Graduation thesis

Final version

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

Research into irrigation determining factors

Author

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University of Applied Sciences

VAN HALL LARENSTEIN

PART OF WAGENINGEN UR

NILE BASIN INITIATIVE

Initiative du Bassin du Nil

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Foreword

This graduation thesis can be seen as the final result of a four year study program. Most themes which have been practiced within the courses and in the traineeships are combined in this study. I have experienced this educational program as an almost unnoticed increase in knowledge which leaves you in the end with some luggage to travel the world of water management.

During these four study years I have always intended to create, in an active way, the most instructive, open, social and pleasurable time possible. The major 'international water management' and the two internships in Africa have given an international accent to this period. It was in these periods that I've realized that water management should be practiced in cooperation with people in order to improve living conditions, and create a healthy living environment.

For this final research the relevance is very clear. The water management strategies should be updated and adapted to the current and future situation. In the view of a global food crisis and the projected population growth in Africa the water resources are under pressure. I'm glad to be part of this project in order to broaden my view of water management and possibly contribute to a better world.

Finally I would like to thank my colleagues and supervisors, Peter Droogers, Wilco Terink and Henk van Hoof for their contribution and suggestions to improve this thesis.

Jaïrus Brandsma
Wageningen – 7 June 2011

Summary

The last years a renewed effort is paid to the increase of agricultural production. Food prices are rising as natural hazard destroy yields, living standards are increasing and world's population is growing. Nearly a billion people world wide, especially in sub-Saharan Africa, are living in hunger every day. Among several solutions to increase food production irrigation stands out. Irrigation can easily double yields compared to rain fed agriculture.
Within the study area, Burundi, eastern DR Congo, Kenya, Rwanda, southern Sudan, Tanzania and Uganda over 80% of the GDP is earned with agriculture and related activities. For this reason irrigation is considered to be a cornerstone for agricultural development and rural poverty reduction.

The Nile Basin Initiative has asked to research the irrigation potential within these seven countries. As a part of that research this thesis will study some irrigation determining factors. The four factors in this study are: 1. Distance to streams 2. Height to streams 3. Slope 4. Infrastructure. These factors include a soil, water and social component, and will therefore give a first impression of the irrigation potential.
As a result the main research question is: *Which areas within each of the Nile Equatorial Lakes (NEL) countries have, based on the selected factors, a high potential for irrigation?*

A literature study will be the starting point, on which this report is based. The available data sets for the factors are reviewed, and the best are used in a GIS based analysis. Each map will be analyzed on a 200m resolution. Each of the four factors is categorized and assigned a score according to their potential for irrigation. These scores are combined in a 'final' map, which shows the irrigation potential based on these four factors. This combined map will be compared with the map of the areas which are currently equipped for irrigation.

The literature study showed that flood irrigation is the most common used irrigation type within the study area. These irrigation areas are either community managed or privately. This study will analyze the potential for flood irrigation.

It is unique to work on a scale of 200 meter as some previous irrigation potential studies worked on a basin or country scale. The scale allows selecting the high potential areas in a precise manner, and even the smaller areas.

The results show large high potential areas in southern Sudan and eastern Kenya. Due to the slopes in Burundi, Rwanda and Eastern DR Congo only small high potential areas can be found here, especially on valley bottoms. The high population density in Burundi and Rwanda brings the advantage of a dens infrastructure. However the pressure on land and water resources is high. The large high potential area in southern Sudan covers the Sudd region, which is one of world's largest wetlands. Despite of the high potential, this area will hardly be suitable for irrigation due to the high ecological and economical value. Within these four factors three are fully or partially based on the Digital Elevation Model (DEM). The three case study areas show that the influence of the DEM is high. To bring more diversity, either the score can be adjusted or more factors added. For this reason it is recommended to continue with more factors, such as actual water availability and soil characteristics. By adding these factors the irrigation potential can be divined much more precise. Depending on the irrigation type, management type, or the agro-ecological zone the analysis can be adjusted.

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Glossary and list of abbreviations

AEZ	– Agro Ecological Zones
DEM	– Digital elevation model
EWUAP	– Efficient Water Use in Agricultural Production
FAO	– Food and Agriculture Organization of the United Nations
IFPRI	– International Food Policy Research Institute
GDP	– Gross Domestic Product
IWMI	– International Water Management Institute
MDG	– Millennium Development Goal
NBI	– Nile Basin Initiative
NEL	– Nile Equatorial Lakes
NELSAP	– Nile Equatorial Lakes Subsidiary Action Program
SRTM	– Shuttle Radar Topography Mission
SSA	– Sub-Saharan Africa
Sudd	– A swamp in Southern Sudan, one of world’s largest wetlands

1. Introduction

Background

Agricultural activities account for a large part of Africa's economies. Within the Nile basin more than 80% of the population depends on agricultural activities for their livelihood. Unfortunately agricultural productivity has not been able to keep up with the population growth. The increasing population, the increasing living standards and the projected climate change put more and more pressure on land and water resources. As *a result the import of cereals is projected to triple between 1990 and 2020 for Sub Saharan Africa.*

The irrigated land in the Nile Equatorial lake (NEL) countries is with around 3% of the cultivated land small compared to the world average of 17%. Crop production is almost entirely rainfed, and although water resources are ample the spatial and temporal variability is high, and the water is spread over a wide range of agro-ecologic zones. Due to irrigation the yield can easily double compared to rainfed agriculture. For this reason irrigation is considered a cornerstone for agricultural development and rural poverty reduction.

Problem definition

The river Nile is the world's longest river, with 6850km. The Nile-basin spreads over 10 riparian countries and covers about 10% of the African continent. Nearly all flow is generated in Ethiopia and the NEL countries which cover just 20% of the Nile basin. The other 80% of the Nile basin area does hardly have any effective rainfall. The evaporation and infiltration losses are large in these areas.

Economic growth in Asia combined with a rapidly increasing world population, are the causes for an increasing food demand. Natural disasters and a changing climate however have put the food supply under pressure and cause lower yields. Besides, agricultural land is used to grow biofuels which limits the effective land availability even further. As a result the food prices are rising. In February 2011 the World Bank Group estimated that these rising food prices have driven 44 million people in developing countries into poverty since June 2010.

The IFPRI states in a 2011 report: “The linkages between agriculture, nutrition, and health seem obvious: adequate levels and qualities of food produced and consumed promote good nutrition and robust health”. Further “Nearly a billion people now go hungry every day, unable to access the food they need for energy and growth”.
People living in hunger have hardly any possibilities to participate in education, and there workforce is low. This makes it so difficult to escape from hunger and poverty.

Intensification of the current agriculture is a must to keep up with the food demand. Among several possibilities for intensification irrigation stands out. Although irrigation is most promising a certain level of water management knowledge is required to make maximum use of the given resources. Within the NEL countries the water scarcity is mainly economical, as can be seen in Figure 1.

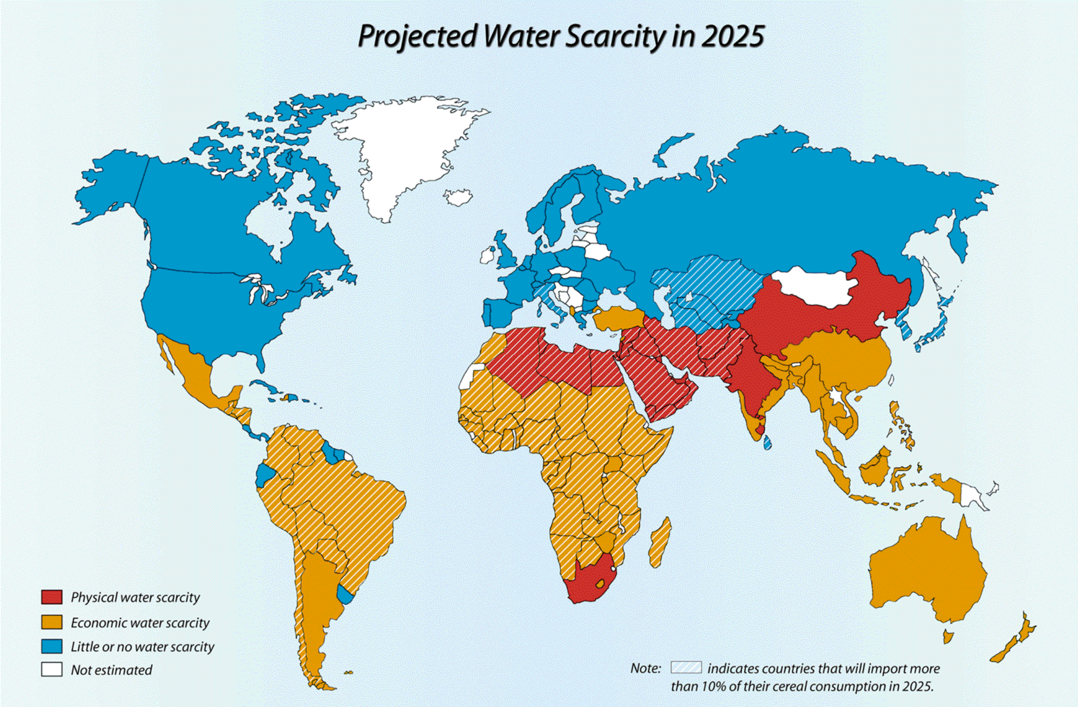

Figure 1: Water scarcity
Source: IWMI

Setting of the research

The Nile Basin Initiative (NBI) and the Regional Agricultural Trade and Productivity Project (NELSAP) have asked for a study to assess the irrigation potential in the Nile Equatorial Lake countries. (Burundi, DR Congo, Kenya, Rwanda, Southern Sudan, Tanzania and Uganda). This research will focus on the physical aspects of irrigation possibilities, and will briefly address the institutional framework and the socio-economic aspects of irrigation. The research will be done in two phases, a first, more global assessment, and a second detailed phase which will focus on the high potential areas which are defined in phase 1.

The company 'FutureWater' in cooperation with 'Water Watch' will carry out this assessment on behalf of the NBI and NELSAP.
(For more information on the organizational structure see appendix 1)

Relevance of FutureWater study

With a rapid rate of population increase and high pressure on arable land, increased food production is one of the main concerns and priorities of the governments of the seven countries involved in the Irrigation Potential study. Improved irrigation technology and better water resources management have been suggested as mechanisms for increased production. One of the constraints identified is the reliance on rain fed agriculture as well as low mechanization.

The goal of the study is to ensure household food security, improve farmers' income and alleviate poverty and malnutrition through increase in agricultural production and productivity resulting from accessibility to irrigation water; and as such, it will contribute to NBI's overall objective of achieving sustainable socio economic development through equitable utilization of and benefits from the common Nile Basin water resources.

The overall objective is to give a better insight on how the agricultural situation can be improved in the NEL countries through irrigation and better water resource management. An assessment based on the characteristics “soil and water” will show which areas have the highest potential for irrigation.

Objectives

Within the limited timeframe for this graduation thesis, I will concentrate on some selected irrigation determining factors. An important condition for selecting these factors was that the information needed was readily available in the public domain data sets. By selecting the factors I tried to have a range of issues which include a water, soil and social component.

Overall objective: Demonstrate for a selected set of factors the potential for irrigated agriculture in the Southern Nile countries.

Derived objectives: Demonstrate the irrigation potential based on the following selected factors. 1. Distance to streams, which will be analyzed by looking at the presence of streams or open water. 2. The height difference from the stream to a possible irrigable area. 3. The slope of the terrain. 4. The infrastructure to bring any yields to a market or supply equipment.

Although I don’t want to pretend that these four factors will give an exhaustive view on which areas are best suited for irrigation practice, I do think these combined issues will supply an indication of the high potential areas.

Research questions

The main question is: Which areas within each of the NEL countries have, based on the selected factors, a high potential for irrigation?

The following sub-question will be answered:

- Which irrigation methods are practiced?
- Which data sets are most reliable?
- What are favorable irrigation characteristics for an area, concerning the selected issues?
- Which criteria can be set to asses the land’s irrigation potential, concerning the four factors?

Report outline

The following chapter will give a brief description of the research area, focusing on irrigation related topics. In chapter three the research methodology will be explained and the relevant data sets reviewed. Furthermore, the criteria will be set, based on the literature and expert judgment and the scores assigned. Chapter four will show the results of the analyses, which are mainly maps with some comments. The fifth chapter will conclude and make recommendations for further study.

2. Area description

The river Nile has brought prosperity to the surrounding civilization for over 5000 years. Great civilizations emerged on the river banks, and many explorers have vainly searched for the Nile's source. No river like the Nile has captured human imagination throughout the history.

The shape of the Nile we know today is complex and is the result of the interconnection of several independent basins by rivers which developed during the last wet period which affected Africa after the retreat of the ice of the last glacial age, some 10,000 years ago. The basins which constitute part of the present river were disconnected, forming internal lakes. At times when the climate was wet, they overflowed their banks and became connected to other basins. At other times, when the climate was very dry, they ebbed, shrank into saline pools or dried altogether. The basins stand out in the longitudinal section of the river, as flat stretches or landings with very little slope are connected today with rivers, which have considerably steeper slopes (Sutcliffe, 2009)

The irrigation potential assessment will be carried out for the seven NEL Countries, with the remark that for DR Congo only the part within the Nile basin will be assessed, and for Sudan only the Southern part. For a detailed map on the study area see Figure 2.

Research area

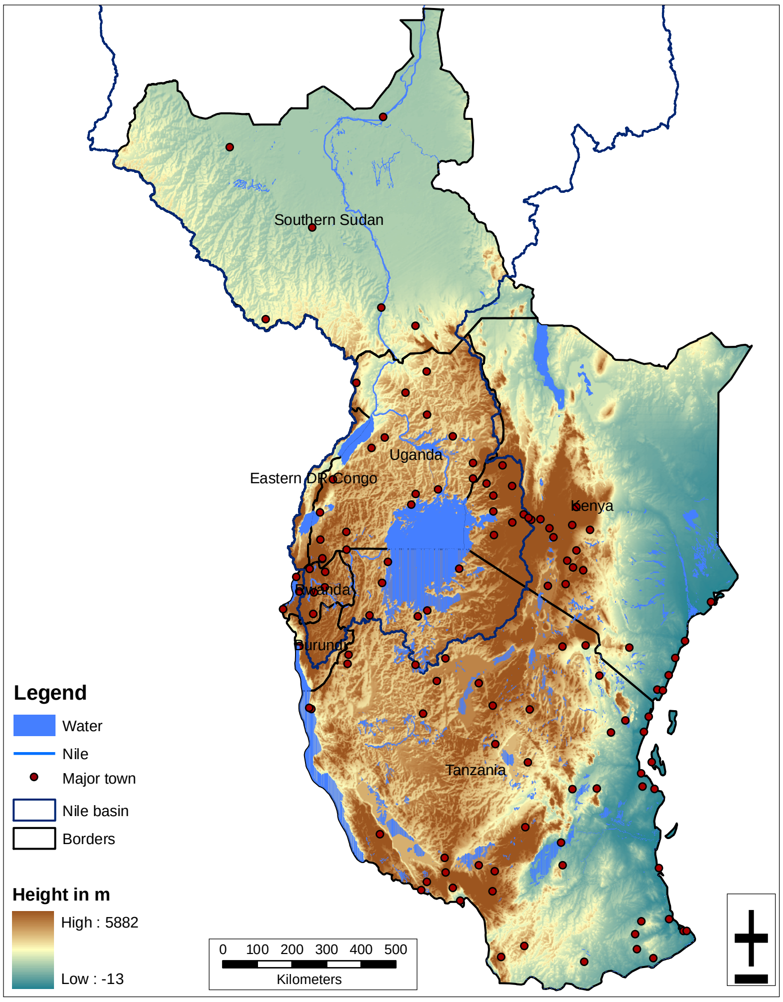

Figure 2: Nile Basin and NEL countries

The NEL region has a large spatial and seasonal variation in precipitation pattern. The average precipitation varies from 500mm/y in central Sudan and increases to 1400mm over Lake Victoria and 1800 in the highlands of Rwanda and Burundi. Although the precipitation is abundant the discharge of the Nile at the end of the Sudd is ‘small’ and relatively constant over the year. Due to the climate conditions and the large areas of open water and swamps, the evapotranspiration is high. Lake Victoria is the second largest freshwater lake in the world. The inflow and outflow of the lake are almost equal, which means that most precipitation over the lake is evaporated. In the Sudd region less than half of the inflow flows out into the White Nile. (Sutcliffe and Parks, 1999)
Due to the growing demand for food, the pressure on land and water resources increases. The expanding industrial sector does require more water as well. These developments ask for an adequate and sustainable solution to manage the water resources.

The precipitation pattern allows rain fed cropping in most areas around Lake Victoria. Depending on the precipitation patterns one or two cropping cycles per year are possible. Irrigation is practiced at *small scale* in all countries but only a part of the potential irrigable area is equipped for irrigation. See Table 1. According to FAOstat, surface irrigation is practiced in most cases. This irrigation method is partly gravity and partly pumped fed. Sprinkler and drip irrigation ask for a larger financial and intellectual input which makes these technologies mainly accessible for public or privately managed irrigation systems. In a continental study carried out by FAO (FAO, 1997) the irrigation potential per country is assessed on a large scale. See Table 1. Despite the scale, these numbers do give a first impression.

	Country area (sq km) (1)	Area within the Nile basin (sq km) (2)	% of the total Nile basin	% of the country in the nile basin	Area equipped for irrigation (ha) 2007 (2)	Irrigation potential (ha) 2005 (2)	Current irrigation as percentage of potential
Burundi	27,830	13,260	0.4	47.6	21430	185000	11.58%
DR Congo	2,344,858	22,143	0.7	0.9	72750	340000	21.40%
Kenya	580,367	46,229	1.5	7.9	103203	353060	29.23%
Rwanda	26,338	19,876	0.7	75.5	8500	159000	5.35%
Sudan	2,505,813	1,978,506	63.6	79.0	1863000	2784000	66.92%
Tanzania	947,300	84,200	2.7	8.9	184330	990420	18.61%
Uganda	241,038	231,366	7.4	98.0	9150	202000	4.53%

Table 1: Irrigation areas per country

[1]*Source: CIA word factbook, 28-04-2011*

[2]*Source: FAOstat 28-04-2011*

All countries have written an ‘Efficient Water Use in Agricultural Production’ (EWUAP) report. (See the literature chapter) In these reports a distinction has been made between areas, based on soil, climate and landform. These so called Agro-ecological zones (AEZ) can be considered as a more or less homogeneous area, with a similar cropping pattern and crop water requirements.
In appendix 2 a fact sheet per country is provided which shows a country specific map, the development of irrigable and agricultural land over the years, and the most important crops per country.

