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

Final Report
Appendix Rwanda

July 2012

Client
Nile Basin Initiative
NELSAP Regional Agricultural Trade and Productivity Project

Report FutureWater: 114

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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: Prime Ngabonziza (NLO), Reverien Harindintwali (Field assessor), Leopord Munyaneza (Data specialist), Vincent Ssebuggwawo (NELSAP), amongst others. Their contribution is highly appreciated.

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1 Introduction[1]

1.1 Background

Rwanda (Figure 1) is located in the Southern West of theVictoria Basin and belongs to the Upper Nile River States. The country shares its borders with the Democratic Republic of Congo in the west, Uganda in the north, Tanzania in the east, and Burundi in the south. Rwanda has a total area of 26,338 km^2 and is divided into two main basins: the Congo basin representing 17% of the area, and the Nile basin representing 83% of the area (Baligira, 2008). Its relief comprisessuccession of relatively large hills and valleys. More than 40% of the country is located on analtitude of between 1,500 MASL and 1,800 MASL. 90% of the national water resources are drained throughthe southern and eastern part by the main rivers Nyabarongo, Akanyaru and Akagera.

The surface occupied by lakes, rivers and marsh is 2,125km^2, hence approximately 8% of the national territory. Lakes have an area of 1,282 km^2,whereby the Kivu Lake alone accounts 1,028 km^2. Permanent rivers cover 73 km^2 whereas the marshes and bottom valleys add up 1700 km^2.

Rwanda belongs to one of the highest populated countries in Africa with 321 persons per km^2, and 90% of the population lives from food subsistence agriculture.

[1] Information in this chapter is among other sources based on: FAOSTAT, CIA world fact book, UNDP, phase 1 report and EDPRS report.

Figure 1: Map of Rwanda.

1.1.1 Socio-economy

Farming is the principal economic activity of the Rwandan people, carried out on more than 1.4 million farm households. According to the general population census in 2002, a ratio of 8 people per 10 is used in agriculture whereby most of them are women. The agricultural sector produces 45% of the GDP in the past decade (1995-2004) and generates nearly 75% of the foreign exchange earnings. In some areas, particularly in the Nile Basin catchment, the population pressure has reduced the area of arable land available per household to about 0.75 ha per household. More recent data might be available from various ministries.

1.1.2 Millennium Development Goals, current status

The Rwandan Economic Development and Poverty Reduction Strategy (EDPRS) run from 2008-2012. The EDPRS is currently the main framework through which the government can fulfill the long term millennium development goals (MDGs). The EDPRS has created a political environment in which development strategies can be implemented by setting priorities and by clearly defining responsibilities and budgets.

Rwanda is on track to achieve most of the MDGs. The economic crisis, however, and the uncertainty about foreign aid are constraints which may slow down the rate of development in the coming years.

A quick overview will be given about the current status (2008 data) of the MDGs.

Goal 1: Eradicate Extreme Poverty and Hunger

The poverty rate in 1990 was 47.5%, which would set the goal on reducing poverty to 23.8% by 2015. Currently the poverty rate is 56.9%. The proportion of population below minimum level of dietary intake increased as well from 34% in 1990 to 37 % in 2008. The only part on track of achieving is the prevalence of underweight children under five years, which decreased from 29% to 15%, nearly reaching the 2015 target.

Goal 2: Achieve universal primary education

For this second goal a good progress has been made. The net enrolment ratio in primary school increased from 62.5% to 94.2% in 2008, coming close to the target of 100% in 2015. However, the percentage of pupils which reach the last grade of the secondary school is 74.5%. So the dropout rate is relatively high, and it is unsure if the 100% target can be reached in 2015.

Goal 3: Promote gender equality and empower women

Good improvement can be seen. The ratio of boy to girls on primary and secondary schools is nearly 1:1. The amount of female seats in the parliament is already exceeding the 50% goal with 52% in 2008. The Share of women in waged employment in the non-agricultural sector increased from 15% in 1990 to 28.4% in 2008, but is not yet close to the 50% goal set for 2015.

Goal 4: Reduce child mortality

The under-five year mortality rate and the infant mortality rate have both been reduced with 27%. The overall goal is to reduce with two thirds to 33% of the 1990 values. The current under-five year mortality rate is 103 out of thousand births, and the goal for 2015 is 47.

Goal 5: Improve maternal health

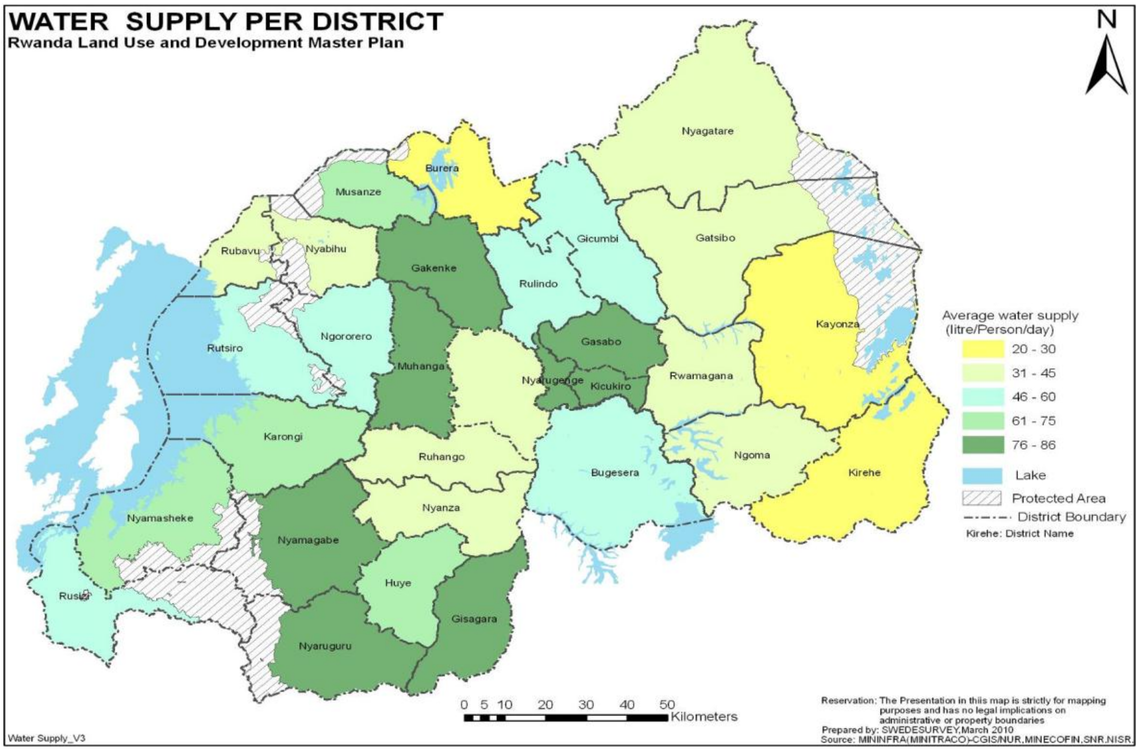
The maternal mortality ratio is improving, but not with the speed to reach the goal of 75% decrease. More and more births are attended by skilled health professionals, counting 52% in 2008.

Goal 6: Combat HIV/AIDS, malaria and other diseases

Although the facts about HIV/AIDS are not always clear, the government is taking good steps to reduce the spreading, and to educate. Treatment for HIV/AIDS is accessible for 77%of the adults and 49% of the children. 100%accessibility is set as target for 2015. The incidence of tuberculosis has nearly tripled from 1990 to 2008.

Goal 7: Ensure environmental sustainability

The amount of people having access to an improved drinking water source improved to 74% in 2005, and is getting close of the aimed 82%. Information about biodiversity loss and sustainable development is not clear, but according to the UN 2010 paper on the Rwanda MDGs, the goals are not on track. The government is putting effort in incorporating environment in laws and policies. The results of these laws can only be observed after implementation.



Goal 8: Develop a global partnership for development
Under the EDPRS the government has put extra effort in improving health. The accessibility to essential drugs is 89% in 2008. In 2008, 13.1 telephones per 100 inhabitants are available and 0.6 personal computers per 100 inhabitants.

1.1.3 Poverty reduction strategy

The information in this section is based on the ‘Poverty Reduction Strategy Paper’, published in March 2011, and covers the 3 year period 2008-2010. This paper is mainly based on the results from the Rwandan Economic Development and Poverty Reduction Strategy (EDPRS), which contributes in achieving the MDGs as well.

Within the fiscal year 2009/2010 the GDP was estimated Rwf 3,160 billion, which is a growth of 11.5% compared to the previous year. The GDP per capita was estimated to be Rwf 308,000 or US$ 541.

Calculated with constant 2006 prices an average GDP growth of 8% over the period 2008-2010 was reached. This growth is mainly driven by a 7% increase in food crop production and 7.6% growth in services. The industry sector grew 0.6%, since it was most affected by the global recession.

Revenue in 2008 outperformed the projections by Rwf 52 billion. And in the fiscal year 2009/2010 the revenue was Rwf 391.5 billion which equals 12.4% of the GDP. 56% of the tax revenue is coming from VAT and PAYE, which is in line with the government strategy to get the well off in the society to provide a larger share of the resources for development.

Exports of goods and services in 2010 dropped by 9%, while the imports increased by 7%, compared to a 17% increase in 2009/2009. Inflation in the end of 2008 reached 15.4%. This can mainly be contributed to high food prices and high international commodity prices. The inflation, however, decreased the years after that to 10.1% in June 2009 and 5.03% in June 2010.

Rwanda is making large steps to reform business regulations, and was awarded as a top performer. Rwanda's market is listed as 6th most competitive market in sub-Saharan Africa.

Agriculturally, the food production has exceeded the consumption for the last three years, for the first time since 1994. This was mainly achieved by intensification, as arable land increased with 1% only, while production increased with 6% in 2010.

1.1.4 Legal framework

The Government of Rwanda formulated its first National Policy on Water Management in 2011. The mandate of water resources management rested under various ministries (Agriculture and Infrastructure) before it was brought under the Ministry of Lands, Environment, Forests, Water and Mines (MINITERE). The policy formulation process reflected global policy changes and opened the sector for public, private and voluntary sector partnerships and references were made to Integrated Water Resources Management (IWRM) principles. In 2004 the Government of Rwanda held discussions with interested stakeholders and produced a water sector policy document that merged the water sector with lands environment and forestry sectors under MINERENA. The water sector policy was agreed by the Council of Ministers in October 2004. The new water policy introduces an institutional reform process in which a National Commission of Water, interdepartmental coordination, basin and catchments committees, and local water users associations are foreseen to be established. The public sector at sub-national level is expected to collaborate with the voluntary and private sector to manage the water resources and to provide water and sanitation services. The existing informal water users groups that manage local water resources will be organized into catchment committees and water user associations to ensure participatory processes in the planning and management of water projects and programs.

1.1.5 Socio-economic context and institutional setting

This section describes the socio-economic context and institutional setting for small scale irrigation development in Rwanda. The main parameters and their sources are summarized respectively in the table on socio-economic context and institutional setting. The highlights are:
Socio-economic context:

- Rwanda retains a largely rural population (81%)
- Poverty levels are modest, if compared to other Nile basin countries (58.5% below national poverty line)
- On main social services: health expenditures (USD 48/ capita), population with access to improved source of drinking water (65%), electric power consumption (25 KWh per capita) and female illiteracy (33.2 %) Rwanda scores better than other countries in the same socio-economic bracket, except the electric power consumption
- Agriculture is the main provider of jobs in Rwanda (87%)
- In economic value Rwanda is a net exporter of agricultural products (import to export is 0.52). The total value of agricultural exports is modest though (USD 234.75 M)
- With respect to food Rwanda is a net importer (value of food imports USD 104.8 M)

Agricultural services:

- Agricultural road density is low (12.2 km/1000 sq. km arable land) – affecting agricultural marketing
- Fertilizer use is at a minimum to modest (8.3 kg/ ha)
- The use of mechanical equipment is very minimal (0.47 tractor per 1000 sq km of arable land

Irrigation and water use:

- Irrigated land is a small fraction of arable land (0.62%)
- Total water abstraction is a small percentage of renewable resources (1.67%)
- No data are available on groundwater usage
- Overall irrigation performance is good (3.6 on a scale of 0-5) – beneficial water use is relatively low (7/8) but reliability and uniformity are high (both 3/8)

Institutions

- The institutional framework for irrigation and water development has been strengthened considerably with the approval of the Rwanda Irrigation Master Plan 2010. In a wider context the Strategic Plan for Agricultural Transformation (PSTA), National Agricultural Policy 2004, Poverty reduction strategy, Vision 2020 are main guiding document to development of water resources and irrigation
- The institutional mandate is vested in the Ministry of Agriculture and Animal Resources (MINAGRI). Other institutions related are Ministry of Natural Resources, mainly involved in groundwater development
- There is no water licensing system in place or payment of water fees
- Land tenure is officially administered by the 2005 Organic Land Law
- On indicators of government effectiveness (48.6.%) and rule of law (-0.51) Rwanda scores high – in relation to other SSA countries.

RWANDA – INSTITUTIONAL	
Main guiding policies, acts and ordinances	• *Rwanda Irrigation Master Plan is the main guiding document for irrigation development in Rwanada. It especially focuses on irrigation potential of the runoff for small reservoirs (125 627 ha), runoff for dams (27 907 ha),direct river and flood water (79 847 ha), lake water resources (100 107 ha), groundwater resources (36 432 ha),and marshlands (219 793 ha). It also includes already detailed irrigation plans for each province.*[2] • *In a wider context the Strategic Plan for Agricultural Transformation (PSTA) is guiding agricultural transformation processes, through which, as stated in JICA (2006) "the agricultural sector shall be transformed into a modern, professionally operated and market-oriented economic undertaking through the promotion of professionalism, specialization, technological innovations, and private-public partnership"* • *Further documents are National Agricultural Policy 2004 (NAP), Poverty Reduction Strategy Paper, Vision 2020, Community Development Plans (JICA, 2006)*
Institutional mandate irrigation development	• *Ministry of Agriculture and Animal Resources (MINAGRI) is directly involved in the development of the IMP (Irrigation Master Plans)*[3] • *MINAGRI is also responsible for the policy and strategy formulation for the PSTA's operational program. The implementation component of PSTA is however organized on district level* o *RAB (Rwanda Agricultural Board to strengthen farmer's supporting activities, like improved farming practice, association development and marketing* • *Ministry of Natural Resources (MINERENA), involved in groundwater development* • *Rural Development Cluster (RDC), its role is harmonization and alignment among the Development Partners (DP)*
Water Permit System – Drillers	• *The availability of a water permit system for drillers and surface water withdrawal is unknown, low access level to official documents* • *One drilling company (Foraky) is active in Rwanda, but Ugandans' companies have contracted drilling projects in the country (Meghami, M. et al. 2007)*
Water Permit System – Users	• *Permits for ground- and surface water withdrawal are unknown* • *Rwanda does not apply user payments for groundwater (Meghami, M. et al. 2007). No prove was found for payments for surface water withdrawal*

[2] *(1) Kirehe district Irrigation Plan, Eastern Province 40,465ha. Conventional irrigation; (2) Nyanza District Irrigation Plan, Southern province: 19,474 ha. Conventional irrigation; (3) Kicukiro District Irrigation Plan, Kigali Province: 4,234 ha. (4) Rulindo District Irrigation Plan, Northern Province: 8,947 ha. (Partners involved in Development Irrigation Master Plan, 2010)*
[3] *It was developed by Ebony Enterprises Limited, an Israelian firm (CGIAR, 2010)*

Other institutions involved in irrigation (groundwater) development	• *IFAD, EU, World Bank, USAID, CIDA, JICA CGIAR and AgroForestre Centre are some international organization involved in funding of policy research in irrigation potential* • *Electrogaz, Foraky, Drillcon concerns are involved in groundwater development for people and cattle* • *LWF, OXFAM and ARC were active during emergence period*
Local organizations	*There are numberous, such as RHIO (Rwanda Horticulture Interprofessional Organization), ROPARWA (The Network of Peasant Organizations of Rwanda), RWARRI (Rwanda Rural Rehabilitation Initiative), UNICOOPAGE (Union of Agricultural Cooperatives of Gikongoro), BAIR (Bureau dÁppui Initiatives Rurales)(Amis, 2011)*
Private sector	*Organized in the Rwanda Private Sector Federation (RPSF)*
Support to small scale irrigation development (vocational sector, land planning)	• *There are number of agricultural institutes / vocational training centres; the main is Institute Superieured'Agriculture et d'Elevation (ISAE)* • *Even at very local level, vocational training centres are found, such as Secondary/Agricultural Vocational School: Mugonero, Rwanda* • *Rwanda's vocational schools are however falling short in turning out of graduates with the required practical skills. (World Bank, 2008, pp. 59). It recommends that the ETOs (Ecole Technique Oficielle) develops courses, in consult with ISAE, on irrigation and water harvesting (Ibid.)*
Land tenure (Uwayezu, E. and Mugiraneza, T. 2011)	*Officially regulated by the 2005 Organic Land Law*
Government Effectiveness (percentile rank 0-100) (Worldbank, 2009)	*48.6*
Rule of Law (-2.5 – 2.5, in which high values represent effective enforcement of law (World Bank, 2009)	*-0,51*

SOCIO-ECONOMIC - RWANDA	
Food exports, FAO (current US$M) (FAO Statistical Yearbook 2010)	19.02
Food imports, FAO (current US$M)	104.77
Imports/exports	5,51
Health expenditure per capita (World Bank, current US$, 2009)	48
Improved water source (% of population with access) (World Bank,	65
Improved water source, rural (% of rural population with access)(WB,	62
Improved water source, urban (% of urban population with	77
Poverty (% below national poverty line) (UNSTAT, 2006)	58.5
Illiteracy rate –Male (15+) (UNICEF, 2009)	25
Illiteracy rate --Female (15+)(UNICEF, 2009)	33.2
Primary completion rate, total (% of relevant age group) (UNICEF,	37.8
Road density (road km/100 sq. km of land area) (IRF, 2004)	53
Road to arable land density (road km/1000 sq. km arable land)(IRF,	12.18
Roads, paved (% of total roads)(IRF, 2004)	19
Electric power consumption (kWh per capita) (CIA, 2005)	25
Country area (km2) (FAOSTAT, 2009)	26,340
Land area (km2) (FAOSTAT, 2009	24,670
Population, Projected/Estimated (FAOSTAT, 2010)	10,624,000
Urban population (% of total population) (FAOSTAT, 2010)	19
Rural population (% of total population) (FAOSTAT, 2010)	81
Population density (pp/km^2) (World Bank, 2010)	431
AGRICULTURAL	
Agricultural exports (US$M) (FAOSTAT, 2008)	234.75
Agricultural Import (Current US$M) (FAOSTAT, 2008)	122.97
Import/export	0,52
Value added in agriculture, growth (%)(WB, 2009)	1.09
Value added, agriculture (% of GDP) (AQUASTAT, 2009)	38.74
Employment agriculture (% of population) (JICA, 2006)	87
Agricultual machinery (tractors /100 square km arable) (World bank,	0.47
Agriculture value added per worker (Constant 2000 US$) (WB, 2003)	218
Fertilizer consumption (kg per hectare of arable land) (WB, 2008)	8.3
Cereal cropland (% of land area) (of which irrigated, %) (WB, 2009)	14
Agricultural area (FAO Resource Stat, 2009)	2,000,000
Arable land (FAO Resource Stat, 2009)	1,300,000

IRRIGATED AGRICULTURE	
Irrigated land (% of crop land) (Aquastat, 2002)	0.62
Irrigated land entire country (ha) (2) (Bastiaansen and Perry, 2009 and AQUASTAT, 2000)	4,000 – 80,067
Actually irrigated (ha)	n.a.
Irrigation potential (entire country) (FAO, 1997 and AQUASTAT, 2007)	150,000-165,000
Irrigated Land nile basin (potential) (Bastiaansen and Perry, 2009)	17,638
Irrigation schemes in Nile Basin	n.a.
Small schemes (national level)	n.a.
Medium schemes (national level)	n.a.
Large schemes (national level)	n.a.
Potential schemes (Nile Basin)	n.a.
Water Sources	n.a.
Water Sources - Names	n.a.
Irrigated area per household (ha) (national level)	n.a.
SUSTAINABLE WATER ABSTRACTION RATES (AQUASTAT, 2000)	
Renewable resources (km3/year)	9.5
Overlap	7
Surface water	9.5
ground water	7
Dependency ratio	0
ACTUAL WATER ABSTRACTION RATES	
Groundwater (km3/year)	n.a.
Surface (km3/year)	n.a.
Total water withdrawal (km3/year) (AQUASTAT, 2000)	0.15
% of renewable water resources	1.67
Water abstraction points	n.a.
Deep Motorized borehole (Western Rift Valley Uganda) (Needed/Potential)	n.a.
Motorized borehole	n.a.
Manual boreholes (Including shallow wells) (Vision 2020) (World Bank)	185 (500)
Protected shallow well	n.a.
Windmill borehole	n.a.
Springs[4] (Vision 2020) (World Bank, 2008)	19,000 (20,000)
Water networks (Vision 2020) (World Bank)	821 (2,046)

[4] Rwanda knows 23,000 springs (World bank, 2008)

IRRIGATION PERFORMANCE (Bastiaansen and Perry, 2009)[5]	
Overall Irrigation performance Large Scale Irrigation (0-5)	3.6
Result Oriented Performance	2.97[6]
Sustainability Oriented Performance	3.8[7]
Process Oriented Performance	3.8[4]
Detailed Irrigation Performance Parameters	
Water Productivity (Performance 0-5) (Rank within Nile Basin 1-8)	3.0 (5)
Agricultural water Productivity	2.9 (6)
Crop consumptive use	3.2 (5)
Beneficial Water Use	2.7 (8)
Adequacy	3.1 (6)
Uniformity	4.5 (3)
Reliability	4.8 (3)
Sustainability	3.3 (6)
AGROPHYSICAL (Bastiaansen and Perry, 2009)	
Irrigated crops (ha)	Rice (2,000) and Vegetables (2,000)
Cereal yield rainfed (kg/ha) (Nett yield)	848
Biomass production (satellites) (kg/ha) (Nett yield)	11,181
Cereal yield irrigated (kg/ha) (Nett yield)	4,846
Yield Increment	3,998
Net Increment	1,199

[5]Specific recommendations for improvement of irrigation performane, as mentioned in Bastiaansen and Perry (2009): Increase transpiration instead of unproductive evaporation through intercropping methods for example, use of fertilzer and improved feed stock
[6]Refered to as average performance in Bastiaansen and Perry (2009), more output orientated irrigation management will help increase this performance aspect
[7] Referred to as good performance in Bastiaansen and Perry (2009), no comment to improve this performance aspect

2 Countrywide irrigation potential

2.1 Terrain and soil

2.1.1 Relief, climate, and hydrography

Annual rainfall ranges from 800 mm to above 1,600 mm, divided between two rainy seasons (March-May and September-December). The amounts of rainfall are good in most parts of the country, but there is a persistent risk of drought in most areas. The temperature regime is specified as “moderate highland equatorial” with average temperatures between 16° and 23°C. Based on elevation, available rainfall and soil conditions, the country has been divided into eight different agriculture regions (Baligira, 2008). Those regions include the Volcanoes Highlands, Buberuka North ridges, Buberuka foot ridges, Lakes Kivu shores, Central plateau, and Eastern lowlands. From the study made by Aquastat in 2005, Rwanda has been divided into 3 mainregions. These regions with their characteristics are shown in Table 1.

According to Verdoodt (2003), twelve agro-ecological zones (AEZs) are currently recognized in Rwanda. These zones have been determined based on climate, soil suitability, geology and geomorphology. A detailed description of these zones can be found in Verdoodt (2003).

Table 1: Agro-climatic zones in Rwanda (AQUASTAT, 2005).

Paramètre	Agro climatic zones of Rwanda		
	High land region	Central Plateau	Eastern Plateau and Western low land
Rainfall (mm/year)	1 300 – 2 000	1 200 – 1 400	700 – 1 400
Temperature (°C)	16 – 17	18 – 21	20 – 24
Evapotranspiration (mm/year)	1 000 – 1 300	1 300 – 1 400	00 – 1 750
Relative Humidity (%)	80 – 95	70 – 80	50 – 70
Runoff coefficient (%)	18	22	10

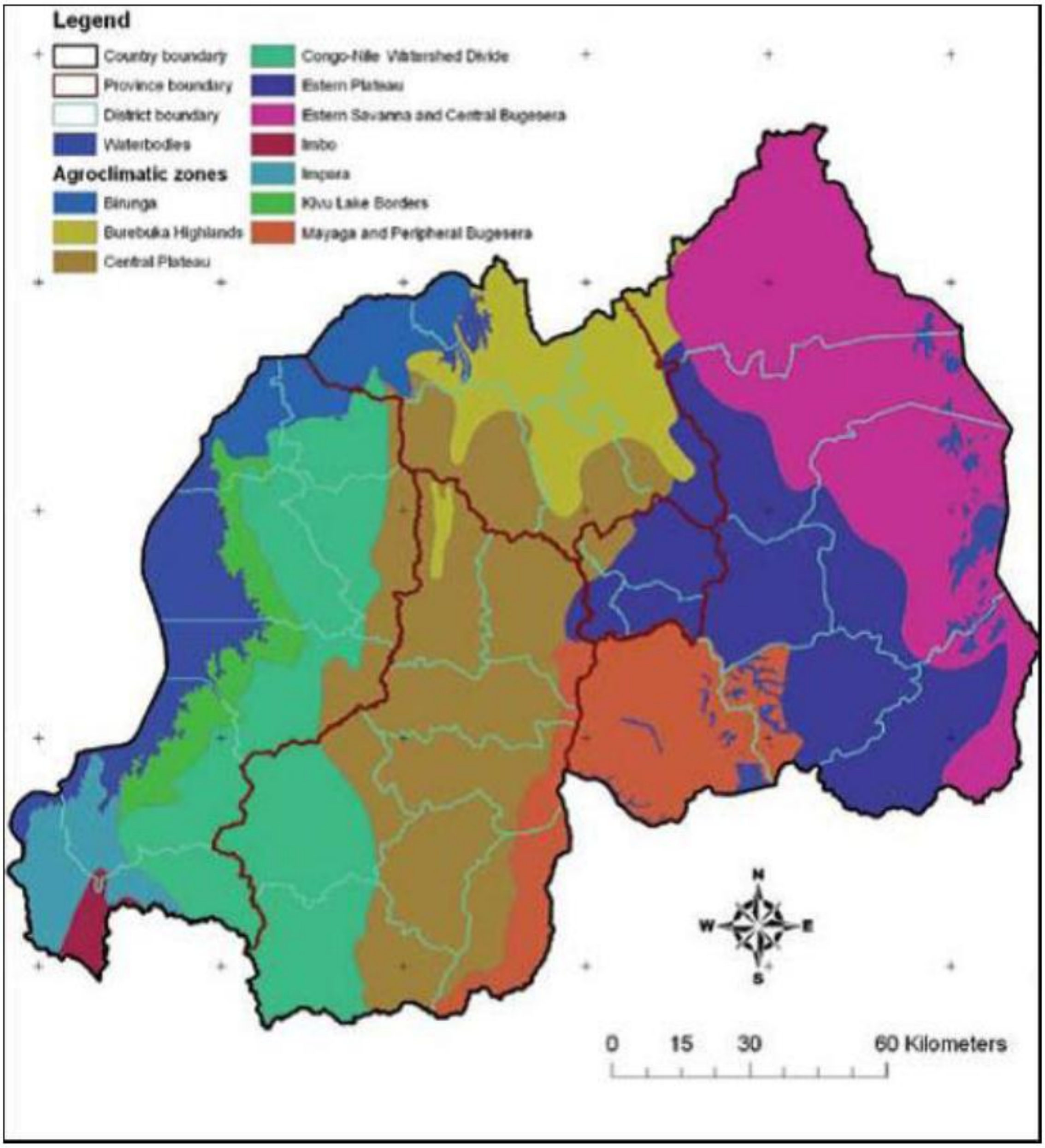


Figure 2: Agro-climatic zones of Rwanda (Source: MinAgri)

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.

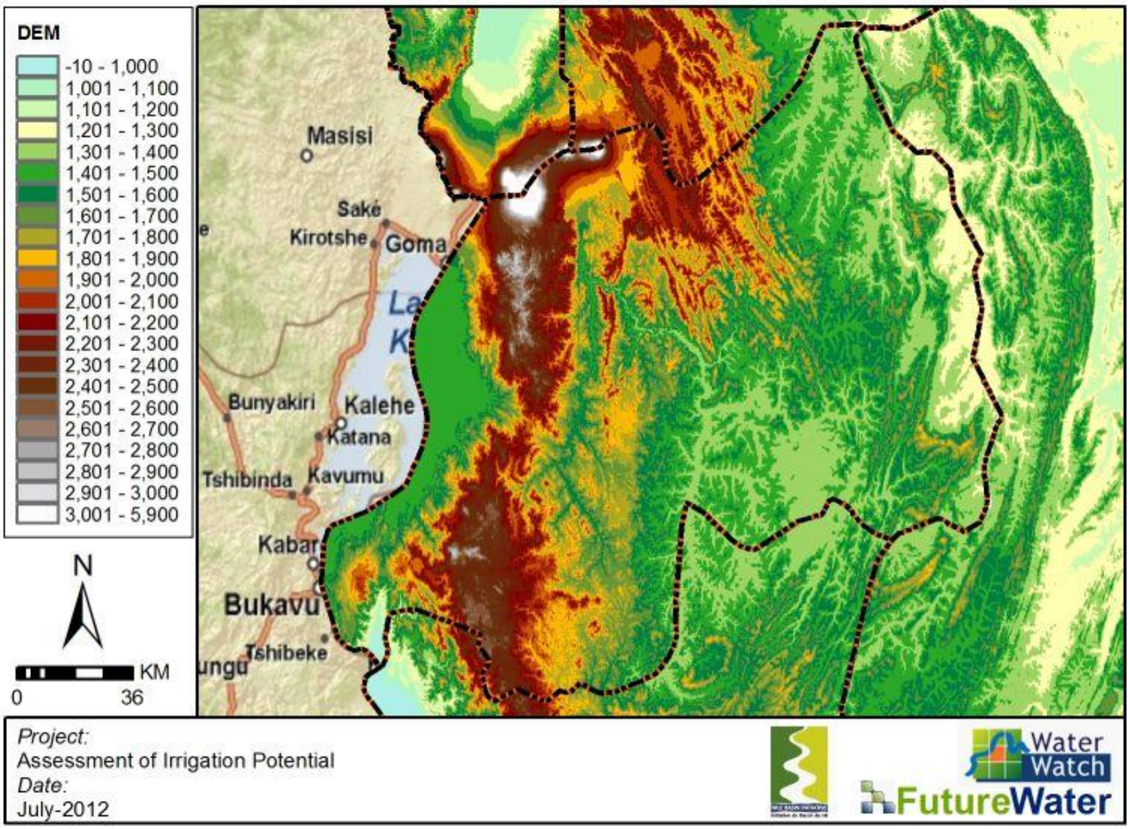
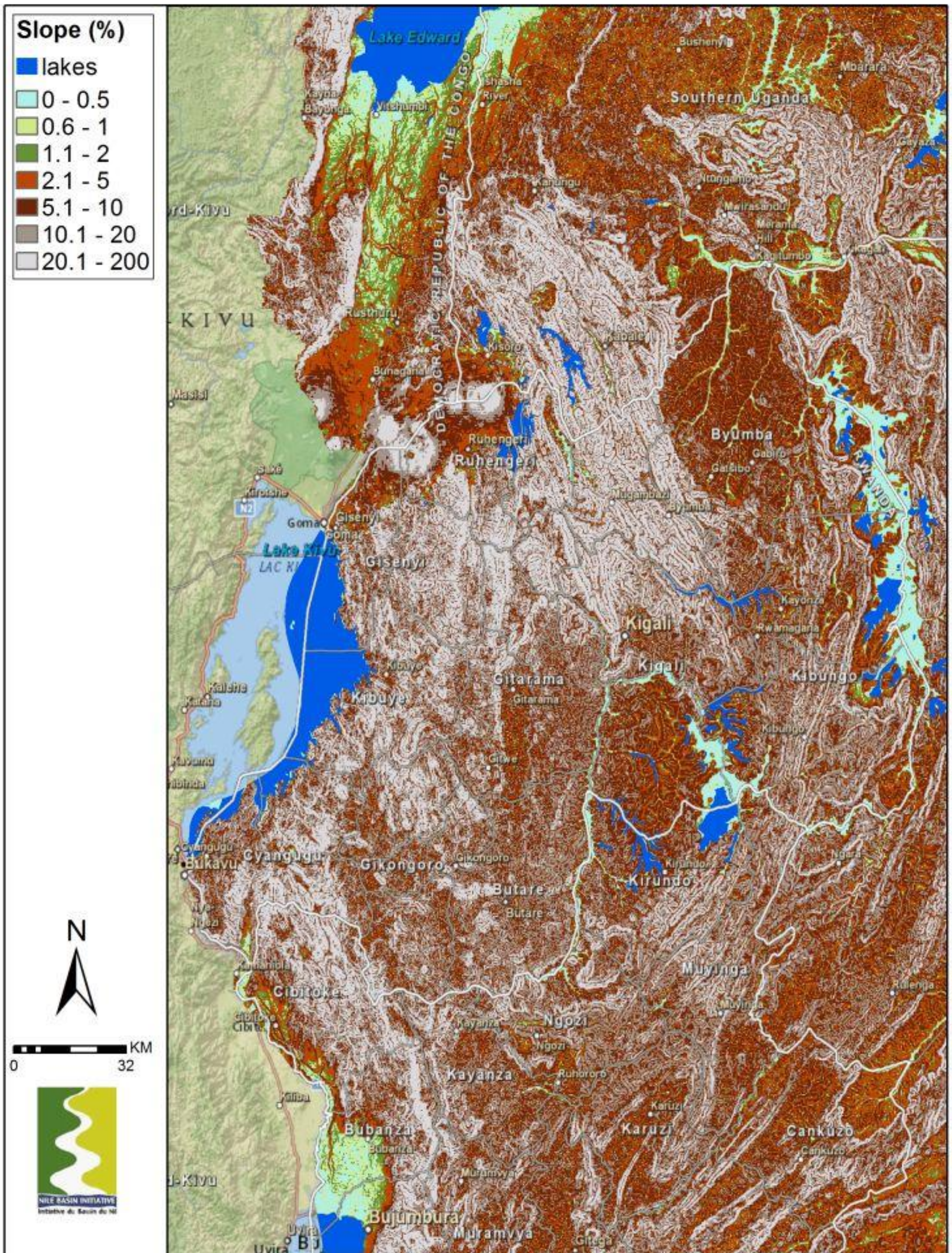


Figure 3: Digital Elevation Model of Rwanda. (Source: ASTER)

In Figure 3 the DEM for Rwanda is shown. The country is characterized by quite some mountains throughout the country with lower elevations in the eastern part. Associated slopes can be seen in Figure 4. Based on these slope classes for each of the three irrigation types, suitability for irrigation has been determined. It is clear that suitability for surface irrigation is very much restricted to some local areas given steep slopes in the country.



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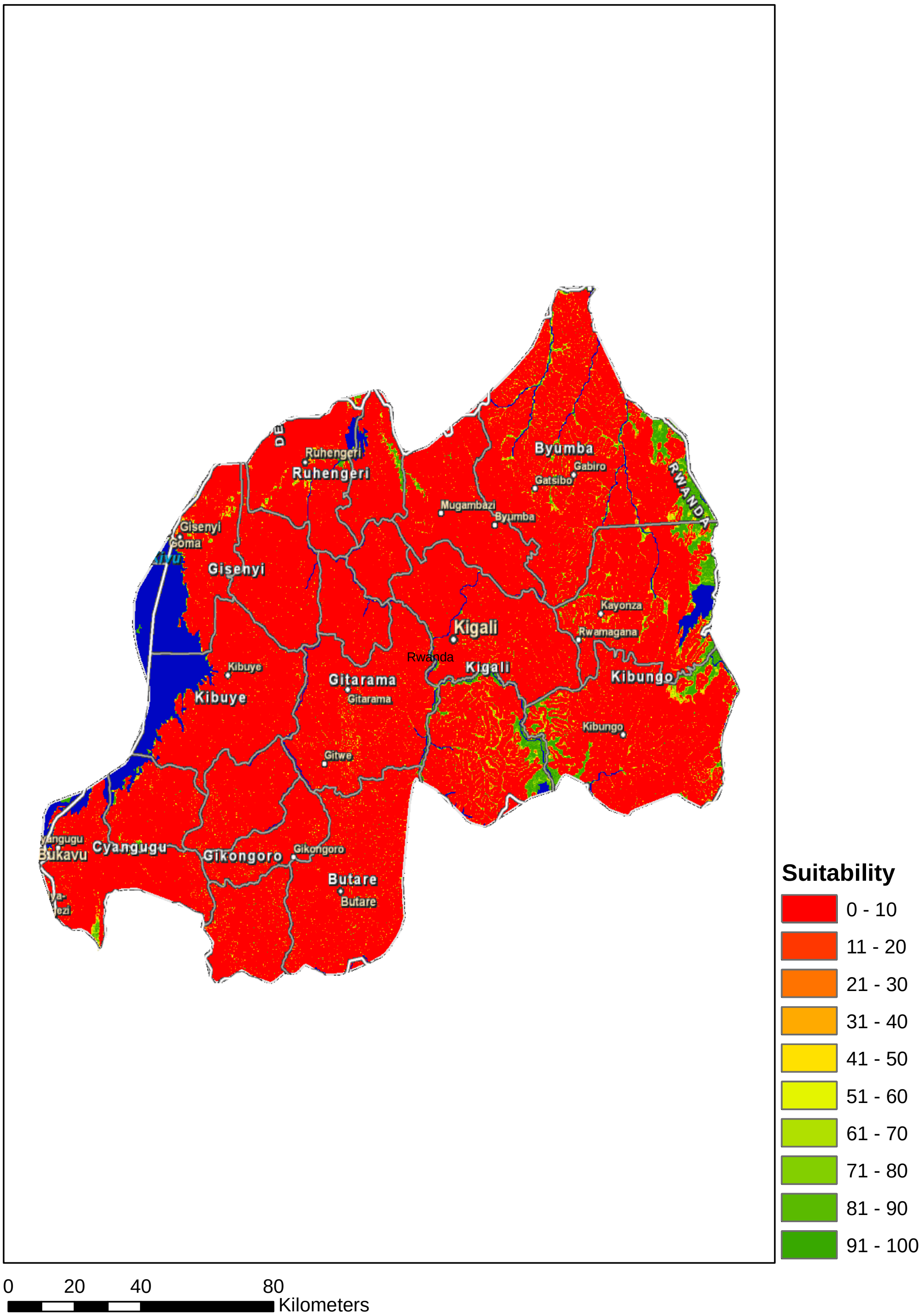
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Cyangugu
Bukavu
Gikongoro
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Butare
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Suitability
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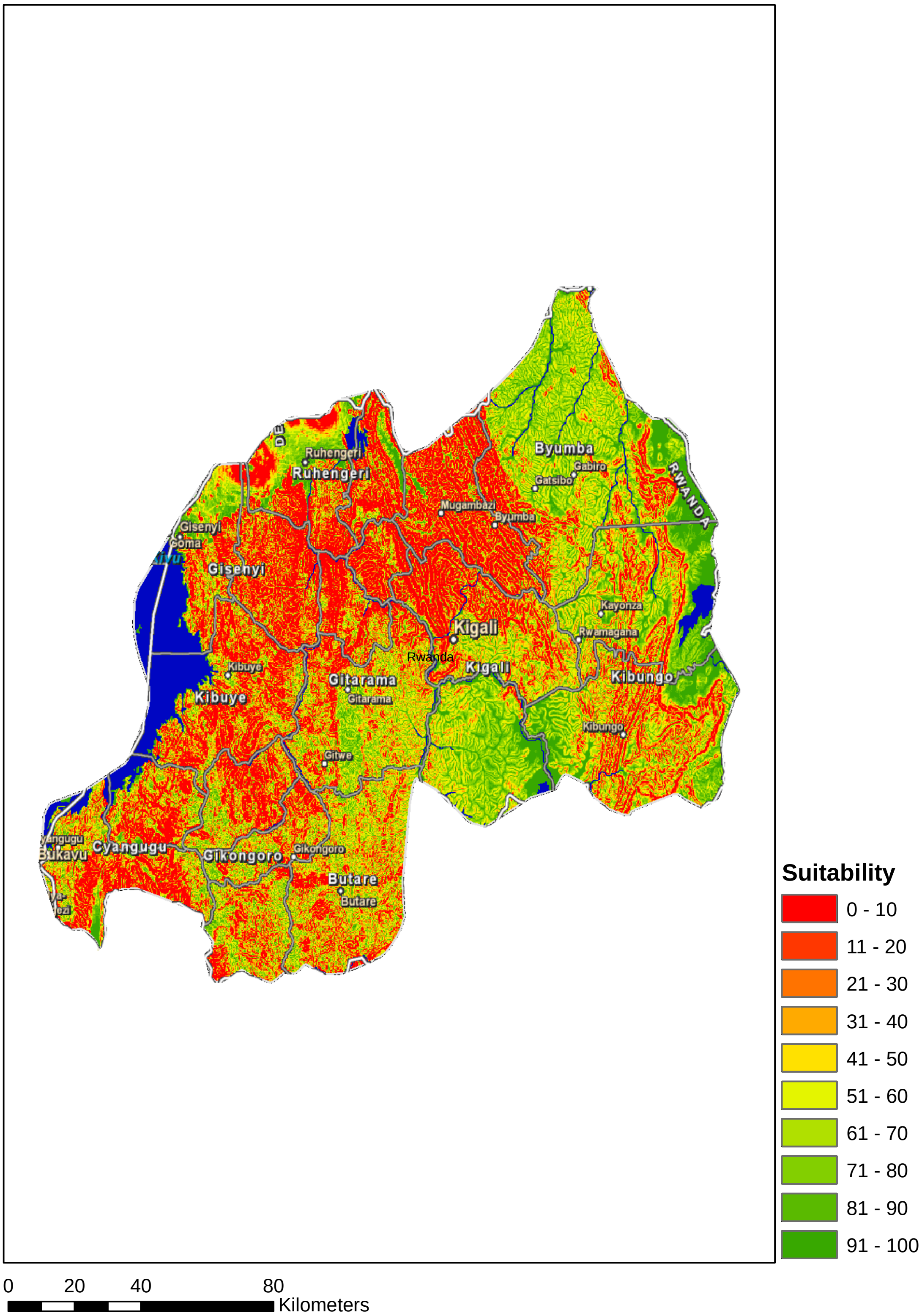
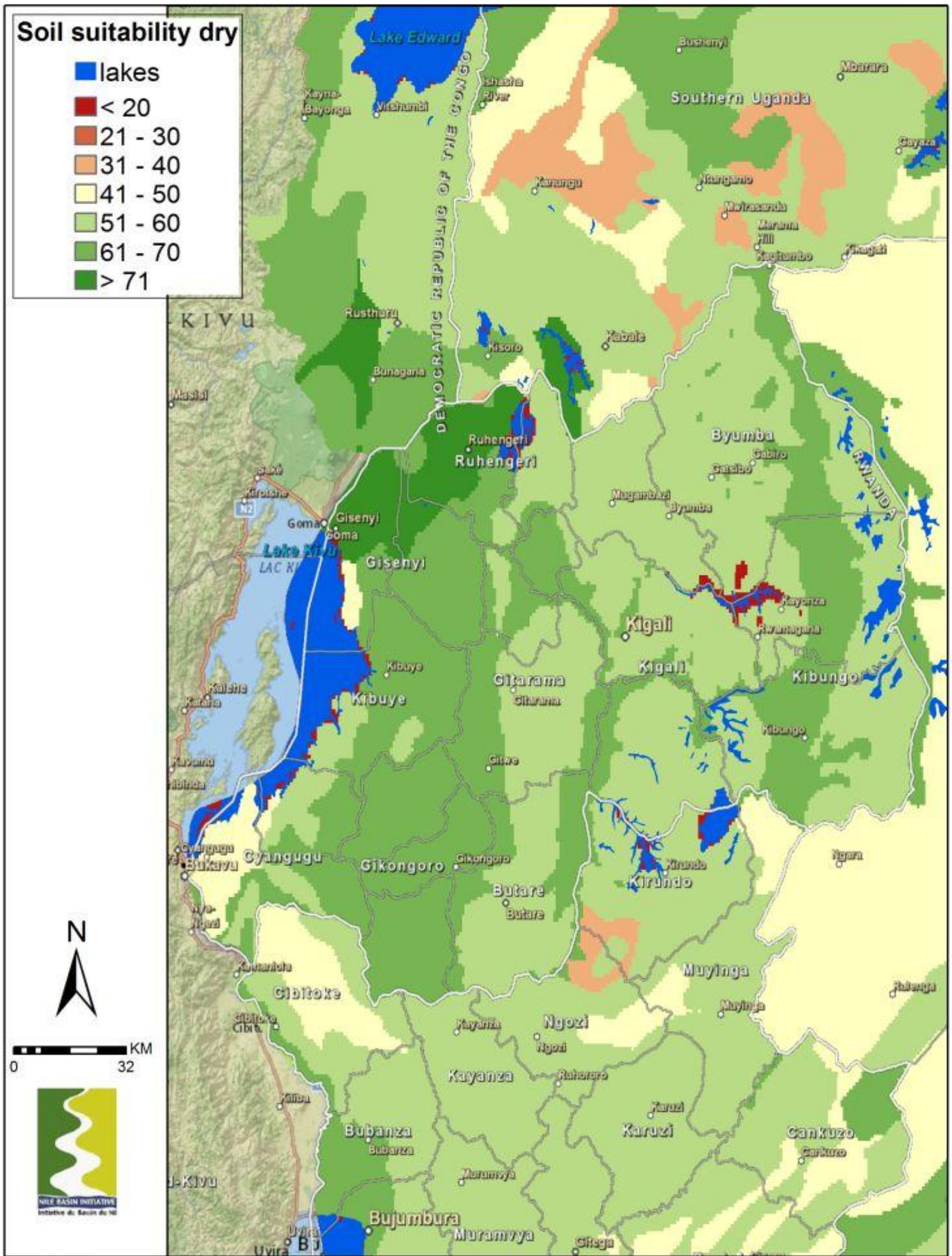


Figure 4: Terrain slope as percentage (top), surface irrigation (middle), and drip irrigation (bottom).

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.

It is clear that soils in Rwanda are by enlarge reasonable suitable to develop irrigation based on soil characteristics. Salinity problems are very rear in the country according to the soil map.



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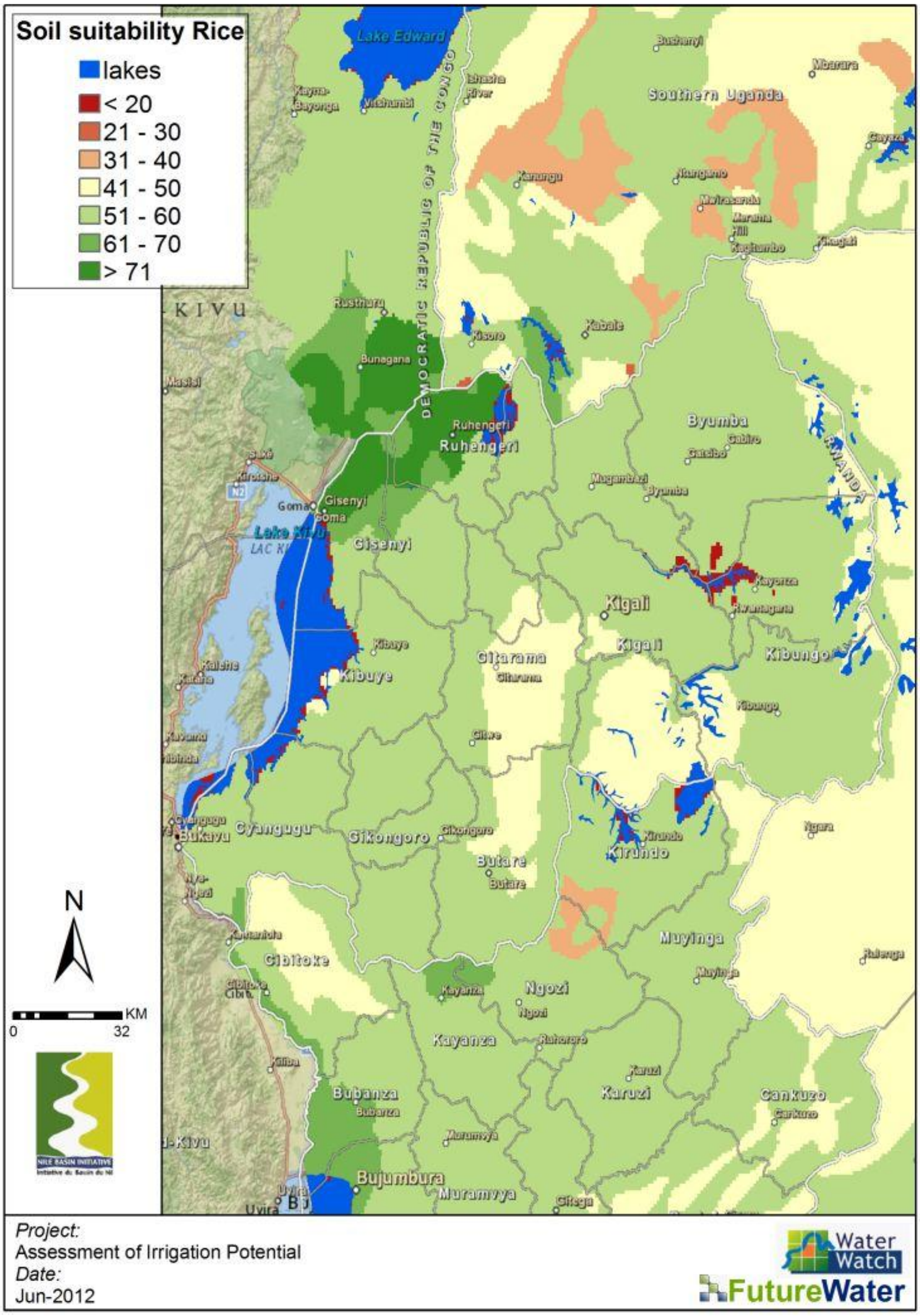


Figure 5: Soil suitability for dry crops (top) and rice/paddy (bottom) (Source: study analysis)

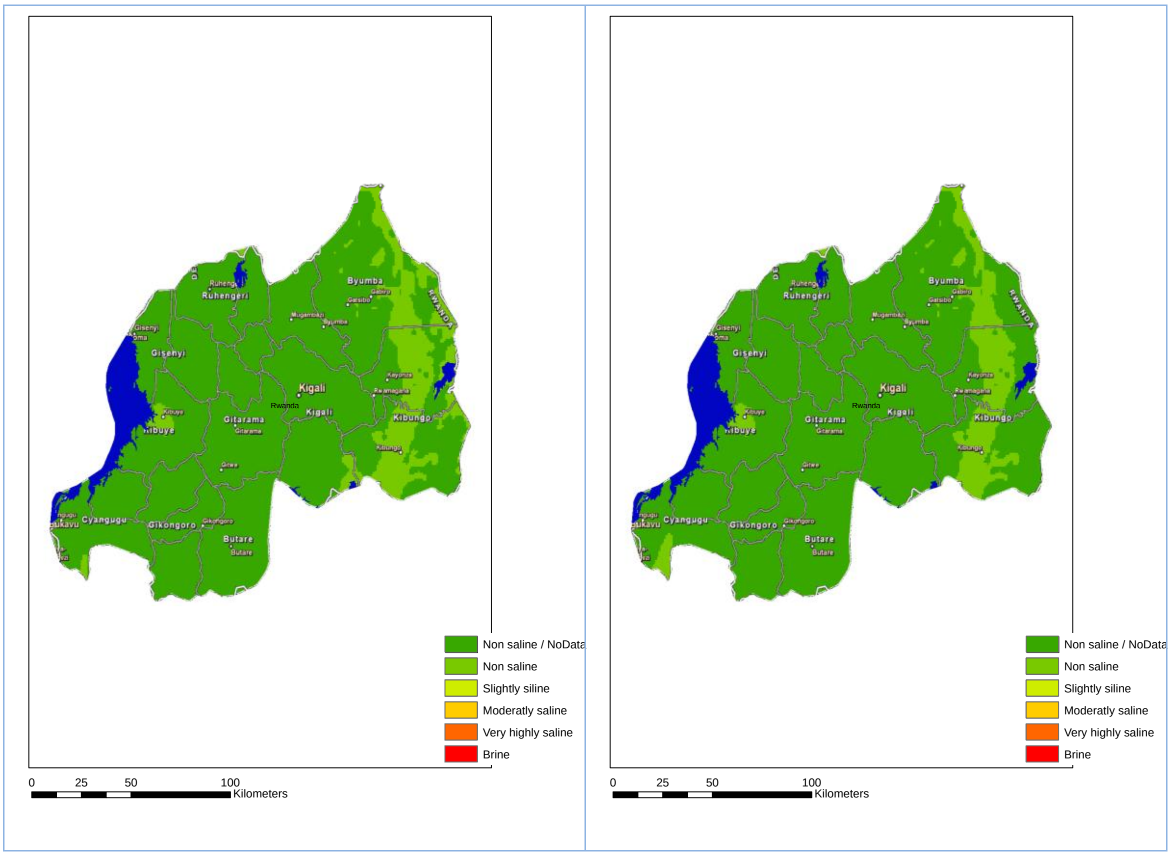


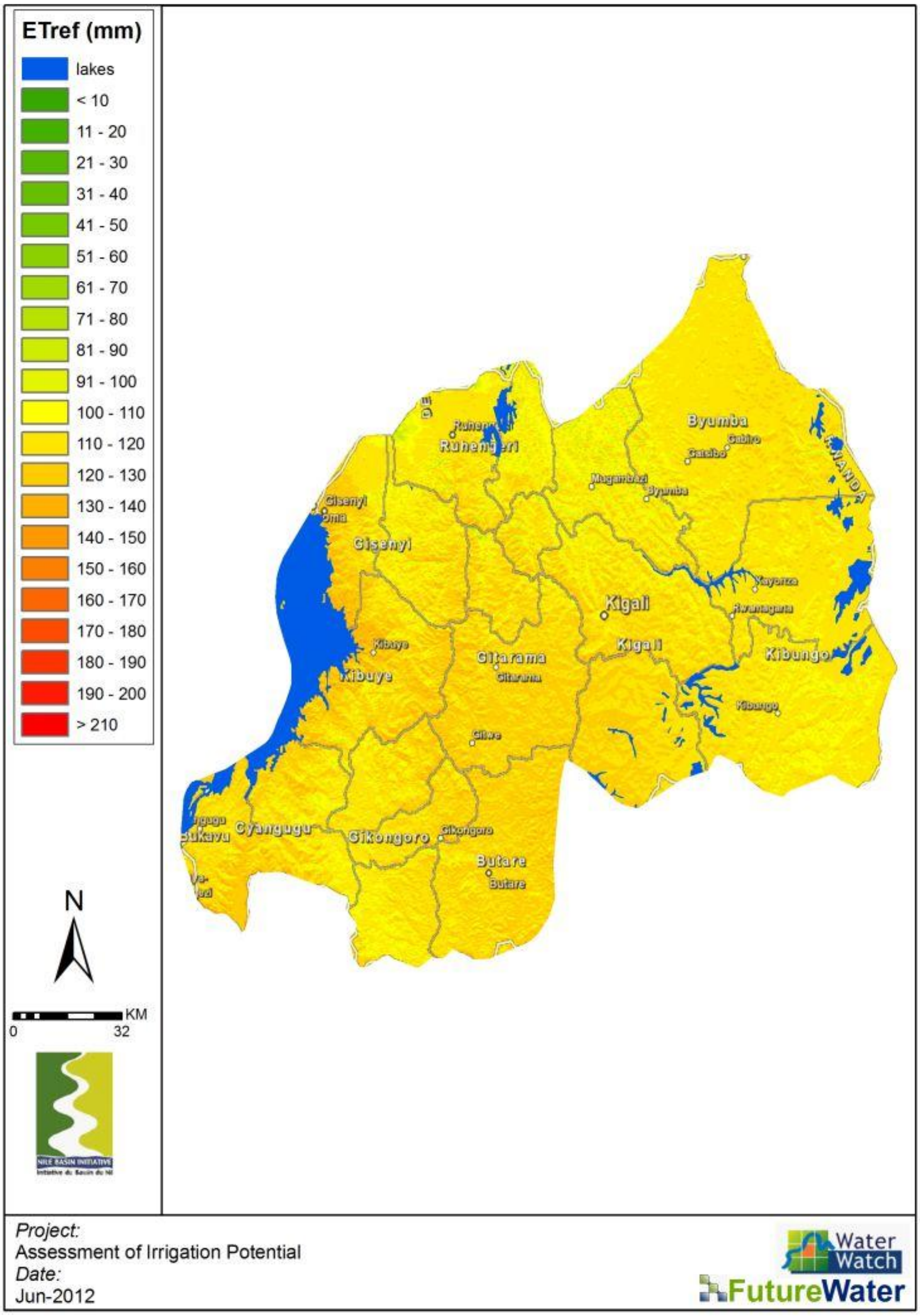
Figure 6: Salinity, top-soil (left) and sub-soil (right). (Source: study analysis).

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



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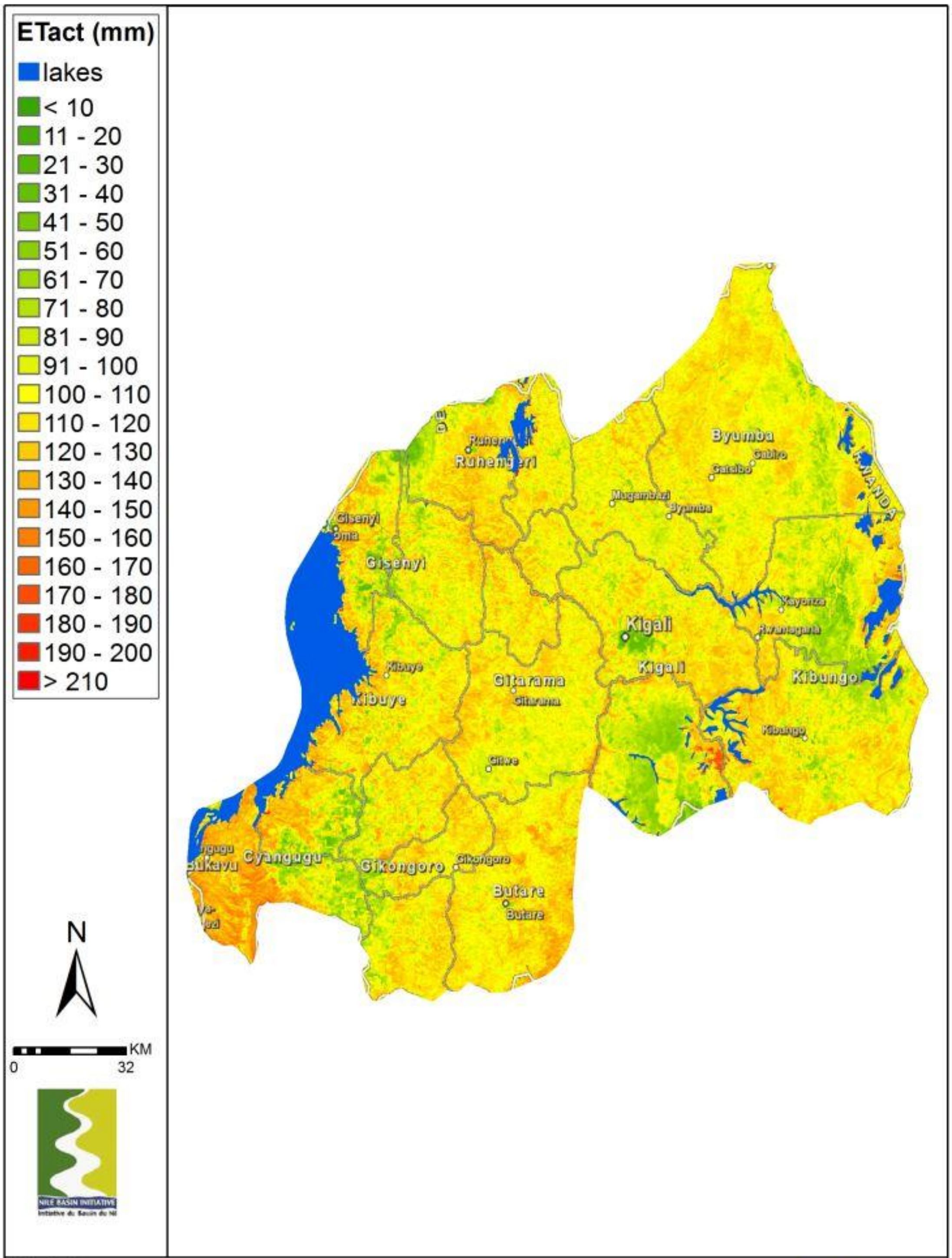

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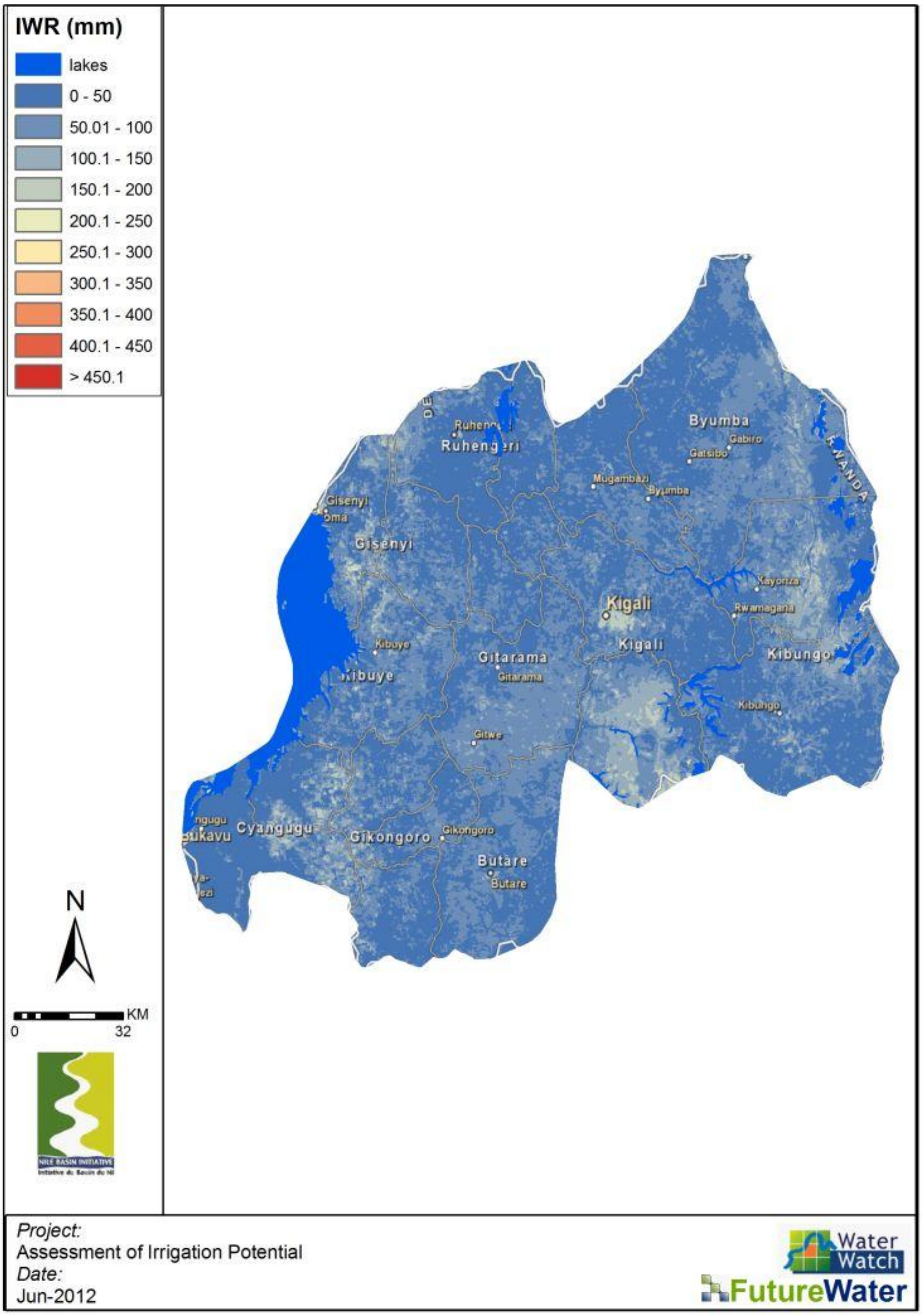
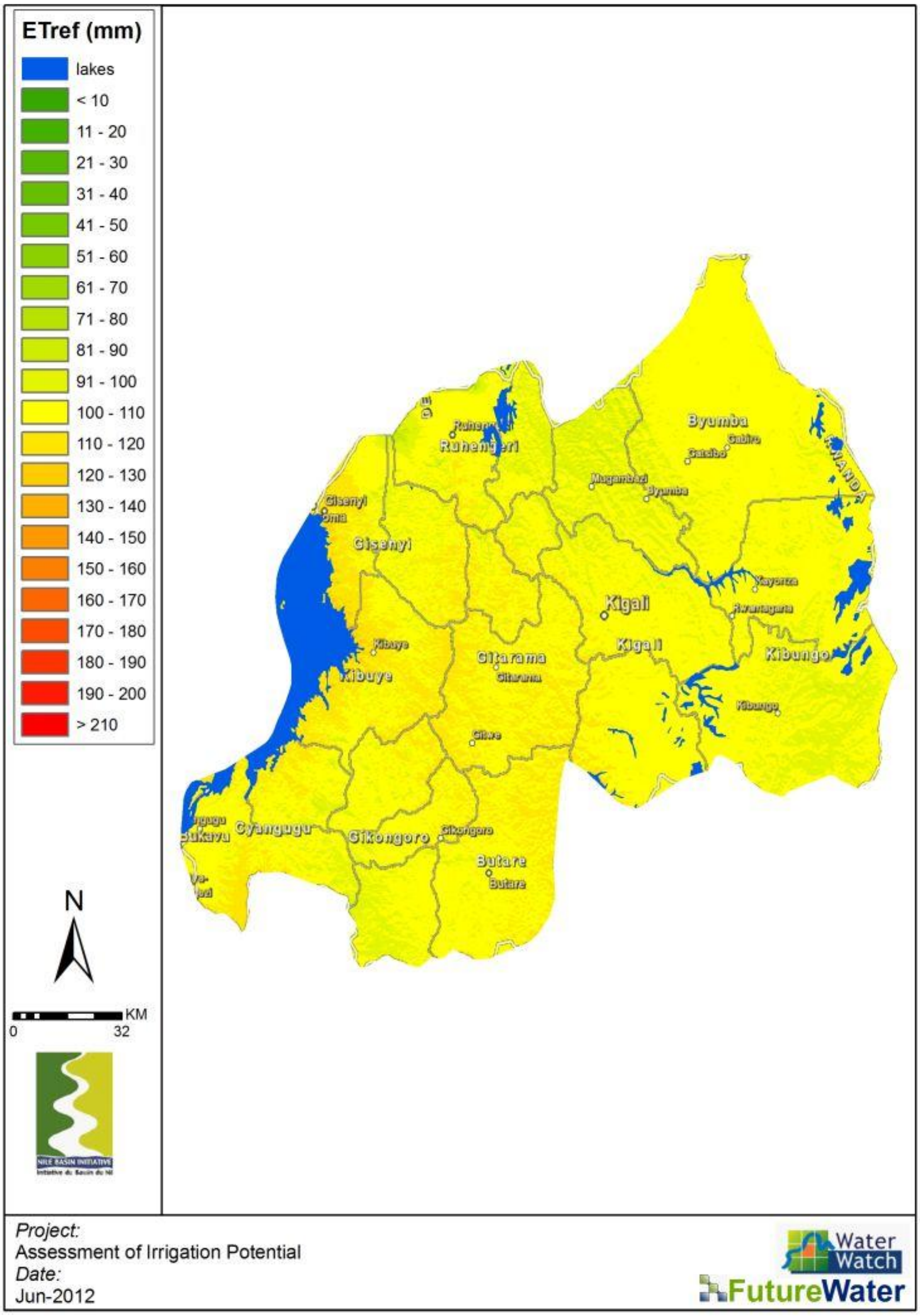


Figure 7: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). for January (Average 2001-2010). (Source: study analysis).

February



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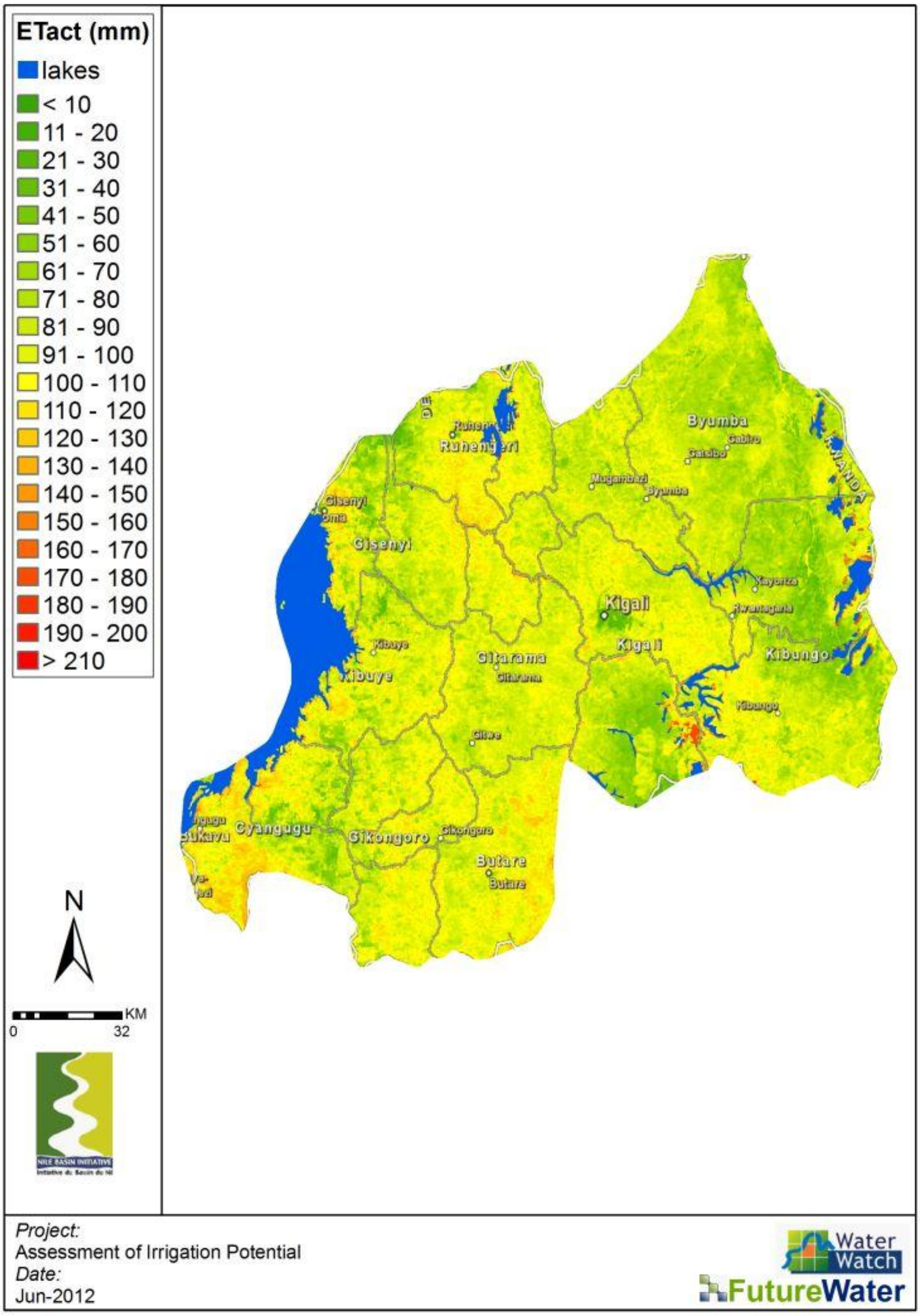
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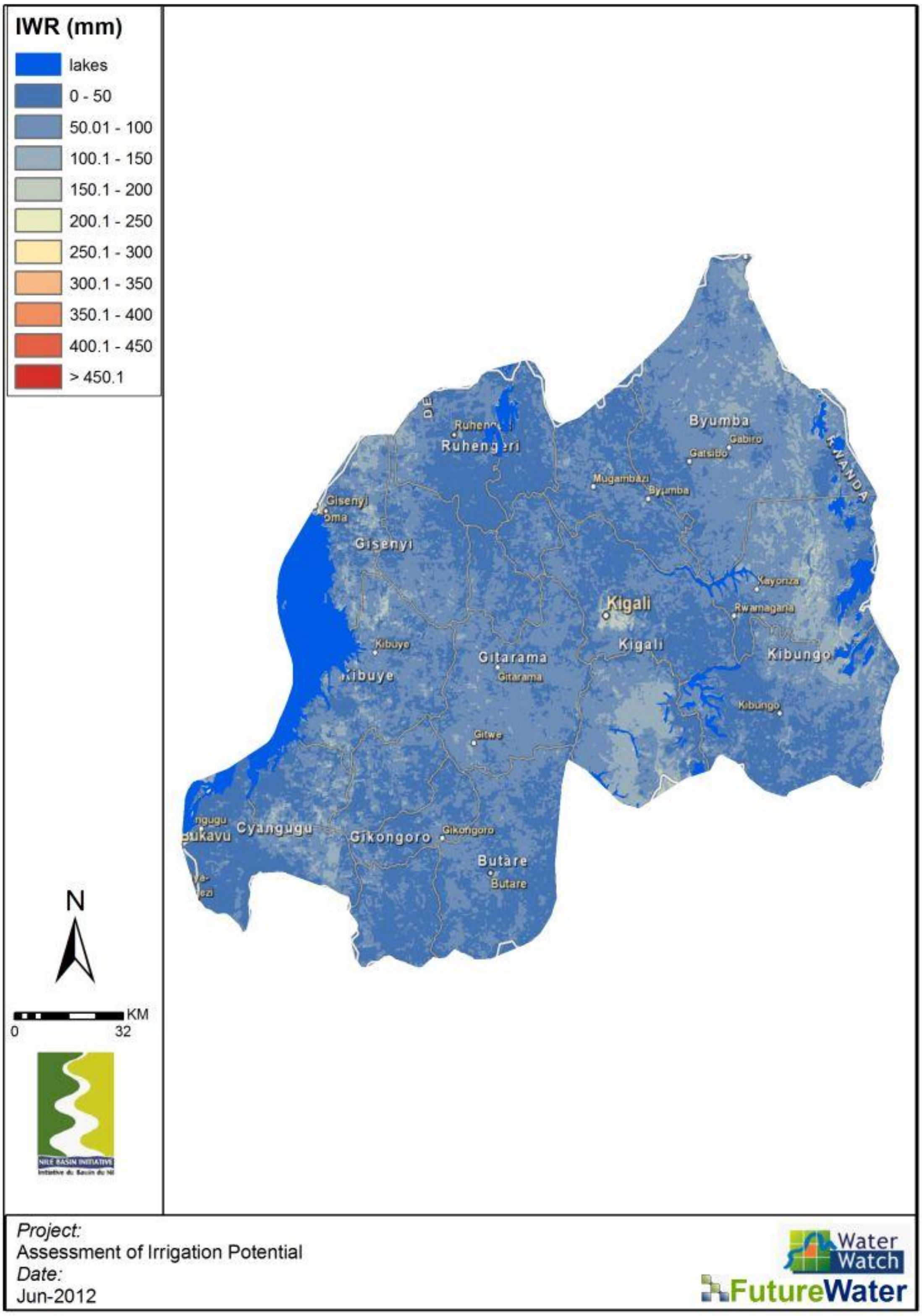
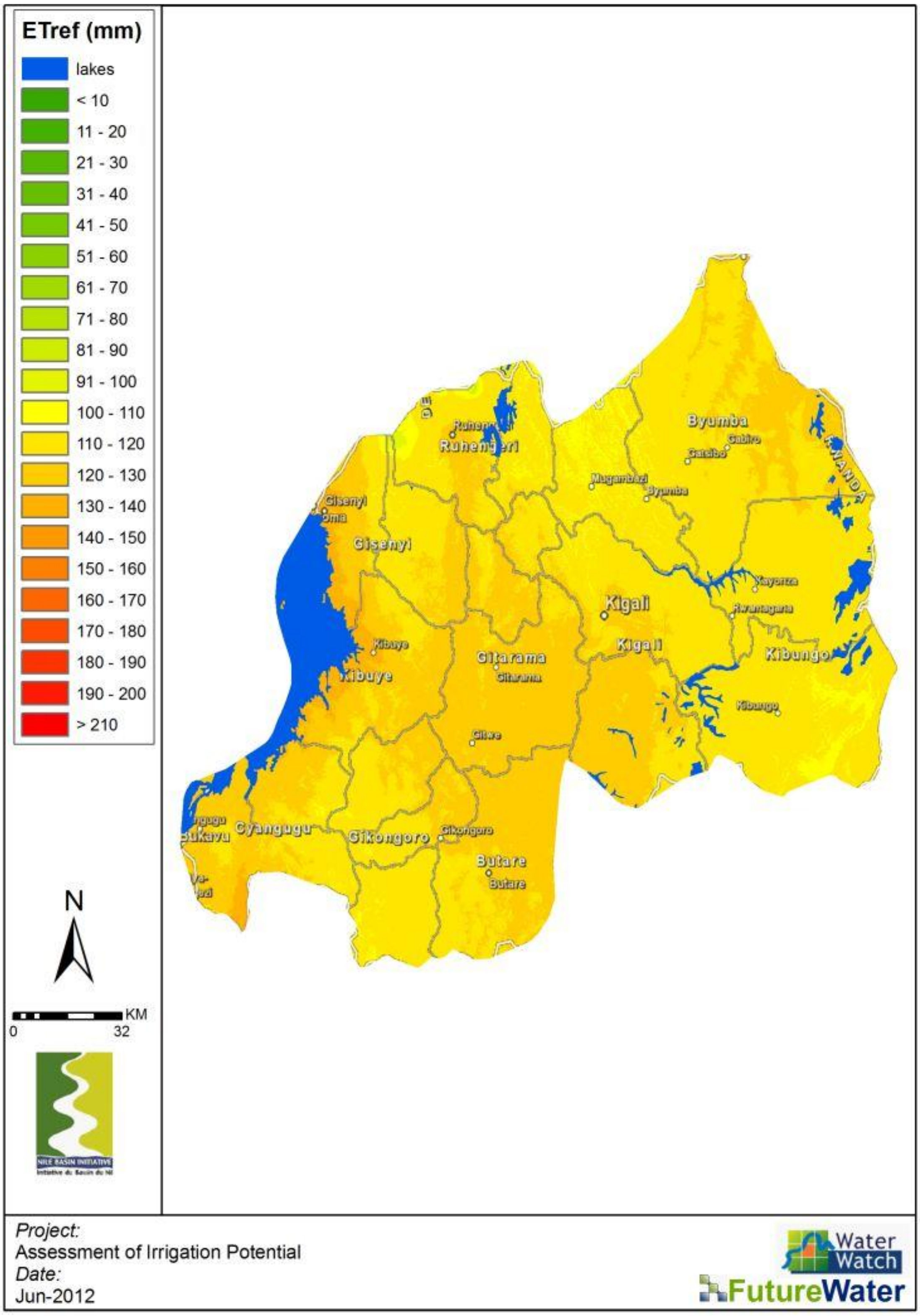


Figure 8: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). for February (Average 2001-2010). (Source: study analysis).

