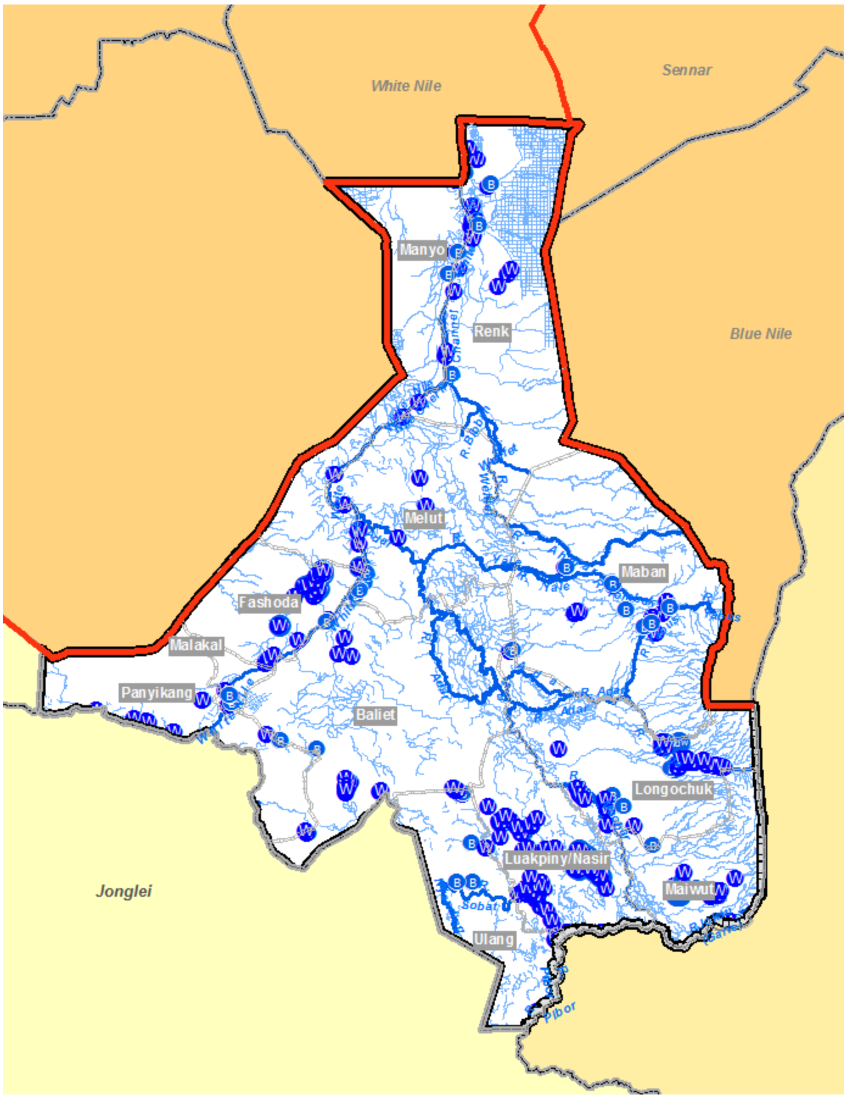


Figure 90. Boreholes (B) and Waterpoints (W) in Upper Nile province in South Sudan (source: South Sudan Information Management Working Group)


Figure 91. Charateristics of Renk focal area.

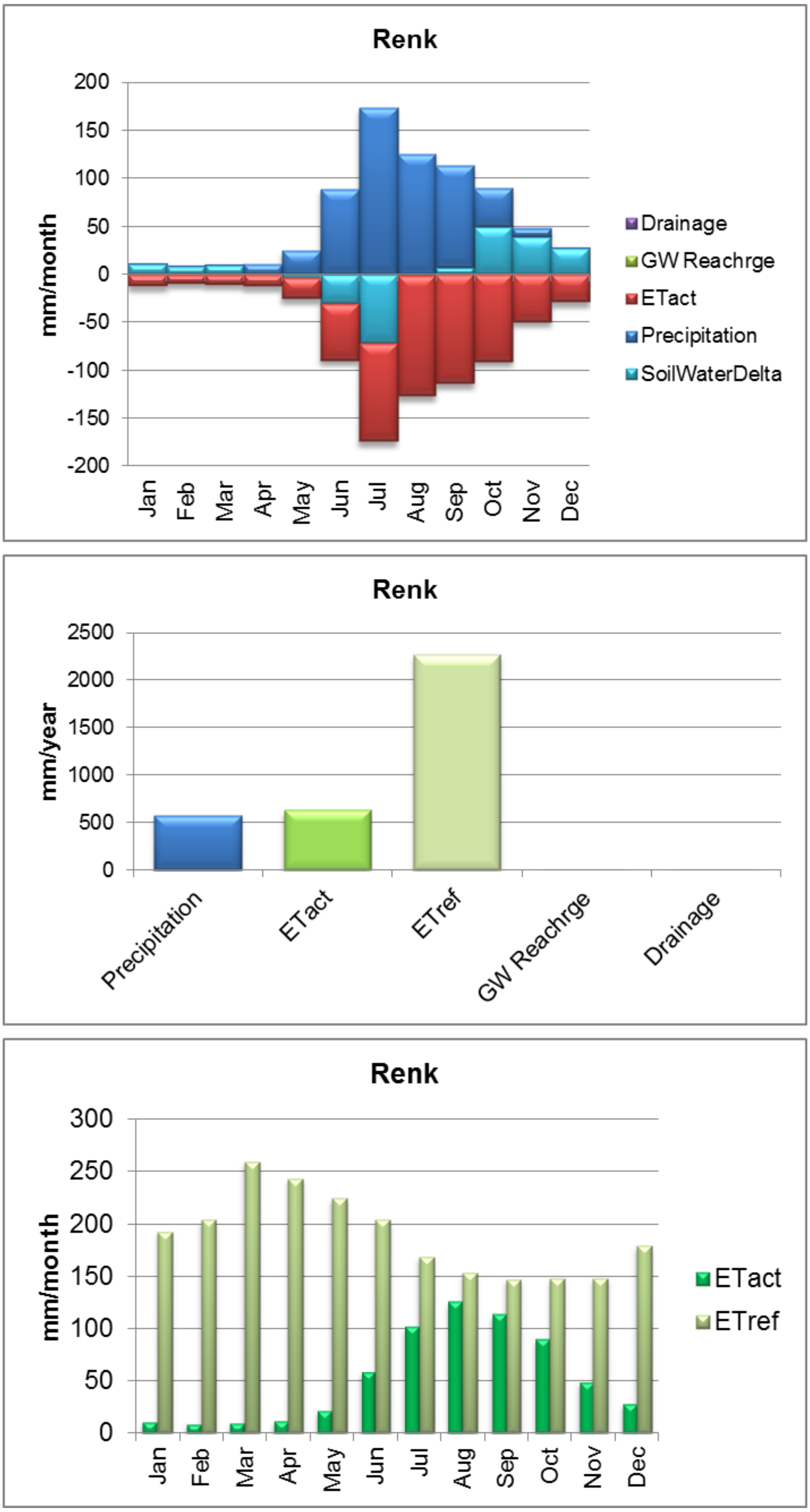
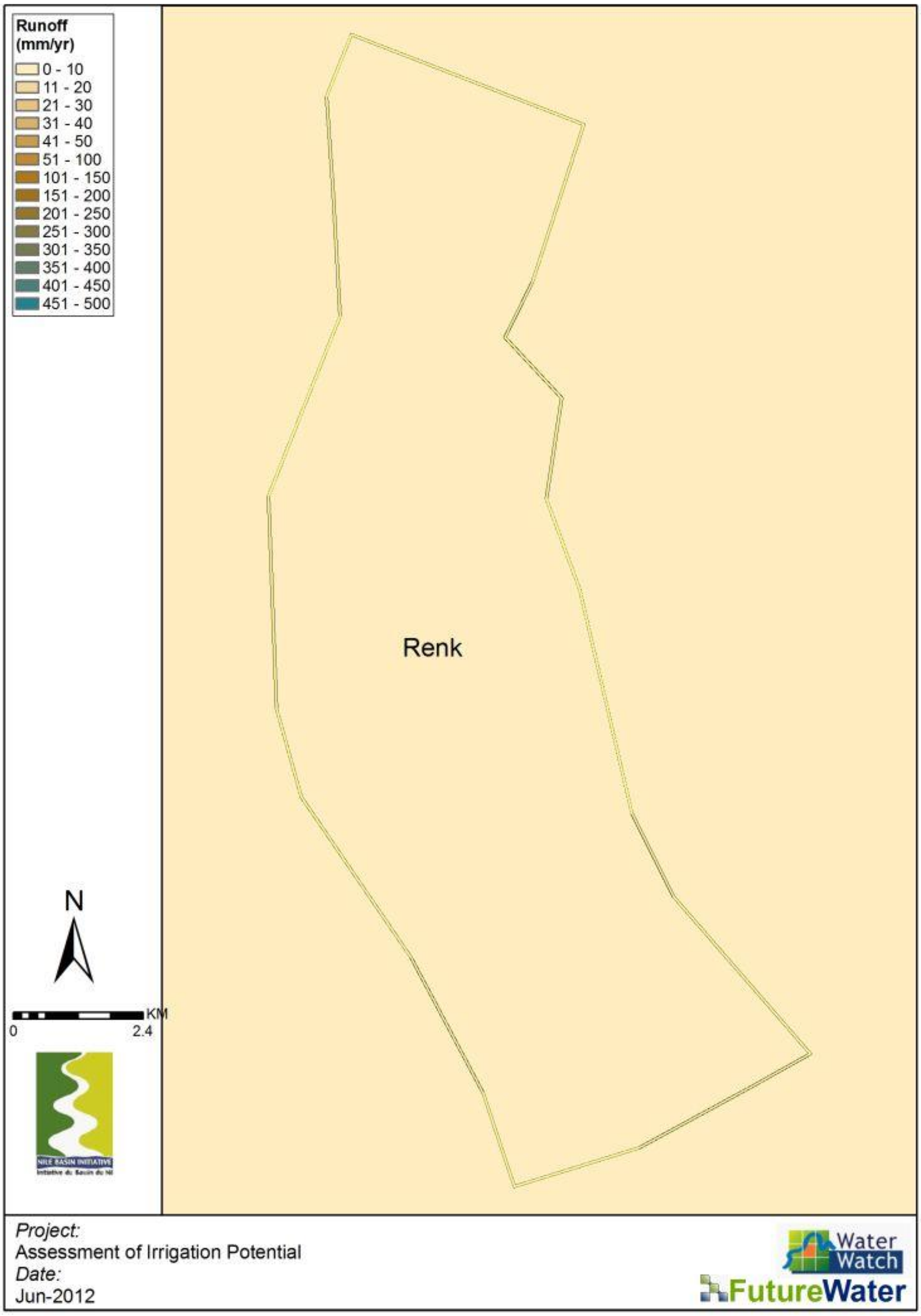
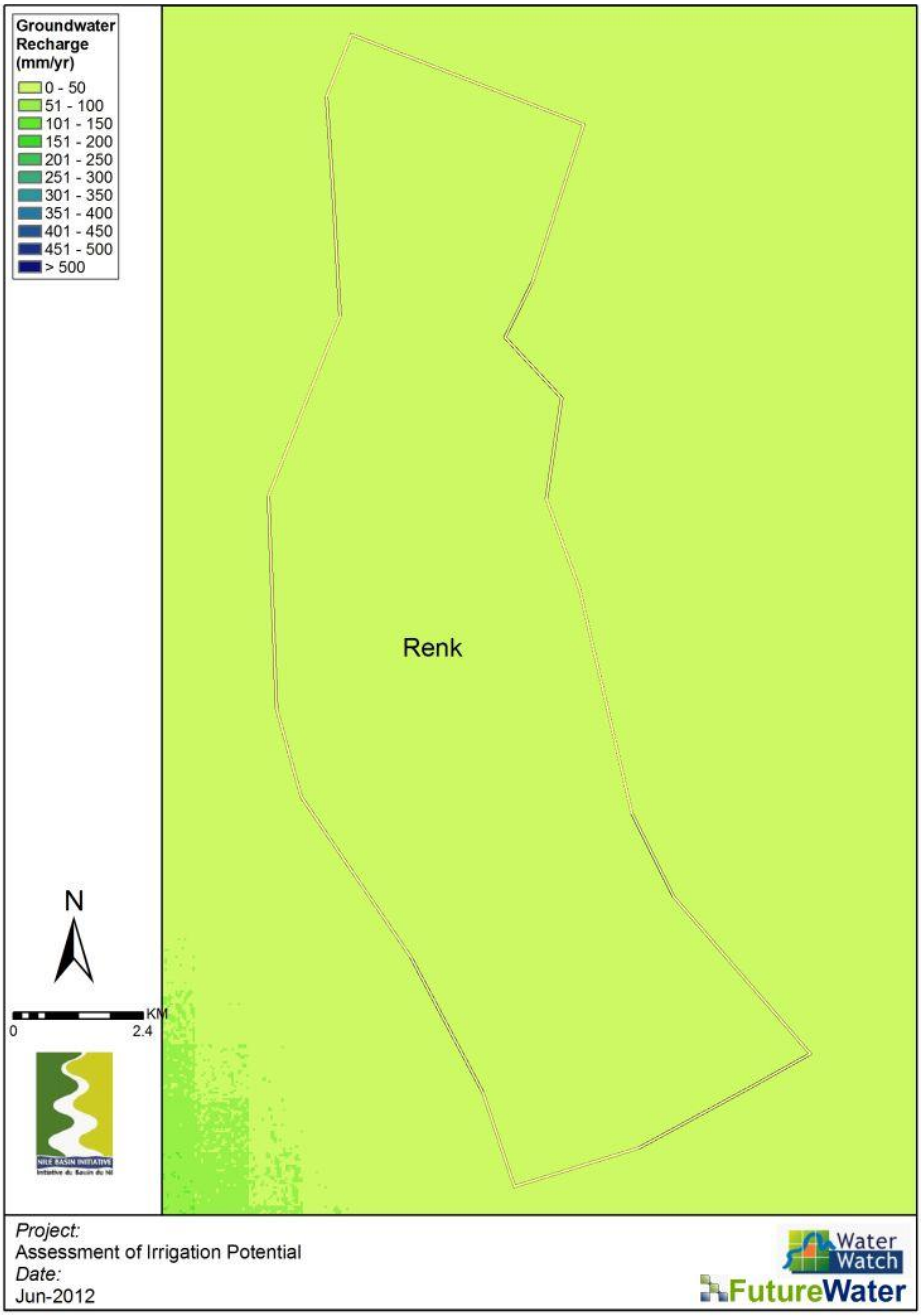


Figure 92: Water balances for the area based on the high resolution data and modeling approach for Renk focal area.