Although the Economies of the NEL countries are growing with about 6% per year, still many people are living below the poverty line. See Table 2. A vast majority of the population is involved in agriculture, in which a relatively small percentage of the GDP is earned. Therefore, development of the agricultural situation and the rural areas, have been given priority in order to reduce poverty.

In the 2007 IFPRI paper from Thurlow et al a good example is given. "*In order to meet the Milenium Development goal (MDG) to half poverty by 2015, it is necessary to accelerate agricultural growth. The increase of agricultural spending to 10 percent of total spending is insufficient to meet this MDG. Achieving this target requires nonagricultural investments, such as roads and market development.*"

	Area in sq km	Population	Population density per sq km	Urban population %	Renewable water resources cu km	gdp per capita in 2010$	% of gdp earned in agriculture	% of labour force active in agriculture	% of population below poverty line
Burundi	27830	10216119	367	11	3,6	300	31.6	93.6	68
DR Congo	2344858	71712867	31	35	1.283	300	37.4	n/a	71
Kenya	580367	41070934	71	22	30.2	1600	22.0	75	50
Rwanda	26338	11370425	432	19	5,2	1100	42.1	90	60
Sudan	2505813	45047502	18	40	154	2200	32.1	80	40
Tanzania	947300	42746620	45	26	91	1500	42.0	80	36
Uganda	241038	34612250	144	13	66	1200	23.6	82	71

Table 2: Country specific socio-economical information
Source: CIA world fact book 27-04-2011

3. Methodology and data used

Literature study

As a start of the research a literature study will be carried out to gather and select all relevant information from previous studies on irrigation potential, best irrigation practices, hydrologic situation and the socio-economic situation.

All seven NEL countries have made a best practice for water harvesting and irrigation report as a part of the Efficient Water Use for Agricultural Production (EWUAP) project. These reports provide relevant information about agro-climatic zones, national climate data and evaluate the current irrigation and water harvesting sites and techniques.

In the context of the EWUAP project five out of the seven countries have written a “Rapid Baseline Assessment of the Agricultural Sector” report. These studies asses the agricultural sector for Kenya, Tanzania, Rwanda, Burundi and Sudan.

The information gathered in this literature study will be the baseline on which the current FutureWater study will proceed. The complete literature study can be found in the last chapter.

For this “*research into irrigation determining factors*” the literature study is used to select the factors and to base the criteria on.

Relevant data sets

The assessment of the four selected factors should be based on the most reliable and accurate information. For each factor the available public domain data sets are compared, and briefly discussed.

DEM

HYDRO1K

HYDRO1K[1] is a geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets, including streams, drainage basins and ancillary layers derived from the USGS 30 arc-second (~1 km) digital elevation model of the world. HYDRO1K provides a suite of geo-referenced data sets, both raster and vector, which will be of value for all users who need to organize, evaluate, or process hydrologic information. The HYDRO1K dataset provides hydrological correct DEMs along with ancillary data sets for use in continental and regional scale modeling and analyses.

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[1] http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30/hydro

SRTM

The most commonly public domain Digital Elevation Model (DEM) dataset is the SRTM dataset which is acquired with the space shuttle during an 11-day mission in 2002. More information on the SRTM can be found at: http://www2.jpl.nasa.gov/srtm/.

The dataset can be downloaded from various sources. Probably the most user-friendly one is provided by the CGIAR (version 4). This DEM has been obtained at a spatial resolution of 200 m for the entire Nile basin. This dataset has been slightly modified from the original version provided by the USGS (seamless.usgs.gov) and data gaps are filled using an automated procedure. For more information reference is made to: http://srtm.csi.cgiar.org/.

Recommendation:

For this research the SRTM DEM will be most suitable as it provides information on an accurate level, which allows for 'normal' editing time, and is relatively detailed. A 90m SRTM DEM is also available, which can be used for the selected areas, in the second phase of the FutureWater research.

Streams

Hydro1k DEM based flow accumulation. Analyzed with arc GIS

> This stream map is based on the 1km raster DEM from Hydro1K. Drains are classified in drainage area.

Hydro1k streams[1] / FAO African streams

> Stream map supplied by Hydro1K, based on the 1km DEM. High threshold value for drains, which results in low stream coverage.

Africover rivers

> The AfriCover Project[2] developed a combined approach to promote the sustainable use of natural resources. The purpose of the AfriCover Project is to establish a digital geo-referenced database on land cover and a geographic referential for the whole of Africa including:
>
> - Geodetically homogeneous referential
> - Toponomy
> - Roads
> - Hydrography
>
> The Multipurpose AfriCover Database for the Environmental Resources (MADE) is produced at a 1:200,000 scale (1:100,000 for small countries and specific areas).
>
> The Eastern Africa module is the first operational component of the AfriCover Project. It was formulated to meet several African countries request for assistance in the set-up of reliable and geo-referenced data-bases on natural resources. It is part of FAO assistance to the Nile Basin countries. The Project has been operational in the period 1995-2002 and was signed by ten countries, including the seven NEL countries. For these seven NEL countries the map scale is 1:100,000.
>
> Country maps available through Africover. Supplies a rough, but for this research incomplete, stream network.

NBI rivers

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[1] http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30/hydro/africa

[2] http://www.africover.org/index.htm

A stream shape file obtained from the NBI in an earlier project. A relatively dens, but imprecise, network of streams. Comparable with a 10.000 ha drainage area streams, but streams are sketched roughly.

HydroSHEDS[1]

The river network layers distributed with HydroSHEDS are directly derived from the drainage direction layers. The flow accumulation layer is used for selection and attribution. Only rivers with upstream drainage areas exceeding a certain threshold are selected: for the 15 arc-second (~500m) resolution a threshold of 100 upstream cells (~2500ha) has been used. The vectorized river reaches are currently attributed with the maximum flow accumulation (in number of cells) occurring within each river reach.
The result is a very dense stream network, which is unclassified in matter of drainage area or discharge.

Arc SWAT 100.000-20.000-10.000 ha drains → based on 200m SRTM DEM

An Arc SWAT analysis based on the 200m SRTM DEM results in several stream networks with different drainage area thresholds. (See annex 2)

Recommendation:
The custom made stream map based on the 200m SRTM DEM gives the most accurate information, compared to satellite images. Furthermore, a decision can be made on the size of the drainage area, which will give an idea of the discharge through the stream. Because the precipitation is not taken into account the discharge through the streams is undefined, and may vary heavily in every climate zone, or due to an upstream reservoir.

Infrastructure

Africover

The Africover road map is available for all research countries except for Uganda. The coverage of roads is insufficient as in comparison to others. A table with a classification of roads is not available.
The Africover layers with major towns or other-towns information is available. These layers supply reliable and accurate information.
For more detailed information about Africover see the above section.

Cloudemate[2]

The files provided on this website are created from OpenStreetMap map data. Because OpenStreetMap is a work in progress many of the countries are only partially mapped or are incomplete. For the research area the maps match the Africover roads, but are much more extensive. A classification of road types is included in the table.

Mapcruzin[3]

Provides an African wide road layer. This map is extracted from the CloudMade data, which are derived from OpenStreetMap. This file is a stripped version of the original Cloudemate version.

African development bank group

These maps are available for Burundi and DR Congo. The level of detail varies per country. Within towns the coverage is very low. The table supplies information on road surface and road condition.

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[1] http://hydrosheds.cr.usgs.gov/hydro.php

[2] http://downloads.cloudmade.com/

[3] http://www.mapcruzin.com/free-africa-arcgis-maps-shapefiles.htm

Recommendation:
The Cloudemate road map contains the highest level of detail and information. Besides, this map is the best option for a uniform map of the research area. For the towns the best option is to use the Africover GIS layers which are accurate and have enough detail for this research.

Setting criteria

The four irrigation determining factors are categorized based on criteria. A classification is made which land will be more or less suitable for irrigation based on each factor. Through literature study and expert judgement the four factors are classified and a score is assigned to each class. This score will be used to combine all factors into a map which will give an indication of the irrigation potential based on these four factors. In the next paragraphs the criteria and classification of each factor will be discussed.

Distance to streams

Water availability is the most important issue in irrigation practice. About 4 percent of the harvested land in sub-Saharan Africa is irrigated. In nearly all African irrigation projects, the irrigation water is derived from surface water. Surface water source for irrigation include: rivers and streams, (artificial) lakes and ponds and marshes. As a result most irrigation projects are located near a surface water source. The distance from the water source to the irrigated area is from mayor importance on the conveyance costs, and the conveyance water losses. In case the water in allocated through pumping, the distance will also determine the transportation costs.

The distance over which the water should be allocated and the size of the irrigation system are from mayor importance on the complexity of the irrigation system. Agricultural land near a water source can easily be watered with low financial and intellectual input. However, an increased distance to the water source will need more and more complex conveyance systems.

Criteria used

As far as we know, no scientific information is available which pays attention to the distance to streams. Based on expert judgment these criteria are set and scores assigned. Within one kilometer from a stream irrigation can take place manually, with low input. A distance exceeding one kilometer requires a more professional system, which increases in costs and complexity in a linear way.

For this analysis streams are defined as natural drains, which drain at least an area of 20.000ha.

The criteria used for the analysis are mentioned in Table 3.

Table 3: Stream criteria

Criteria	Score
<1 km	10
1-5 km	8
5-10 km	6
10-15 km	4
15-20 km	2

Elevation to streams

This factor will assess the height difference between the land and the closest stream. The lifting height will largely influence the water transportation cost and the complexity of the conveyance system. The most sustainable systems will be gravity fed, which allows only for a small height difference. If groundwater is used for irrigation the water depth is important. For this research groundwater is not considered as an irrigation water source.

Criteria used

Nowadays it is possible to pump water uphill without limits. The only constraints are the costs, and complexity, which increase significantly with the head. For this assessment all areas below the nearest stream are considered ideal for irrigation, and the areas above the nearest stream decrease in potential with an increasing height difference. See Table 4.

Table 4: Criteria elevation to streams

Criteria in m	Score
< -5	10
-5 - 0	10
0 - 5	9
5 - 20	8
20 - 40	6.5
40 - 80	5
80 - 150	3
150 - 250	2
>250	1

Slope

The slope is one of the soil characteristics which determine whether an area is suitable for irrigation and which type of irrigation can be practiced best. Steep slopes limit or eliminate irrigation possibilities. Especially for basin or furrow irrigation the land should be flat or flattened. According to *Green et al 1996* furrow irrigation is used with highest probability under limited slopes, and drip irrigation in the steeper areas. See Figure 3. With the invention of the drip irrigation techniques, areas could be cultivated which had been unproductive before.

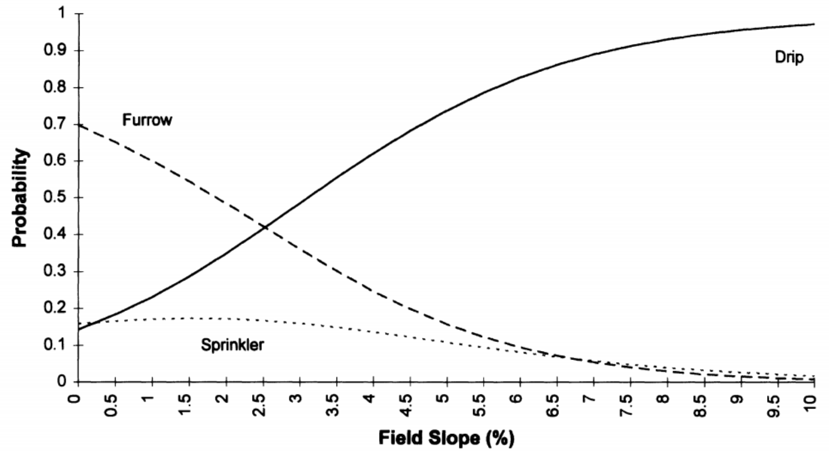


Figure 3: Irrigation methods used under a ranging slope.

For this analysis many aspects of the issue slope have been taken into consideration. According to 'The irrigation guide' by the United States department of agriculture a distinction should be made between slope irrigation in arid or semi-arid regions and humid regions. In humid regions the maximum allowable slope is much lower than in arid regions. This is caused by lower soil stability and a consequent higher erosion risk in sloping, humid areas.
Depending on whether a crop is grown in sods or not the allowable slopes will differ. Crops which are grown as a sod will have a higher soil holding capacity and as such reduce erosion. This allows them to be grown on slightly steeper slopes.
Slope irrigation requires terracing or other high financial input techniques. For this reason this chapter will mainly focus on flood irrigation methods.

Criteria used

Based on the available scientific articles the slopes are classified as can be seen in Table 5. For this factor the decision is made to focus on flood irrigation, which influences the land suitability. Slopes under the 2% are most ideal for flood irrigation; steeper slopes are assigned a rapidly descending score.

Table 5: Criteria slope

criteria	score
< 0.5%	10
0.5-1%	9
1-2%	7
2-4%	5
4-6%	4
6-8%	3
8-12%	1
12-20%	0.5
> 20%	0

Infrastructure

The infrastructure in developing countries is limited, especially in rural areas. The link between infrastructure and rural development is obvious, through an adequate road network the transportation time and cost can be reduced, this will increase competition and reduce marketing margins. In this way farm incomes and investment opportunities can be improved. In a FAO document they conclude: "infrastructure services are limited in all rural areas, although they are of key importance to stimulate agricultural investment and growth." (FAO 1996)

The importance of infrastructure for rural development is well established, a recent report states: "Since the 1960s the importance of agriculture to drive the overall economic growth has been emphasized. Agricultural productivity increase is an important driver for poverty reduction. The productivity increase depends on good rural infrastructure, well functioning domestic markets, appropriate institutions, and access to appropriate technology." (Andersen P. P. and S. Shimokawa 2006)

Criteria used

In this combined analysis of roads and markets it is assumed that every town will have a market. The *catchment* area of major town is larger than those of small towns. The influence of the roads, small town and major towns within each category are assumed to be equal. So a piece of land will belong to category one, if it is situated either within 3 km of a road, or within 5 km of a small town or within 25 km of a major town, or a combination. In Table 6 the categories are further explained.

Table 6: Infrastructure criteria

Category	Roads	Small towns	Major towns	Score
1	0-3km	0-5km	0-25km	10
2	3-6km	5-10km	25-50km	8
3	6-10km	10-30km	50-100km	6
4	10-20km			4
5	>20km	>30km	>100km	2

Data analysis

The data sets are all analysed with arc Gis. The SRTM 200m DEM is used as a basis raster for all analysis in order to make the factors inter-comparable.

The height difference between the nearest stream and the surrounding land is analysed by allocate each raster cell to the nearest stream with the spatial analyst function ‘Euclidean allocation’. The stream is assigned the height of the DEM, and then this file is subtracted from the allocated DEM file. The result is the height difference compared to the nearest stream.

With the spatial analyst functions a buffer was created around the streams, roads and towns.

For the final map the first maps are assigned a score per category, which is summed. This results in a map which assigns each cell a value between 4 and 40. The score 40 will be the maximum irrigation potential with these four factors.

4. Results

This chapter will show the results of the analysis of the four factors. For each factor a map is made, which shows which areas are most suitable for irrigation concerning that specific factor. A graph for each factor shows the distribution of land over the categories.