March



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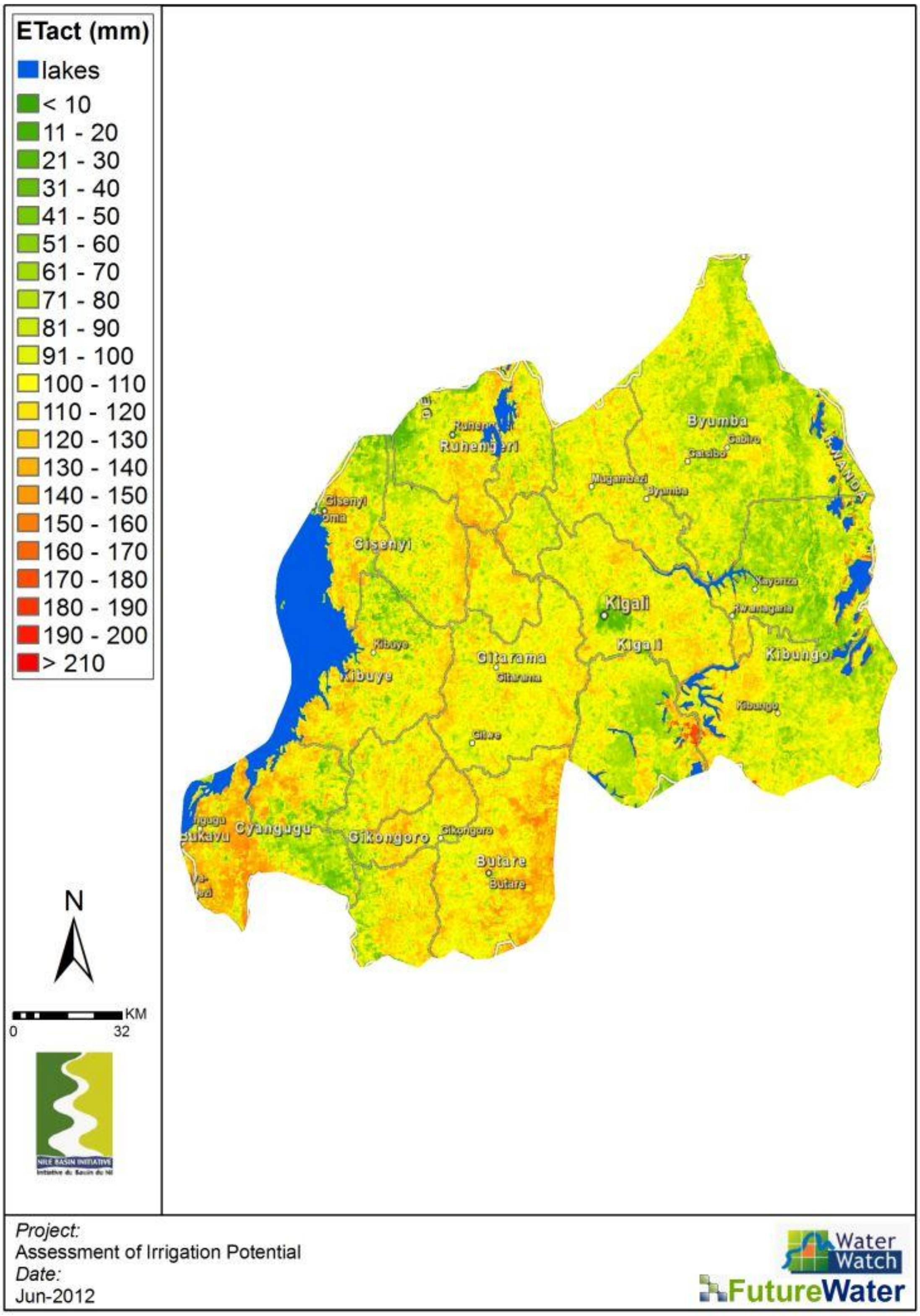
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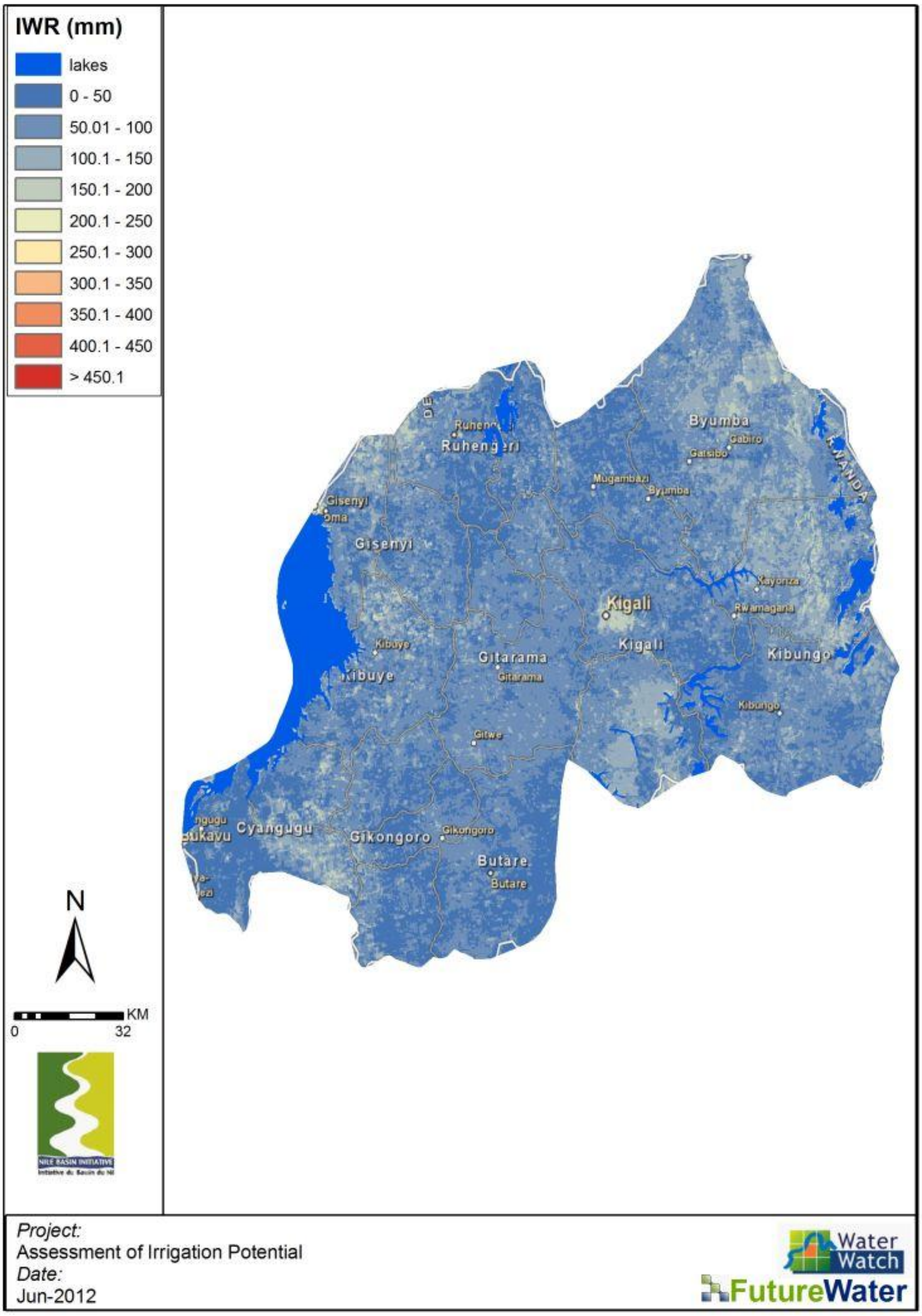
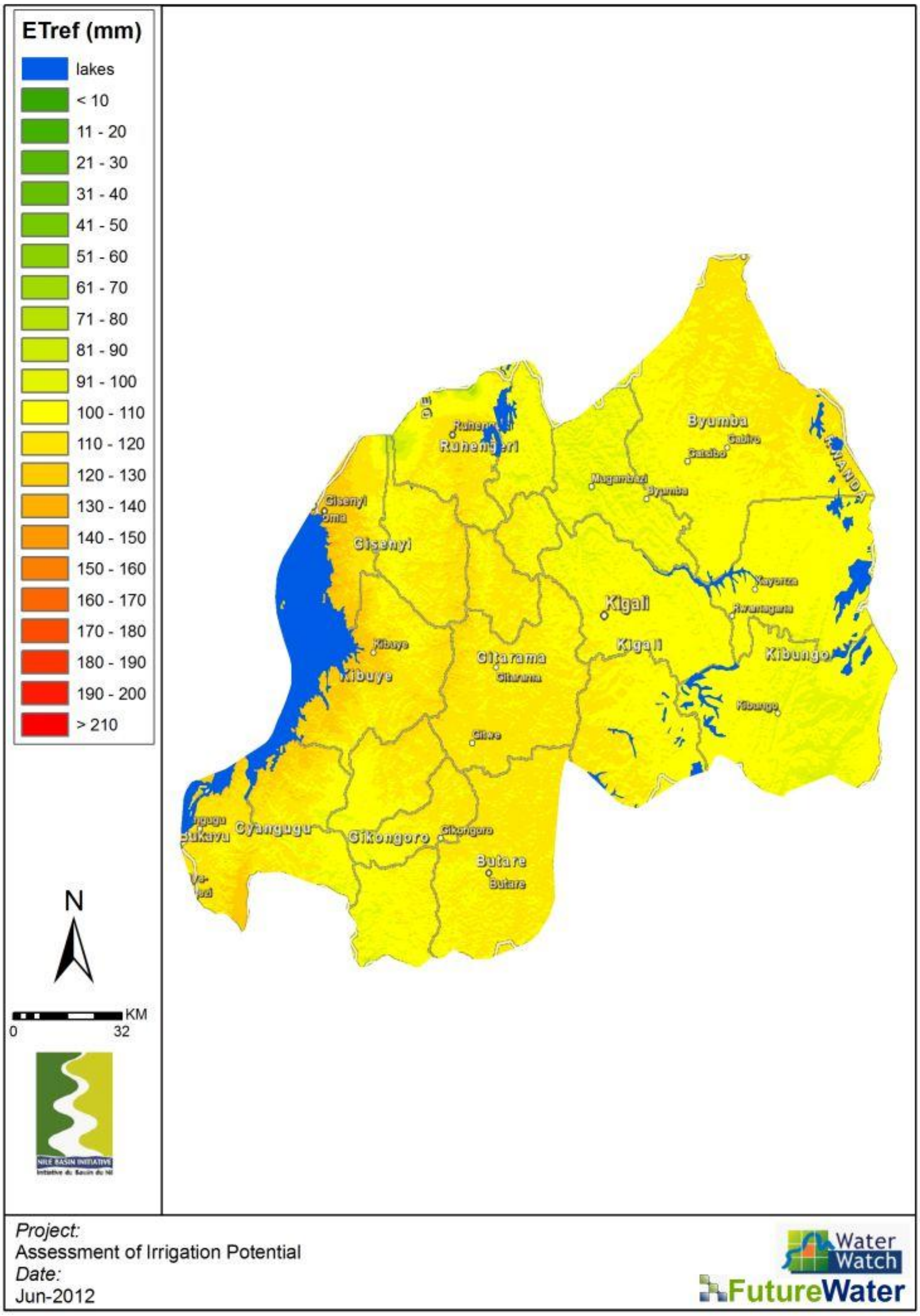


Figure 9: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). for March (Average 2001-2010). (Source: study analysis).

April



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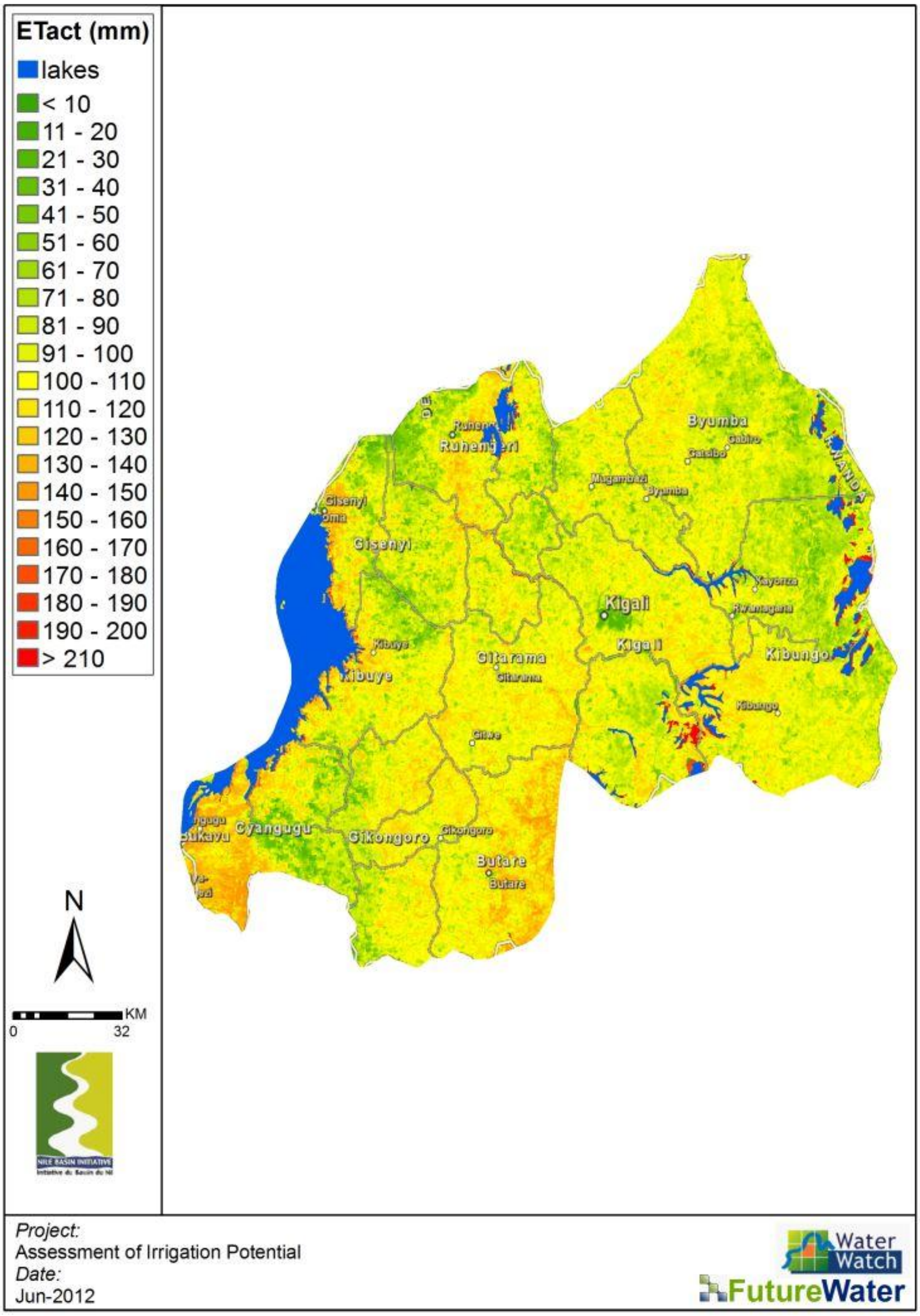
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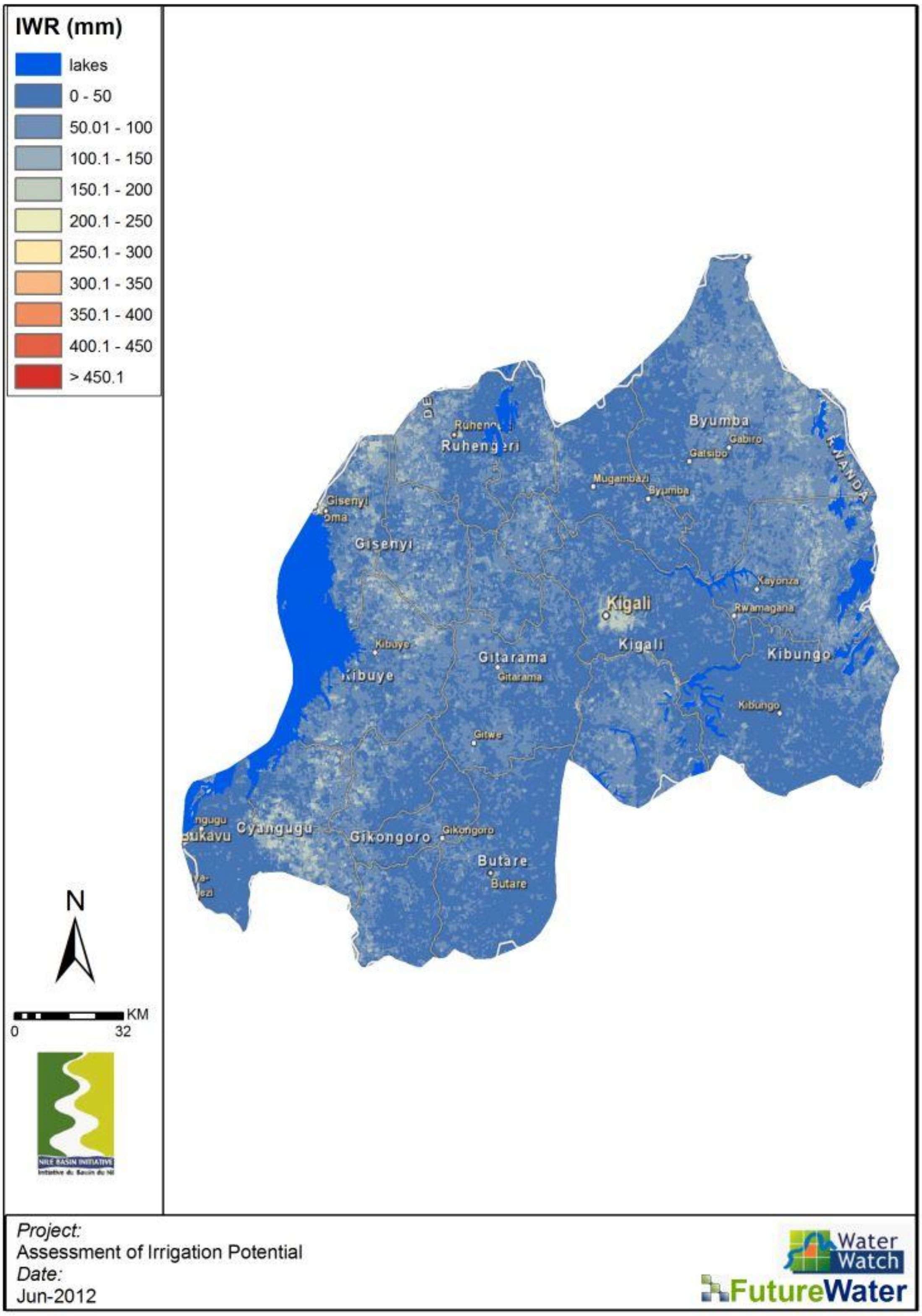
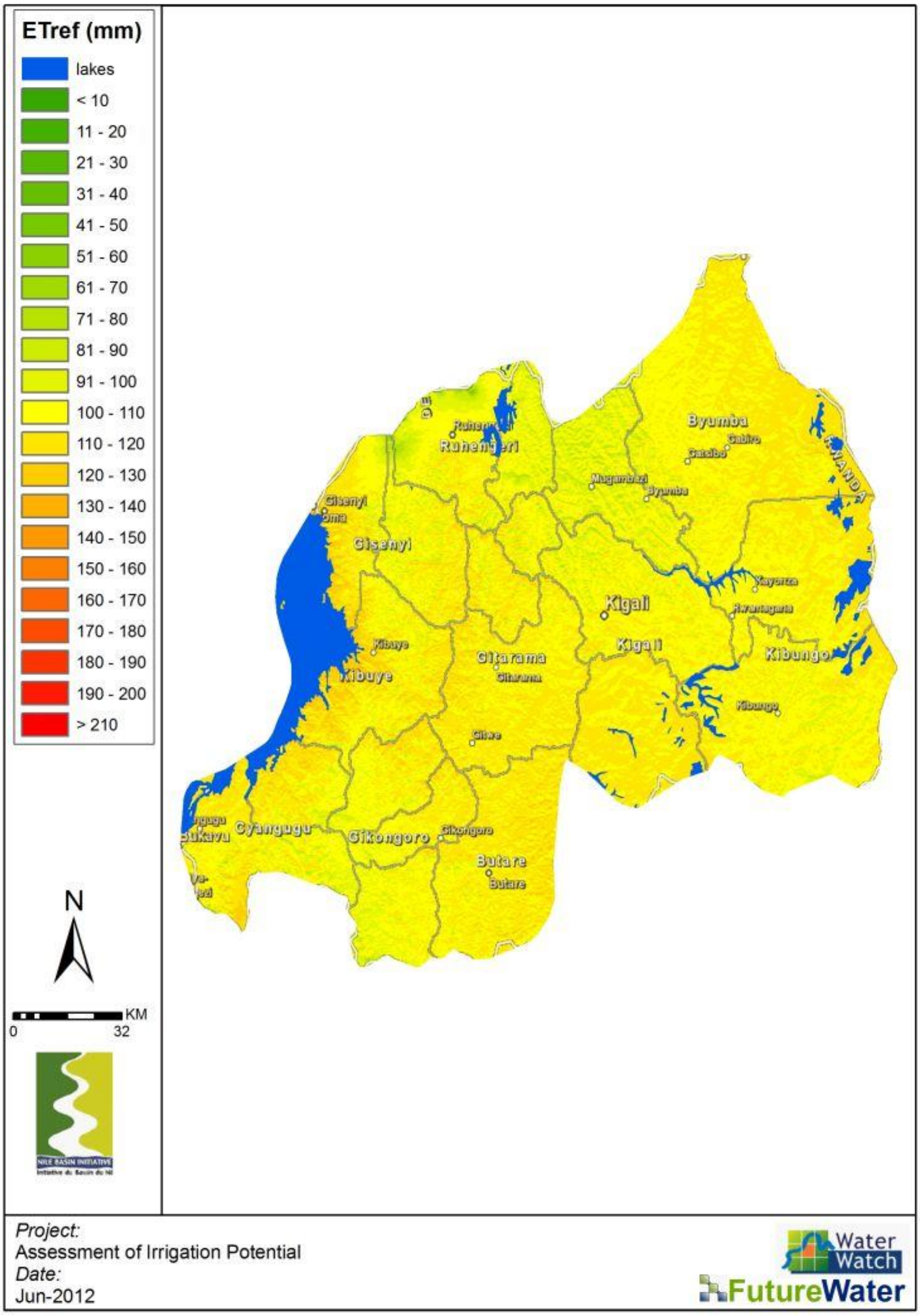


Figure 10: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). for April (Average 2001-2010). (Source: study analysis).

May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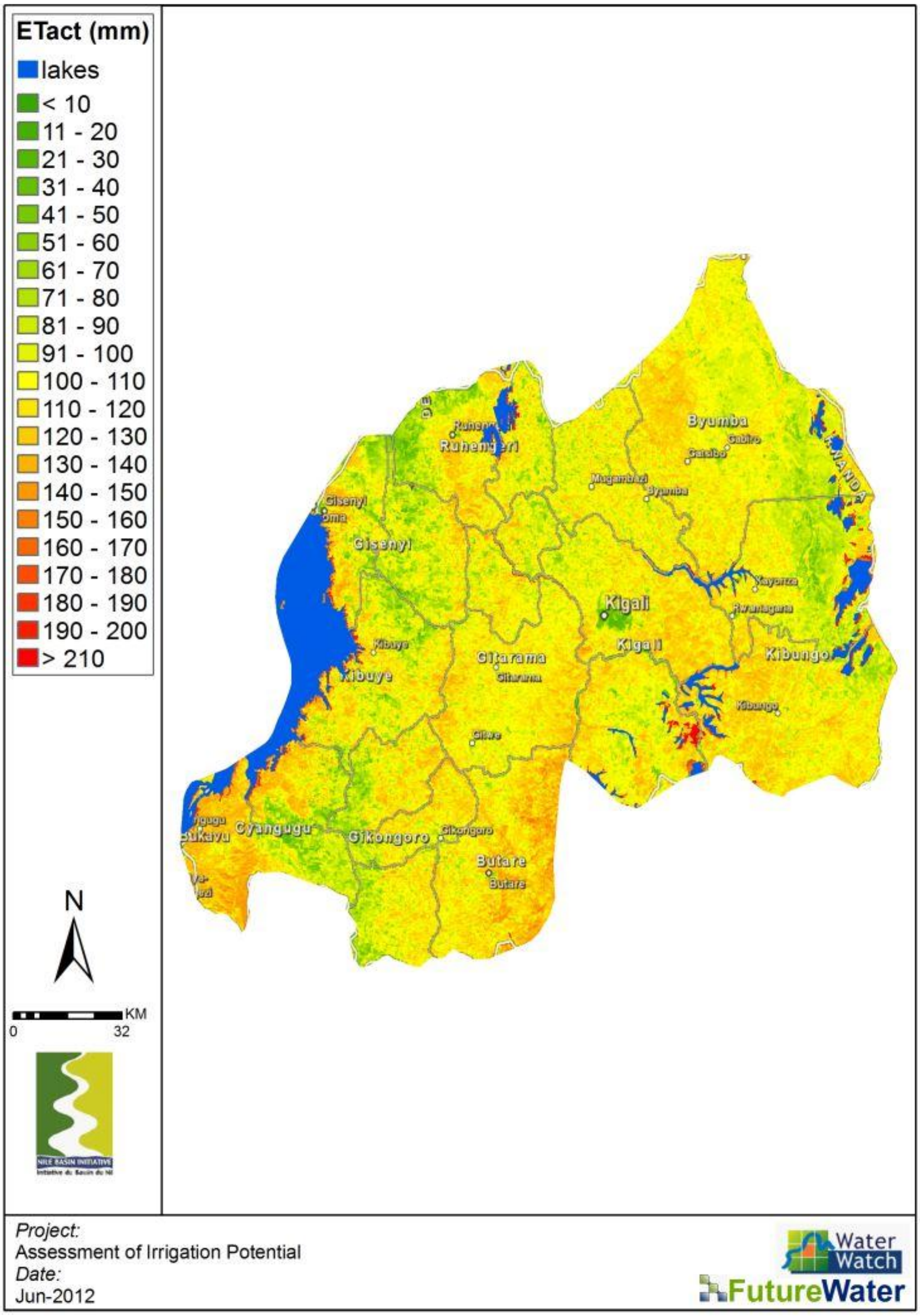

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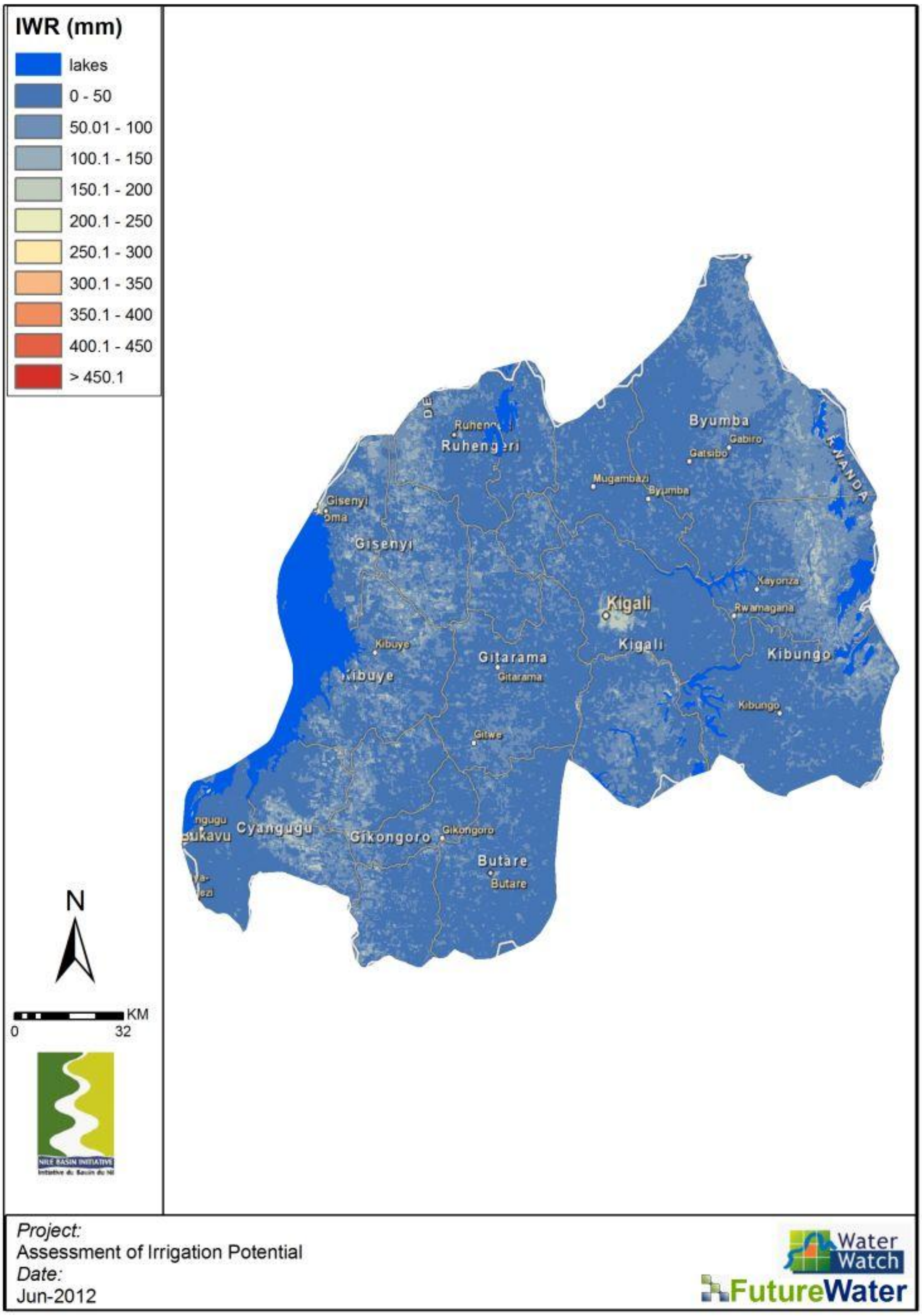
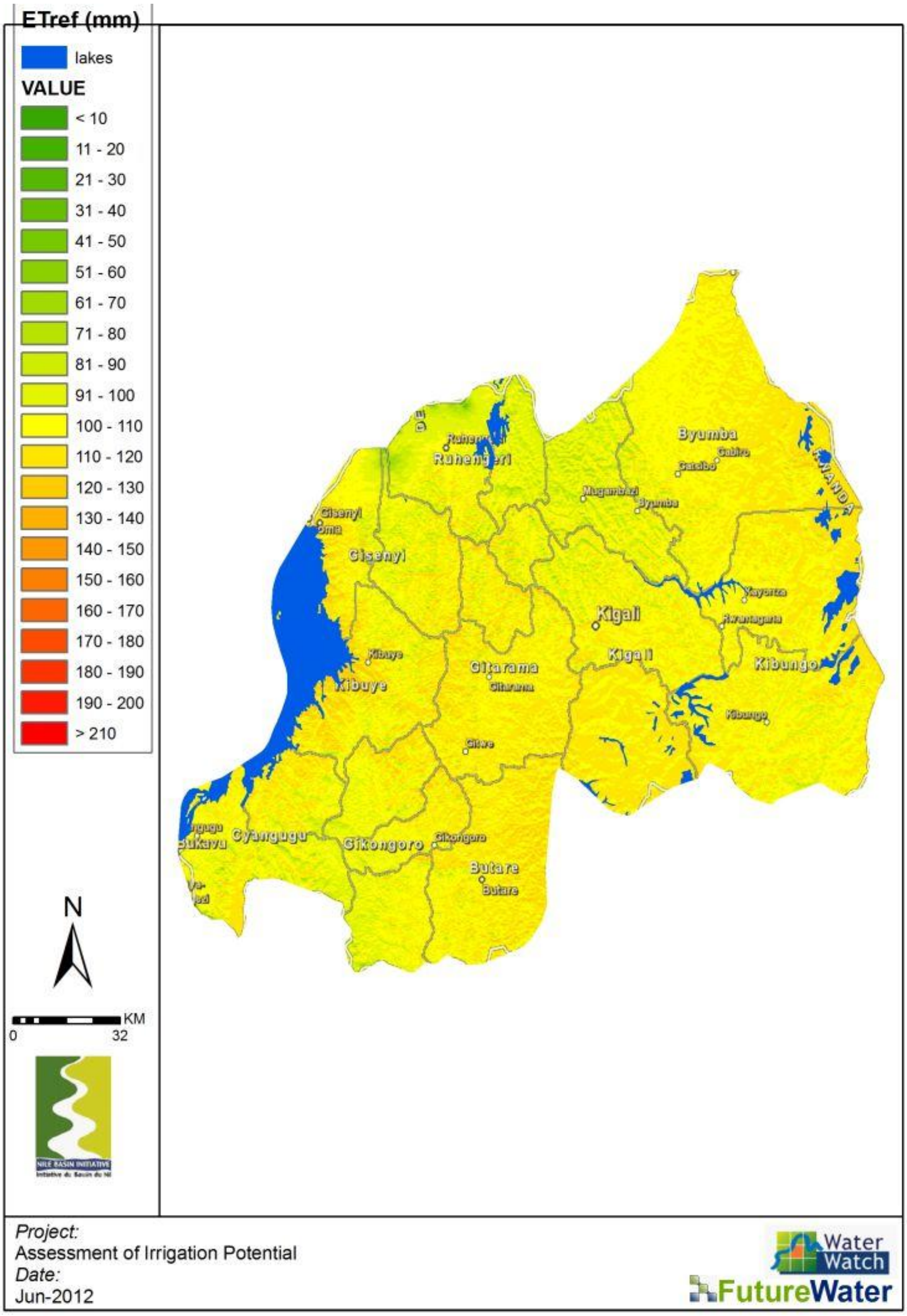


Figure 11: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for May (Average 2001-2010). (Source: study analysis).

June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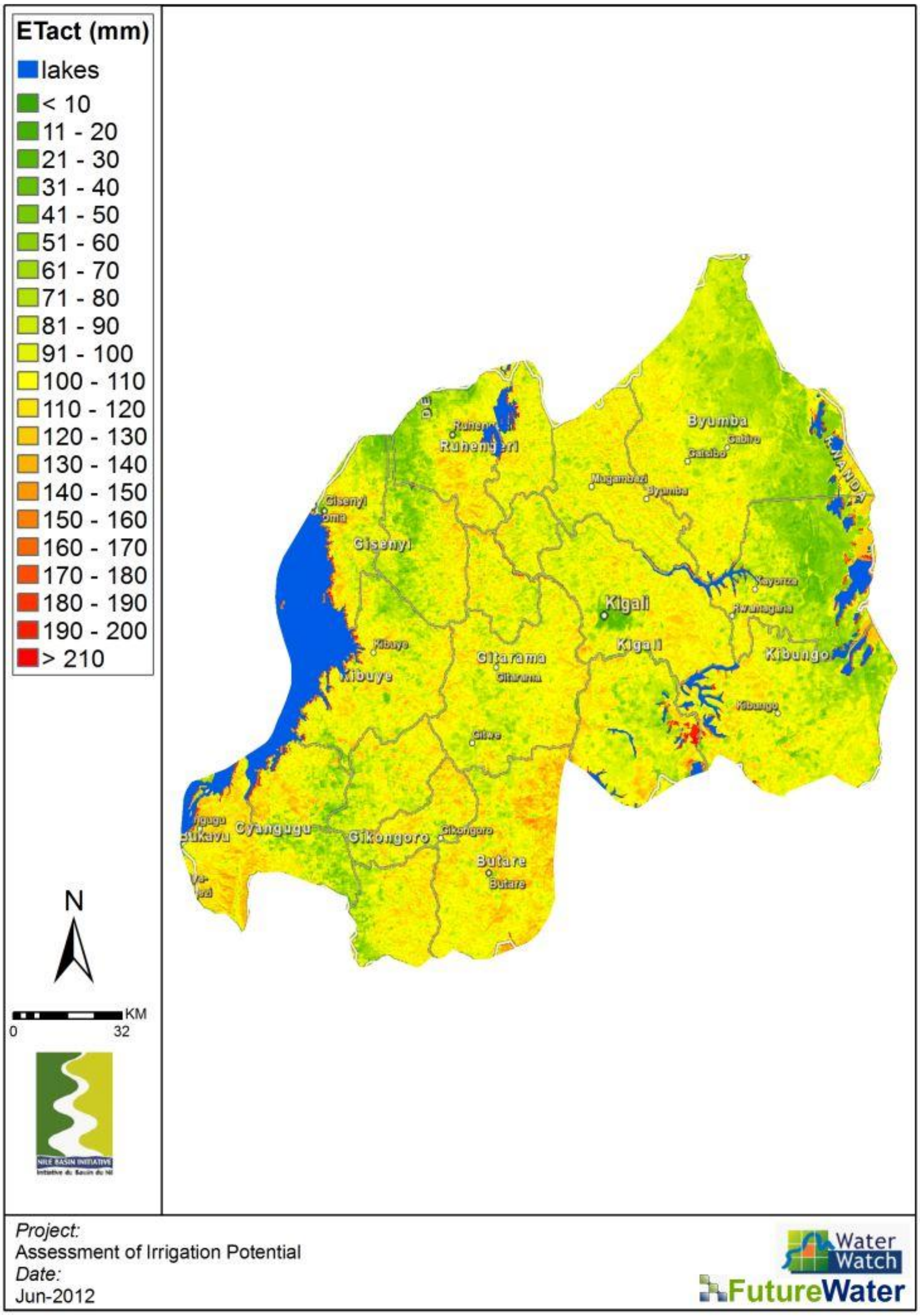
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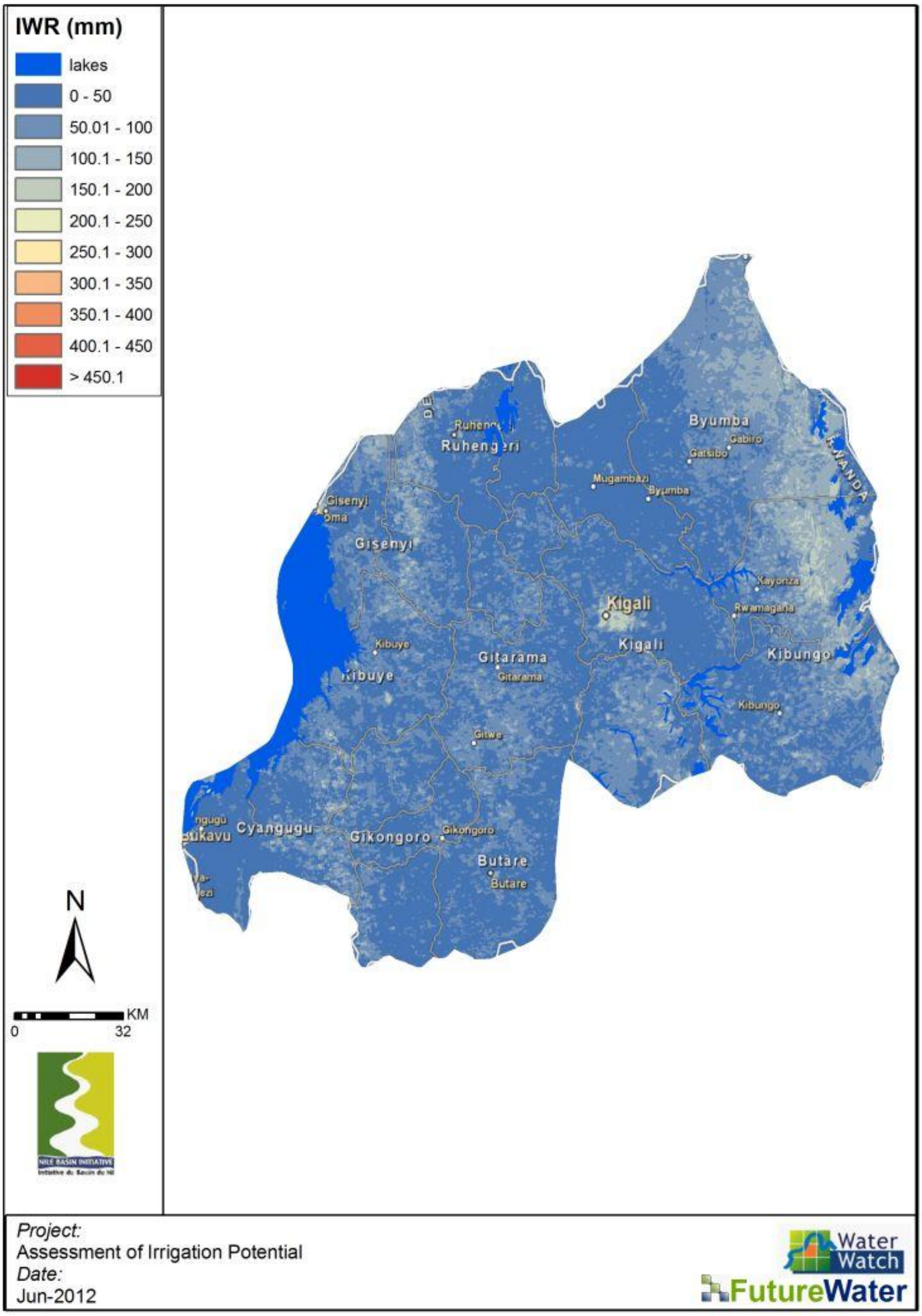
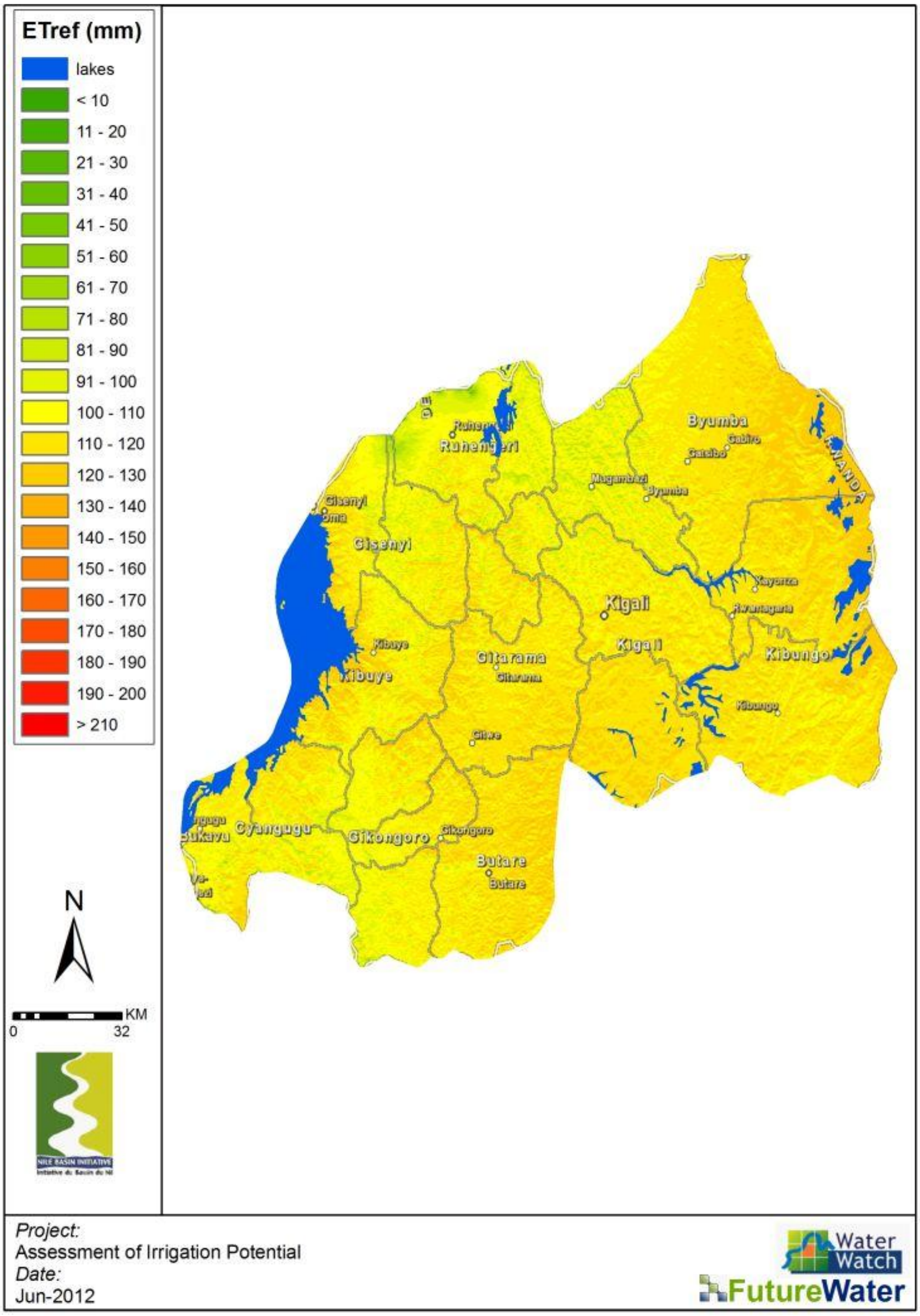


Figure 12: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom). For June (Average 2001-2010). (Source: study analysis).

July



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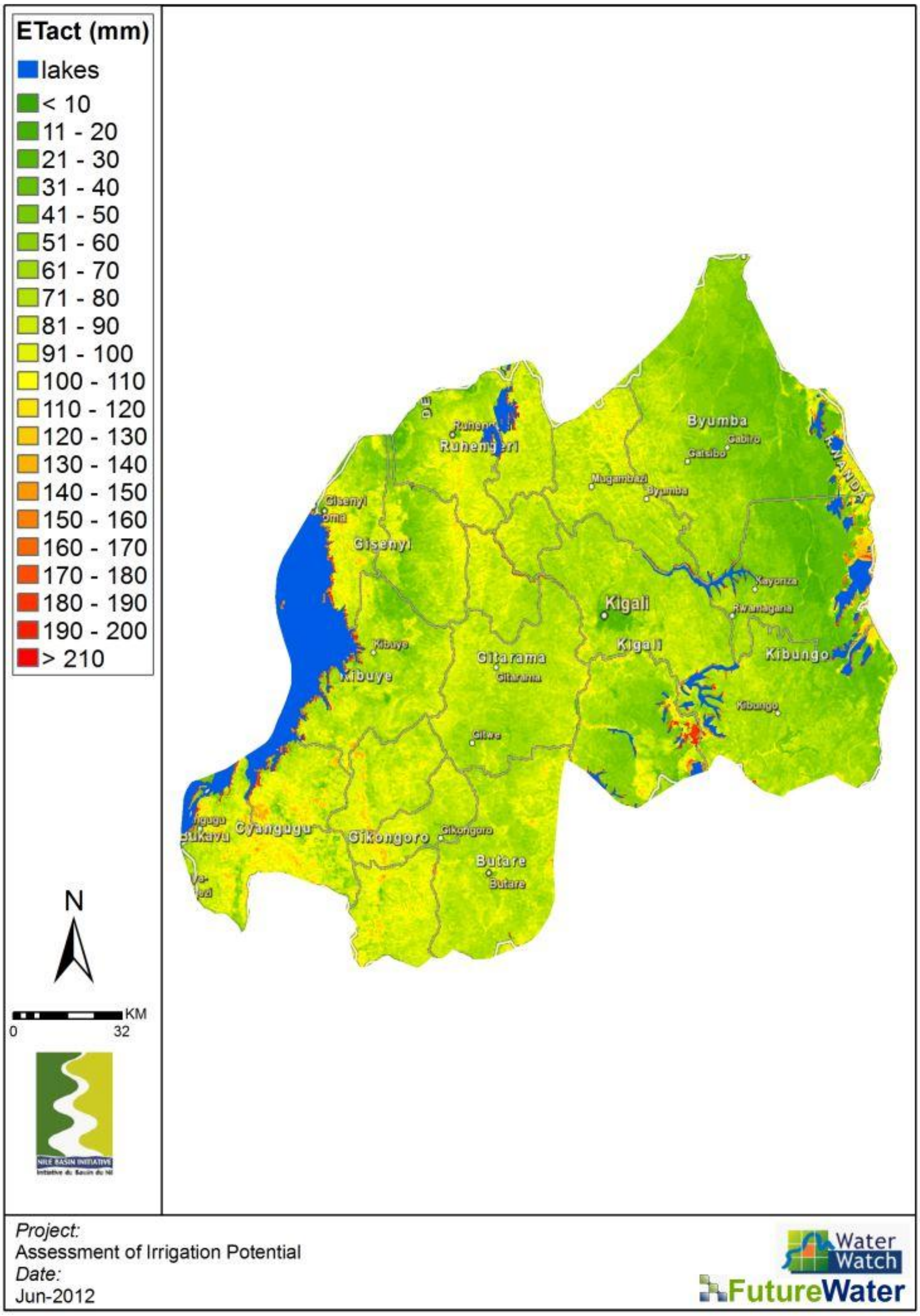
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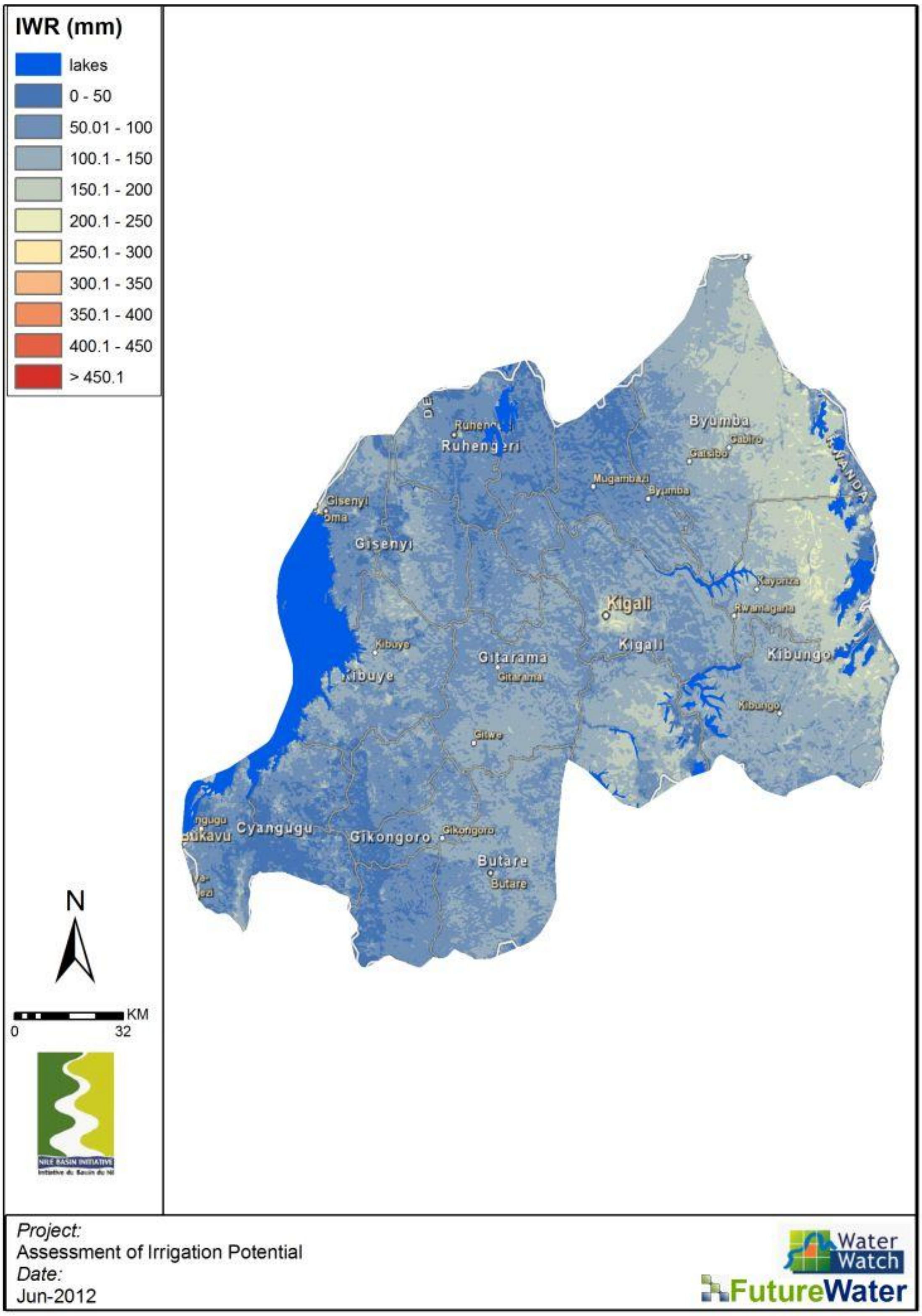
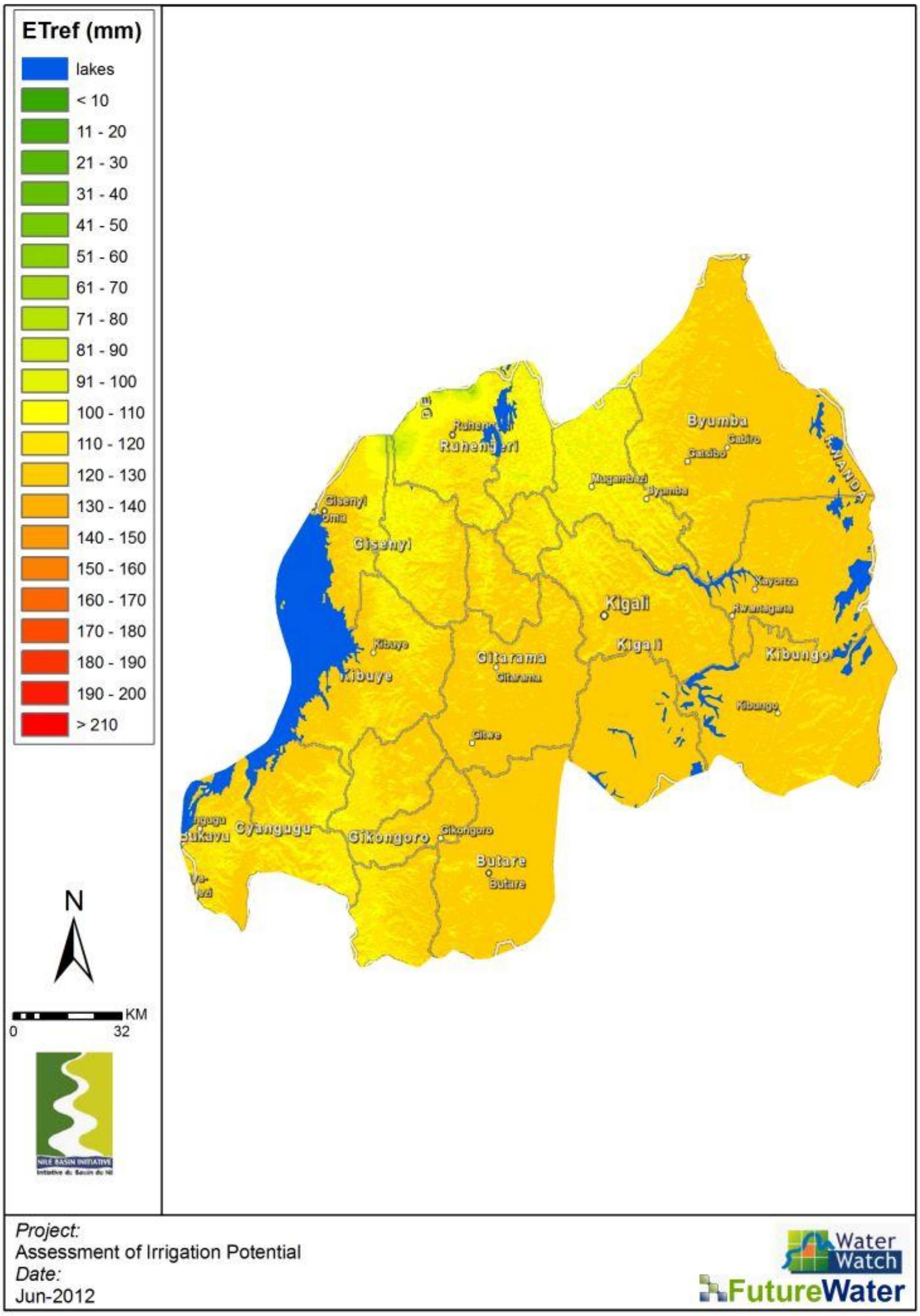


Figure 13: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for July (Average 2001-2010). (Source: study analysis).

August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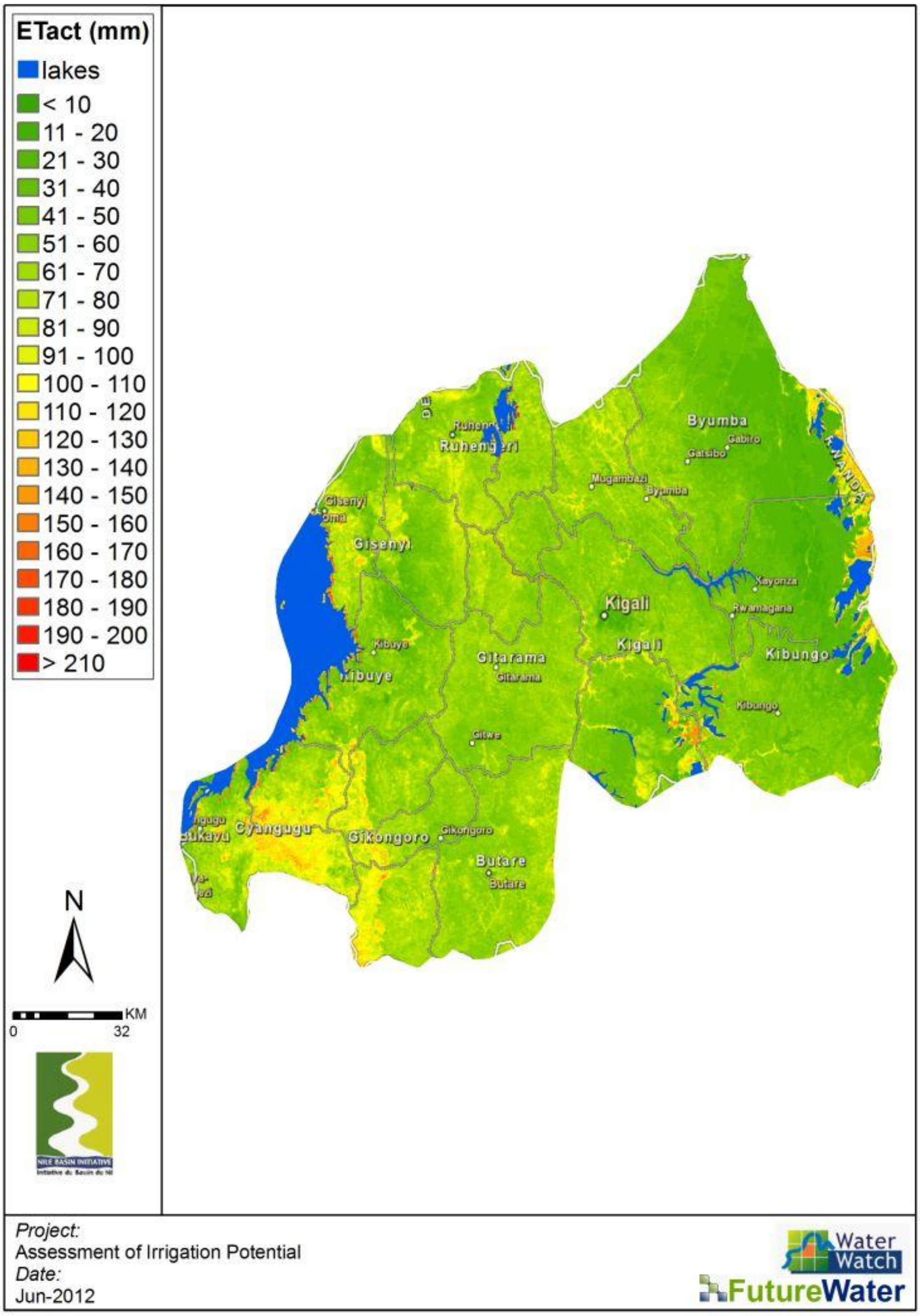
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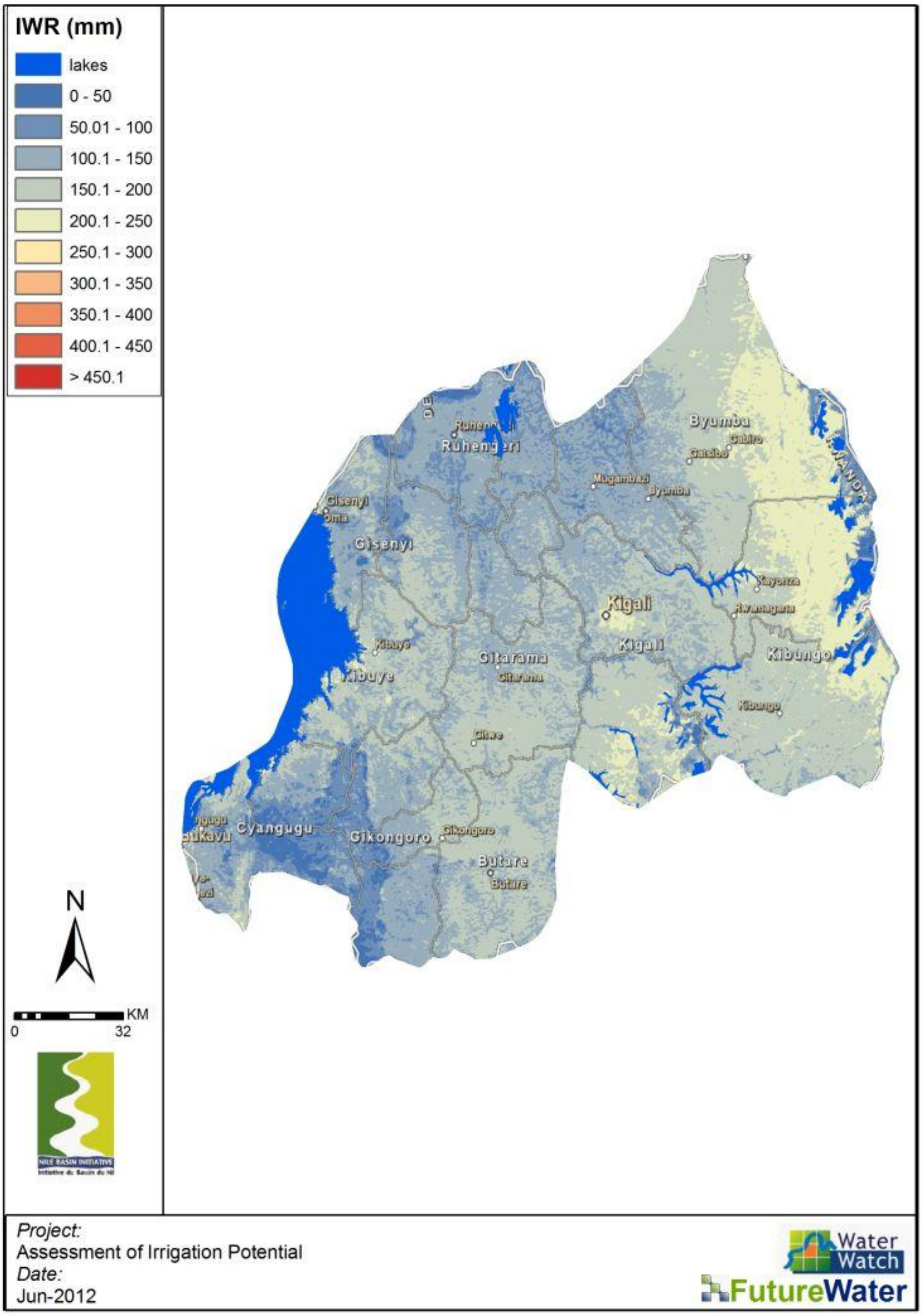
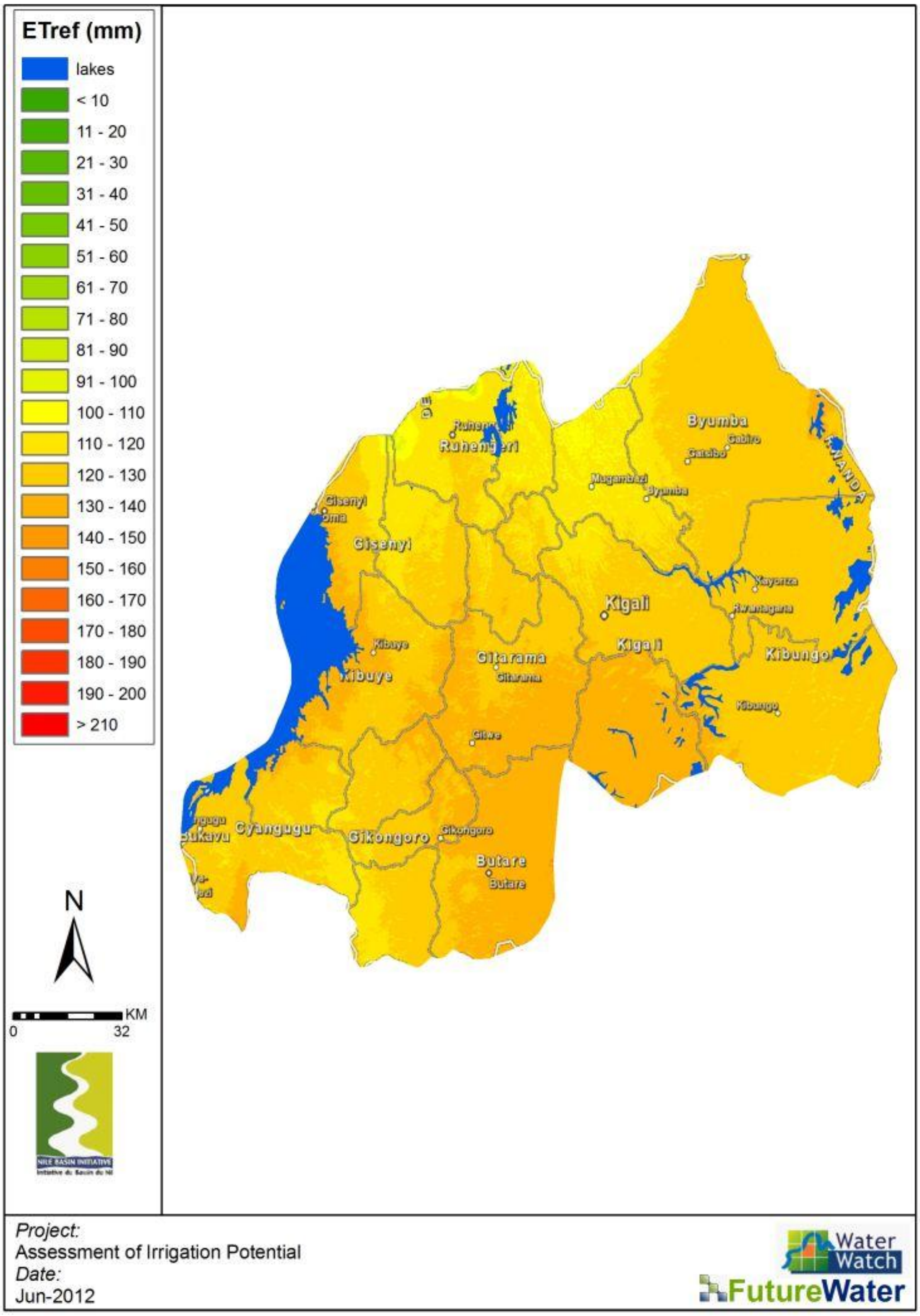


Figure 14: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for August (Average 2001-2010). (Source: study analysis).

September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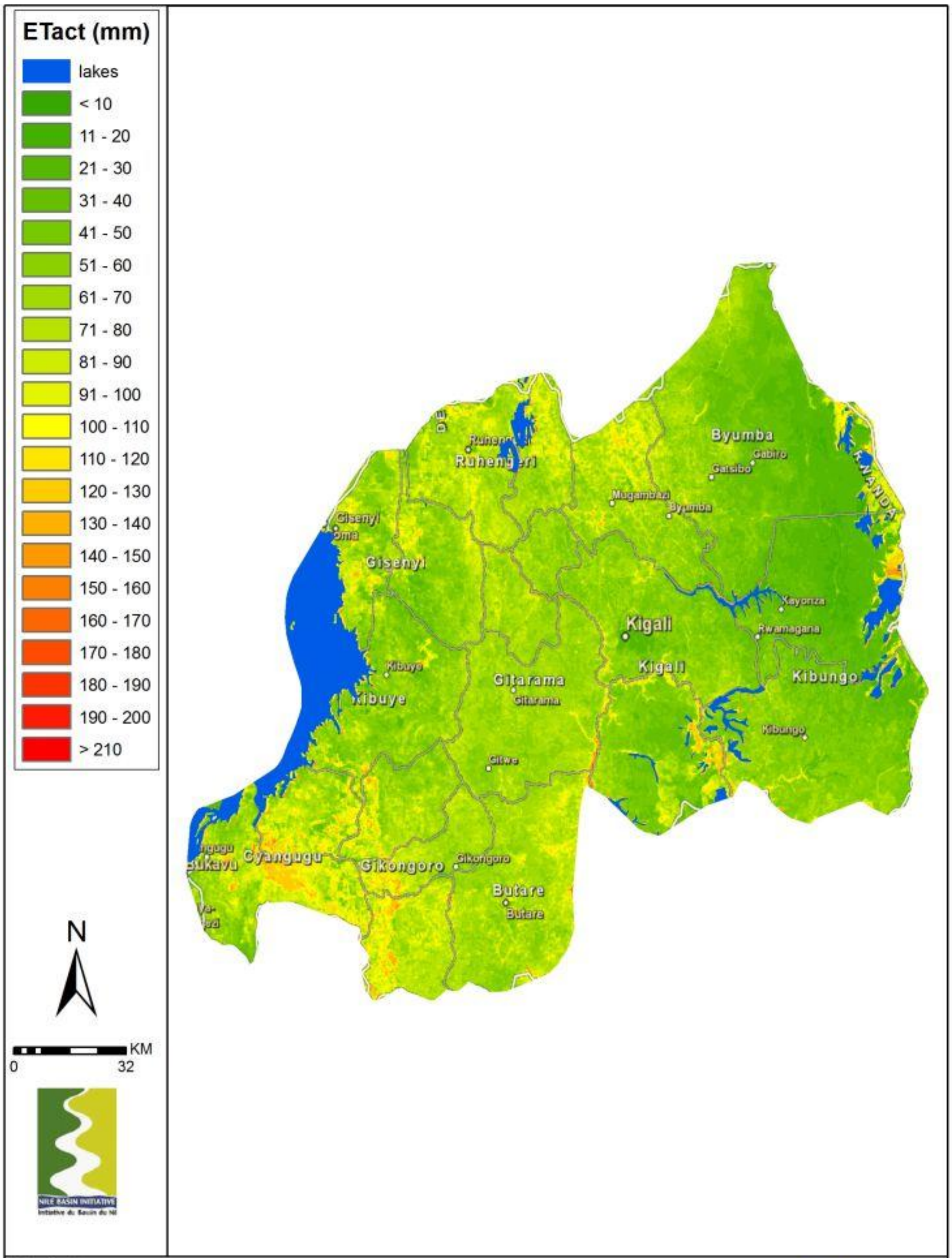

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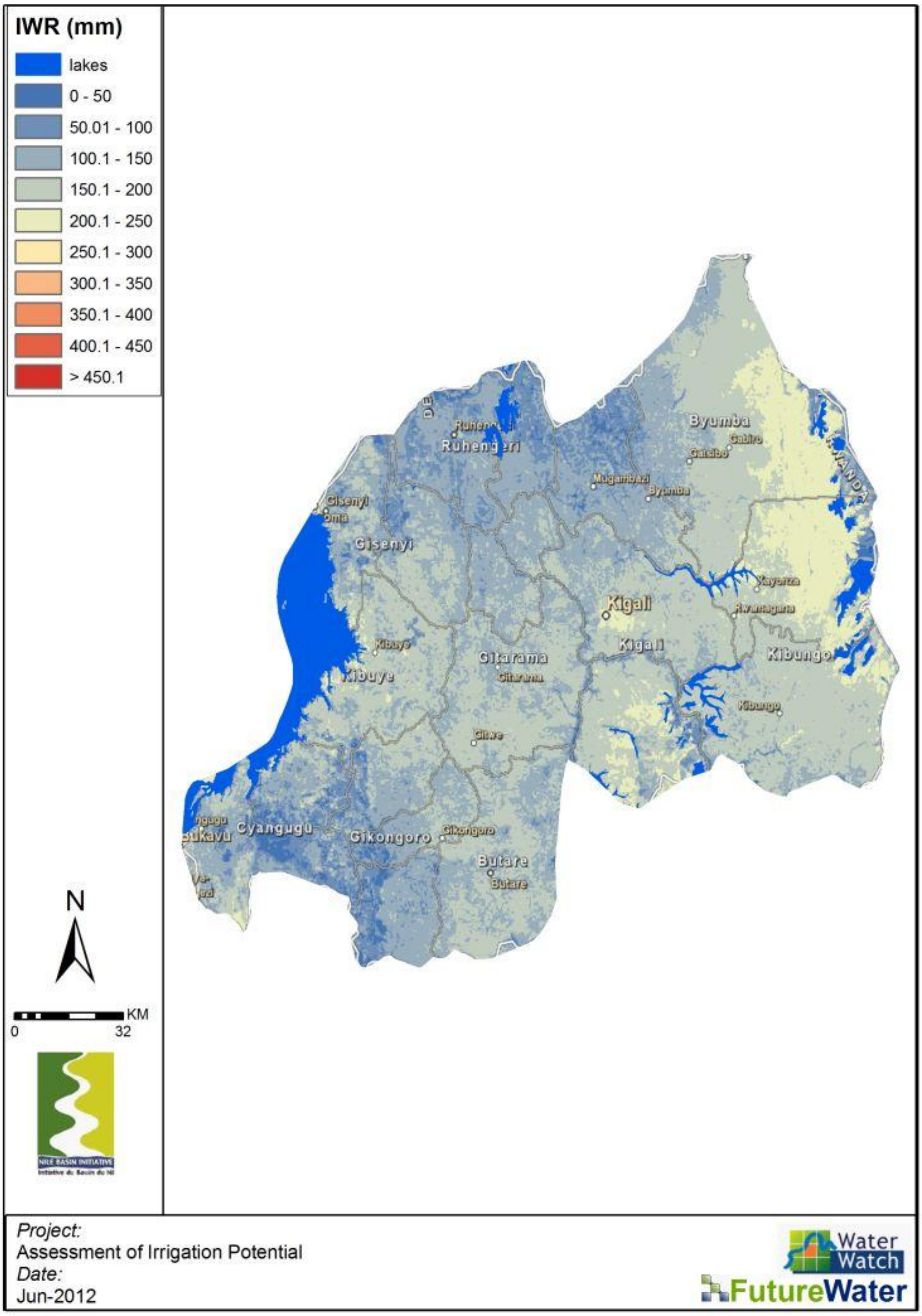
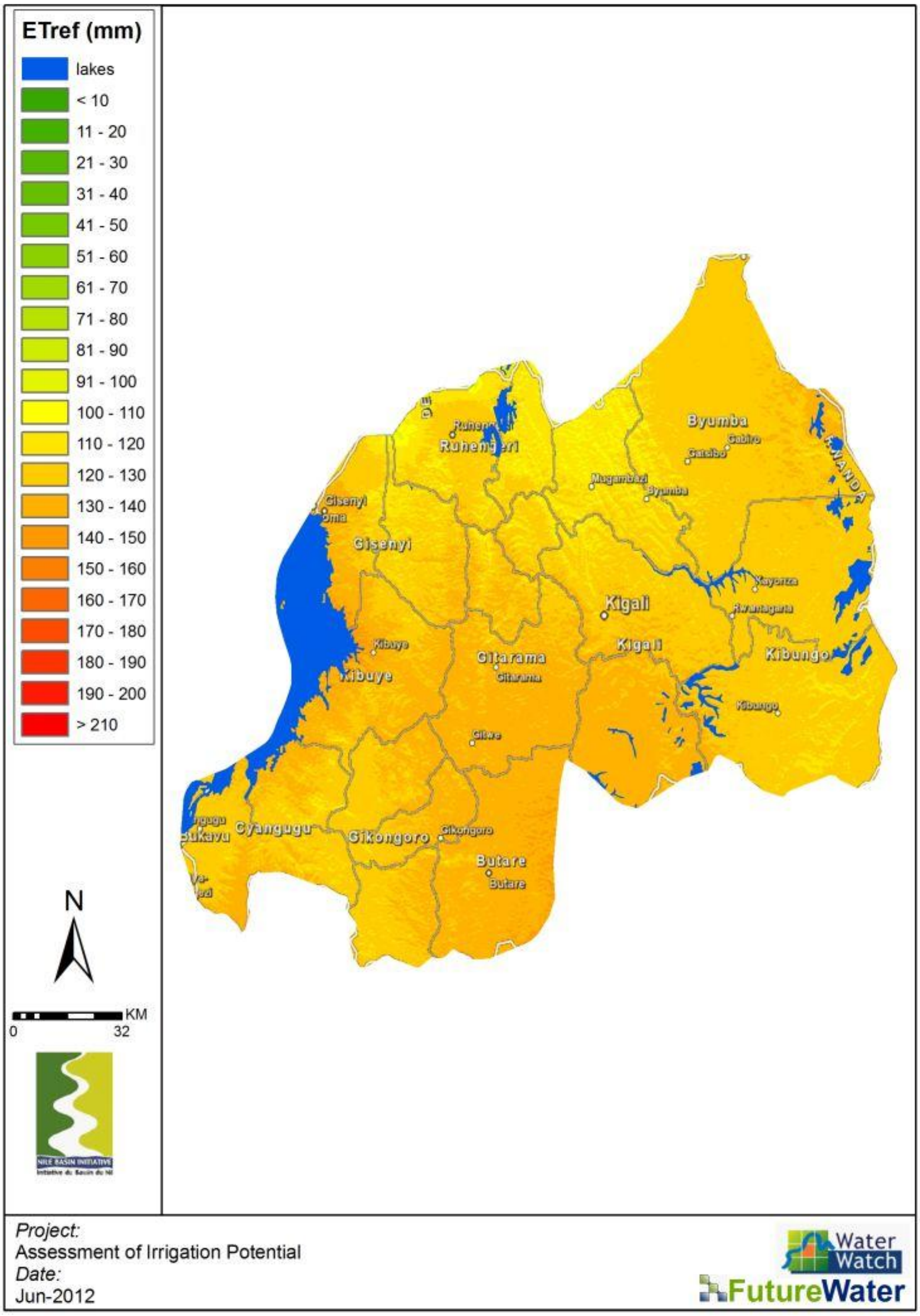


Figure 15: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for September (Average 2001-2010). (Source: study analysis).