Runoff
(mm/yr)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
451 - 500
Renk
N
KM
0
2.4
Project:
Assessment of Irrigation Potential
Date:
Jun-2012


Groundwater Recharge (mm/yr)
0 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
451 - 500
> 500
N
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NILE BASIN INITIATIVE
Renk
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

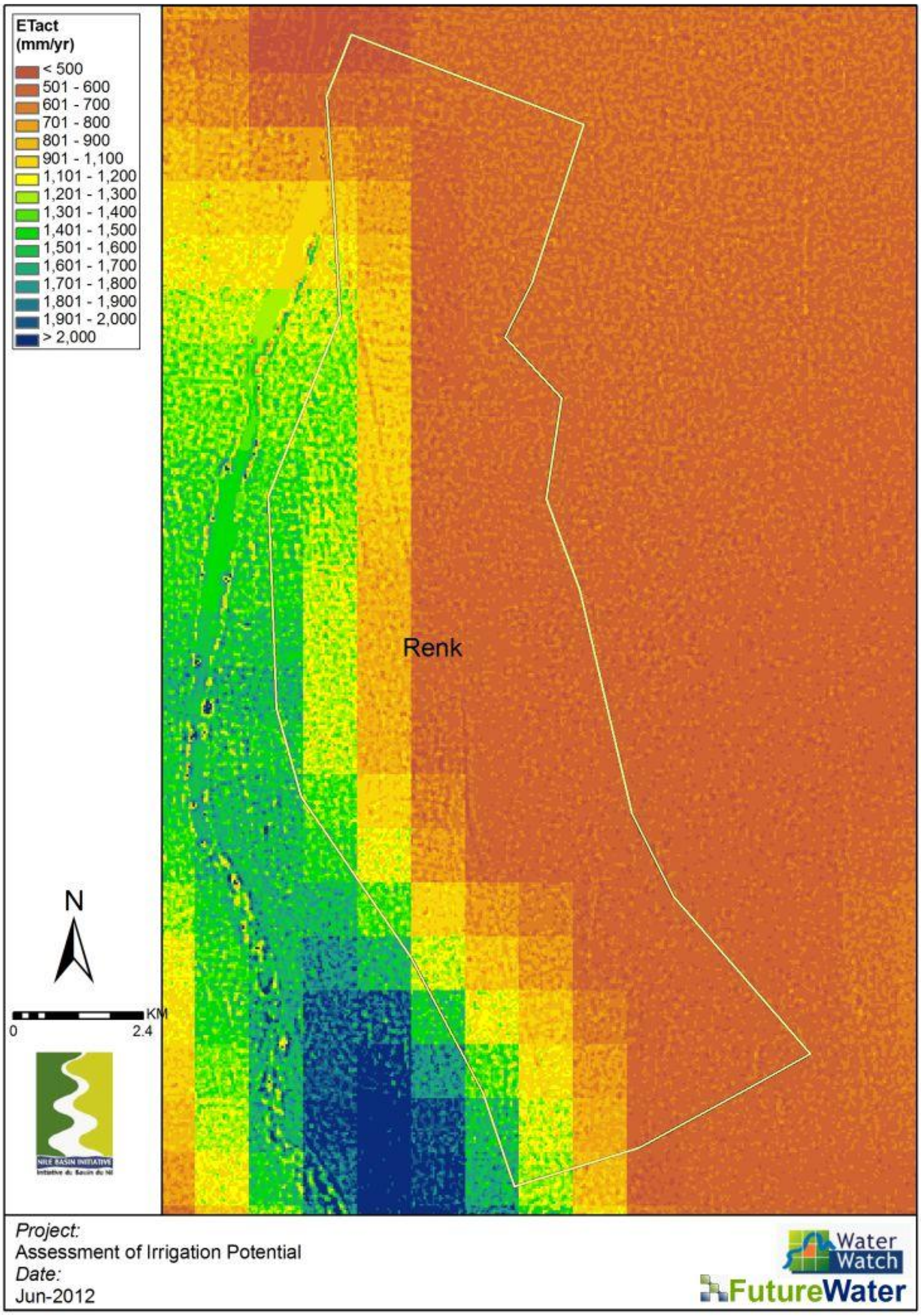


Figure 93: Water balances for the area based on the high resolution data and modeling approach for Renk focal area.

6.4 Assessment of irrigation water requirements

6.4.1 Irrigation water requirements

Irrigation water requirements depend on many factors such as: climatic conditions, crop, growing season, irrigation practices etc. A first estimate of irrigation requirements could be based on the difference between rainfall and reference evapotranspiration. It was however selected for this pre-feasibility assessment to provide a first estimate of irrigation needs based on the most promising crops. To this end, FAO's AquaCrop, the successor of CropWat was setup for local and crop specific conditions.

In the table below the irrigation water requirements for each selected crop are provided based on AquaCrop calculations. All units are provided in mm per growing season for the specific crops. Note that for various crops, like vegetables and similar crops, multiple croppings per years might occur.

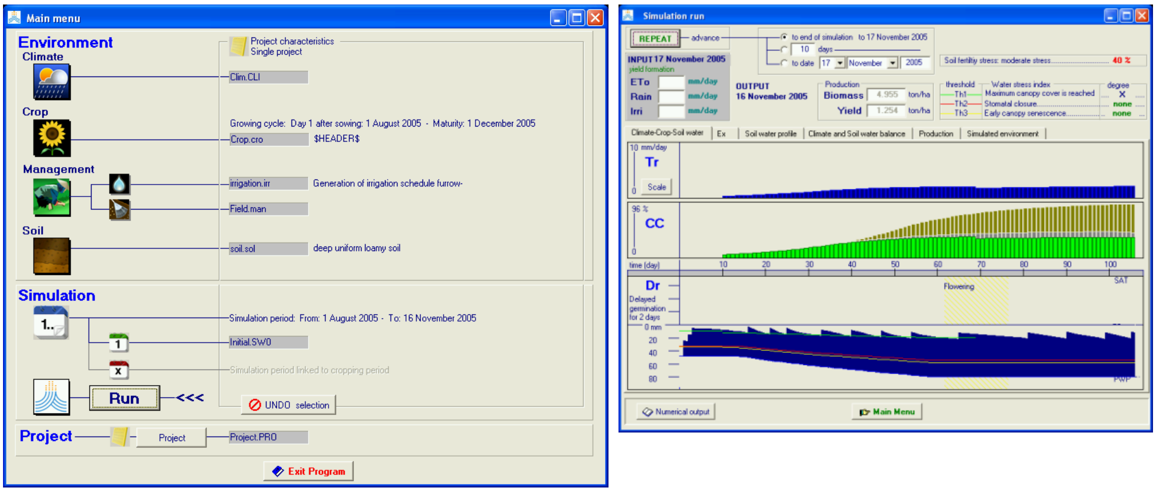


Figure 94: Typical example of AquaCrop input and output screens.

Table 9: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season.

Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year	===	== (day of year) ==		======== growing season =======			
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Maize	579	2268	121	238	395	450	722	629
Rice	579	2268	213	320	279	370	524	467
Sorghum	579	2268	121	243	417	450	751	647
Cassava	579	2268	121	350	568	450	1277	637

6.4.2 Irrigation systems and irrigations efficiencies

Irrigation in the Renk focal area will be mainly based on the rehabilitation of the already existing irrigation schemes. These schemes are designed for surface irrigation. Therefore, it is advised to stick to border or furrow irrigation at first. Since water will be available abundantly around the year from the White Nile, there is no real limit on the irrigable area. However, all the water should be pumped up from the river, and although the elevation difference is not much, this does have a large influence on the conveyance costs of the water. So to enhance irrigation water efficiency it is an option to focus more on sprinkler irrigation or even drip irrigation. These two techniques, however, are much more capital intensive as they have high initial cost, and require a certain educational level from the farmers. It is advised in a detailed feasibility study for Renk focal area, to evaluate the costs for pumping, and whether the reduced water use for sprinkler or drip irrigation can pay back for development costs of these systems.

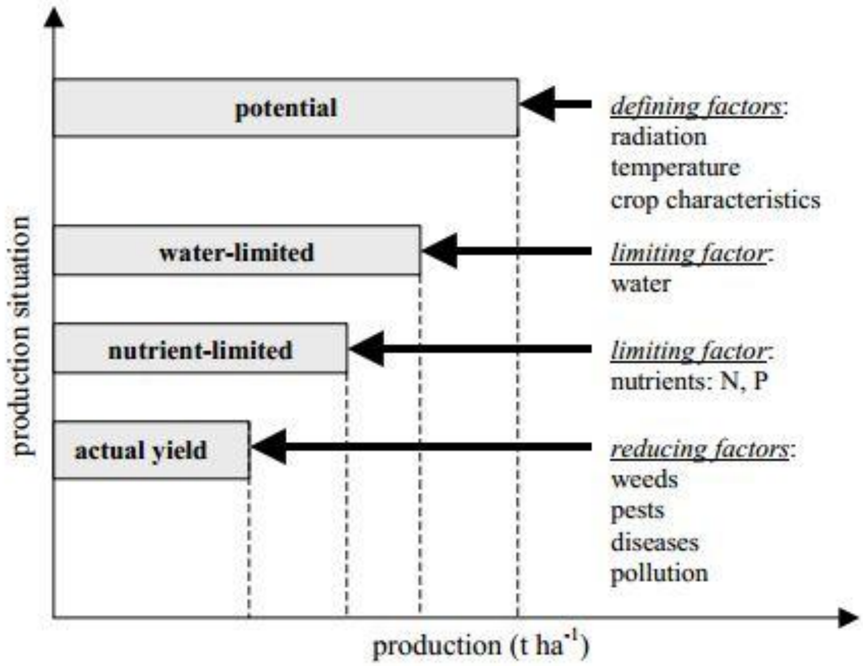
6.4.3 Water source

The water source for irrigation will be the White Nile. The river has an elevation difference of approximately 10 meters within the most eastern part of the focal area, thus the water needs to be pumped up. There is a need for a proper intake structure and pumping station, as the water needs to be relocated over a distance of about 2 km. The intake structure should be strong, as the discharge of the rivers is large with an annual average of 1400 m^3/s, and fluctuates over the year. Due to the technical part of the operational irrigation system, some technical knowledge and farmers associations are needed to work with the pumps and ensure the water intake.

6.5 Potential crop yield assessment

The yield gap describes the difference between the current yield, and the maximum possible yield. Mostly the maximum possible yield is defined as the highest yield in the world, but it can also be assessed against a regional background which makes the yield gap more realistic and the maximum yield possible to achieve under the given circumstances.

The gap between the actual yield and the potential yield can be caused by several processes. Factors which may cause that the maximum possible yield is not reached can be the water availability, the soil and the available nutrients, or yield reducing factors like diseases, weeds or pollution.



6.5.1 Yield gap analysis potential dominant crops[1]

Yields in Sudan are relatively high compared to surrounding countries. There is, however, a large differentiation between crops. Sudan has extremely high yields for dry beans, bananas, sugar cane, sweet potatoes and potatoes. For paddy and cotton seeds Sudan performs better than the world's average yields. Most probably, this finds its origin in the intensification and irrigation programs that have been introduced in the past to increase food production and to meet the demand. In Figure 95, the yield gap is shown relatively to the highest obtainable yield in the world, to the world's average, and to Africa's average. Within Renk focal area the yields are much lower than Sudanese average yields, mainly due to low precipitation. With irrigation the water availability is no issue anymore due to abundant water resources. This creates a large potential, and yields are expected to increase significantly with irrigation. Within the irrigated area it is advised to focus on rice, as rice is expected to give the highest yields and economic benefits. Under irrigation the production of rice is expected to increase towards 60% of the world's highest obtainable, which would mean an increase of 200%. Besides the increase in yield, also the harvested area will increase, and a second growing cycle will greatly push the yields and economic development. Later on, some part can be planted with sugarcane, as Sudan keeps good record for sugarcane production.