Distance to streams

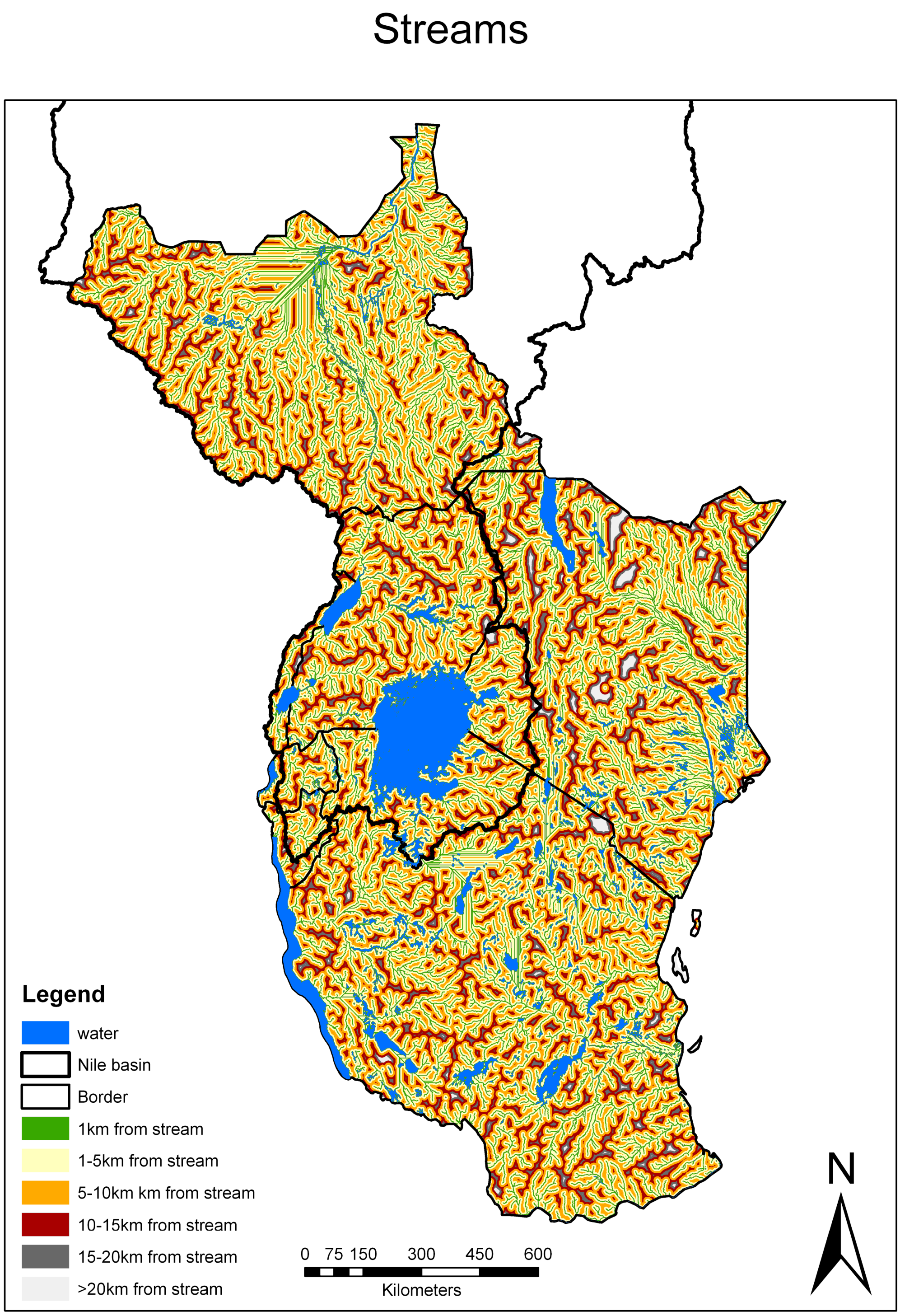


Figure 4: Distance to streams map

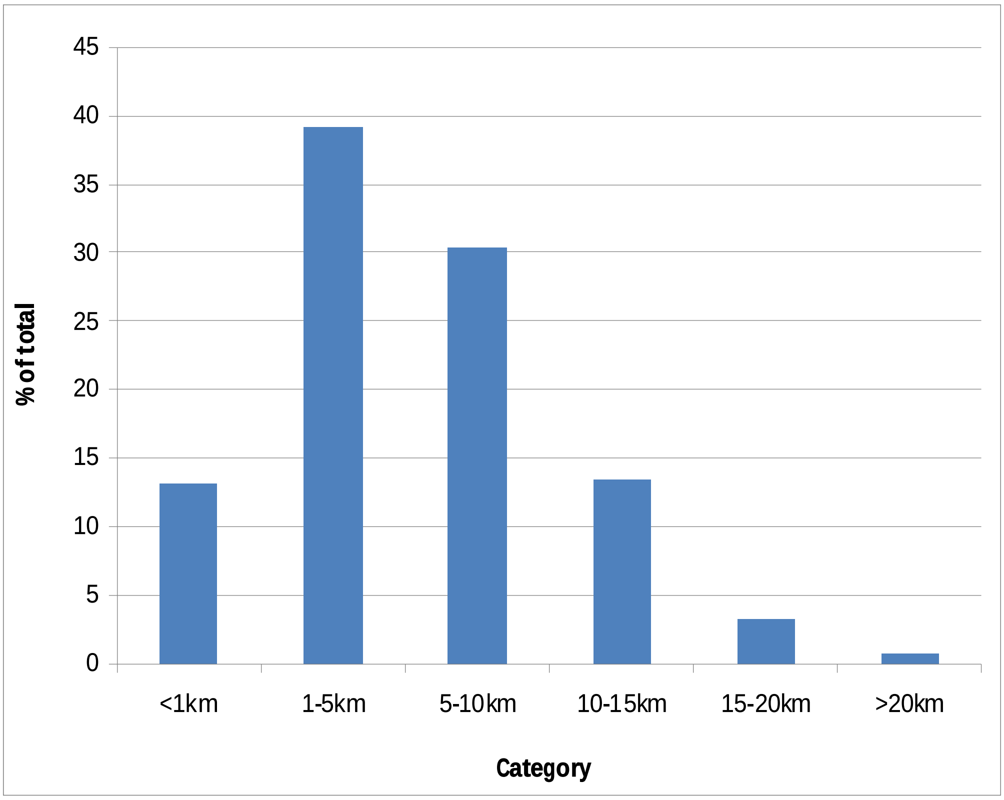


Figure 5: Distribution of land within the categories

Discussion

The distribution of land over the categories is well spread. Due to the relatively dens stream network just over 50% of the land is situated within 5km from the nearest stream. Although these streams drain at least an area of 20.000ha the discharge through the streams in not known. The combination of this map with the actual water availability over the year will emphasis some specific areas. This result shows a distribution independent of height difference, although solitary mountains stand out because of their large distance to streams. Flat wetland areas have a changing and very dens stream network and have therefore a high potential in this analysis.

Height to streams

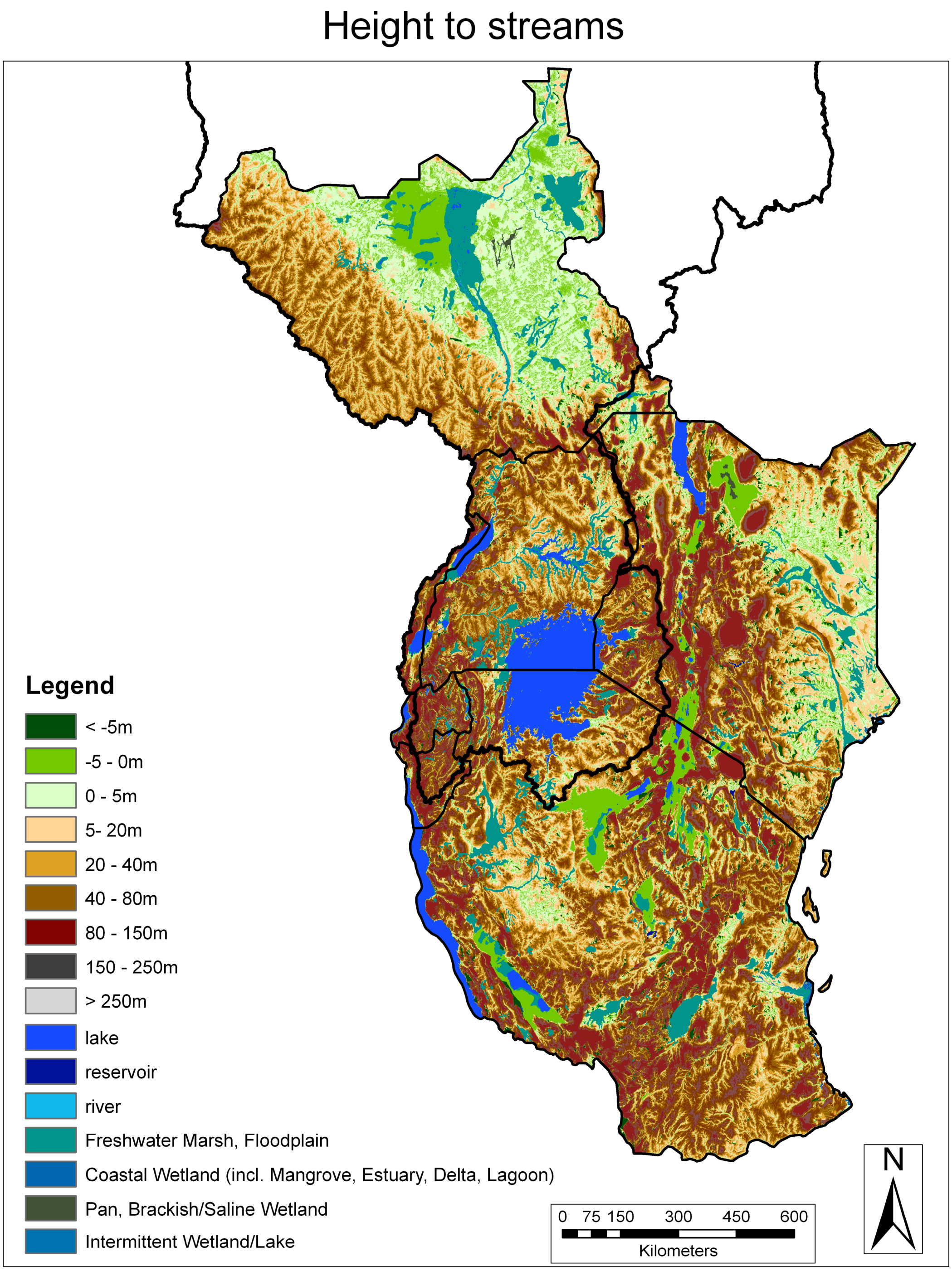


Figure 6: Height to nearest stream map

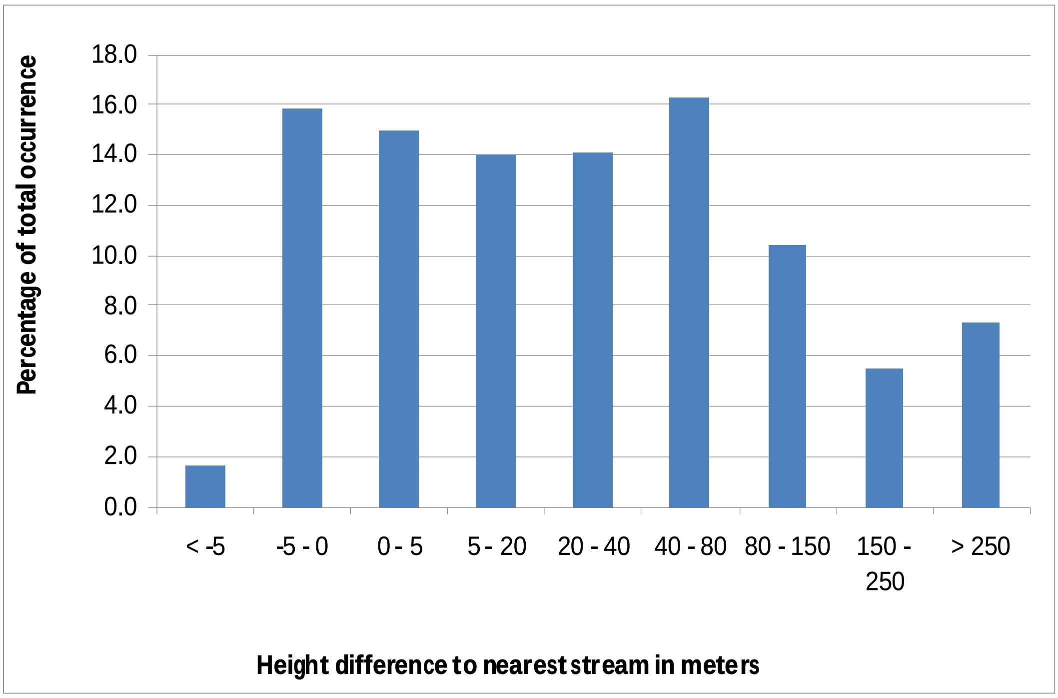


Figure 7: land distribution over the categories

Discussion

In this analysis the flat areas stand out. Eastern Kenya and South-East Sudan have large flat areas which are favourable. Mountainous areas like Burundi, Rwanda and the mountain ridges in Kenya and Tanzania are more limited through this factor. If flood irrigation is practiced the scale of the irrigation projects will depend on this height difference. Most probably small scale irrigation will be practiced in the mountainous areas.

Slope

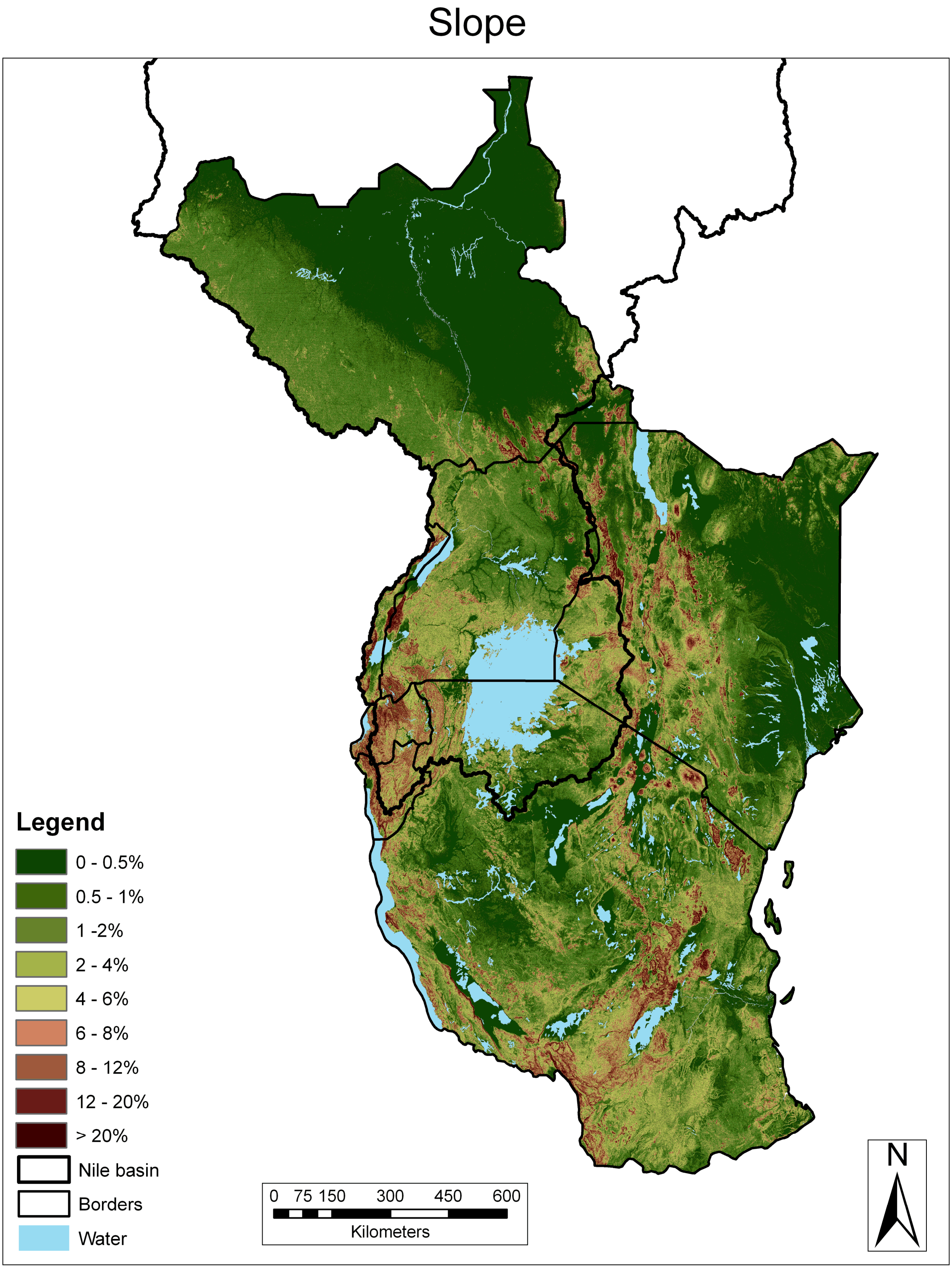


Figure 8: Slope map

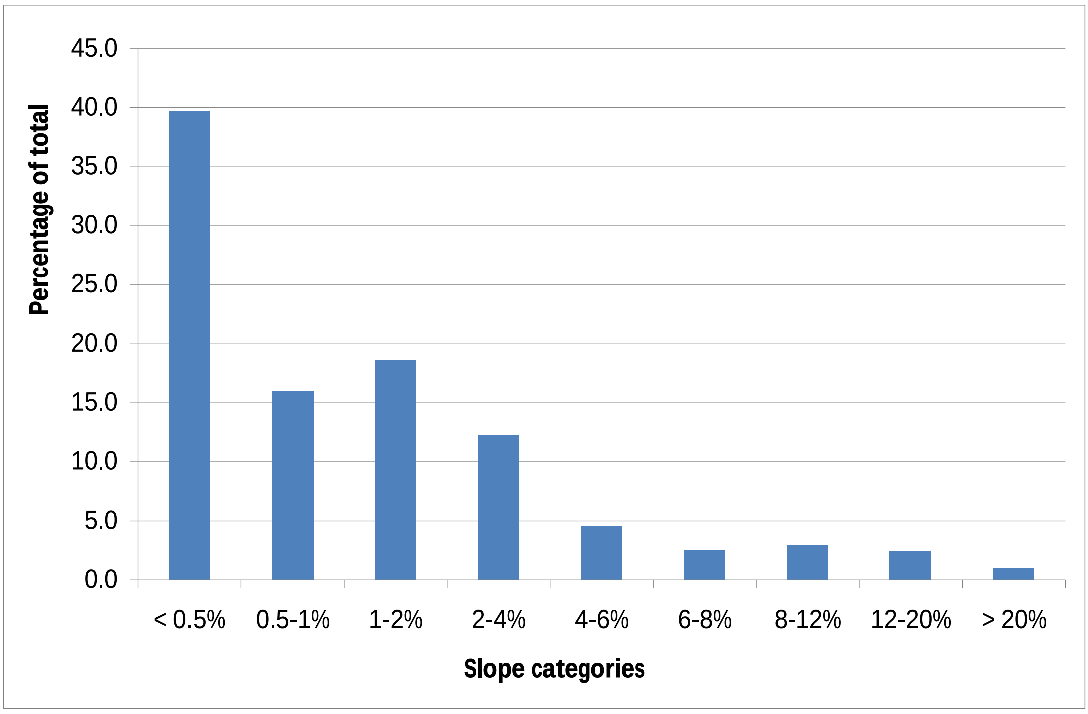


Figure 9: Slope: land distribution over the categories

Discussion

Within the study area over 70% of the land has a slope under the 2 percent. Favourable areas include flat areas in East Kenya en South Sudan. Burundi and Rwanda are characterized by their mountains, so their flat areas are still quite rolling. Depending on the slope different irrigation techniques can be practiced. For this analysis the focus is put on flood irrigation, which allows minimal slopes.