October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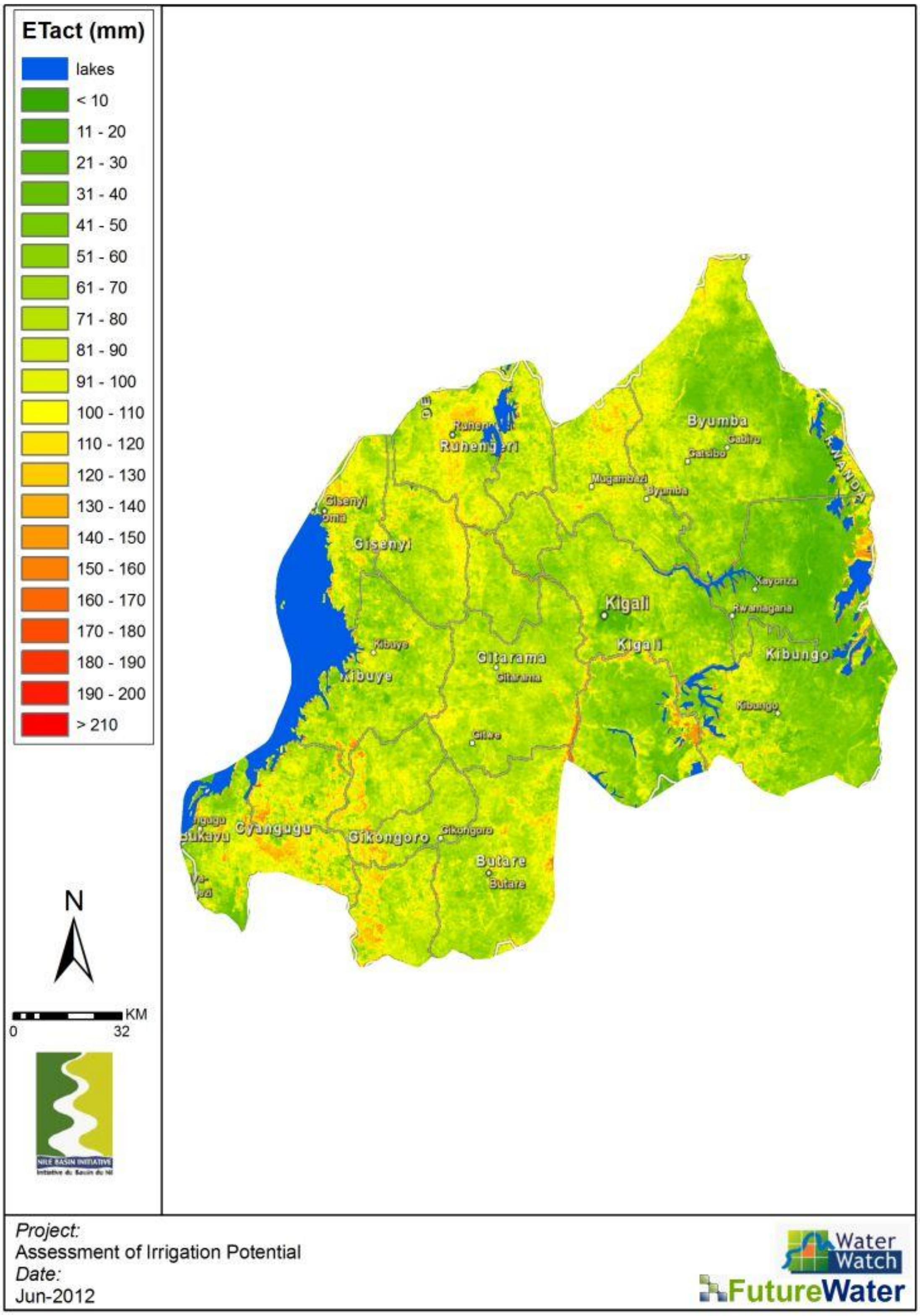
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Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

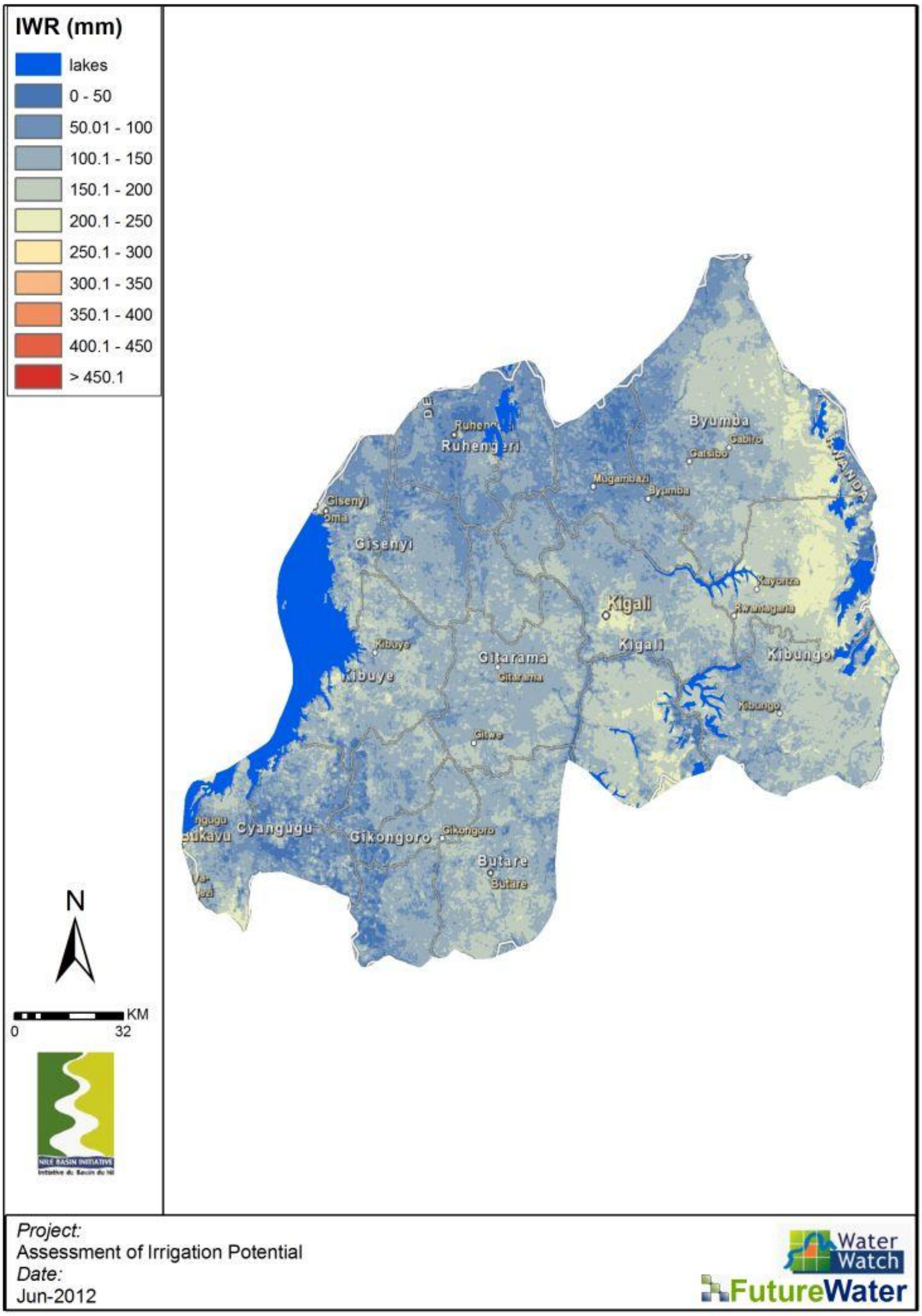
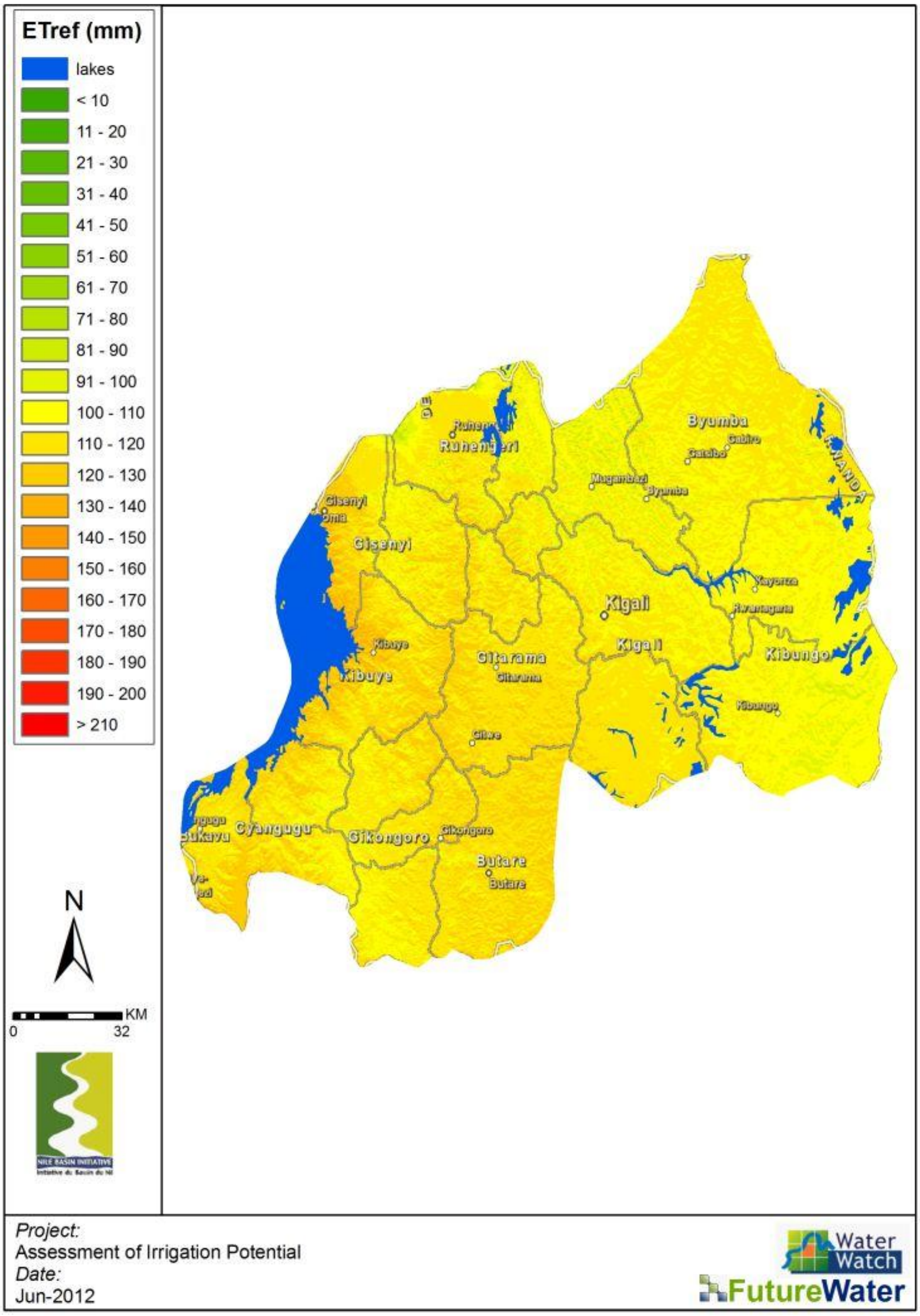


Figure 16: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for October (Average 2001-2010). (Source: study analysis).

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
32
Byumba
Ruhengeri
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Project:
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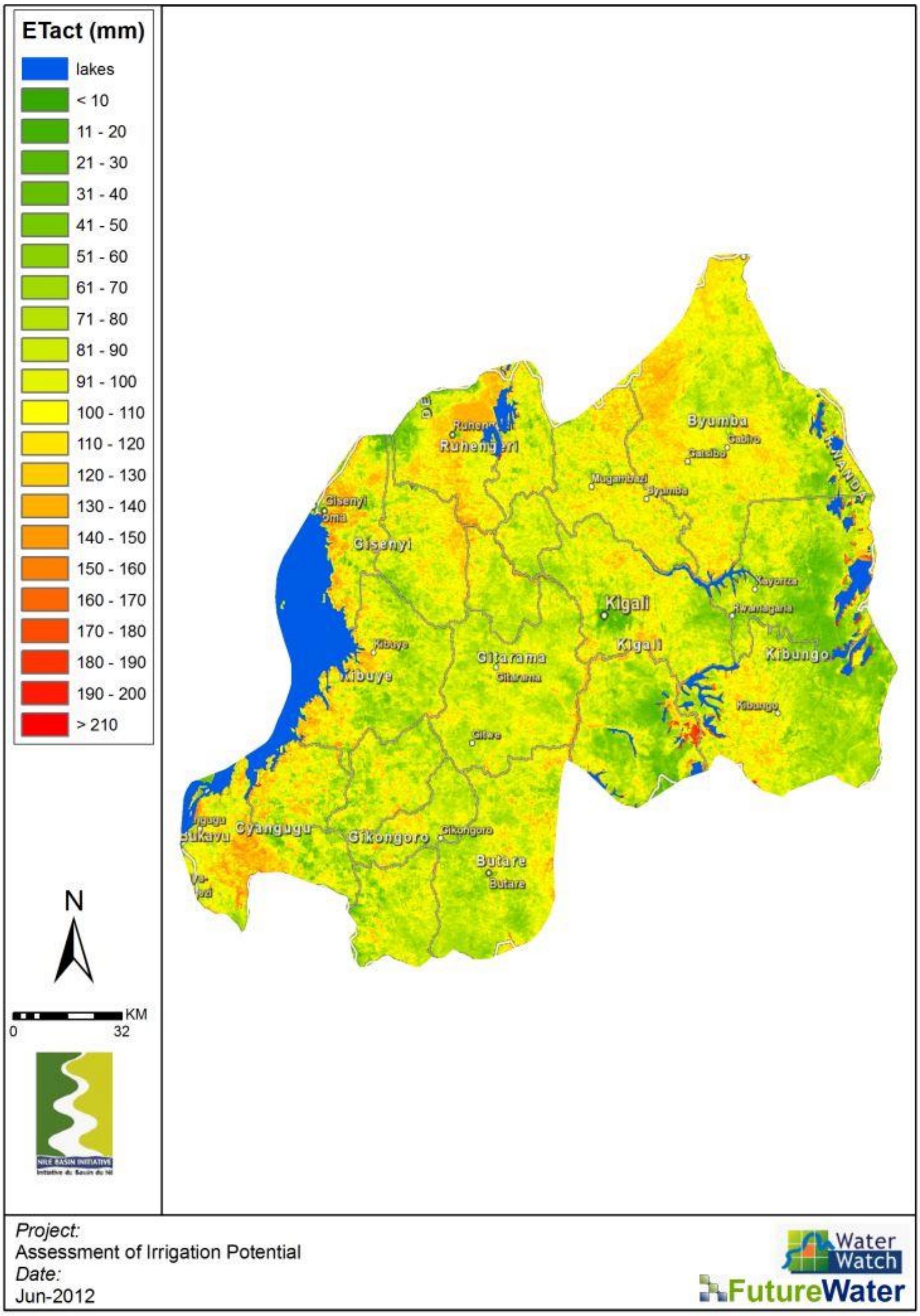
Date:
Jun-2012
Water Watch
FutureWater


ETact (mm)
lakes
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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
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160 - 170
170 - 180
180 - 190
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Project:
Assessment of Irrigation Potential
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Water Watch
FutureWater

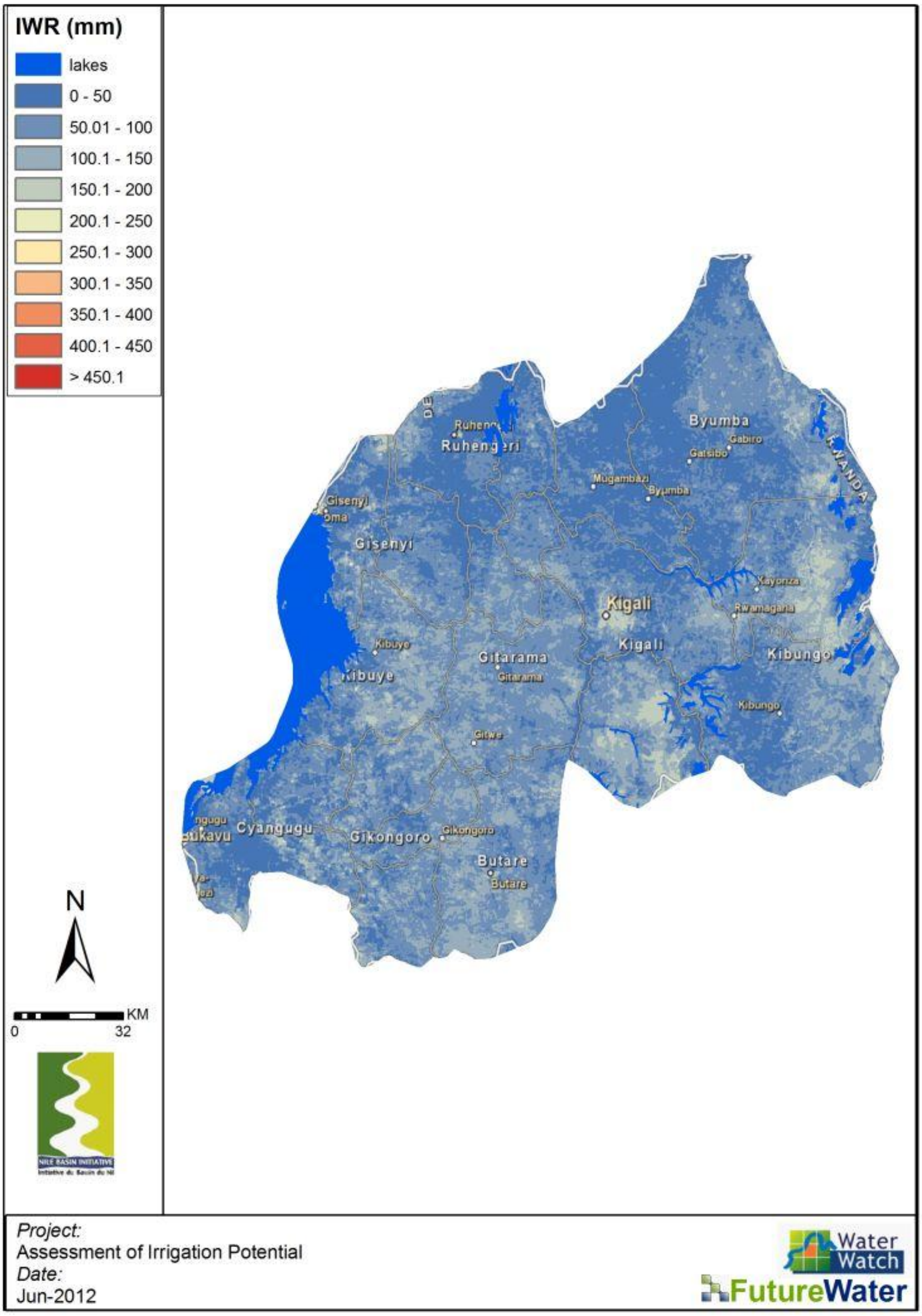
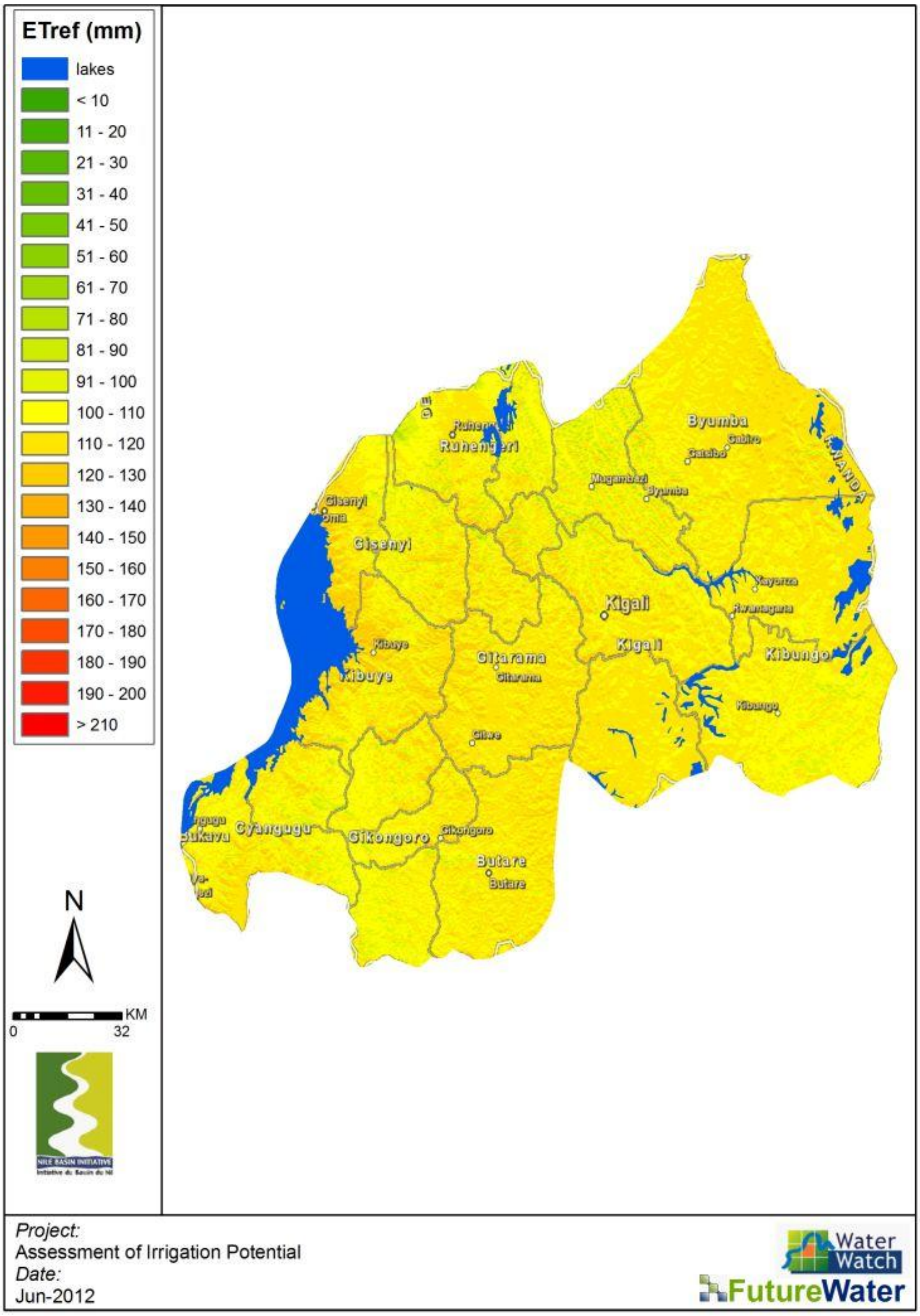


Figure 17: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for November (Average 2001-2010). (Source: study analysis).

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
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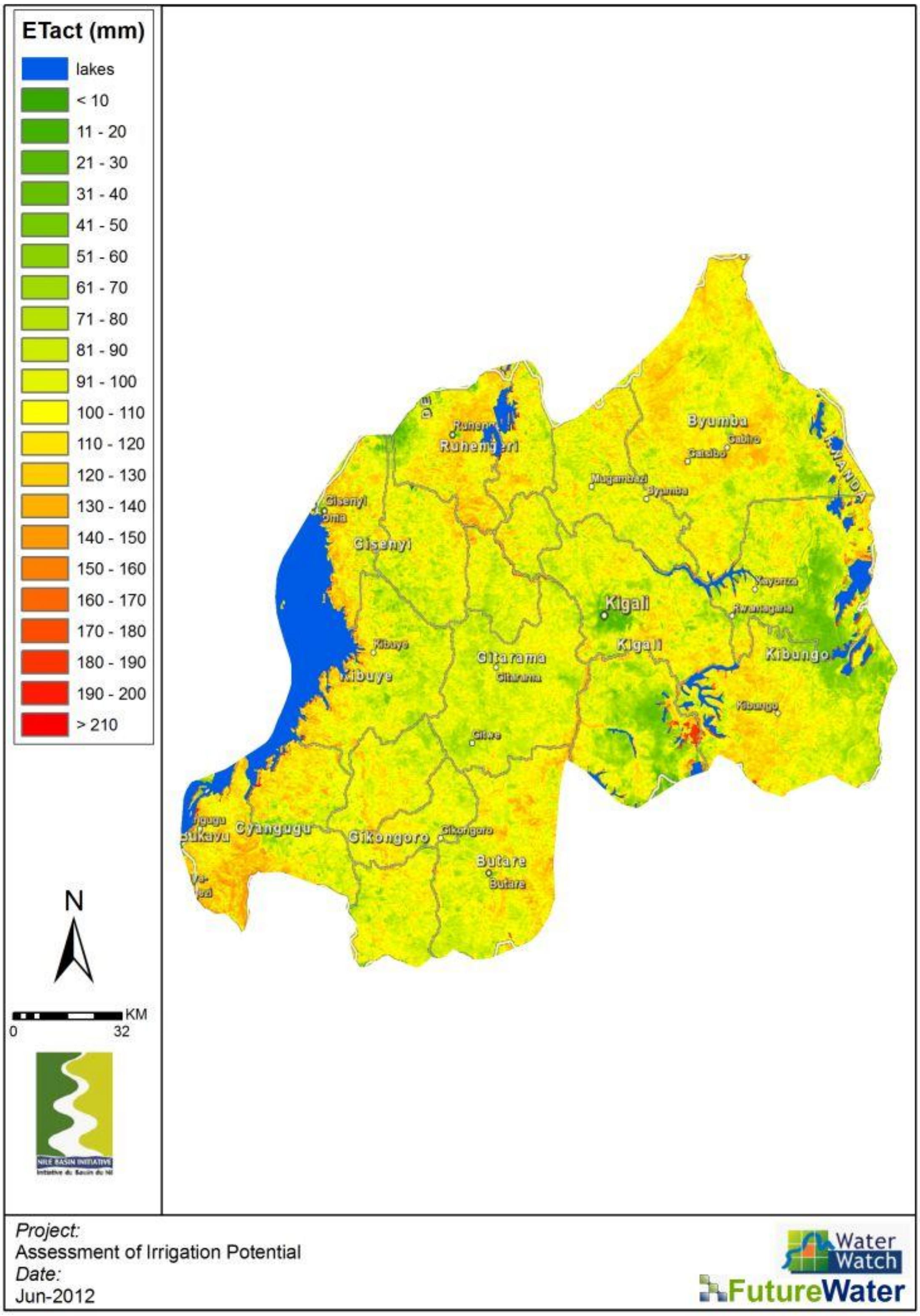
Project:
Assessment of Irrigation Potential
Date:
Jun-2012


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
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150 - 160
160 - 170
170 - 180
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Project:
Assessment of Irrigation Potential
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Jun-2012
Water Watch
FutureWater

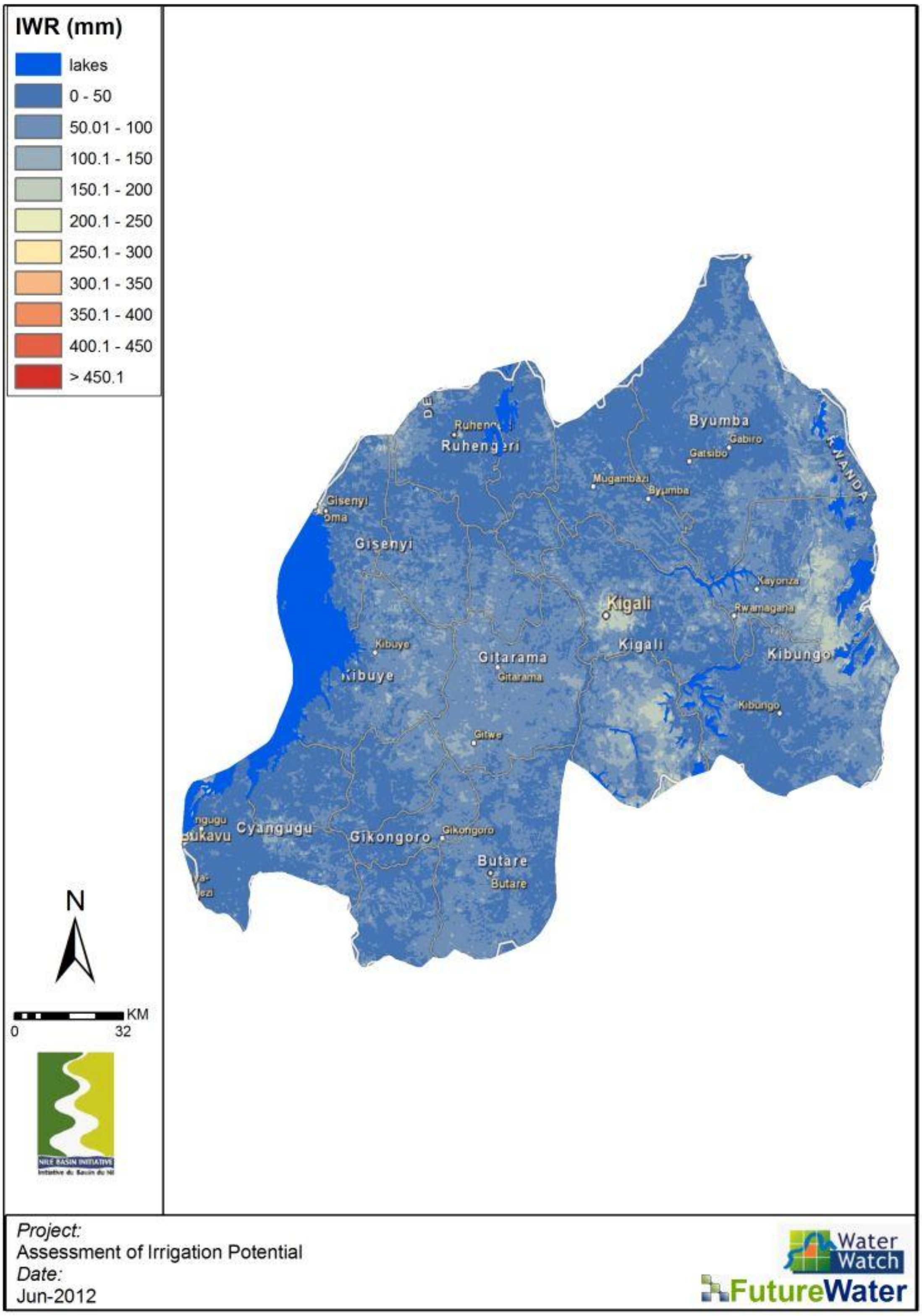


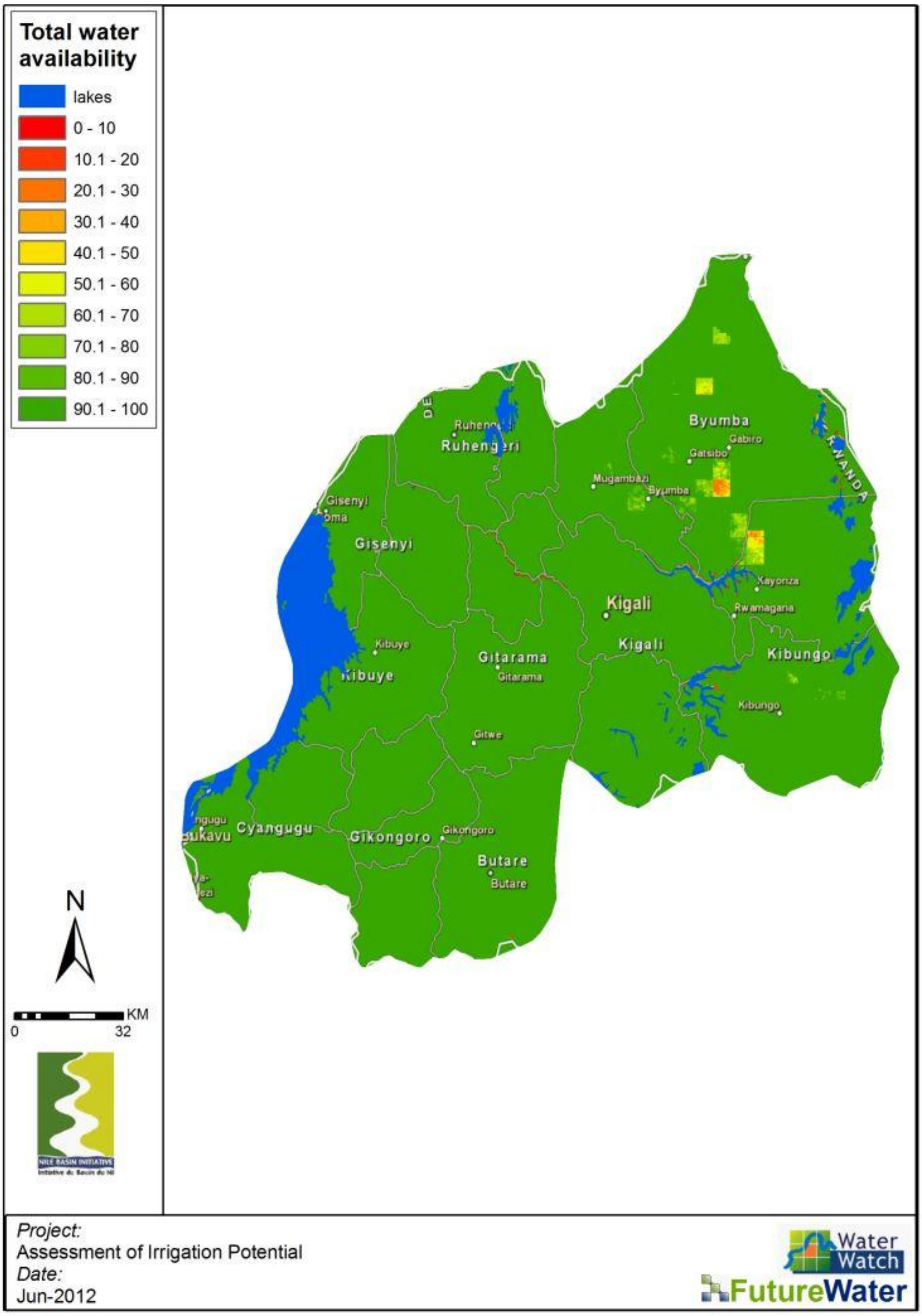
Figure 18: Reference evapotranspiration (top), actual evapotranspiration (middle), and irrigation water requirement (bottom) for December (Average 2001-2010). (Source: study analysis).

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 very high except for the higher mountainous areas. Main sources are the potential reservoirs and water from existing streams.



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
Byumba
Gabiro
Gatsibo
Mugambazi
Byumba
Ruhengeri
Gisenyi
Kigali
Kayonza
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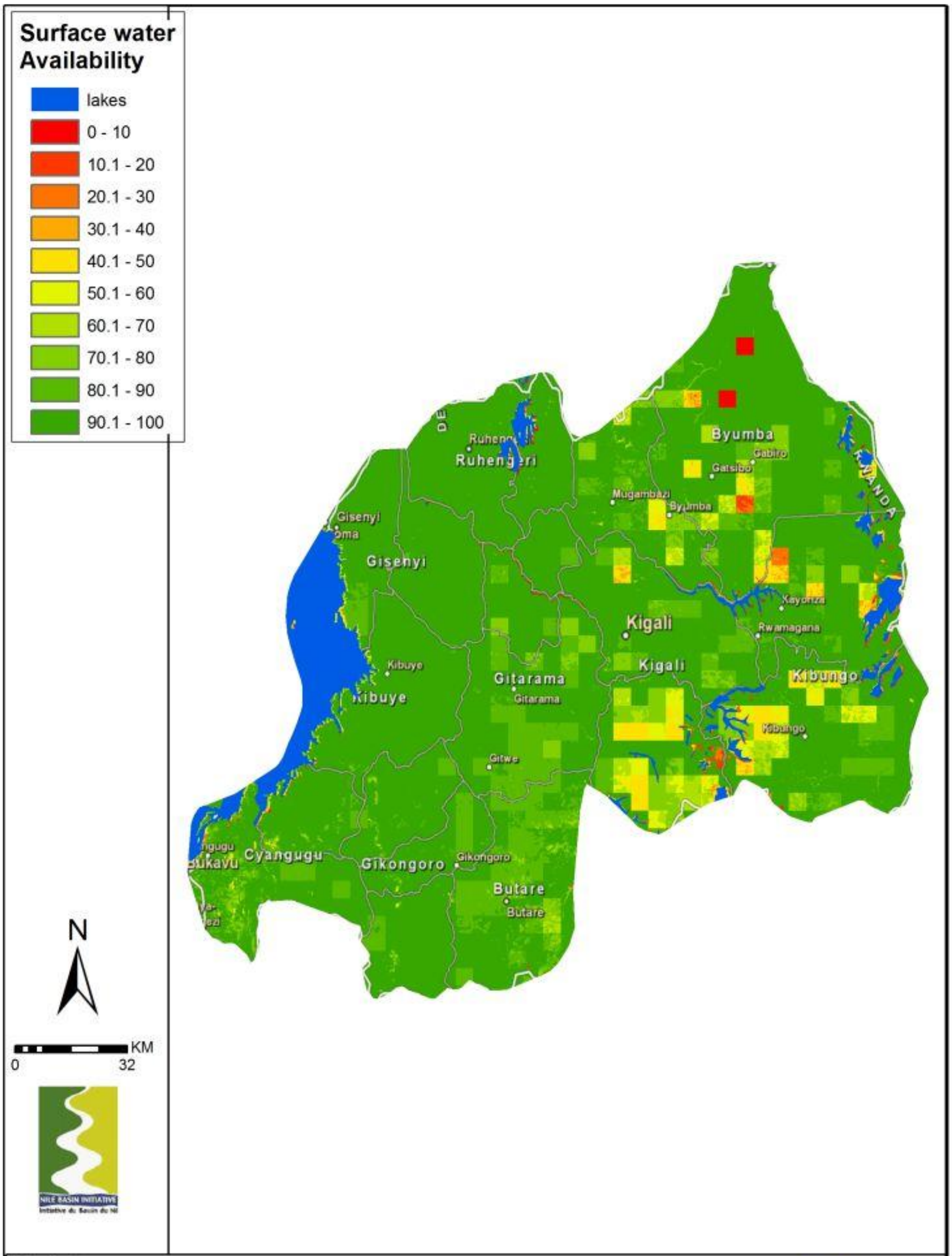
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater



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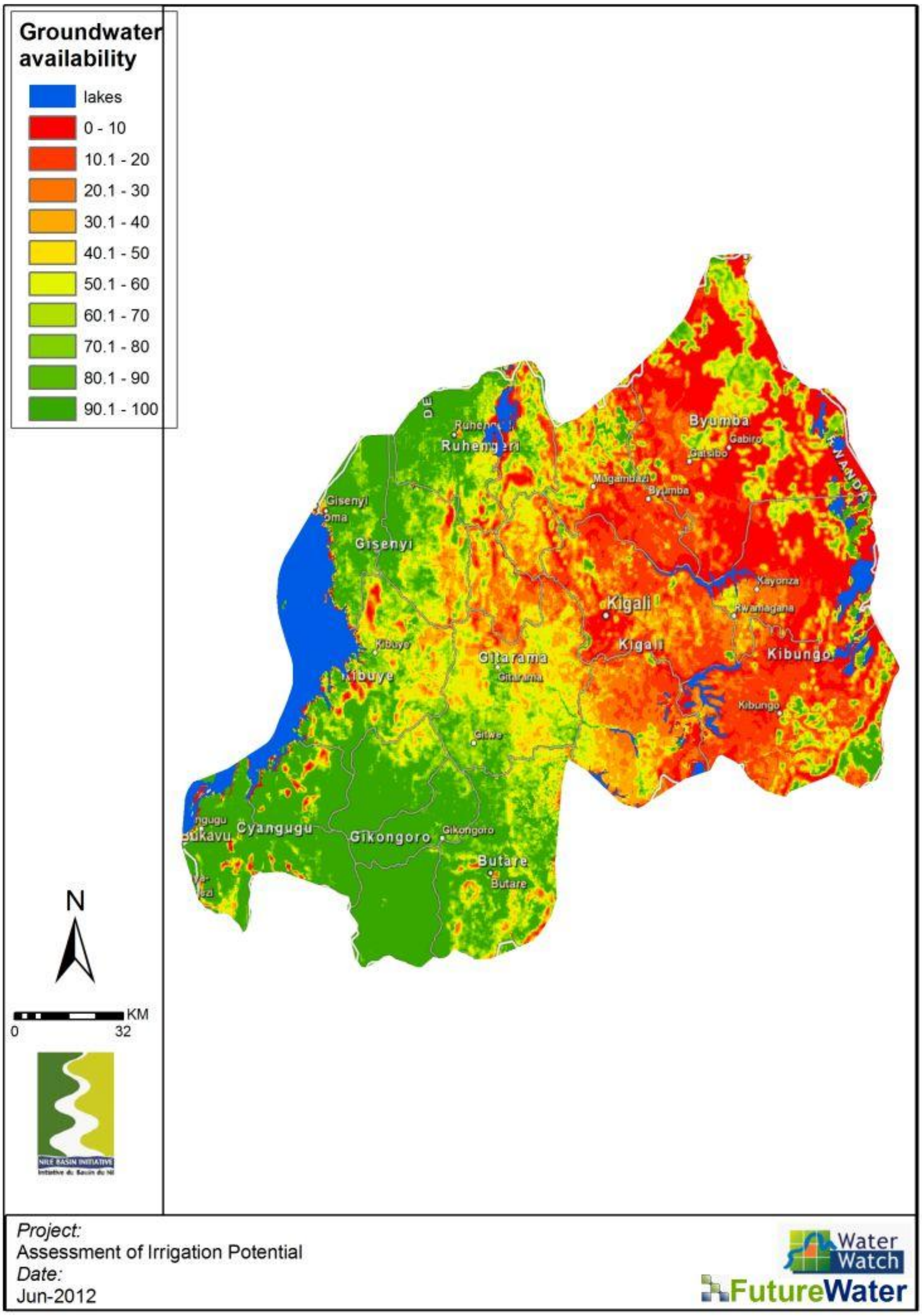
Groundwater availability
lakes
0 - 10
10.1 - 20
20.1 - 30
30.1 - 40
40.1 - 50
50.1 - 60
60.1 - 70
70.1 - 80
80.1 - 90
90.1 - 100
Ruhengeri
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Jun-2012
Water Watch
FutureWater

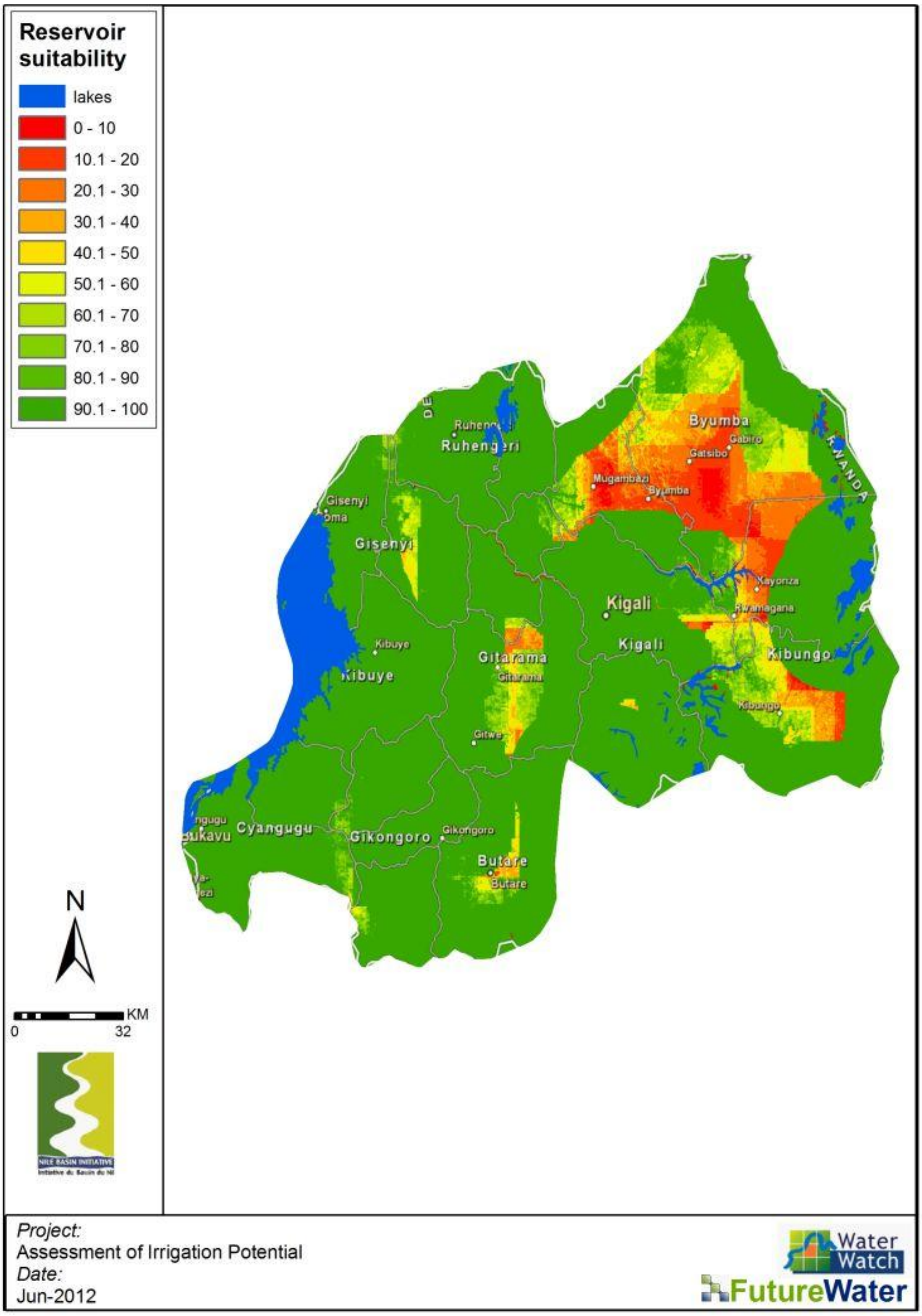


Figure 19: Water availability for irrigation. Total coverage (top), coverage from surface water (second), coverage from ground water (third), and from potential reservoirs (bottom). (Source: study analysis).

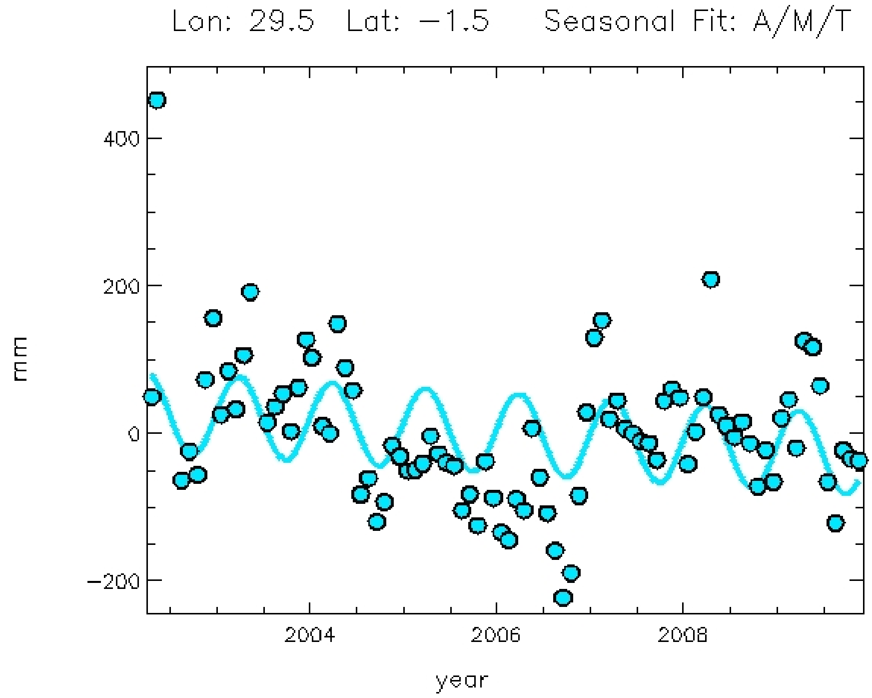


Figure 20: Annual groundwater storage trends for Rwanda, based on GRACE satellite observations (Source: UoC, 2011).

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 20. It is clear that the overall trend is a small reduction in groundwater levels over the last 10 years. Groundwater recharge based on NELmod is presented in Figure 21. Overall groundwater recharge is quite high in the somewhat lower areas in the country.

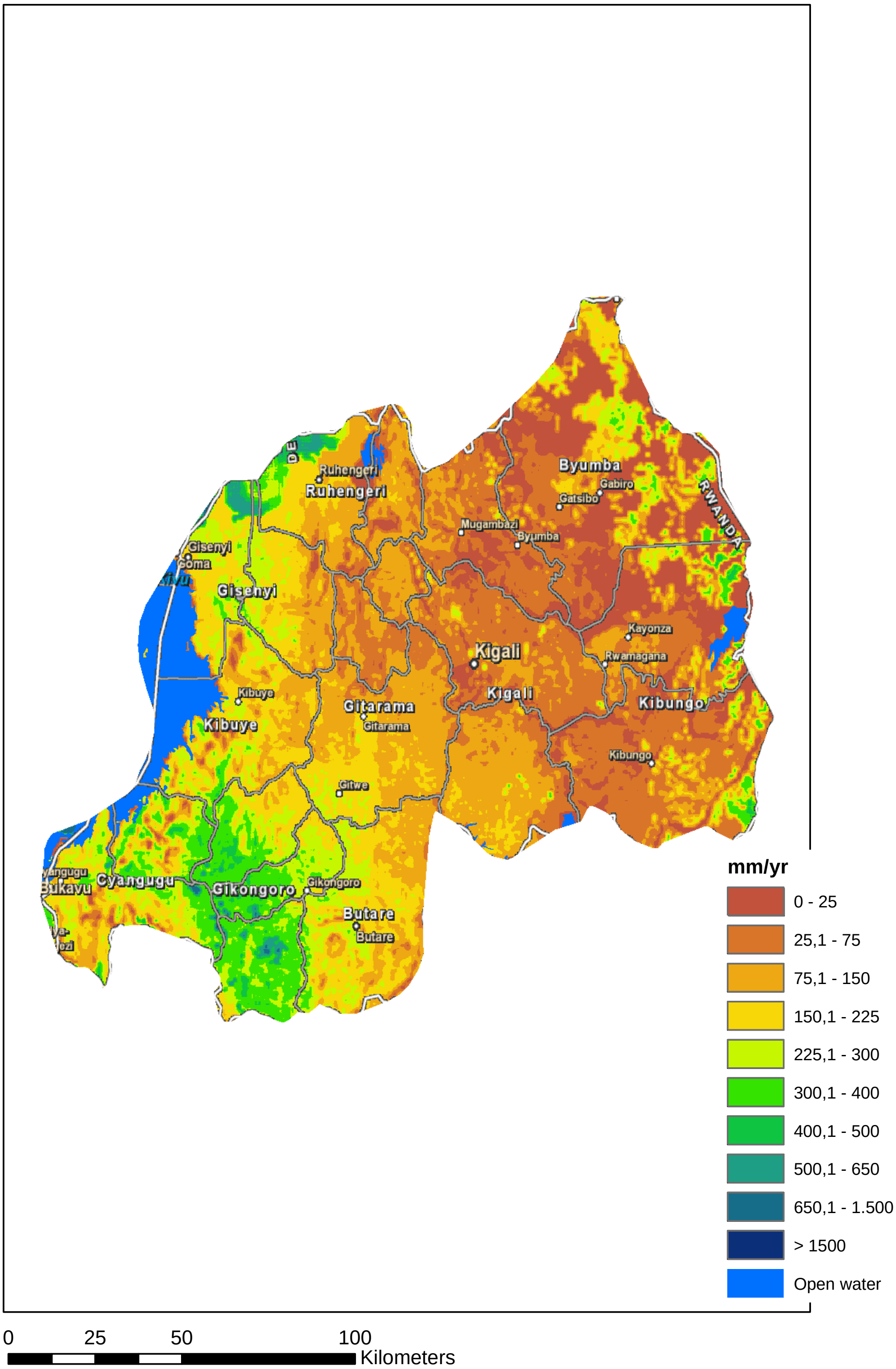
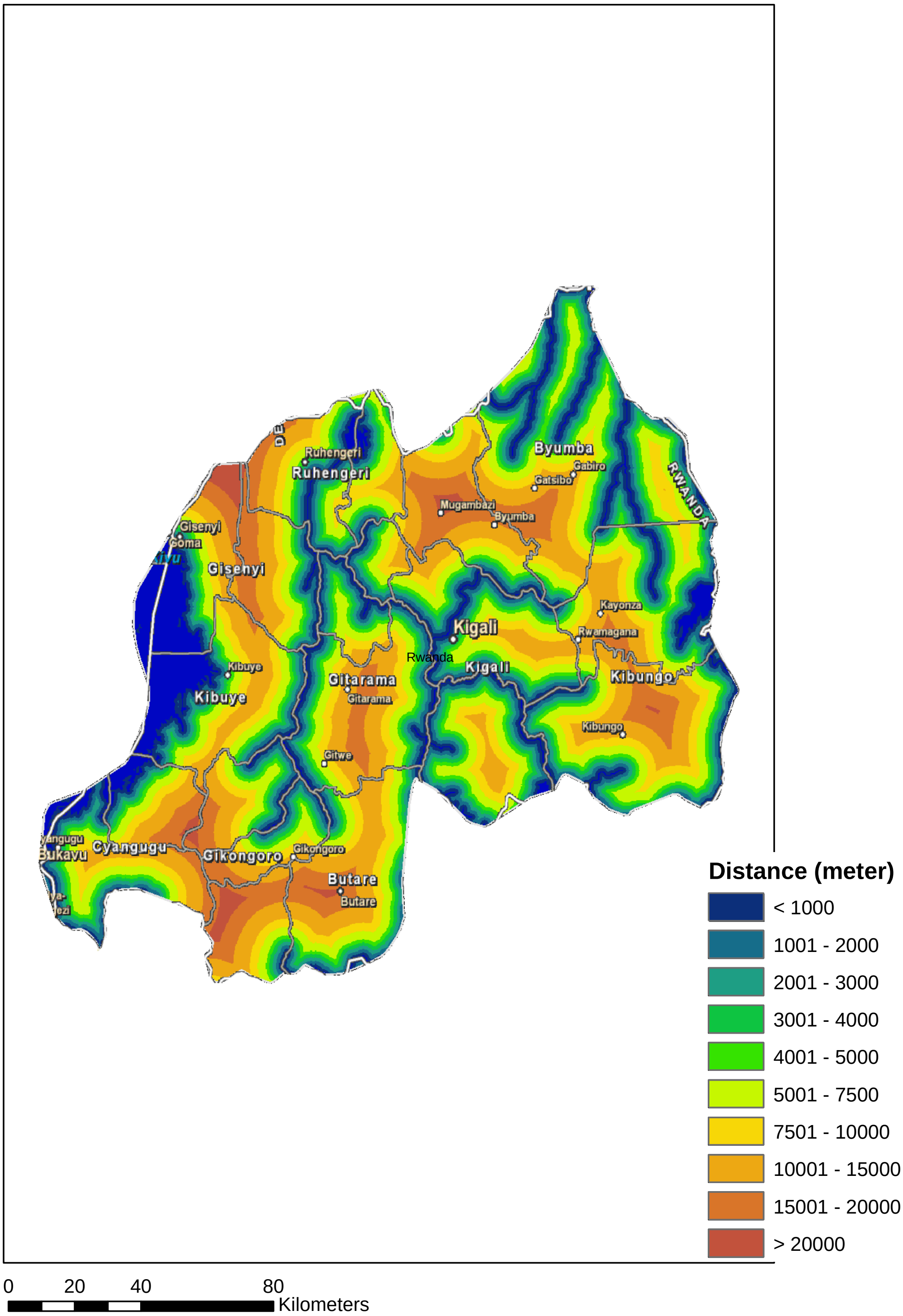
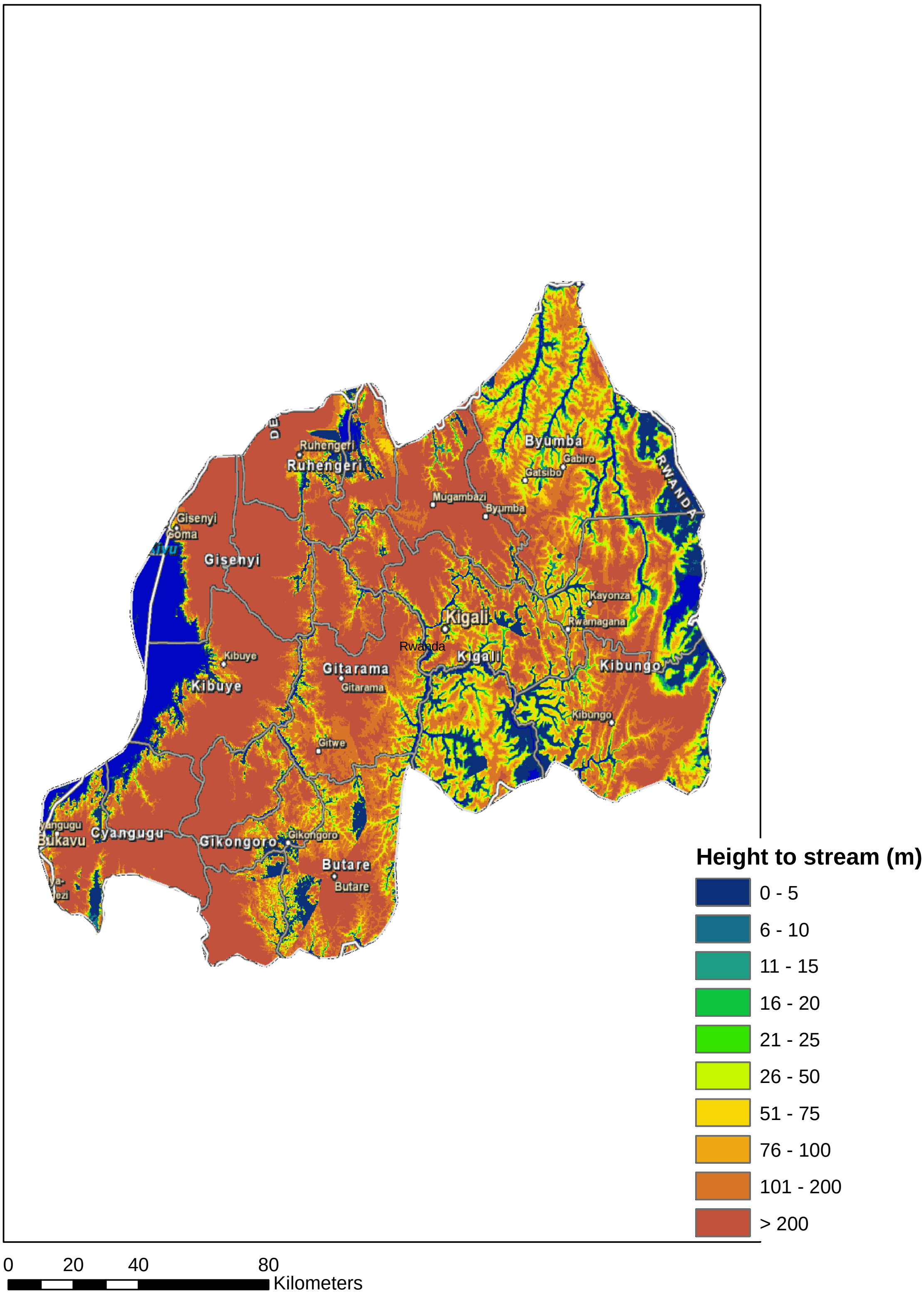


Figure 21: Annual groundwater recharge based on NELmod. (Source: study analysis).

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 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.




Gisenyi
Ruhengeri
Byumba
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Rwanda
Height to stream (m)
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 50
51 - 75
76 - 100
101 - 200
> 200
0
20
40
80
Kilometers

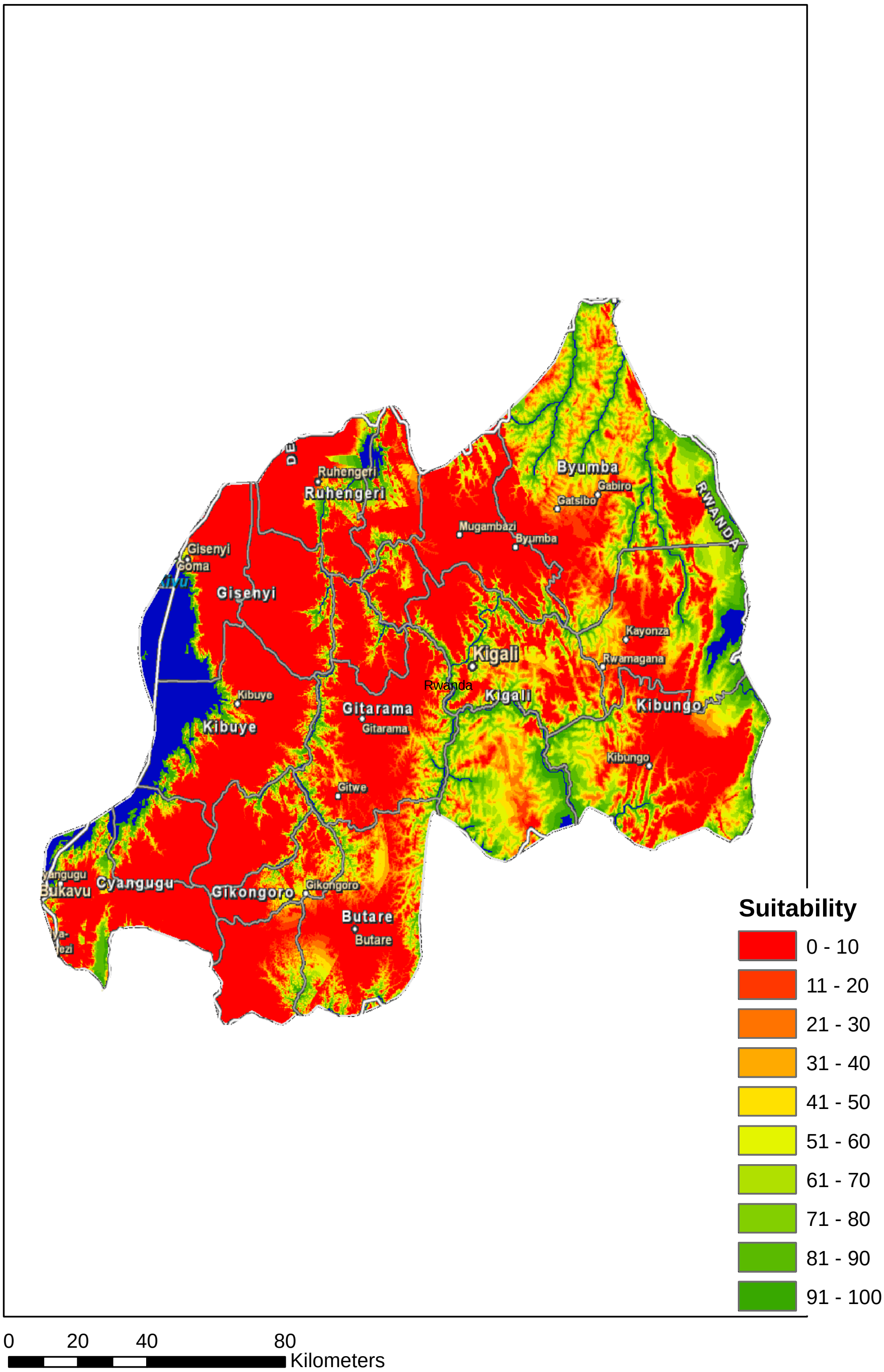


Figure 22: Average distance to a natural stream, lake or reservoir (top), elevation above natural stream, lake or reservoir (middle), and access to water suitability score (bottom). (Source: study analysis).

2.3 Land use

2.3.1 *Current land use*

Actual land cover based on AfriCover is shown in Figure 23. Distribution of irrigated and rainfed crops are shown in Figure 24. Specific maps for 26 crops are included in the database attached to the report.

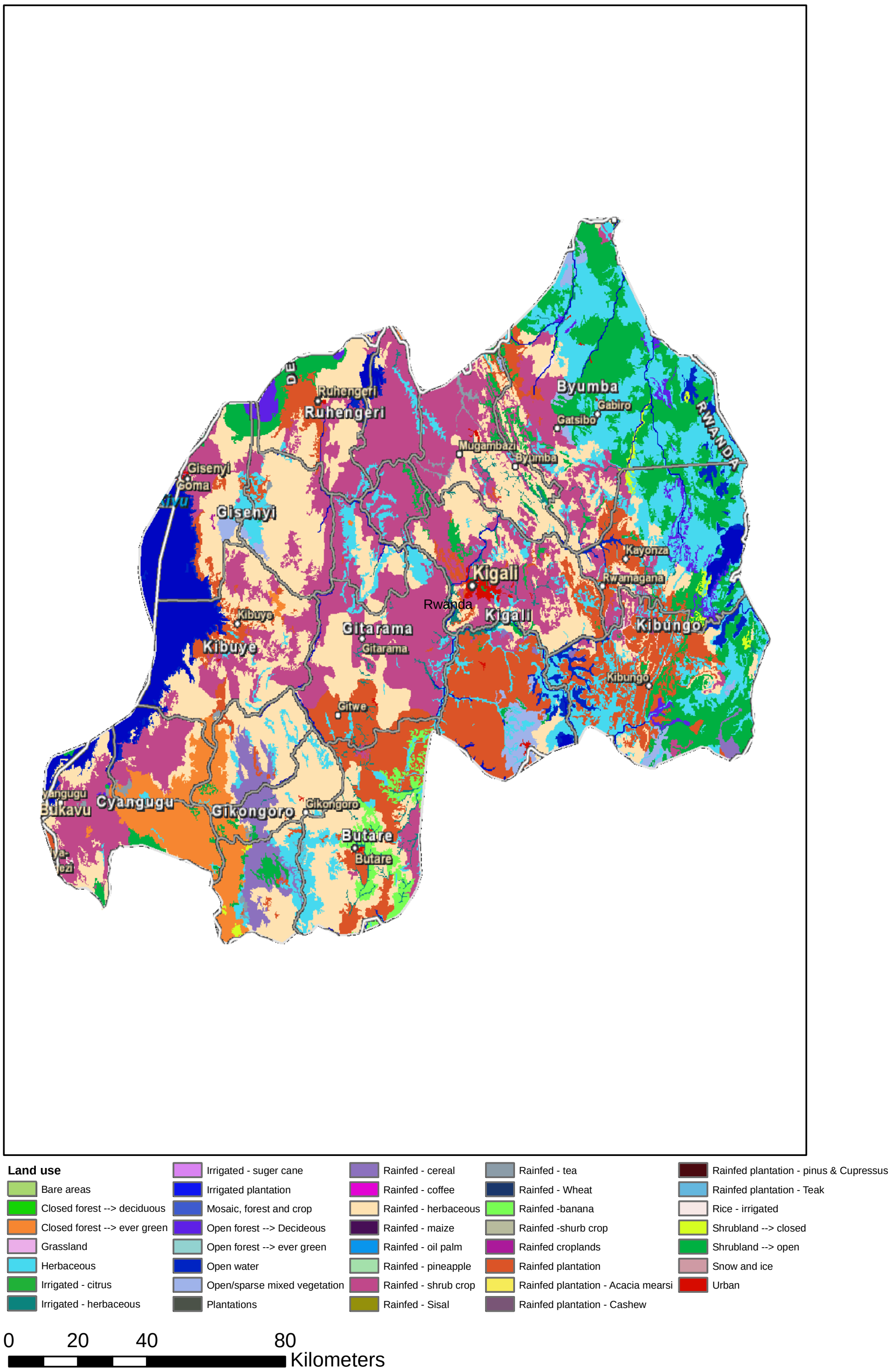
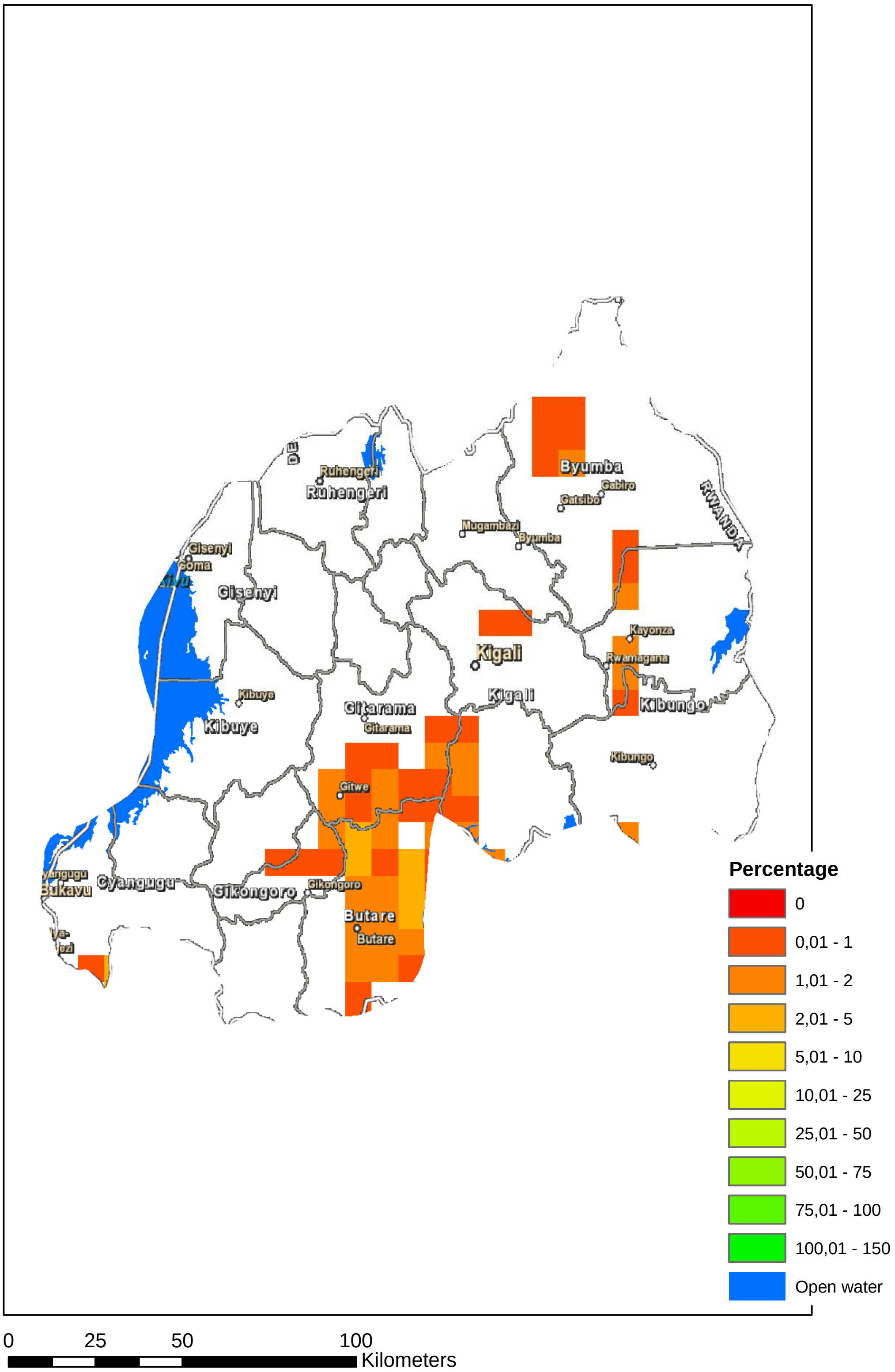


Figure 23: Land use in Rwanda, based on AfriCover.