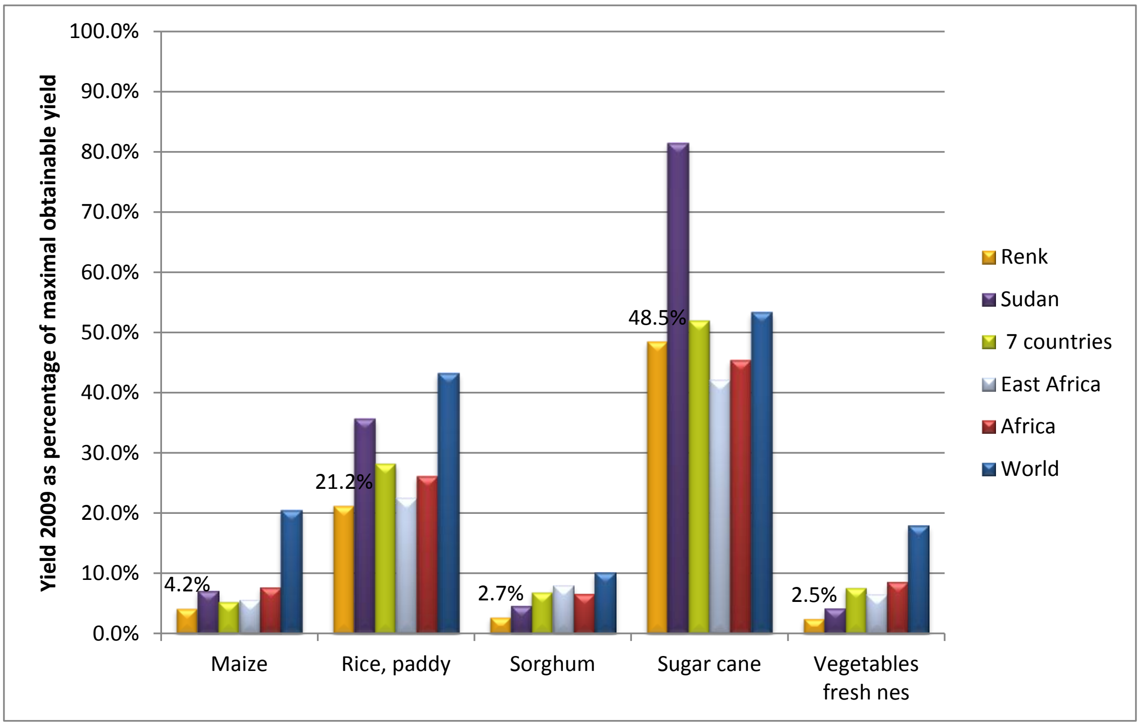


Figure 95: Yield gap Renk (source: FAOSTAT, 2010).

[1] This section is bases on FAOSTAT with yields from former Sudan.

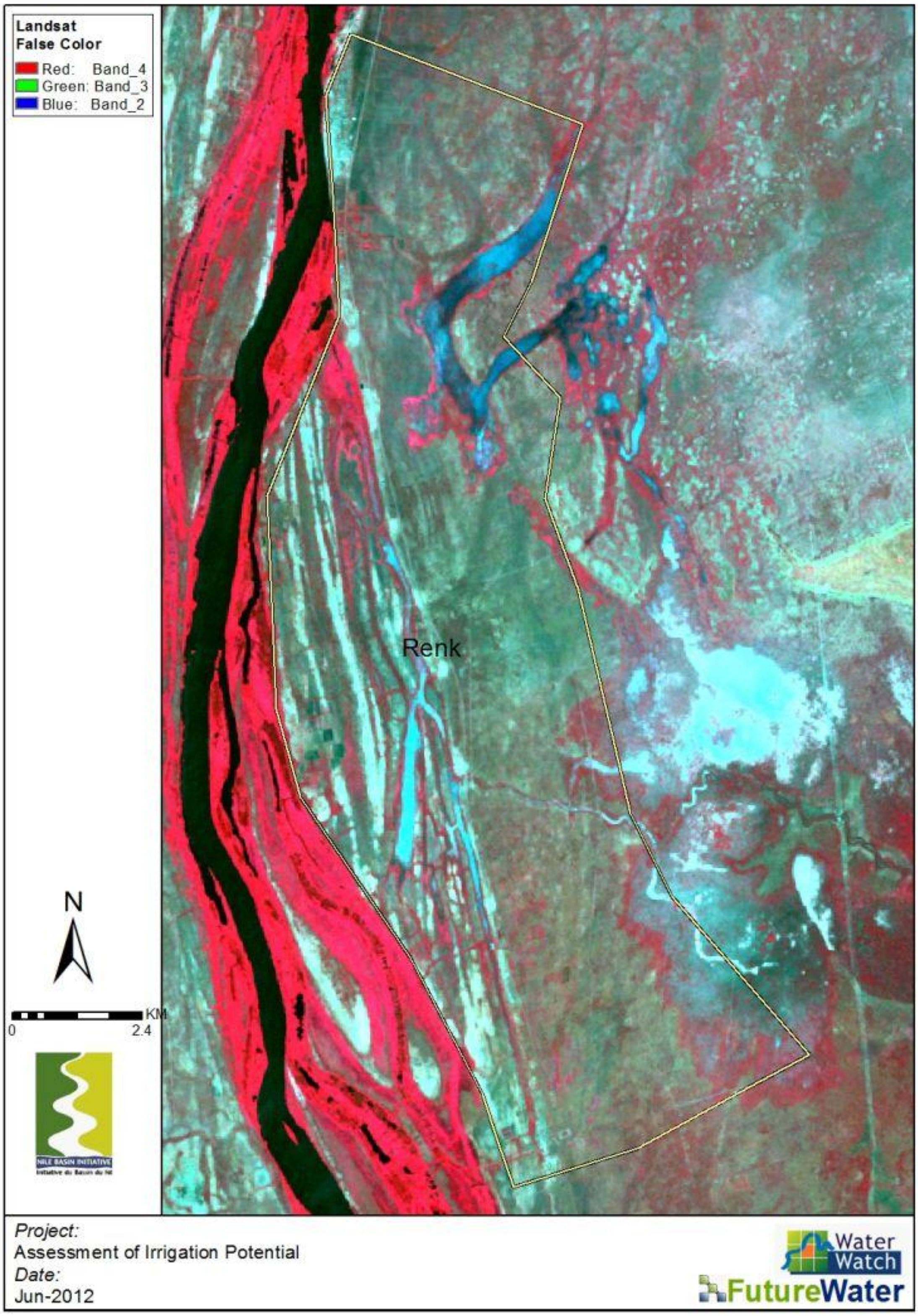


Figure 96: Landsat False Color Composite indicating current productivity of Renk focal area.

6.6 Environmental and socio-economic considerations

6.6.1 Population displacements

The population in Renk area mainly lives in Renk town, which is quite far from some parts of the irrigated area. At the western side of the road there are some small settlements, and a few solemn houses. Within the abandoned irrigation scheme there are already some places where people live in a community. Since the development of Renk focal area will mainly consist of the rehabilitation of the already existing irrigation scheme, population displacements are not expected. However, on small scale it may be necessary. With the design and rehabilitation of this irrigation scheme, it is advised to limit any population displacement. The exact numbers of effected houses can only be known after designing the scheme, which is beyond the scope of this pre-feasibility study.

6.6.2 Social

Population density in the Upper Nile state is marginally smaller compared to South Sudanese average. The population density is about 12 people/km^2, compared to the South Sudanese average of 13 people/km^2. This country wide population density is among the lowest in the African sub-tropical countries. (CIESIN) Remarkably the ratio male to female is 1.20. In 2008 it is estimated that half (51%) of the population is below the age of 18 years. Within South Sudan, 51% of the population lives below the national consumption poverty line (SSDP). Within the Upper Nile state this percentage is the lowest of South Sudan with 26%. However, in rural areas in which the focal area is located, this may be higher. The people that live in the area do have average knowledge on agriculture and irrigation, as irrigation has been practiced before and is still practiced in small areas. People hardly have any experience on farmer's cooperatives, which could be improved with trainings. The infrastructure is quite good; a tarmac road passes directly by the focal area and Renk town in not far away. Other markets are more difficult, as Renk is situated in a corner of South Sudan. There is a connection to Sudan. The area seems to be further developed in some aspects compared to the rest of South Sudan; with 65% of the people between 15-24 year being literate, and "just" 59% of the population that depends on crop farming or animal husbandry as their primary source of living (SSNBS). This is a small percentage compared to the South Sudanese average of 78%.

6.6.3 Upstream downstream consideration

The water for Renk focal area will directly come from the river Nile, and will easily be drained again on the river Nile. This is a rather small system, which does hardly interact with a larger area or catchment. The use of fertilizer, which is recommended, can influence the downstream water quality. Therefore, it is advised to use fertilizer very careful, not to affect the water quality of the drainage water in a negative way.

6.6.4 Protected areas

Within the focal area no protected areas are reported.

6.7 Benefit-cost Analysis

A simplified benefit-cost analysis is undertaken for the area. Information for this is based on various sources such as FAO publications, IFPRI publications, local expertise and data. A full benefit-costs analysis has to be undertaken in a sub-sequent feasibility study for the area.

Note that this is a first-order benefit-cost analysis. A feasibility study can provide a more rigorous benefit-cost analysis, which is required before taking any implementation planning. However, the following table shows that based on this first-order analysis, investments in irrigation can have a very positive impact.

Main assumptions for the benefit-costs analysis include:

- Irrigated land based on GIS and local experts for boundaries
- Number of farmers based on average land tenure area
- Irrigation infrastructure based on irrigation type and source
- Social infrastructure based on local expert judgment on farmers' trainings need
- Accessibility infrastructure based on generalized road conditions
- Internal Rate of Return based on 25 years
- Crop revenues based on local crop potentials and local market prices (crop, kg/ha, $/kg):
    - Maize: 4,000 kg/ha, 0.22 $/kg
    - Rice: 6,000 kg/ha, 1.10 $/kg
    - Sorghum: 5,000 kg/ha, 0.65 $/kg
    - Cassava: 12,000 kg/ha, 0.28 $/kg

Based on expert knowledge on the suitability to develop irrigation in the area scores between 1 (negative: low suitability or expensive) to 10 (positive: high suitability or low investments) have been marked. The filled radar plot below indicates the options for the focal area. Overall, the weak part of the site lies under farmers capacity, accessibility to roads, to markets and the initial investment cost. This in-turn affects access to market as farmers cannot transport their yield easily and more importantly may not fetch golden prices. However, soil suitability and water availability is a great deal for the area that will foster an increase yields.

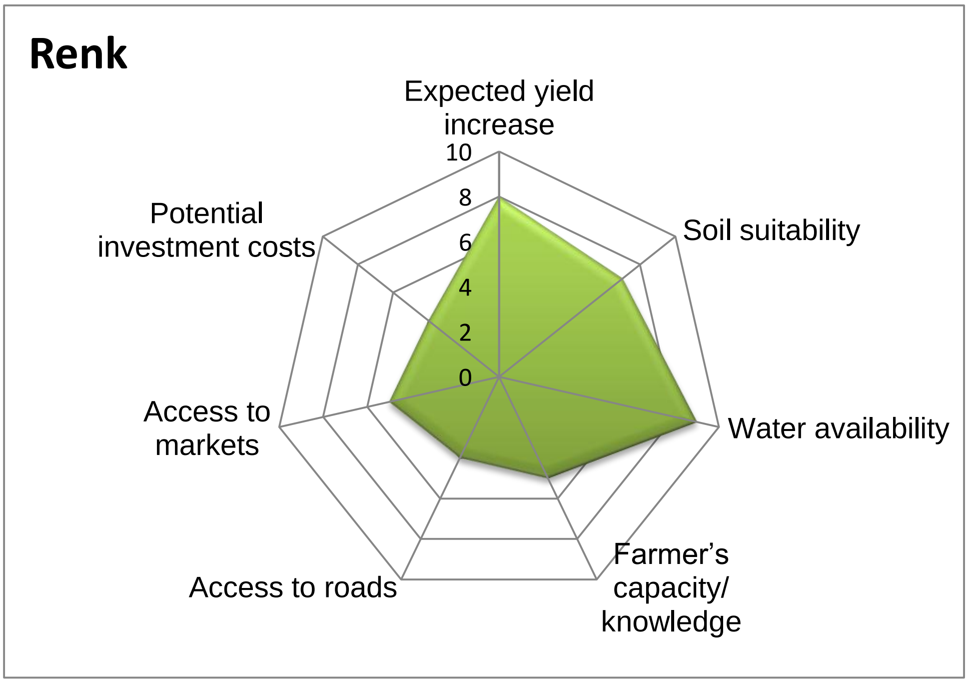


Figure 97: Filled radar plot indicating expert knowledge score to develop irrigation in the Renk focal area (1 = negative, 10 = positive). (Source: local experts and study analysis).

Table 10: Benefit-cost analysis for Renk area.

Characteristics	
Irrigated land (ha)	5,000
Farmers	7,692
Investment Costs	
Irrigation infrastructure (US$/ha)	3,000
Social infrastructure (US$/farmer)	500
Accessibility infrastructure (million US$)	0.5
Operational Costs	
O&M irrigation (US$/ha/yr)	60
Extension service (US$/farmer)	10
O&M roads (US$/yr)	10,000
Summary	
Initial investments (million US$)	19.3
O&M costs (million US$/yr)	0.387
Net benefits per year (million US$/yr)	10.568
IRR (Internal Rate of Return)	100.0%

7 Wau focal area

7.1 Introduction

This chapter will describe the current state of the Wau focal area, concerning land and water resources, and will discuss the potential to develop irrigation in the area. This irrigation potential will be based on the land and water resources, the irrigation requirements, the potential crop yields and will also involve the socio-economic considerations and institutional frameworks. Based on these aspects the potential for irrigation will be described, and cost for irrigation development calculated. In Figure 99 a detailed map of the area is given. Total area is 5080 ha.