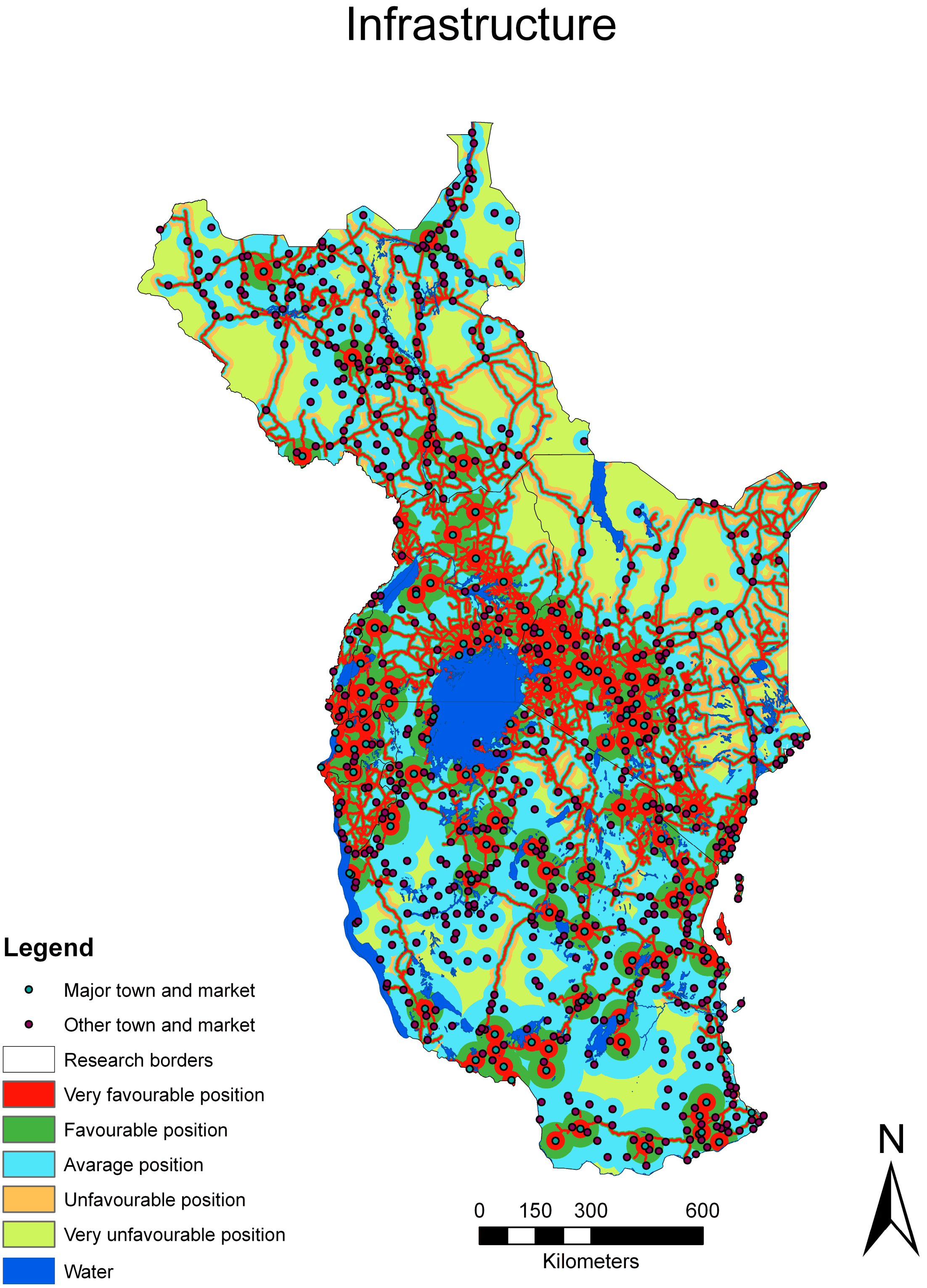


Figure 10: Infrastructure map

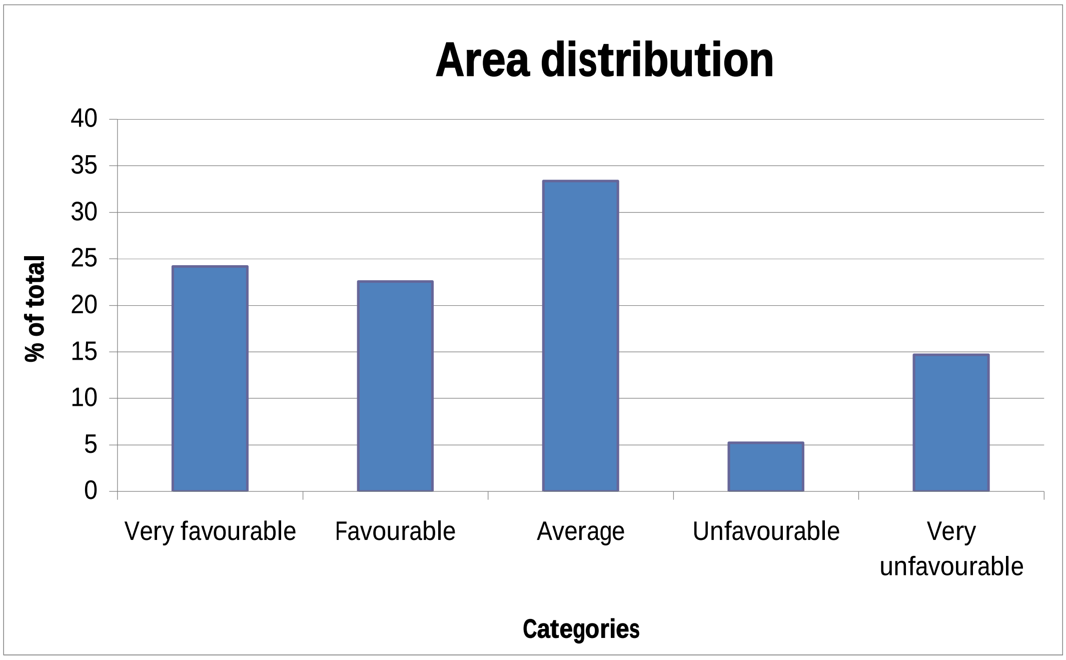


Figure 11: Infrastructure, area distribution over the categories

Discussion

This analysis focuses on the presence of roads, markets and towns. Through this focus the densely populated areas around Lake Victoria and in Rwanda en Burundi stand out as favourable. In densely populated areas market prices for food products are more profitable, but the pressure on land and water resources is high.

Combined results

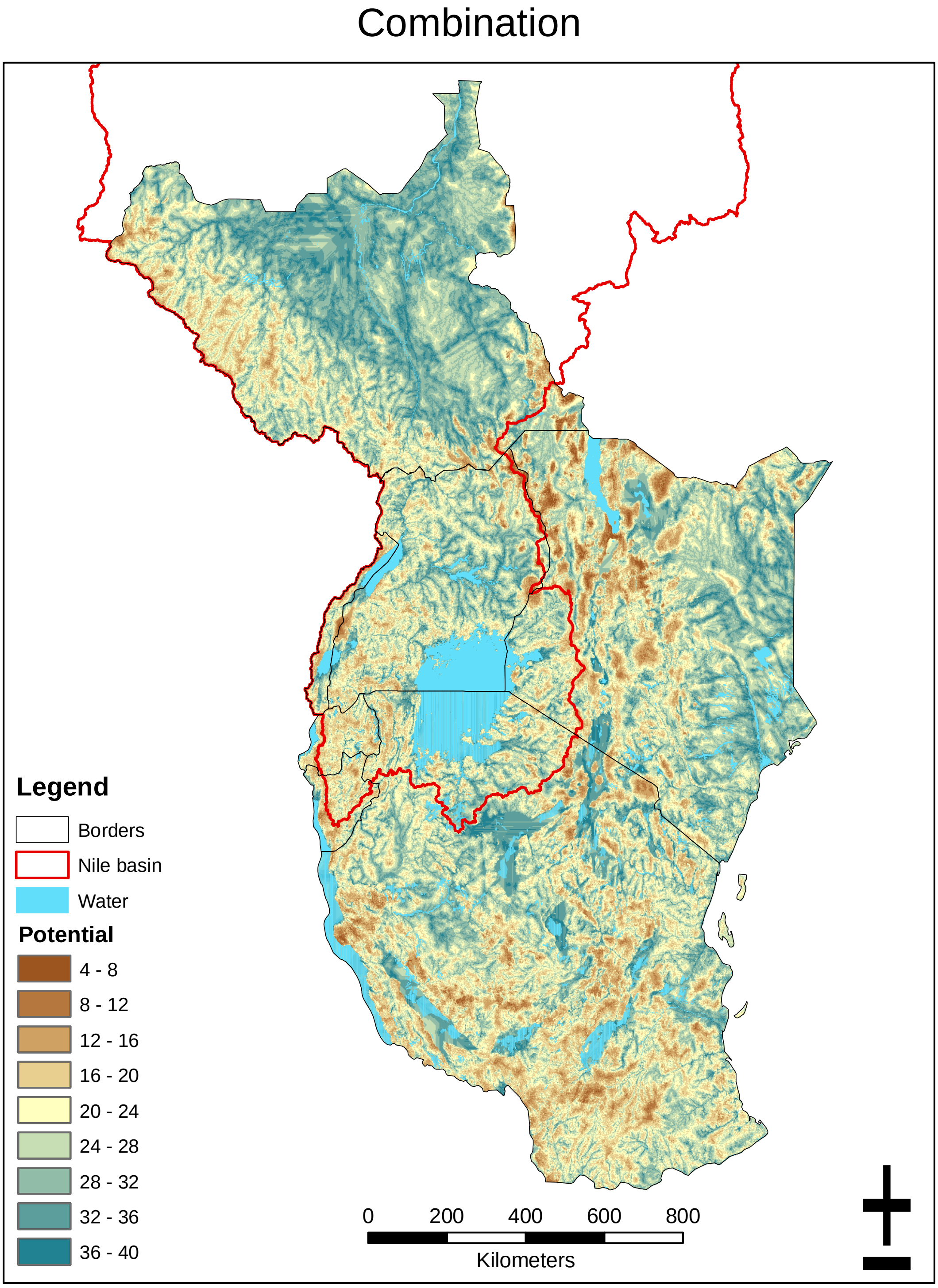


Figure 12: Combined results map, irrigation potential for the four factors

Discussion

In this final map the scores of all five factors are summed up. The high scores have the highest irrigation potential, concerning these factors. The most outstanding area is in South Eastern Sudan. The flatness and many streams make this area homogeneous; the infrastructure alone brings diversity in this area. Other large high potential areas can be found around lakes. Although these areas have a high potential, these areas might be used as seasonal flood plains as well. These areas have the advantage that they are near large water resources.

Case studies

This paragraph will zoom in on tree small case study areas. This will create a better understanding on how the combination map is composed, and which factors play an important role for the irrigation potential. Furthermore it gives a good impression of the scale of the four analyses and shows the diversity in the irrigation potential. The location of these tree case study areas are marked in Figure 13. The areas are spread over the research area to create more diversity.
Musenyi is located in a humid and mountainous area. Kitui has an arid to semi-arid climate and is located at the foothills of the lake plateau. Jalang is characterized through its position at the Nile’s border and its flatness. (See next three pages)

The scale of the DEM based maps, slope and height to stream, is much smaller than the distance to streams and the infrastructure map. These two maps consist of large concatenated areas due to their distance based criteria.

Outstanding, for all three areas, is the remarkable pattern similarity in the distance and height to streams map. Nearly the same pattern can be found in the slope map. The result is a high irrigation potential on the valley bottoms and other flat areas. This raises the question whether the DEM based analyses are too strongly represented in the combined map. In the combined map all four factors have been given the same score scales. Maybe a correction factor should be used or other factors added to reduce the impact of the DEM on the irrigation potential. Especially in the Jalang map it becomes clear that the factor infrastructure brings the most diversity in the combined map.
Soil characteristics and actual water availability could bring more diversity and detail when combined with this map.

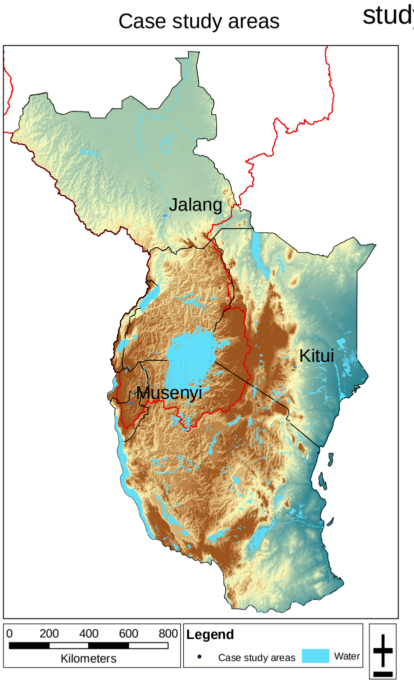
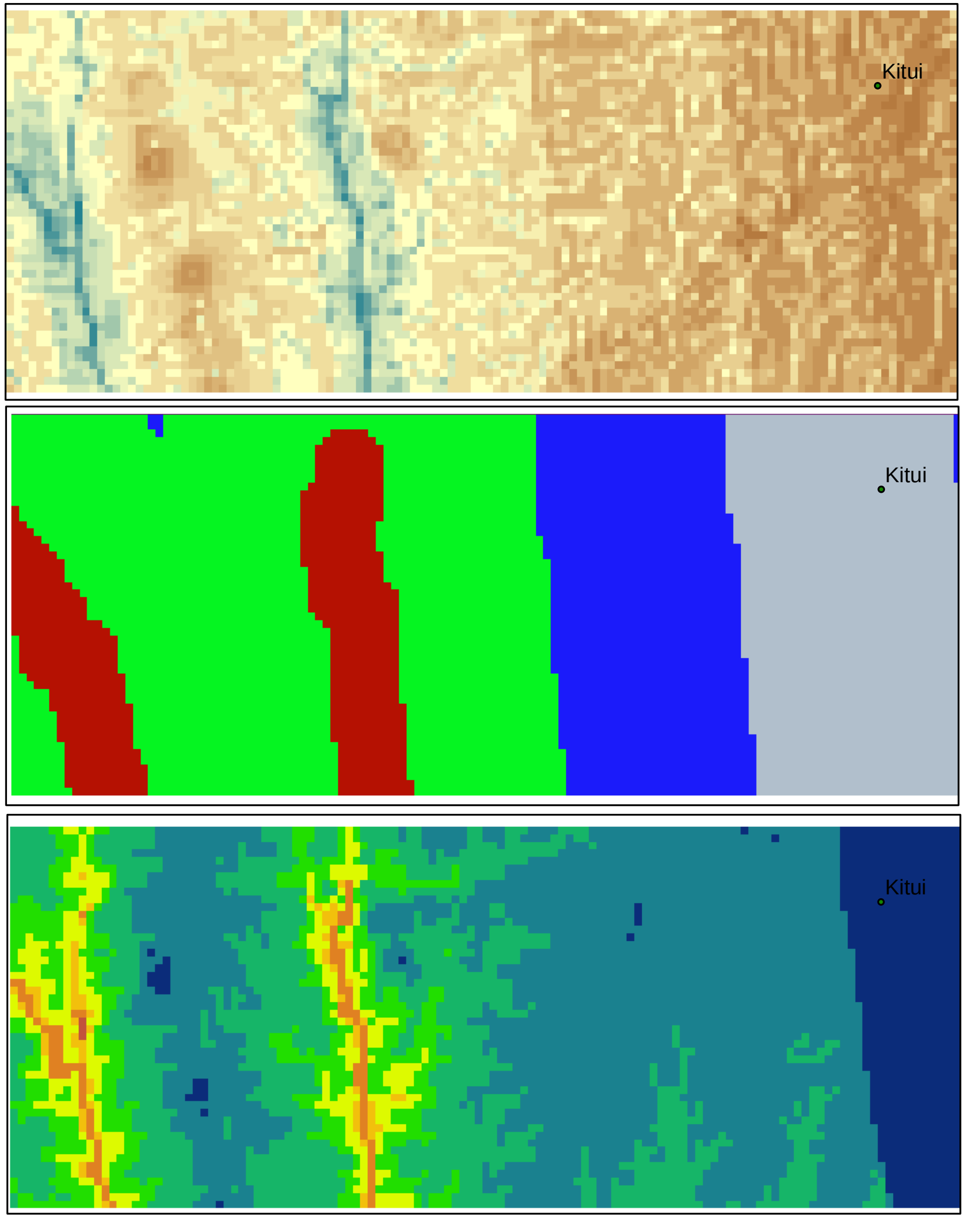


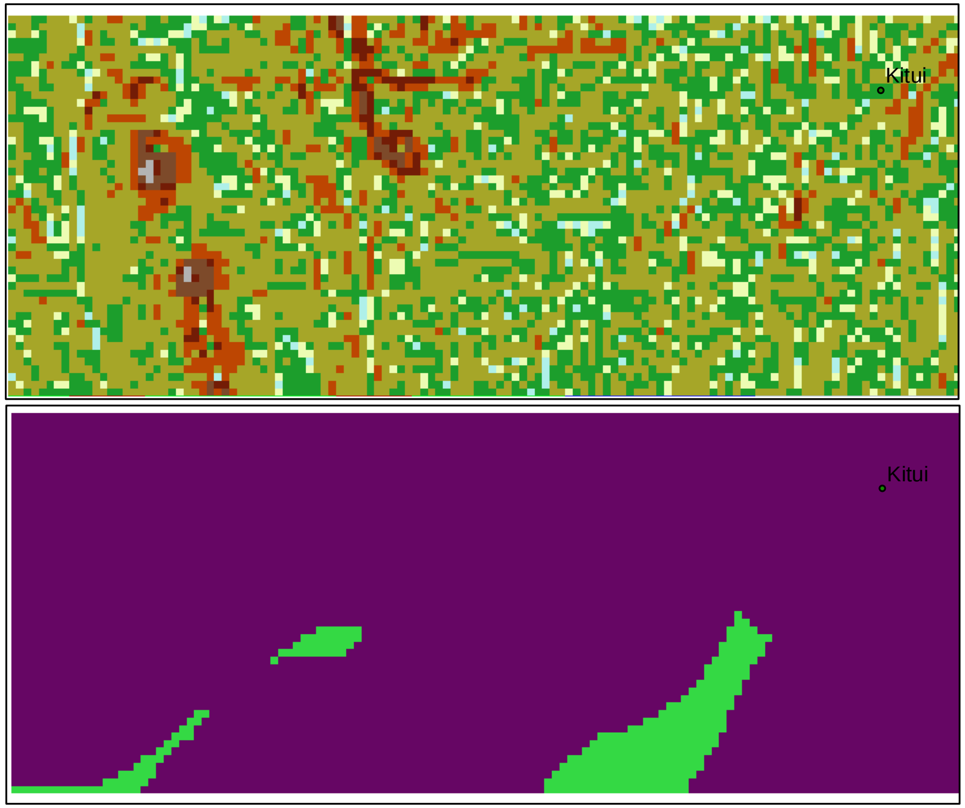
Figure 13: Case study areas

The slope in the Kitui area is very much scattered, so no concatenated high potential areas can be found. In Musenyi on contrary the slopes are much steeper on average, but on the valley bottom a high potential area can be found. This shows that the results of the analyses should focus much more on absolute values rather than average scores. In the Jalang area a high potential can be found around the two rivers. In reality however these areas may be to wet, and should rather be drained to practice agriculture. This makes it much more likely that irrigation is practiced on the transition from river to the hill.