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Gitarama
Kibuye
Kibungo
Gitwe
Cyangugu
Bukavu
Gikongoro
Gikongoro
Butare
Butare
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
25
50
100
Kilometers

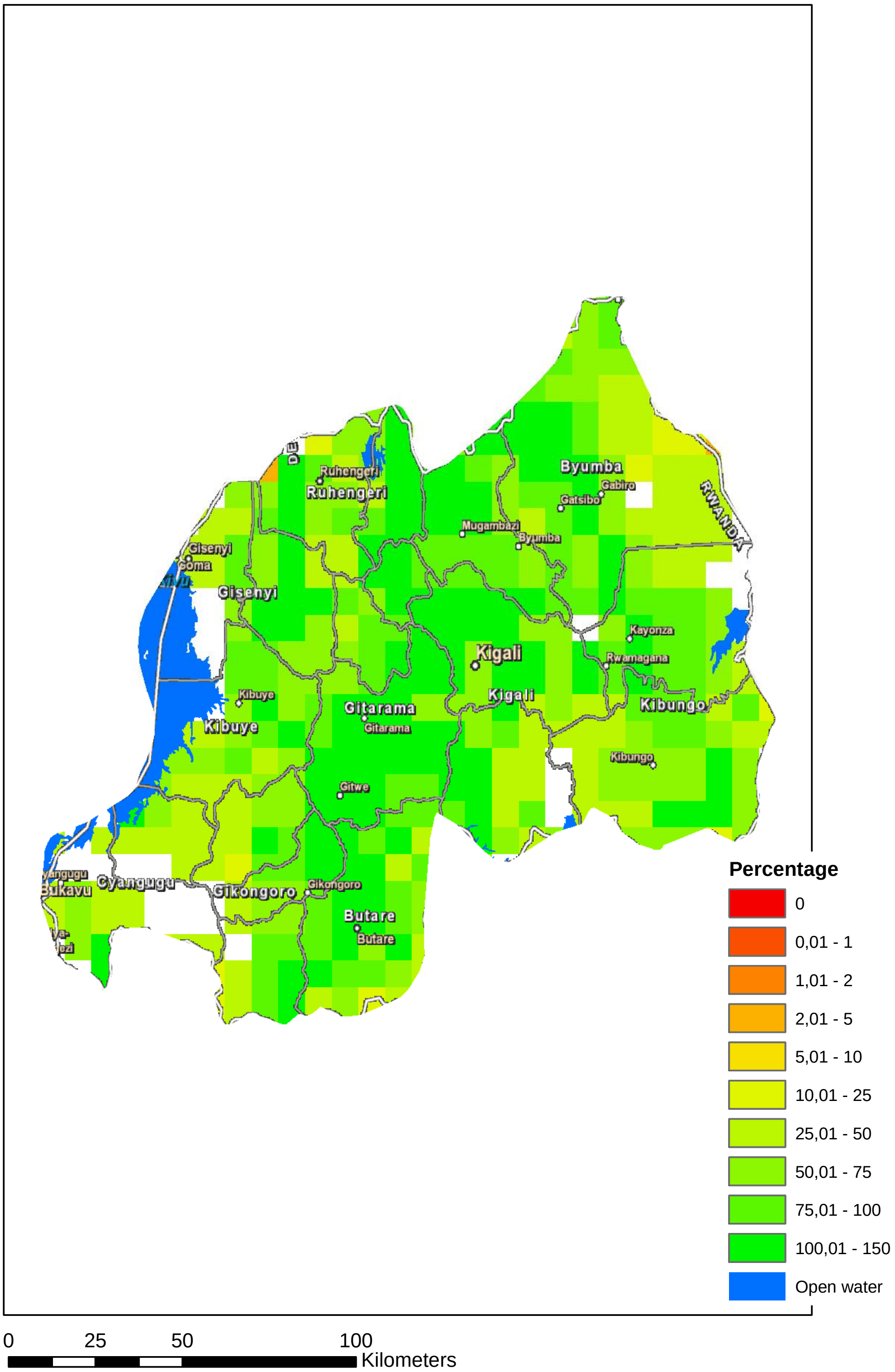


Figure 24. Irrigated (top) and rainfed cropping intensities[1] (bottom) as percentage of cells of about 10 x 10 km (Source: Mirca2000).

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

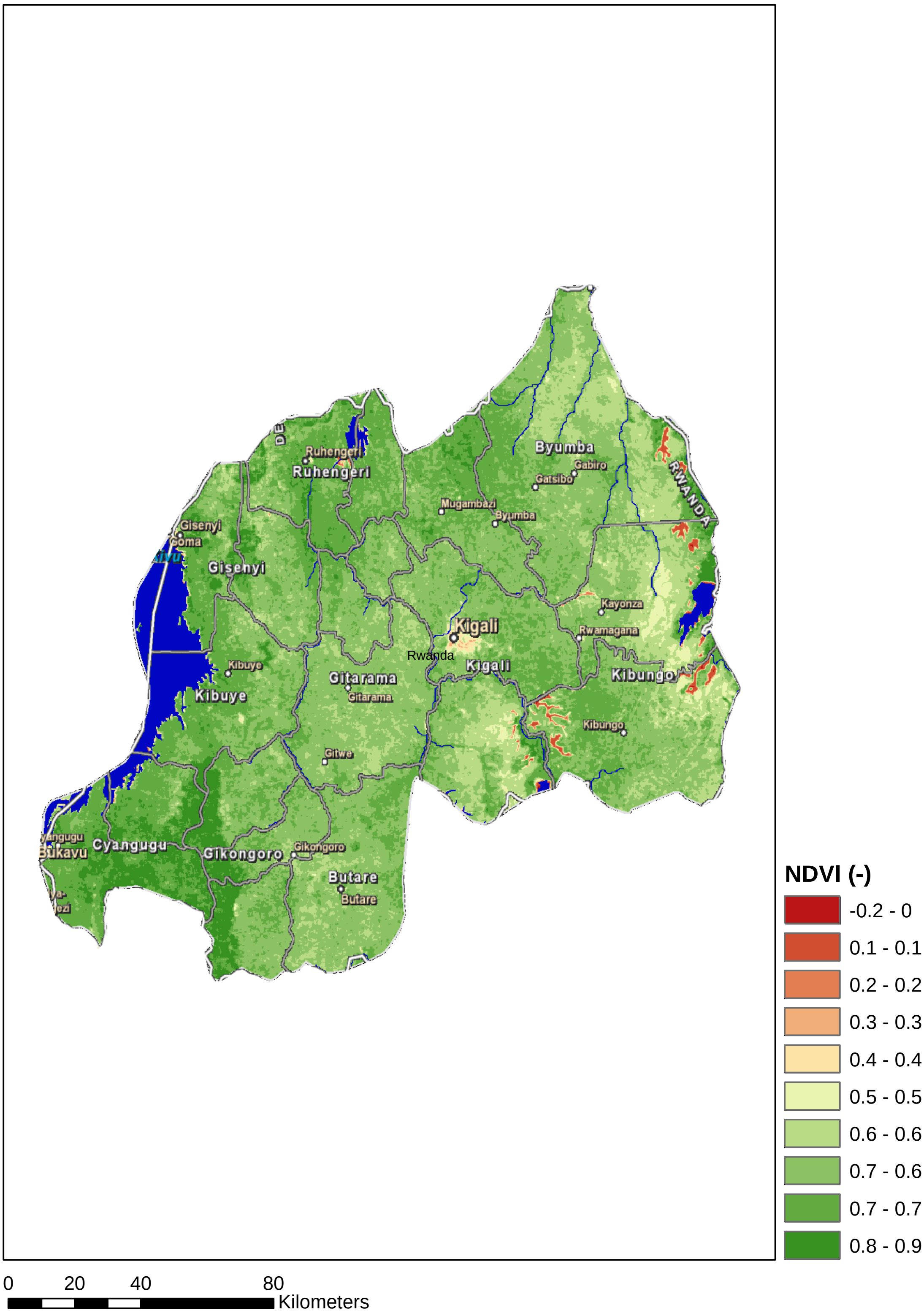
2.3.2 *Current land productivity (NDVI)*

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 region is high and monthly variation is limited to the eastern part of the country.

The NDVI formula is:

$$\frac{(NIR - RED)}{(NIR + RED)}$$

The NDVI is calculated based on remote sensing Modis images, and in more detail the Nearly InfraRed band (NIR) en de visible RED band (RED). The ratio between these two bands shows the productivity between -1 and 1. Plants absorb the red light for their photosynthesis, and reflect the NIR light.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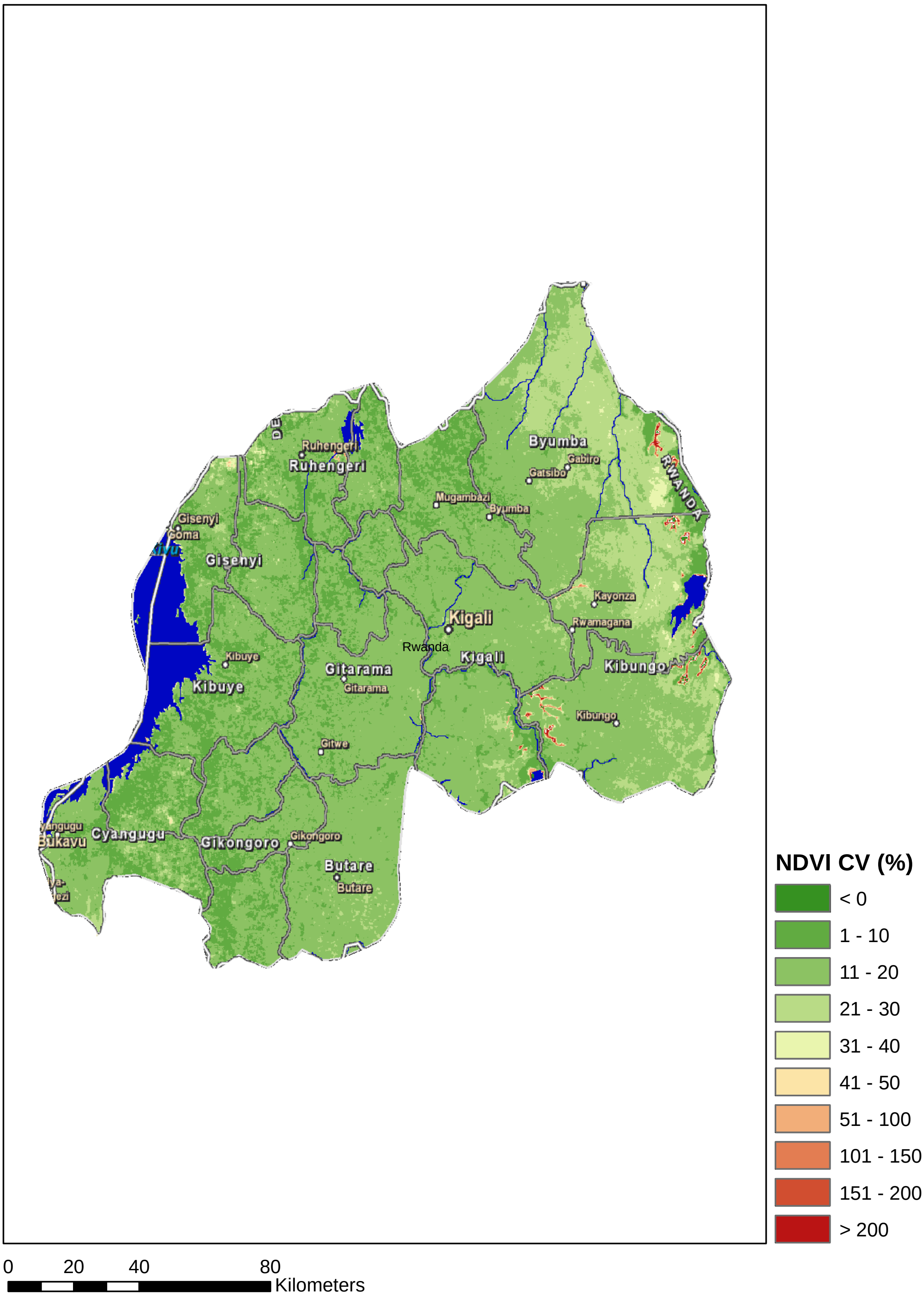
NDVI (-)
-0.2 - 0
0.1 - 0.1
0.2 - 0.2
0.3 - 0.3
0.4 - 0.4
0.5 - 0.5
0.6 - 0.6
0.7 - 0.6
0.7 - 0.7
0.8 - 0.9
0
20
40
80
Kilometers



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Gitarama
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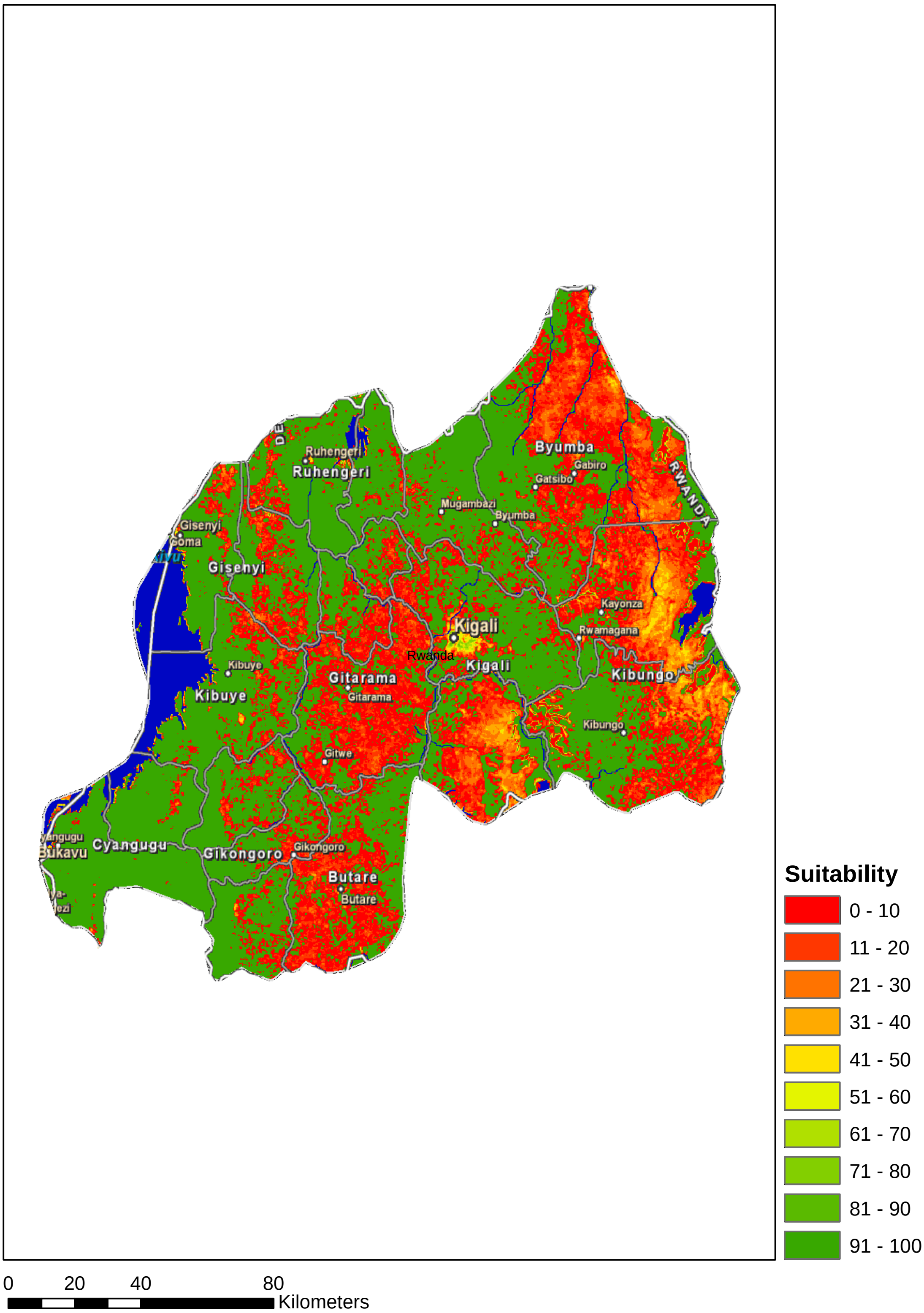
Kibungo
Gitwe
Cyangugu
Bukavu
Gikongoro
Gikongoro
Butare
Butare
NDVI CV (%)
< 0
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 100
101 - 150
151 - 200
> 200
0
20
40
80
Kilometers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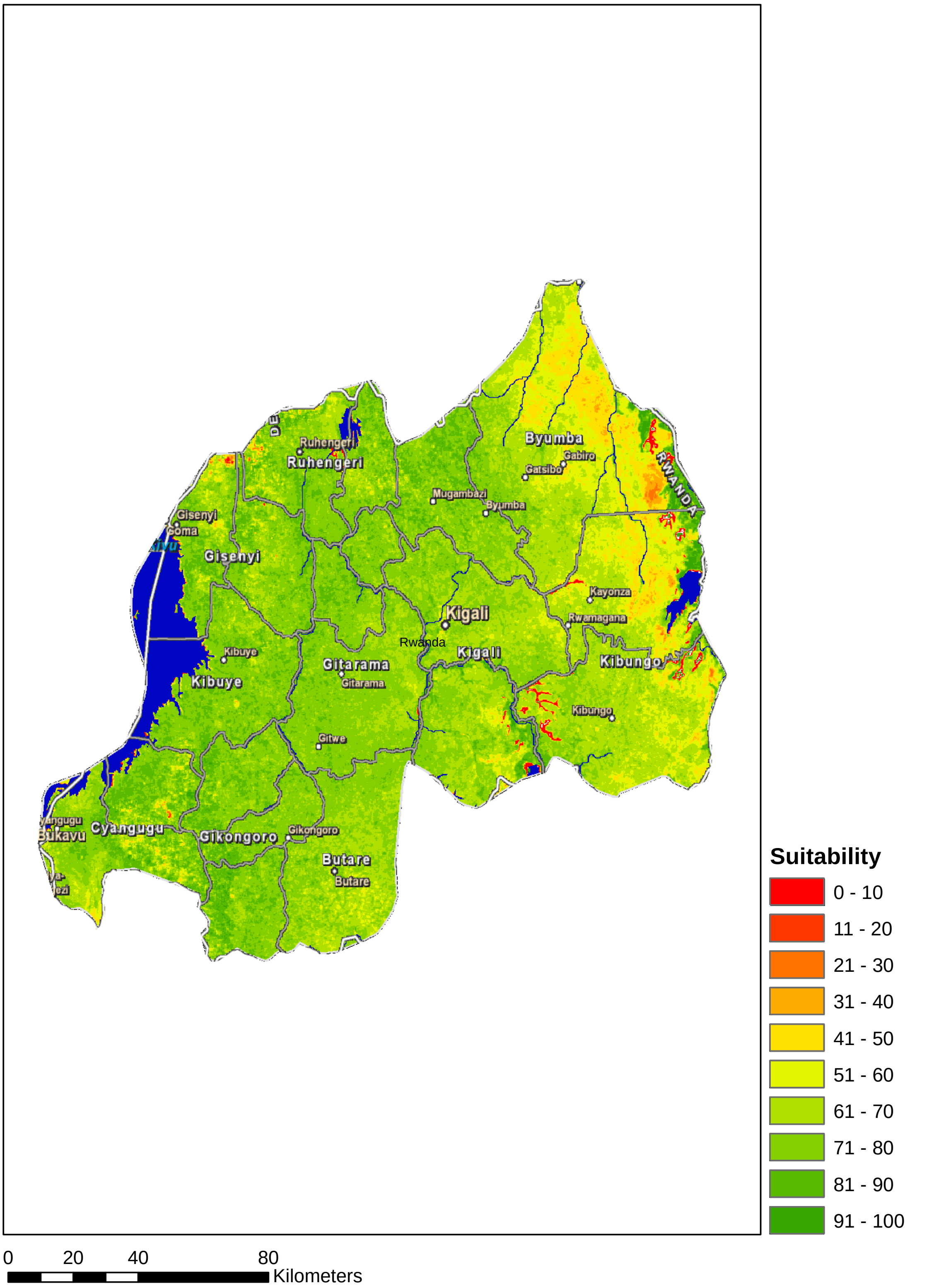


Figure 25: Current land productivity based on NDVI. Average NDVI (top), average monthly coefficient of variation (second), and the land productivity scores based on average NDVI (third) and monthly coefficient of variation (bottom). (Source: study analysis).

2.4 Agriculture

2.4.1 Background

Rwanda is facing a serious problem of low availability of the cultivable lands. The arable land is13,850 km^2, corresponding to 52% of the total surface of the country.39% of the arable land has a high erosionrisk. A consequence of farming more intensively, and farming on steep slopes is the highincidence of soil loss due to erosion, and, along with it, declining soil fertility. Rwanda's Agricultural Development Agency estimated that half the country's farmland suffers from moderate to severeerosion. Demographic pressure is driving soil degradation in Rwanda.

The cultivated area is 8,520 km^2, i.e. 61.5% of the arable land and 31% of the total surface of the country. The size of cultivable land per family is 0.6 ha. Each farm in Rwanda comprises 5 to 6 members, half of them below 15 years of age. The crop for food consumption occupies 92%. The export of agricultural goods is dominated by coffee and tea. Rwanda does not satisfy the food needs for its population with its own agricultural production.

In terms of potential agriculture lands, Rwanda has 1,649 km^{2}of swamps of which 1,119km^2 belong to the lower hydrographic systems and 531 km^2 to the primary system. The total surfacearea under use is estimated at 938 km^2, equivalent to 57% of the total area of marshlands in thecountry. Those marshlands are regularly flooded during the rainy season and prevent anyagriculture activity. These marshlands, however, reduce the maximal flow rates during the rainy seasons andmaintain a relatively high flow rate during dry seasons. Only 130 km^2 of swamp is currentlymanaged with moderate irrigation structures.Different techniques aiming at water control and soil conservation in the steep terrains are used. The agricultural survey carried out in 1984, showed that of the 1.34 million ha available for agricultural sector, only 1.1 million ha were effectively used for food production, reforestation and pastures.In regard of the Marshland Master Plan framework, Rwanda defined the priority of products to becultivated in order to reduce the costs intended for food importation.

Hillside irrigation is practiced at small scale in the following places (Government of Rwanda, 2010):

- 12 ha in Gashora for cassava production (sprinkler irrigation)
- 50 ha of coffee farms in Ngugu near lake Rwampanga in Kirehe district
- (sprinkler irrigation)
- 100 ha of different crops along a stretch of 8 km from Ntaruko, Ndaba, to
- Rubengera in Karongi District (gravity-fed irrigation)
- 600 Ha at Nasho (pressurized irrigation)
- 1750 Ha in MUVUMBA (pressurized irrigation)
- 400 Ha in KAGITUMBA (pressurized irrigation)

2.4.2 Irrigation

Agriculture in Rwanda is susceptible to the vagaries of the climate, due to the absence of sufficient irrigation and water storage systems. To address this problem the Rwandan Ministry of Agriculture has introduced measures to increase food production. First, the government is carrying out a large scale study into the potential for rolling out a national irrigation system across Rwanda. Secondly, the government is seeking the means to provide irrigation by working on hillside rainwater catchment and household level irrigation methods. Thirdly, the government has plans to reclaim swampland in order to facilitate a major increase in rice production. Rice was chosen as a government priority crop, because of its limited vulnerability to rainfall and its suitability for planting in marshlands. (AfDB/OECD (2007) African Economic Outlook).

In 2010 the Rwanda government completed the Irrigation Master Plan (IMP) in collaboration with ICRAF. The IMP covered a broad set of topics and was specifically meant to support decision making. The study concentrated mainly on the use of GIS. In addition to collecting physical data, the study gathered administrative, social and economic information. The data were categorised into four groups:

- Administrative and infrastructural: political subdivisions, roads, electricity
- Land and soils: land use, land cover, geology, lithology, geomorphology, detail of soil layers, topographic data, elevation, slope
- Climate: temperature, precipitation, potential evapotranspiration, agroclimatic zones
- Water resources: hydrography, hydrometric stations, hydrogeology

The disciplines applied in analysis include irrigation engineering, pedology, agronomy, socioeconomics, environmental and social impact assessment, livestock husbandry, agroforestry and GIS. As a tool, it enables the decision maker to choose from among relevant options, rank areas in order of suitability, and support priority settings for scheduling the development and allocation of irrigation resources.

The IMPof Rwanda indicated that the irrigation potential of the country is nearly 600,000 ha, taking into consideration the following domains:

- Runoff for small reservoirs (125 627 ha)
- Runoff for dams (31 204 ha)
- Direct river and flood water (80 974 ha)
- Lake water resources (100 153 ha)
- Groundwater resources (36 434 ha)
- Marshlands (222 418 ha)

The IMP mentioned that there are pertinent policy and legal issues for the Government of Rwanda to tackle in order to set the right environment for implementation of irrigation schemes. Quite often, the lack of incentives has resulted in the collapse of many an irrigation project.The government will have to develop policies geared towards the reduction of energy tariffs and cost of irrigation equipment. The government should also offer tax rebates for the importation of irrigation equipment.

Regarding Institutional arrangements, an inter-ministerial committee charged with the responsibilities of guiding and monitoring irrigation implementation should be established to look into the following issues:

- Review and improvement of all irrigation projects
- institutional linkages in a view to reduce duplication;
- implementation of acts and by-laws developed by Government or local support agencies; and
- training and capacity building of various actors and support to irrigation research.

According to the IMP socioeconomic considerations include gender balance, food security, family income and national wealth creation through enhancement of GDP. Since women contribute the majority of labour for both cash and food crop production, user-friendly and affordable technologies should be identified to encourage their participation and boost the livelihoods of the poor. Labour-saving capacity can contribute to the mitigation of HIV/AIDS impacts through enhanced production of nutritious foods for improved diets and enhanced generation of family income.

Table 2: Area equipped for irrigation in Rwanda according to FAO-Aquastat, 2010.

Rwanda	ha
1965	4,000
1975	4,000
1985	4,000
1995	5,000
2005	9,000
2012	24,000

2.4.3 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.

Table 3: Area harvested in ha for the 10 most dominant crops (FAOstat, 2010).

	1980	1990	2000	2005	2009
Beans, dry	257.154	262.563	333.205	313.019	345.851
Bananas	224.600	400.570	360.470	361.251	333.774
Maize	71.800	98.522	89.053	109.400	147.129
Sorghum	144.600	133.421	174.195	196.732	146.338
Cassava	45.500	131.768	120.463	115.694	135.519
Potatoes	32.240	42.055	108.983	135.622	126.167
Sweet potatoes	114.175	175.893	174.663	148.526	123.386
Coffee, green	38.000	55.000	23.000	29.625	47.000
Peas, dry	50.600	45.896	29.993	34.796	45.487
Wheat	3.081	9.313	10.043	24.157	42.438
Total	981.750	1.355.001	1.424.068	1.468.822	1.493.089

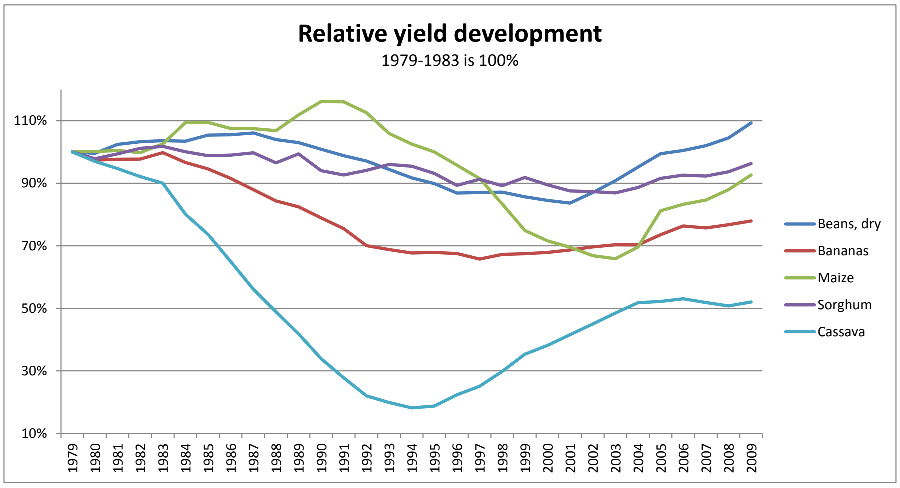


Figure 26. Trend in yields per ha for the five most dominant crops. Average of first five years has been indexed to 100% (FAOstat, 2010).

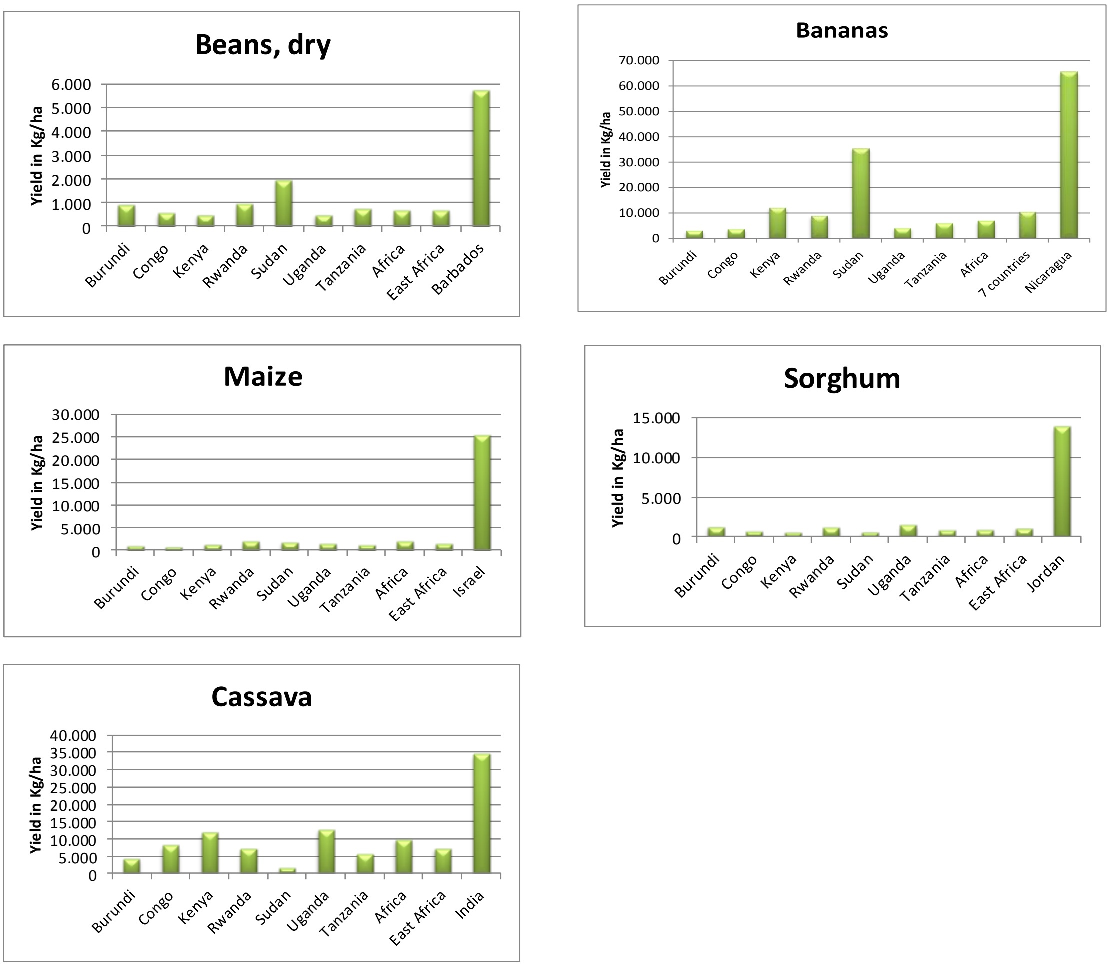
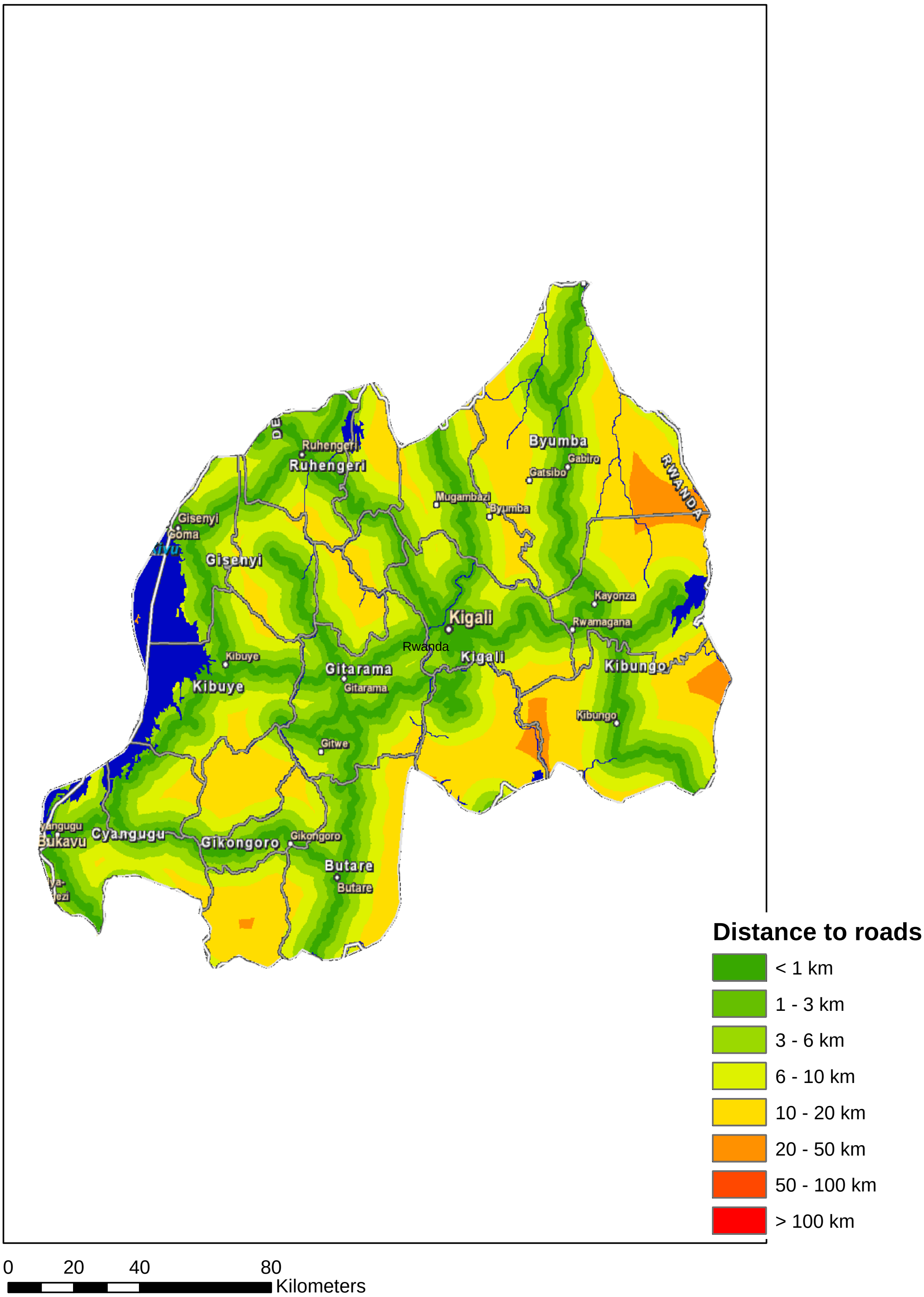


Figure 27.Yield comparison for the five dominant crops in the country. (Source: FAOstat, 2010)

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 regions in the country have good access to transportation. Only some of the more mountainous areas are lacking proper transportation.


Ruhengeri
Ruhengeri
Byumba
Gabiro
Gatsibo
Mugambazi
Byumba
RWANDA
Gisenyi
Goma
Gisenyi
Kigali
Rwanda
Kigali
Kayonza
Rwamagana
Kibungo
Kibungo
Kibuye
Kibuye
Gitarama
Gitarama
Gitwe
Bukavu
Cyangugu
Gikongoro
Gikongoro
Butare
Butare
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 20 40 80
Kilometers

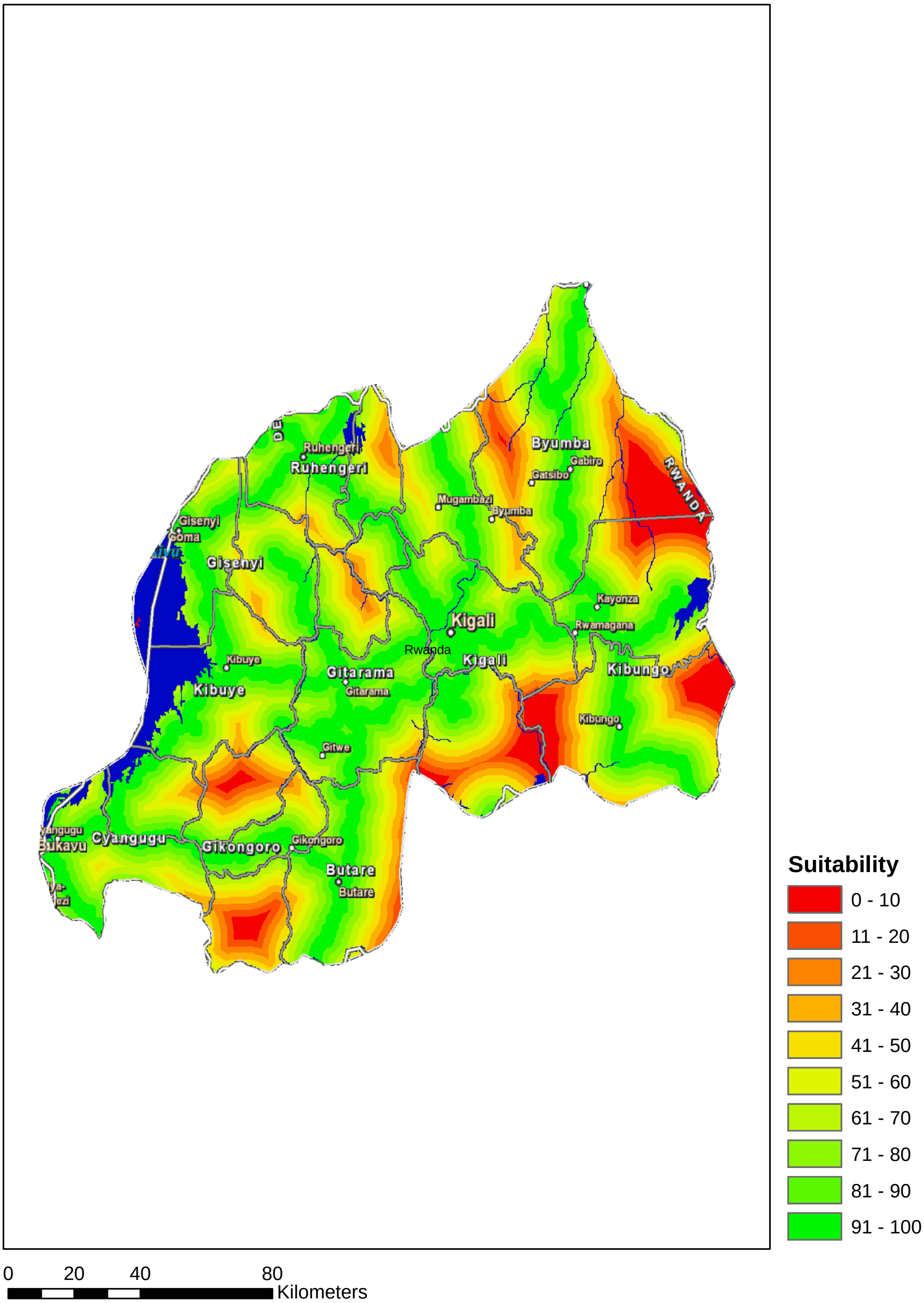
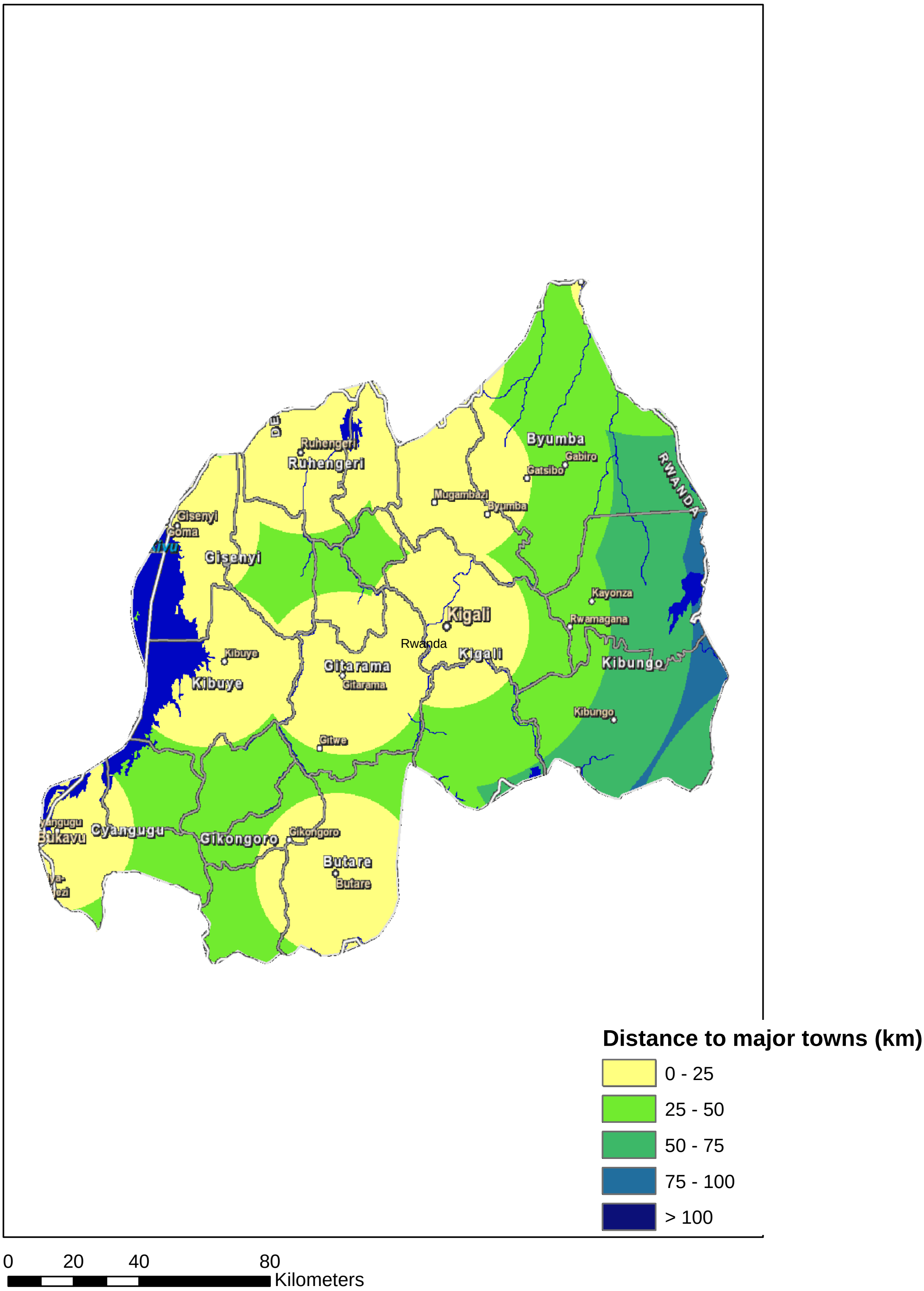
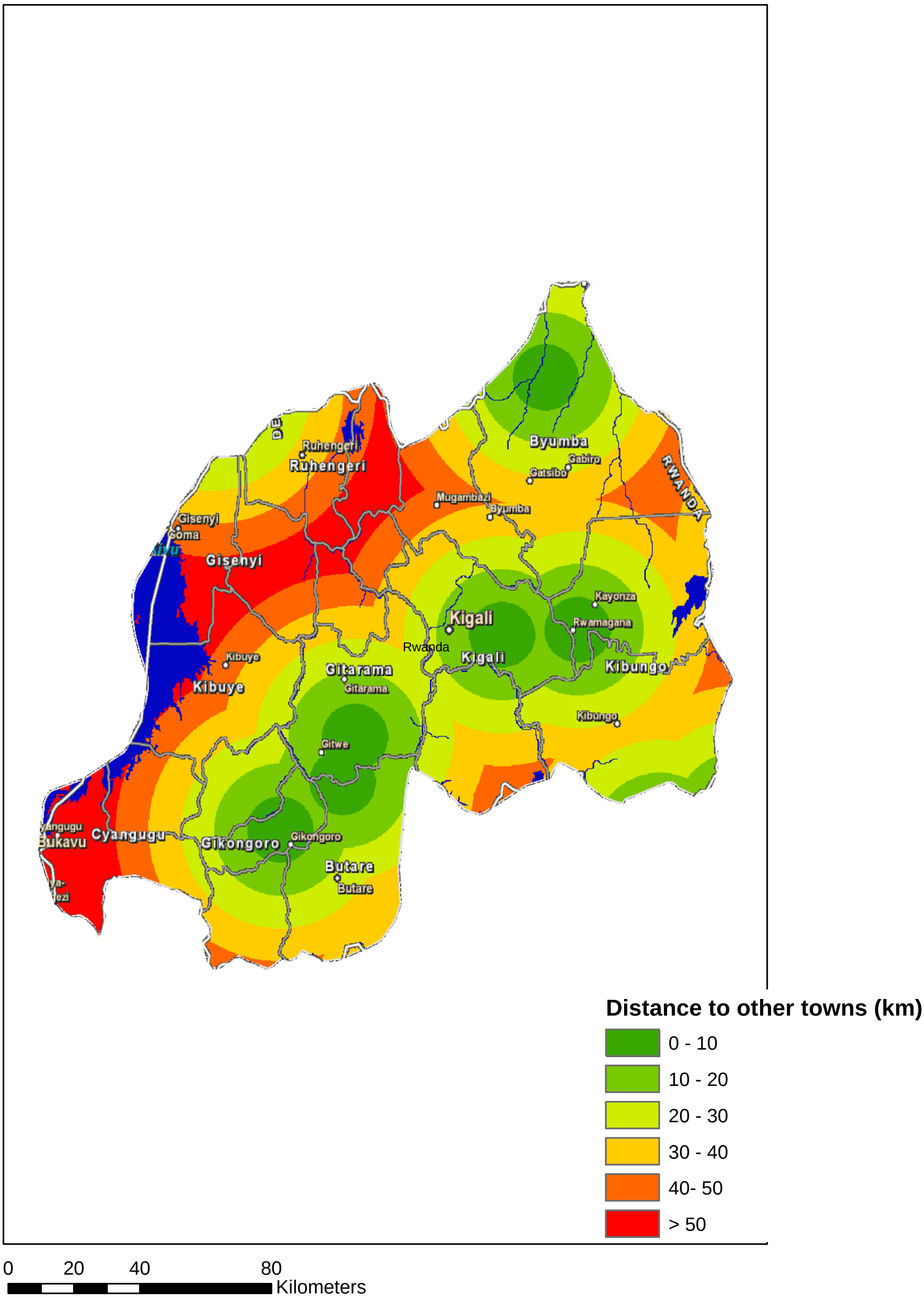


Figure 28: Distance to transportation (top), and suitability (bottom). (Source: study analysis).

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).




Byumba
Gabiro
Gatsibo
Mugambazi
Byumba
Ruhengeri
Ruhengeri
Gisenyi
Goma
Gisenyi
RWANDA
Kayonza
Rwamagana
Kigali
Rwanda
Kigali
Kibungo
Kibungo
Kibuye
Kibuye
Gitarama
Gitarama
Gitwe
Bukavu
Cyangugu
Gikongoro
Gikongoro
Butare
Butare
Distance to other towns (km)
0 - 10
10 - 20
20 - 30
30 - 40
40- 50
> 50
0
20
40
80
Kilometers

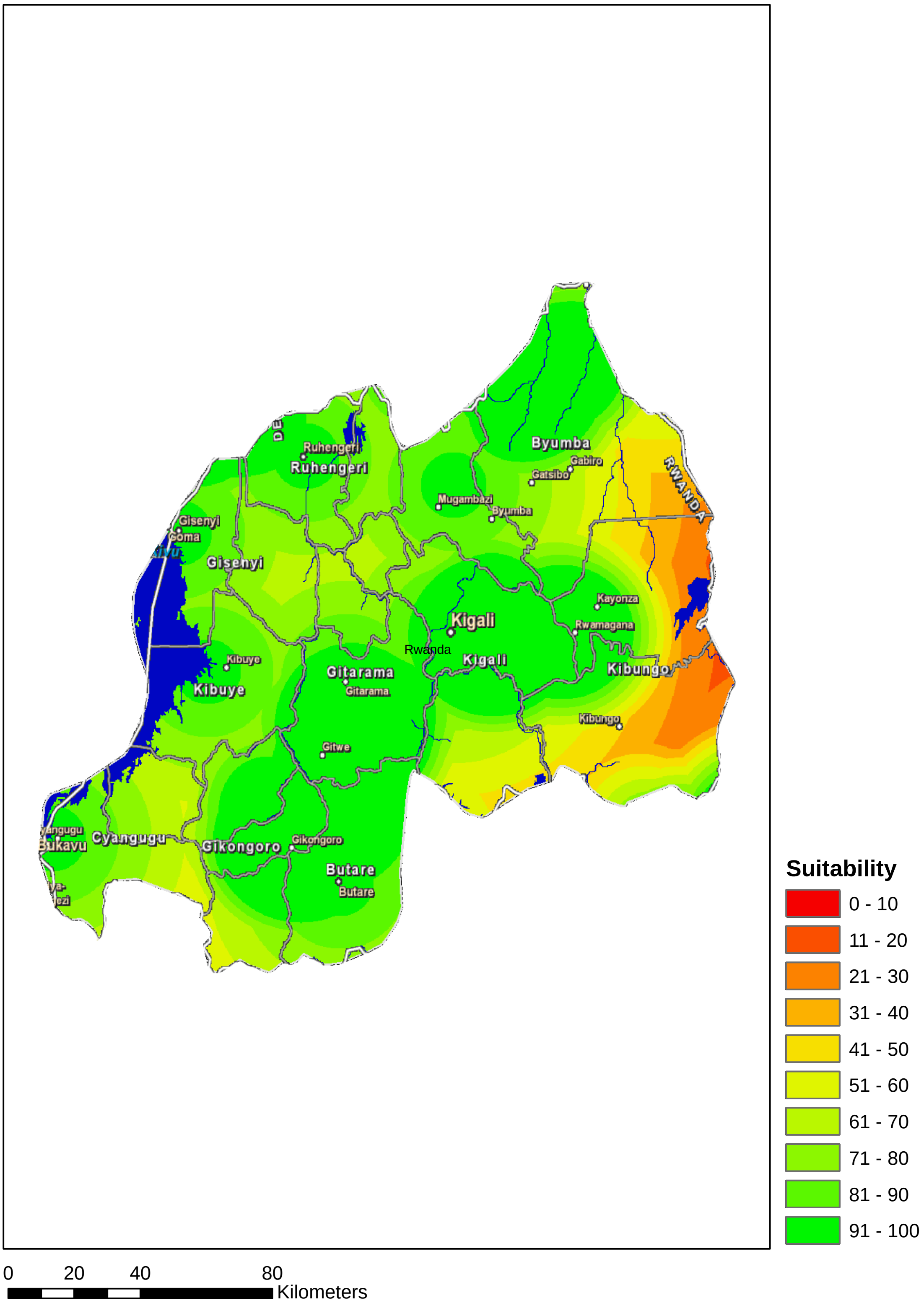


Figure 29: Distance to major towns (top), distance to other towns (middle), and combined suitability index (bottom). (Source: study analysis).

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. Population density can be observed in the following figure. Overall, population density is relatively low in the region.

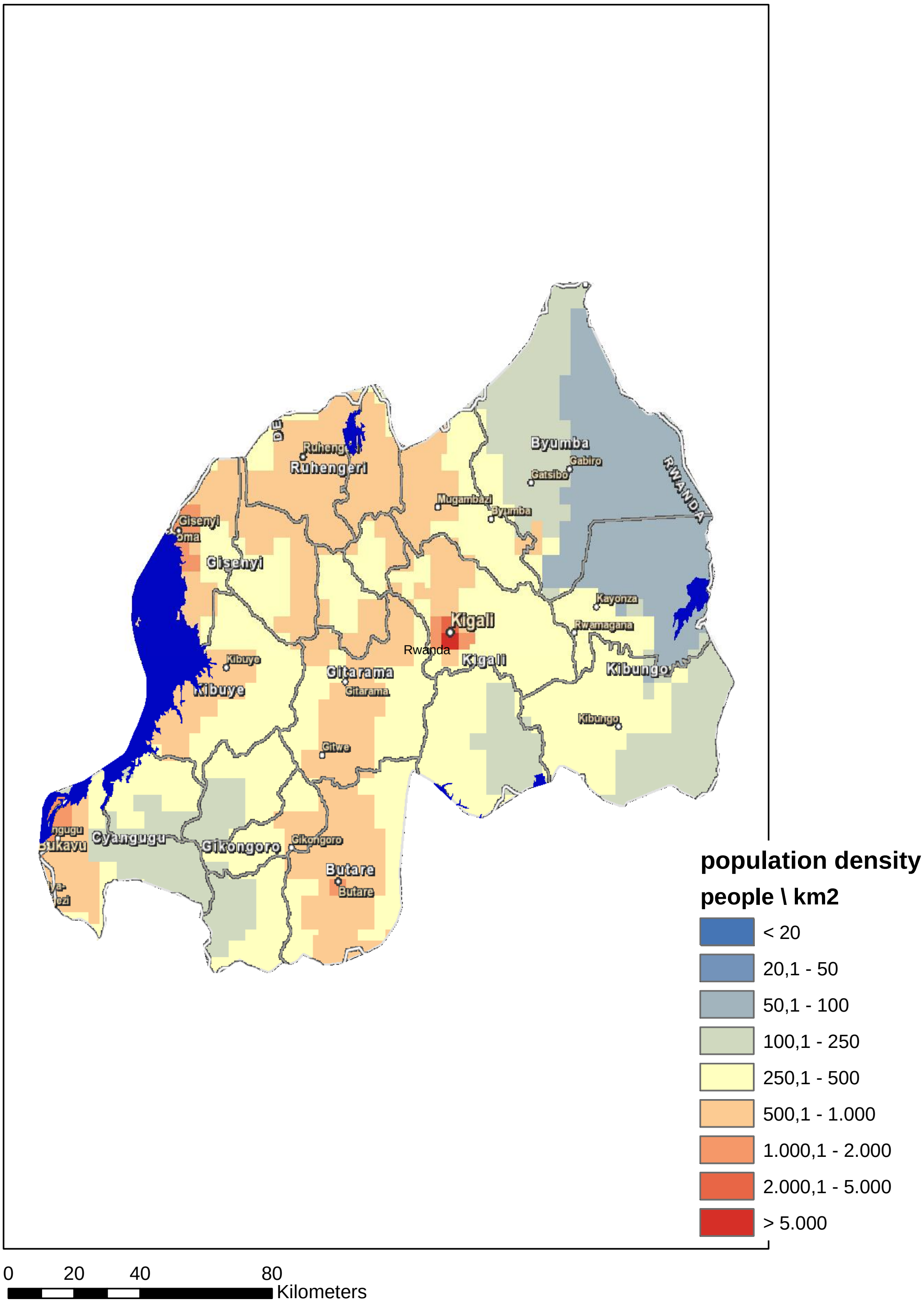


Figure 30: Population density distribution (source: CIESIN).

2.7 Institutional and legal framework

2.7.1 Water treaty agreements

On national level water management is the concern of a large number of ministry departments. Different ministries are responsible for rural water and sewage, - urban sewage and drinking water, - drinking water quality, public health and hygiene. At the same time there are plans to create a national water commission, which will consist of State representatives, national Councilors and representatives from different public and private water user categories and other competent people. This commission can contribute to integrate water aspects more within an IWRM framework on a catchments scale. Authorities on national level are:

- The Rwanda Environment Management Authority), which is responsible for environmental monitoring and preventing damage to the environment.
- The Rwanda Utilities Regulation Authority (RURA), which is supervising the operators in drinking water and distribution. Authority (REMA
- The Rwandan Agricultural Board (RAB) which is in charge of efficiency water use for food security and agriculture purposes.

The districts are the legal entities that own the water and sewage infrastructure.

At the moment of writing the New Partnership for Africa's Development (NEPAD) action plan (2004) the Nile Basin Initiative (NBI) is the only active organization which is internationally managing and developing the trans-boundary rivers within the Nile basin. Another organization, the Kagera Basin Organization (KBO) was established in 1977, but is hardly active anymore nowadays. Under the Nile Equatorial Lakes Subsidiary Action Program (NELSAP) several programs take place on (trans- boundary) basin scale, of which the Kagera Basin project is one of them. Currently, the 1929 agreement and the subsequent 1959 agreement signed by Egypt and Sudan are still in place. This 1959 agreement is purely bilateral; it seeks to apportion the entire flow of the Nile to Egypt and Sudan, excluding the interests of any other riparian countries. Currently under the NBI new negotiations take place to come to an agreement with all the Nile countries. At the time of writing the results from these negotiations are not yet published.

Other international corporations joined by Rwanda are: the Ramsar Convention on wetlands, the African Ministers' Council on Water (AMCOW), the East African Community (EAC), and the Lake Victoria environmental Management Project (LVEMP).

2.7.2 Land ownership rights[1]

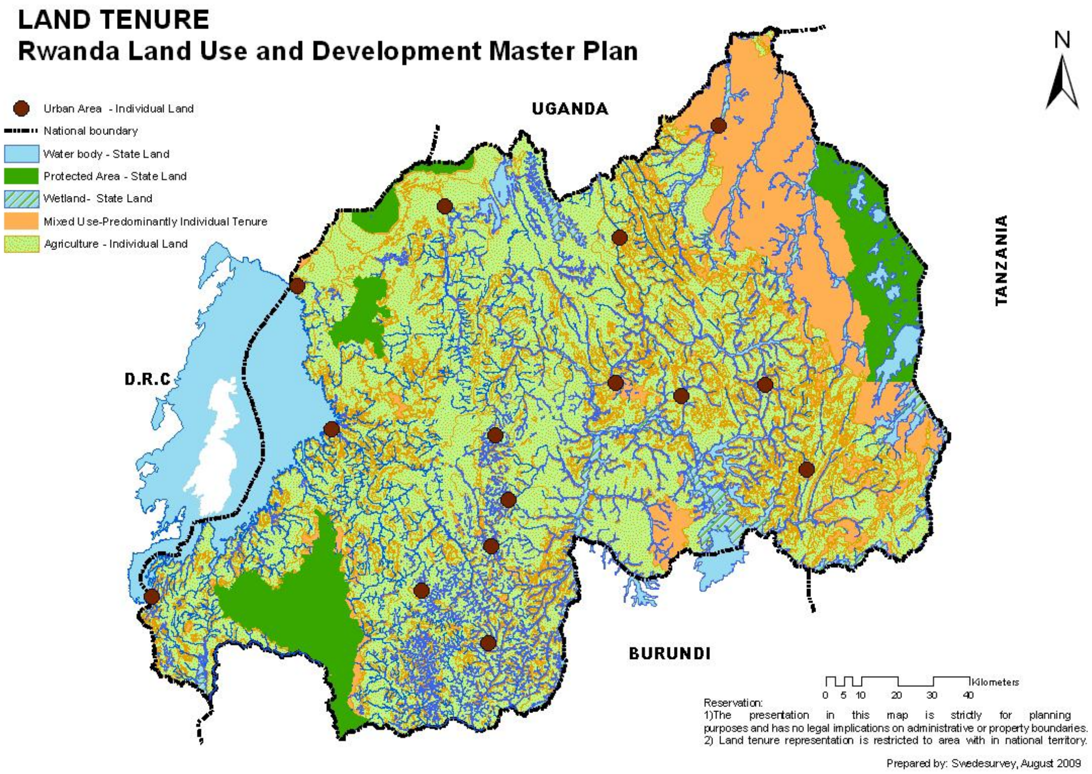
Seventeen years after the conflicts, the Government of Rwanda has made significant progress in reconciliation, governance, and land tenure reform. The government established the Ministry of Lands, Environment, Forestry, Water and Mines (MINITERE) in 1999 (which is now known as the "Ministry of Natural Resources," or "MINIRENA"), drafted a National Land Policy in 2000, passed that policy in 2004, and passed the Organic Land Law in 2005.

Triggers for developing the land law where the high population density, which results in a very high pressure on the land, land degradation, and the lack of appropriate land institutional

[1]This section is based on reports from USAID (2008), and the land ownership document from the government of Rwanda.

framework and laws for land management. The land law developed in 2004 seeks to improve those issues. In general, land tenure is long term lease, by which the lease time depends on the land use. Registration of land became mandatory. Land registration and ownership is seen as a good way to avoid land conflicts and to improve towards a sustainable land use.

Given that 90 percent of the Rwandan population depends on land as their main source of livelihood, peaceful resolution of competing land claims is critical to continued peace.
Current MINIRENA land-related initiatives are focused on implementing the Organic Land Law, including piloting a process for formalizing land rights, drafting the necessary implementing laws and decrees, and developing land administration capacity.



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 Figure 31 and Table 4. 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 100 thousand hectare, including hill-side irrigation. 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. 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.

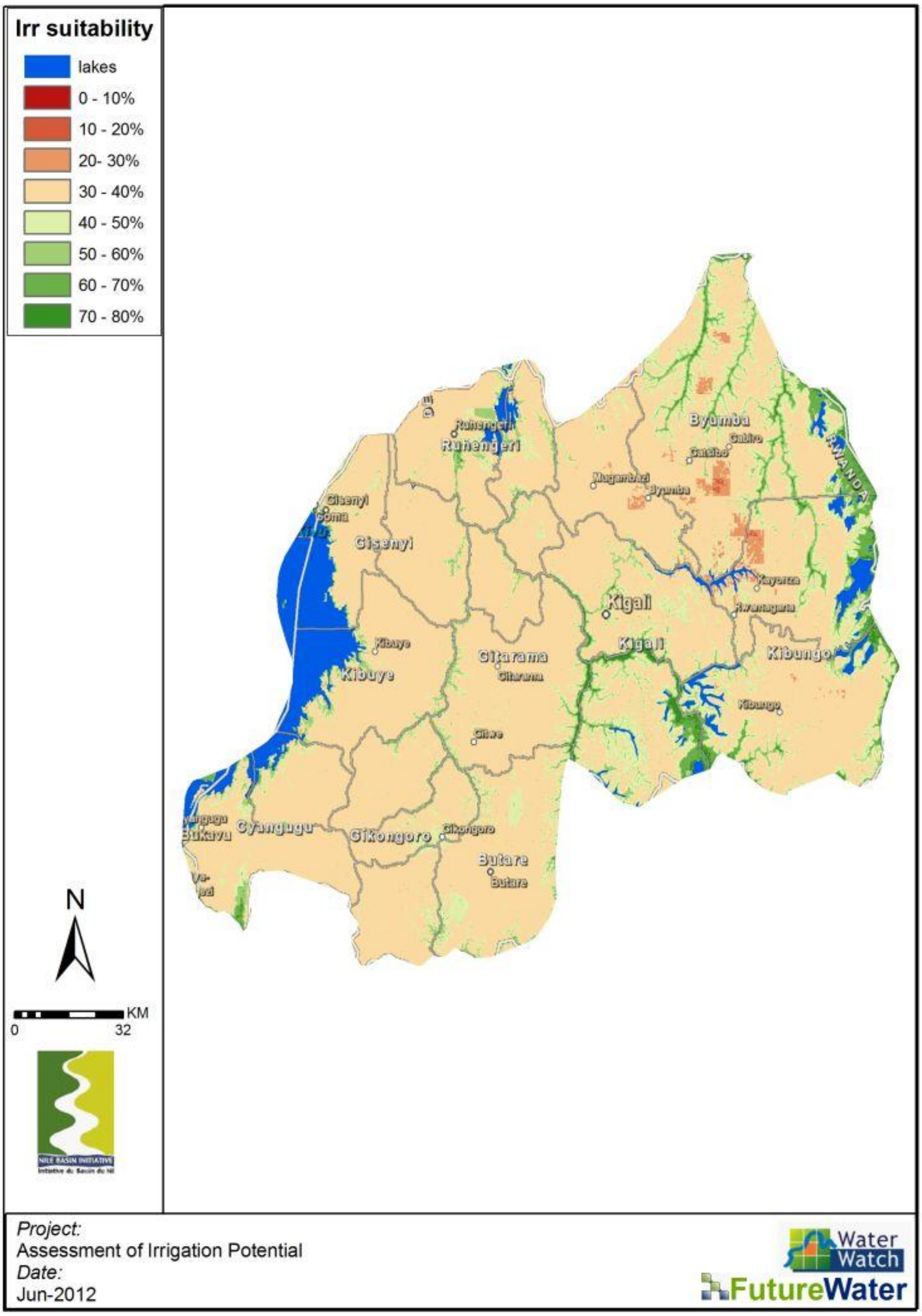


Figure 31: Irrigation suitability score. (Source: study analysis).

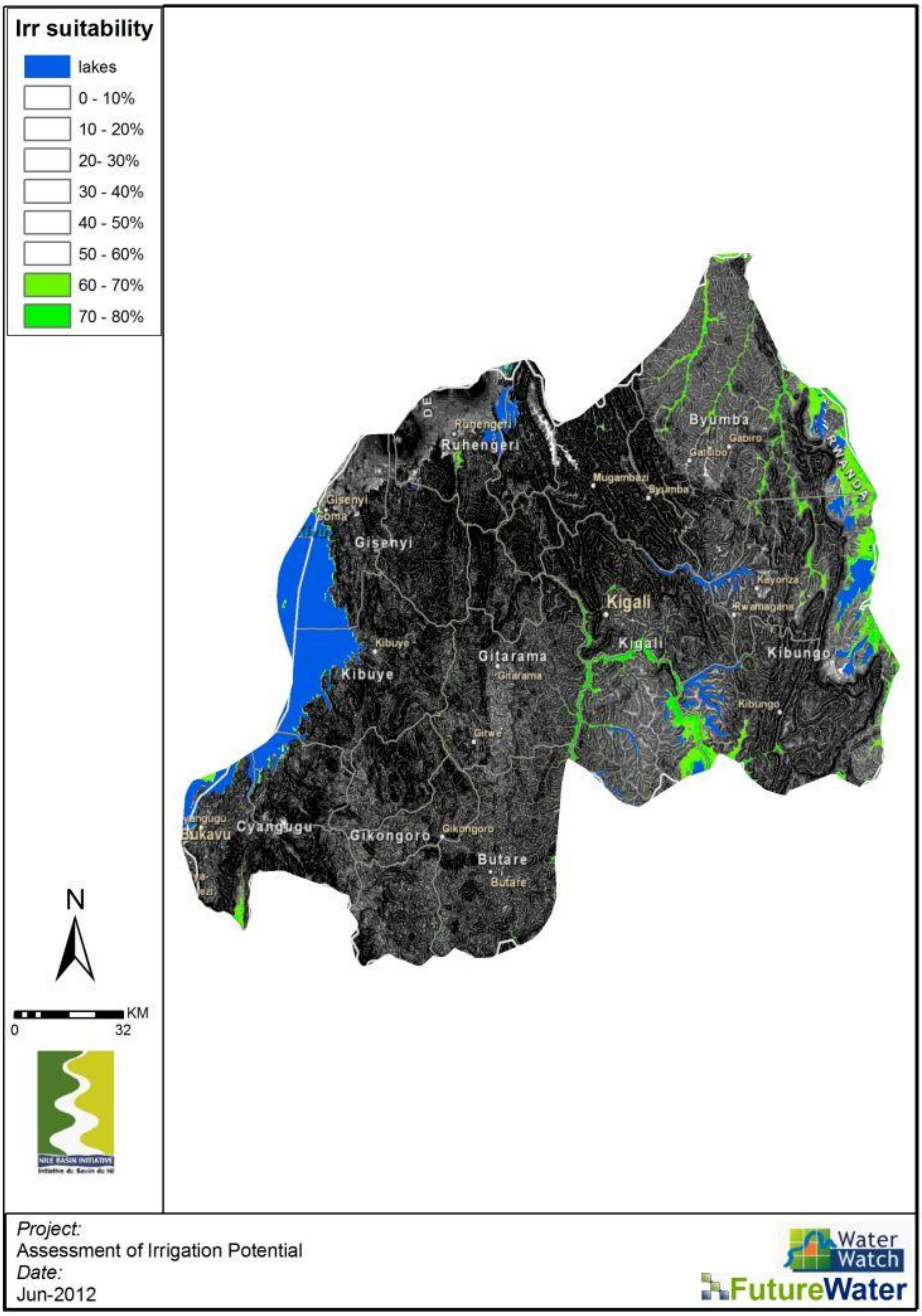


Figure 32.Final map indicating areas suitable for irrigation. (Source: study analysis).

Table 4.Suitability classes. (Source: study analysis).

Suitability	Irrigation potential (ha)
0 - 10%	0
10 - 20%	1,375
20 - 30%	25,531
30 - 40%	1,779,888
40 - 50%	363,463
50 - 60%	125,275
60 - 70%	69,919
70 - 80%	29,938
80 - 90%	0
90 - 100%	0
Total >60%	99,856

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 5the names and areas are given, and in Figure 33 a map is supplied on which the focal areas are shown.

Table 5: Focal areas Rwanda. (Source: study analysis).

	Muyira/Butare	Sake	Akagera NP	Nyabitekeri	Kigali
Area in ha	6818	2073	6558	12927	2694

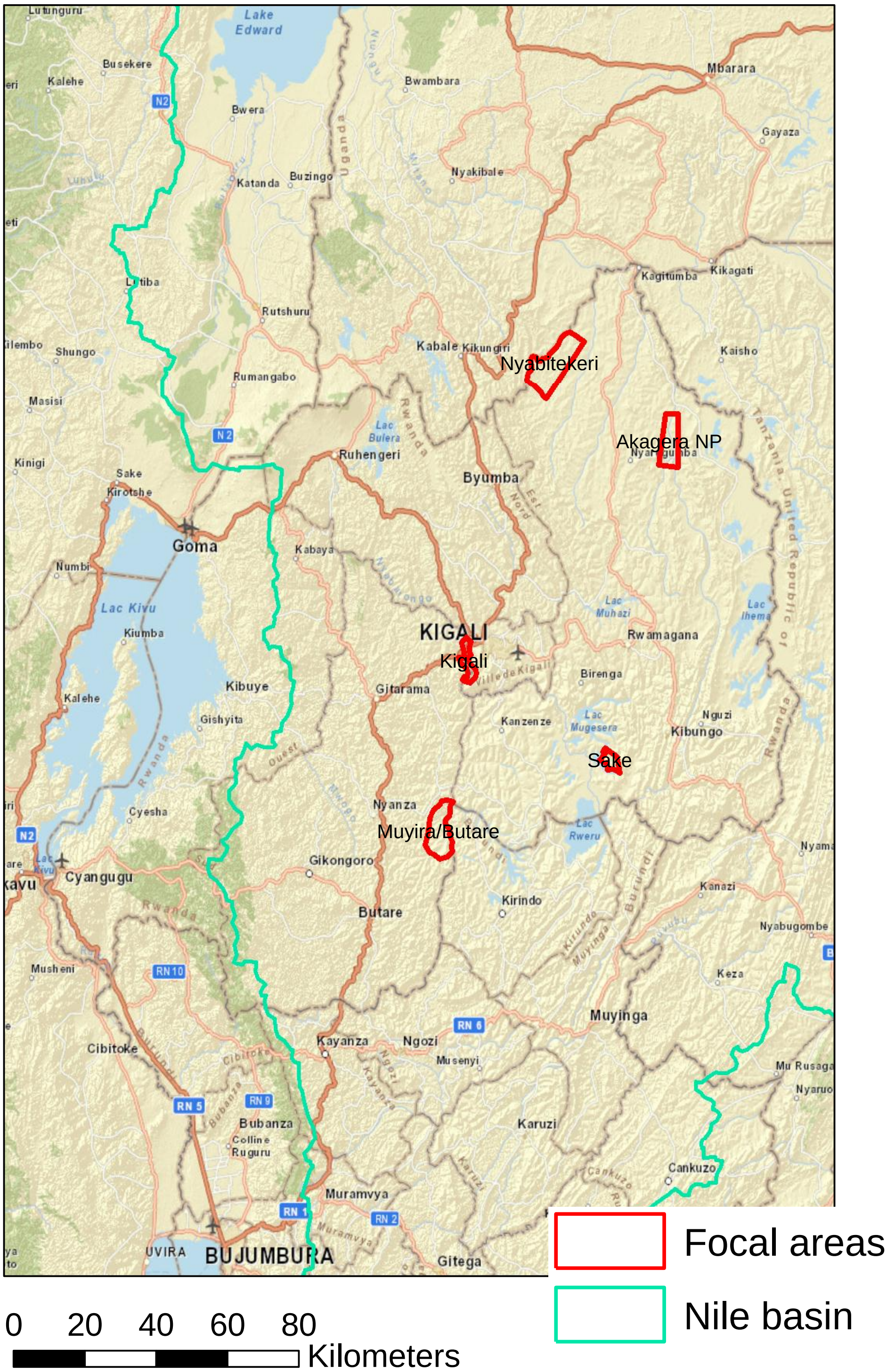


Figure 33: Overview focal areas Rwanda. (Source: country experts)

3 Muyira/Butare focal area

3.1 Introduction

This chapter will describe the current state of the Muyira/Butare 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 35a detailed map of the area is given. Total area is 6818 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 in March 2012.

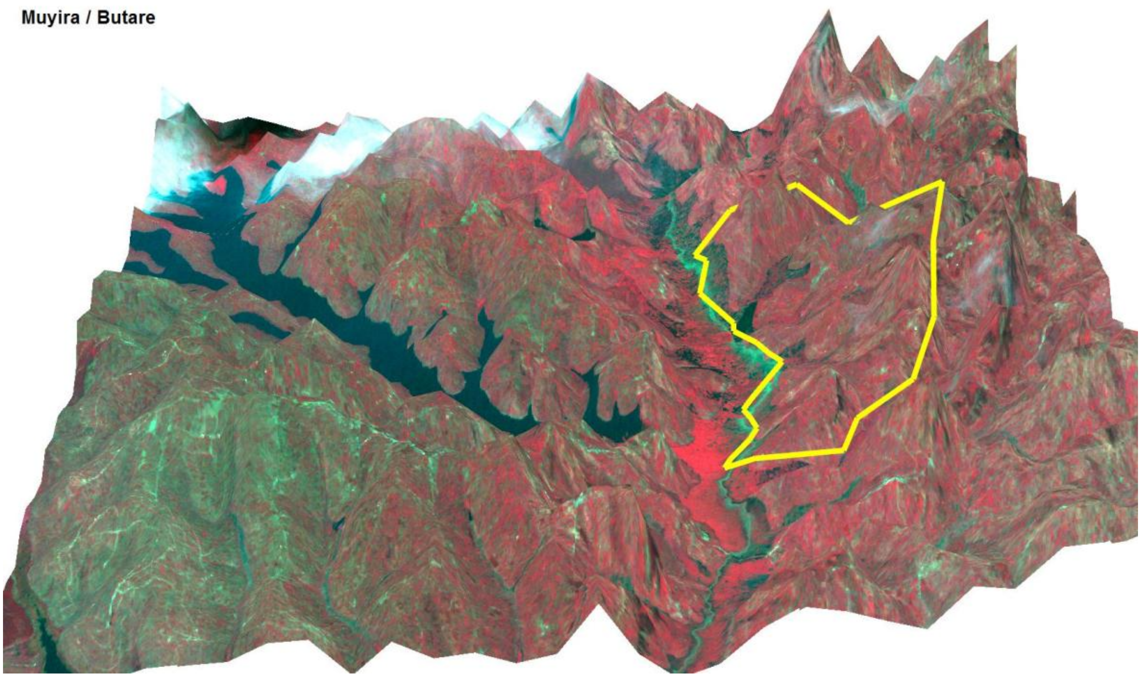


Figure 34: 3D impression of Muyira / Butare focal area, Rwanda. (Source: Landsat)

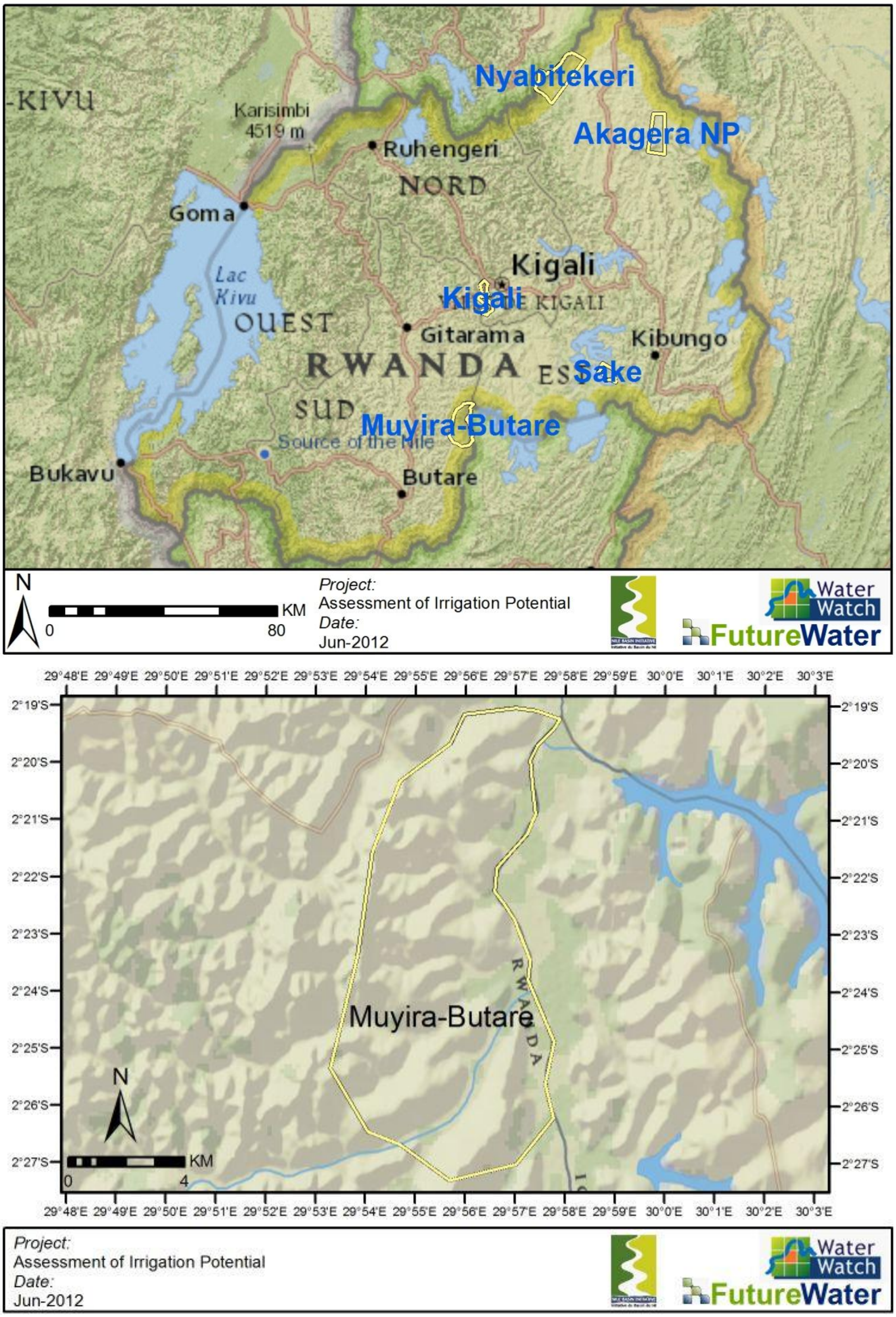


Figure 35: Muyira/Butare focal area, Rwanda. (Source: country experts).