Selection of this specific focal area was based on results of Phase 1 of this study, while final selection was the responsibility of the relevant country representatives. Results presented hereafter have been obtained from a broad range of sources: Phase 1, previous other studies and reports, modeling results, remote sensing, expert knowledge and field visits by Jal Fnom, Makuac Deng and Mary Loki as supervisor in April and May 2012.

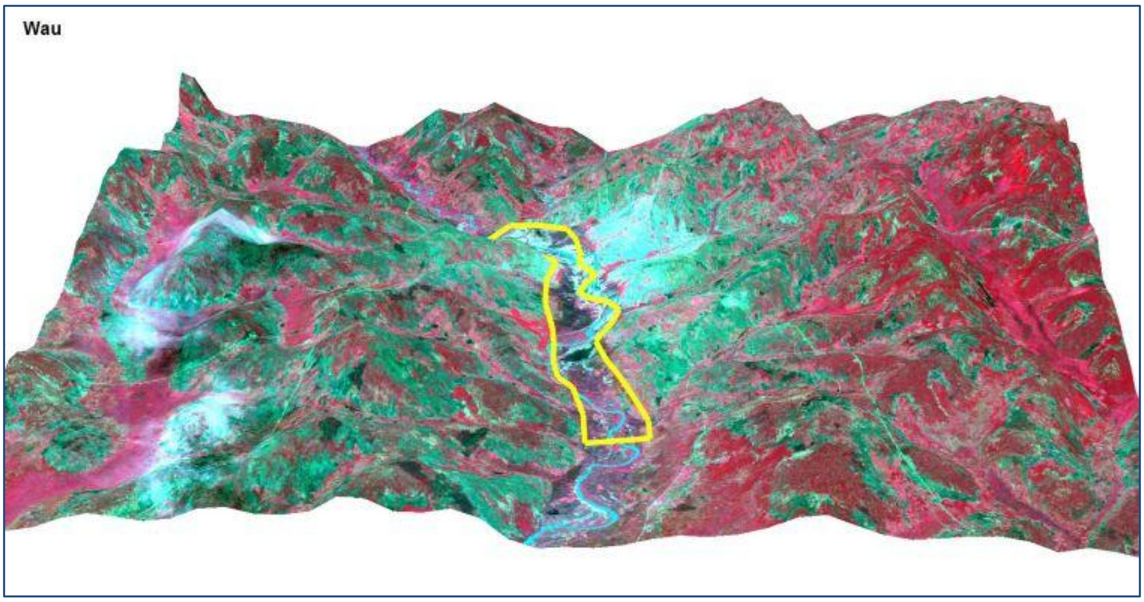


Figure 98. 3D impression of Wau focal area, South Sudan.

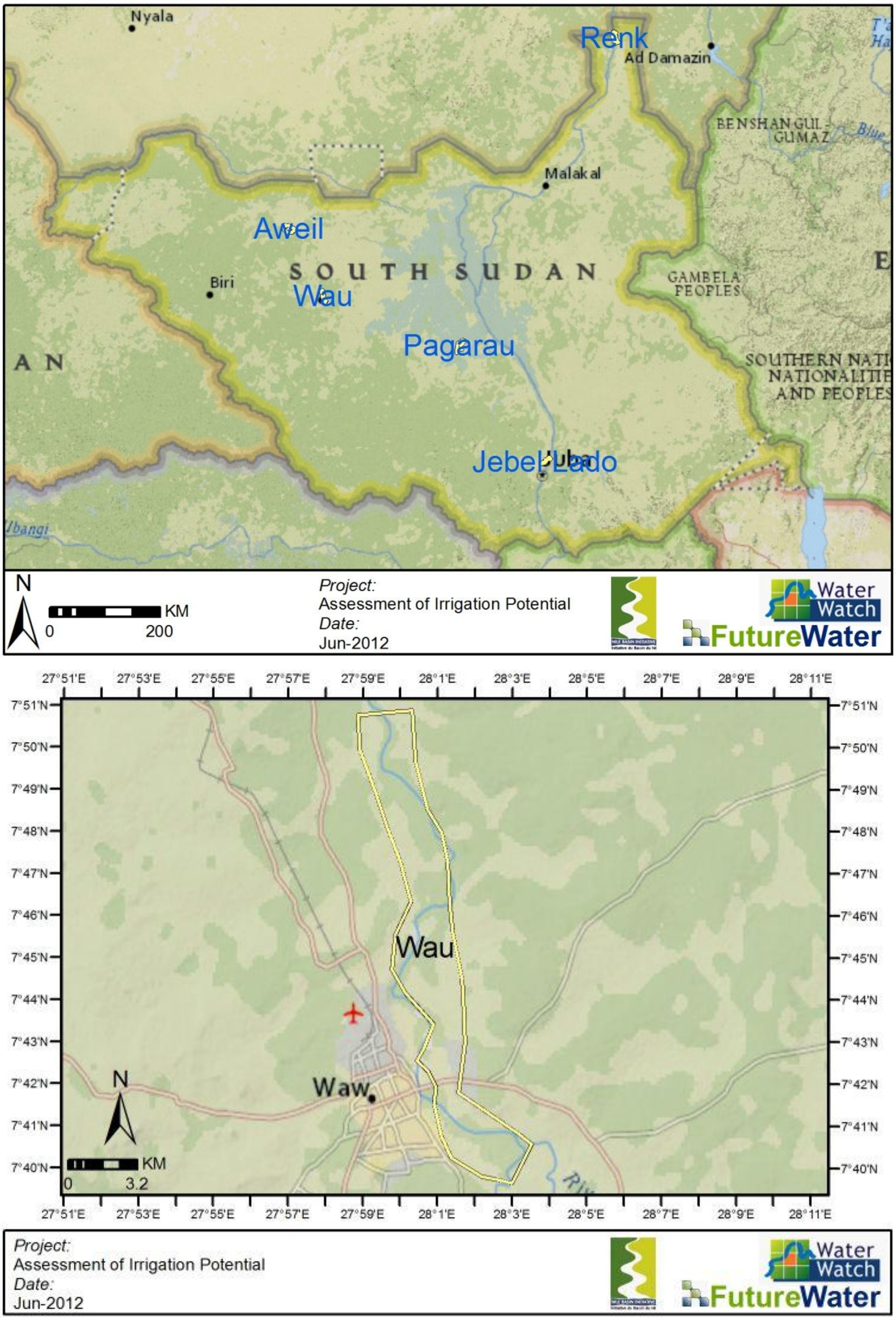


Figure 99: Wau focal area, South Sudan.

7.2 Land suitability assessment

7.2.1 Terrain

The Wau focal area is located in the western part of South Sudan within the Western Bahr El Ghazal State. The area covers the valley of the Nahr al Jur River, which is one of the largest rivers in South Sudan. The area descends from South (440 m) to North (425 m) (Figure 100). The topography is very much suitable for surface irrigation. The river meanders through the focal area, and the location of the river within the valley has changed over the years. The cross section of the focal area is rather flat; land may ascend slightly towards the sides with 2-3 meters. The slopes in the focal area are almost 0% on most places, with some exceptions reaching towards 5-15 % (Figure 101).

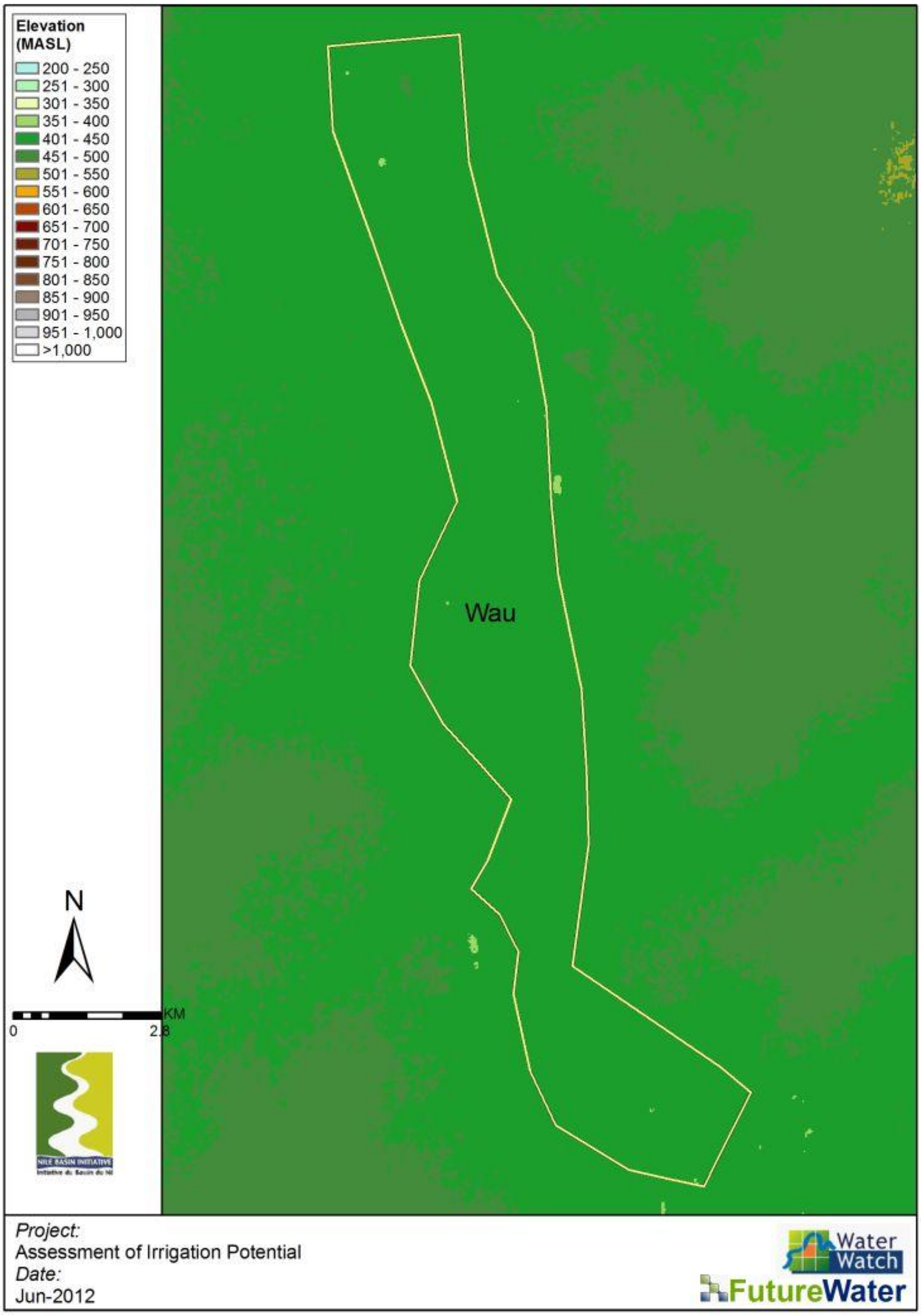


Figure 100: DEM Wau focal area. Resolution 1 arc second (+/- 30m).

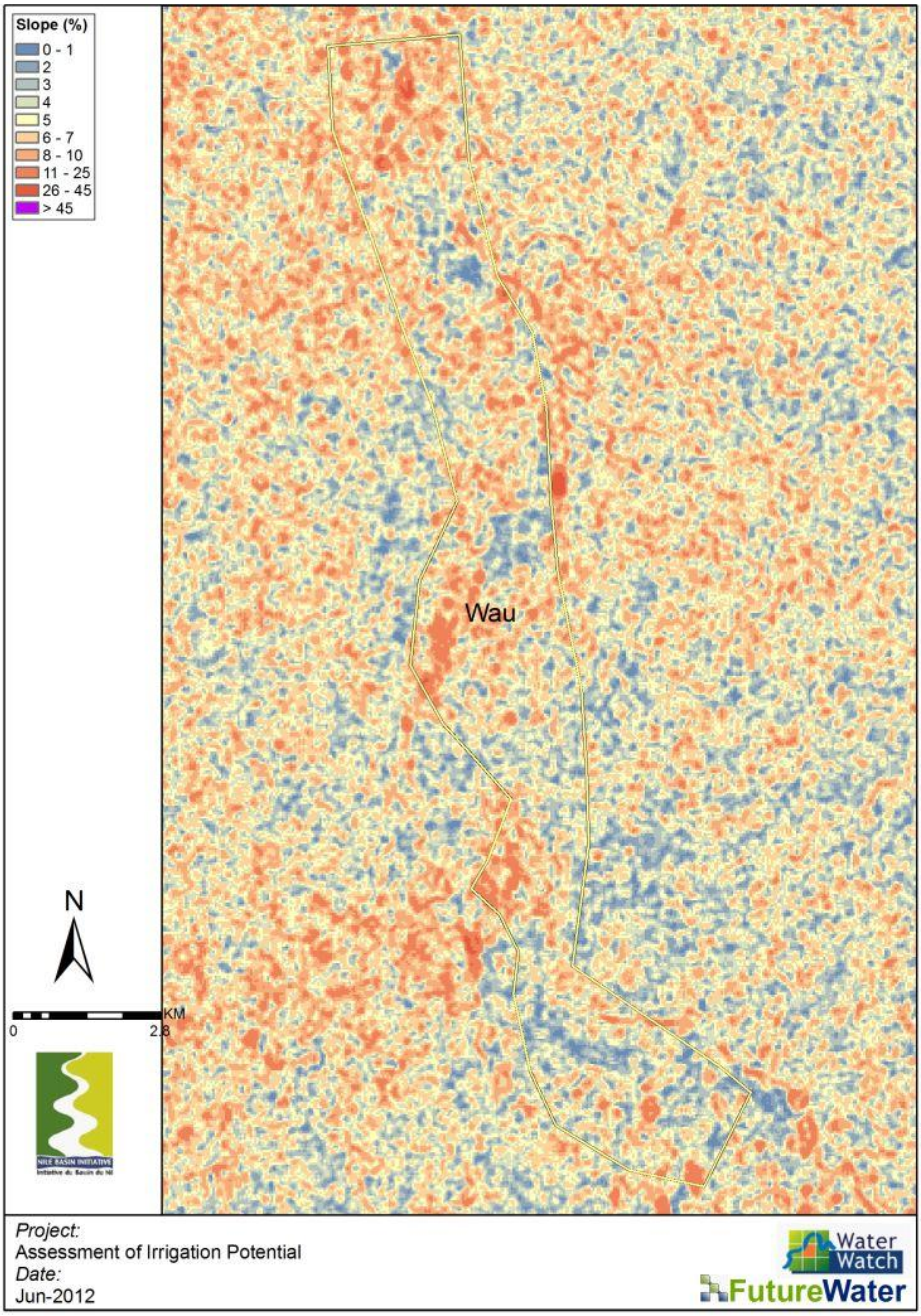


Figure 101: Slope map Wau focal area (source: ASTER).