Kitui



Kitui



Legend

- Town
- Water

Combination

High : 40

Low : 15

Distance to streams

- <1km
- 1-5km
- 5-10km
- 10-15km

Height to streams

- -5 - 0m
- 0-5m
- 5-20m
- 20-40m
- 40-80m
- 80-150m
- 150-250m
- >250m

Slope

- 0 - 0.5%
- 0.5 - 1%
- 1 - 2%
- 2 - 4%
- 4 - 6%
- 6 - 8%
- 8 - 12%
- 12 - 20%
- >20%

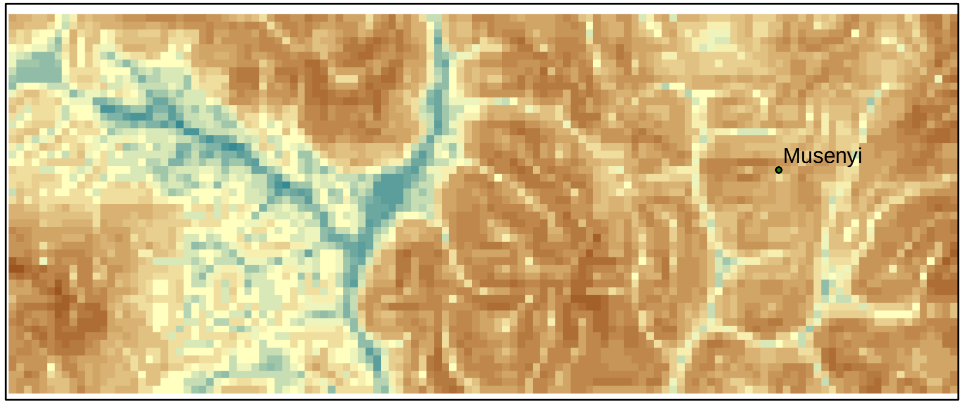
Infrastructure

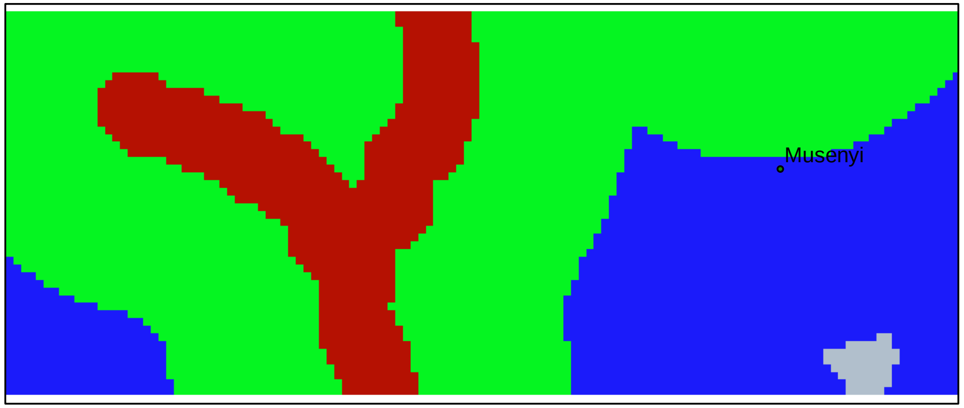
- Very favourable
- Favourable
- Avarage

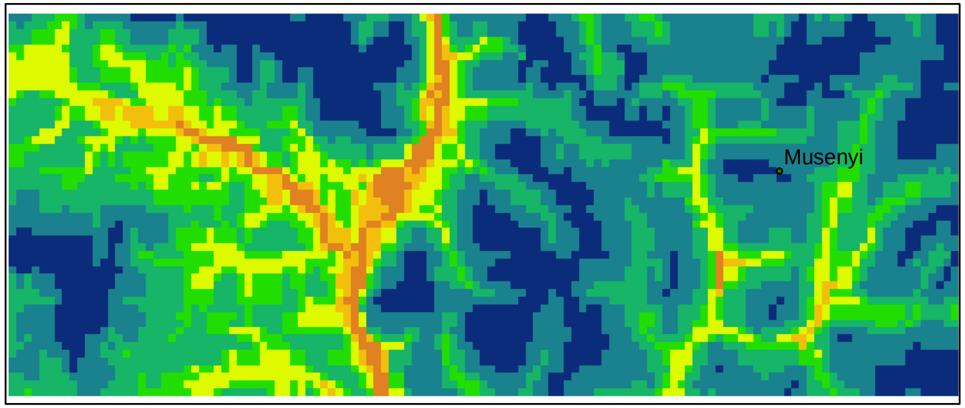
0 2 4 6 8

Kilometers

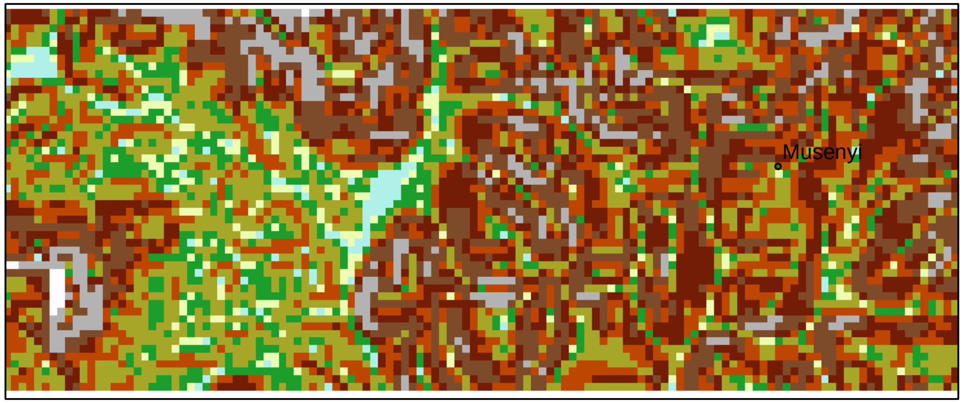
Musenyi







Musenyi



Legend

- Town
- Water

Combination

- High : 40
- Low : 15

Distance to streams

- <1km
- 1-5km
- 5-10km
- 10-15km

Height to streams

- -5 - 0m
- 0-5m
- 5-20m
- 20-40m
- 40-80m
- 80-150m
- 150-250m
- >250m

Slope

- 0 - 0.5%
- 0.5 - 1%
- 1 - 2%
- 2 - 4%
- 4 - 6%
- 6 - 8%
- 8 - 12%
- 12 - 20%
- >20%

Infrastructure

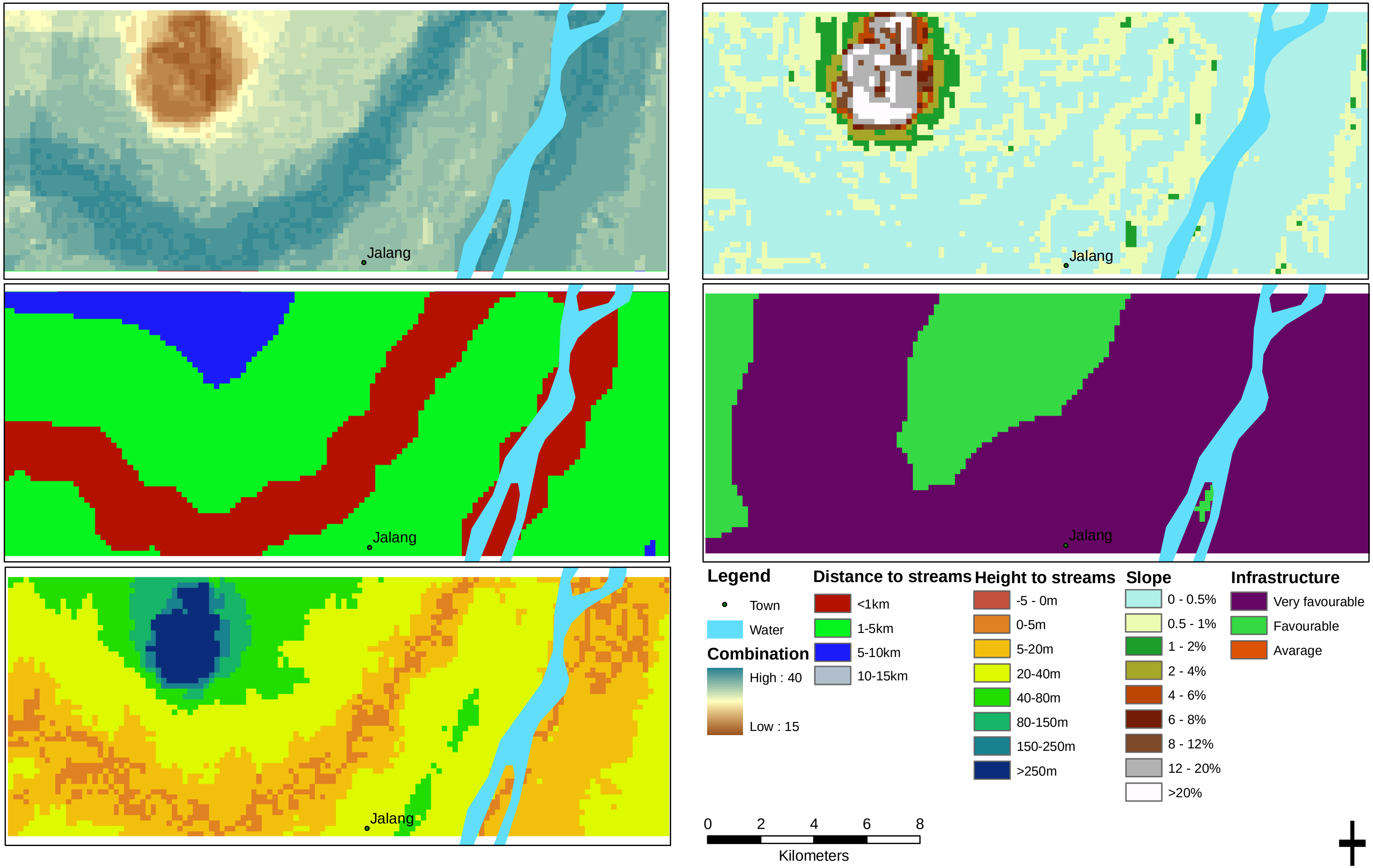
- Very favourable
- Favourable
- Avarage

0 2 4 6 8

Kilometers

Jalang

Jalang



This paragraph will compare the irrigation potential which is the result of the four factors from this study and the irrigation potential according to the FAO. FAO conducted a study in 1997 (see the literature chapter) and updated the irrigation potential under the Aquastat program. In Figure 14 a comparison is made between these numbers. For the irrigation potential according to the four factors only the scores 35-40 are classified as high irrigation potential.

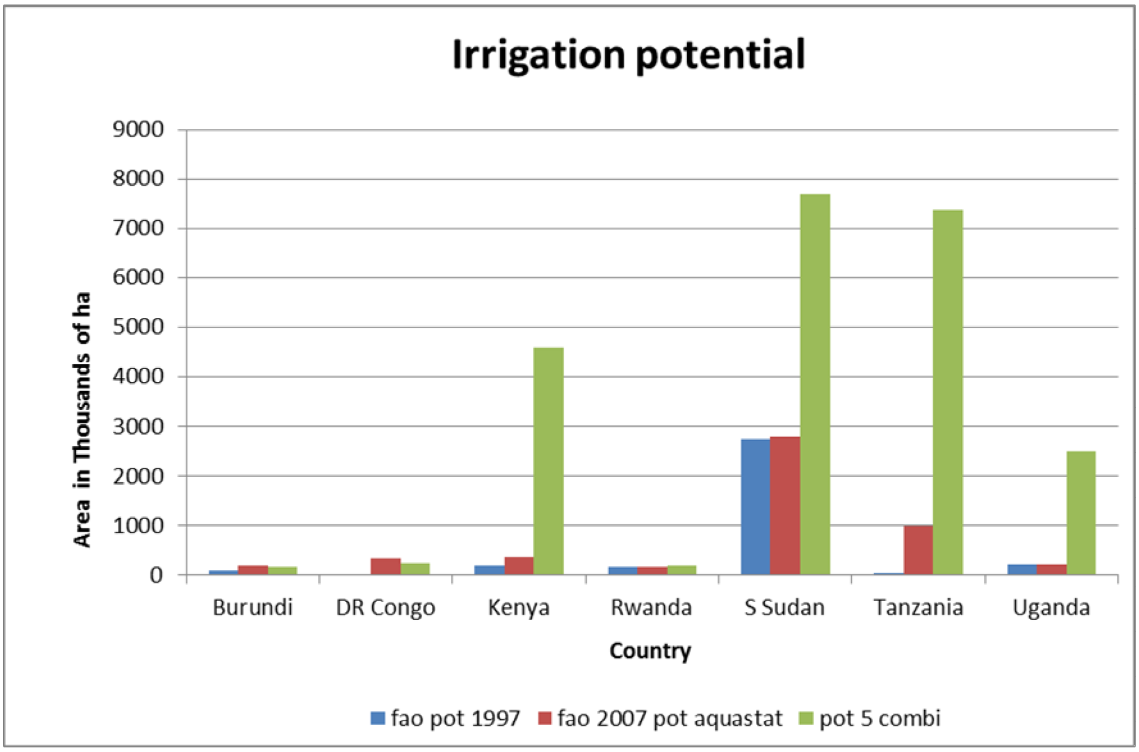
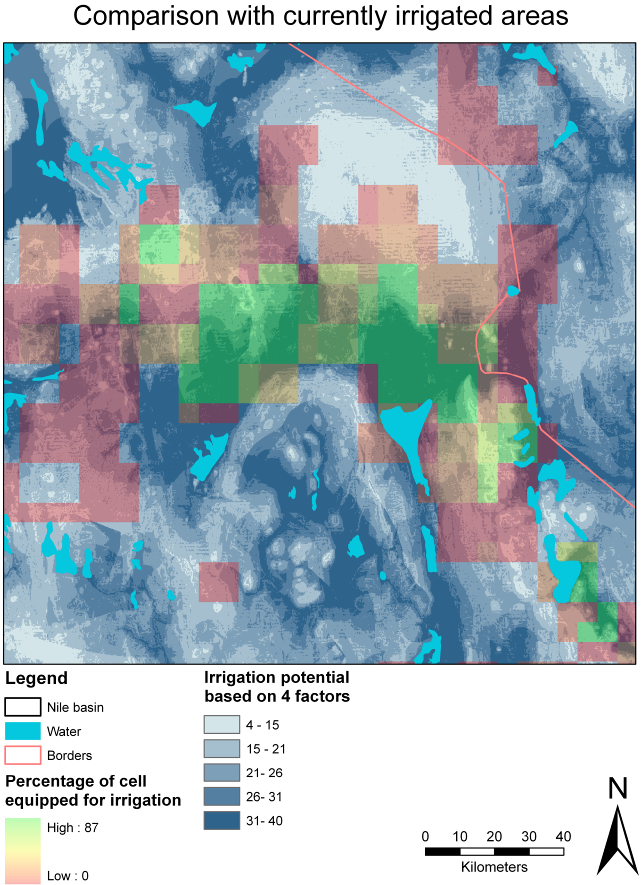


Figure 14: Irrigation potential
Remark: FAO numbers for DR Congo and Sudan are for the whole country.

A large difference is visible in Kenya, in which the potential for this study is more than 12 times as high as the FAO irrigation potential. Southern Sudan, Tanzania and Uganda show a similar gab. Burundi, Rwanda and Eastern DR Congo however, show a remarkable similarity. The difference between these regions suggest that other factors, like actual water availability and soil characteristics do play a major role in Kenya, Southern Sudan, Tanzania and Uganda, in contrary to Burundi, Eastern DR Congo and Rwanda. Which on it turn suggests, that Burundi and Rwanda have fertile soils and abundant water resources. Another explanation could be that the scale of the FAO studies is much larger than the scale of this study. Especially in mountainous areas where just small concatenated areas have a high potential, this areas might be overlooked or up scaled into a larger raster cell.

Within the study area some areas have been irrigated for many decades. Partially this has been an organic process, originating from an increasing demand for food on a certain place. And partially it has been a well-designed process, which prepared irrigable land on large scales. In both cases irrigation was practiced on fertile land with enough water resources. This paragraph will combine the 'combi' map of the four factors and the map of the areas which are currently prepared for irrigation. A combination of these maps may show similarities as one map shows the high potential areas and the other map the currently irrigated areas. See Figure 16.

Two maps of the currently irrigated areas are available. On from the IWMI, and one from the FAO in cooperation with the university of Frankfurt am Main. The latter one supplies a more detailed map (10km resolution), which will be used in this paragraph. (Siebert, S., Hoogeveen, J., Frenken, K. 2006)
This map is based on remote sensing, and shows therefore the area's which are equipped for irrigation. Possibly these irrigation areas are not in use anymore. After researching with remote sensing the values are adjusted to match the FAOStat values. Either the area equipped for irrigation is extrapolated, or the percentage is adjusted.



The resolution of the currently irrigated area is much larger, which results in a slightly distorted picture. However it does give a good impression, and shows that both maps correspond well. Large high potential areas which are based on the four factors are not irrigated; these areas are most interesting for further study. Additional factors will eliminate even more areas, which leaves only the excellent irrigation potential areas. This comparison shows that the research is on the right track.

Figure 15: close up from Figure 16: Kilimanjaro area.

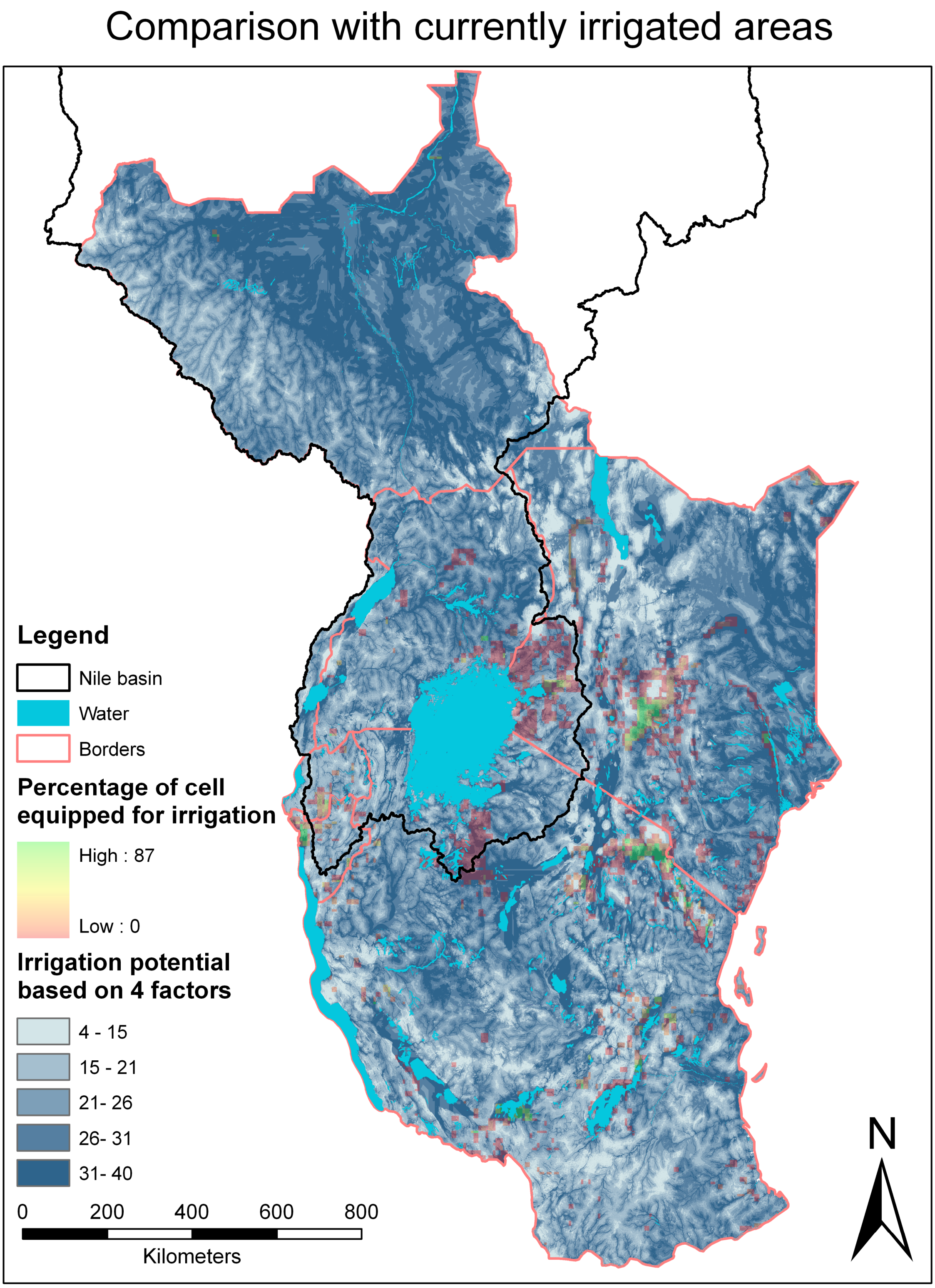


Figure 16: Currently irrigated areas

Source: http://www.geo.uni-frankfurt.de/ipg/ag/dl/forschung/Global_Irrigation_Map/index.html

5. Conclusions and recommendations

In the study area almost all irrigation is flood irrigation, of which approximately half is gravity fed and half is under pumping. The analyses in this report have been carried out for flood irrigation.