3.2 Land suitability assessment

3.2.1 Terrain

This focal area is situated on the border with Burundi and is expanding from the Akanyaru River towards the west. The river is located at an average height of 1350m above sea level and the focal area is rising from the valley bottom and expends over several foothills reaching up to 1500m (Figure 36).The valley bottom is flat, and towards the west the slope increases rapidly reaching as much as over a ten percent slope.The transmission slopes from the foothills towards Akanyaru swamp are steep, but the slopes on the hilltop decrease to 1-5% (Figure 37).The diversity in slope percentage suggests that a range of irrigation methods should be assessed for their suitability within this focal area.

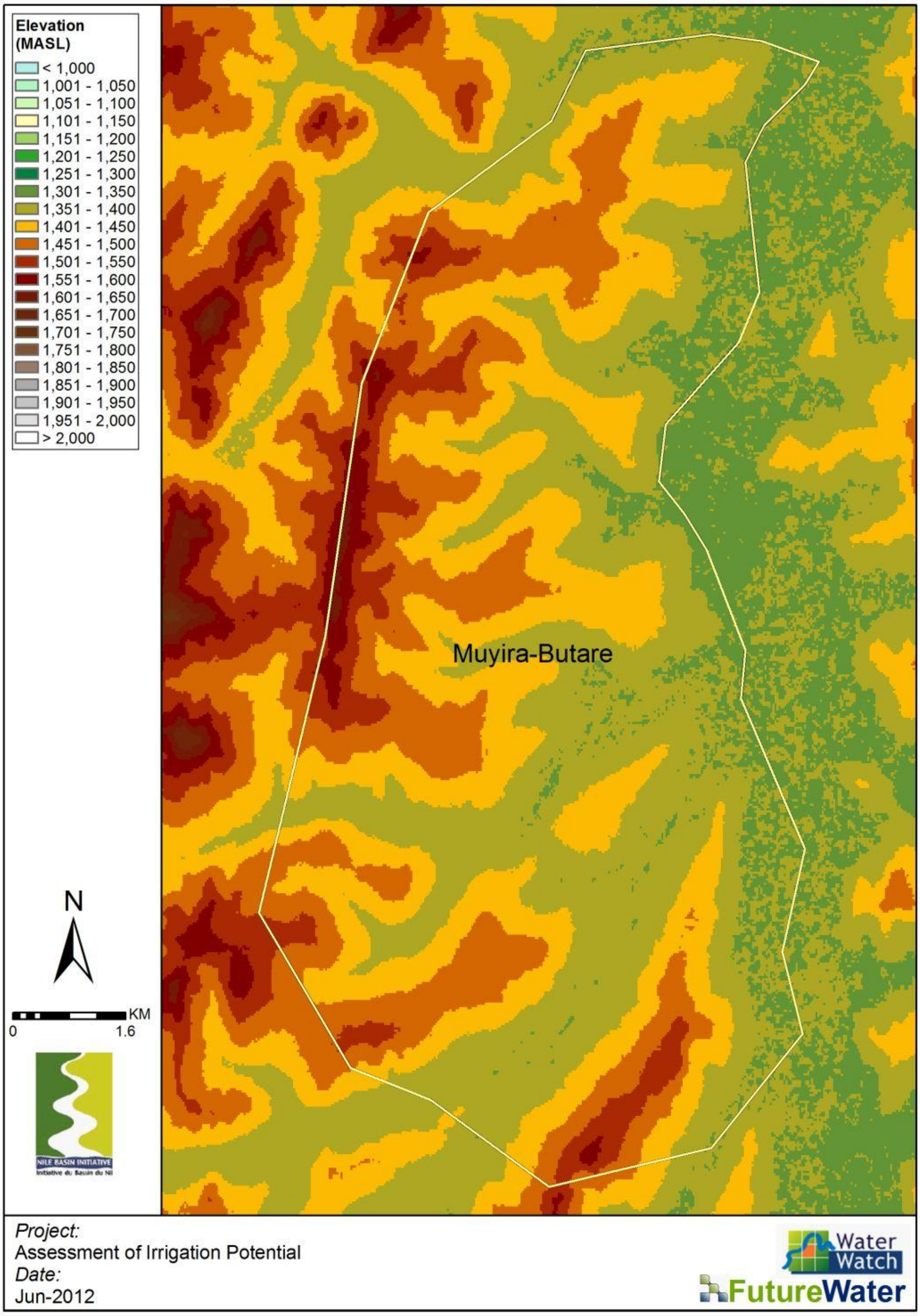


Figure 36: DEM Muyira focal area. Resolution 1 arc second (+/- 30m). (Source: ASTER)

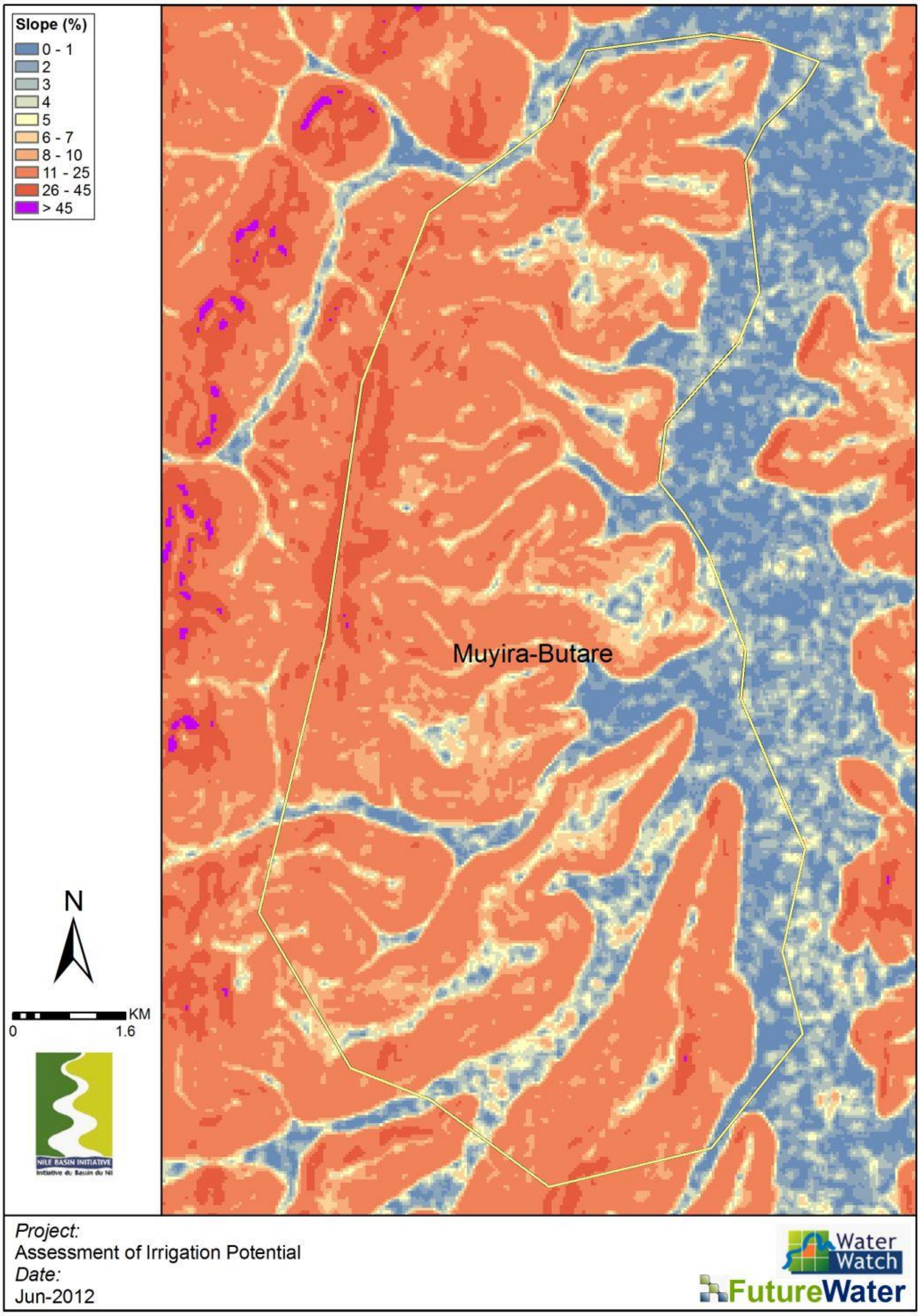


Figure 37: Slope map Muyira/Butare focal area. (source: ASTER)

3.2.2 Soil

Geomorphological the focal area is split into two parts;the alluvial plain in the east, formed by the Akanyaru-river, and the rounded hills towards the west. The soil on the foothills consists alternately of granite, granitic gneiss, meta-sediment, quartziticmicaceous schist and amphibolites. In practice this means that soils are mainly well drained deep soils (>60%). Soils are dark brown and sandy loam to clay with a relative high percentage of organic matter in the top soil (>2%). Due to erosion and the high pressure on agricultural land, the land is degraded in some places. Fertilizer is used on small scale. On the steep slopes, the stones restrict the agricultural practice slightly. There are no signs of salinization.

3.2.3 Land productivity

The focal area has averagehigh land productivity,which is comparable to the Rwandan average. The Normalized Difference Vegetation Index(NDVI) shows that the Akanyaru valley has a yearly average NDVI of 0.7, and decreases to 0.55 higher on the foothill in the west (Figure 39). The coefficient-of-variation is most stable in the valley as well, and shows a bit more variation in the hills. The year-round stable water supply in the valley can explain this difference, while the land productivity in the foothills is depending on the different rainfall seasons.

The NDVI formula is:

$$\frac{(NIR - RED)}{(NIR + RED)}$$

The NDVI is calculated based on remote sensing Modis images, and in more detail the Nearly InfraRed band (NIR) en de visible RED band (RED). The ratio between these two bands shows the productivity between -1 and 1. Plants absorb the red light for their photosynthesis, and reflect the NIR light.

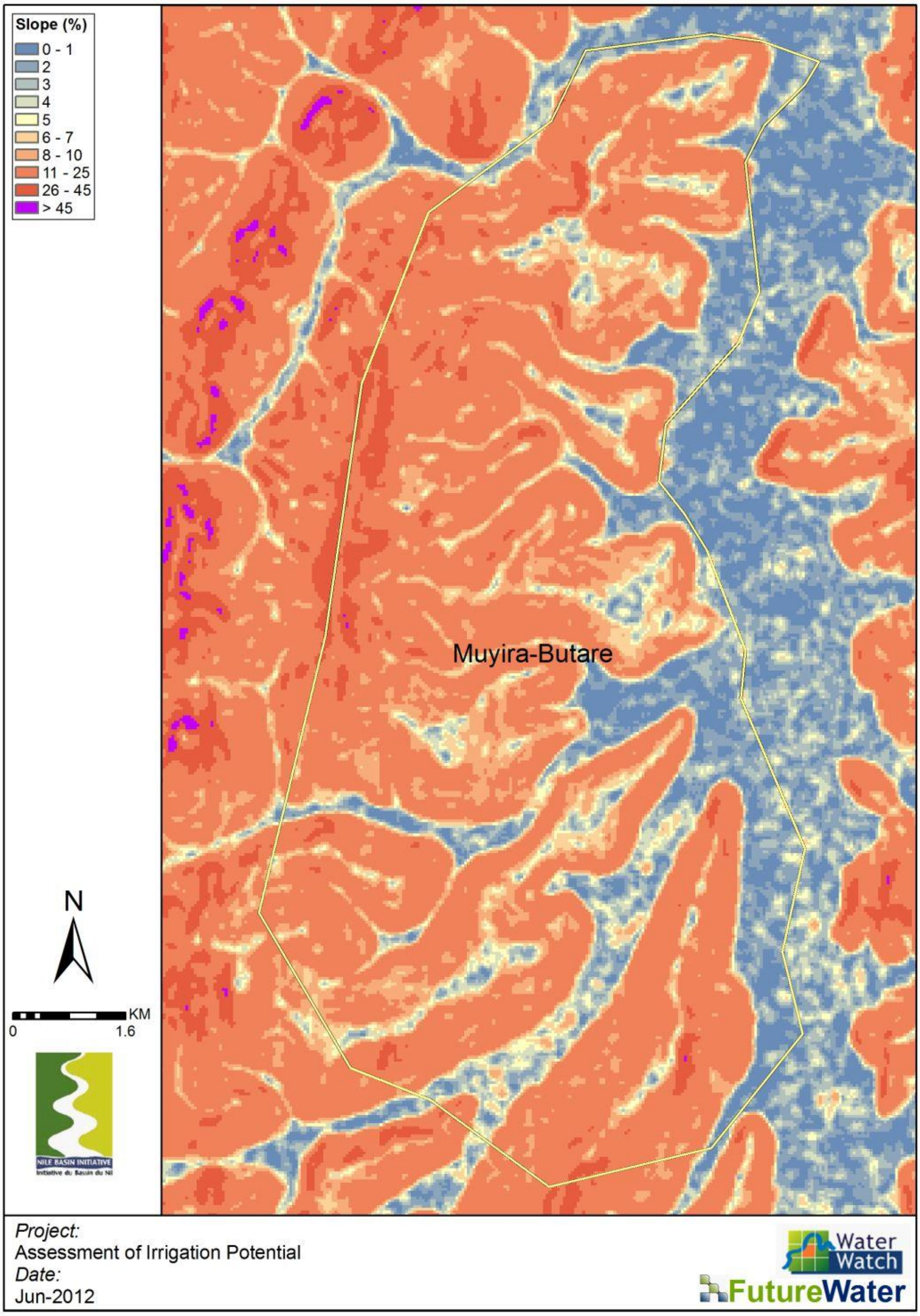


Figure 38: High resolution NDVI for Muyira/Butare focal area. (Source: Landsat)

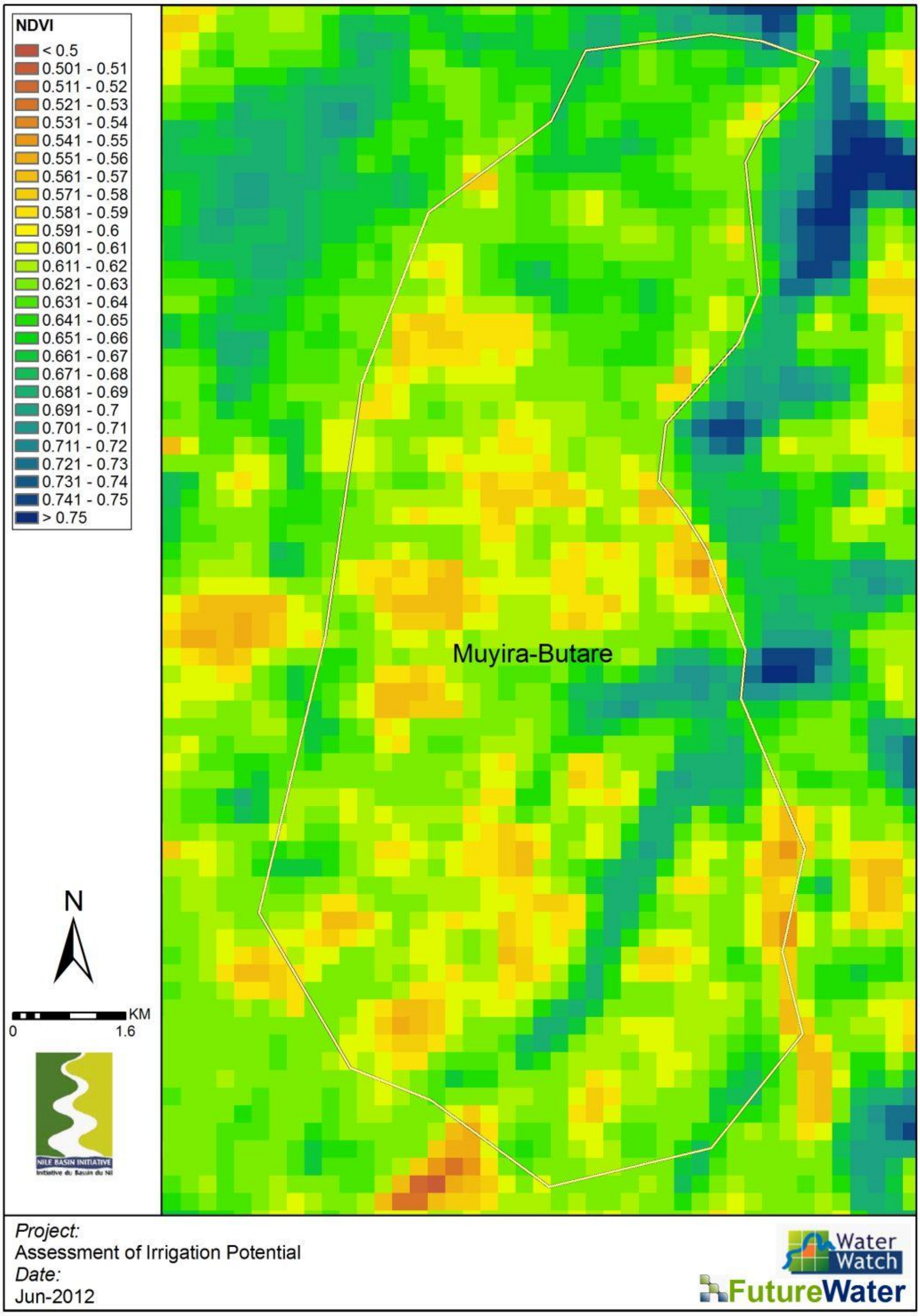


Figure 39: Yearly average NDVI values for Muyira/Butare focal area. (Source: MODIS).

3.2.4 Potential cropping patterns

Currently,approximately 90% of the land is used for agriculture. Half of the land is covered with perennial crops, such as banana (40%) and coffee (10%). In one growing cycle per year, maize and cassava are grown on approximately 30% of the land surface. Beans are grown on the remaining 10% agricultural land, and are grown in two cycles per year. Other crops, which are grown on a small scale, include cassava, soya, groundnuts and sweet potato.

The government policy, regarding irrigation development, is to focus on high value crops with agro industry linkage. Therefore, the potential future crops include maize, pineapple, soy beans and green beans. In the Akanyaru valley maize will be the dominant crop. With irrigation the cropping intensity can be increased, and most crops can be grown in two or even three growing cycles.

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 constant temperatures during the year ranging from about 15°C to 26°C. Annual average precipitation is 1180 mm and reference evapotranspiration 1470 mm per year.

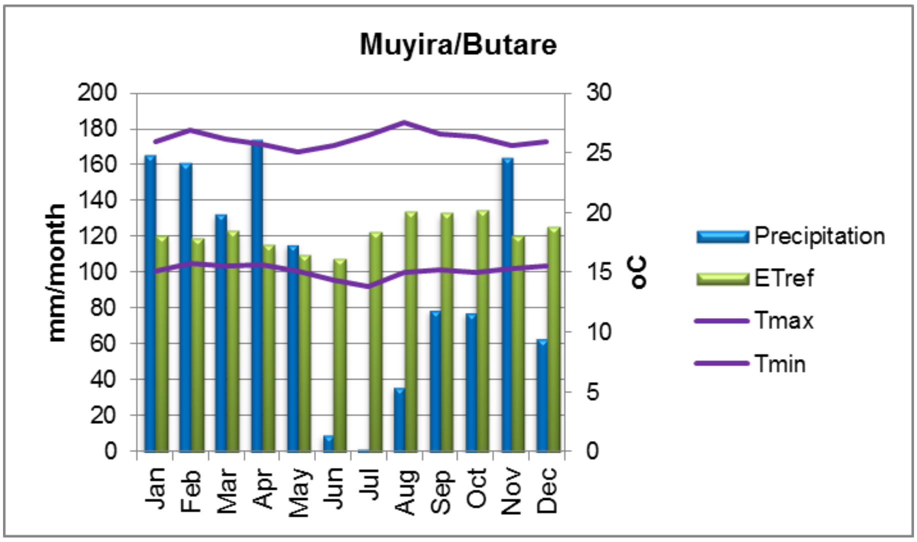


Figure 40: Average climate conditions for the focal area. (Source: study analysis).

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.

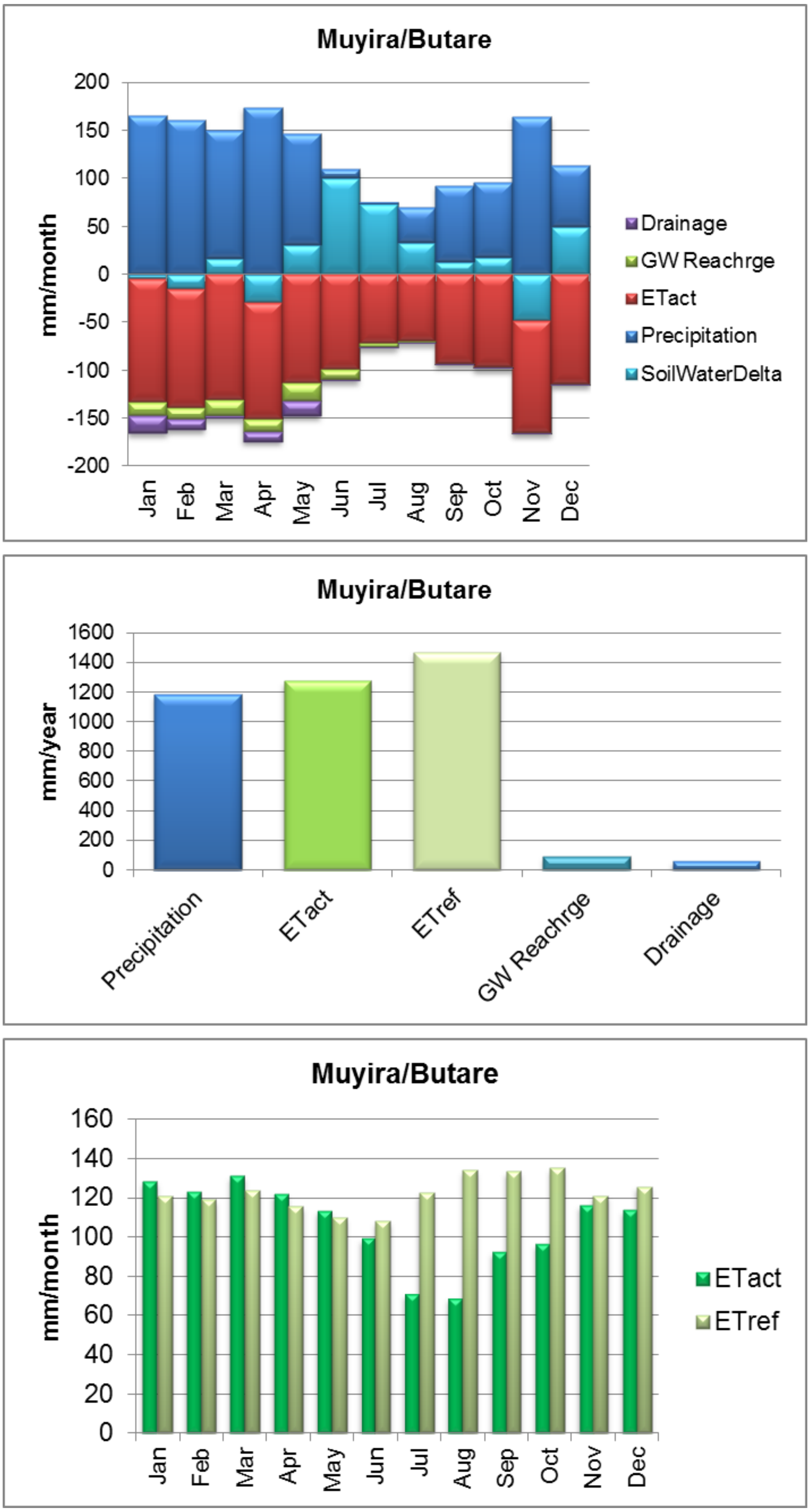
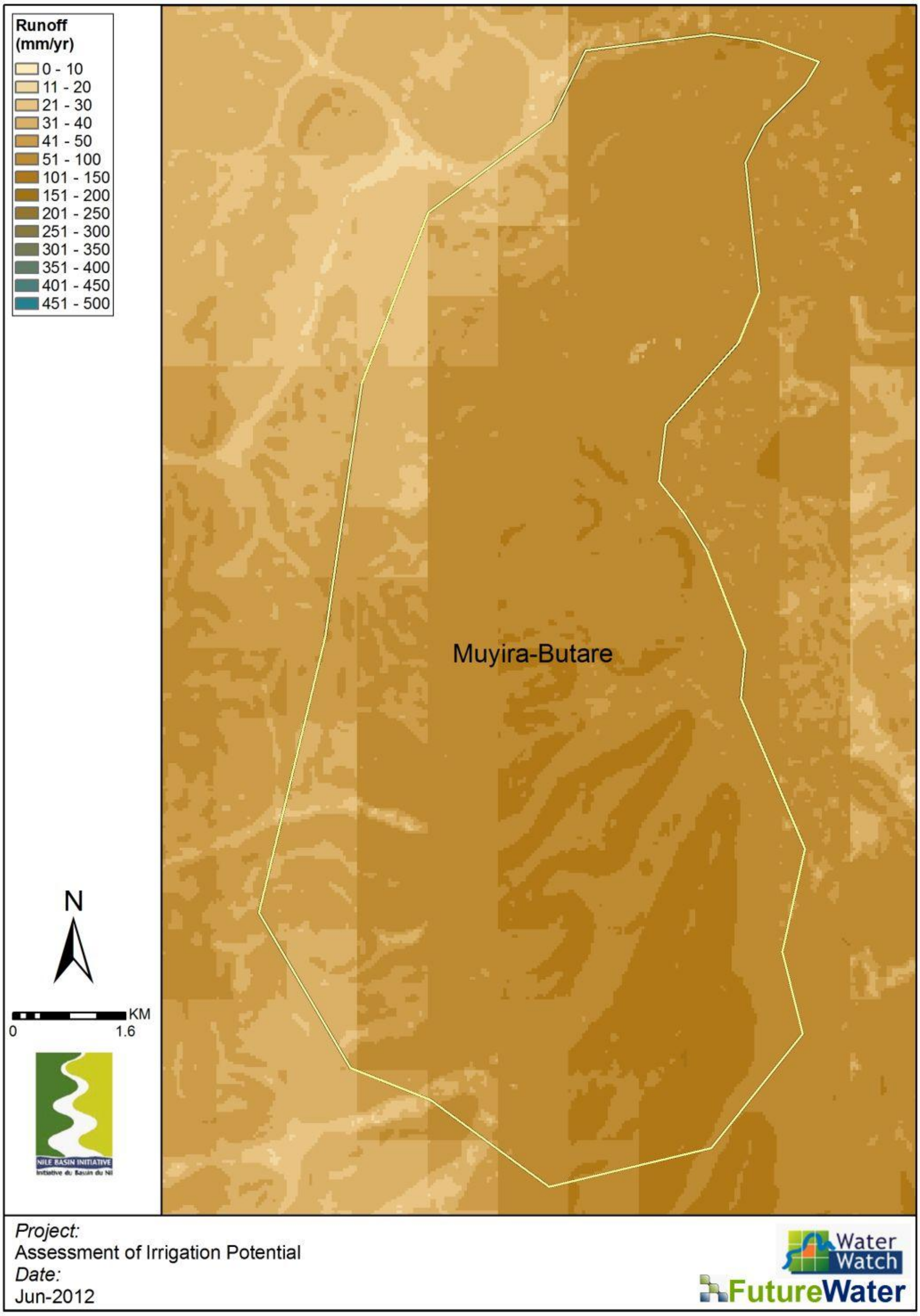
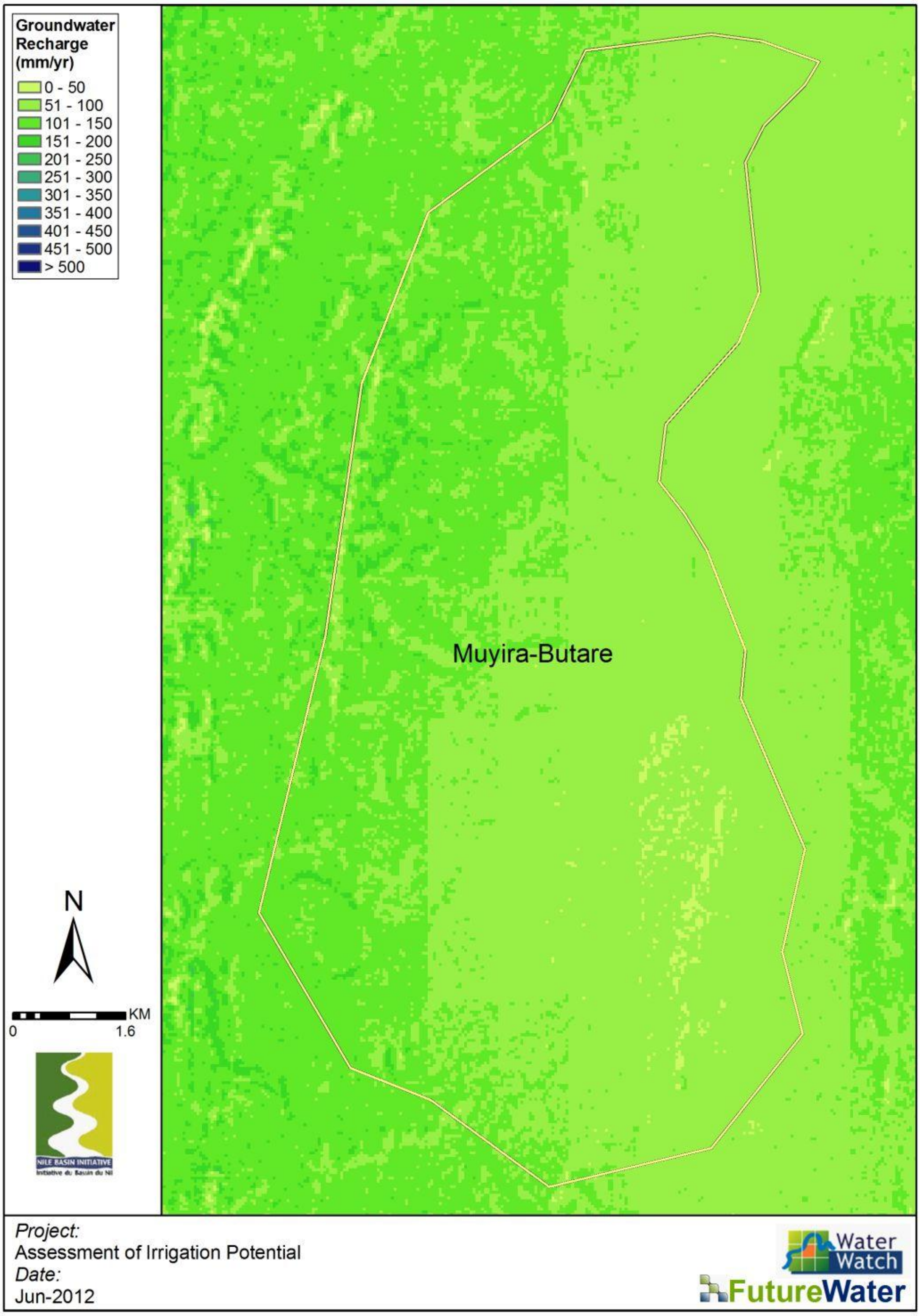


Figure 41: Water balances for the area based on the high resolution data and modeling approach for Muyira/Butare focal area. (Source: NELmod).


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
Muyira-Butare
N
KM
0
1.6
NILE BASIN INITIATIVE
Initiative du Bassin du Nil
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
Muyira-Butare
N
KM
0
1.6
NILE BASIN INITIATIVE
Initiative du Bassin du Nil
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

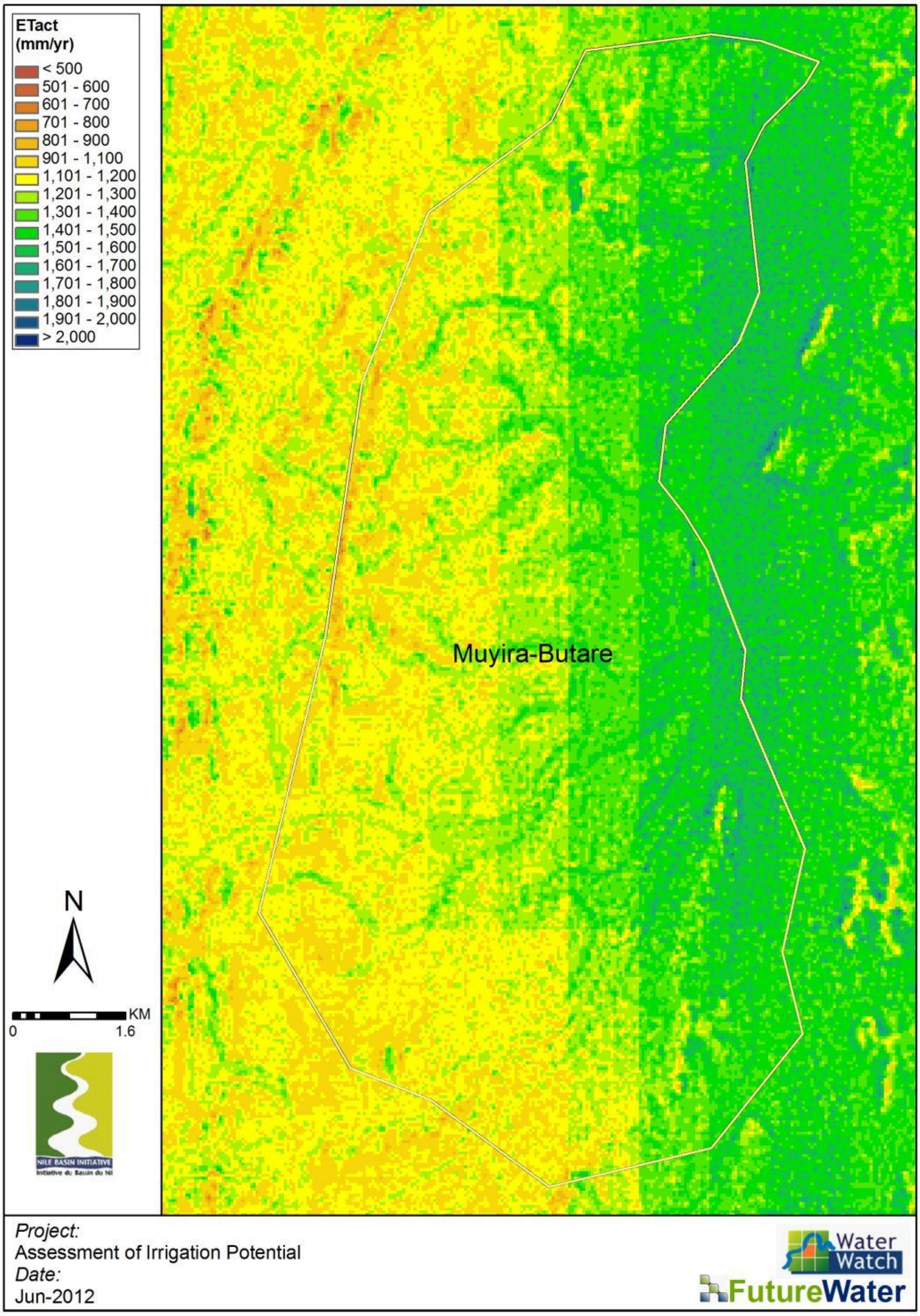


Figure 42: Water balances for the area based on the high resolution data and modeling approach for Muyira/Butare focal area. (Source: NELmod).

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.

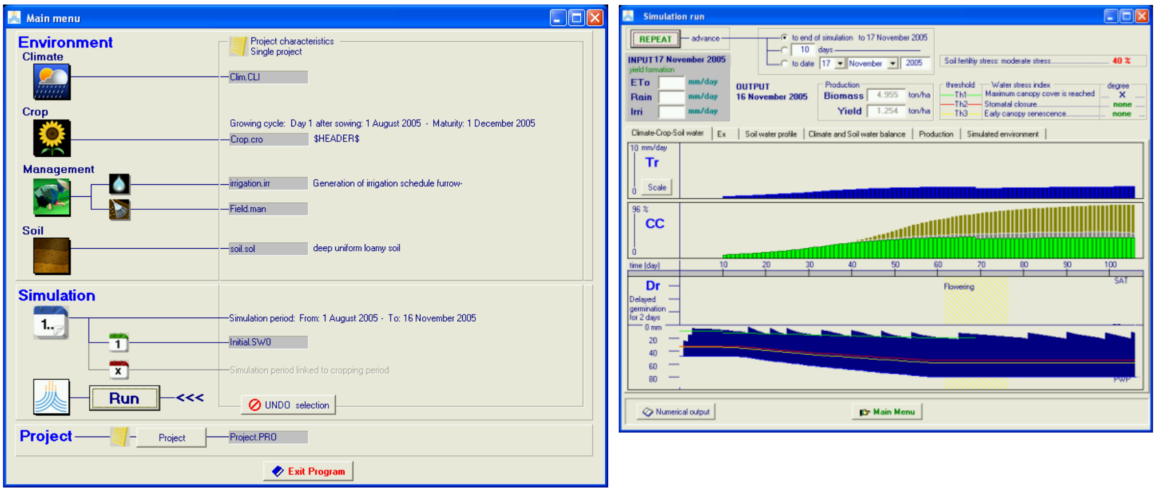


Figure 43: Typical example of AquaCrop input and output screens.

Table 6: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season. (Source: AquaCrop).

Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year ===		== (day of year) ==		======== growing season =======			
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Maize	1184	1468	274	30	469	230	502	459
Pineapples	1184	1468	1	365	1186	120	1464	670
Soybeans	1184	1468	16	182	673	90	632	442
Beans, green	1184	1468	1	365	1186	90	1464	673

3.4.2 Irrigation systems and irrigations efficiencies

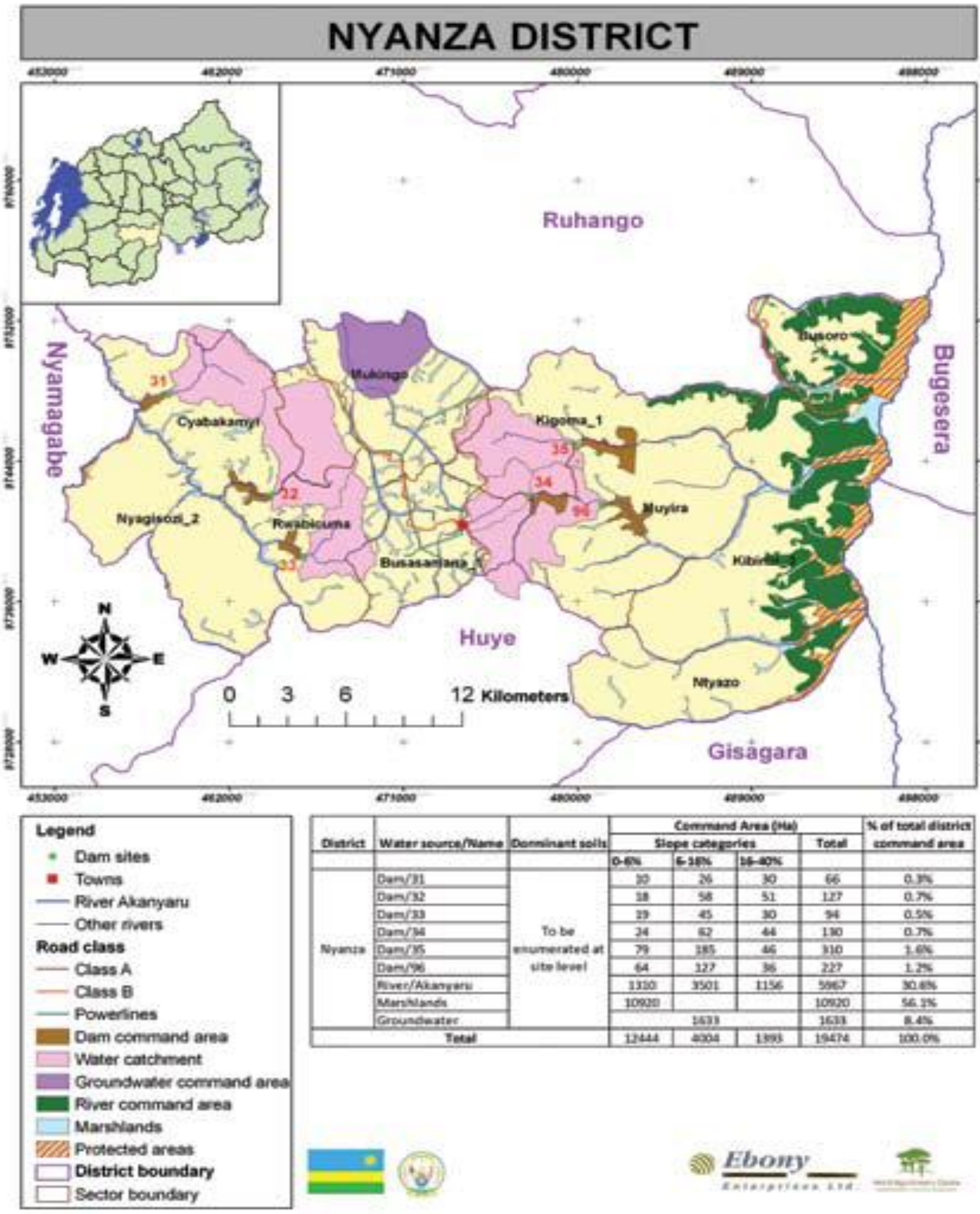
In the Akanyaru valley, border irrigation and in some places furrow irrigation will be most suitable. These irrigation systems have a low initial cost, and are easy to use. Therefore the maintenance and operation can be learned and carried out by the farmers. Since the area is flat, or nearly flat towards the foothills, hardly any leveling is needed. The water use efficiency for border and furrow irrigation is low, and uses two to three times more water than advanced pressurized irrigation systems. However, since this area is located in the riverbed, and can be irrigated under gravity, the water efficiency on a larger scale is better since the drained and percolated water will largely return to the river.

On the foothills, which covers most of the focal area, a different irrigation method is needed. The water needs to be pumped from the river, and lifted for about 150m. Therefore, there is a greater need for a high irrigation efficiency to reduce the operation costs.

3.4.3 Water source

The source if the irrigation water will be Akanyaru river. (Figure 44). During the dry season, the flow is reduced to roughly 10 m^3/s. This is still sufficient for irrigating an area of approximately 10.000 ha, with an average irrigation requirement of 5mm/day and an efficiency of 60%. During the dry season, the water can best be used for low cost operation irrigation systems, thus if choices should be made which areas to irrigate during dry season, it is best to optimize for the flat land in the valley.

A first estimate of the total amount of water, that is required to bring the full area under irrigation, is based on the sum of the monthly water deficit (difference between precipitation and crop water requirements). For this focal area, it is estimated that approximately 820 thousand m^3 water per year is needed for irrigation.



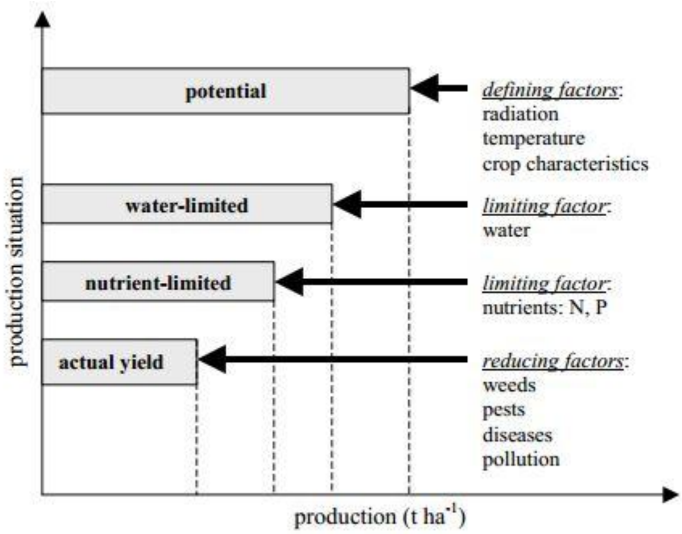
District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district command area
			Slope categories			Total	
			0-6%	6-16%	16-40%		
Nyanza	Dam/31	To be enumerated at site level	10	26	30	66	0.3%
	Dam/32		18	58	51	127	0.7%
	Dam/33		19	45	30	94	0.5%
	Dam/34		24	62	44	130	0.7%
	Dam/35		79	185	46	310	1.6%
	Dam/96		64	127	36	227	1.2%
	River/Akanyaru		1310	3501	1156	5967	30.6%
	Marshlands		10920			10920	56.1%
	Groundwater			1633		1633	8.4%
Total			12444	4004	1393	19474	100.0%

Figure 44: Potential irrigation water source

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*

Rwanda has relatively high yields compared to surrounding countries. Population pressure and the increasing food demand have been triggers for the intensification of agriculture. In Figure 45 the yield gap is shown relatively to the highest obtainable yield in the world, to the world average, and to Africa's average. It becomes clear that the Muyira focal area has high yields compared to the African standards. Compared to the world's average, however, quite some improvements can be done to reach realistic maximum yield. Maize reaches towards 8.2% of the theoretical maximum yield in the world, and to 40% of the world's average. Pineapple yields are at 11.6% of the maximum yield, and 45% of the world's average yields. Soybeans, however, reach to 75% of world's average, but to only 4.9% of the maximum obtainable yield. In order to focus on realistic yield increases, it is recommended to focus on the growth of maize and pineapple, as yields can be expected to double or increase even more.

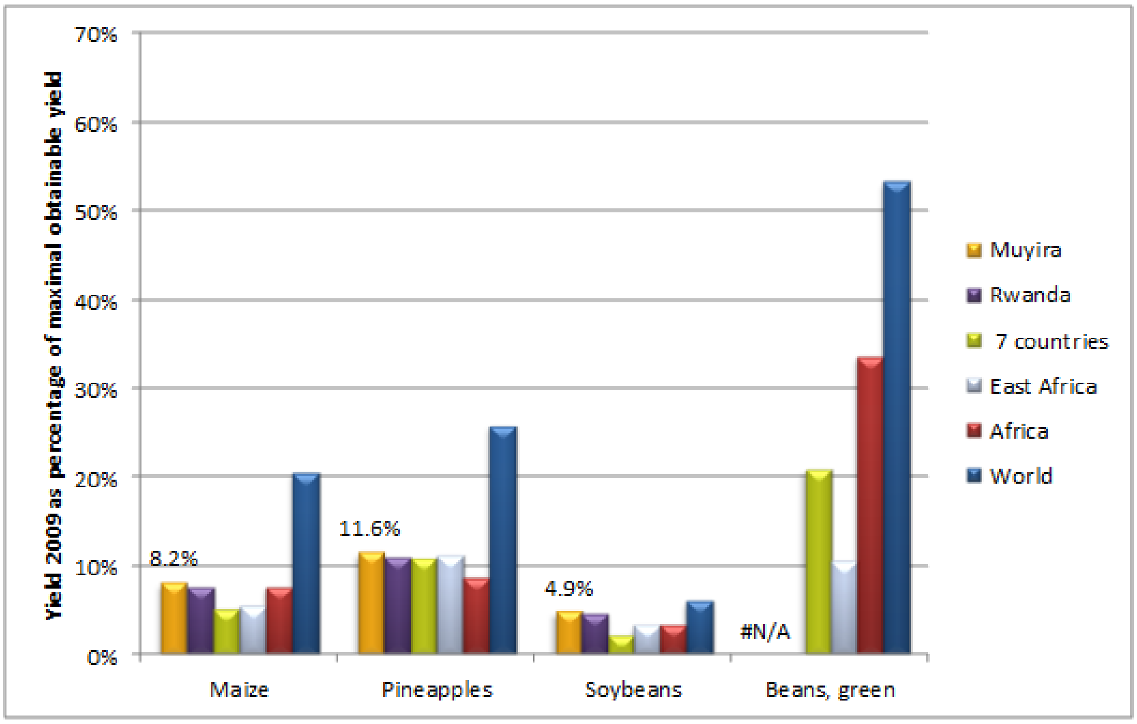


Figure 45: Yield gap Muyira (Source: FAOSTAT, 2010)

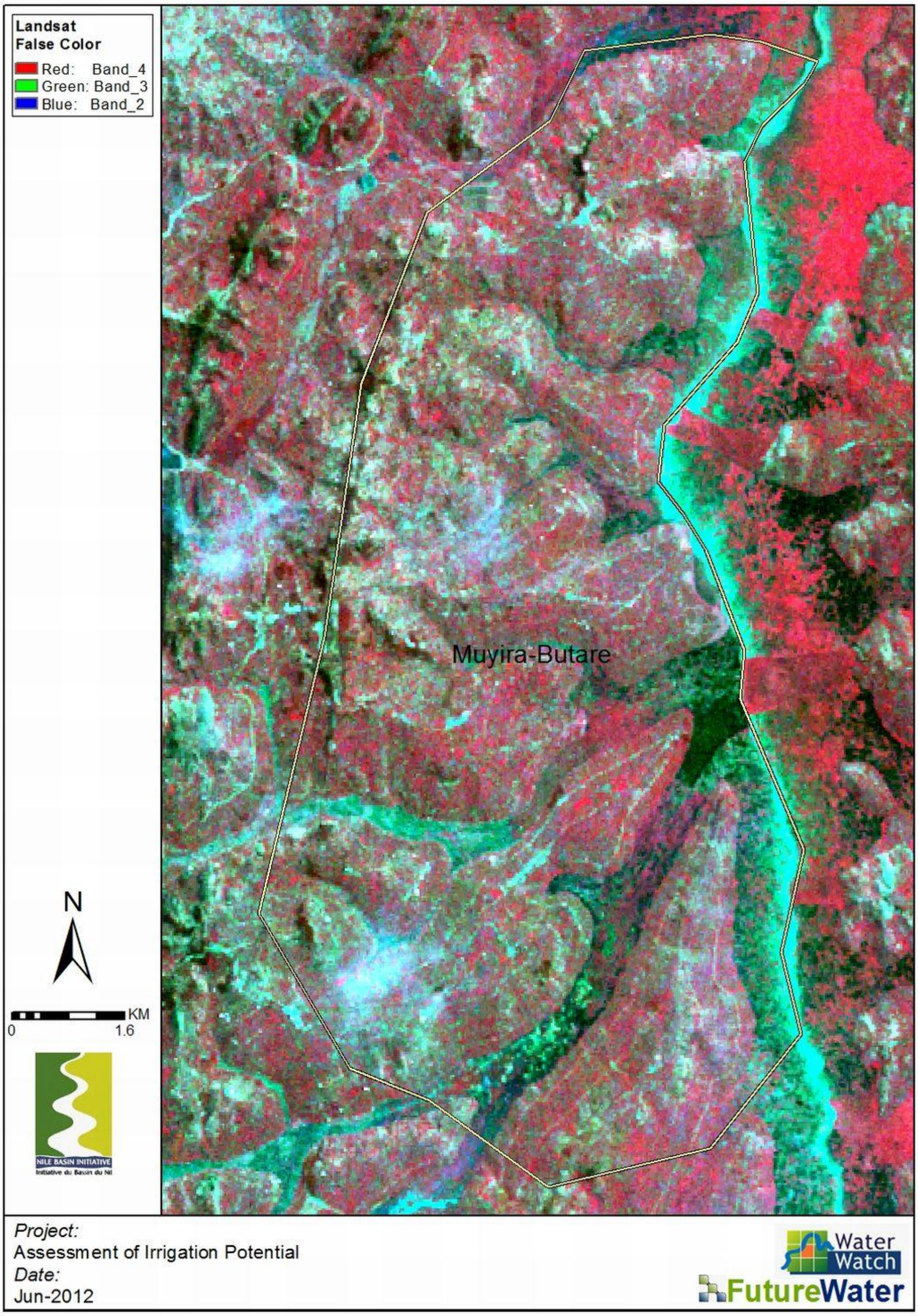


Figure 46: Landsat False Color Composite indicating current productivity of the area for Muyira/Butare focal area. (Source: Landsat)

3.6 Environmental and socio-economic considerations

3.6.1 Population displacements

Population displacements are not preferred, since it makes the process of irrigation developments much slower, and reduces the support the inhabitants of the area have for the irrigation development.

In the valley, where the most intensive irrigation takes place, there are currently no people living because of the high flood risk. Therefore displacements are not necessary. On the foothills people live mainly along streets following the contour lines. There are no villages or large clusters of houses. With the layout design of the irrigation system, the current houses can be taken into account, and the irrigation system can be planned around.

3.6.2 Social

The population density in the Muyira focal area is relatively low with only 300people/km^2. This area is the food granary of the district, because soils are fertile, people work hard, and have good agricultural knowledge. Most people know about irrigation through the nearby located rice irrigation scheme in the Nyarubogo perimeter. Historically, coffee was grown a lot as compulsory cash crop, which still leaves its signs today. Nearby markets include Nyanza, and the Bujumbura-Kigali highway.

3.6.3 Upstream downstream consideration

The water for this irrigation scheme comes directly from the Akanyaru River, which is a trans-boundary river at the border between Rwanda and Burundi. Upstream the river is used as a relatively intense irrigation water source for both Rwanda and Burundi. Although part of this upstream irrigation consist mainly of draining the valley bottom. This drainage increases the flow during the rainy season, since the storage in the ground is decreased. During dry season irrigation water is applied, and the flow will decrease. In order to develop irrigation in a sustainable manner, good arrangements should be made between Rwanda and Burundi about the water use.

In order to keep the soil fertile and to avoid downstream problems, it is important to minimize erosion from slopes. Currently, some anti-erosion measures are in place, but whenever developing irrigation systems, extra attention should be paid to keep the soil in place. In some places the slope can be minimized by terracing, which will enhance irrigation possibilities as well.

3.6.4 Protected areas

Within the focal area there are no protected areas.

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.

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, Table 7shows 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: 4,500 kg/ha, 0.22 $/kg
    - Pineapples: 50,000 kg/ha, 0.22 $/kg
    - Soybeans: 3,000 kg/ha, 0.28 $/kg
    - Beans, green: 4,000 kg/ha, 0.71 $/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. The local expert has been very positive about all Rwanda focal areas, however; 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.

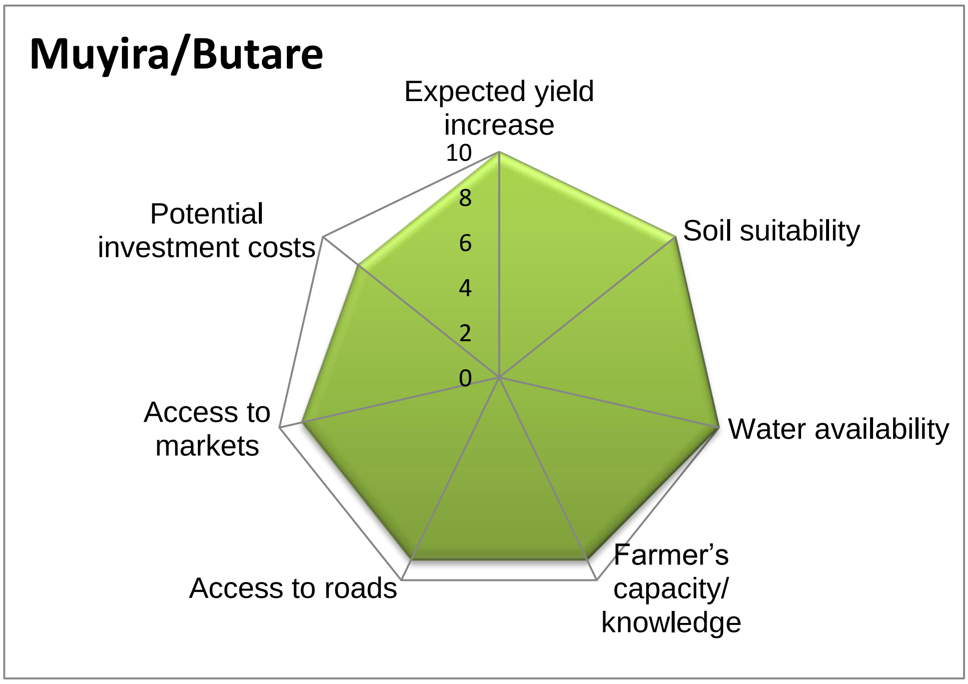


Figure 47: Filled radar plot indicating expert knowledge score to develop irrigation in the Muyira/Butare focal area (1 = negative, 10 = positive). (Source: local expert and study analysis).

Table 7.Benefit-cost analysis for the area.

Characteristics	
Irrigated land (ha)	5,500
Farmers	11,000
Investment Costs	
Irrigation infrastructure (US$/ha)	6,000
Social infrastructure (US$/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$)	39.5
O&M costs (million US$/yr)	0.460
Net benefits per year (million US$/yr)	12.763
IRR (Internal Rate of Return)	45.2%

3.8 Recommendations

This pre-feasibility study describes the topics on a screening and scoping level. The available local data are included in the analysis and description, but final results give a first impression of the irrigation possibilities. Recommendations to be included in a detailed feasibility study are: i) possible design of the irrigation scheme ii) In depth analysis of possible reservoir sites iii) the implications of the legal framework and local law on irrigation development in the focal area iv) make an economic analysis per crop and irrigation system and v) a in depth cost benefit analysis, fully based on the local situation.

4 Sake focal area

4.1 Introduction

This chapter will describe the current state of the Sake 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 2073 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 in March 2012.

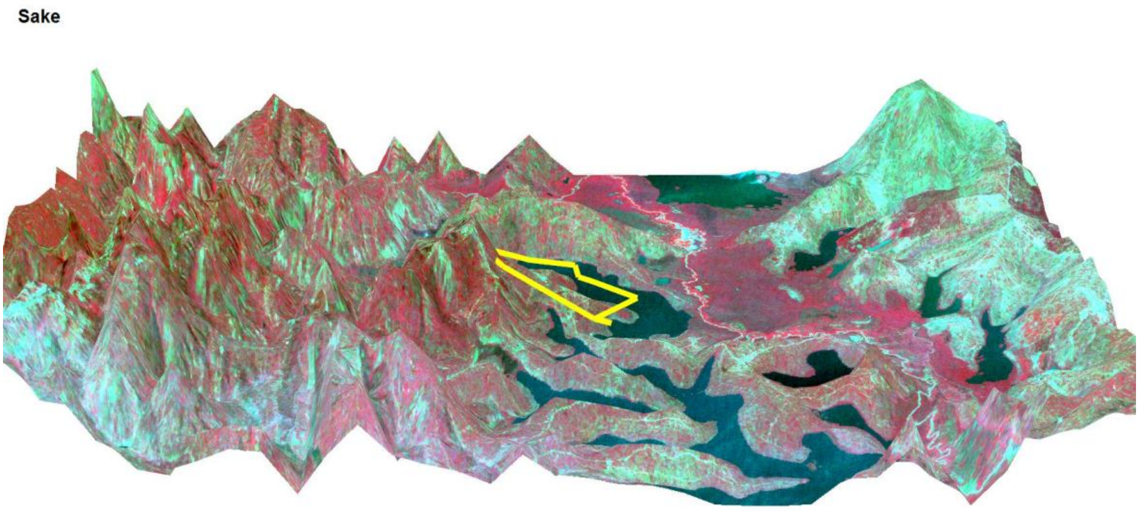


Figure 48: 3D impression of Sake focal area, Rwanda. (Source: Landsat)

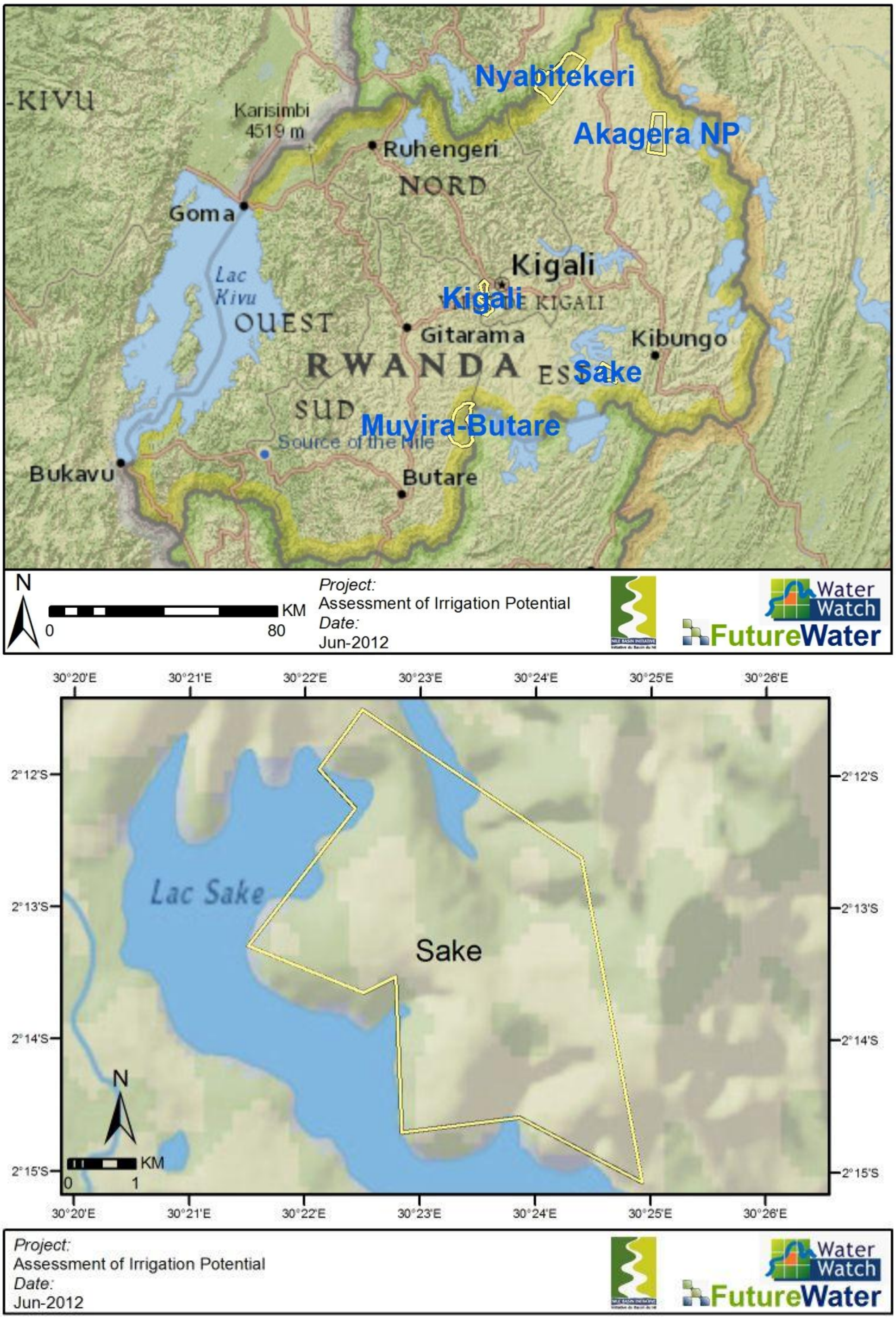


Figure 49: Sake focal area, Rwanda

4.2 Land suitability assessment

4.2.1 Terrain

Sake Focal area is situated in the South-East of Rwanda, at the eastern shores of lake Sake. In the north it is bordered by one arm of Lake Mugesera. This focal area with a total surface of 2073 ha has a height of 1300m at the lake shores and is going up to 1450m at the eastern side (Figure 50). The focal area is covering one foothill, and on the nearly flat top Sake village is situated. Slopes vary from 1-2% near the lake and on the top of the hill around Sake to 10% in parts going up from the lake. Towards the East the slopes increase even more reaching as much as over 15% (Figure 51).

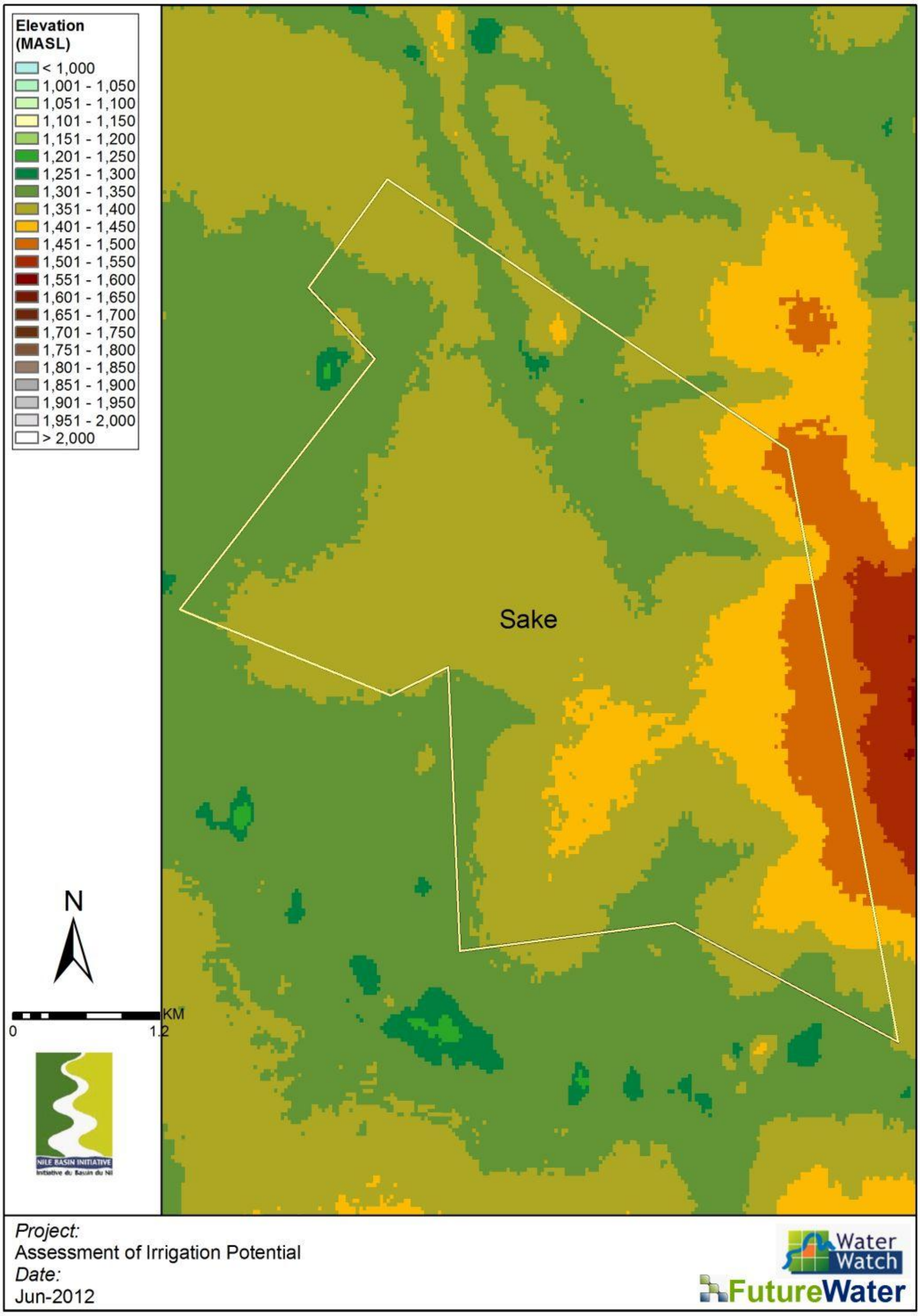


Figure 50: DEM Sake focal area. Resolution 1 arc second (+/- 30m). (Source: ASTER)

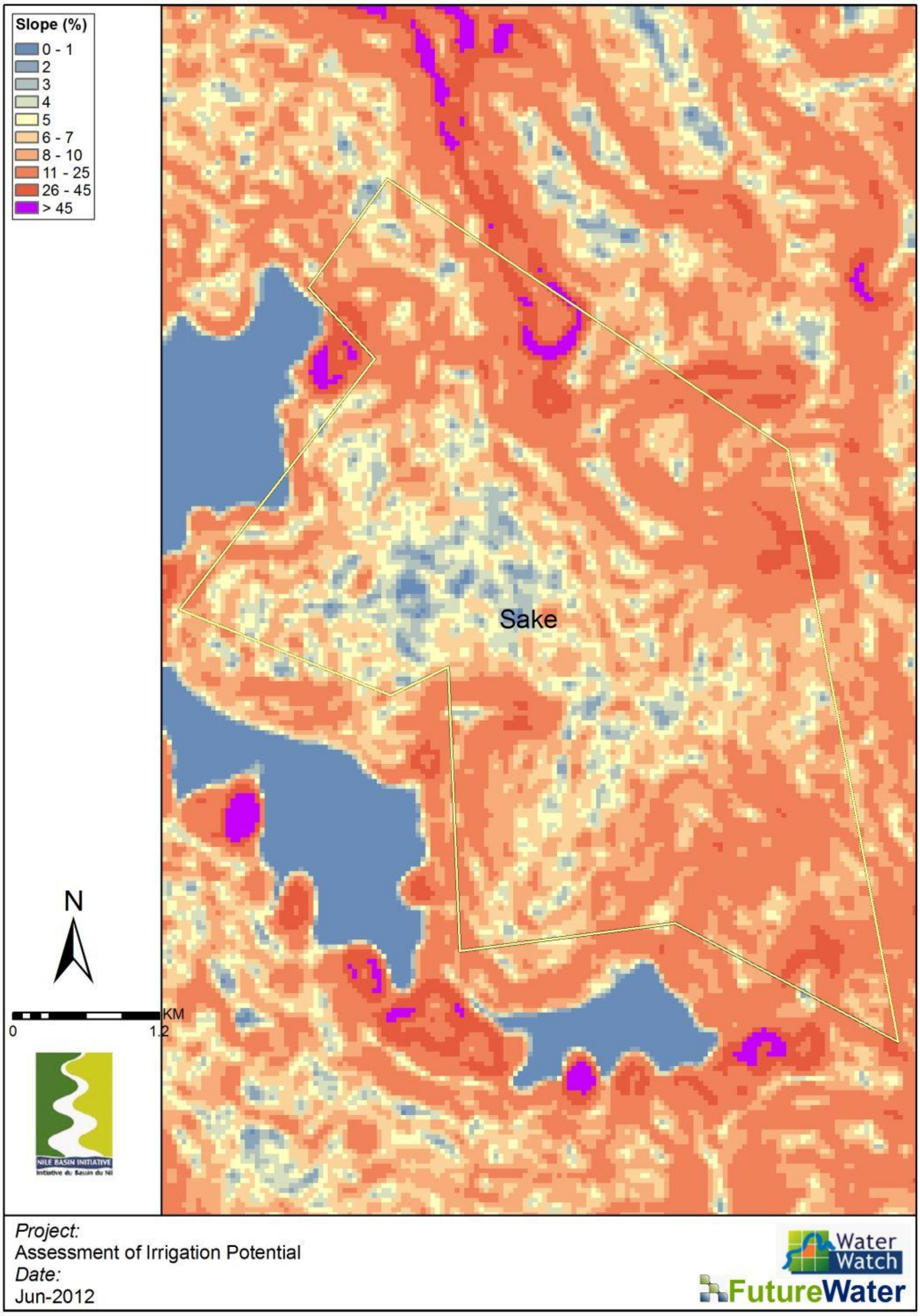


Figure 51: Slope map Sake focal area (source: ASTER).

4.2.2 Soil

The soils in this area are quite homogeneous. Along the shores the soils are yellow and well drained. This soil is derived from acid magmatic rocks. The soil consists of sandy clay or clay loam and is moderately deep, limited between 50 and 100cm, and sandy underneath. Apart from this, the slopes rising from the lake are somewhat stoniness. The soil on the foothill, covering the plateau on which the village of Sake is situated, is yellow or red, and well drained. The deep soil varies from clay to sandy clay and holds more than 2% organic matter. On the steeper parts towards the lake, erosion is a serious problem. Fertilizer is used in the area on a moderate scale, to improve the yields and soil qualities. The fertility of the soils has suffered from the high population density, which puts a large pressure on the agricultural land.

4.2.3 Land productivity

The average Normalized Difference Vegetation Index (NDVI) is 0.613, which is just above the Rwandan average of 0.579. On the slopes from the lake to the Sake plateau and the steep slopes in the east, the land productivity is highest with average values between 0.65-0.70. On the plateau the average NDVI is in the range of 0.55-0.60 (Figure 53). The variation in plant productivity is smallest in the south east of the focal area, and least stable at a small strip surrounding lake Sake and lake Mugesera.

The NDVI formula is:

$$\frac{(NIR - RED)}{(NIR + RED)}$$

The NDVI is calculated based on remote sensing MODIS images, and in more detail the Nearly InfraRed band (NIR) and the visible RED band (RED). The ratio between these two bands shows the productivity between -1 and 1. Plants absorb the red light for their photosynthesis, and reflect the NIR light.

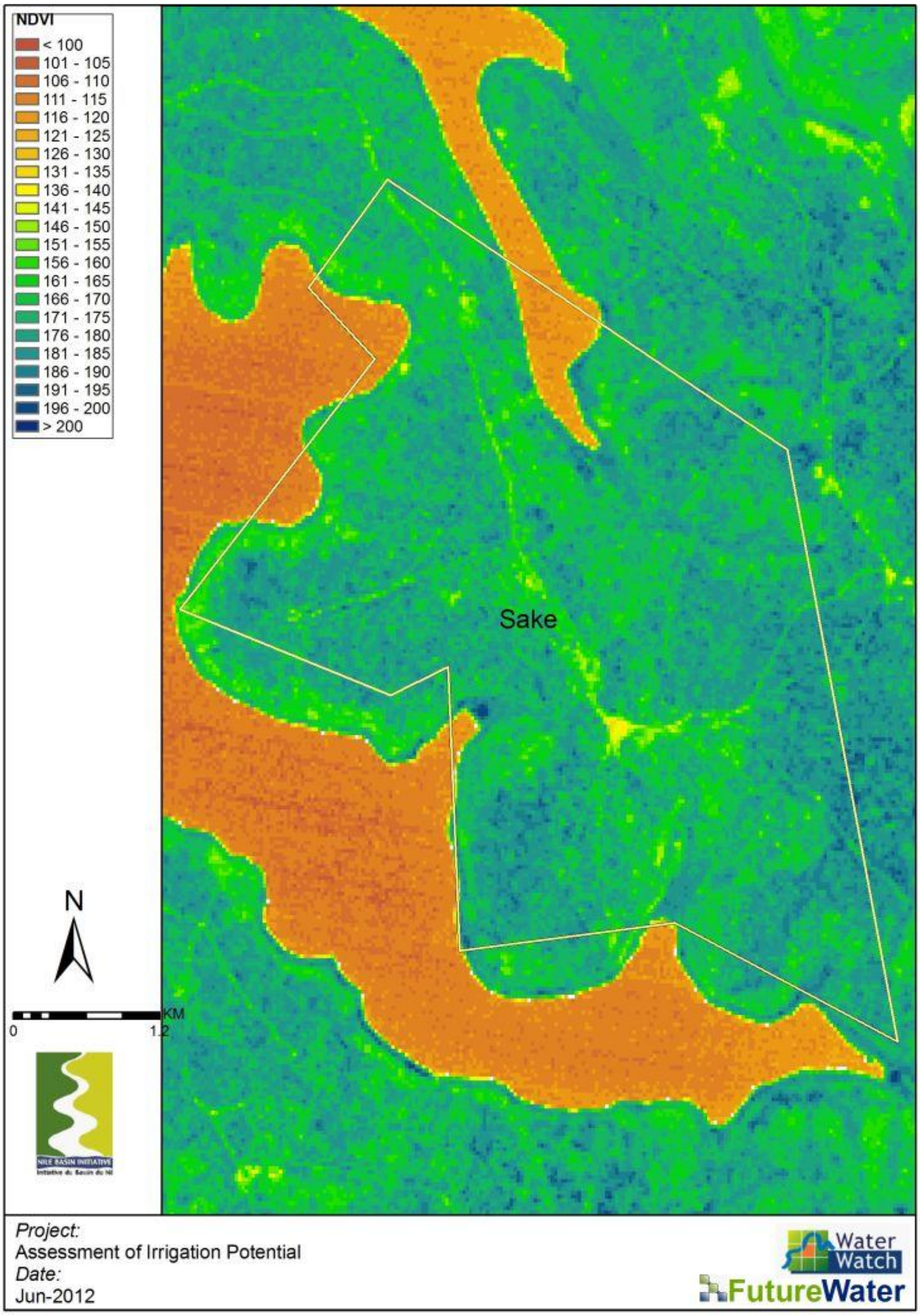


Figure 52: High resolution NDVI for Sake focal area. (Source: Landsat).