7.2.2 Soil

The focal area is located in an alluvial plain, and the soil can be characterized as a Chromic Combisol. The texture of the soil is loamy to sandy clay, and the organic carbon is rather low (<1%). Drainage is somewhat poor, and the available water holding capacity is large with more than 150 mm/m. Cambisols are characterized by slight or moderate weathering of parent material, which proceeds much faster in the tropics than in associated temperate climatic zones. Cambisols generally make good agricultural land and are used intensively. Cambisols in the humid tropics are typically poor in nutrients, but are still richer than associated Acrisols or Ferralsols, and they have a greater CEC. Cambisols with groundwater influence in alluvial plains are highly productive paddy soils.

7.2.3 Land productivity

The annual average land productivity (NDVI) in the five South Sudanese focal areas ranges between 0.30 and 0.60. Compared to the South Sudanese average of 0.50, Wau focal area has a lower than average land productivity with an NDVI of 0.41. The land productivity is lowest around Wau town and close to the river. This can be attributed to the very sandy river banks, with rapidly changing circumstances, such that the system is too unstable to be covered by any vegetation. Therefore, the variation in land productivity on these locations is lowest in these parts too. The areas that currently have the highest land productivity have been in use for agriculture and have been irrigated before. The rehabilitation of these irrigation systems will be difficult, as they have not been used or maintained for a long time.

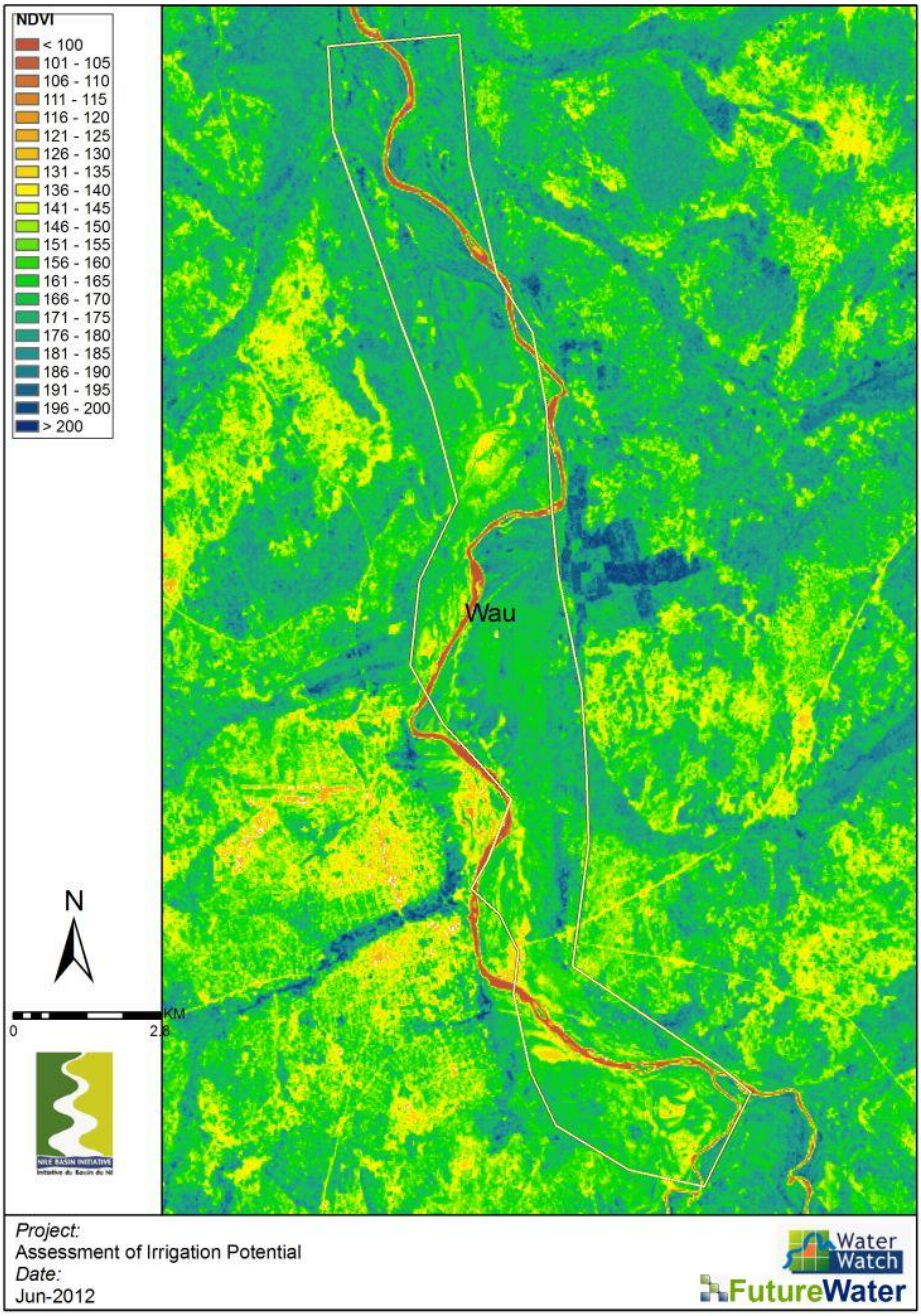


Figure 102: High resolution NDVI for Wau focal area

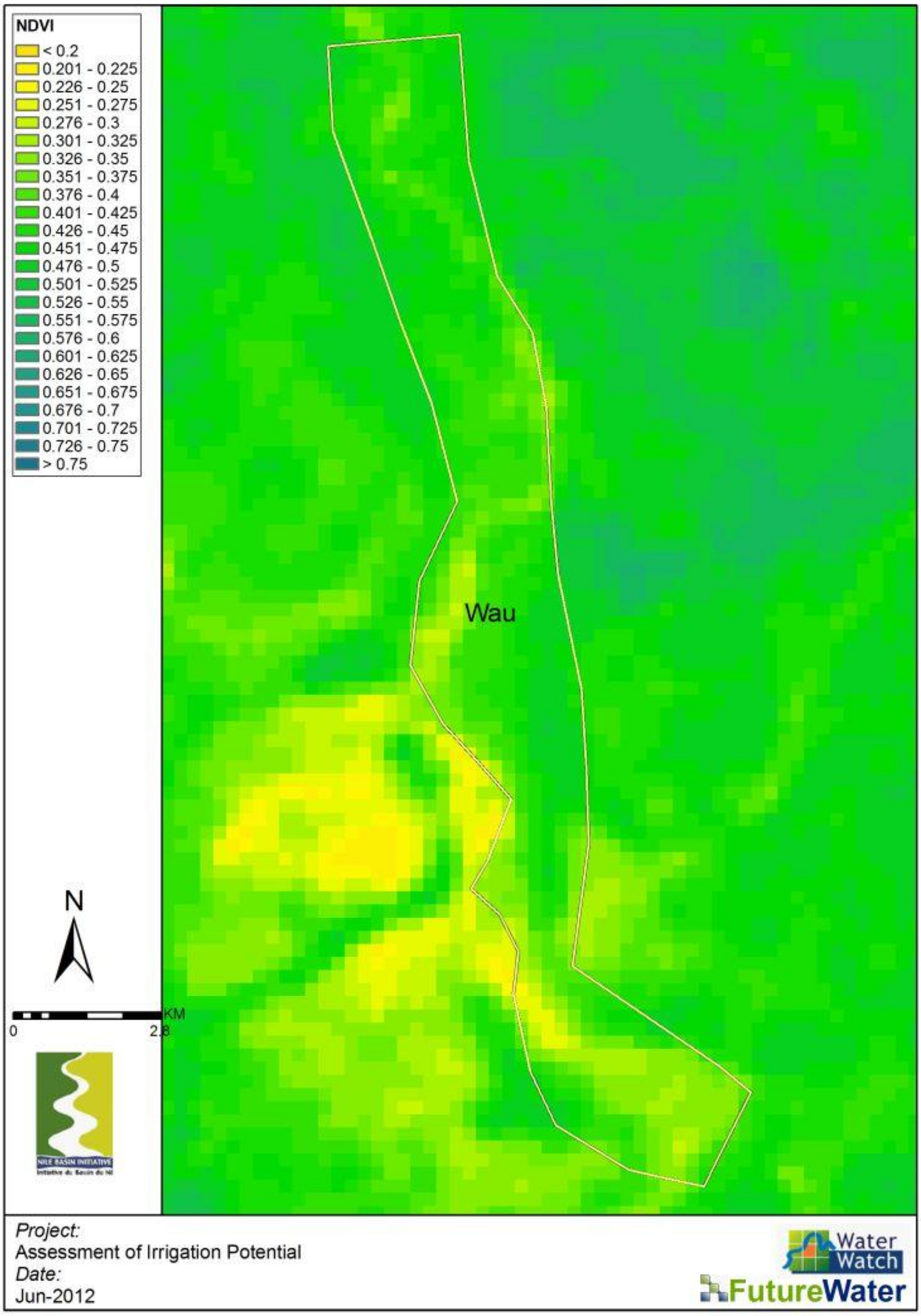


Figure 103: Yearly average NDVI values for Wau focal area.

7.2.4 Potential cropping patterns

Currently, agriculture is practiced in a small part of the area (2%). Furthermore, most of the land in the river valley is covered with open scrubland. The agricultural land is mainly used for growing rice. Rice is grown once a year from June till December during the rainy season. An area on the eastern banks of the river has been irrigated before. Nowadays, the fields are abandoned, but with good water management they would make very productive paddy fields. When rehabilitating the irrigation scheme it is advised to focus partially on staple crops; in this case mainly paddy and vegetables, and partially with an eye on the future, on cash crops, such as sugar cane, which could diversify the economy. However, the priority should be crops that reduce hunger as first priority and poverty as second priority, so that the economic situation of the rural area can be strengthened. When irrigated, the focal area can be used within two growing cycles per year, which will increase food security and reduces poverty.

7.3 Water resource assessment

7.3.1 Climate

Average climate conditions for the area are shown in the figure below. Precipitation is based on an advanced calibration/validation algorithm using satellite derived precipitation and calibrated using local observations. Details can be found in the Phase 1 Report. Reference evapo-transpiration (ETref) is calculated using the well-known Penman-Monteith approach. Input data for ETref is based on local observations and an advanced spatial downscaling algorithm.

The climate of the area can be characterized as warm with temperatures during the year ranging from about 24°C to 36°C. Annual average precipitation is 1149 mm and reference evapotranspiration 1902 mm per year.

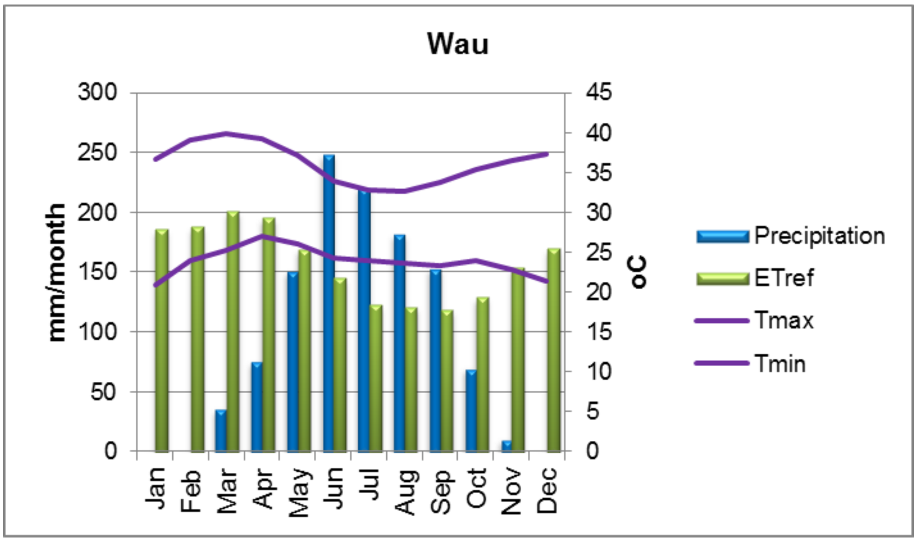


Figure 104: Average climate conditions for Wau focal area.

7.3.2 Water balance

A very detailed high resolution model was built for NEL countries (NELmod). For a detailed description see Phase 1 report. Results from NELmod were extracted for this specific focal area and are shown below.