The analyses of the available data sets have shown that the SRTM DEM gives the most reliable information, and supplies enough detail for this study with a 200m resolution. For the infrastructure the Cloudemate road map is most detailed, as roads are classified, and the map is available for the whole area in a uniform manner. The towns are obtained from Africover, which is most accurate.

Based on the four irrigation determining factors, Distance to streams, Height to streams, Slope and Infrastructure, it becomes clear that high potential areas can be found in all countries. In Burundi, eastern DR Congo and Rwanda these areas are relatively small compared to the other countries. This is caused by the mountains, and the coherent steep slopes and large height differences.

The slope and height difference limits the possibilities for irrigation, as pumping water up hill will be cost ineffective, which will cut profits with an increasing height. Furthermore, irrigation canals shouldn't be too steep to prevent erosion. Terracing of mountains, lining the canals, or create drops, will require a large financial input, and will create a complex system.
Distance to streams and infrastructure are both a distance related factor. These factors are very favourable nearby a stream, road or market, and descend in score in an almost linear way, as efforts increases.

This study adds value to previous studies due to the small scale, and diversity in factors. This study is based on a 200m resolution which gives a very detailed result compared to the FAO study from 1997 which have followed a basin approach. When this study is continued it will result is a very detailed and holistic irrigation potential map.

The case studies show that the impact of infrastructure is very high in the flat areas. Due to the three DEM based analyses the diversity of the factors is not large enough to bring diversity in large swampy areas. The same argument is valid for the mountainous areas which have a relatively low potential due to the three DEM based factors. The score per factor can be adjusted to give the infrastructure a stronger weight, but a better option is to combine more factors.

This study is not at all covering the most important irrigation factors, nor is it giving an exhaustive view of the irrigation potential, but it does supply an insight in how irrigation potential can be determined. At the same time it does give an impression of the areas which are likely to have a high potential. This is proofed in the comparison of the combined factors map with the map of the areas which are currently equipped for irrigation.

It is recommended to proceed with this study in order to combine more physical and social aspects with this study. Other irrigation determining factors such as soil fertility, drainage capacity, texture, infiltration, and water factors like evapotranspiration, water quality and quantity and its temporal variation are factors which definitely have to be included. When the physical irrigation potential is defined the social factors will make irrigation projects successful or not. In order to work in a sustainable and durable manner these social aspects have to be included.

References

Bourguignon, F. and Pleskovič, B. 2007. *Rethinking infrastructure for development. Annual World Bank conference.*

CIA. 1999. World Factbook. https://www.cia.gov/library/publications/the-world-factbook/

FAO. 2005. Aquastat survey: Irrigation in Africa in figures. FAO Water Reports, 29

FAO. 1996. *Technical back-ground Documents 6-11, Volume 2. World Food Summit, Rome.*

FAO.1997. Irrigation potential in Africa: a basin approach. FAO Land and Water Bulletin 4.

Green, G. et al 1996*. Explaining Irrigation Technology Choices: A Microparameter Approach*. Amer. J. Agr. Econ. 78 p: 1064-1072

Thurlow, J., J. Kiringai, M. Gautam. 2007. Rural Investments to Accelerate Growth and Poverty Reduction in Kenya. IFPRI Discussion Paper 00723

IFPRI, FAO Trade and Food Security Database (2005)

Pinstrup-Andersen. P, and Shimokawa, S. 2006. *Rural Infrastructure and Agricultural Development.* Worldbank conference, Tokyo.

Siebert, S., Hoogeveen, J., Frenken, K. 2006. Irrigation in Africa, Europe and Latin America. Update of the Digital Global Map of Irrigation Areas to Version 4. Frankfurt Hydrology Paper 05, University of Frankfurt (Main), Germany and FAO, Rome, Italy.

Sutcliffe, J.V. 2009. The Hydrology of the Nile Basin. Monographiae Biologicae. Volume 89, IV, 335-364, DOI: 10.1007/978-1-4020-9726-3_17

Sutcliffe, J. V., Y. P. Parks. 1999. The hydrology of the Nile. IAHS Special Publication no 5.

USDA, United States Department of Agriculture, 1997. *Irrigation Guide.*

More references which are used as background information, but which are not explicitly referred to in this report can be found in the literature chapter.

An enormous amount of studies focusing on the Nile has been undertaken over the last centuries. In the scientific literature alone, over half a million publications can be found related to the Nile (Google Scholar, 14-Mar-2011). Beside these scientific studies hundreds to thousands other non-scientific literature and publications are made related to the River Nile. Using the search term River Nile in Google resulted in over five million pages found (Google, 14-Mar-2011).

This section of the report is not meant to provide an inclusive summary of all publications related to the Nile. The focus of this section is to give an overview of the most relevant publications and studies in the context of the current project. A distinction is made between more general irrigated related studies, other relevant studies and country specific studies.

Most relevant studies

Döll, P. and S. Siebert. (2002) *Global modeling of irrigation water requirements.* Water Resources Research, Vol. 38, No. 4.

World wide almost 90% of the water consumption is used for irrigation purpose. With a rapidly increasing population it can be questioned whether enough water will be available to increase the food production accordingly.
This study aims to give a global view, at a relatively small scale (0,5º by 0,5º), of the irrigation water requirements. For this reason the current distribution of irrigated land is modeled first. As there is not sufficient information available on what crops are grown under irrigated conditions where and when, the cropping patterns and the growing seasons are also simulated by the model, based on soil suitability and climate. Furthermore, a distinction is made between only two crop types, rice and nonrice

FAO 1997 – irrigation potential in Africa, a basin approach.

There is a growing concern about the food security in sub Saharan Africa as the import of cereals is projected to triple from 1990 to 2020. Africa is (apart from Australia) the driest continent in the world, with a highly unstable rainfall regime. Droughts are frequent, which put more people are at risk each year. Agricultural productivity has not been able to keep up with the population growth. As the cultivated land can hardly be increased the solution should be to increase the yields.
The irrigated area of 8.5% of the cultivated area is far beneath the world average of 17%. In the areas where irrigation is most needed the water is getting scarce due to population growth, urbanization, and industrialization.
This study concentrates on the quantitative assessment based on physical criteria.

Definition of irrigation potential

This study refers to irrigation as the process by which water is diverted from a river or pumped from a well and used for the purpose of agricultural production. Areas under irrigation thus include areas equipped for full and partial control irrigation, spate irrigation areas, equipped wetland and inland valley bottoms (including fadamas), irrespective of their size or management type. It does not consider techniques related to on-farm water conservation like water harvesting.

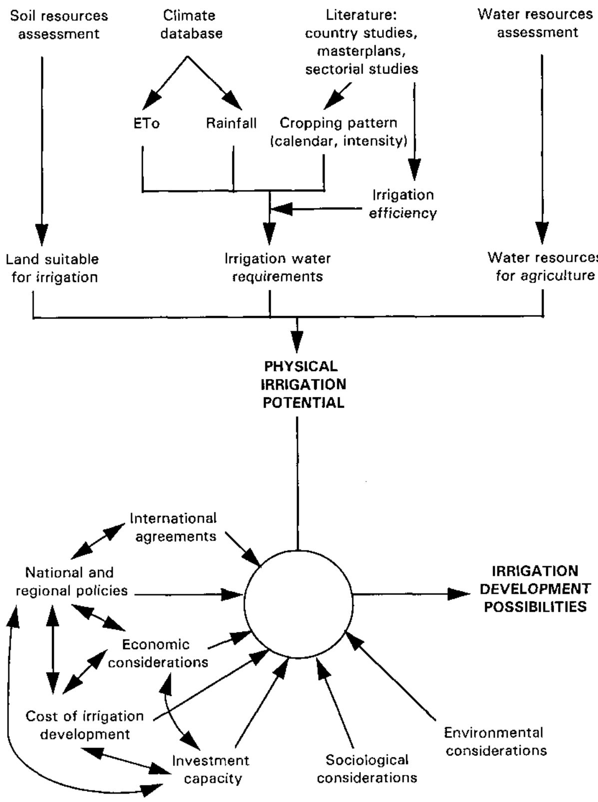


Figure 17: Assessment of irrigation potential

Methodology

This study is carried out per river basin. This summery will be focused on the Nile river basin. Criteria are defined to determine the physical resources. The type of irrigation is set on surface irrigation. Annual renewable water resources are calculated per country mainly based on surface water. Non renewable water resources are not taken into account.

Assessment of the irrigation potential, based on soil and water resources, can only be done by simultaneously assessing the irrigation water requirements, which in turn depend on the cropping pattern and climate. For this reason, irrigation cropping pattern zones were defined for current and potential scenarios and (net and gross) water requirements were computed.

Although the physical resources are the main concern of this study, it is acknowledged that economical, political, social and environmental issues are essential for a holistic view. This study will highlight the most important environmental issues related to irrigation.

Soil and terrain suitability for surface irrigation

Two land use types have been considered, the upland crops and rice under irrigation. In case the soil is suitable for both; priority will be given to rice.

The following characteristics have been used to asses the soil quality: topography, drainage, texture, surface and subsurface stoniness, depth, calcium carbonate level, gypsum status, salinity and alkalinity conditions.

Table 7: Soil and terrain suitability for surface irrigation by country

Area in ha Country (1)	Total area of the country (2)	Soil suitable for irrigation of rice (3)*	Soil suitable for irrigation of upland crops (4)*	Total area of soils suitable for surface irrigation (5)	As % of total area of country(5/2)* 100 (6)
BURUNDI	2 783 400	302 100	286 700	588 800	21
CONGO	34 200 000	9 257 600	45 600	9 303 200	27
EGYPT	100 145 000	6 477 400	655 900	7 133 300	7
KENYA	58 037 000	11 405 600	5 979 100	17 384 700	30
RWANDA	2 634 000	220 600	80 300	300 900	11
SUDAN	250 581 000	66 955 100	1 814 100	68 769 200	27
TANZANIA	94 509 000	23 344 700	908 700	24 253 400	26
UGANDA	23 588 000	7 652 000	23 700	7 675 700	33
Total for Africa	3 029 020 800	511 998 900	84 961 100	596 960 000	20

Water resources

The water resources can only be assessed on basin level, although the exchange of water through rivers is very important for some countries.

The available information comes from a multitude of sources so no reference period has been set.

The internal renewable water resources and global renewable water resources have been calculated. If no information was available an estimation was made by multiplying the precipitation by the runoff coefficient. Evaporation from open waters does have a significant influence on the water balance. This has been considered as much as possible. The distribution of the water resources have not been specified further than country level.

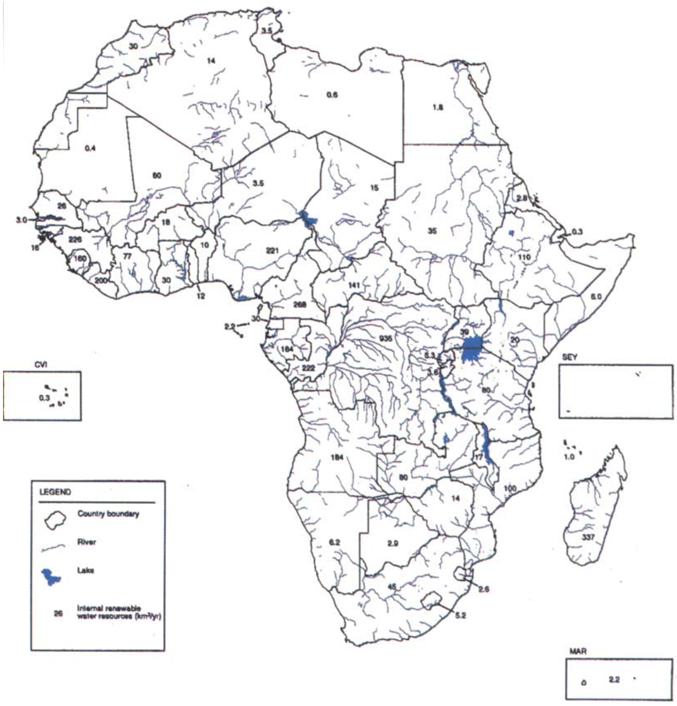


Figure 18: Internal renewable water resources by country

Irrigation water requirements (IWR)

By dividing the available water by the gross irrigation water requirement the maximum irrigated area can be calculated. (If water is the limiting factor.)
Because of the scale, assumptions had to be made on the definition of areas to be considered homogeneous in terms of rainfall, potential evapotranspiration, cropping pattern, cropping intensity and irrigation efficiency. First the major irrigation cropping patters where delineated. Second the climatic zones are defined, based on climate stations. The combination of the cropping zones with the climate zones resulted in 1437 areas, homogeneous in irrigation cropping characteristics and climate. The model to calculate the Nett IWR was run for three scenarios and divided by the efficiency to calculate the Gross IWR.
The influence of selecting cropping pattern zones and the estimations used for cropping intensity and irrigation efficiencies are of prime importance for the final results. The potential efficiency and the net and gross irrigation water requirement per area have been listed in a table. (nr8)

Results Nile basin

A review has been given per river basin. This review describes the hydrological situation, the water resources, and the irrigation potential. **Error! Reference source not found.** gives a quick insight. The complete review is available at the following link.(visited 17-02-2011) (http://www.fao.org/docrep/w4347e/w4347e0k.htm#the nile basin)

Table 8: Nile basin, irrigation potential, water requirements, water availability and areas under irrigation

Country area within the Nile basin	Irrigation potential	Gross irrigation water requirement		Actual flows		Flows after deduction for irrigation and losses		Area already under irrigation
		per ha	total	inflow	outflow	inflow	outflow	
	(ha)	(m^3/ha.year)	(km^3/yr)	(km^3/yr)	(km^3/yr)	(km^3/yr)	(km^3/yr)	(ha)
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Burundi	80 000	13 000	1.04	0.00	1.50	0.00	0.46	0
Rwanda	150 000	12 500	1.88	1.50	7.00	0.46	4.09	2 000
Tanzania	30 000	11 000	0.33	7.00	10.70	4.09	7.46	10 000
Kenya	180 000	8 500	1.53	0.00	8.40	0.00	6.87	6 000
Zaire	10 000	10 000	0.10	0.00	1.50	0.00	1.40	0
Uganda	202 000	8 000	1.62	28.70	37.00	23.83	30.51	9 120
Ethiopia	2 220 000	9 000	19.98	0.00	80.10	0.00	60.12	23 160
Eritrea	150 000	11 000	1.65	0.00	2.20	0.00	0.55	15 124
Sudan	2 750 000	14 000	38.50	117.10	55.50	90.63	31.13	1 935 200
Egypt	4 420 000	13 000	57.46	55.50	rest to sea	31.13	minus26.33	3 078 000
Sum of countries	10 192 000		124.08					5 078 604
Total for Nile basin	< 8 000 000							

Environmental and socio economic considerations
Irrigation has contributed to poverty alleviation and food security, but the sustainability of irrigated agriculture is questioned, both economically and environmentally. To ensure a sustainable project, funds for maintenance should be available, and the project should be environmental and social embedded. Large scale irrigation project can change the hydrological situation, which may cause groundwater drop, reduced downstream water supply, pollution, erosion, waterlogging, salinization and increased nutrient levels. Water-related diseases which are commonly associated with the introduction of irrigation should be considered as well.
The construction of an irrigation scheme could have numerous of social impacts, which have to be considered in terms of equity, ownership and poverty to develop a sustainable area.

Climate fluctuations may influence the possibilities for irrigation development. In this study this is not taken into account.
In regions where the irrigation is most important for agriculture, between 60% and 100% of the potential is already irrigated. Most of the potential is located in humid areas.
It is estimated that over 50% form the current irrigation schemes need rehabilitation if they are to be managed to the maximum of their potential.

FAO Aquastat survey (2005) *Irrigation in Africa in figures*.
This comprehensive report presents the most recent information available, up to 2005, on water availability and its use on the African continent, with an emphasis on agricultural water use and management. *It analyses the changes that have occurred since the first survey in 1995.*
Many terms related to water and irrigation have been defined.

Sutcliffe, J. V., Y. P. Parks. (1999) The hydrology of the Nile. IAHS Special Publication no. 5

Compared to the size of the Nile basin the total flow is relatively small. Higher precipitation is associated with mountainous areas.