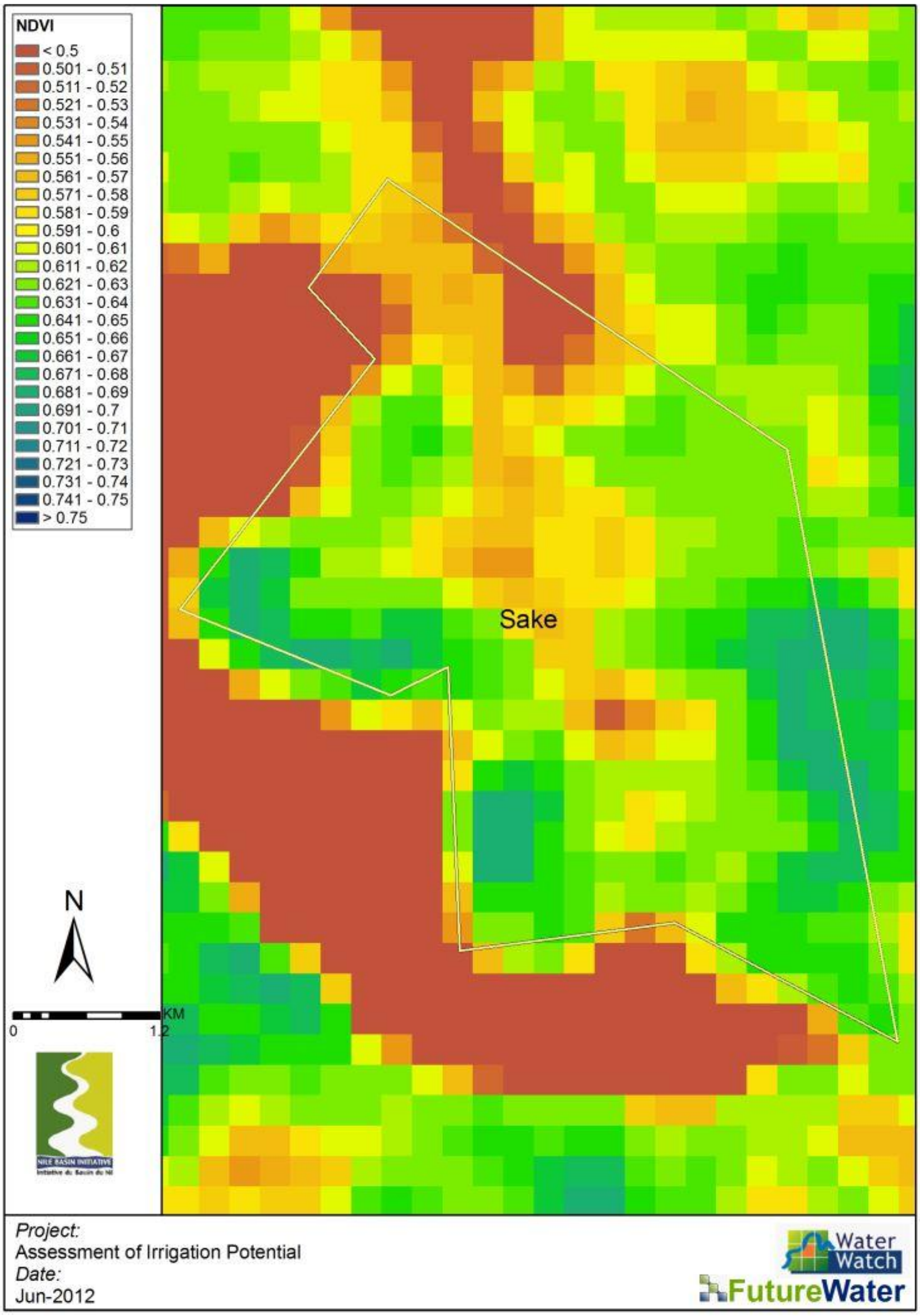


Figure 53: Yearly average NDVI values for Sake focal area. (Source: MODIS)

4.2.4 Potential cropping patterns

Within the Sake focal area,approximately 95% of the land is used for agriculture. Banana is the staple crop, and occupies roughly 40% of the area. Other perennial crops include pineapple and fruit trees, which both occupy about 10% of the land. The banana and fruit trees have one harvest period each year, and the pineapple gives two harvests per year. Maize is grown on 30% of the area, and Cassava on 10%. Maize has the advantage that it can be grown twice a year in each raining season. Other crops include Soy beans and groundnuts.

Government policy for potential future crops under irrigation is to focus on high return crops with a strong agro-industry linkage. Therefore, Pineapple is very suitable as farmers are already organized in production cooperatives, and the infrastructure for selling is already rolled out. The same is true for tomatoes and green beans. Maize will remain, and will play an important role for food security. Yields for maize are expected to triple when irrigated, and the cropping intensity of the area can increase with the use of irrigation and fertilizer.

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 constant temperatures during the year ranging from about 17^{o}C to 28^{o}C. Annual average precipitation is 940 mm and reference evapotranspiration 1390 mm per year.

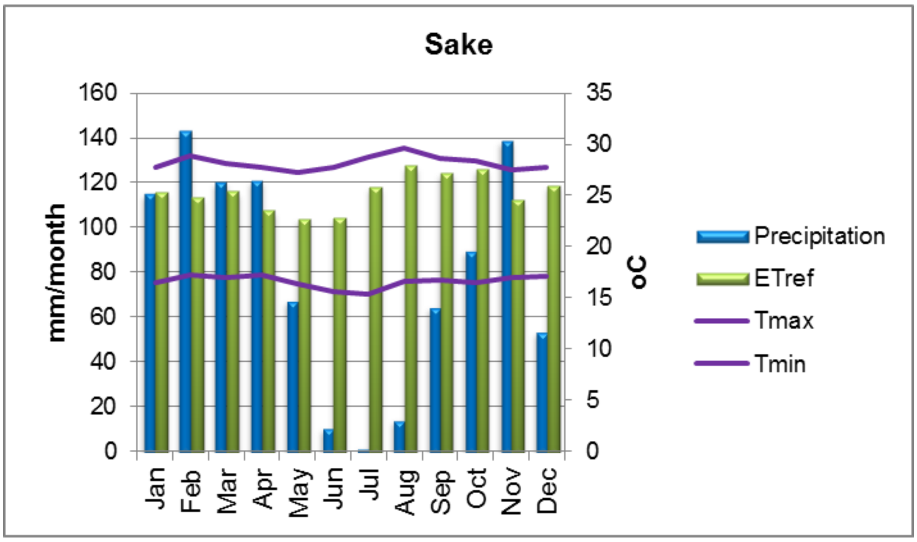
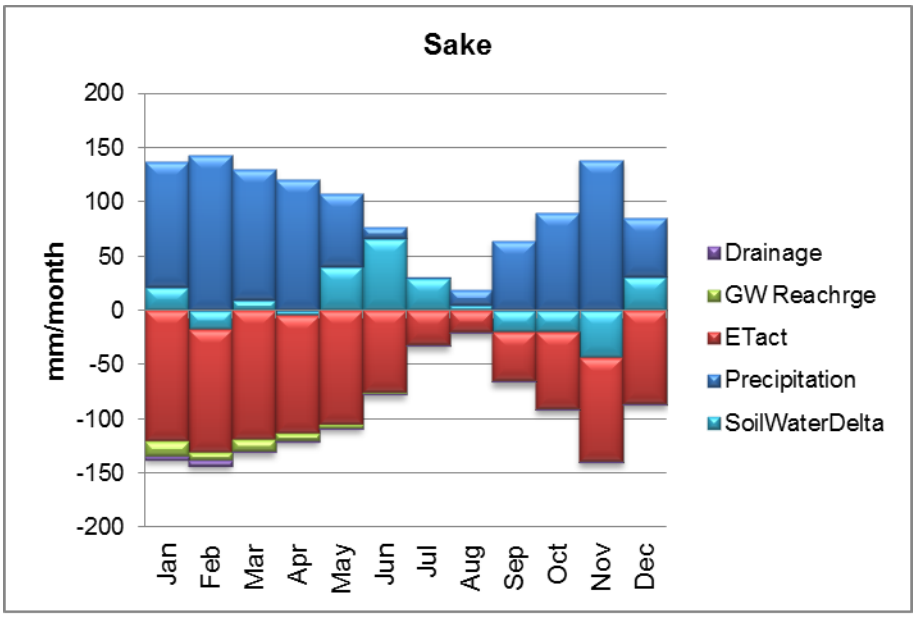
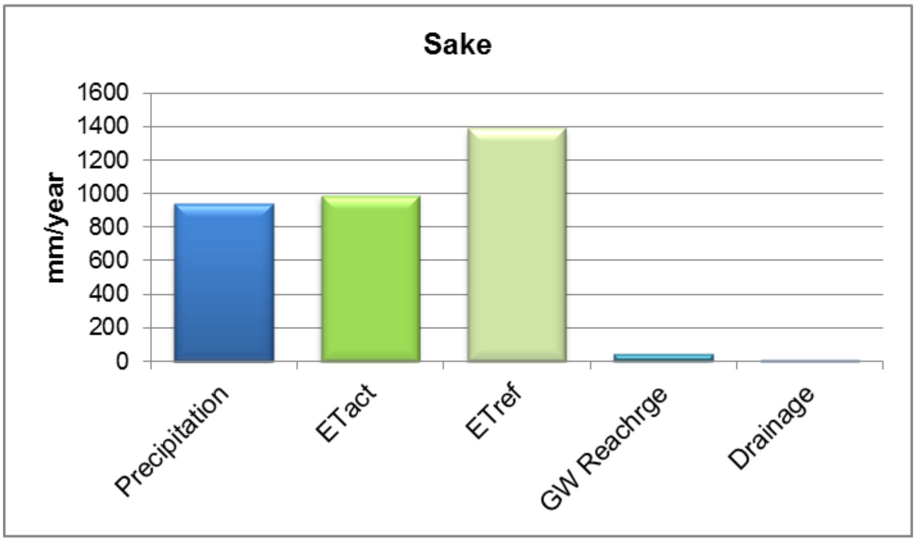


Figure 54: Average climate conditions for Sake focal area. (Source: study analysis).

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.





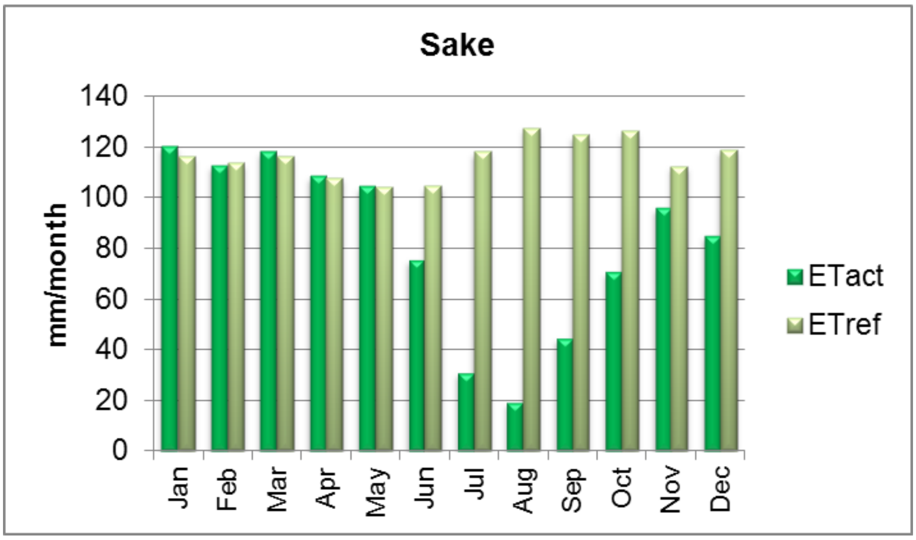
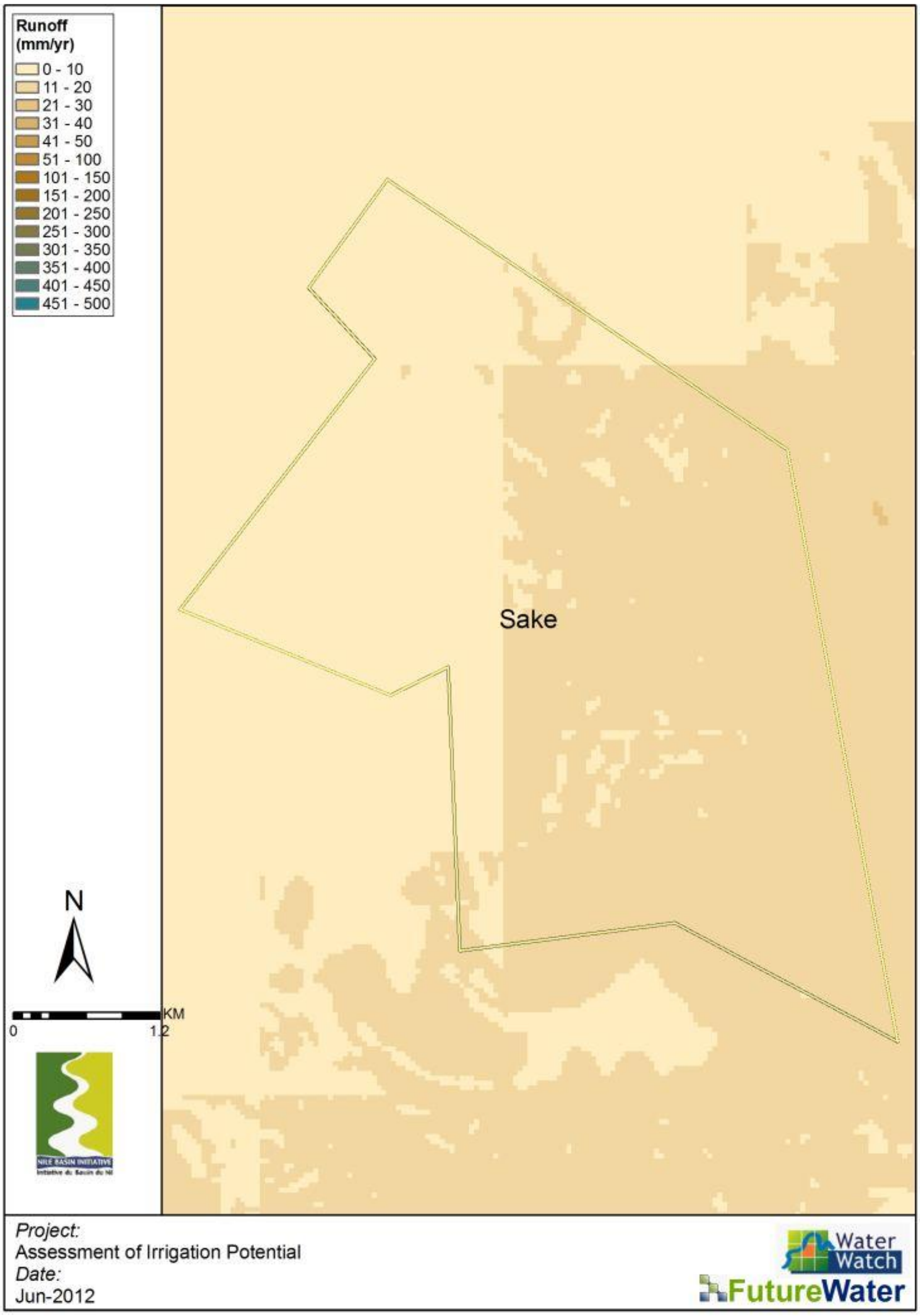
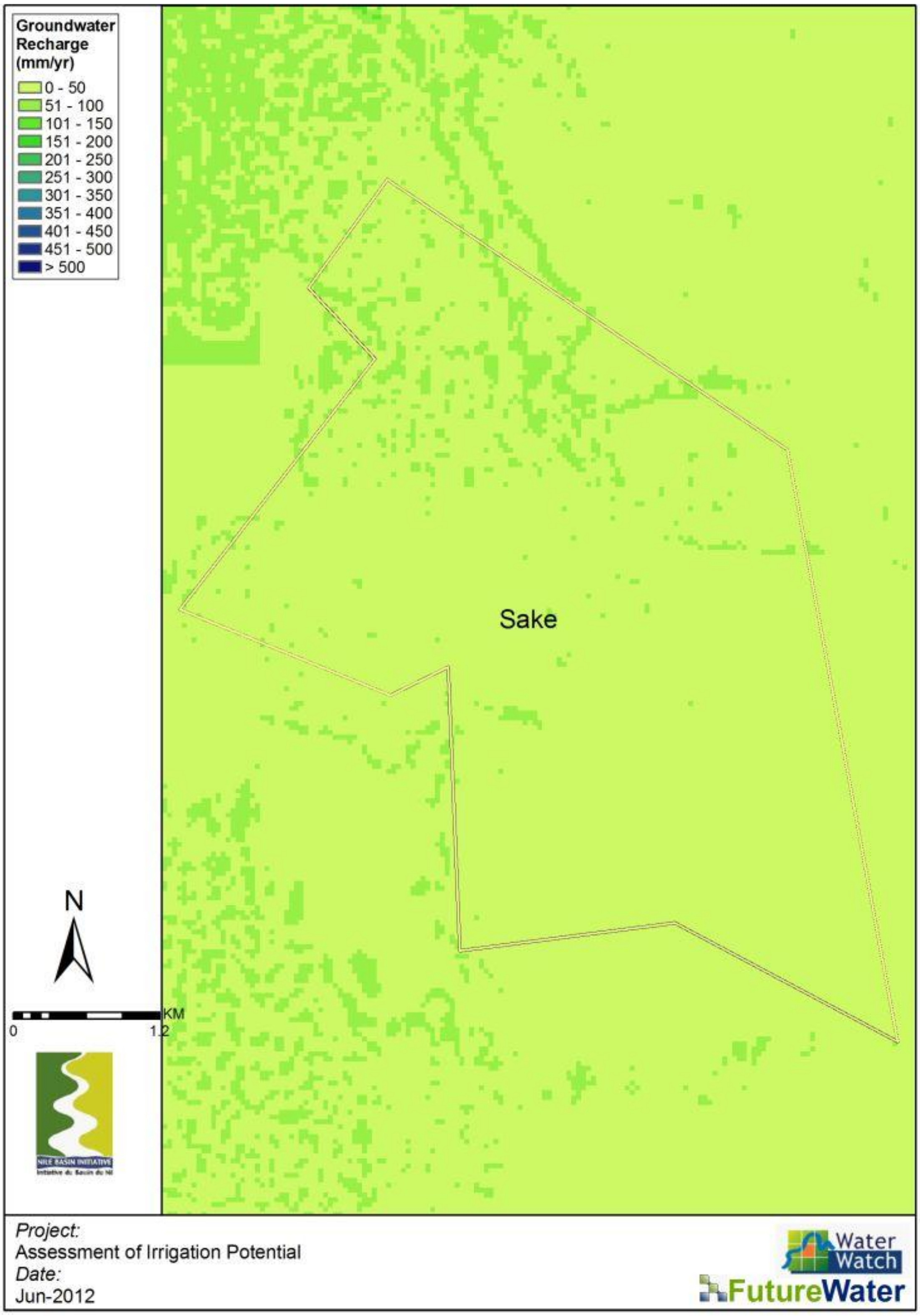


Figure 55: Water balances for the area based on the high resolution data and modeling approach for Sake focal area. (Source: NELmod).


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
Sake
N
KM
0
1.2
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
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Project:
Assessment of Irrigation Potential
Date:
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Water Watch
FutureWater

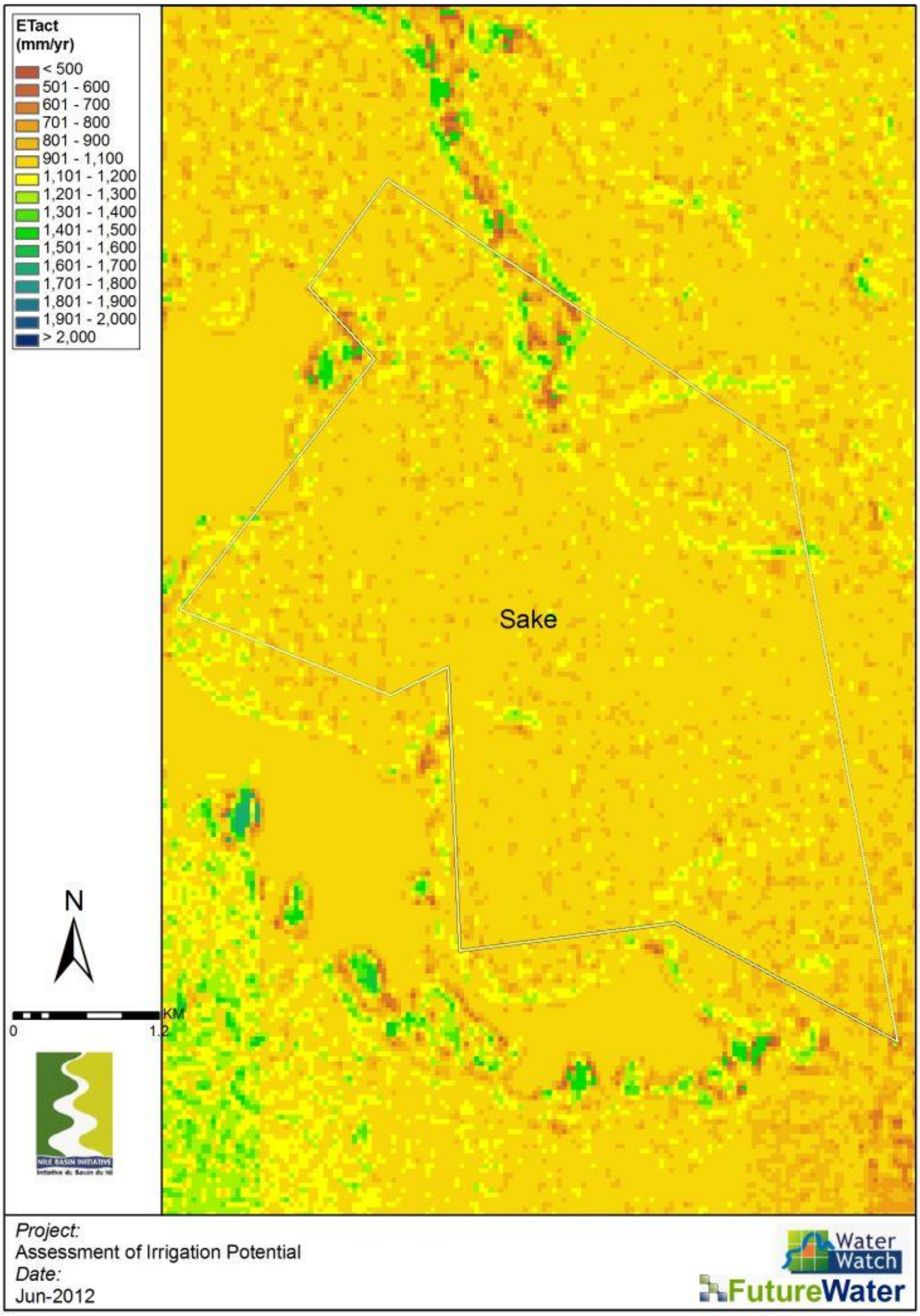


Figure 56: Water balances for the area based on the high resolution data and modeling approach for Sake focal area. (Source: NELmod).

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.

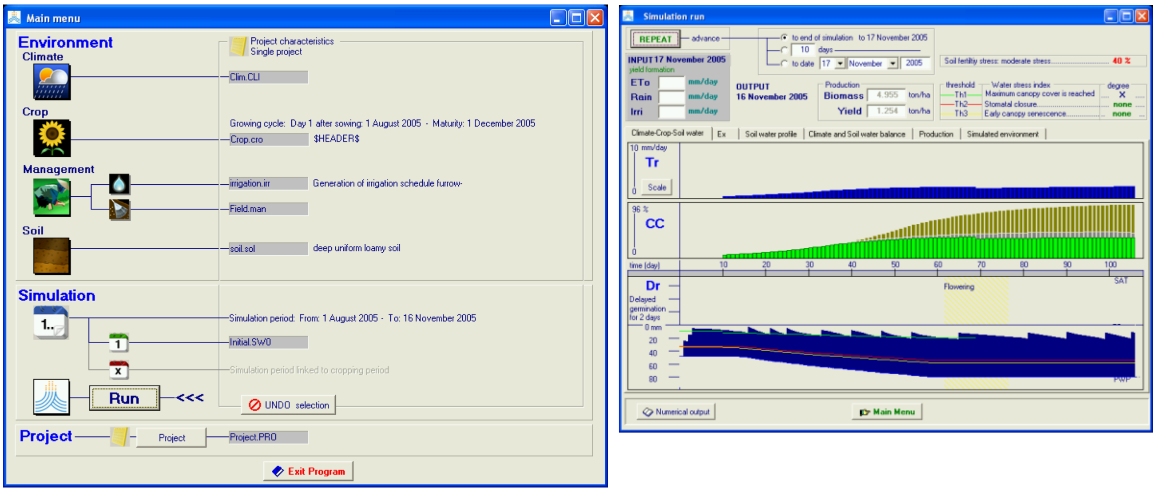


Figure 57: Typical example of AquaCrop input and output screens.

Table 8: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season. (Source: AquaCrop).

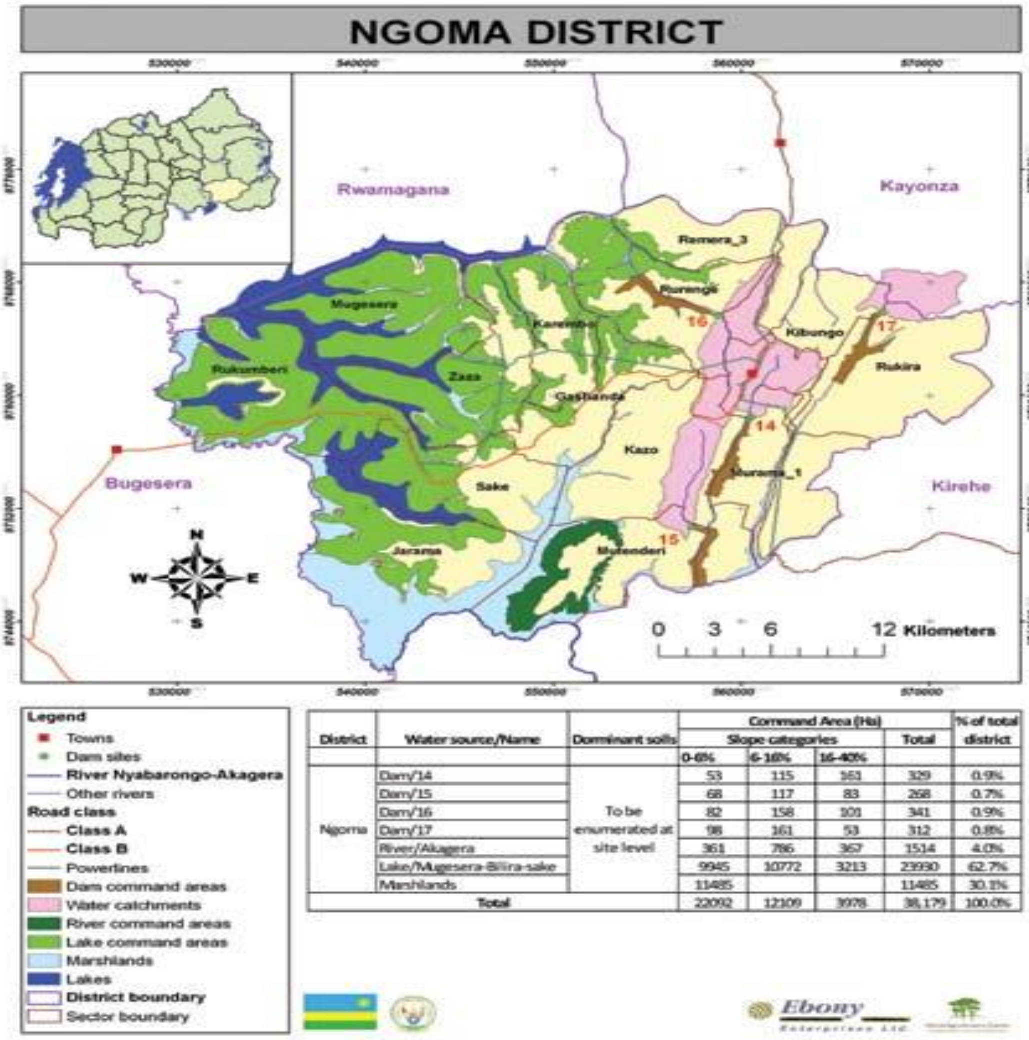
Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year	===	== (day of year) ==		======== growing season =======			
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Maize	942	1391	274	30	395	240	474	437
Pineapples	942	1391	1	365	941	170	1388	577
Beans, green	942	1391	1	365	941	100	1388	580
Tomatoes	942	1391	1	365	941	100	1388	580

4.4.2 Irrigation systems and irrigations efficiencies

The water for irrigation will be subtracted from Lake Sake. The water resource is there for nearly unlimited, as the lake sake is connected to the river Nyabarongo, which drains approximately 60% of Rwanda's surface. This means that all the water for irrigation should be pumped up the hill from the lake level at 1326m above sea level to Sake village which is at 1423m above sea level. This makes that the water should be lifted for approximately 100m at maximum. In the scope of this pre-feasibility study, it is expected that the best irrigation technique will be either sprinkler or drip irrigation. These irrigation techniques have the highest water efficiency and will result in the lowest operational costs. Initial development costs are relatively high with sprinkler and drip irrigation. The farmer's irrigation expertise in the region is high, which makes that the development of a sprinkler or drip irrigation system in this area has a low risk. In order to increase efficiency, the installation of various small pumping stations is recommended. Efficiencies will be lower in the dry season as evaporation is higher.

4.4.3 Water source

The water used will come from Lake Sake. (Figure 58) The water in the lake is abundant and available all-year-round. Nyabarongo River passes by the lake, and guarantees a stable water supply throughout the year.



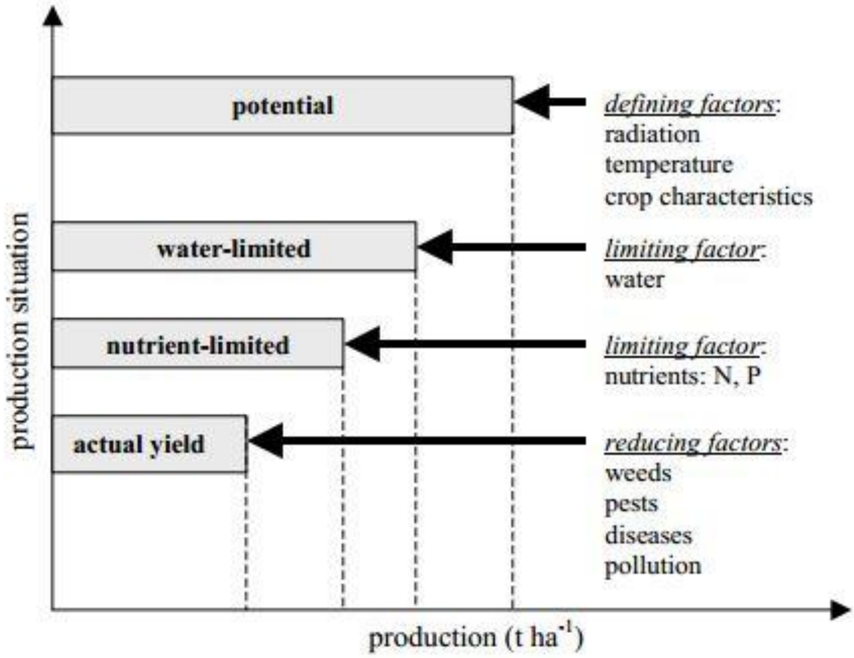
District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district
			Slope categories			Total	
			0-6%	6-16%	16-40%		
Ngoma	Dam/14	To be enumerated at site level	53	115	161	329	0.9%
	Dam/15		68	117	83	268	0.7%
	Dam/16		82	158	101	341	0.9%
	Dam/17		98	161	53	312	0.8%
	River/Akagera		361	786	367	1514	4.0%
	Lake/Mugesera-Bilira-sake		9945	10772	3213	23930	62.7%
	Marshlands		11485			11485	30.1%
Total			22092	12109	3978	38,179	100.0%

Figure 58: Potential water source for Sake focal area

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 analysisdominant crops

Yields in Sake focal area are slightly higher than the average yields in Rwanda. For maize and pineapples, the Rwandan yields exceed the (East) African average, reaching towards 8.1 and 11.6 percent of the maximum obtainable yield respectively. Compared to the world's average, which can be seen as a realistic yield gap, maize yields reaches 40% and pineapple 45%. For green beans no data is available in Faostat, but the yields worldwide are relatively close to each other. Tomatoes are grown at 1.5% of the maximum obtainable yield, and 23% of the world's average. With an average yield of 0.8kg/m^2, the yield gap can be decreased easily with irrigation to yields reaching 4-6kg/m^2. Yields of maize can be increased considerablyto reach 5000kg/ha, which is just under the world's average.Pineapple yields are expected to grow to 80.000kg/ha, nearly reaching the maximum obtainable yield(Figure 59).

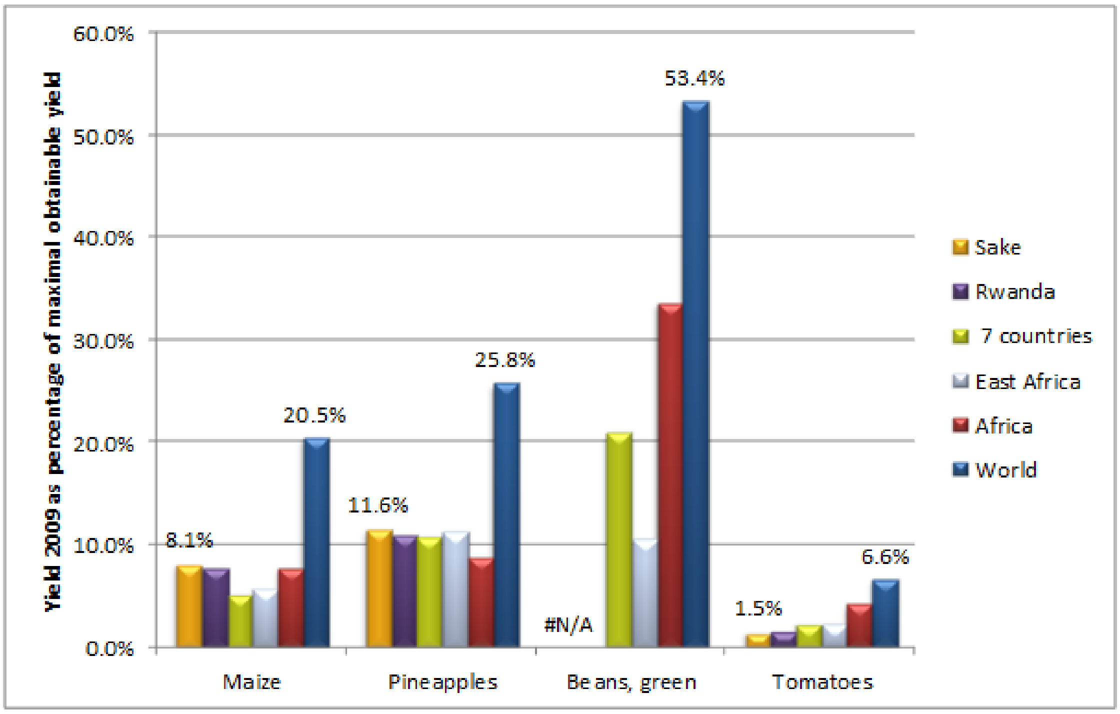


Figure 59: Yield gap Sake (source: FAOSTAT, 2010)

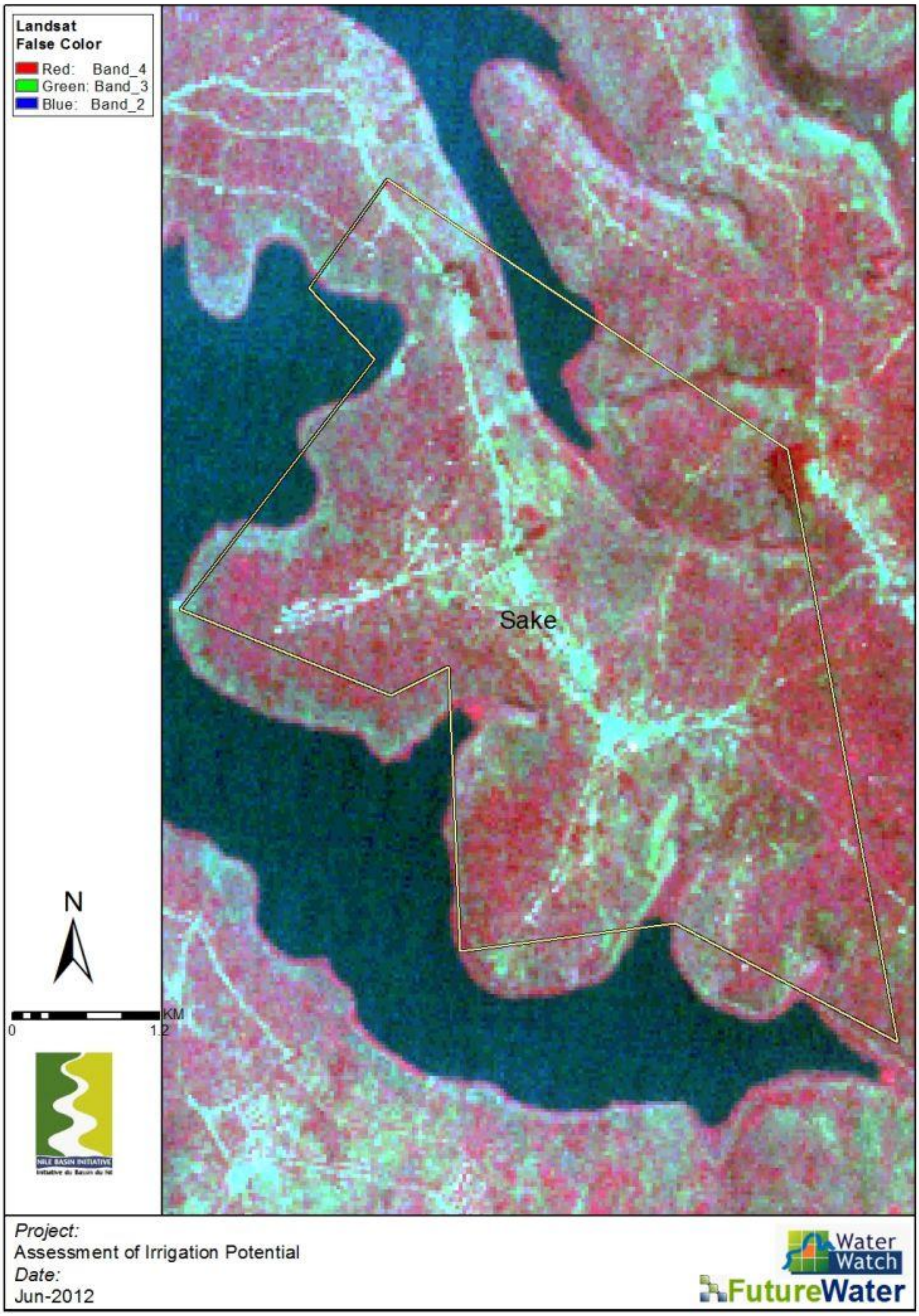


Figure 60: Landsat False Color Composite indicating current productivity of the area for Sake focal area. (Source: Landsat).

4.6 Environmental and socio-economic considerations

4.6.1 Population displacements

Much of the area can be irrigated without any population displacements. People in the area are eager on irrigation development, but it is recommended to leave the current infrastructure as much as possible as it is. Sake village is built on the flattest area on top of the hill. This flat area would be most suitable concerning irrigation, but the village does restrict the area and irrigation possibilities. Houses are built wide apart, which makes the areas in between barely useful. Whenever designing the irrigation system,either a drastic approach including many displacements should be chosen, or an approach that focuses on irrigation of the slopes that rise from the lake towards Sake village. This decision is beyond the scope of this pre-feasibility study, and should be decided together with the inhabitants, local government and other stakeholders.

4.6.2 Social

The population density in Sake focal area is around Rwanda's average with 400 people/km^2. The area is developed quite well, and infrastructure is in place and planned to increase. The road network is well developed, as Sake is within 20km of the Bujumbura/Kigali highway, and within 30km to the road connecting to Tanzania. There are plans to develop a Bugesera international airport, and a railway line passing by. Besides this, an electricity network is passing through the area, which makes the development of the area much easier. People are very motivated for irrigation development, and have good knowledge regarding agriculture and irrigation. Besides agriculture, fishing is the people´s other source of income.

4.6.3 Upstream downstream consideration

Since the water for irrigation is coming from Lake Sake,in which the water is nearly inexhaustible, there are no issues concerning equal distribution of the water. In this area more attention should be paid to erosion matters and anti-erosion measures. People should be aware of the erosion risks, and the measures they can take to decrease erosion. Measures like contour ditches or vegetation that prevent erosion, should also be included in any irrigation design. The use of fertilizer is recommended, however, people should be aware of the influences excessive use and leaching can have for the environment and the water quality in the lake.

4.6.4 Protected areas

Within Sake focal area there are no protected areas.

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 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: 5,000 kg/ha, 0.22 $/kg
    - Pineapples: 80,000 kg/ha, 0.22 $/kg
    - Beans, green: 6,000 kg/ha, 0.71 $/kg
    - Tomatoes: 50,000 kg/ha, 0.85 $/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. The local expert has been very positive about all Rwanda focal areas, however; overall, the weak part of the site lies under farmers capacity and the initial investment cost. Soil suitability and water availability is a great deal for the area that will foster an increase yields.

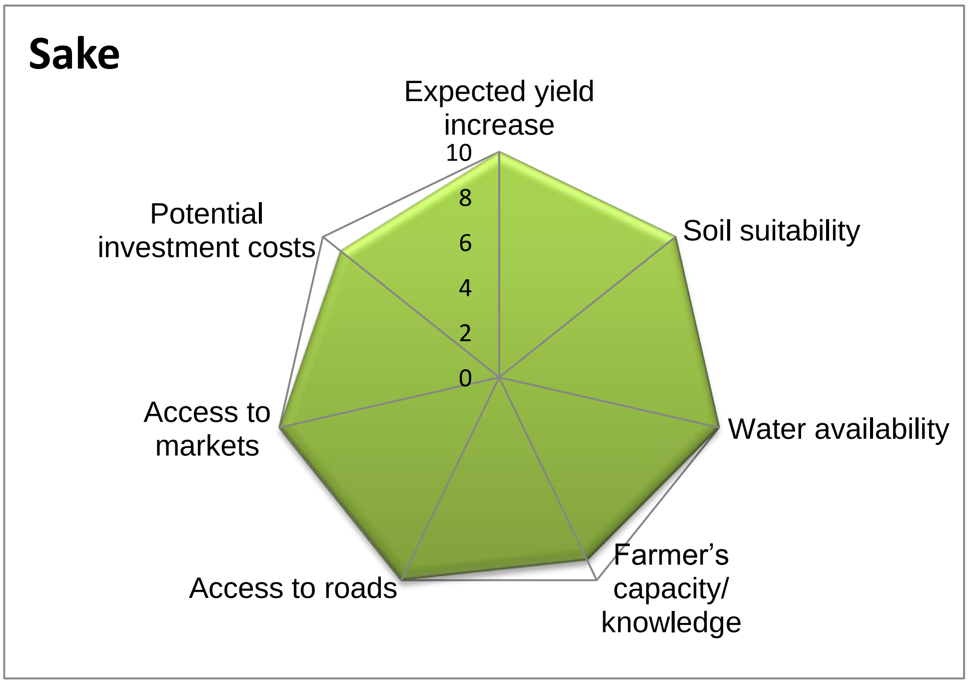


Figure 61: Filled radar plot indicating expert knowledge score to develop irrigation in the Sake focal area (1 = negative, 10 = positive). (Source: local expert and study analysis).

Table 9.Benefit-cost analysis for the area.

Characteristics	
Irrigated land (ha)	1,500
Farmers	3,000
Investment Costs	
Irrigation infrastructure (US$/ha)	6,000
Social infrastructure (US$/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$)	11.5
O&M costs (million US$/yr)	0.140
Net benefits per year (million US$/yr)	14.655
IRR (Internal Rate of Return)	#NUM!

4.8 Recommendations

This pre-feasibility study describes the topics on a screening and scoping level. The available local data are included in the analysis and description, but final results give a first impression of the irrigation possibilities. Recommendations to be included in a detailed feasibility study are: i) possible design of the irrigation scheme ii) In depth analysis of possible reservoir sites iii) the implications of the legal framework and local law on irrigation development in the focal area iv) make an economic analysis per crop and irrigation system and v) a in depth cost benefit analysis, fully based on the local situation.

5 Akagera NP focal area

5.1 Introduction

This chapter will describe the current state of the Akagera NP 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 63 a detailed map of the area is given. Total area is 6558 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 Reverien Harintwali and Prime Ngabonziza as supervisor in March 2012.

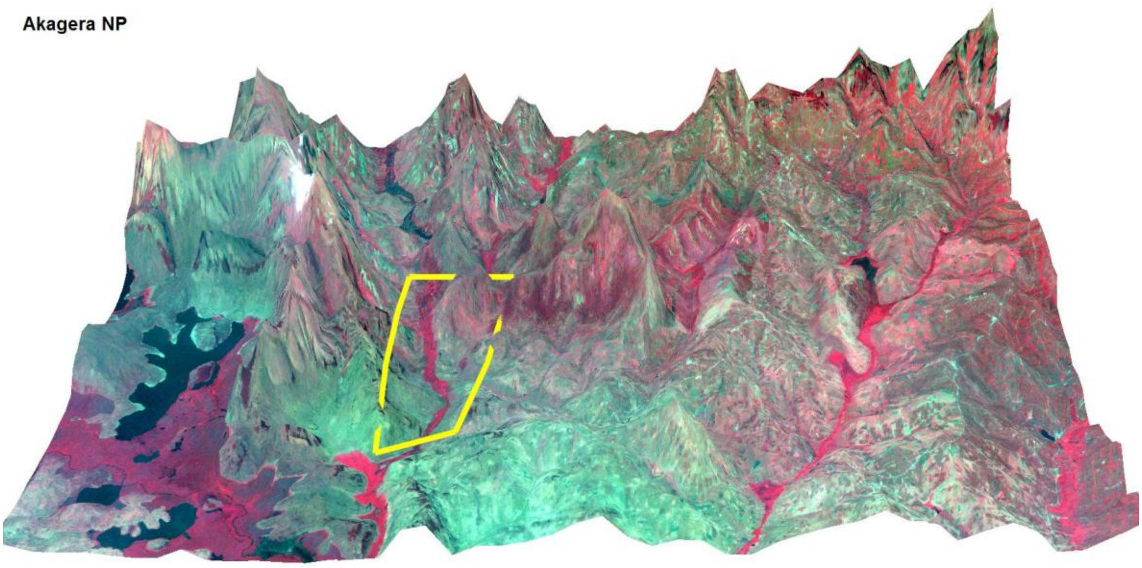


Figure 62: 3D impression of Akagera NP focal area, Rwanda. (Source: Landsat).

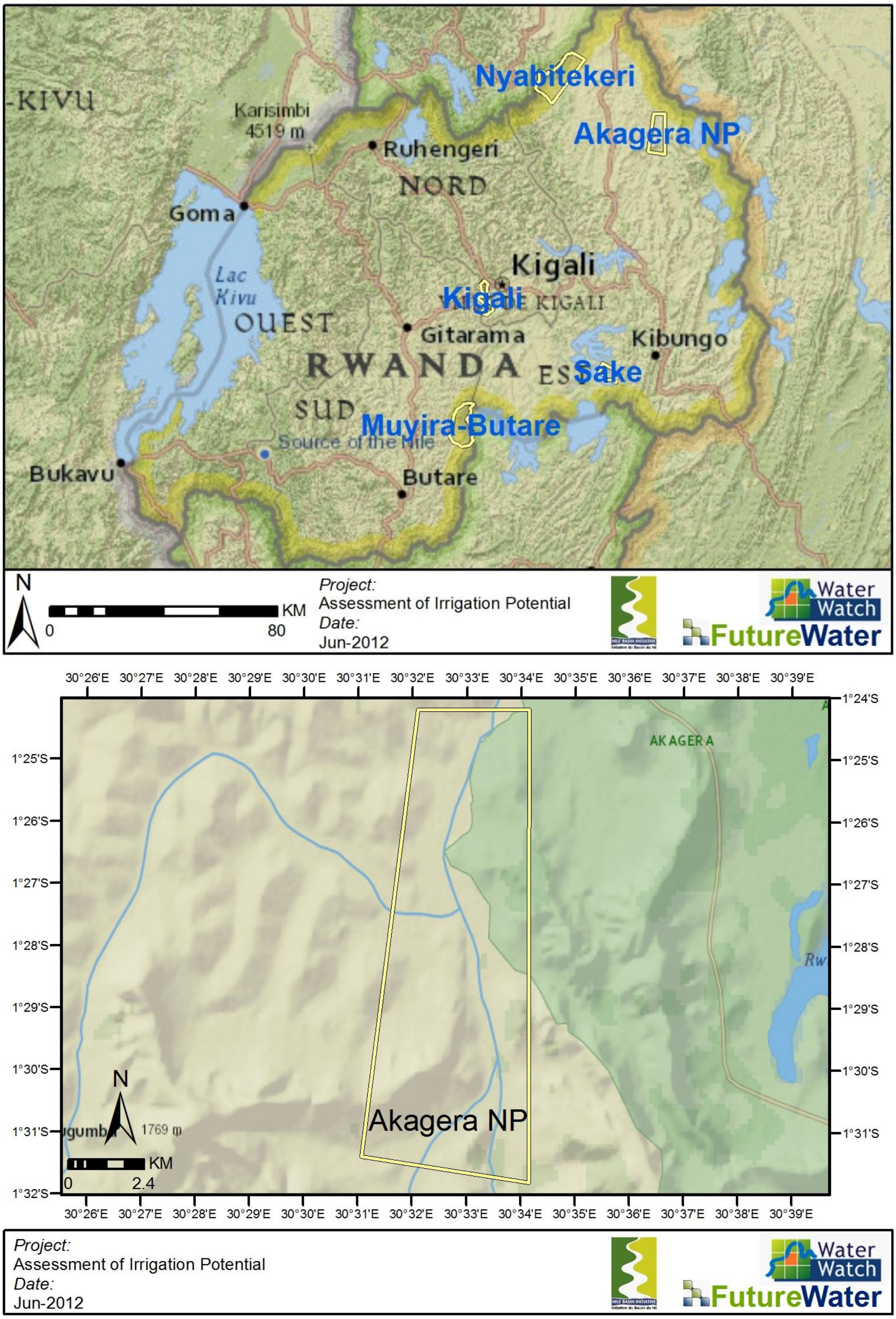


Figure 63: Akagera NP focal area, Rwanda

5.2 Land suitability assessment

5.2.1 Terrain

Akagera NP focal area is situated in the Eastern province, in between the town of Nyarugumba and the Tanzanian border. The elevation in the valley is around 1250m above sea level and from there it's going up to 1450 meters on the hills (Figure 64).The focal area is covering mainly the valley bottom and the foothills on the sides. On the western side another stream is joining half way. Slopes range from 0% in the valley to about 7% on the foothills. Slopes over 20% can be found on the hill in the south west of the focal area (Figure 65).

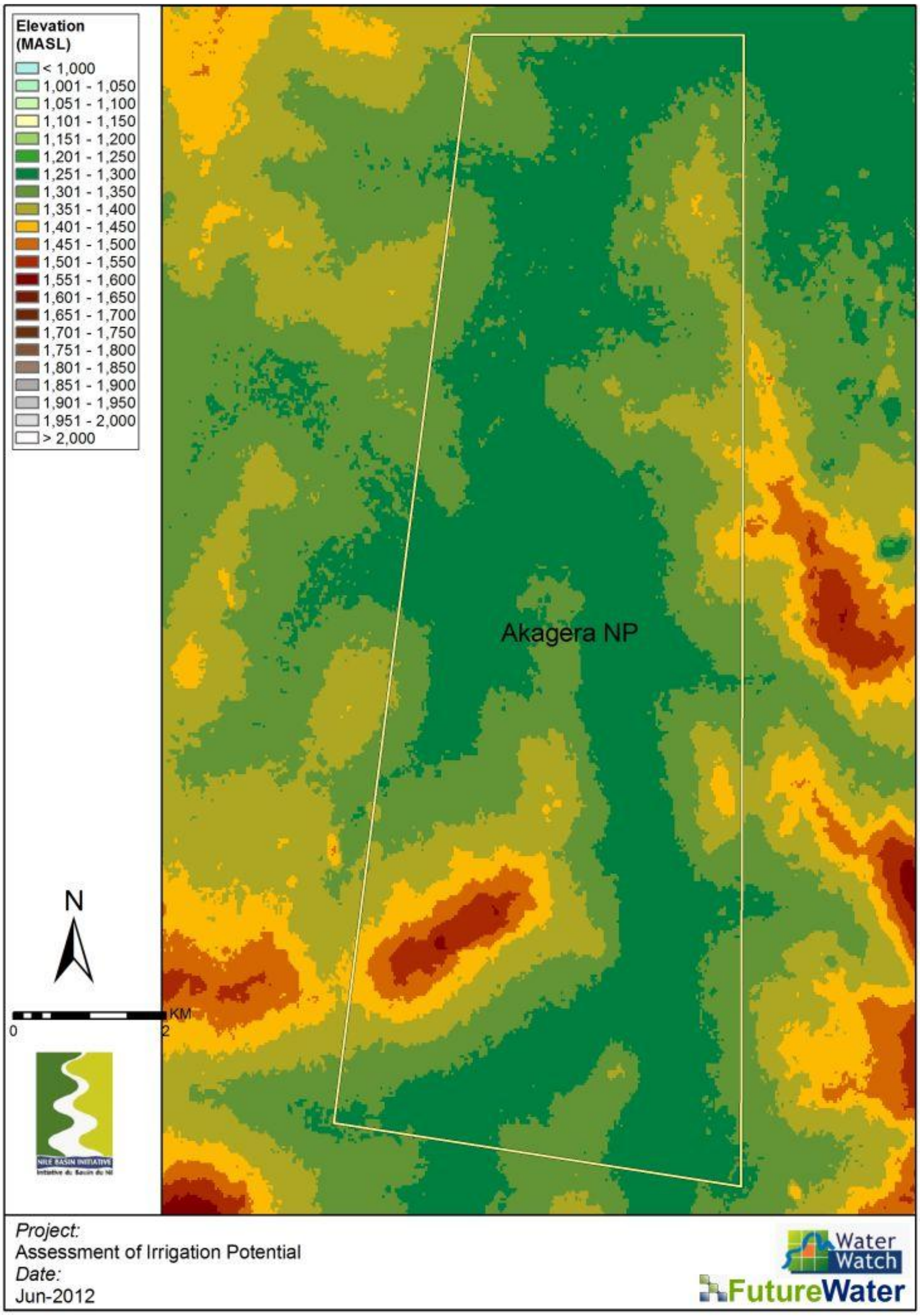


Figure 64: DEM Akagera NP focal area. Resolution 1 arc second (+/- 30m). (Source: ASTER).

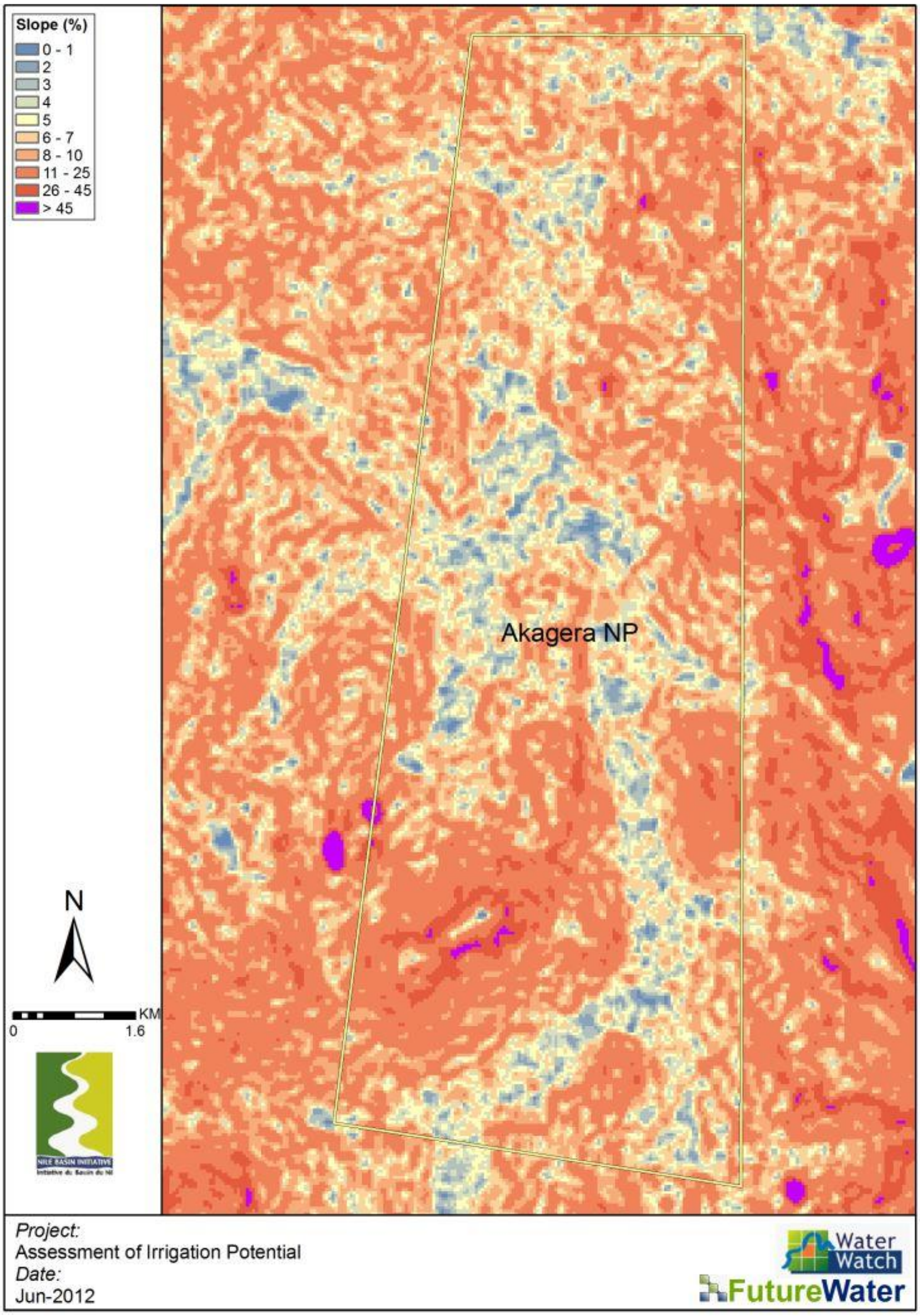


Figure 65: Slope map Akagera NP focal area. (source: ASTER)

5.2.2 Soil

The soils in this focal area are diverse and have different genesis. Soils in the valley are formed by alluvial and colluvial processes. Soils on the foothills in the north of the area are formed by metamorphic processes, and towards the South-west the soils are derived from magmatic acid rocks. The soils in the valley are for 80% very poorly to poorly drained, and consist of heavy clay. The other 20% is drained slightly better. The soils on the foothills in the north are a mixture, but mainly consist of sandy to loamy clay, and are yellow to red, predominantly laterite. The soils in the South-West are mainly yellow soils, well drained and sandy clay alternate with red sandy clay soils, which are derived from granite, andare limited by 50cm depth by gravelly layer. At the moment no fertilizer is used in the area, and only 3% is used for agriculture. Therefore, erosion is hardly noticed, despite of the steep slopes. Due to the poor drainage capacity of the soils in the valley salinization is a real risk. On the slopes the percentage of organic matter is low, and the slopes are quite stony.

5.2.3 Land productivity

The average land productivity within this focal area is lowest from the five Rwandan focal areas. With an average NDVI of 0.585 it is just slightly above the Rwandan average. NDVI values are higher in the valley, as water supply is most reliable. Values here stay just under the 0.7. Average NDVI values on the slopes in the West and East are rather uniform around the 0.55 (Figure 67). Consequently, the coefficient-of-variation in plant productivity is lowest in the valley, and much higher at the slopes on the side. Especially the northern end of the focal area has a large coefficient-of-variation.

The NDVI formula is:

$$\frac{(NIR - RED)}{(NIR + RED)}$$

The NDVI is calculated based on remote sensing MODIS and Landsat images, and in more detail the Nearly InfraRed band (NIR) en de visible RED band (RED). The ratio between these two bands shows the productivity between -1 and 1. Plants absorb the red light for their photosynthesis, and reflect the NIR light.

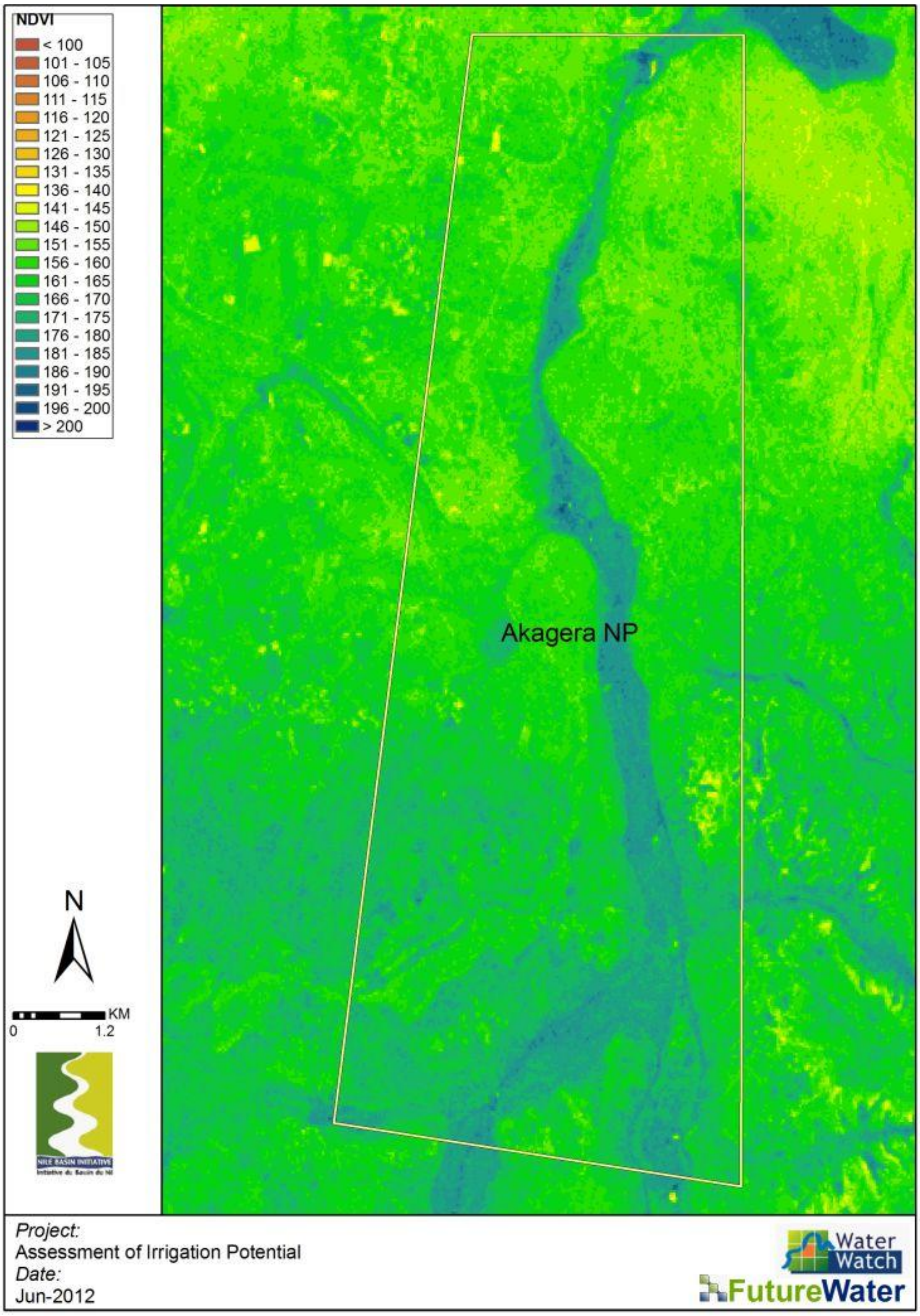


Figure 66: High resolution NDVI for Akagera NP focal area. (Source: Landsat).

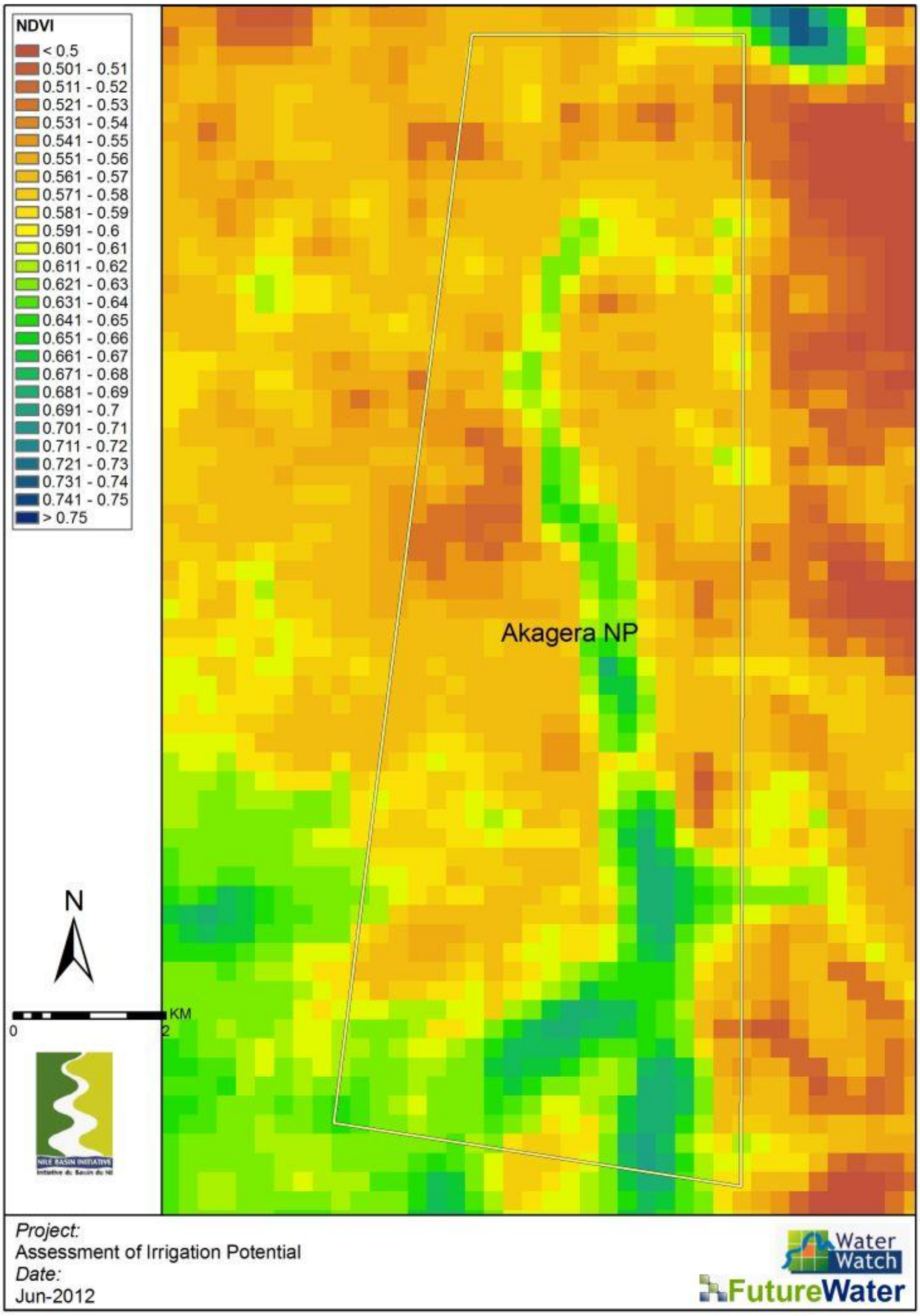


Figure 67: Yearly average NDVI values for Akagera NP focal area. (Source: MODIS).

5.2.4 Potential cropping patterns

Within this focal area agriculture is hardly developed so far, and most land is used for livestock, cow holders and herders. Only about 3% of the land is cultivated for agriculture. On this land only maize is grown. Harvests are relatively low with about 1000kg/ha. The rainfall regime is erratic and therefore unreliable. Irrigation can therefore increase the yields 4-5 fold.

Future potential cropping patterns will mainly enhance maize production as maize can fit in this area with the activities of livestock keeping. Maize will be the staple food, and increase the food security of the area.

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 constant temperatures during the year ranging from about 15^{o}C to 28^{o}C. Annual average precipitation is 899 mm and reference evapotranspiration 1424 mm per year.

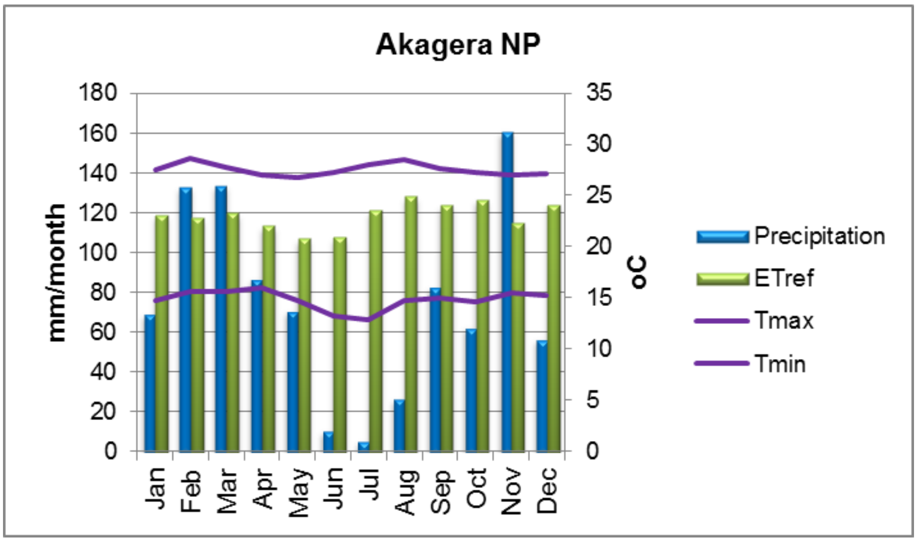
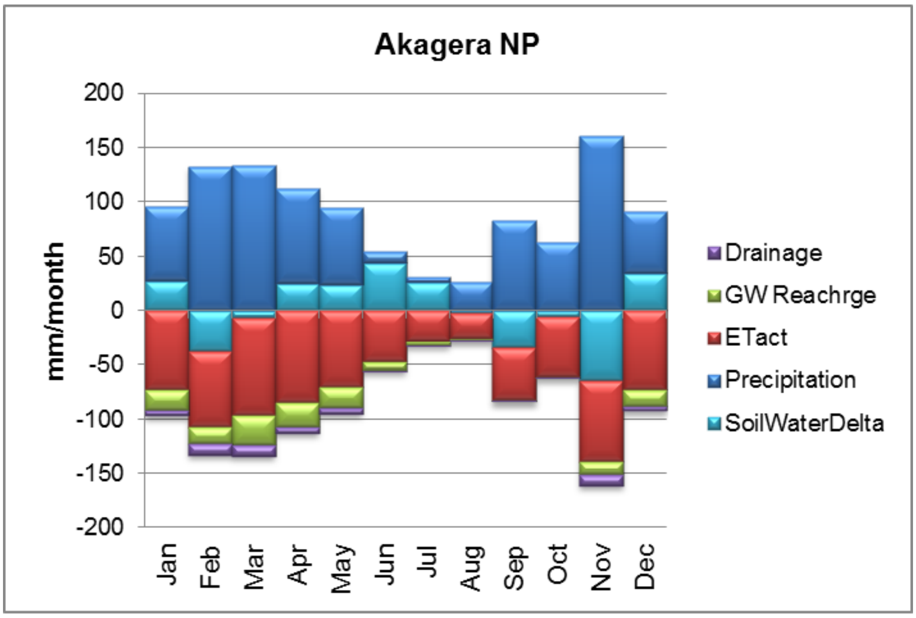
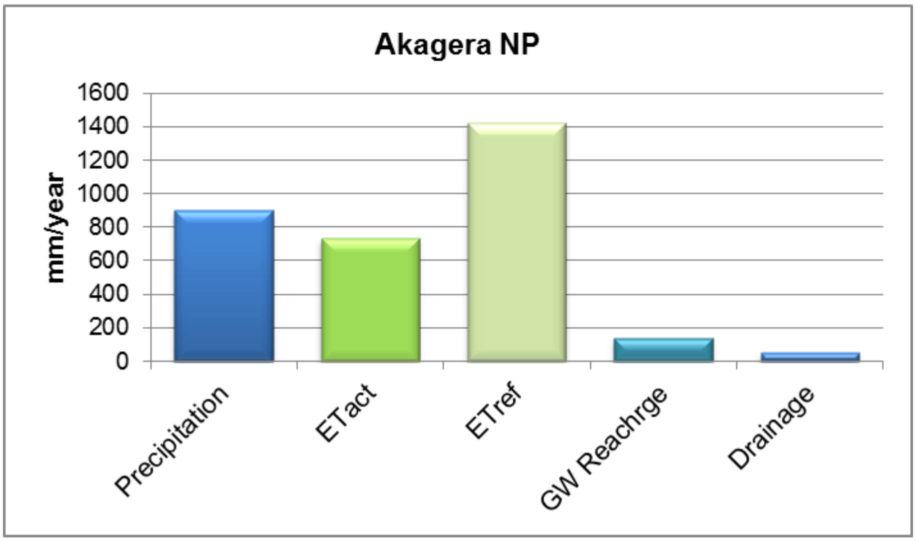


Figure 68: Average climate conditions for Akagera NP focal area. (Source: study analysis).

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.