The focal area is located in the state Western Bahr el Ghazal. Already quite some existing boreholes and water points can be found in the region (Figure 40 107)

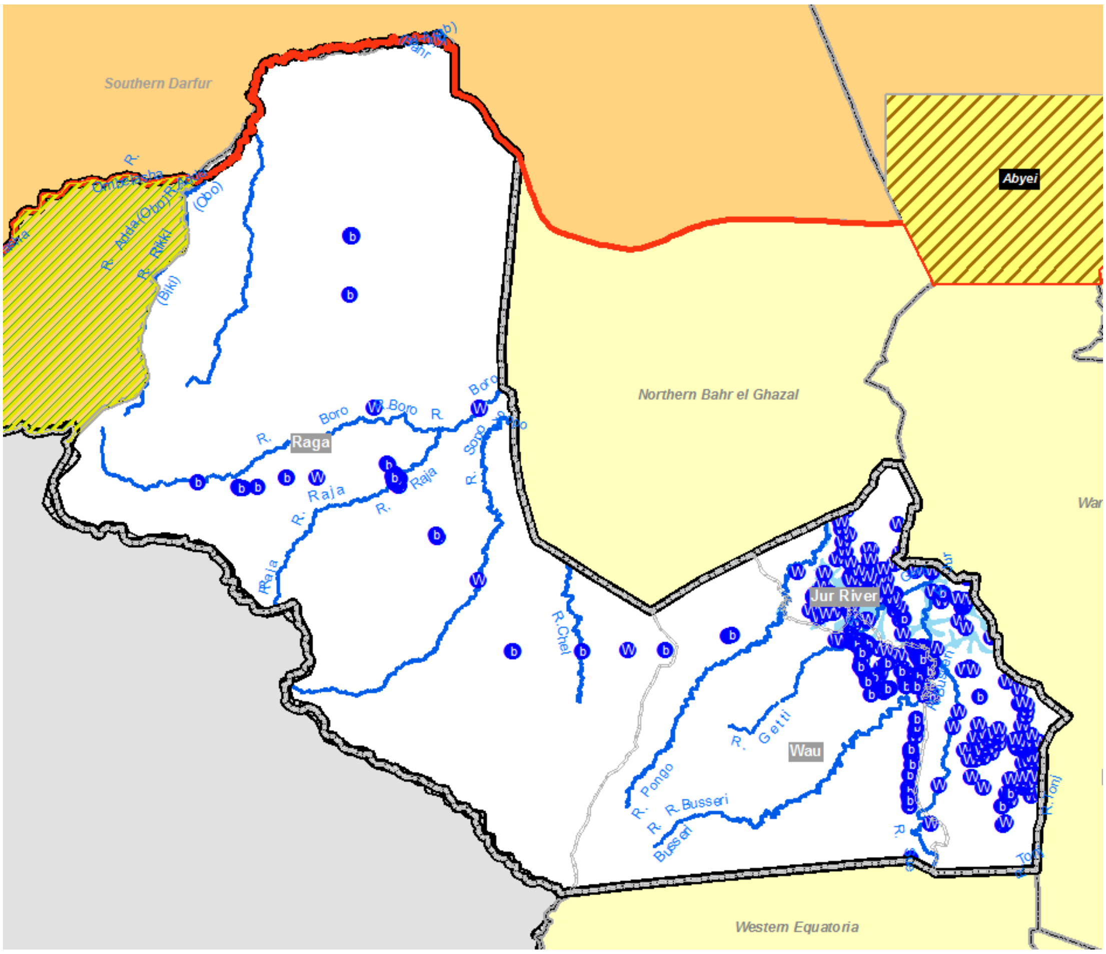


Figure 105. Boreholes (B) and Waterpoints (W) in Western Bahr el Ghazal province in South Sudan (source: South Sudan Information Management Working Group)

Figure 106. Charateristics of Wau focal area.

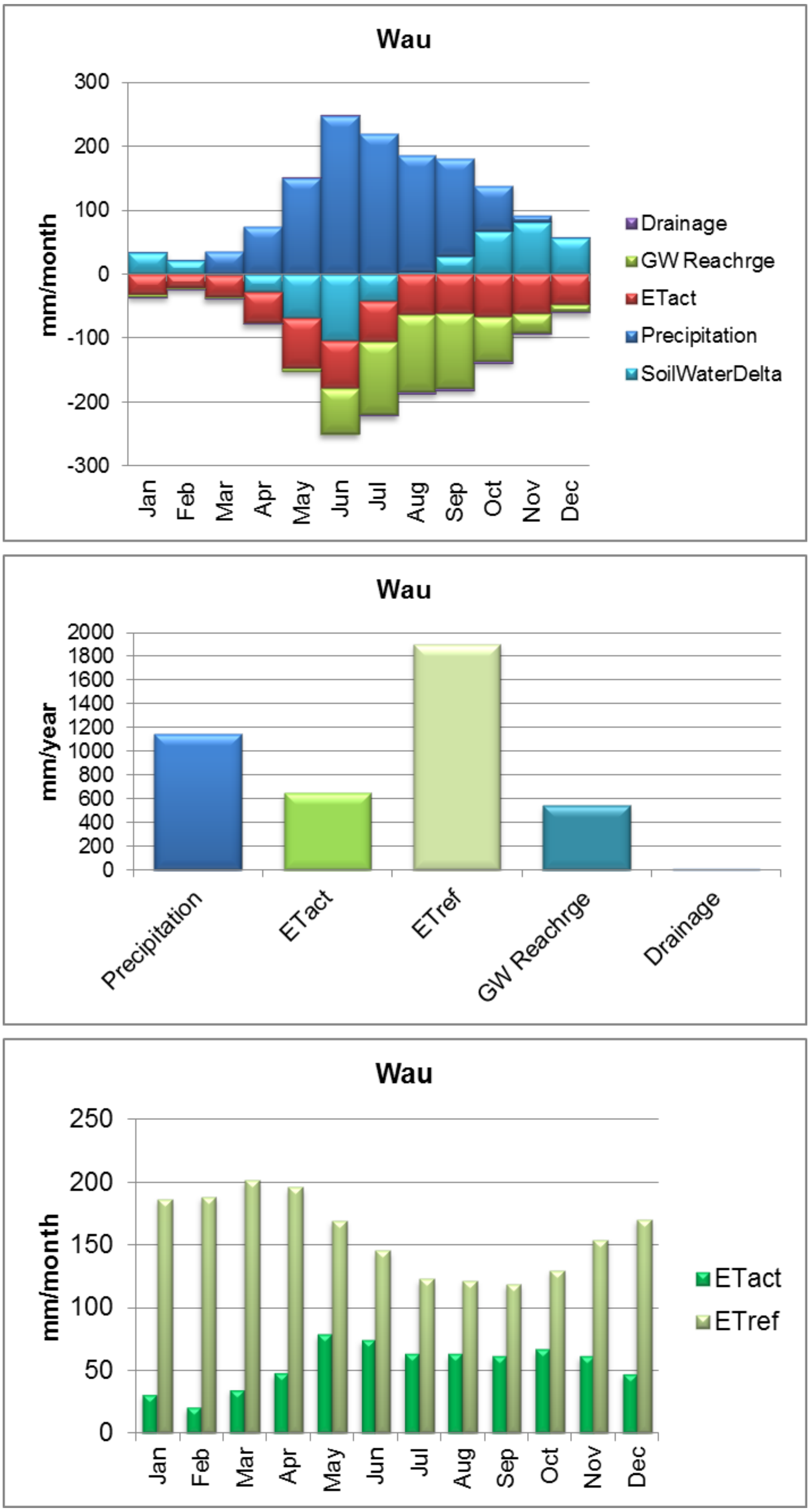
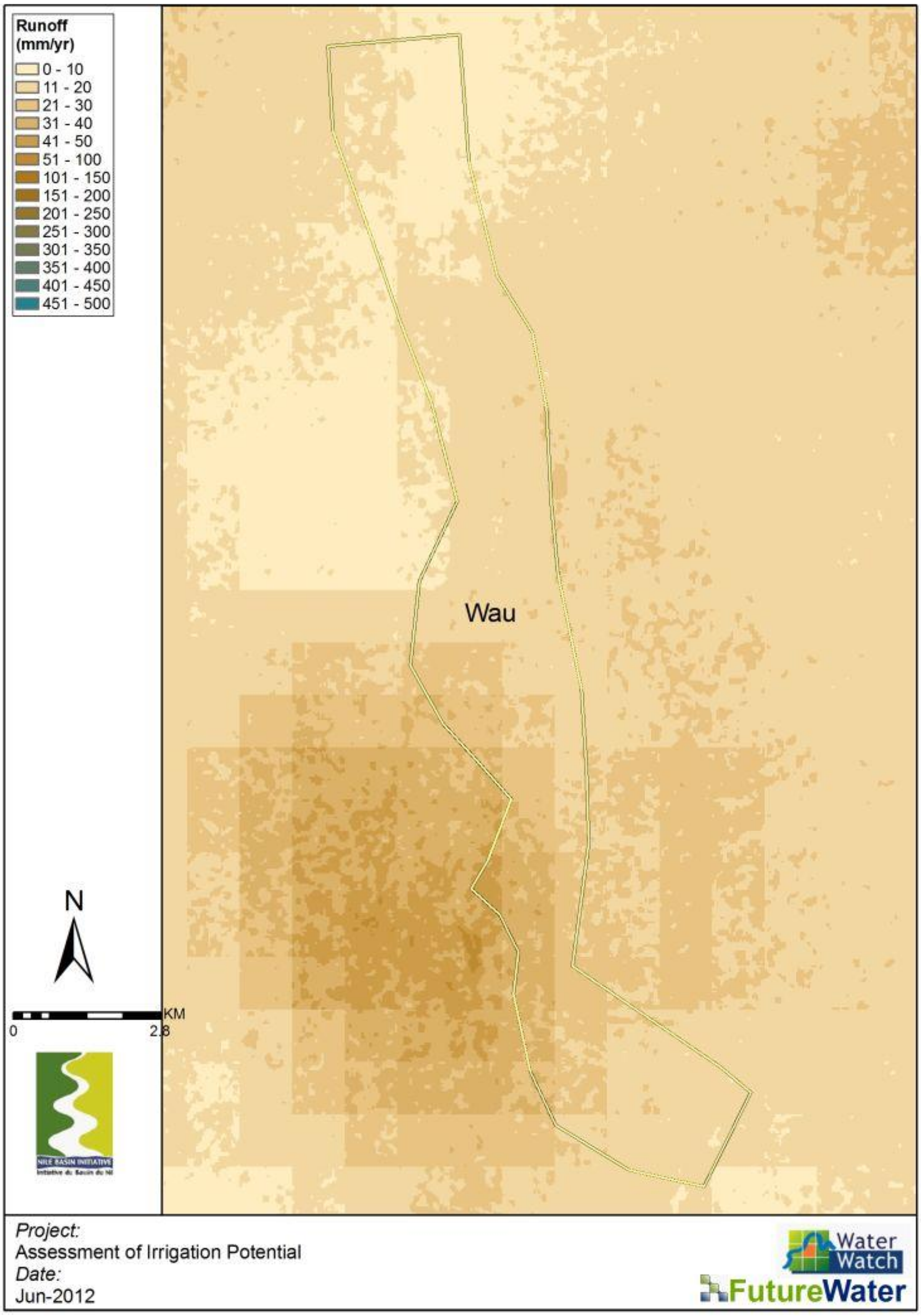
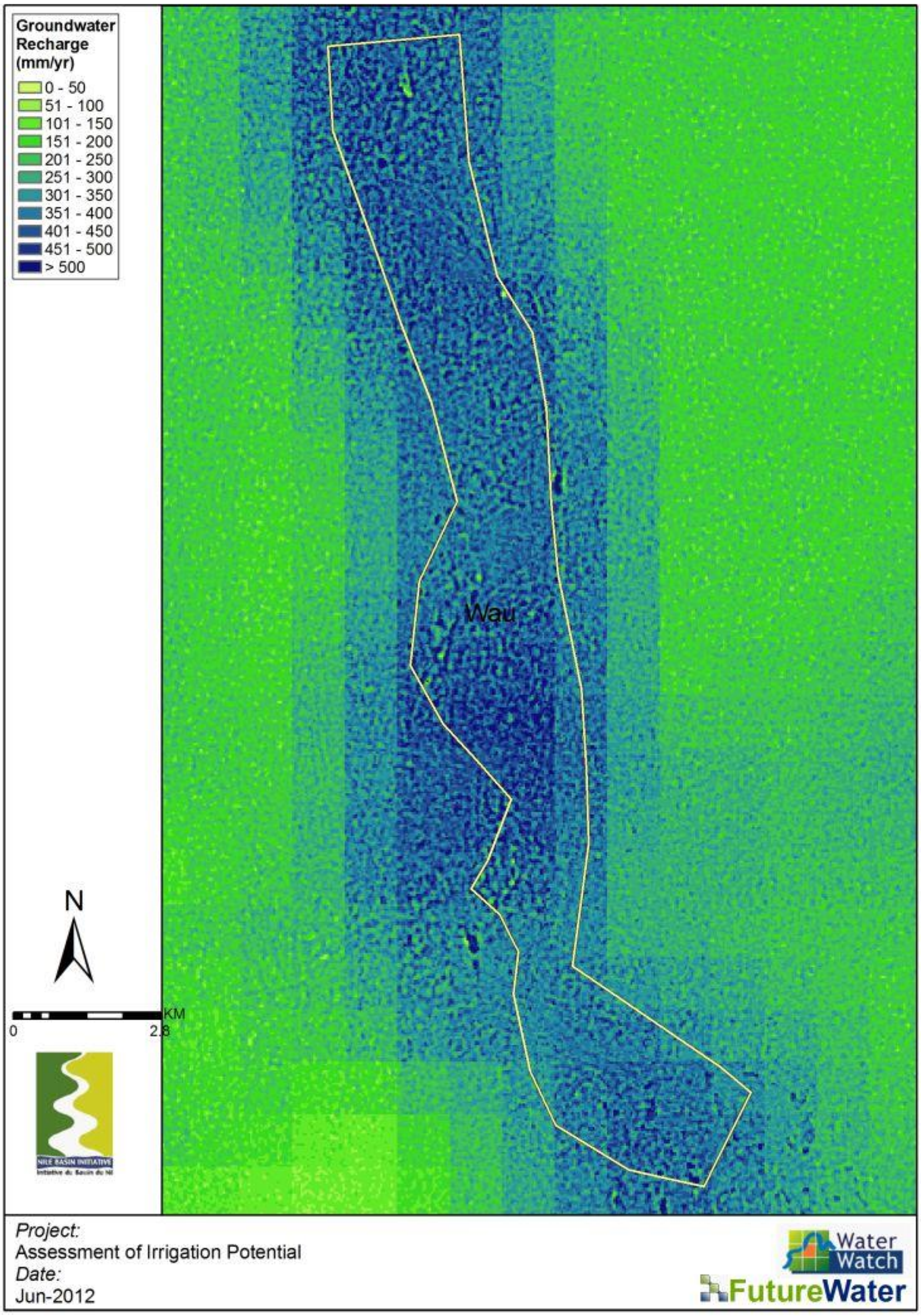


Figure 107: Water balances for the area based on the high resolution data and modeling approach for Wau focal area.