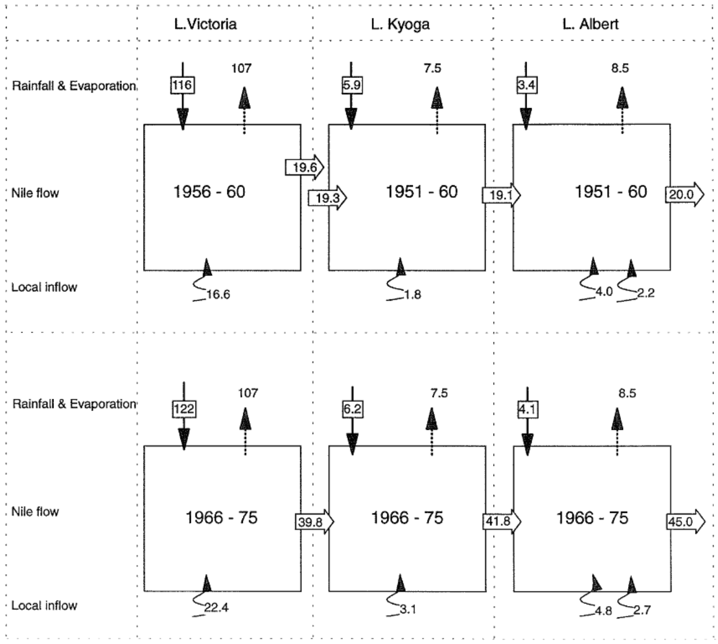


Table 9: Schematic balance of Lake Victoria, Kyogo and Albert, Km^3 year^{-1}

The furthest tributary to the Nile is the Kagera, which drains the mountain areas of Burundi and Rwanda, into Lake Victoria. A number of tributaries drain the forested escarpment to the northeast of the lake. Other less productive water courses drain the plains of the Serengeti to the southeast of the lake and the swamps of Uganda to the northwest. From Lake Victoria the flow continues towards the north, and reaches Lake Kyoga. This lake is essentially a grass-filled valley. Through swamps the Kyoga Nile flows towards the west into Lake Albert. The lake also receives the inflow of the river
Semliki, draining Lake Edward, Ruwenzori and other mountains. The Albert Nile leaves the lake at its northern end and flows towards Juba and Mongalla. In the reach between Lake Albert and Mongalla the river receives seasonal runoff from a number of streams known as the torrents; these provide the high flows of the river following the single rainfall season. Within the Sudd the higher flows spill from the main channel into swamps and seasonally flooded areas. Evaporation from the flooded areas greatly exceeds rainfall. The effect of this spilling is that the outflow from the swamp is only about half the inflow and has little seasonal variation. At Lake No the Bahr el Jebel turns east and becomes the White Nile, and the Bahr el Ghazal flows into the lake from the west. The Bahr el Ghazal basin is relatively large and has the highest rainfall of any basin within the Sudan. However, the flows of the various tributaries of the Bahr el Ghazal are spilled into seasonal and permanent swamps, and virtually no flow reaches the White Nile.
This research describes the hydrological situation for every river section, lake or contributory. Possibilities to increase river flow are discussed. Examples include the Jonglei canal, and measures to reduce evaporation from the swamps.

You, L. et al (2010) – What is the irrigation potential for Africa? A Combined Biophysical and Socioeconomic Approach. IFPRI discussion paper 00993

Although irrigation in Africa has the potential to boost agricultural productivities by at least 50 percent, food production on the continent is almost entirely rainfed. The area equipped for irrigation, currently slightly more than 13 million hectares, makes up just 6 percent of the total cultivated area. Eighty-five percent of Africa's poor live in rural areas and mostly depend on agriculture for their livelihoods. As a result, agricultural development is a key to ending poverty on the continent. Many development organizations have recently proposed to significantly increase investments in irrigation in the region. However, the potential for irrigation investments in Africa is highly dependent upon geographic, hydrologic, agronomic, and economic factors that need to be taken into account when assessing the long-term viability and sustainability of planned projects. This paper analyses large, dam-based and small-scale irrigation investment needs in Africa based on agronomic, hydrologic, and economic factors. This type of analysis can guide country- and local-level assessment of irrigation potential, which will be important to agricultural and economic development in Africa.

Food production in the NEL basin is almost entirely rain fed. Although the water resources are ample the variability is high, and the water is spread over a wide range of agro-ecologic zones. Due to irrigation the yield can easily double compared to rain fed agriculture. For this reason irrigation is considered a main cornerstone for agricultural development and rural poverty reduction.
About three percent of the cultivated area is equipped for irrigation, which is about 11 percent of the irrigation potential for the NEL countries.

This study has been carried out in five steps:
1. The assessment of the production geography, existing and potential performance of irrigated agriculture is done with the SPAM model.
2. Calculation of the potential runoff that could be used for small-scale irrigation. Attention has been paid to the interaction between crop water needs, rainfall during the cropping season, and excess rainfall throughout the year. These factors determine the potential for yield increases. Calculated with a hydrological model.
3. Identification of the potentially irrigable areas and associated water delivery costs. All dam and potential dams are mapped, as they assume 30% of dam storage available for large scale irrigation purpose. Rehabilitation of existing dams could play an important role for irrigation. The identification of irrigable areas is based on geographical issues, rather than physical aspects. Assumed is that small scale irrigation does not have any delivery costs. The cost for large scale irrigation, combined with water storage is calculated.
4. The annual net revenue due to irrigation expansion is maximized across potential areas and crops. The experience with irrigation is taken into account together with the investment potential for each country.
5. The internal rates of return (IRRs) to irrigation are calculated. These results show that the IRR is quite high (7%) in Kenya and probably Sudan, for the other NEL countries this number is much lower at about 2%.

This mainly economic report tries to give a better understanding of the conditions under which irrigation investments will yield their full potential. According to You et al. it is important to ensure that planned investments do not surpass a country's financial capacity and that investments are proportional to other agricultural expenditures and value added.
The investments can be based on pure economic considerations, such as maximizing yields and profits. Another approach could be to secure food to all countries, or to limit the area for instance by targeting the poorer regions.
Investment decisions seldom depend on physical or economical criteria alone. Other non-irrigation related factors, like policies, drinking water, energy, rural development or donor suggestion may play an important role. Furthermore, irrigation is one of more productivity improving measures. Other measures

include fertilizer use, advanced seed delivery systems, postharvest processing facilities, and access to markets.

Other studies

Allen, Richard G. et al. *Crop Evapotranspiration (guidelines for computing crop water requirements)* FAO Irrigation and Drainage Paper No. 56

This study provides a methodology to calculate the reference evapotranspiration in a more accurate manner as has been done since the publication of FAO Irrigation and Drainage Paper No. 24 in 1977.

Beyene, T., D. P. Lettenmaier and P. Kabat. (2007) *Hydrologic Impacts of Climate Change on the Nile River Basin: Implications of the 2007 IPCC Climate Scenarios*.

A multimodel ensemble method is used to asses climate change inducted changes in hydrology, for the IPCC's A2 and B1 scenarios.

Precipitation is expected to increase up to 117% till 2040 compared to 1950-1999, and from 2040-2100 the average will be below 100% of the reference period.

Camberlin, P. (1996) *Rainfall Anomalies in the Source Region of the Nile and Their Connection with the Indian Summer Monsoon*. Journal of Climate Volume 10.

The author examines both the interannual and intraseasonal variabilities of the July–September rains and compares them to the Indian summer monsoon. Analysis shows that a direct statistical link exists between monsoon variations in these two regions, independent of the Southern Oscillation.

Camberlin, P. (2009) *Nile Basin Climates*.

The climate is characterized by a gradual transition between the dry north of Sudan and the increased monsoon precipitation south in the Nile basin.

The interannual climate variation is strong, but is only indirect influenced by El-Nino. Furthermore, the NEL region can be characterized by the occasional very wet years. (e.g. 1961, 1997)

Conway, D. and M. Hulme (1993) *Recent fluctuations in precipitation and runoff over the Nile Sub-basins and their impact on main Nile discharge.* Climatic Change 25

FAO (2003) *Review of world water resources by country.* Water Reports 23.

This review, based on climate and hydrological data sets, of the renewable resources per country presents an overview of the physical internal and external water resources in the current situation. An attempt is made to estimate the exploitable water resources per country.

Inocencio, A. et al. (2005) *Costs and Performance of Irrigation Projects: A Comparison of Sub-Saharan Africa and Other Developing Regions.* IWMI research report 109

This study aims to establish systematically whether costs of irrigation projects in SSA are truly high, determine the factors influencing costs and performance, and recommend cost-reducing and performance-enhancing options. Among other recommendation special attention should be paid to the size of the irrigation schemes, the type of crops grown, the farmer's involvements and the integration of irrigation projects. The high failure rate of irrigation projects in SSA contributes to the fact that irrigation projects in SSA are more expensive than those in other developing regions.

Kay, M. (2001). *Smallholder irrigation technology: Prospects for Sub-Saharan Africa.*

Experience in sub-Saharan Africa has shown that successful smallholders generally use simple technologies and have secure water supplies over which they have full control. The most successful technologies are those that improve existing farming systems rather than those that introduce radically new ideas.

Speeding up development does not necessarily mean building irrigation schemes faster but building many more of them. An important lesson learned over the past 20 years is that smallholder schemes develop through a slow incremental process of improvement, usually in response to farmer demand. Unfortunately this is at odds with the way in which most donor and government agencies work to specific time schedules.

Mohamed, Y. A., B. J. J. M. van den Hurk, H. H. G. Savenije, and W. G. M. Bastiaanssen. (2005) ***Hydroclimatology of the Nile: results from a regional climate model.* Hydrol. Earth Syst. Sci. Discuss: 2.**

A regional climate model is applied in order to reproduce the regional water cycle as close as possible. Observations on runoff, precipitation, evaporation and radiation have been used to evaluate the model results.

Probst, J.L. and Y. Tardy. (1987) *Long range streamflow and world continental runoff fluctuations since the beginning of this century. Journal of Hydrology, 94*

Rosegrant, M.W. and N. D. Perez. (1997) *Water resource development in Africa: a review and synthesis of issues, potentials, and strategies for the future.* EDTP discussion paper no.28.

This literature review examines how water resources development and water policy reform can be deployed to address the twin problems of food insecurity and water scarcity in Africa.
Agricultural water use accounts for approximately 85% of the water withdrawals municipal for 14% and industrial for 3%. The total makes up about 2,5% of the internal water resources in eastern Africa region.
Several policy reforms can stimulate and contribute to efficient water (re)use.

Svendsen M., M. Ewing and S. Msangi. (2009) *Measuring Irrigation Performance in Africa.* IFPRI Discussion Paper 00894

This research for Sub-Saharan Africa looks at six indicator categories — *institutional framework, water resource use, irrigation area, irrigation technology, agricultural productivity, and poverty and food security* — to assess the potential for improving performance in the agricultural food security sector through increasing irrigation sector investments. With these indicators a baseline is set to assess the improvements in the irrigation performance with extra investments.
Average groundwater utilization in Sub-Saharan Africa is less than 20 percent of renewable supplies. Groundwater is a resource particularly well suited for small-scale irrigation and for multiple-use systems.

Tate, E., J. SUTCLIFFE, D. CONWAY, F. FARQUHARSON. (2004) *Water balance of Lake Victoria: update to 2000 and climate change modelling to 2100.* Hydrological Sciences 49.

Change in precipitation and to a lesser extent temperature over the Nile basin, could have serious consequences on regional water resources throughout the basin. To understand runoff the processes of precipitation and evapotranspiration should be understood first.

Taye, M. T., V. Ntegeka, N. P. Ogiramoi, and P. Willems (2011) *Assessment of climate change impact on hydrological extremes in two source regions of the Nile River Basin.* Hydrol. Earth Syst. Sci., 15.

Yates, D. N., and K. M. Strzepek. (1998) *Modeling the Nile basin under climate change.* Journal of hydrologic engineering.

A monthly water balance model is used to assess the potential climate change impacts on Nile runoff. Almost all models give a significant increased discharge for the NEL region.

You, L. et al. (2007) *Generating Plausible crop distribution and performance maps for Sub-Saharan Africa using a spatially disaggregated data fusion and optimization approach.* IFPRI discussion paper 00725

Modelling the spatial distribution of 20 cash crops.

Country specific studies

Burundi

- Ntamavukiro, A. (2007) Rapid baseline assessment of agricultural water in Burundi. EWUAP project, Nile basin Initiative. (French)
- Niyongabo, H. (2007) Best Practices in Water Harvesting and Irrigation in Burundi. EWUAP project, Nile basin Initiative.
  - In this UWUAP report Burundi is divided in 5 agro ecological zones. 1.57% of the total irrigable area is currently under irrigation, of which most is situated in the IMBO plain. Irrigated area has grown from 3000ha in 1960 till around 17000ha in 2008. More than 80% of the irrigation consists of rice irrigation and the other 20% is mad up by food crops like tomatoes, onions, corn and potatoes. There is hardly any diversification in irrigation techniques; nearly all irrigation is done by gravity, mostly by flooding. Energy deficit doesn't allow for mechanization and modern techniques.
    Multi-criteria analysis are carried out to assess the used technologies and the sites with a high potential for irrigation.
    Water harvesting for irrigation purpose is not commonly used in Burundi, although new initiatives are emerging. Four sites are known were runoff is stored in artificial ponds to irrigate in the dry season. Water harvesting for domestic use is more common.
    The terrain is a limiting factor for irrigation, as irrigation in mountains is almost non-existent. However, irrigation in marshes is increasing.
    Points of attention are: stagnant water to cause diseases; cattle destroy canals in search for food left after harvesting or soil compression by cattle. Competition for water is a serious issue is some places as well as erosion.
    A major challenge is to make irrigation systems sustainable in all aspects, such as management, farmer involvement and design as deficient maintenance and vandalism are reported.
    A list of actors is included.

Eastern DRC

- Lessime, N. Best Practices in Water Harvesting and Irrigation in DR. Congo EWUAP project, Nile basin Initiative. (French)

Kenya

- Blank, H.G. et al. (2002) The changing face of irrigation in Kenya: Opportunities for anticipating changes in eastern en southern Africa. IWMI.
- Kenyan government (2010) Agricultural sector development strategy 2010-2020.
- Kenyan government, ministry of water and irrigation (2009) Irrigation and drainage master plan.
- Mburu, D. (2008) Best Practices in Water Harvesting and Irrigation. EWUAP project, Nile basin Initiative.
  - The FAO decided on seven agro-climatic zones for Kenya. Combined with the six main agro-ecological zones these results in a large number (71) of sub-agro-ecological zones.
    A diversity of water harvesting techniques are discussed and classified as in which agro-climatic zone they are most commonly practiced. Furthermore a criterion based ranking of the different water harvesting techniques gives a clear overview of the best techniques per agro-climatic zone. For zone 1-3 bench terraces are most suitable and for zone 4-7 the sand dams are ranked best.
    Over 80% of the irrigation methods are made up of furrow or basin irrigation. Half is fed by gravity, the other half is pumped. In the list of best practiced

irrigation method the gravity fed sprinkler is ranked first, followed by drip irrigation. The best practices sites are ranked as well.
The greatest challenge in Community Managed Irrigation (CMI) is lack of stable and organized market. Gravity fed systems proved to be more sustainable than pumped systems.

- Ngigi,. S.N. Review of Irrigation Development in Kenya. University of Nairobi.
- Sijali, I.V. (2007) Rapid baseline assessment of agricultural water in Kenya. EWUAP project, Nile basin Initiative.
    - The EWUAP project is mandated to bring together the regional and national stakeholders in the riparian countries to develop a shared vision on common issues related to the increase of the availability of water and its efficient use for agricultural production.
    - Development of the irrigation sector in Kenya is still very low as indicated by the small percentage of the developed potential. In addition, a substantial proportion of the developed schemes are performing poorly due to poor system operation and maintenance and weak farmers' organizations. Irrigation development in the Lake Victoria basin is low with only 5% of the potential exploited. In order to accelerate, policies are being reformed. Water use efficiency could be improved significantly till over 60% by scaling up new technologies like drip and sprinkler irrigation. Land and water degradation is an issue, and should be dealt with to avoid water scarcity.
- Thurlow, J., J. Kiringai, M. Gautam. (2007) Rural Investments to Accelerate Growth and Poverty Reduction in Kenya. IFPRI Discussion Paper 00723
    - In order to meet the Milenium Development goal (MDG) to half poverty by 2015, it is necessary to accelerate agricultural growth. The increase of agricultural spending to 10 percent of total spending is insufficient to meet this MDG. Achieving this target requires nonagricultural investments, such as in roads and market development.
- UN (2005) Kenya National Water Development Report. World water assessment programme.

Rwanda

- Baligira, R. (2008) Rapid Baseline Assessment. EWUAP project, Nile basin Initiative.
    - Agriculture in Rwanda is executed on all land types, including on land of marginal quality and on moderate to steep sloping hillsides. In large parts, soils are originally fertile, and the bimodal rainfall makes two crops a year possible, with a third crop grown in the bottom valley and drained marshlands. Due to the slopes soil erosion conservation measures are needed. Rwanda's National Agricultural Commission estimated that half the country's farmland suffers from moderate to severe erosion. Demographic pressure is driving soil degradation in Rwanda.
      The country's main exports remains tea and coffee and, to a lesser extent, pyrethrum extract.
      Main constraints for agriculture are: the very steep slopes (50% of fields have a slope gradient above 35%), uncontrolled deforestation which leads to erosion, and the population growth which causes over-farming.
      In large areas the top soil layer is relatively thin, which under present land use, can be result is a total disappearance of the fertile arable layer in less than 30 years.
      This study includes social aspect related to agriculture.
      Current fertilizer use stands on less than 2kg/farmed ha, compared to the 150kg recommended.
      All types of water resources are briefly discussed
- Nile basin Initiative. Best practices for water harvesting and irrigation. EWUAP project, Nile basin Initiative.
    - A description of all 12 agro-ecological zones is given. Criteria to assess the best practices are discussed, and irrigation sites mentioned.

Some gaps are noted, as a recommendation is given to carry out a study to asses the water resources per watershed. In addition the soil fertility should by monitor in order to note changes and adopt cropping pattern. Another advice is that the government thinks about a policy to stimulate private irrigation initiatives.