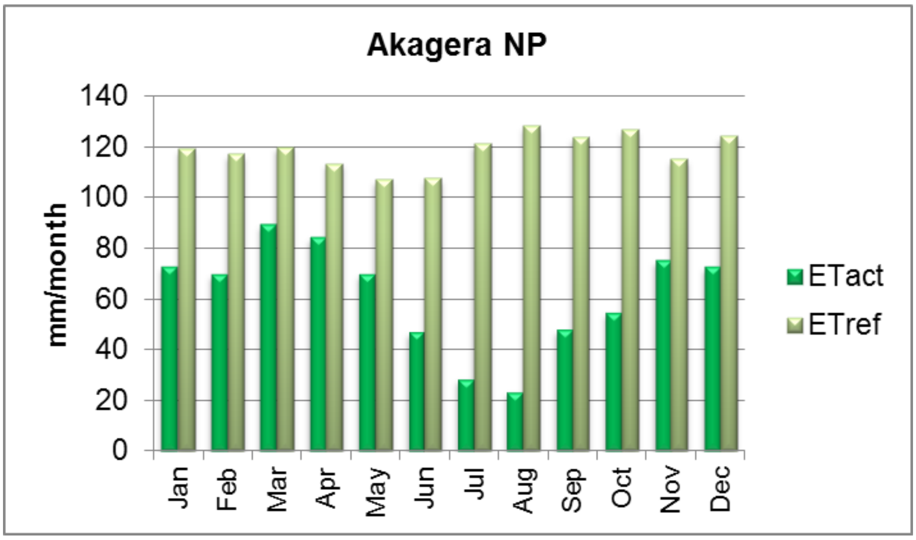
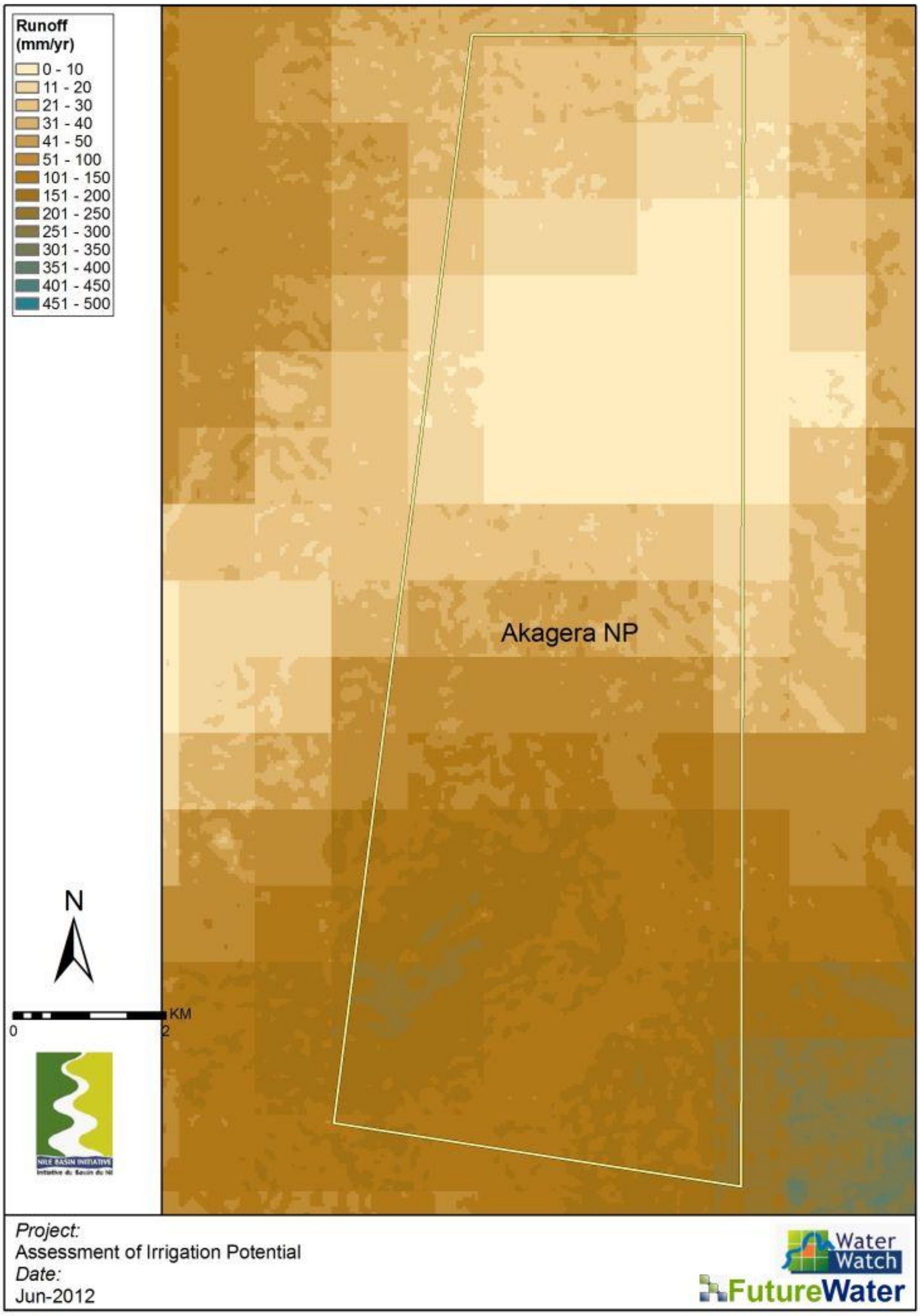
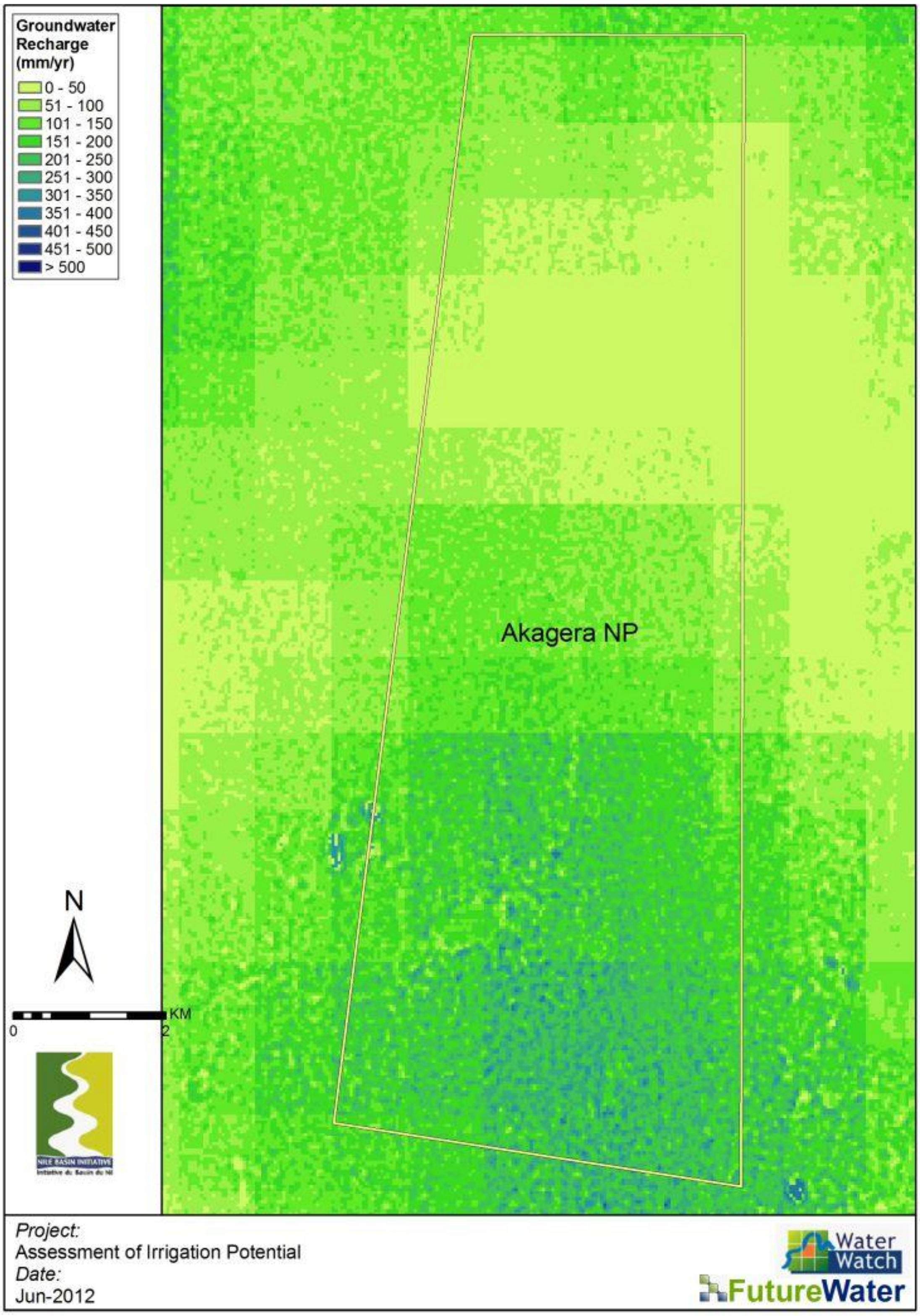


Figure 69: Water balances for the area based on the high resolution data and modeling approach for Akagera NP focal area. (Source: NELmod).



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
Akagera NP
N
KM
0
2
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
Akagera NP
N
0
2
KM
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater

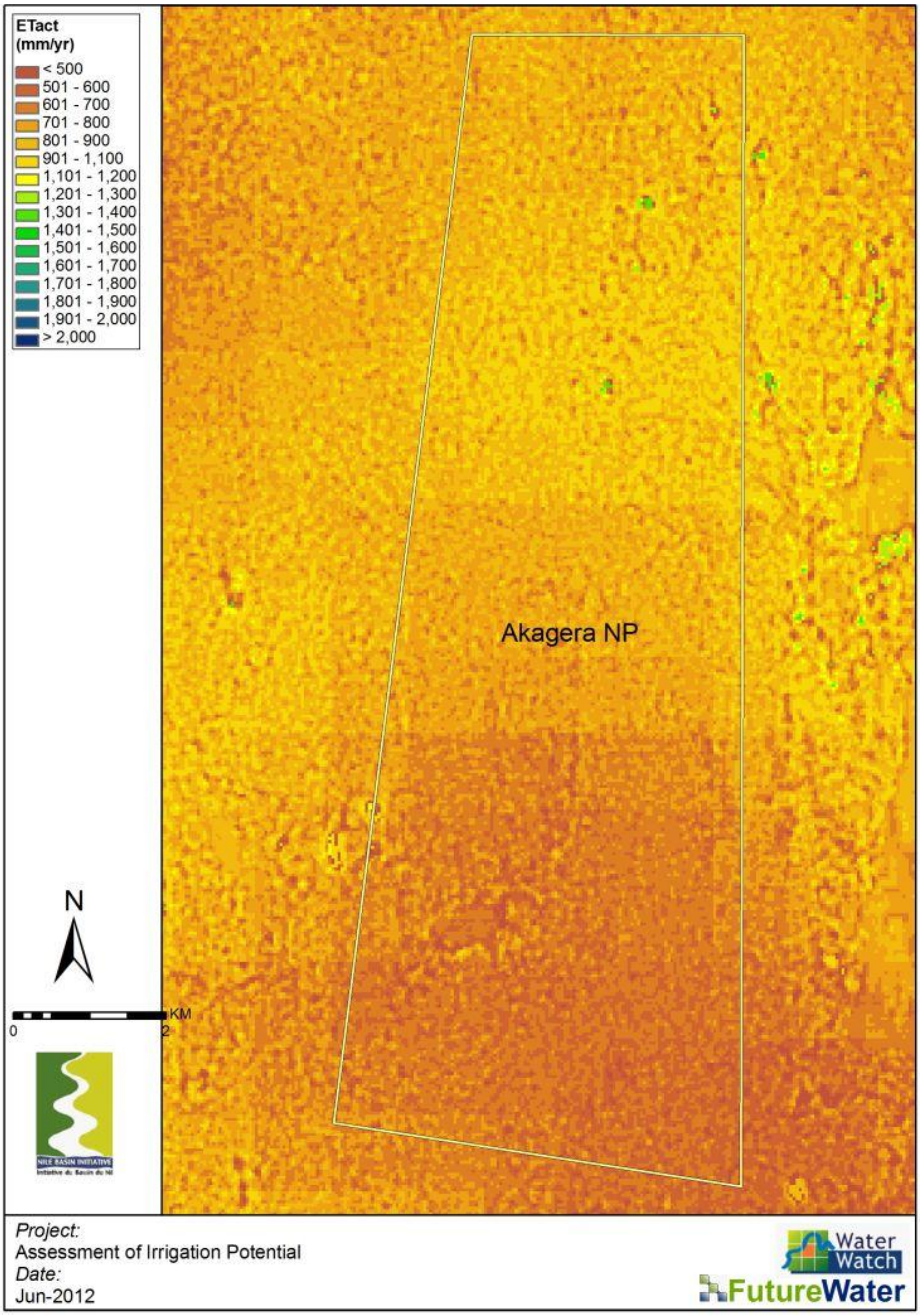


Figure 70: Water balances for the area based on the high resolution data and modeling approach for Akagera NP focal area. (Source: NELmod).

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 year might occur.

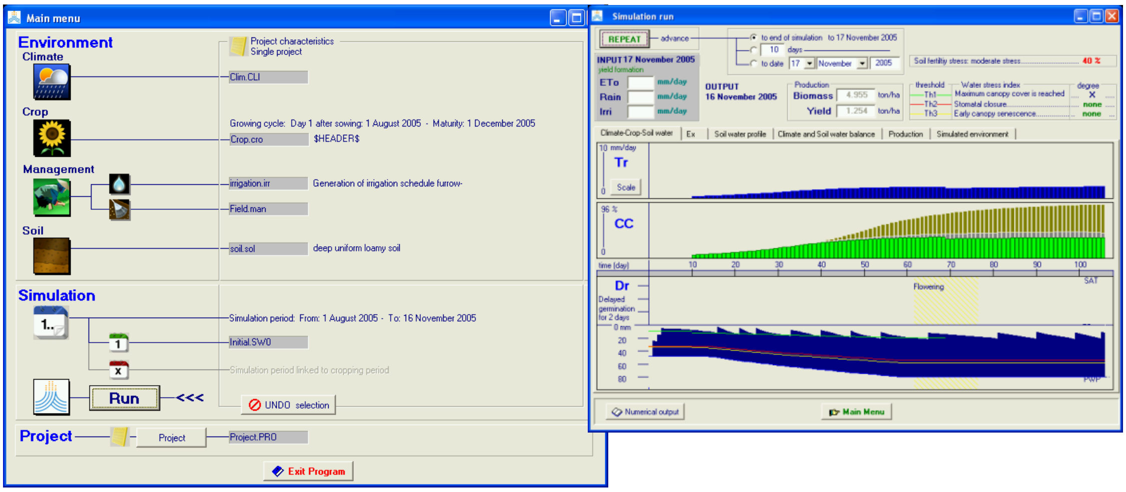


Figure 71: Typical example of AquaCrop input and output screens.

Table 10: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season. (Source: AquaCrop).

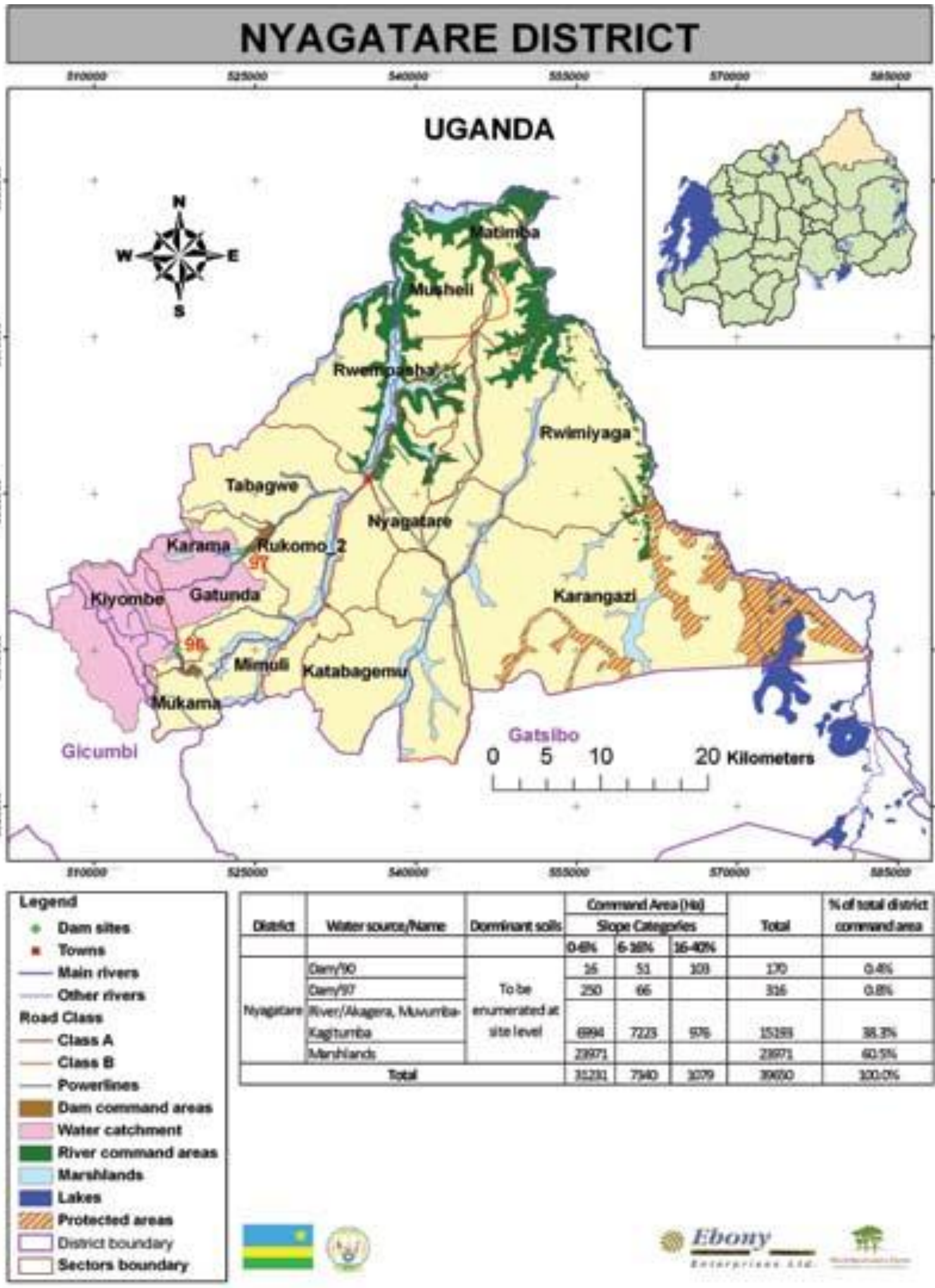
Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year	===	== (day of year) ==		======== growing season		=======	
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Maize	899	1424	41	182	399	210	529	394

5.4.2 Irrigation systems and irrigations efficiencies

In this focal area it is recommended to make use of the flat areas on or just up from the valley bottom, as most of the area is not cultivated for agriculture until now. For maize production the valley bottom is not very much suitable as drainage is poor. Either the drainage should be improved, which is a costly process, or the maize can be grown on the foothills bordering the valley. In the case of irrigating the side slopes, pumping is needed, which will increase the operation costs. Regarding the soil the valley bottom is very much suitable for growing rice under border irrigation, and the slopes on the side can be irrigated under pressure with sprinklers. Since not much agriculture is in place currently it is advised to develop the irrigation systems piece by piece. In that way the people can get used to the techniques and the transition from livestock to agriculture will be smooth. The farmer's expertise has to be developed to create sustainable irrigation systems, and to enhance high water use efficiencies. It is expected that water use efficiency for border irrigation will be around 0.3-0.4 depending on the infrastructure and the farmer's capacity. For sprinkler irrigation efficiency will go up to 70%.

5.4.3 Water source

The source of the water will mainly be Agakera river and one of the tributaries towards Akagera river. (Figure 72) Akagera river can be used to irrigate the northern part, and the tributary more upstream. This tributary drains an approximate area of 1667 square kilometer. Groundwater is a reliable water source in the southern half of the area. The use of groundwater is more expensive, and it's beyond the scope of this pre-feasibility study to make a detailed cost benefit analysis.



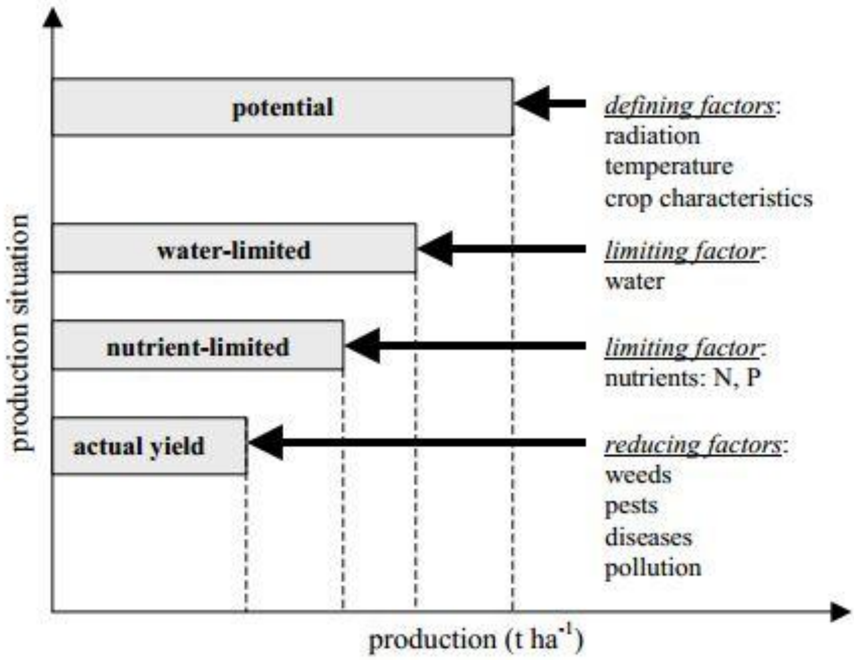
District	Water source/Name	Dominant soils	Command Area (Ha) Slope Categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Nyagatare	Dam/90	To be enumerated at site level	16	51	103	170	0.4%
	Dam/97		250	66		316	0.8%
	River/Akagera, Muvumba-Kagitumba		6994	7223	976	15193	38.3%
	Marshlands		23971			23971	60.5%
Total			31231	7340	1079	39650	100.0%

Figure 72: Potential water source for Akagera NP focal area

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*

For Akagera NP focal area the potential future crop is mainly maize. The figures for the current maize yields are not consistent since the area is hardly used for agriculture. According to the land productivity and the Faostat figures, the yield is around 1.960kg/ha while local expert data describe yields reaching 1.000kg/ha. In the scope of a detailed feasibility study these numbers should be narrowed down. Calculated with the Faostat yields the yield gap is 62% toward the world's average yield and 92.2% towards the maximum obtainable yield. According to local experts, yields can increase under irrigation towards the world's average, reaching 5000kg/ha (19.8% of maximum obtainable yield) (see Figure 73).

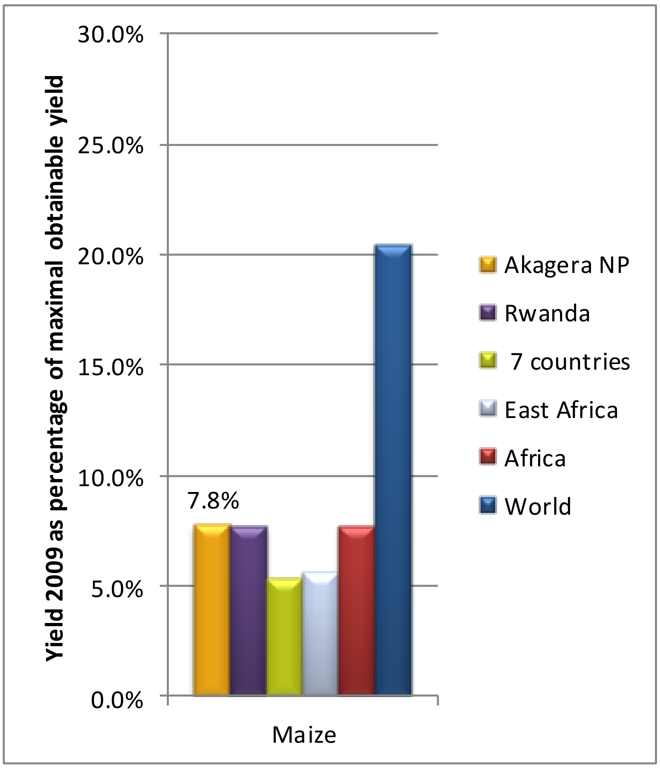


Figure 73: Yield gap Akagera NP (source: FAOSTAT, 2010)

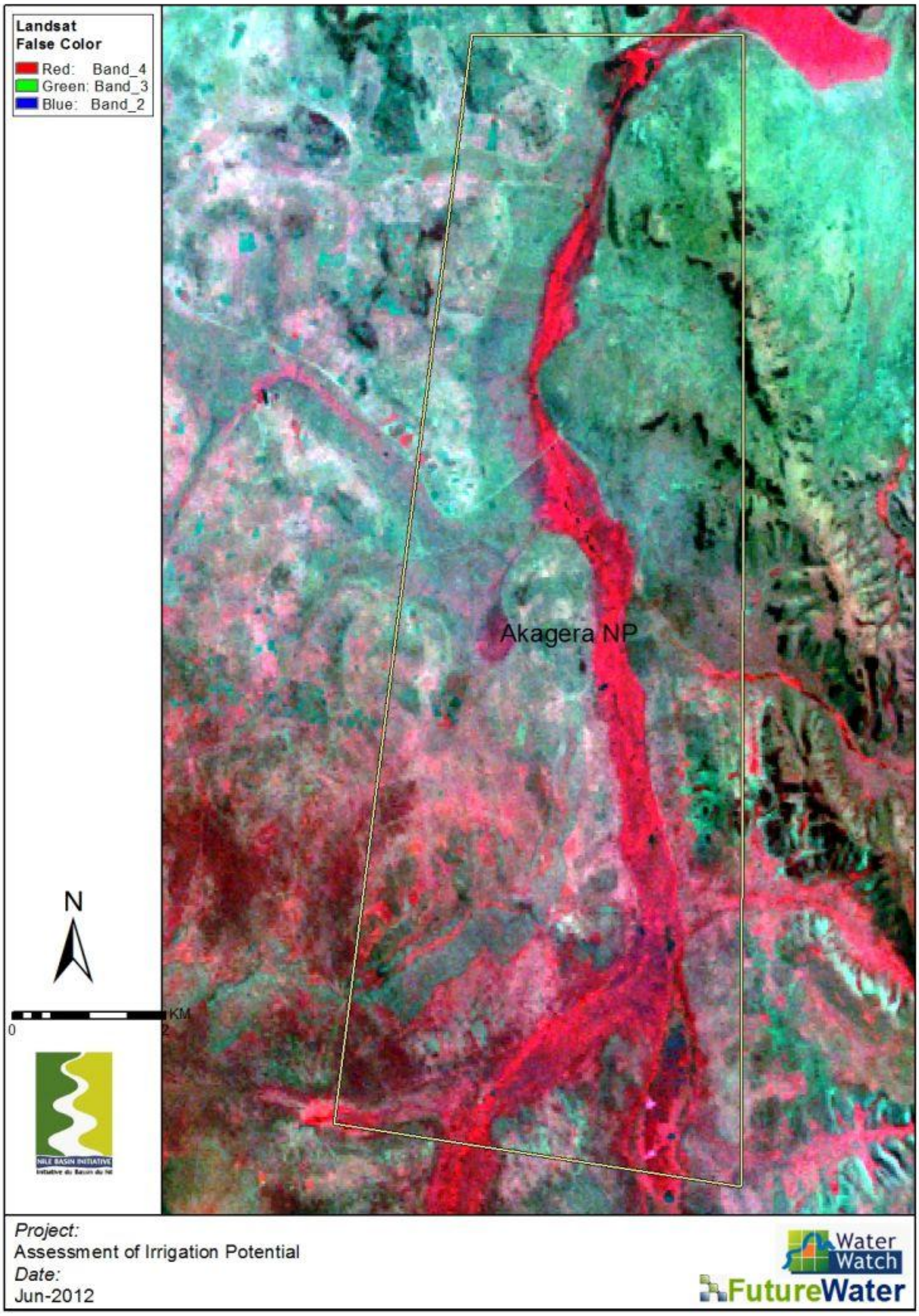


Figure 74: Landsat False Color Composite indicating current productivity of the area for Akagera NP focal area. (Source: Landsat).

5.6 Environmental and socio-economic considerations

5.6.1 Population displacements

The area is hardly inhabited as the population density is just 10people/km^2. There are no villages in the focal area, and just some solemn houses. It is not expected that these houses will be a problem with irrigation development.

5.6.2 Social

Population density in the area is very low. People's main activity for living is keeping livestock. The area is very newly occupied, so population density is expected to increase within the coming years. This however means that the social structure and the capacity and knowledge for farming are generally very low. Current infrastructure is poorly developed and the area is far (+/- 20 km) from the nearest tarmac road. Consequently, the area is not always well accessible in rainy seasons. Wild animals are wandering around in the area as well; this may be a problem for agriculture. It is however planned to build an electric fence along the national park.

5.6.3 Upstream downstream consideration

This area is a good example of an area with no upstream or downstream problems. As agriculture is hardly practiced and population density is low, there is hardly any erosion and water quality is not affected. With irrigation development, however, this can easily change as farmers' knowledge is limited, which increases the chance on erosion or eutrophication. Since the area is draining into Akagera river/swamp, which is a national park, it's recommended to pay special attention to the quality of the water. In a detailed feasibility study attention should be paid on how to minimize erosion and water pollution.

5.6.4 Protected areas

This area is located along Akagera national park, and within the Akagera national park buffer zone. Therefore it is really important that a feasibility study will show what will be the effects of an irrigation scheme in this area for the environment. Although the pressure on land and resources is increasing rapidly, the added value from national parks and protected areas are studied and proven to be substantial. Therefore a careful consideration should be made whether an irrigation scheme is giving any added value to the region, in economic, social, and environmental sense.

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 small financial 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: 5,000 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. The local expert has been very positive about all Rwanda focal areas, however; 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.

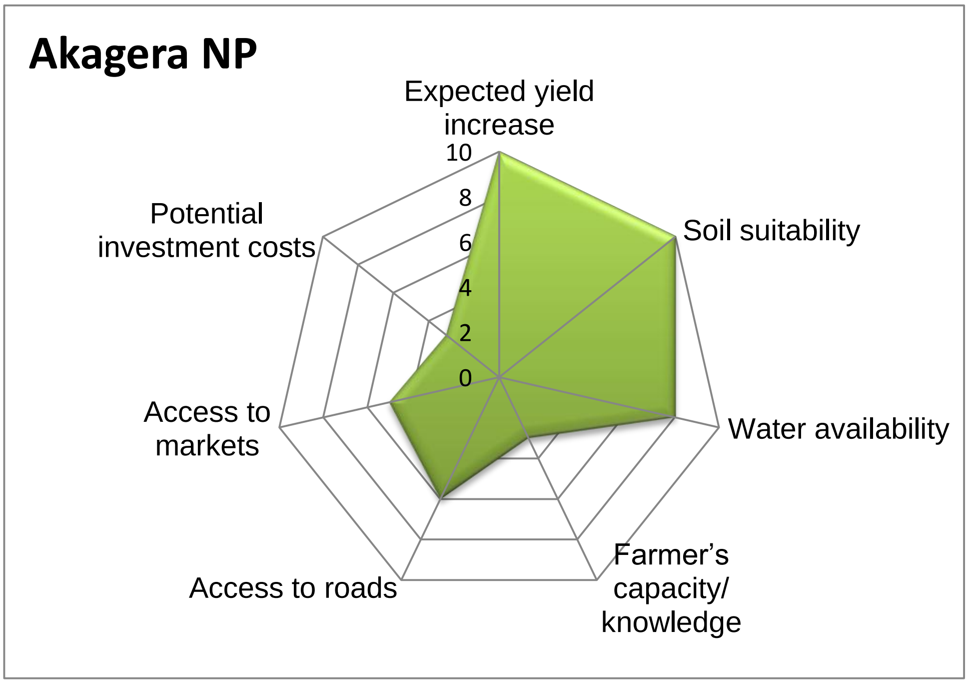


Figure 75: Filled radar plot indicating expert knowledge score to develop irrigation in the Akagera NP focal area (1 = negative, 10 = positive). (Source: local expert and study analysis).

Table 11: Benefit-cost analysis for the area.

Characteristics	
Irrigated land (ha)	5,000
Farmers	5,000
Investment Costs	
Irrigation infrastructure (US$/ha)	6,000
Social infrastructure (US$/farmer)	750
Accessibility infrastructure (million US$)	3.0
Operational Costs	
O&M irrigation (US$/ha/yr)	60
Extension service (US$/farmer)	15
O&M roads (US$/yr)	60,000
Summary	
Initial investments (million US$)	36.8
O&M costs (million US$/yr)	0.435
Net benefits per year (million US$/yr)	3.364
IRR (Internal Rate of Return)	6.9%

5.8 Recommendations

This pre-feasibility study describes the topics on a screening and scoping level. The available local data are included in the analysis and description, but final results give a first impression of the irrigation possibilities. Recommendations to be included in a detailed feasibility study are: i) possible design of the irrigation scheme ii) In depth analysis of possible reservoir sites iii) the implications of the legal framework and local law on irrigation development in the focal area iv) make an economic analysis per crop and irrigation system and v) a in depth cost benefit analysis, fully based on the local situation.

6 Nyabitekeri focal area

6.1 Introduction

This chapter will describe the current state of the Nyabitekeri 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 77a detailed map of the area is given. Total area is 12927 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 Reverien Harindintwali and Prime Ngabonziza as supervisor in March 2012.

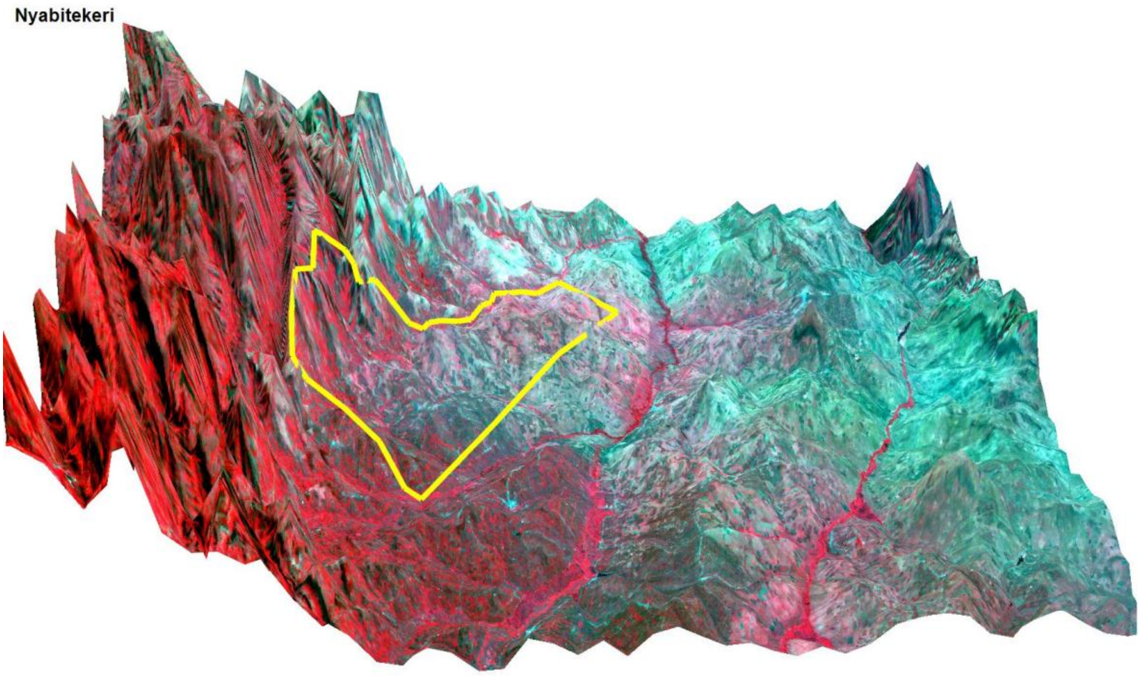


Figure 76: 3D impression of Nyabitekeri focal area, Rwanda. (Source: Landsat).

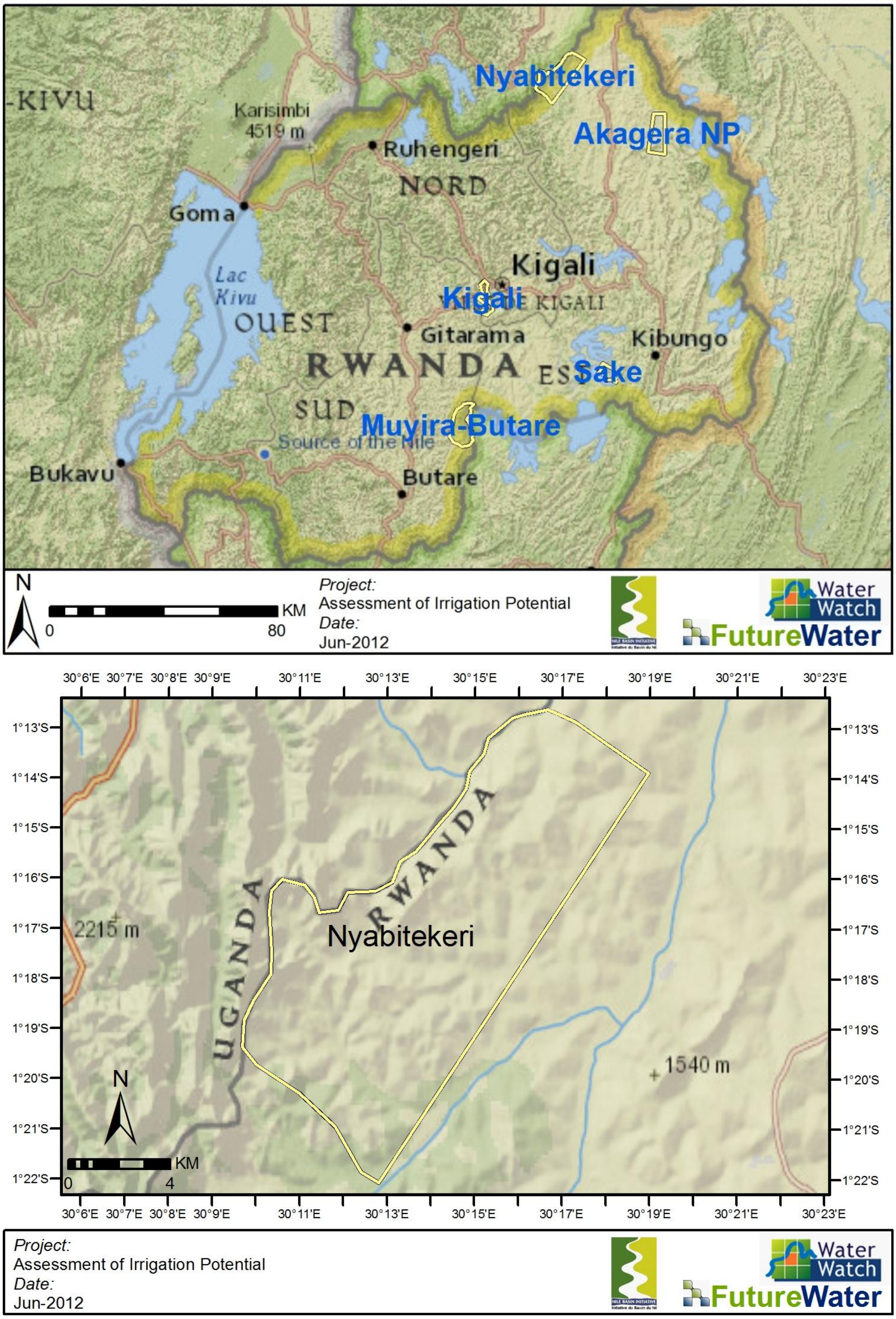


Figure 77: Nyabitekeri focal area, Rwanda

6.2 Land suitability assessment

6.2.1 Terrain

This focal area in Rwanda’s eastern province is situated at the border to Uganda. It covers the transmission zone between the hills in Uganda and the lower land in Rwanda. Therefore the elevation difference within this zone is large with an elevation of 1800m in the west, and an elevation of just above 1300m towards the valley (Figure 78). Slopes vary accordingly, from over 20% in a small area towards the western border, and show a homogeneous variation of slopes between 3-8% over the whole area (Figure 79).

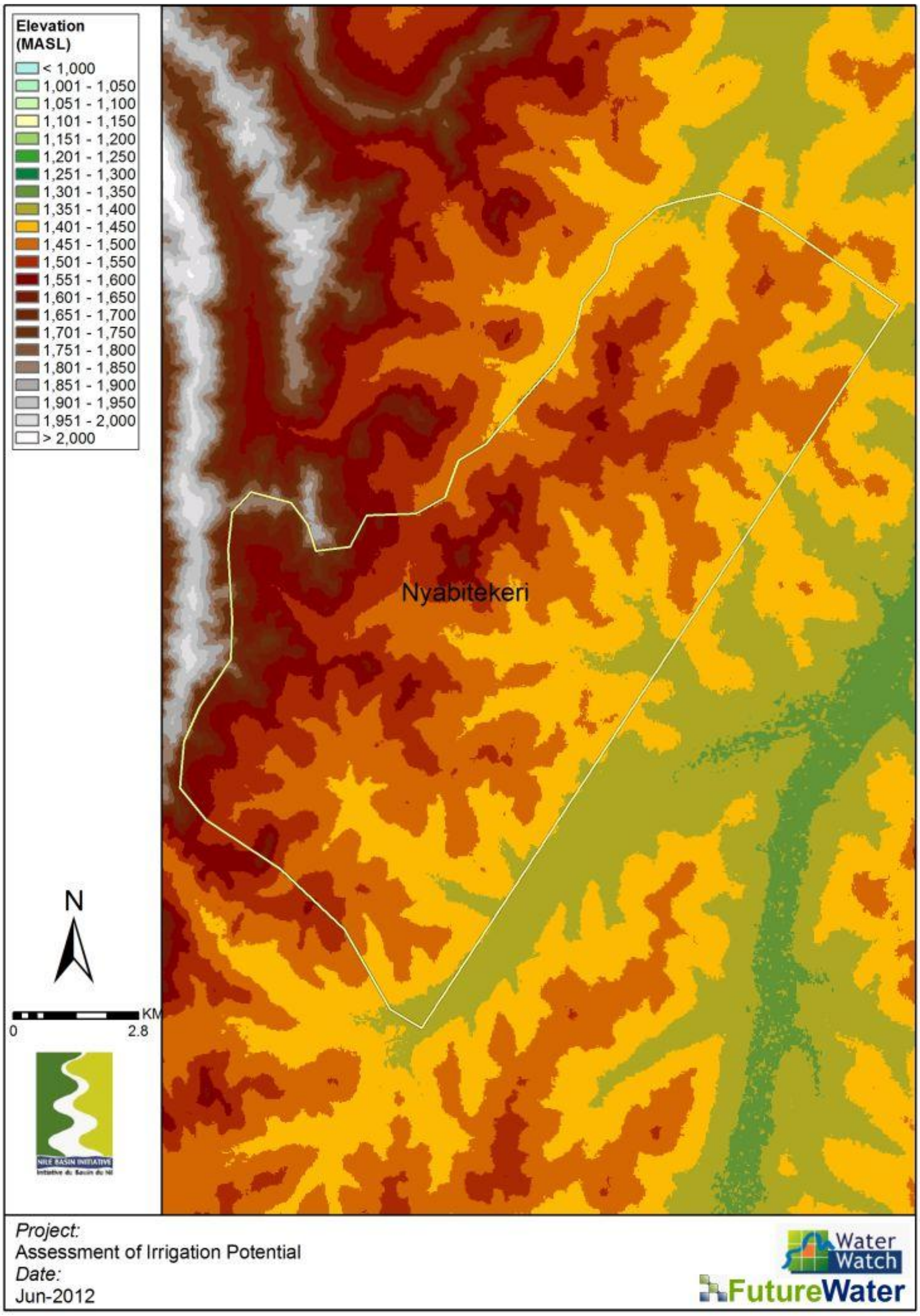


Figure 78: DEM Nyabitekeri focal area. Resolution 1 arc second (+/- 30m). (Source: ASTER).

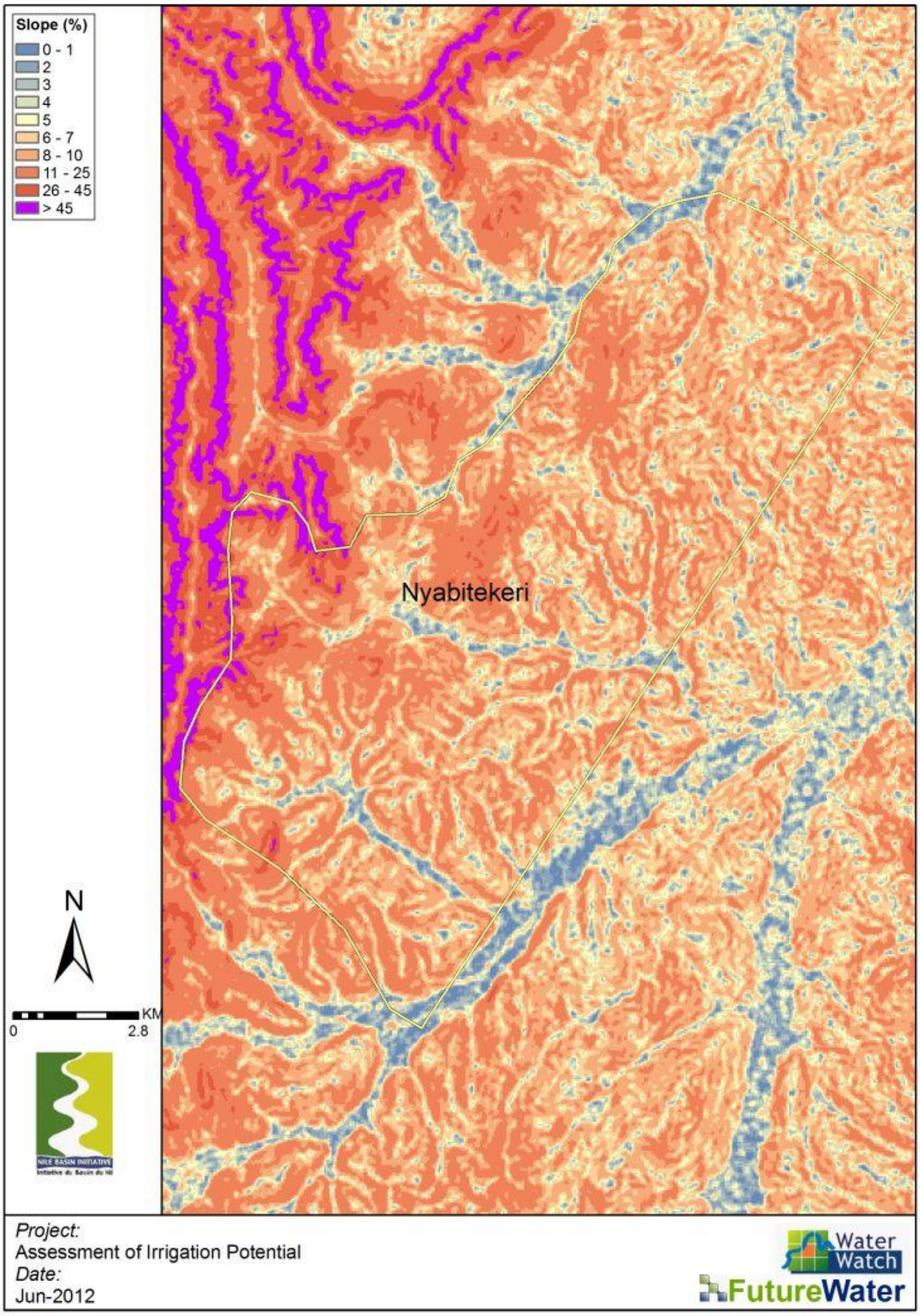


Figure 79: Slope map Nyabitekeri focal area. (source: ASTER)

6.2.2 Soil

The soil shows a very fragmented picture. In the West towards the Ugandan highlands the soils show a small part of shallow well drained clay or loamy clay soil with a rocky sub soil within 50cm. A bit further down the slope the rocky sub soil descends to over 100 cm from surface. The largest part of the area, which is located under the 1450m are formed by magmatic processes. These yellow soils are deep, well drained, loamy clay to clay, and have a limiting gravel layer between 50-100cm. This gravel consists of granitic sand mixed with laterite. These soils are interspersed with pieces of well drained clayey soils, which are very shallow and have saprolite or bedrock at around 50cm. In the stream valleys deep alluvial soils can be found, they are very clayey, and drain imperfectly to moderately. These soils are combined with soils which are heavy clay, and drain poor to very poorly.
Soils are very poorly fertilized, as agriculture is not the main business in this area. Despite the large available amounts of cattle excreta it is not used. Chemical fertilizer is not used either. The percentage of organic matter in the soil is very low, and slight erosion was observed.

6.2.3 Land productivity

The land productivity is with 0.611 above the Rwandan average of 0.579. Especially in the steep South-West and in the stream valleys the NDVI is high with values around 0.65. Further the NDVI is quite stable at 0.6 over the area, with some less productive parts on the higher places (Figure 81). The coefficient-of-variation in the area is low in the western part and relatively high in the eastern part of the area where most of the agriculture takes place.

The NDVI formula is:

$$\frac{(NIR - RED)}{(NIR + RED)}$$

The NDVI is calculated based on remote sensing Modis images, and in more detail the Nearly InfraRed band (NIR) en de visible RED band (RED). The ratio between these two bands shows the productivity between -1 and 1. Plants absorb the red light for their photosynthesis, and reflect the NIR light.

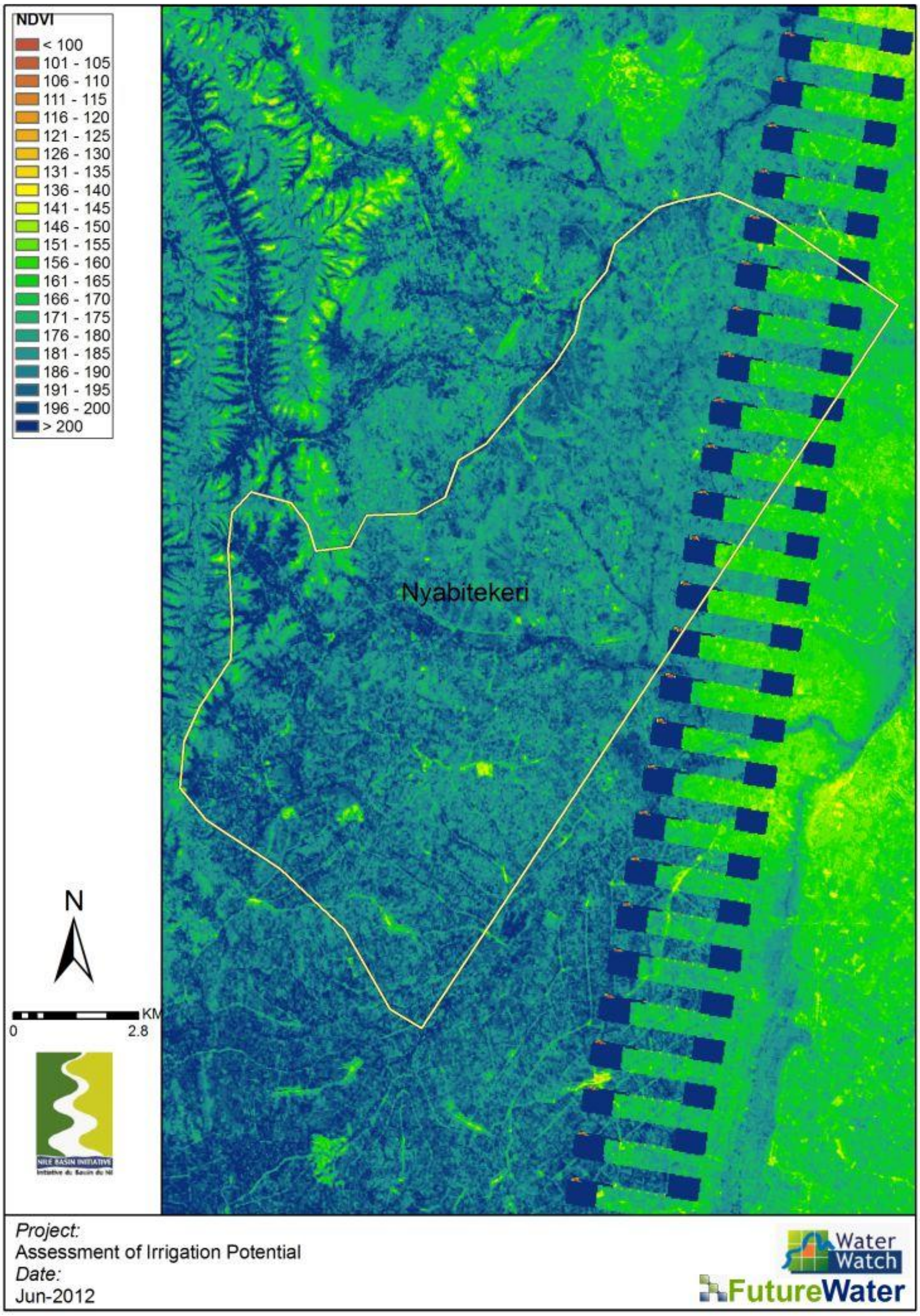


Figure 80: High resolution NDVI for Nyabitekeri focal area. (Source: Landsat).

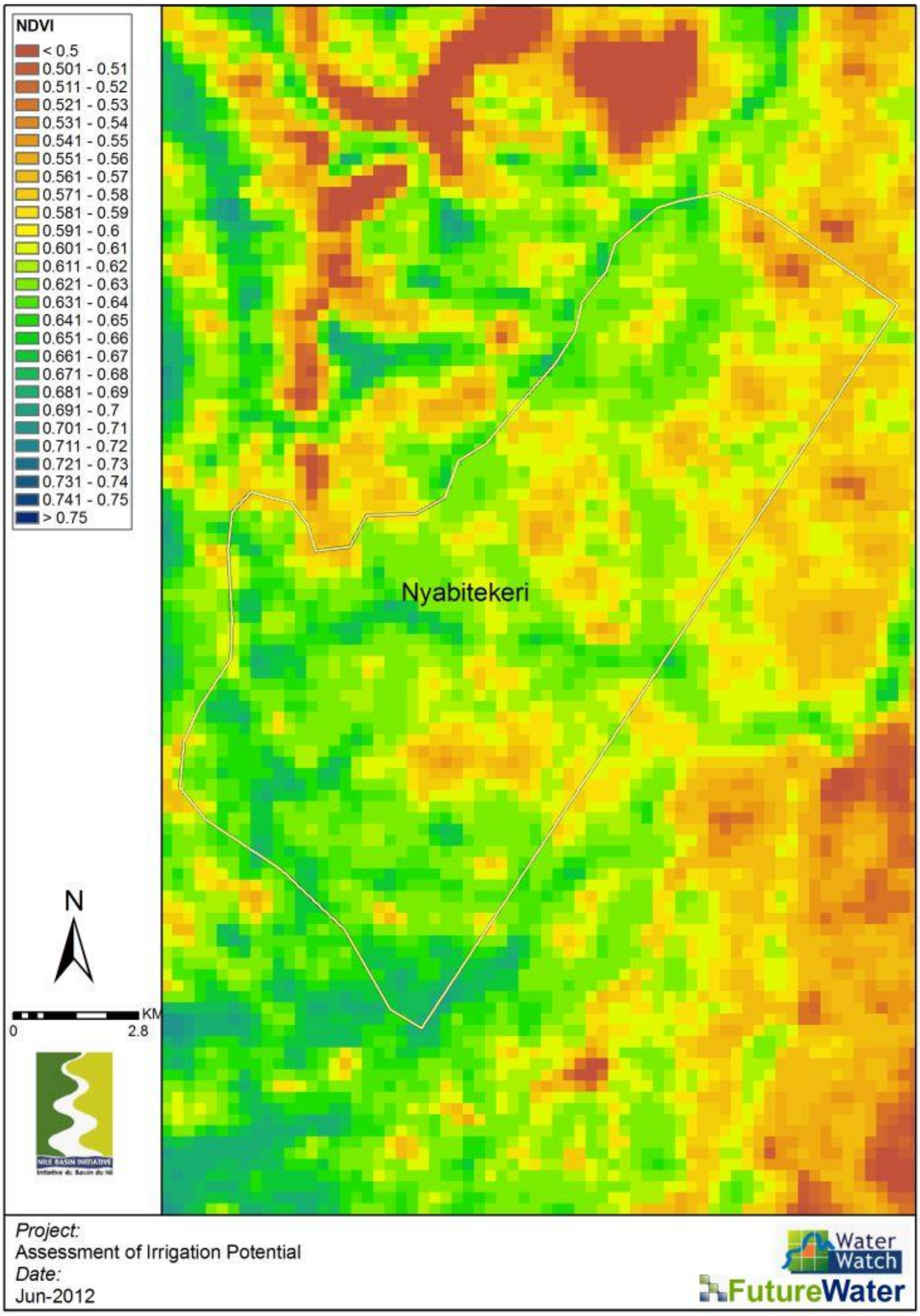


Figure 81: Yearly average NDVI values for Nyabitekeri focal area. (Source: MODIS).

6.2.4 *Potential cropping patterns*

The area is mainly used for keeping livestock. About 5% of the area is used for agricultural activities. Within that area there is a relatively large variation of crops grown. Bananas with 50% occupy the largest area. Further, Cassava is growing on 20% of the area; Maize on another 20% and beans take the remaining 10%.

Future potential crops will be Maize and pineapples. The crops all fit within the policy of the government, and maize is especially recommended as the yields, with 4.000-6.000kg/ha, are good in the region. Within the 'land use consolidation program' the government recommends to grow maize. Rice is suitable to be grown in the valleys, as land is flat and soils most suitable. Under irrigation, both rice and maize can give at least 2 harvests per year, and the yield may double.

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 relatively warm with constant temperatures during the year ranging from about 14°C to 27°C. Annual average precipitation is 965 mm and reference evapotranspiration 1351 mm per year.

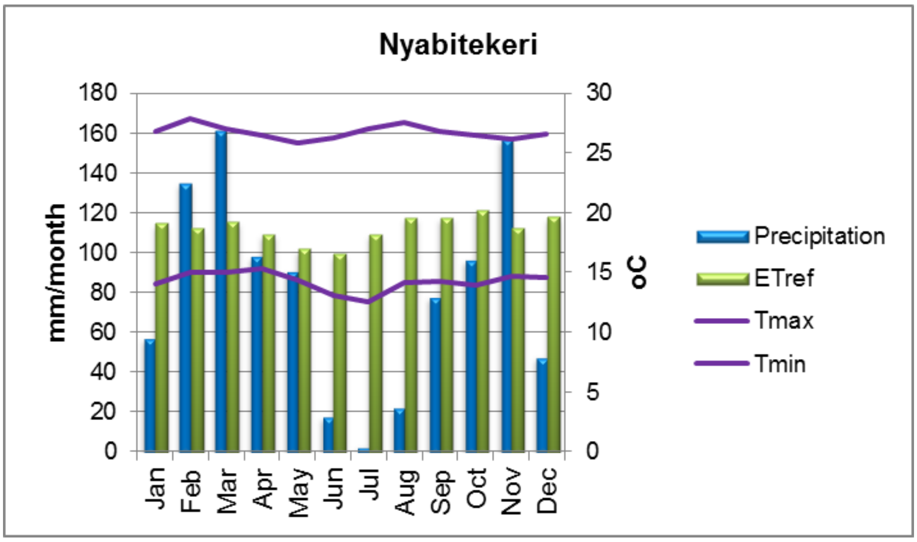


Figure 82: Average climate conditions for Nyabitekeri focal area. (Source: study analysis).

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.

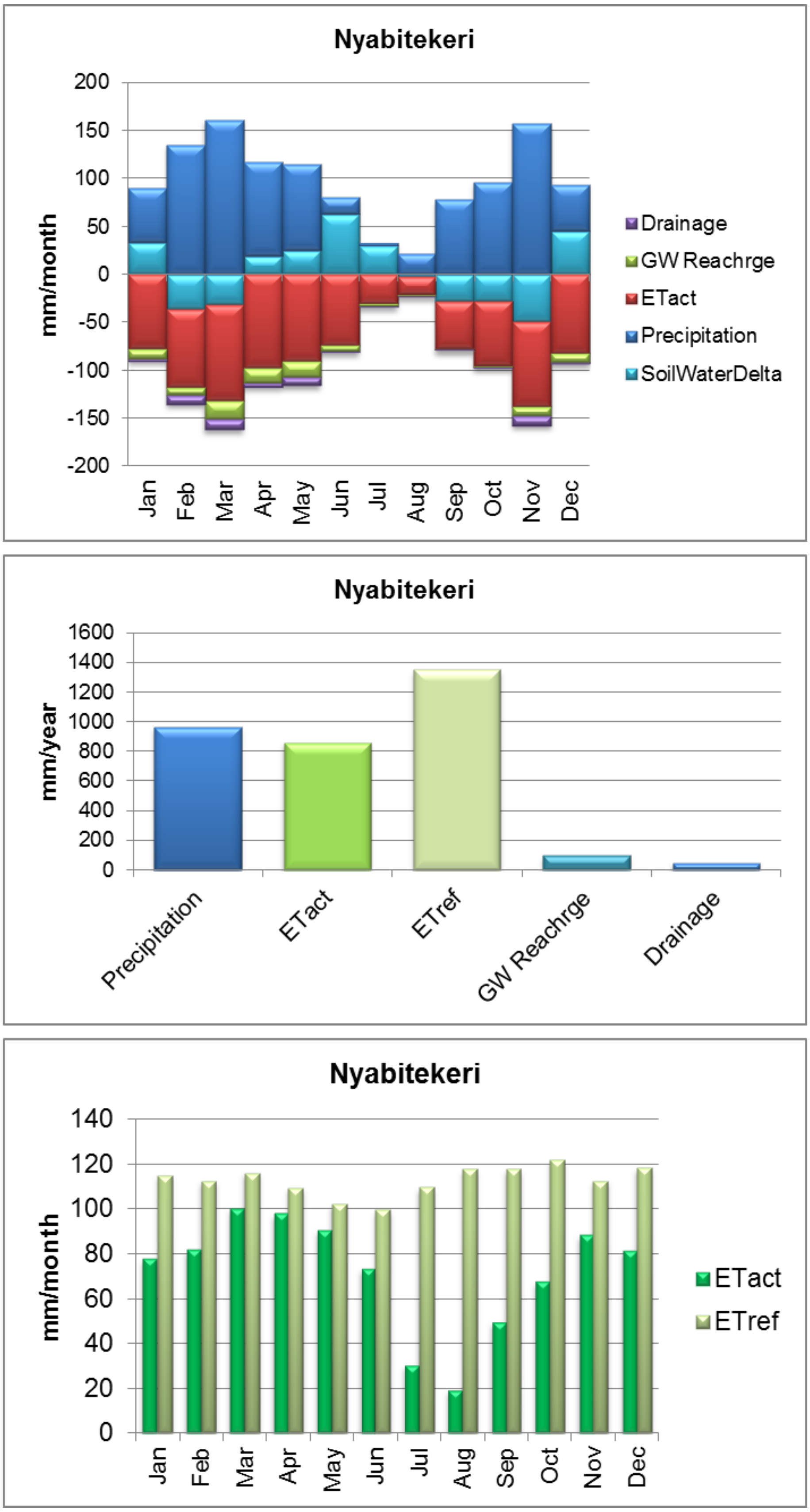
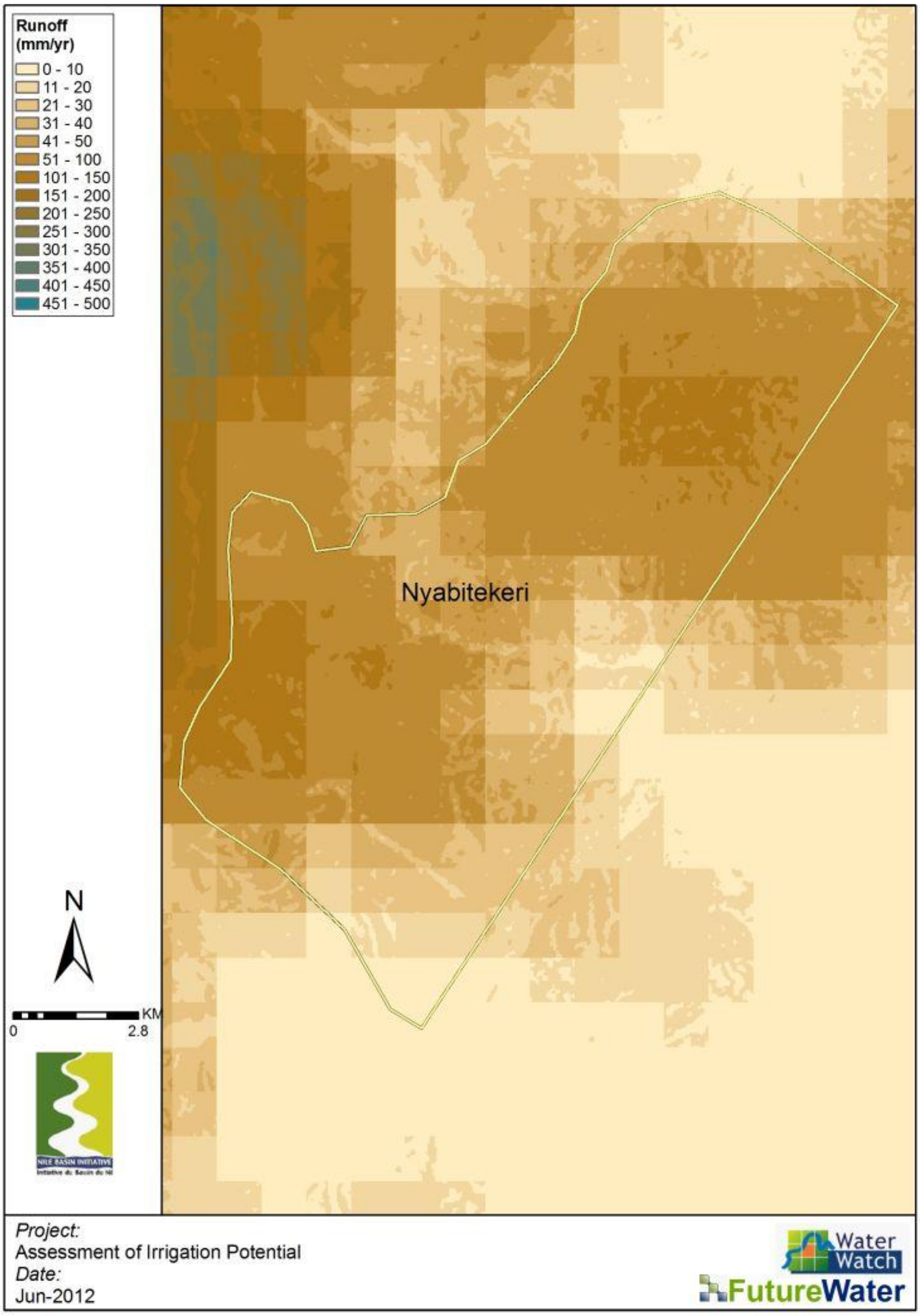


Figure 83: Water balances for the area based on the high resolution data and modeling approach for Nyabitekeri focal area. (Source: NELmod).


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
Nyabitekeri
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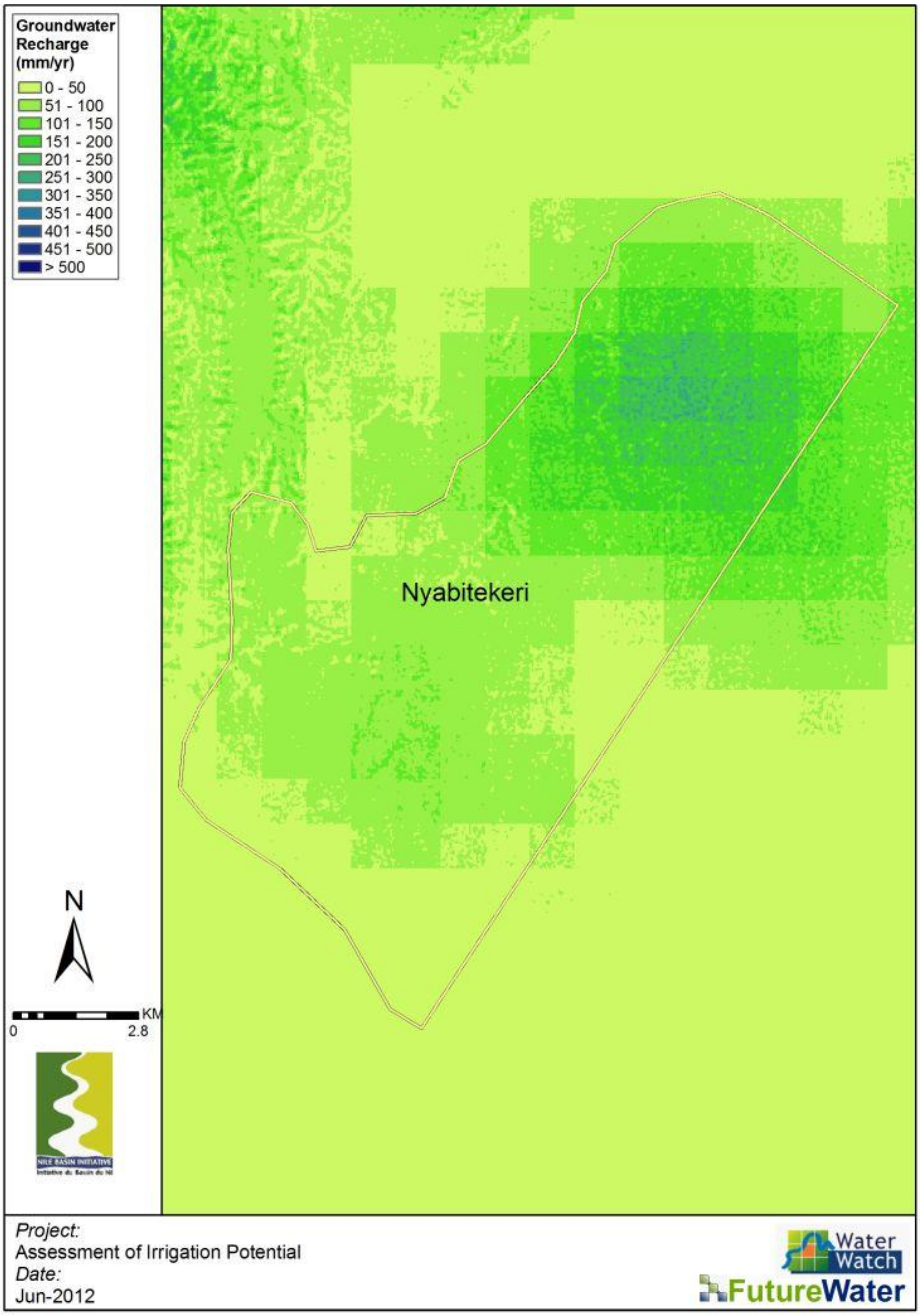
KM
0
2.8
Project:
Assessment of Irrigation Potential
Date:
Jun-2012
Water Watch
FutureWater


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
Nyabitekeri
N
KM
0
2.8
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FutureWater

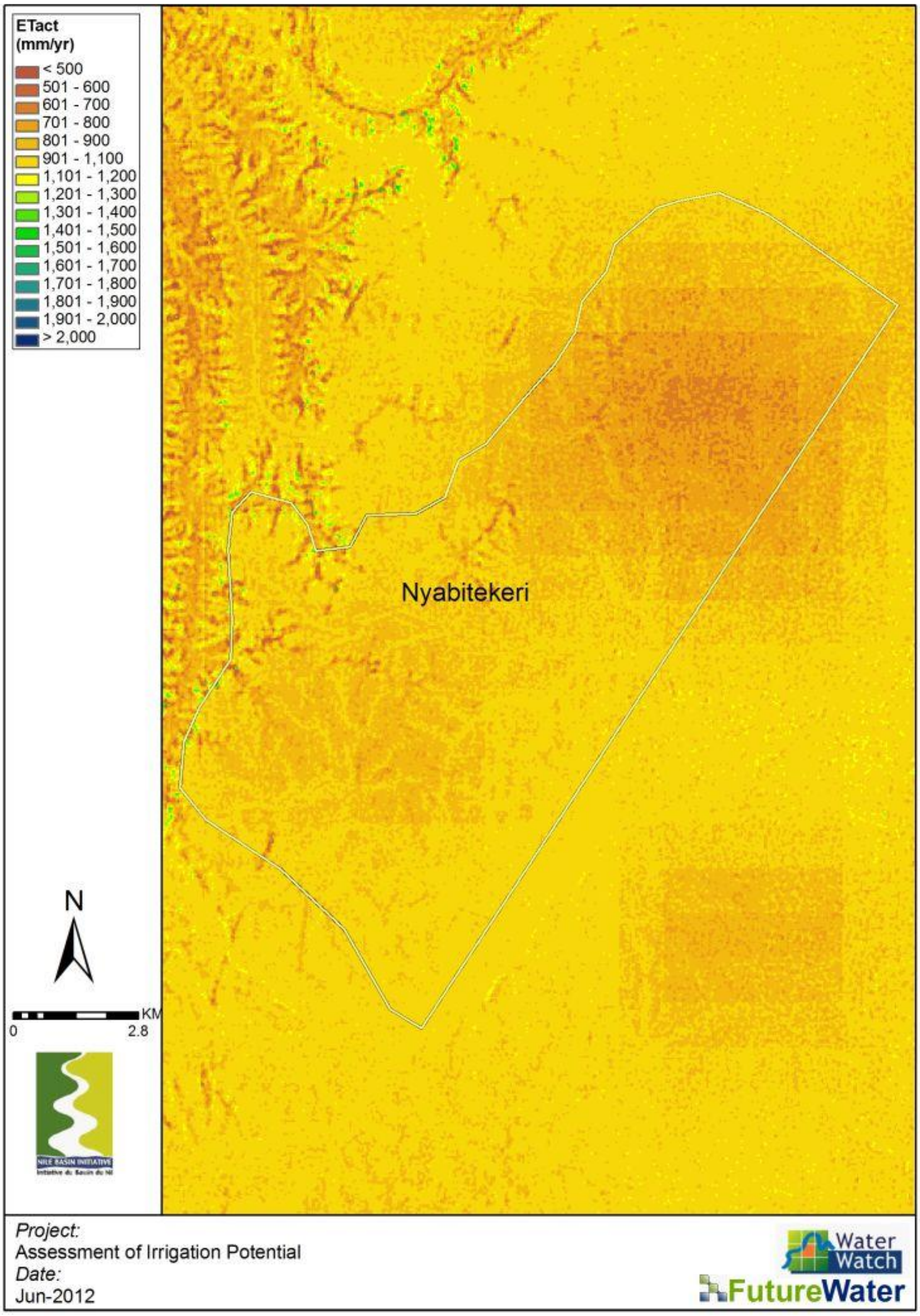


Figure 84: Water balances for the area based on the high resolution data and modeling approach for Nyabitekeri focal area. (Source: NELmod).

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 year might occur.

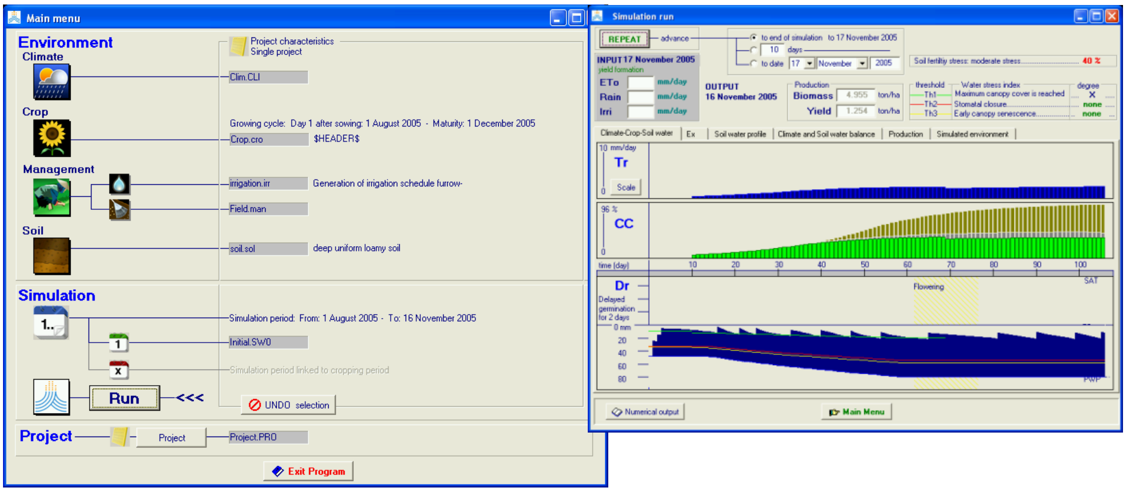


Figure 85: Typical example of AquaCrop input and output screens.

Table 12: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season. (Source: AquaCrop).

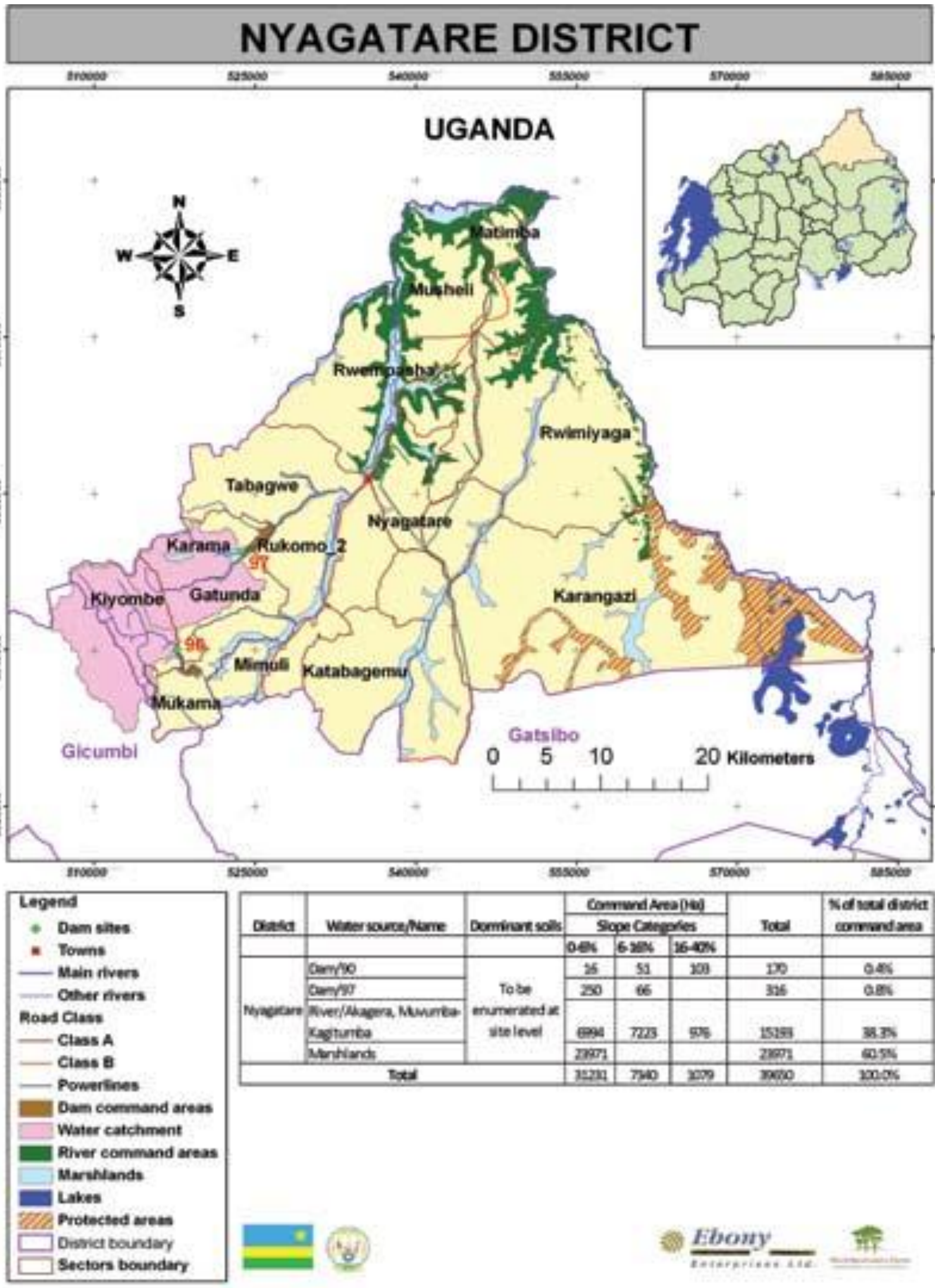
Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year	===	== (day of year)	==	======== growing season		=======	
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Maize	965	1351	274	30	356	260	467	420
Rice	965	1351	1	136	508	180	503	460
Pineapples	965	1351	1	365	965	230	1348	635

6.4.2 Irrigation systems and irrigations efficiencies

Due to the small drainage area of the streams crossing trough the focal area, surface water will not be sufficient for irrigation. The western mountainous part of the area is advised not to irrigate, as top soils are shallow, and water availability poor, or expensive to pump up. Areas towards the South and East can be irrigated. But due to the irregular elevation and slope it's recommended to use small scale irrigation systems, which can deal with height differences. Therefore it's recommended to focus on the use of drip or sprinkler irrigation. The application efficiency in that case can reach up to 70-80%. Pumping from the river is required, which will increase the operation costs. In the river valley there is the possibility to use border irrigation for rice, as is done in the nearby located “Muvumba river valley rice plantation”.