Runoff (mm/yr)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
451 - 500
Wau
N
0
2.8
KM
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater


Groundwater Recharge (mm/yr)
0 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
451 - 500
> 500
Wau
N
KM
0
2.8
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

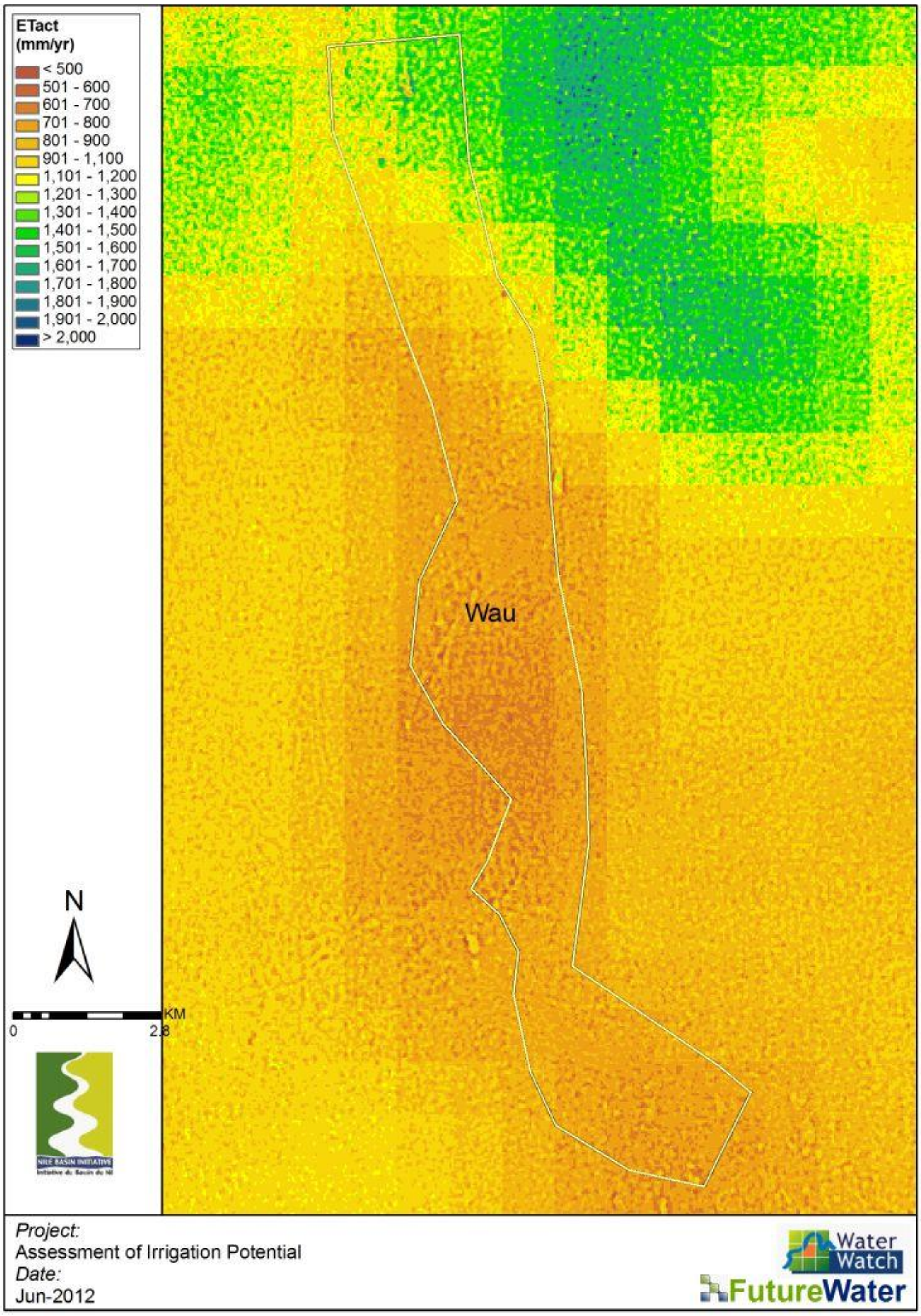


Figure 108: Water balances for the area based on the high resolution data and modeling approach for Wau focal area.

Figure 109. Charateristics of Wau focal area.

7.4 Assessment of irrigation water requirements

7.4.1 Irrigation water requirements

Irrigation water requirements depend on many factors such as: climatic conditions, crop, growing season, irrigation practices etc. A first estimate of irrigation requirements could be based on the difference between rainfall and reference evapotranspiration. It was however selected for this pre-feasibility assessment to provide a first estimate of irrigation needs based on the most promising crops. To this end, FAO's AquaCrop, the successor of CropWat was setup for local and crop specific conditions.

In the table below the irrigation water requirements for each selected crop are provided based on AquaCrop calculations. All units are provided in mm per growing season for the specific crops. Note that for various crops, like vegetables and similar crops, multiple croppings per years might occur.

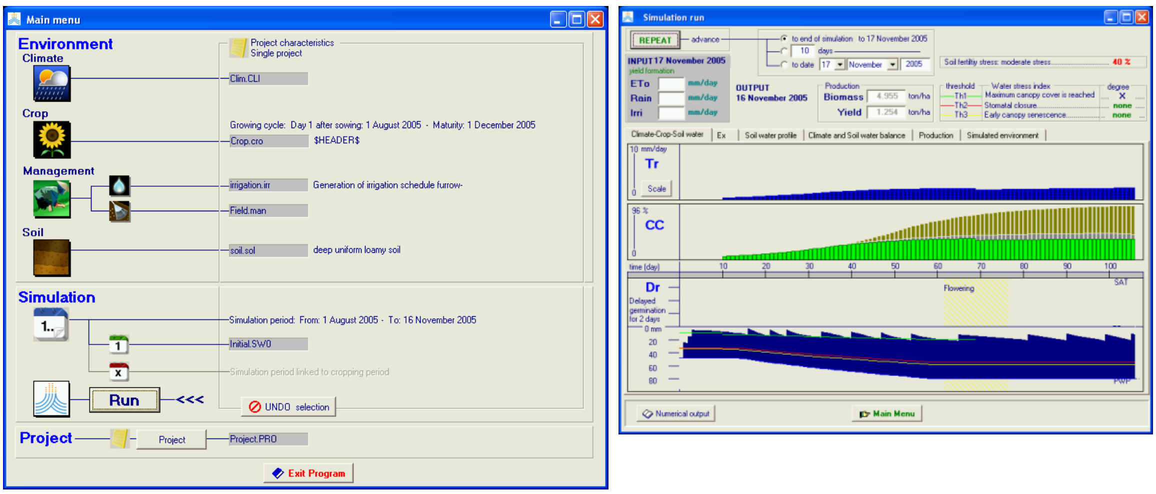


Figure 110: Typical example of AquaCrop input and output screens.

Table 11: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season.

Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year	===	== (day of year) ==		======== growing season =======			
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Rice	1149	1902	213	320	414	200	450	399
Sorghum	1149	1902	121	243	804	130	560	515
Cassava	1149	1902	167	350	757	80	799	380
Maize	1149	1902	121	238	772	140	537	494

7.4.2 Irrigation systems and irrigations efficiencies

River Jur flows through the focal area and drains a very large area with two rivers joining just at the southern tip of the focal area, which together drain a total area of about 52,000 km^2. The soil is very suitable for paddy rice production, and therefore the advised irrigation method is border irrigation. The topography is very suitable for surface irrigation as slopes are limited. Preferably gravity irrigation is installed, but it seems that not all parts of the area can be irrigated under gravity. Some parts can be irrigated with pumping. This increases the conveyance costs and requires a higher educational level for some farmers working with the pumps. Vegetables can be grown with furrow irrigation.

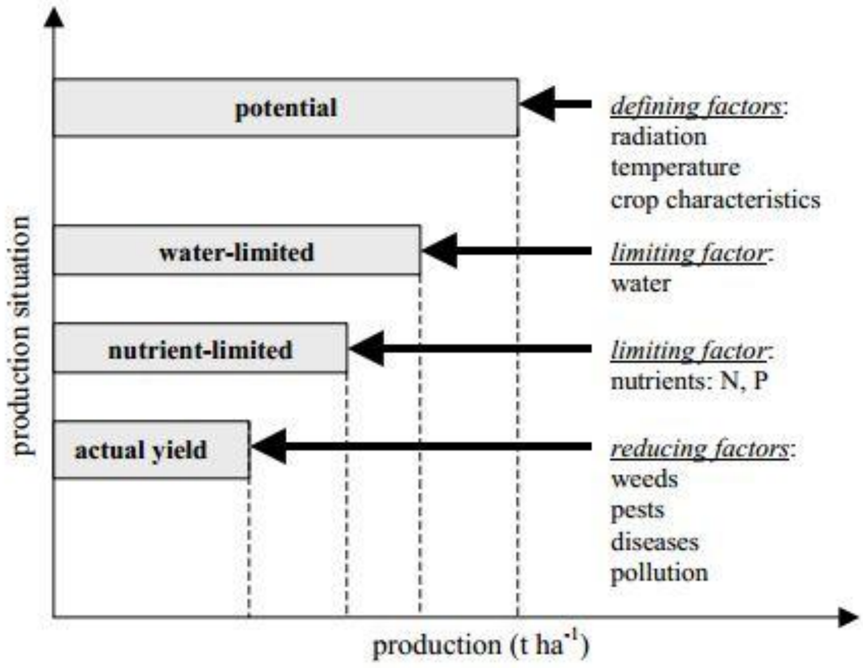
7.4.3 Water source

The water source for irrigating the Wau focal area will be Jur River. The river drains a very large area of 52,000 km^2, and has an annual average flow of 70 m^3/s. The high seasonality of the river and the absence of river water management make it hard to create an intake structure for gravity irrigation, which will be long lasting. A pumping station is more realistic, but even then it is advised to control the flow of the river more, and to create an upstream reservoir, which will enhance all-year-round water supply.

7.5 Potential crop yield assessment

The yield gap describes the difference between the current yield, and the maximum possible yield. Mostly the maximum possible yield is defined as the highest yield in the world, but it can also be assessed against a regional background which makes the yield gap more realistic and the maximum yield possible to achieve under the given circumstances.

The gap between the actual yield and the potential yield can be caused by several processes. Factors which may cause that the maximum possible yield is not reached can be the water availability, the soil and the available nutrients, or yield reducing factors like diseases, weeds or pollution.



7.5.1 Yield gap analysis potential dominant crops[1]

Yields in Sudan are relatively high compared to surrounding countries. There is, however, a large differentiation between crops. Sudan has extremely high yields for dry beans, bananas, sugar cane, sweet potatoes and potatoes. For paddy and cotton seeds, Sudan performs better than the world's average yields. Most probably, this finds its origin in the intensification and irrigation programs that have been introduced in the past to increase food production and to meet the demand. In Figure 111, the yield gap is shown relatively to the highest obtainable yield in the world, to the world's average, and to Africa's average. Within the Wau focal area the yields are about 10-20% lower than Sudanese average yields. It is expected that the production of rice and later sugarcane have a high potential to increase yield. The exact yield increase depends largely on river flow regulation. Under good water management circumstances it is expected that the yields of rice can increase much, surpassing the world's average towards 60% of the highest obtainable. Vegetables will definitely increase largely under irrigation and production will probably reach the threefold. Sugarcane is a good cash crop, which can be introduced after a few years of good practice. Sudan keeps good record with sugar cane, and yields are expected to reach towards the worlds' highest. Irrigation will not only increase yields due to proper water management, but also enable for a second growing cycle per year, which enhances productivity.

[1] This section is bases on FAOSTAT with yields from former Sudan.