6.4.3 Water source

The water source will largely be the streams on the South and East side flowing along the focal area, including Muvumba River. (Figure 86) In the north the use of groundwater is realistic, and probably the best source as the stream passing by at the North Western top of the area is a trans-boundary river.

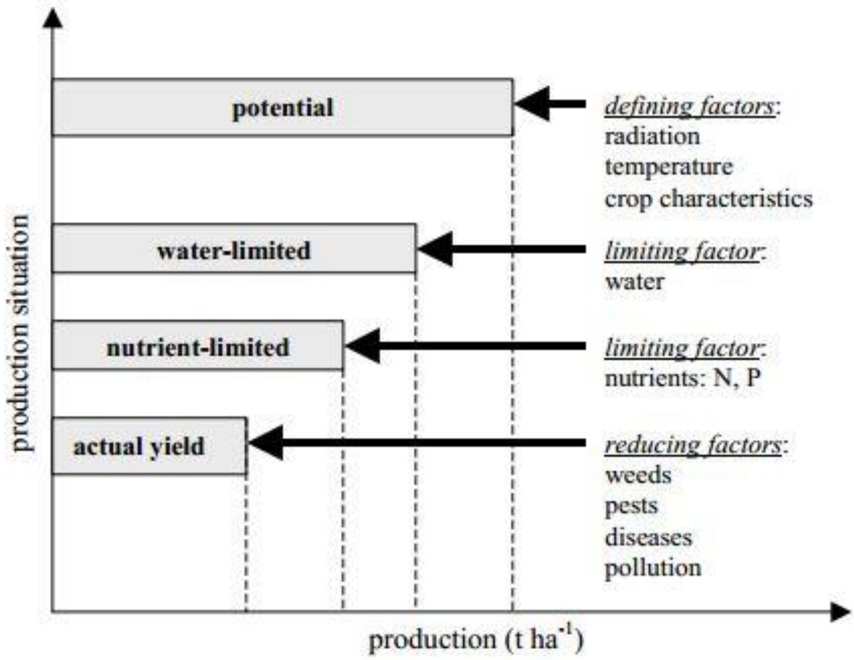


District	Water source/Name	Dominant soils	Command Area (Ha) Slope Categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Nyagatare	Dam/90	To be enumerated at site level	16	51	103	170	0.4%
	Dam/97		250	66		316	0.8%
	River/Akagera, Muvumba-Kagitumba		6994	7223	976	15193	38.3%
	Marshlands		23971			23971	60.5%
Total			31231	7340	1079	39650	100.0%

Figure 86: Potential water source

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

Yields in this focal area are slightly higher than Rwanda's average. For maize and pineapples yields are at 40% and 45% respectively of the world's average yield, and at 8.1% and 11.5% respectively of the maximum obtainable yield. Rice, however, is performing really well with yield almost doubling the world's average and reaching 81.2% of the maximum obtainable yield. The comparison is not completely fair as rice is usually grown under irrigation, which decreases the yield gap. The figure however shows that Rwanda is successful in growing rice, and that an increase of rice production will enhance agricultural productivity. Maize and Pineapples are expected to increase the yields by 2.5-3 times under irrigation (Figure 87).

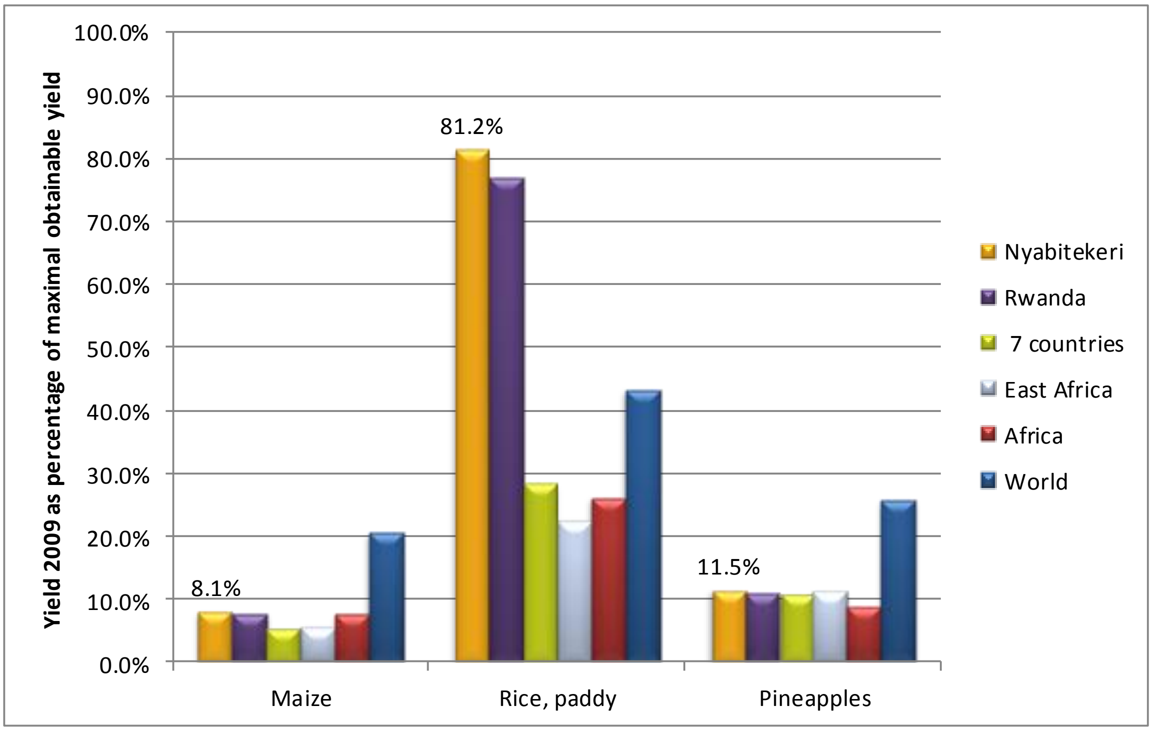


Figure 87: Yield gap Nyabitekeri (Source: FAOSTAT, 2010)

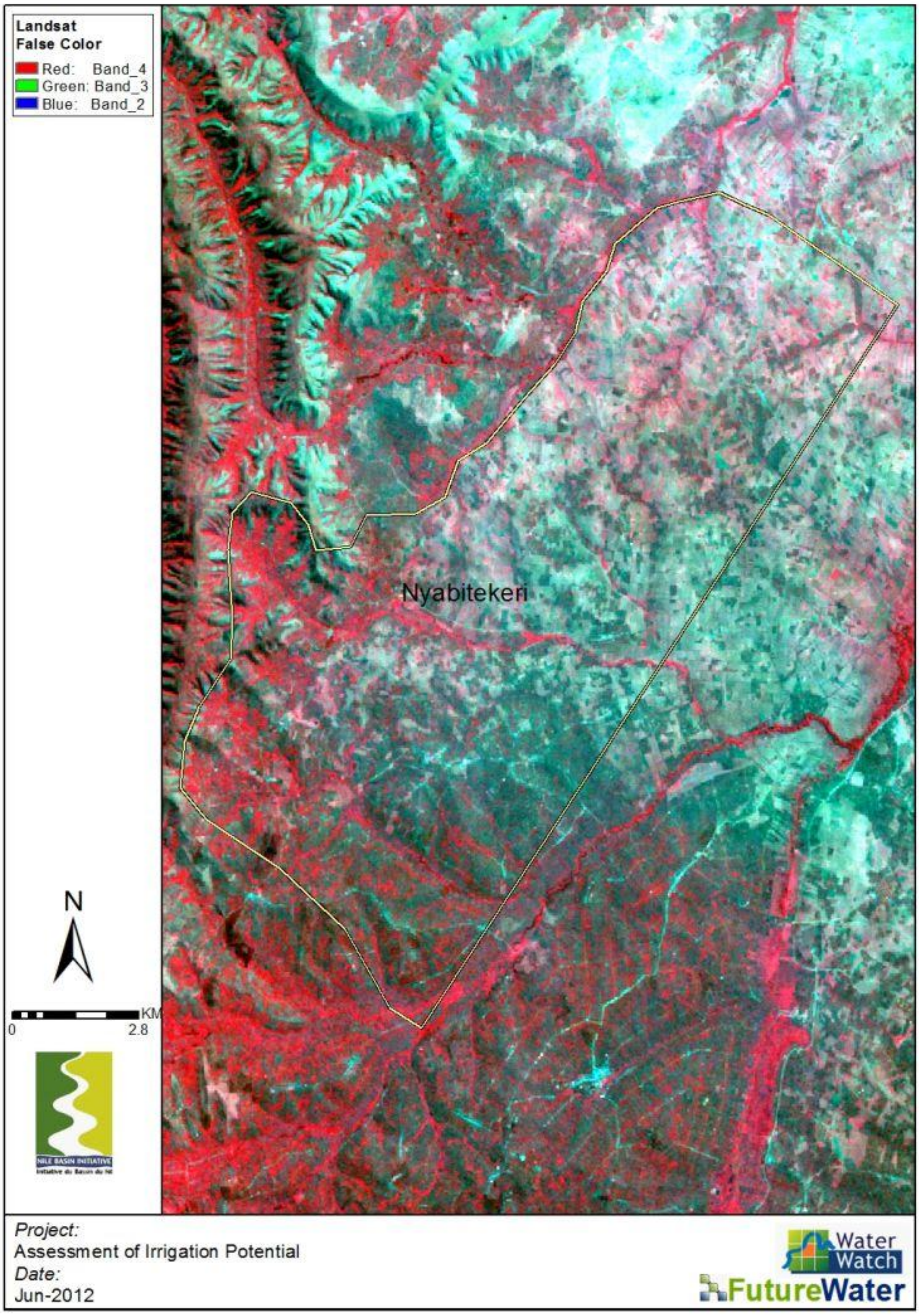


Figure 88: Landsat False Color Composite indicating current productivity of Nyabitekeri focal area. (Source: Landsat).

6.6 Environmental and socio-economic considerations

6.6.1 Population displacements

Population density is low with 50people/km^2. Most people live in small villages and some houses are scattered around the focal area, mainly along the roads. With any irrigation system design it should be possible to work around most of the villages and strips of houses.

6.6.2 Social

The area is sparsely populated compared to Rwanda´s average, and people mainly live from cattle keeping and livestock. The area is well accessible, as roads are crossing through the area, which are accessible year round. Markets are nearby and well accessible. Concerning irrigation development, the people's mindset is said to be conservative and not eager for a quick change. The knowledge for agriculture and irrigation is low and the people have hardly any experience with agricultural cooperatives. Maybe a nearby planned irrigation system within Nyagatare district can enhance and increase the farmers irrigation capacity.

6.6.3 Upstream downstream consideration

The area suffers under slight erosion, as upstream slopes are very steep. Depending on the irrigation water source different problems may occur,as most of the water in the streams passing by/through the area is coming from Uganda. Therefore this project will only be possible with the cooperation and collaboration of the Ugandan authorities. Currently, a study is being undertaken for building a multipurpose dam alongside the focal area. Upstream erosion may cause problems with the construction and operation of a dam, as efficiencies will decrease as dam capacity reduces.

6.6.4 Protected areas

Within the focal area there are no protected areas.

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: 5,000 kg/ha, 0.22 $/kg
    - Rice: 7,000 kg/ha, 1.10 $/kg
    - Pineapples: 30,000 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. The local expert has been very positive about all Rwanda focal areas, however; overall, the weak part of the site lies under farmers capacity and the initial investment cost. Soil suitability and water availability is a great deal for the area that will foster an increase yields.

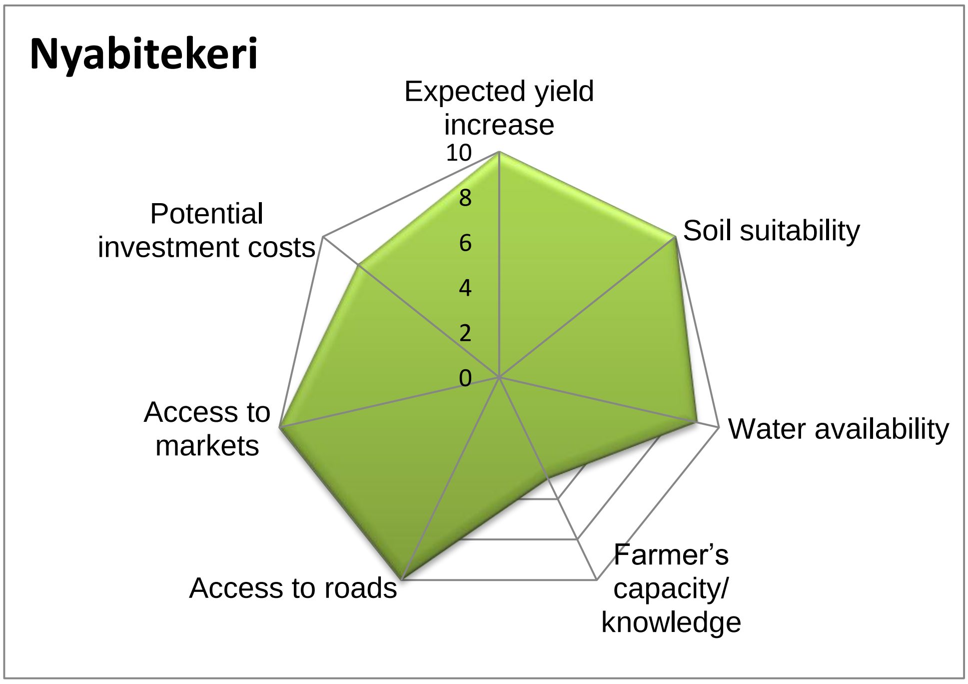


Figure 89: Filled radar plot indicating expert knowledge score to develop irrigation in the Nyabitekeri focal area (1 = negative, 10 = positive). (Source: local expert and study analysis).

Table 13: Benefit-cost analysis for the area.

Characteristics	
Irrigated land (ha)	6,000
Farmers	7,500
Investment Costs	
Irrigation infrastructure (US$/ha)	6,000
Social infrastructure (US$/farmer)	750
Accessibility infrastructure (million US$)	1.0
Operational Costs	
O&M irrigation (US$/ha/yr)	60
Extension service (US$/farmer)	15
O&M roads (US$/yr)	20,000
Summary	
Initial investments (million US$)	42.6
O&M costs (million US$/yr)	0.493
Net benefits per year (million US$/yr)	18.360
IRR (Internal Rate of Return)	72.2%

6.8 Recommendations

This pre-feasibility study describes the topics on a screening and scoping level. The available local data are included in the analysis and description, but final results give a first impression of the irrigation possibilities. Recommendations to be included in a detailed feasibility study are: i) possible design of the irrigation scheme ii) In depth analysis of possible reservoir sites iii) the implications of the legal framework and local law on irrigation development in the focal area iv) make an economic analysis per crop and irrigation system and v) a in depth cost benefit analysis, fully based on the local situation.

7 Kigali focal area

7.1 Introduction

This chapter will describe the current state of the Kigali 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. Based on these aspects the potential for irrigation will be described, and cost for irrigation development calculated. In Figure 91 a detailed map of the area is given. Total area is 2694 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 March 2012.

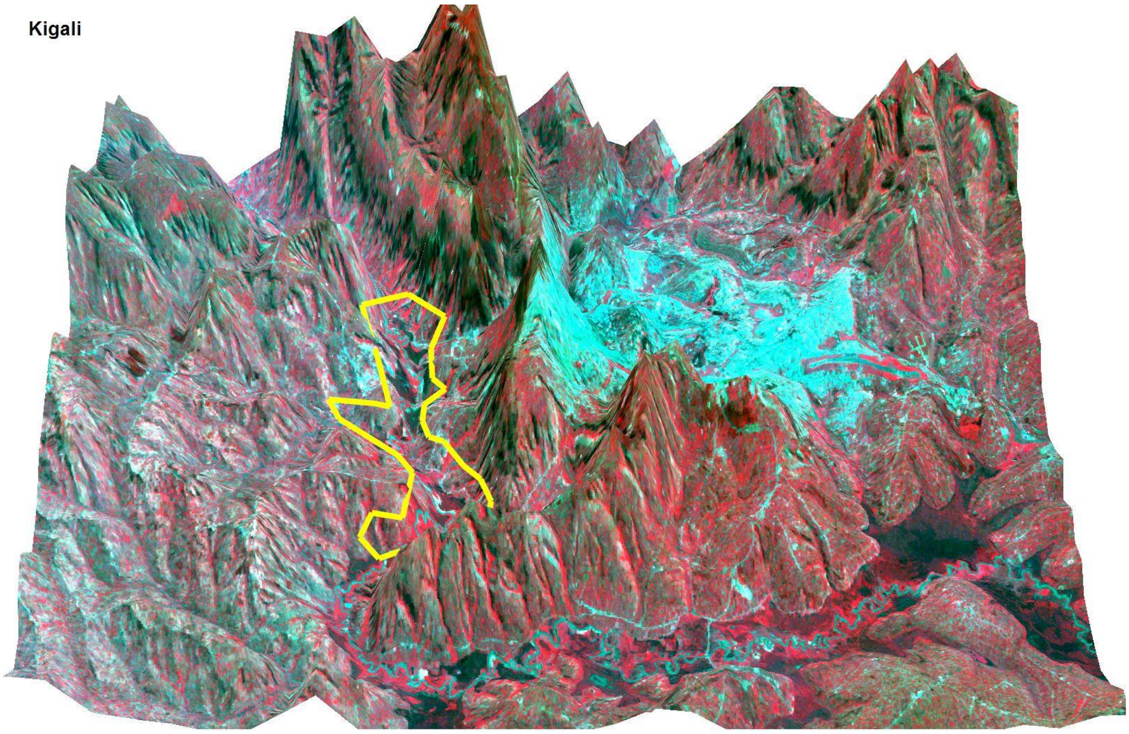


Figure 90: 3D impression of Kigali focal area, Rwanda. (Source: Landsat).

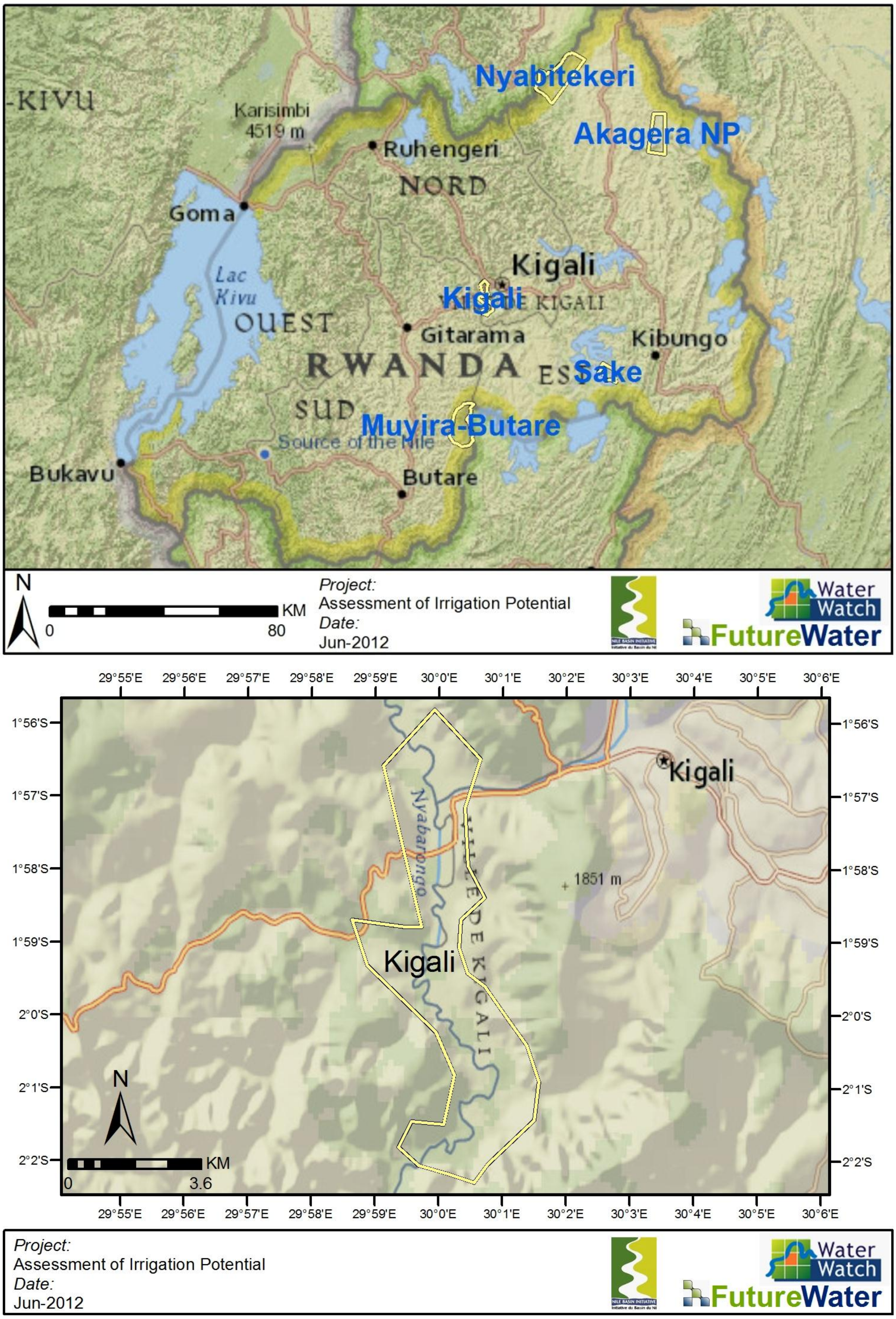


Figure 91: Kigali focal area, Rwanda

7.2 Land suitability assessment

7.2.1 Terrain

This Focal area, located just a few kilometers west of Kigali, spreads around Nyabarongo River for about 10Km, covering the plains around the river and the foothills on both sides. The valley bottom descends from North to South from 1362m to 1350m. The foothills within the focal area mostly remain under the 1400m. Although the elevation difference in not too large, the slopes can easily reach up to 10%, or even over 30% in some small areas (Figure 92 and Figure 93).

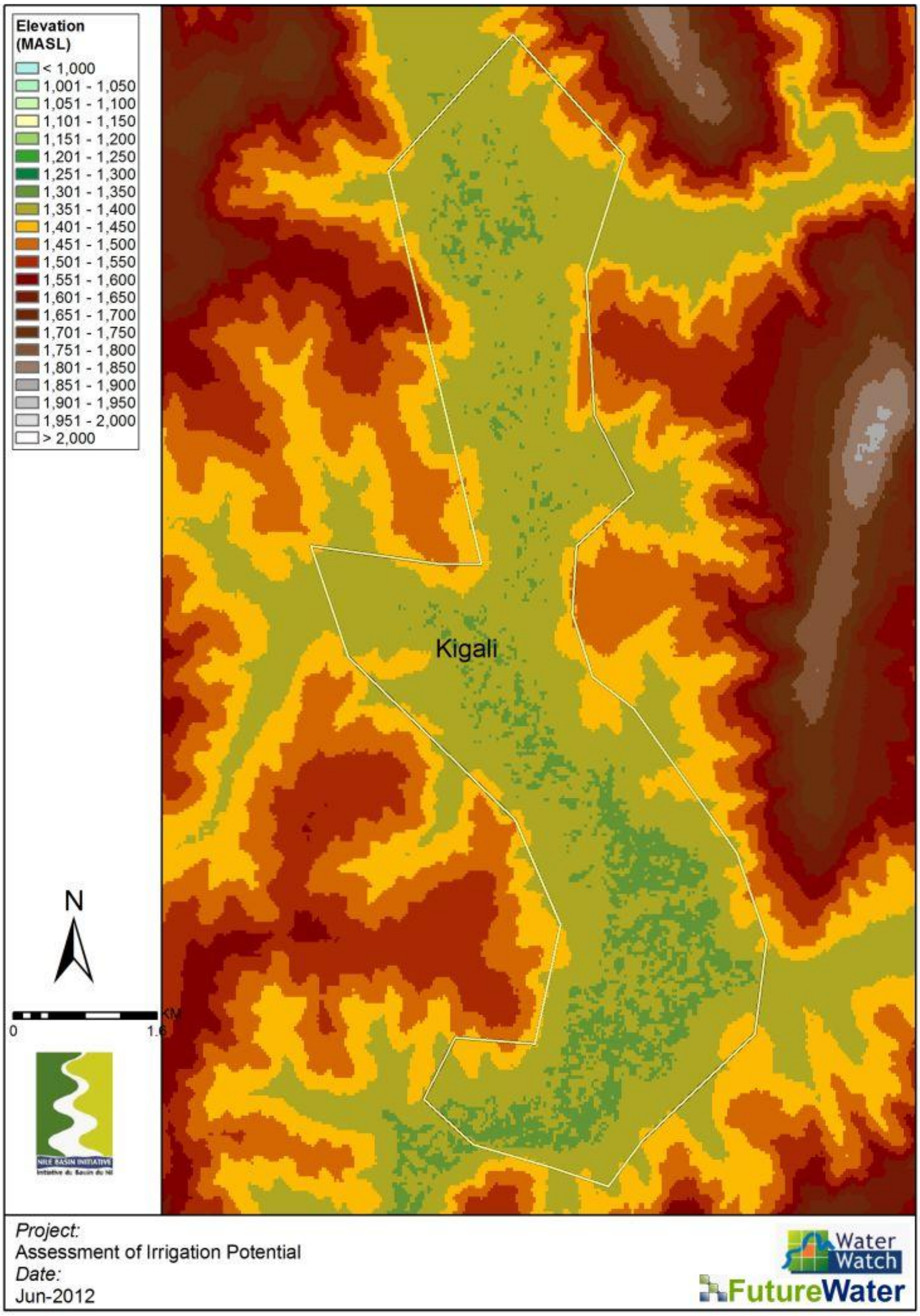


Figure 92: DEM Kigali focal area. Resolution 1 arc second (+/- 30m). (Source: ASTER).

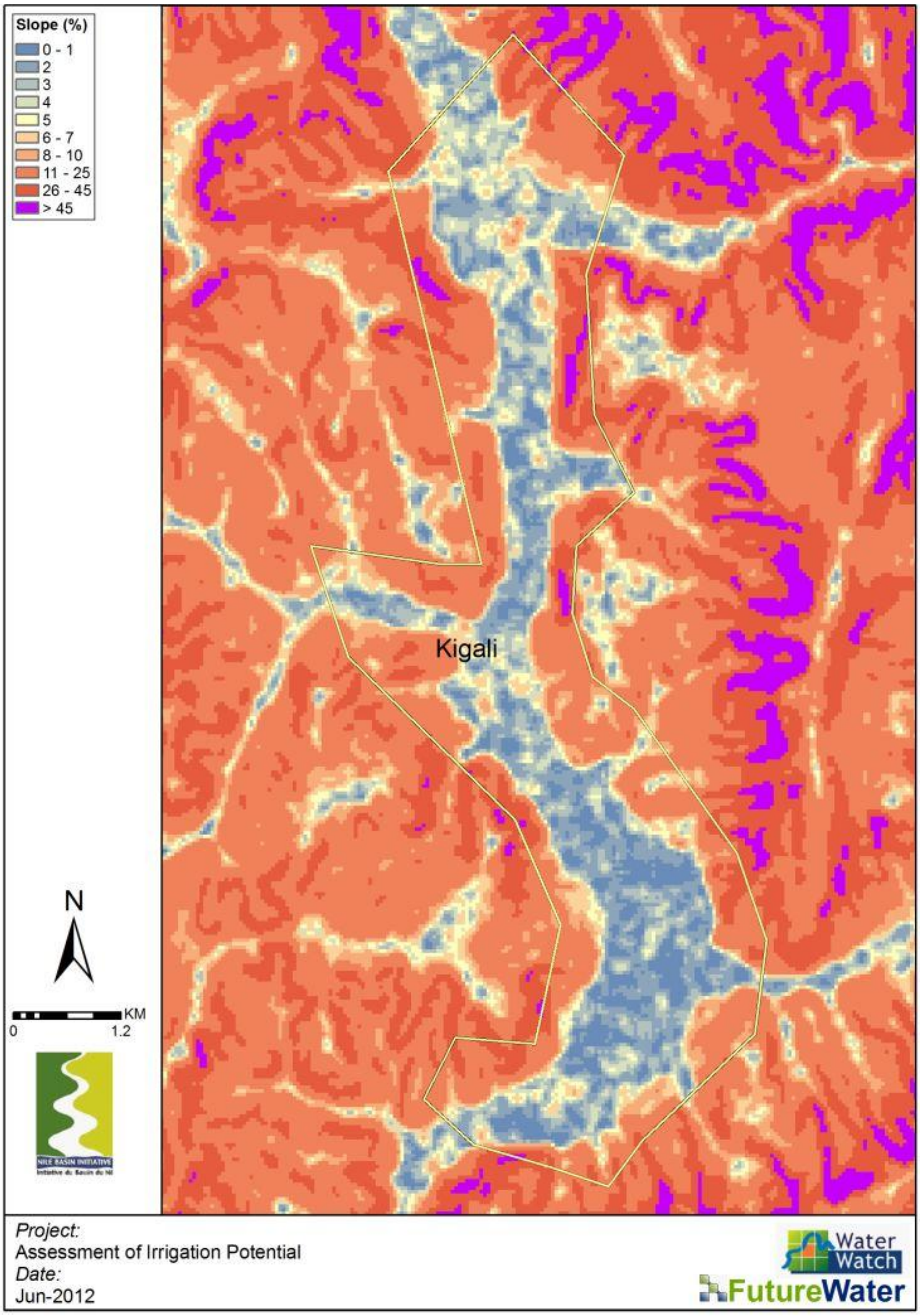


Figure 93: Slope map Kigali focal area. (source: ASTER)

7.2.2 Soil

Soils in the area are formed under different processes. The soils in the valley are formed with alluvial processes, due to long term erosion and sedimentation. Soils on the slopes are sedimentary or weakly metamorphic. Within the valley soils are clayey, poorly drained and contain a relative high percentage of organic matter, reaching over 10% in the Nyabarongo valley. Since the soils are nearly flat, erosion in the valley is not a major issue. Currently no fertilizer is used. On the slopes, the soil changes slightly into loamy clay and drainage capacity increases. Water holding capacity in the whole area is high with numbers above 150mm/m.

7.2.3 Land productivity

The average land productivity in the Kigali focal area is with 0.594 just above the Rwandan average. Some build up and industrial areas in the north have a very low NDVI under the 0.5. The Nyabarongo Valley had the highest average land productivity with values fluctuating between 0.6 and 0.7. The coefficient-of-variation is very small in the valley and fairly small on the slopes on the sides. This means that the land has nearly the same productivity around the year (Figure 95).

The NDVI formula is:

$$\frac{(NIR - RED)}{(NIR + RED)}$$

The NDVI is calculated based on remote sensing Modis images, and in more detail the Nearly InfraRed band (NIR) en de visible RED band (RED). The ratio between these two bands shows the productivity between -1 and 1. Plants absorb the red light for their photosynthesis, and reflect the NIR light.

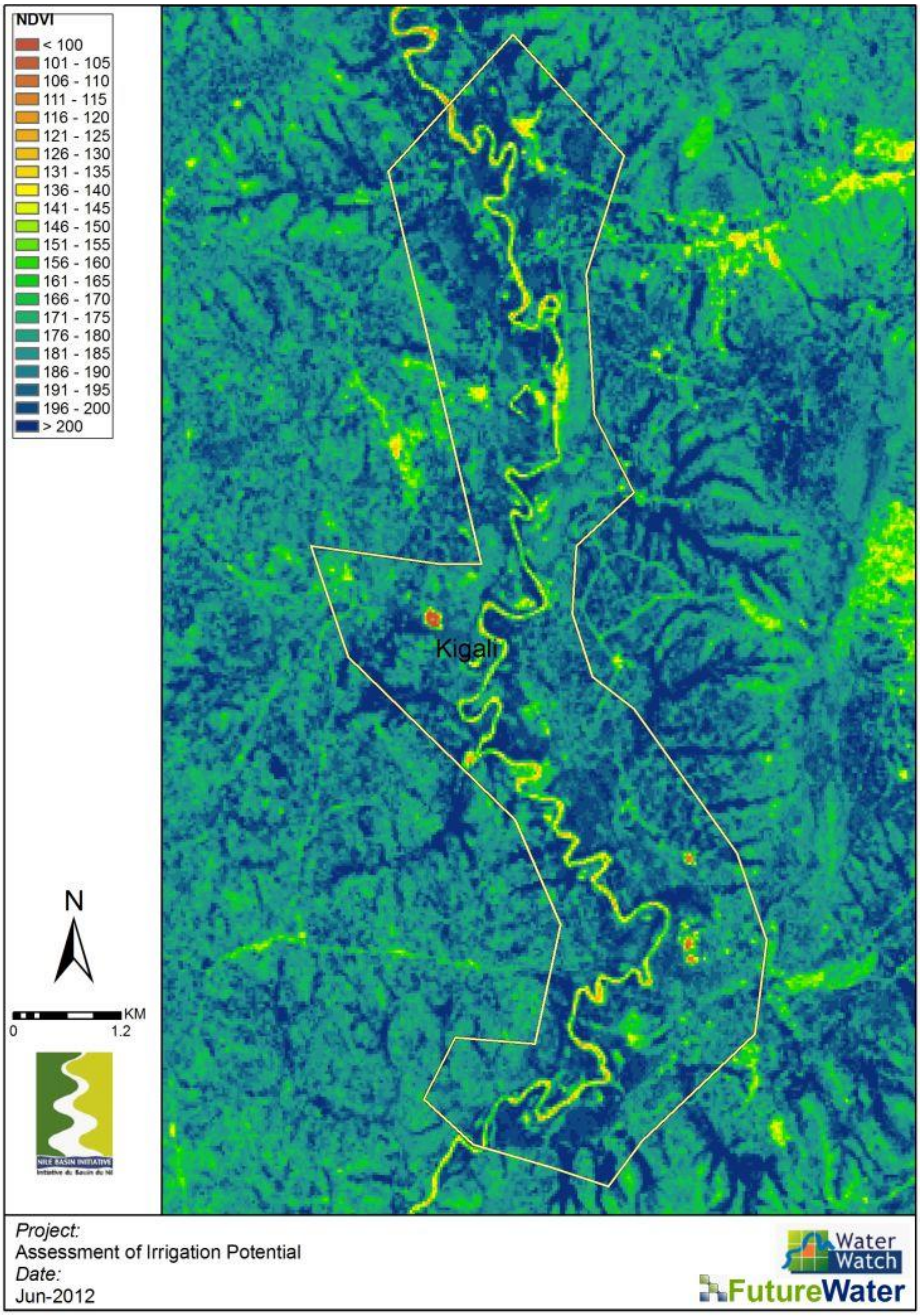


Figure 94: High resolution NDVI for Kigali focal area. (Source: Landsat).

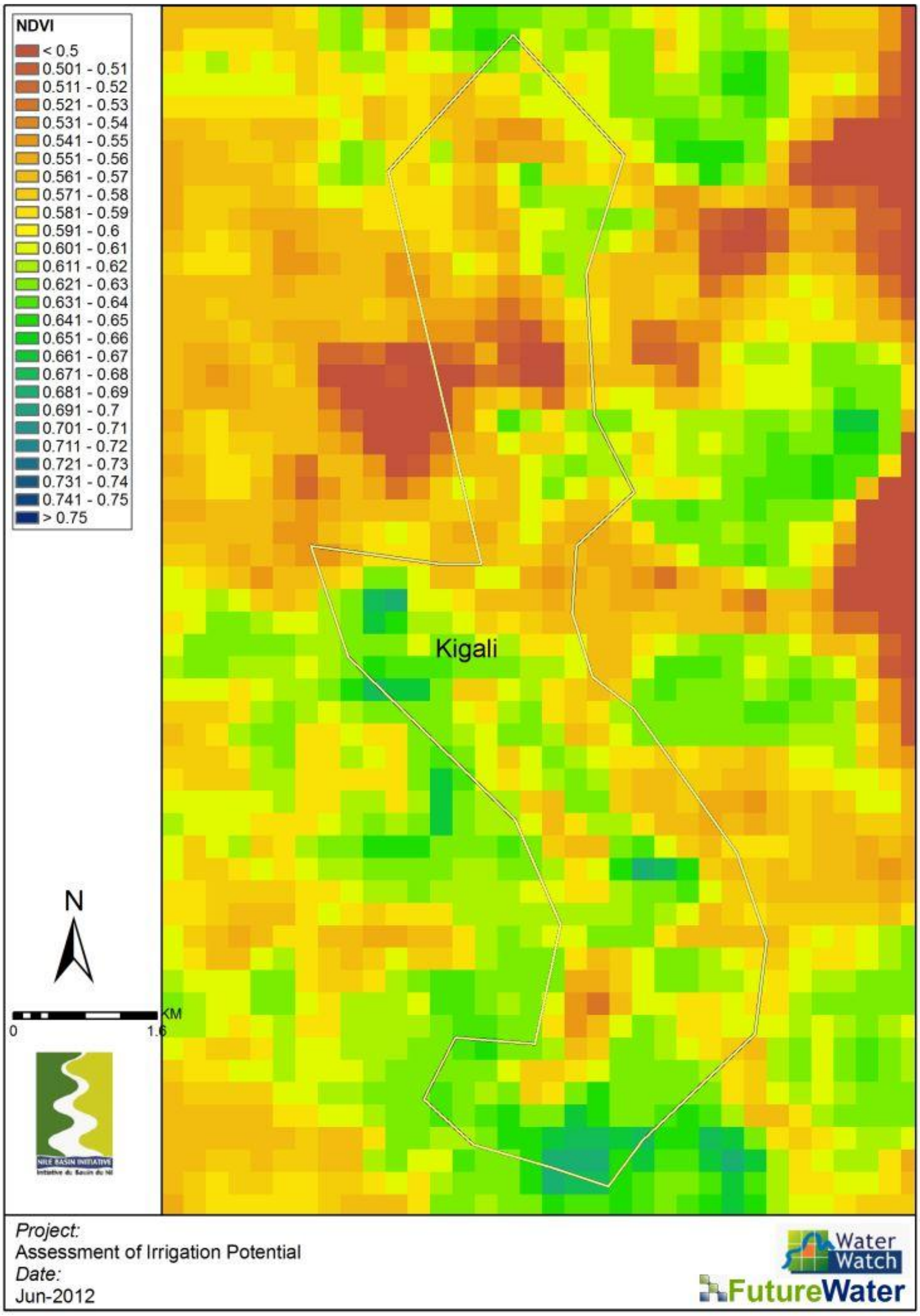


Figure 95: Yearly average NDVI values for Kigali focal area. (Source: MODIS).

7.2.4 Potential cropping patterns

At the moment 40% of the area is used for agriculture. Sugar cane is the only crop allowed to be grown in the valley. A large part of the land (3000ha) within the focal area is leased from the Rwandan government by the Madhvani investment group. They focus on growing sugar cane in this area, as current domestic sugar production just meets 30% of the national demand.

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 relatively warm with constant temperatures during the year ranging from about 15^{o}C to 26^{o}C. Annual average precipitation is 1068 mm and reference evapotranspiration 1413 mm per year.

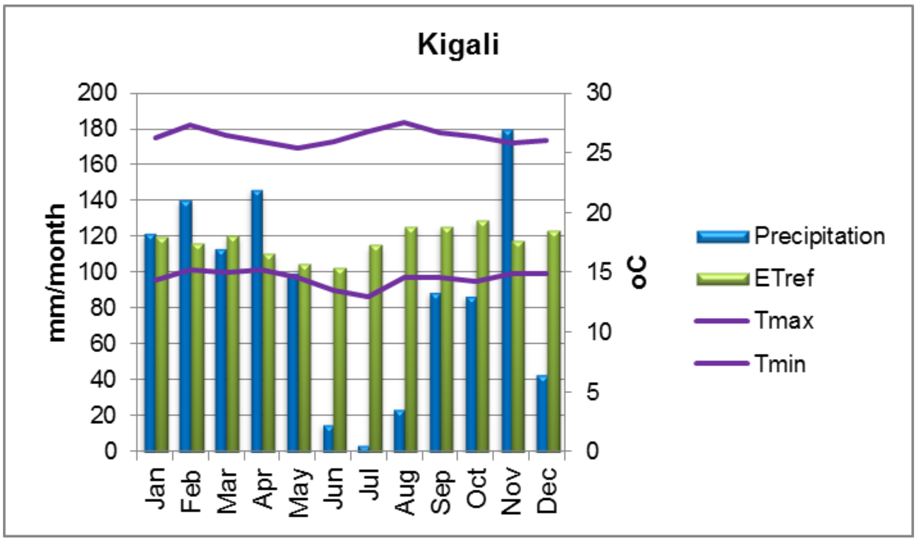
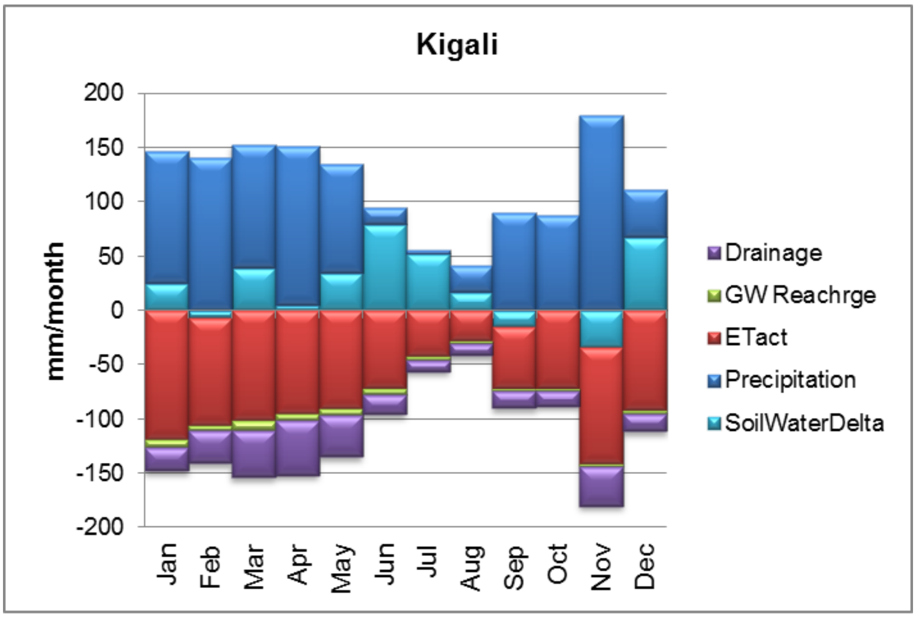
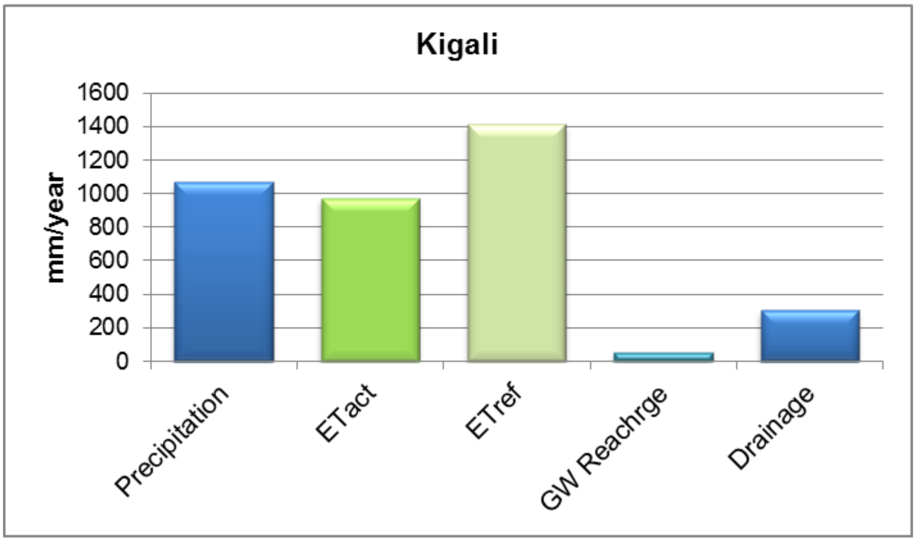


Figure 96: Average climate conditions for Kigali focal area. (Source: study analysis).

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.





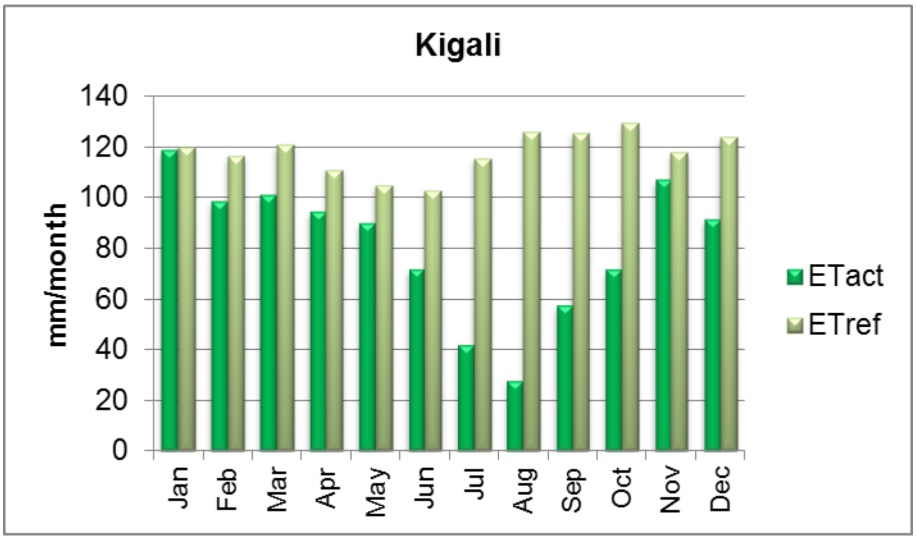
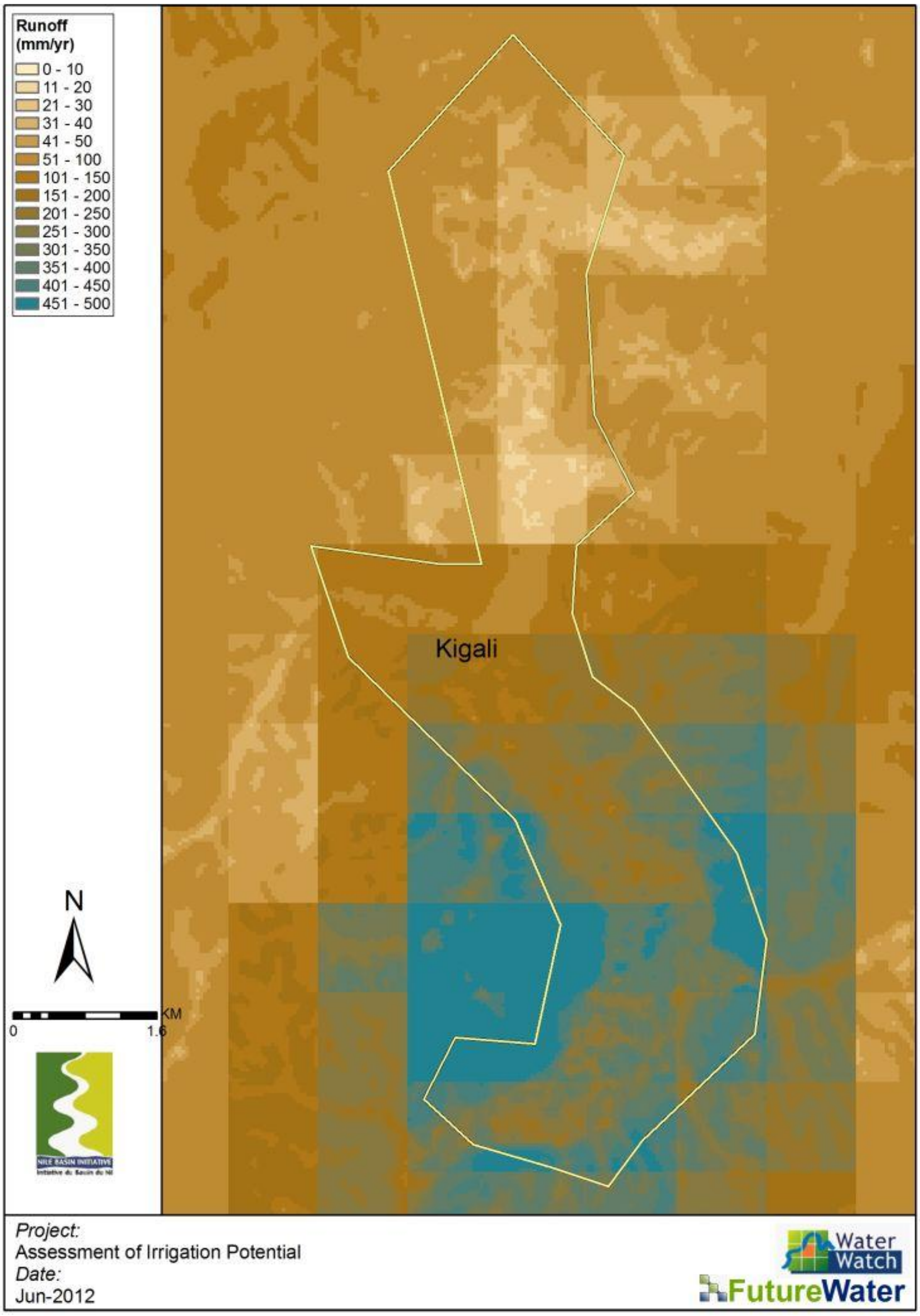


Figure 97: Water balances for the area based on the high resolution data and modeling approach for Kigali focal area. (Source: NELmod).


Runoff (mm/yr)
0 - 10
11 - 20
21 - 30
31 - 40
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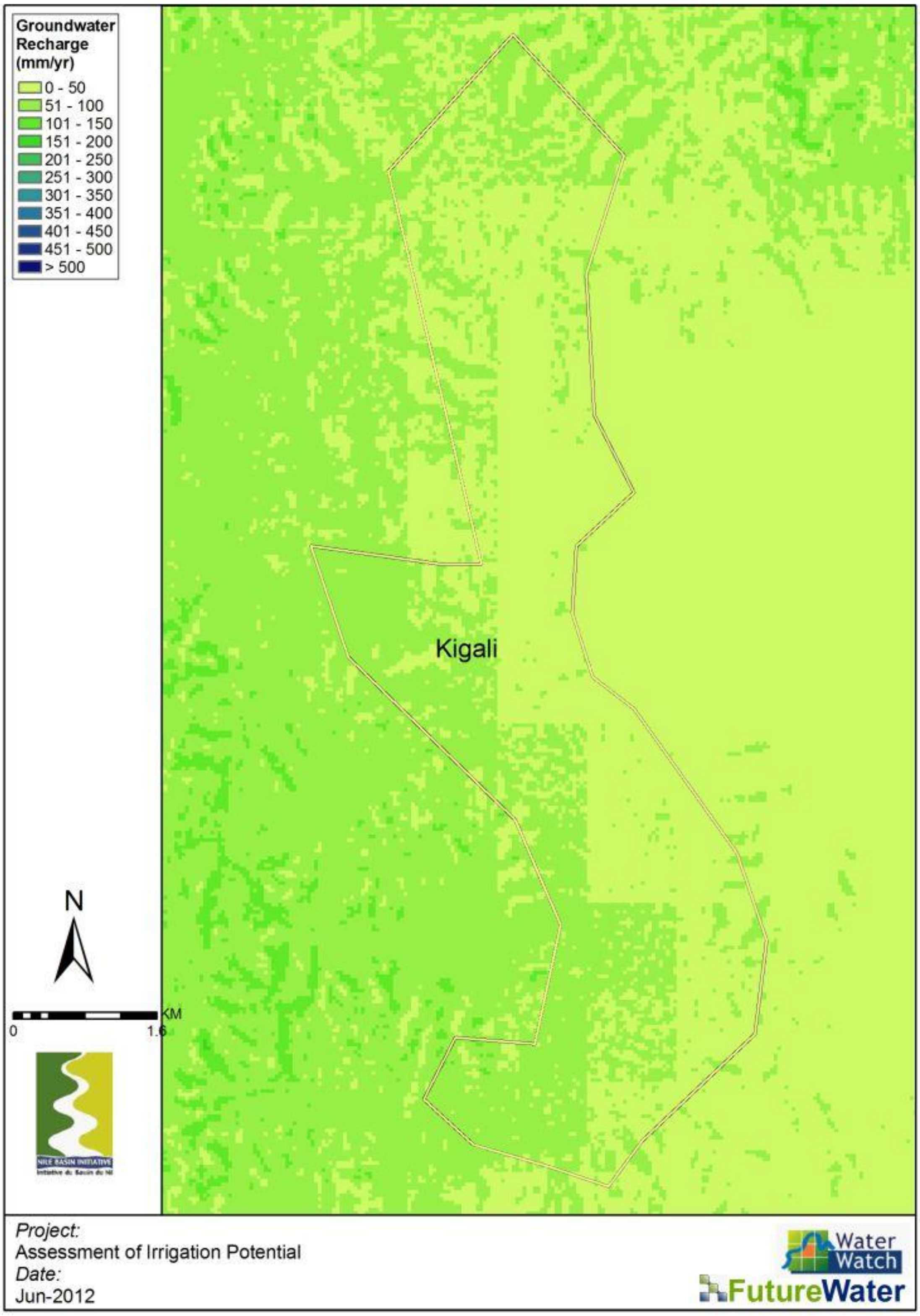
Groundwater Recharge (mm/yr)
0 - 50
51 - 100
101 - 150
151 - 200
201 - 250
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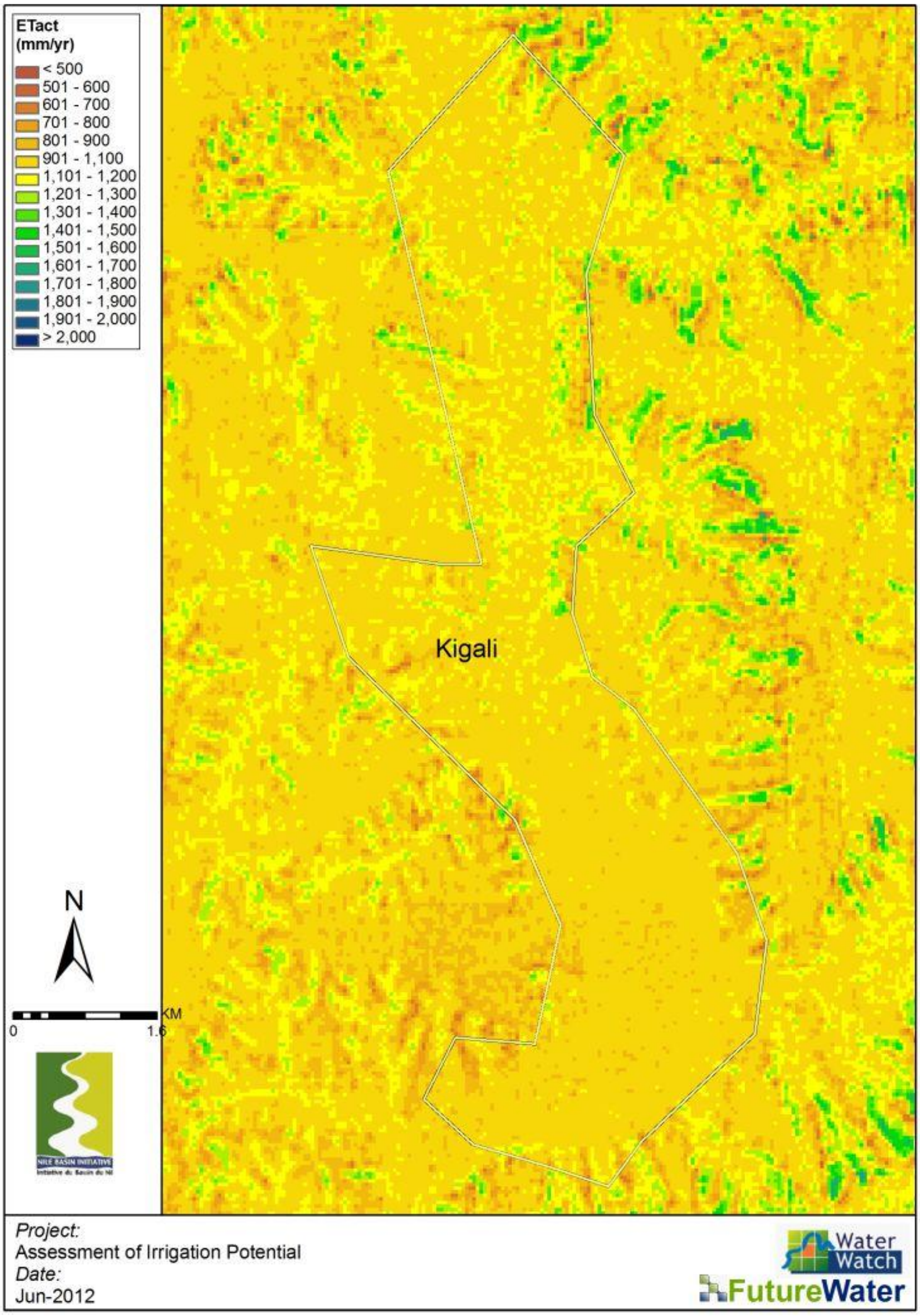


Figure 98: Water balances for the area based on the high resolution data and modeling approach for Kigali focal area. (Source: NELmod).

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 year might occur.

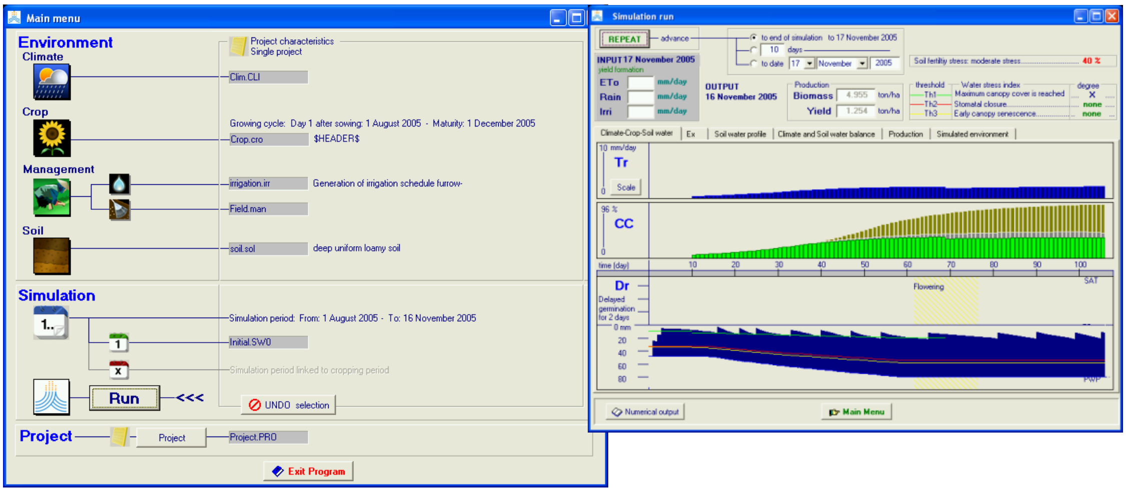


Figure 99: Typical example of AquaCrop input and output screens.

Table 14: Irrigation water requirements for the selected crops in the focal areas. All units are given in mm per growing season. (Source: AquaCrop).

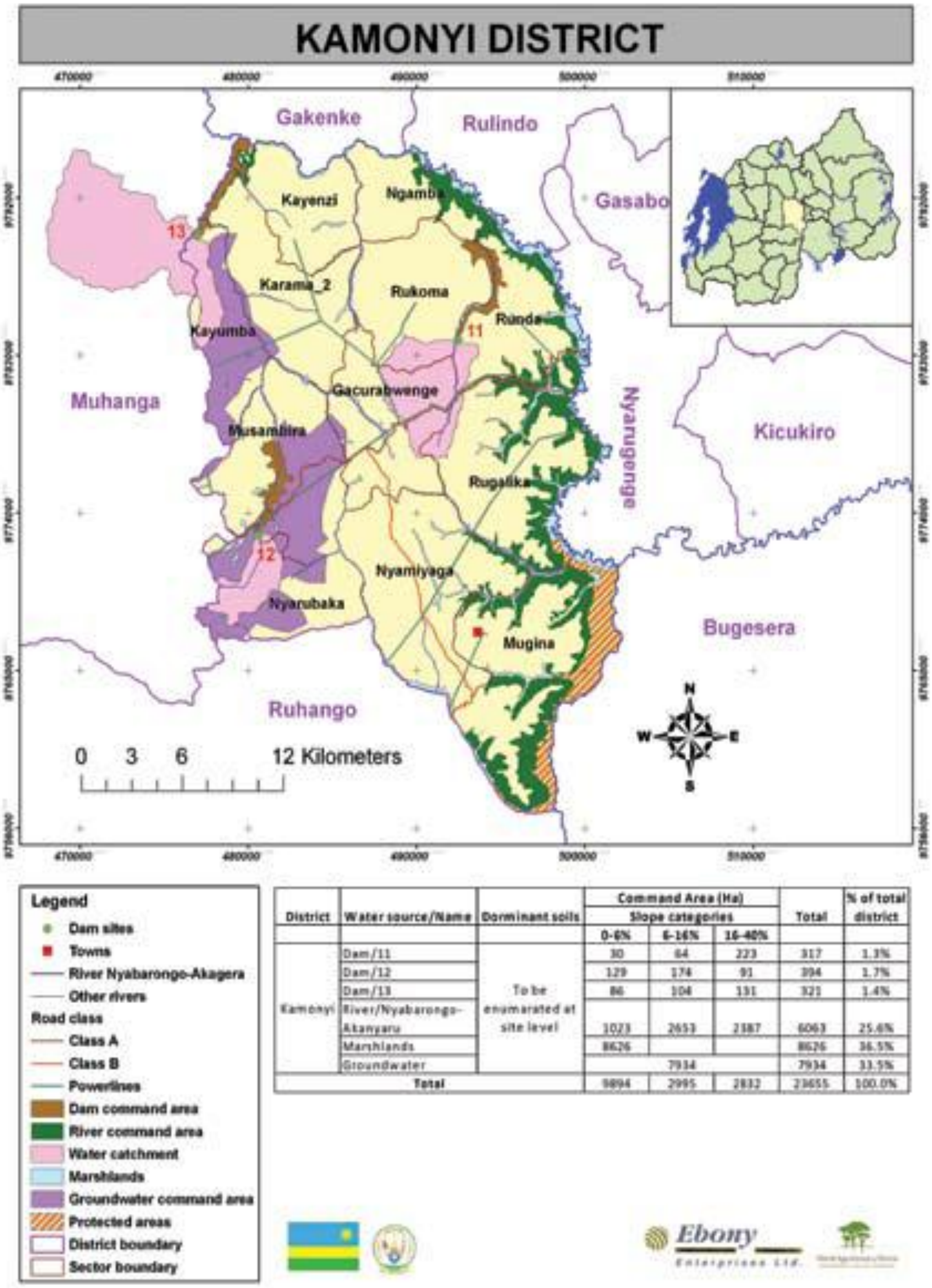
Crop	Rain	ETref	Planting	Harvets	Rain	Irrigation	ETref	ETact
	=== year ===		== (day of year) ==		======== growing season =======			
	(mm)	(mm)			(mm)	(mm)	(mm)	(mm)
Sugar cane	1068	1413	1	365	1068	180	1410	659

7.4.2 Irrigation systems and irrigations efficiencies

Irrigation of sugarcane in this area can best be done under gravity irrigation. As elevation differences on the valley bottom are limited to a few meters and water is available abundantly. An intake point in the higher north of the area can bring the water slightly up so that gravity irrigation will be possible in a larger area. Since the area will be developed by a large private company, they will have enough knowledge to develop sprinkler irrigation as well. Sprinkler irrigation will be a higher investment, but will allow for larger plot sizes. Since they apply the water more accurately, with sprinkler irrigation the change for water logging and salinization decreases, and the use of fertilizer becomes more efficient.

7.4.3 Water source

The water source will be Nyabarongo river. (Figure 100) This river is draining about 60% of Rwanda, and has a flow of 40-60m^3/s in the dry season.

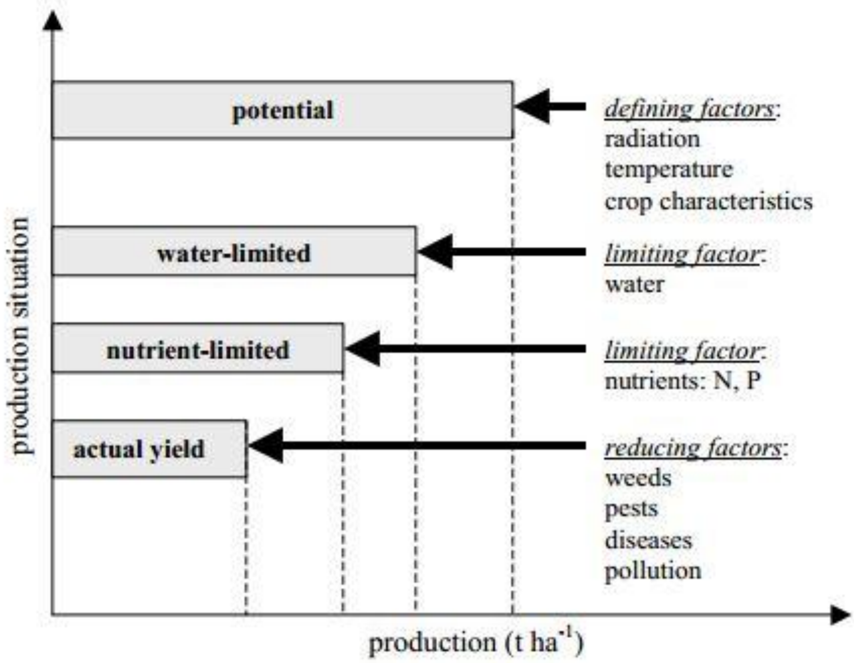


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district
			0-6%	6-16%	16-40%		
Kamonyi	Dam/11	To be enumarated at site level	30	64	223	317	1.3%
	Dam/12		129	174	91	394	1.7%
	Dam/13		86	104	131	321	1.4%
	River/Nyabarongo-Akanyaru		1023	2653	2387	6063	25.6%
	Marshlands		8626			8626	36.5%
	Groundwater		7934			7934	33.5%
Total			9894	2995	2832	23655	100.0%

Figure 100: Potential water source

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 gapanalysis potential dominant crops

Concerning the majority of crops, Rwanda's yield is above Africa's average. For sugar cane, however, this is not the case. With an average sugar cane yield of about 18.000kg/ha, Rwanda is at 30% of Africa's average of 60.000kg/ha. Rwanda has (had) a serious sugar crisis, and therefore the current yields should be increased and new areas should be developed. The Kigali focal area is very suitable for growing sugar cane, as groundwater levels are shallow and water is available abundantly. Yields when irrigated are expected to surpass the worlds and Africa's average towards 100.000kg/ha (Figure 101).

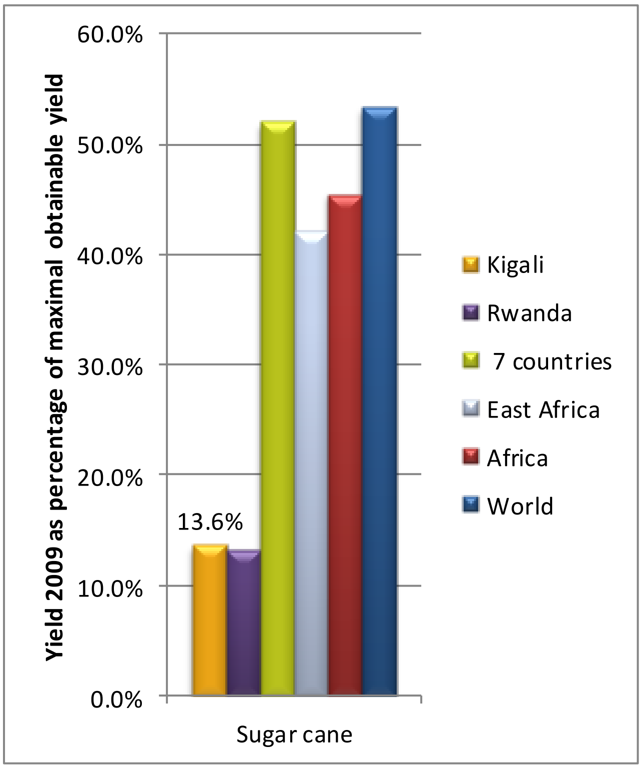


Figure 101: Yield gap Kigali (Source: FAOSTAT, 2010)

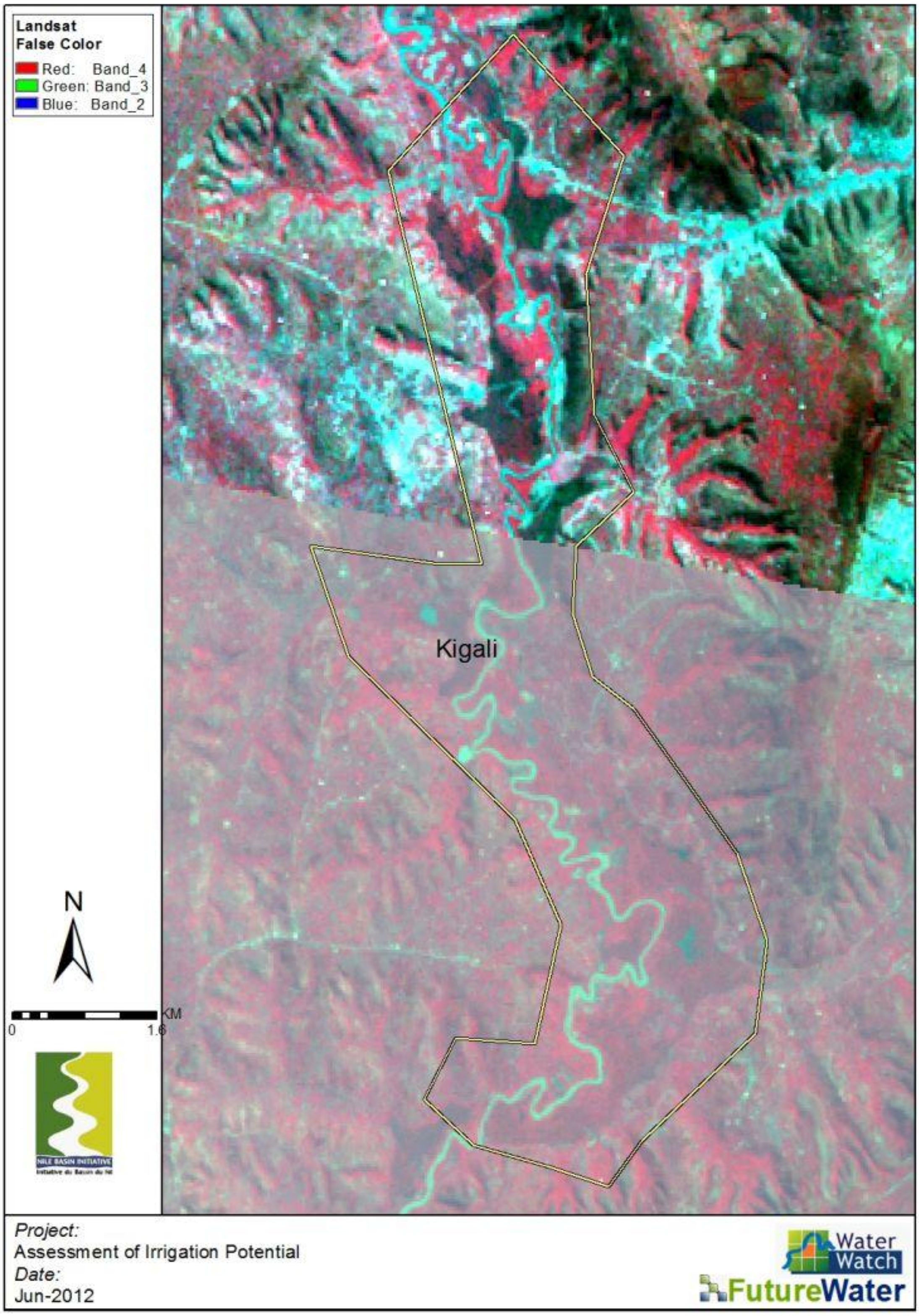


Figure 102: Landsat False Color Composite indicating current productivity of Kigali focal area. (Source: Landsat).

7.6 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 has a profitable internal rate of return at about 15%.

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):
    - Sugar cane: 100,000 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. The local expert has been very positive about all Rwanda focal areas, however; overall, the weak part of the site lies under farmers' capacity and the initial investment cost, which are very high due to the needed water control structures. Soil suitability and water availability is a great deal for the area that will foster an increase yields.

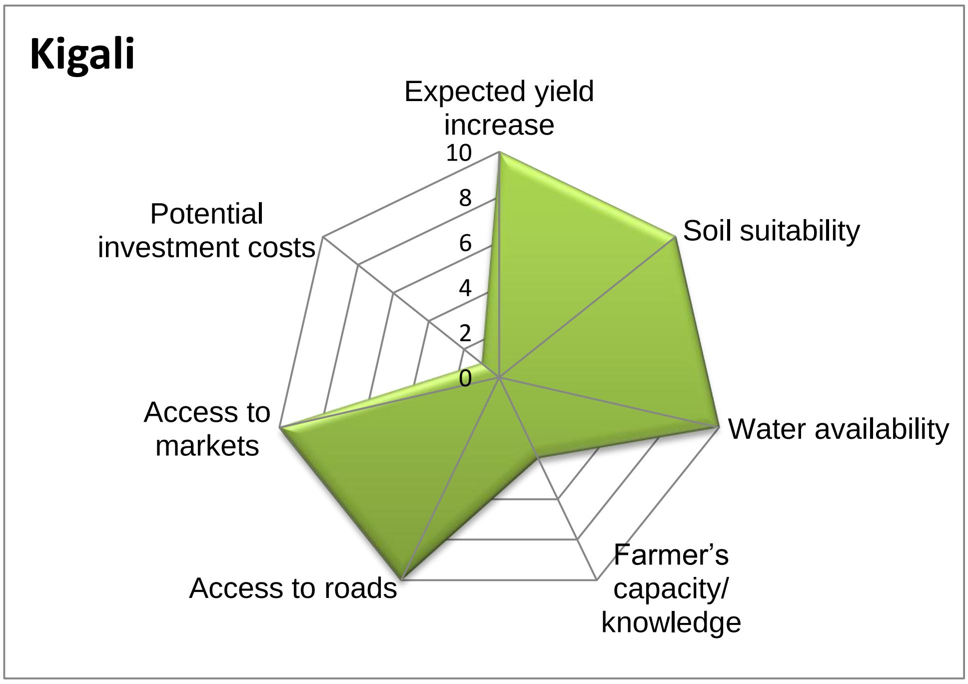


Figure 103: Filled radar plot indicating expert knowledge score to develop irrigation in the Kigali focal area (1 = negative, 10 = positive). (Source: local experts and study analysis).

Table 15: Benefit-cost analysis for the area.

Characteristics	
Irrigated land (ha)	2,000
Farmers	500
Investment Costs	
Irrigation infrastructure (US$/ha)	20,000
Social infrastructure (US$/farmer)	500
Accessibility infrastructure (million US$)	2.0
Operational Costs	
O&M irrigation (US$/ha/yr)	100
Extension service (US$/farmer)	10
O&M roads (US$/yr)	40,000
Summary	
Initial investments (million US$)	42.3
O&M costs (million US$/yr)	0.245
Net benefits per year (million US$/yr)	6.000
IRR (Internal Rate of Return)	15.2%

7.7 Recommendations

This pre-feasibility study describes the topics on a screening and scoping level. The available local data are included in the analysis and description, but final results give a first impression of the irrigation possibilities. Recommendations to be included in a detailed feasibility study are: i) possible design of the irrigation scheme ii) In depth analysis of possible reservoir sites iii) the implications of the legal framework and local law on irrigation development in the focal area iv) make an economic analysis per crop and irrigation system and v) an in depth cost benefit analysis, fully based on the local situation.