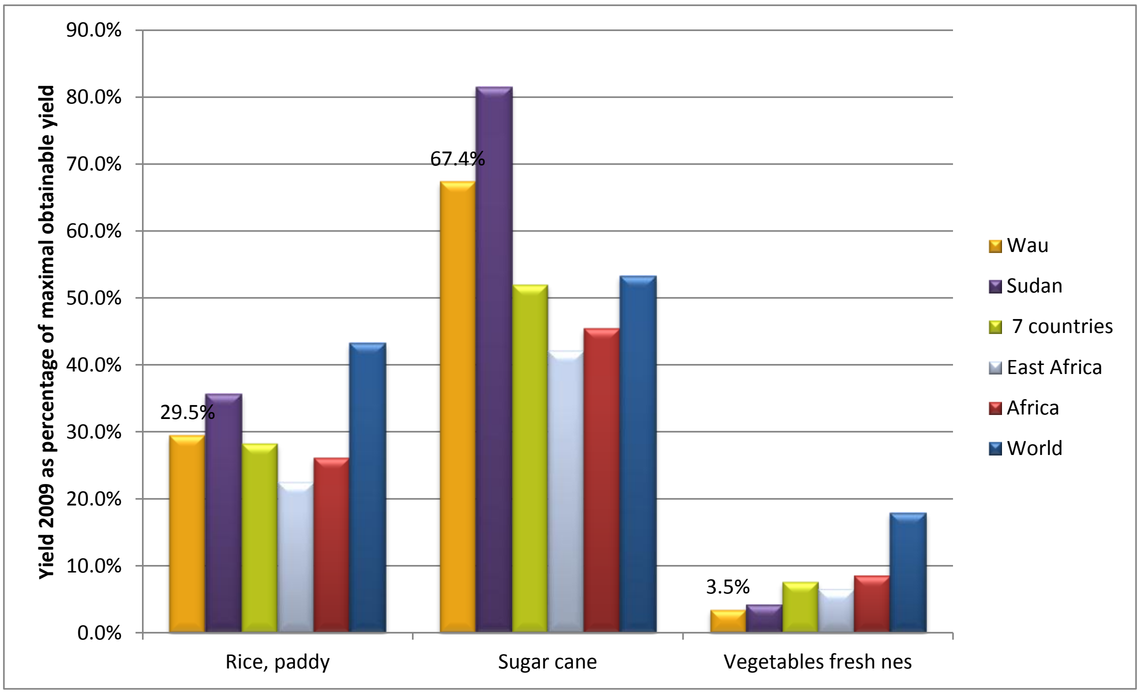


Figure 111: Yield gap Wau (source: FAOSTAT, 2010).

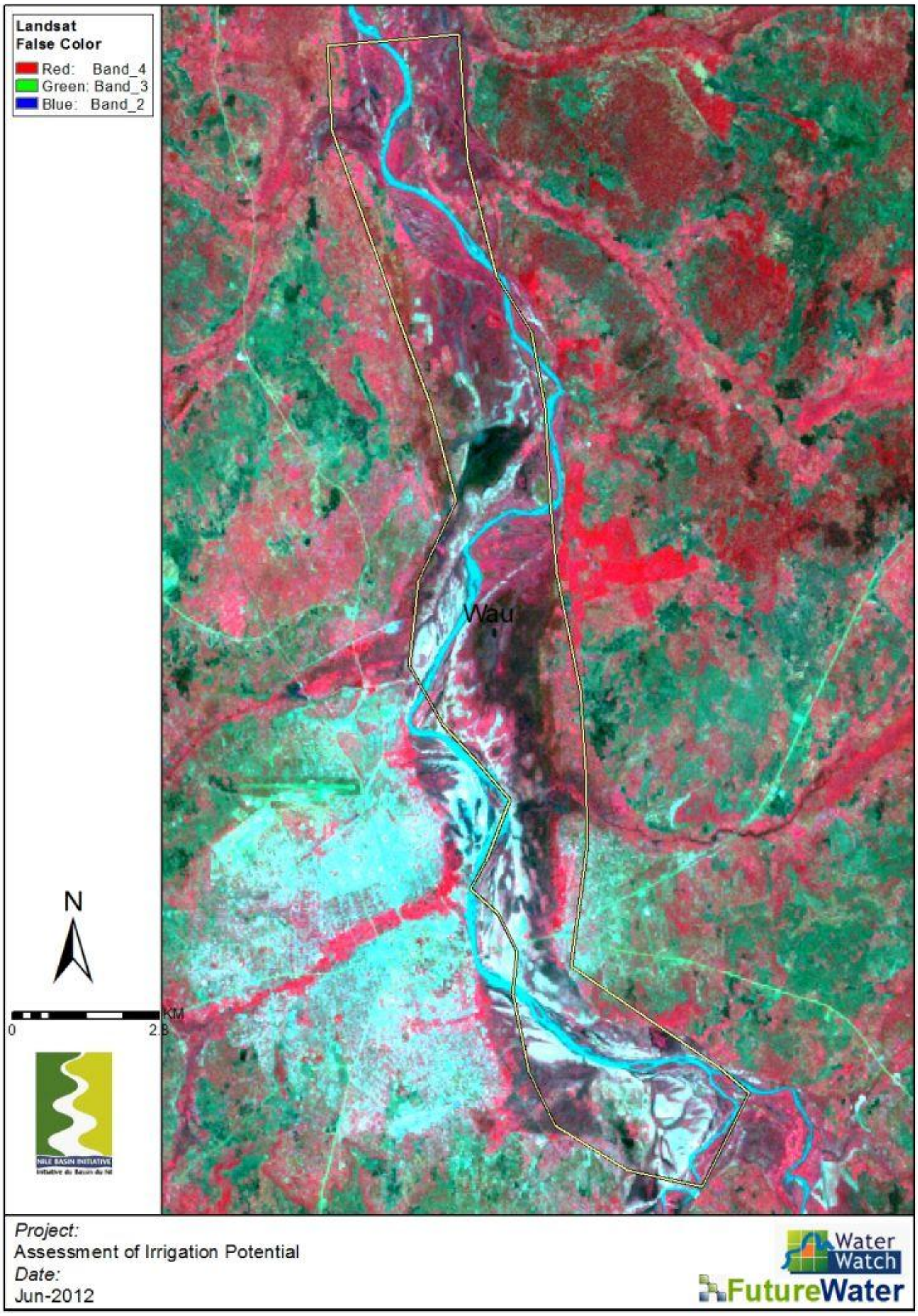


Figure 112: Landsat False Color Composite indicating current productivity of WAU focal area.

7.6 Environmental and socio-economic considerations

7.6.1 Population displacements

The area is somehow densely populated. Most people live in Wau town, which is bordering the focal area on the southwest. However, on the eastern banks of the river, on the opposite of Wau town, there are quite some settlements too. Along the eastern shores of the river there is a long line of houses, buildings and industries going north along the river. On the western banks of the river, a build-up area continues some kilometers north of Wau, after which houses become more scattered. When developing irrigation schemes, it is advised to avoid population displacements and design the scheme around the already build up area. However, in this focal area the irrigation scheme may become very much fragmented. With the design or rehabilitation of any irrigation scheme, it is advised to limit any population displacement. The exact numbers of effected houses can only be known after designing the scheme, which is beyond the scope of this pre-feasibility study.

7.6.2 Social

Population density in the Western Bahr el Gazal state is much lower compared to the South Sudanese average. The population density is about 4 people/km^2, compared to the South Sudanese average of 13 people/km^2. This average is the lowest of South Sudan. The country wide population density is among the lowest in the African sub-tropical countries. (CIESIN) Remarkably the ratio male to female is 1.13. In 2008 it is estimated that half (48%) of the population is below the age of 18 years. Within South Sudan 51% of the population lives below the national consumption poverty line (SSDP). Within Western Bahr el Ghazal, this percentage is slightly lower (43%). In rural areas in which the focal area is located this may be higher. The area is inhabited by Dinka, Fartit and Jur Chol people, which have an average experience with agriculture and farmers cooperatives. This can largely contribute to a successful introduction of an irrigation scheme. The accessibility of the focal area is very good, as Wau is a transport hub within South Sudan. Therefore the markets are easy to reach. The net enrolment rate in primary school is 53% in 2009, and literacy rate among 15-24 years old is 50%, which is unevenly distributed among males and females. 57% of the population in Western Bahr el Gazal is rural, and 64% of the population depends on crop farming or animal husbandry as their primary source of living (SSNBS).

7.6.3 Upstream downstream consideration

The river that flows through Wau focal area drains a large area of the hills in the South and West of the focal area. The flow generated here is highly seasonal, and therefore it is recommended to search for measures that first retain the precipitation water, and try to store it upstream. This will enhance the upstream ecosystem, and groundwater levels. On a larger scale the groundwater is recharged, which can become available downstream again, and evaporation enhances the water cycle and the precipitation in the area. Erosion is observed on a low level. If an irrigation scheme is developed, then attention should be paid on how to reduce erosion in the irrigated area. The use of fertilizer is recommended, but it is needed to use fertilizer in a responsible and well considered way. Otherwise the water quality downstream may be compromised.

7.6.4 Protected areas

Within the focal area no protected areas are reported.

7.7 Benefit-cost Analysis

A simplified benefit-cost analysis is undertaken for the area. Information for this is based on various sources such as FAO publications, IFPRI publications, local expertise and data. A full benefit-costs analysis has to be undertaken in a sub-sequent feasibility study for the area.

Note that this is a first-order benefit-cost analysis. A feasibility study can provide a more rigorous benefit-cost analysis, which is required before taking any implementation planning. However, the following table shows that based on this first-order analysis, investments in irrigation can have a positive financial impact.

Main assumptions for the benefit-costs analysis include:

- Irrigated land based on GIS and local experts for boundaries
- Number of farmers based on average land tenure area
- Irrigation infrastructure based on irrigation type and source
- Social infrastructure based on local expert judgment on farmers' trainings need
- Accessibility infrastructure based on generalized road conditions
- Internal Rate of Return based on 25 years
- Crop revenues based on local crop potentials and local market prices (crop, kg/ha, $/kg):
    - Rice: 6,000 kg/ha, 1.10 $/kg
    - Sorghum: 3,000 kg/ha, 0.65 $/kg
    - Cassava: 12,000 kg/ha, 0.28 $/kg
    - Maize: 2,500 kg/ha, 0.22 $/kg

Based on expert knowledge on the suitability to develop irrigation in the area scores between 1 (negative: low suitability or expensive) to 10 (positive: high suitability or low investments) have been marked. The filled radar plot below indicates the options for the focal area. Overall, the weak part of the site lies under farmers capacity, accessibility to roads, to markets and the initial investment cost. This in-turn affects access to market as farmers cannot transport their yield easily and more importantly may not fetch golden prices. However, soil suitability and water availability is a great deal for the area that will foster an increase yields.

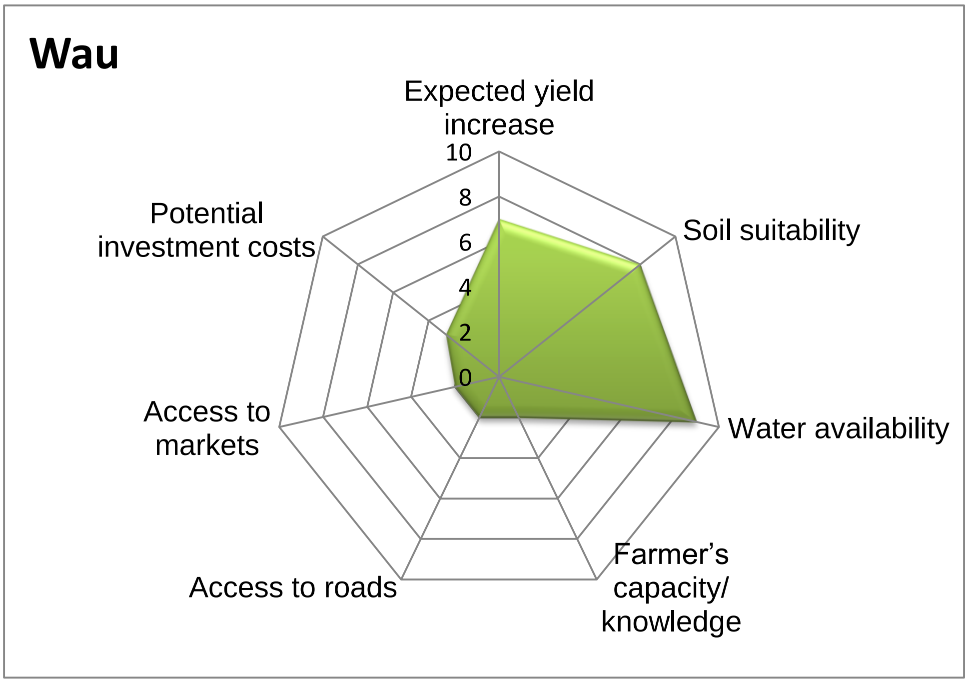


Figure 113: Filled radar plot indicating expert knowledge score to develop irrigation in the Wau focal area (1 = negative, 10 = positive). (Source: local experts and study analysis).

Table 12: Benefit-cost analysis for Wau area.

Characteristics	
Irrigated land (ha)	2,000
Farmers	2,500
Investment Costs	
Irrigation infrastructure (US$/ha)	6,000
Social infrastructure (US$/farmer)	500
Accessibility infrastructure (million US$)	0.5
Operational Costs	
O&M irrigation (US$/ha/yr)	60
Extension service (US$/farmer)	10
O&M roads (US$/yr)	10,000
Summary	
Initial investments (million US$)	13.8
O&M costs (million US$/yr)	0.155
Net benefits per year (million US$/yr)	3.738
IRR (Internal Rate of Return)	35.2%