- Government of the Republic of Rwanda, Ministry of Agriculture and Animal Resources (2007) Action Plan for Implementation of Agricultural Rainwater Harvesting Interventions in Rwanda.
- Government of the Republic of Rwanda, Ministry of finance and economic planning (2000) Rwanda vision 2020

Sudan

- Dawelbeit, M. I. (2008) Best practices for water harvesting and irrigation. EWUAP project, Nile basin Initiative.
    - Sudan is divided in six agro-ecological zones of the Sudan according to Harrison and Jackson (1958)
      A criterion based ranking of the best practices water harvesting and irrigation areas is carries out.
- Salih, A. A. Rapid baseline assessment of agricultural water in Sudan. EWUAP project, Nile basin Initiative.
- UNESCO (2008) Case study volume: facing the challenges. World water development report 3

Tanzania

- Droogers, P., W. Bastiaanssen (2008) Irrigation Potential Lake Victoria, Tanzania.
    - This study evaluates and ranks five potential irrigation schemes in the Tanzania part of the Lake Victoria Basin. Schemes included in the analysis are Bugwema, Manonga, Isanga, Nkona and Mara Valley.
- Rwehumbiza, P. (2007) Best practices for water harvesting and irrigation. EWUAP project, Nile basin Initiative.
    - The agricultural sector is very much affected by inadequacy, seasonality, and unreliability of rainfall as well as periodic droughts.
      The three highly ranked RWH practices are bunded field plots (*jaluba*), spate irrigation, and *ndiva* in first, second and third position respectively. The second and third ranked practices are well adopted in the best site.
- Sisila, S. Rapid baseline assessment of agricultural water in Tanzania. EWUAP project, Nile basin Initiative.
    - This study addresses some general constraints for agriculture and for community managed irrigation schemes. General constraints include: poor rural infrastructure and market access, low investments in irrigation and the decline of the use of improved seeds, fertilizer and agrochemicals. Constraints for the community managed irrigation schemes mainly focus on management issues like: leadership, management formation and irrigation knowledge.
      Strategies to address these constraints focus on a proper project planning and documentation, to contribute to a good interaction between science and practice and to stimulate good management.
- Tanzanian government, ministry of water and irrigation. (2009) The national irrigation policy.
- Tanzanian government (2005?) Agricultural sector development programme (ASDP)

Uganda

- Iwadra, M. (2007) Best practices for water harvesting and irrigation. EWUAP project, Nile basin Initiative.
    - Due to the fact that farmers can produce at least one crop or two per year using rain fed agriculture, irrigation development is rather low in Uganda although the need for irrigation is becoming increasingly serious due to unreliable rainfall and the effect of global warming. Harvest could be increased by 50% or 100% or more if supplemental irrigation was used.
      The best roof water harvesting is Ferro Cement Tank (FCT) and valley tank for on stream surface runoff harvesting. These technologies are relatively cheaper to install and manage than similar category technologies. The cost of construction can be recovered in one year.
- PELUM (2010) A Review and Analysis of Agricultural Related Policies that Support Sustainable Agriculture.
- Rugumayo, A. I., N. Kiiza and J. Shima. (2003) Rainfall reliability for crop production: A case study in Uganda. Diffuse Pollution Conference Dublin 2003
- Ugandan government, Ministry of Agriculture, Animal Industry & Fisheries (2010) Agriculture Sector Development Strategy and Investment Plan: 2010/11- 2014-15.
- Ugandan government (2010) National development plan (2010/11 – 2014/15)
- UN (2005) Uganda National Water Development Report. World water assessment programme.
    - An extensive study concerning the water resources and all it sustainable uses. Key challenges per sector are given and the actions taken are mentioned.

Appendix 1: Organizational structure

Contract Details
The Nile Basin Initiative (NBI), under the Nile Equatorial Lakes Subsidiary Action Program (NELSAP) and the project Regional Agricultural Trade and Productivity Project (RATP) has 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).

FutureWater, in association with WaterWatch, has 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 at 5-Feb-2011 and total project duration is 16 months.

Nile Basin Initiative
The Nile Basin Initiative (NBI) is a partnership of the riparian states that seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security through its shared vision of "sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources". NBI's Strategic Action Program is made up of the Shared Vision Program (SVP) and Subsidiary Action Programs (SAPs). The SAPS are mandated to initiate concrete investments and action on the ground in the Eastern Nile (ENSAP) and Nile Equatorial Lakes sub-basins (NELSAP). This study falls under NELSAP.

The Nile Equatorial Lakes Subsidiary Action Program (NELSAP)
The Nile Equatorial Lakes Subsidiary Action Program has its Coordination Unit (CU) based in Kigali, Rwanda and reports to the Nile Equatorial Lakes Technical Advisory Committee (NELTAC) and the NBI Secretariat for strategic guidance. The NELTAC reports to the Nile Equatorial Lakes Council of Ministers (NELCOM). The Nile Basin Initiative (NBI) through the Nile Equatorial Lake Subsidiary Action Program (NELSAP) seeks to promote a productive water use in Nile basin agriculture.

The NELSAP through its sub basin programs implements pre-investment programs in the areas of power trade and development and natural resources management. The NELSAP-CU in partnership with the countries carries out selected preparatory initiatives that have trans-boundary implications and helps the countries to mobilize resources for project development including planning, data collection, surveys and feasibility studies. Pre-investment programs comprise specific studies of the various users of the water resources, formulation of options for water resources development taking in to account various intervening factors and users, identification of specific water resources developments integrating options, preliminary design of each project, cost benefit evaluation, preliminary Environmental Impact Assessment, comparative studies based on technical, socio-economic and environmental criteria, selection of priority projects and comparison with other sectoral possibilities. Within the pre-investment framework, the Regional Agricultural Trade and productivity Project, in concert with the

NELSAP, will promote irrigation development as a contribution towards agricultural development in the NEL Countries.

Regional Agricultural Trade & Productivity (RATP) Project

RATP is a technical assistance project financed by Canadian International Development Agency (CIDA) through a recipient-executed trust fund. The project is managed by a Project Management Unit (PMU) based in Bujumbura-Burundi, and is administratively linked to the NBI's Subsidiary Action Program for the Nile Equatorial Lakes (NELSAP), which has a coordinating unit (NELSAP-CU) based in Kigali. Although the activities of the proposed project focus on the Nile Equatorial Lakes sub-basin area, it supports generation of agricultural knowledge that is basin-wide, in line with the aims of the NBI's Institutional Strengthening Project (ISP) and NELSAP's Subsidiary Action Program.

Appendix 2: Fact sheets

BOX: FAOstat definitions

Agricultural area
This category is the sum of areas under a) arable land; (b) permanent crops - land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee); land under trees and shrubs producing flowers, such as roses and jasmine; and nurseries (except those for forest trees, which should be classified under "forest"); and (c) permanent meadows and pastures - land used permanently (five years or more) to grow herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

Arable land
This category include land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for “Arable land” are not meant to indicate the amount of land that is potentially cultivable.

Total area equipped for irrigation
Area equipped to provide water (via irrigation) to the crops. It includes areas equipped for full and partial control irrigation, equipped lowland areas, pastures, and areas equipped for spate irrigation.

Int$
International US Dollar.

MT
Metric Ton, a unit of weight equivalent to 1000 kilograms.

Source: FAO Statistics Division.

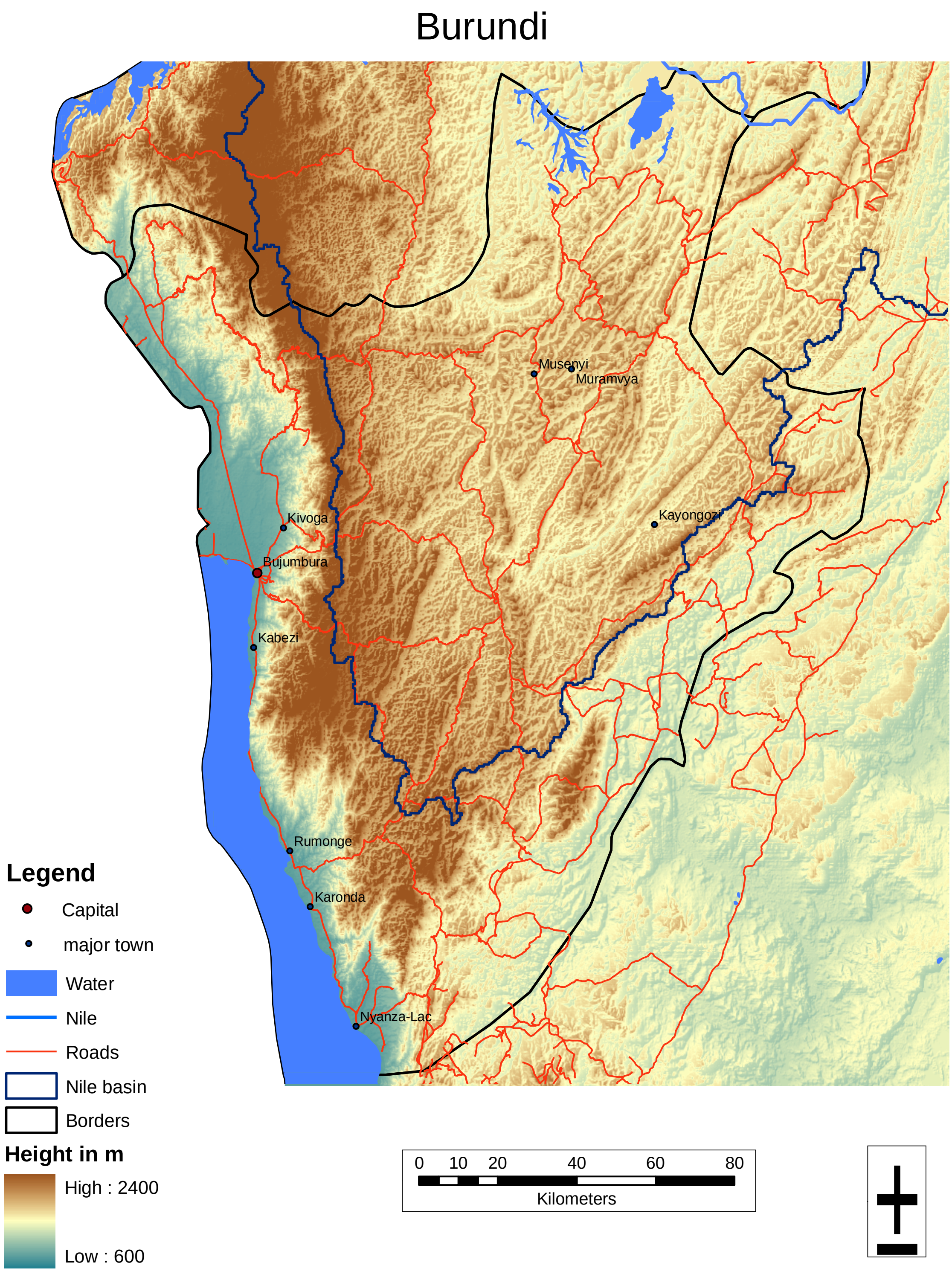


Figure 19: Map of Burundi with the Nile basin.

The following Figures and Table give a quick overview of some key facts regarding agriculture and irrigation in the country. All data are based on FAOstat and AquaStat.

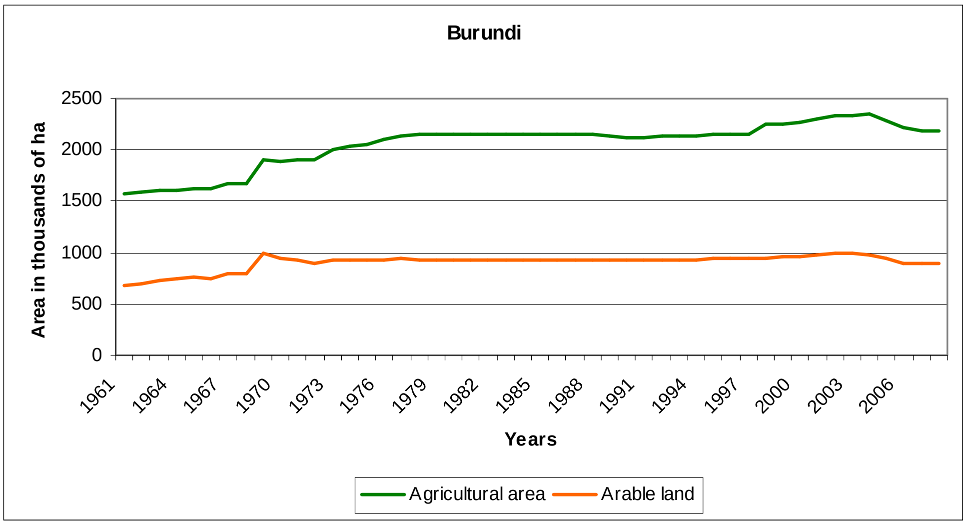


Figure 20: Agricultural area and arable land in Burundi.

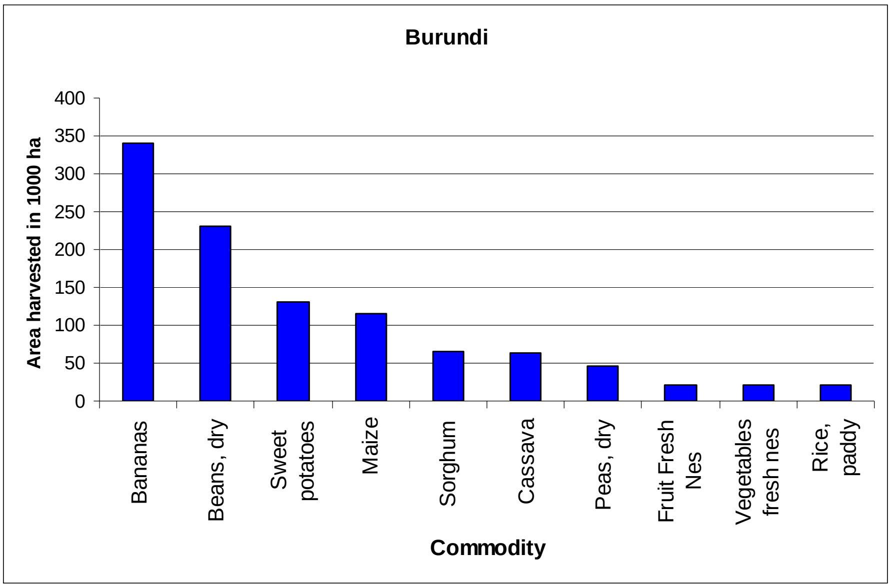


Figure 21: Agricultural production in Burundi.

Table 10: Area equipped for irrigation in Burundi.

Burundi	ha
1965	14,000
1975	14,000
1985	14,000
1995	18,000
2005	23,000

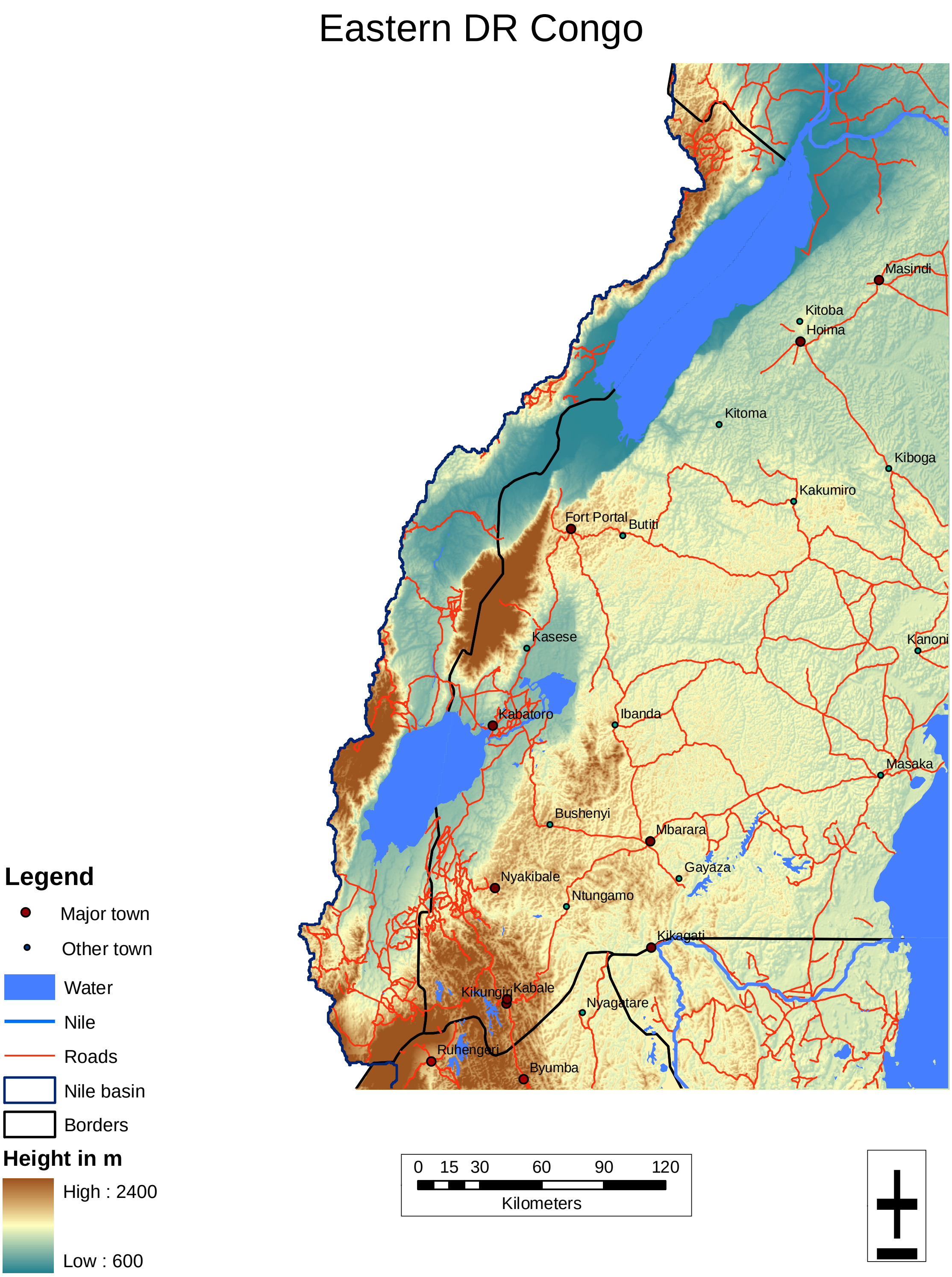


Figure 22: Map of Eastern DRC with the Nile basin.

The following Figures and Table give a quick overview of some key facts regarding agriculture and irrigation in the country. All data are based on FAOstat and AquaStat.

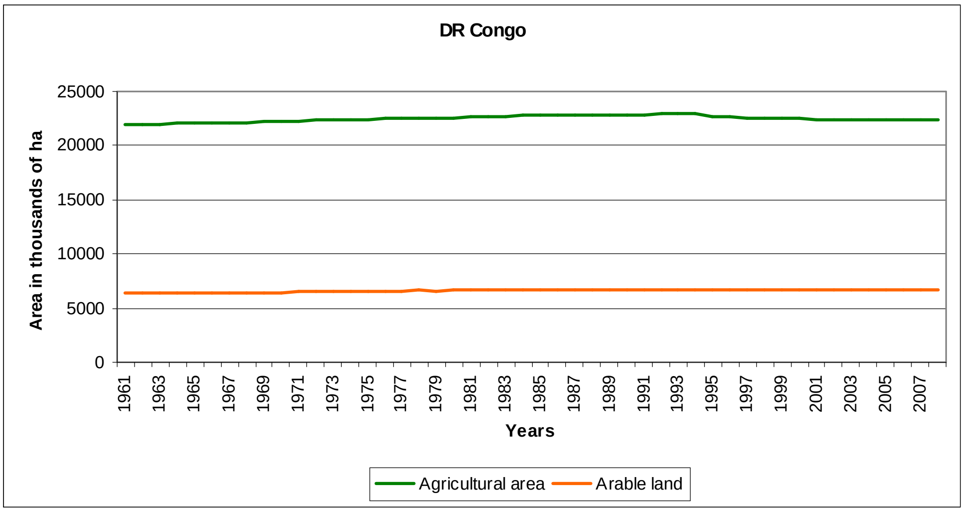


Figure 23: Agricultural area and arable land in DR Congo.

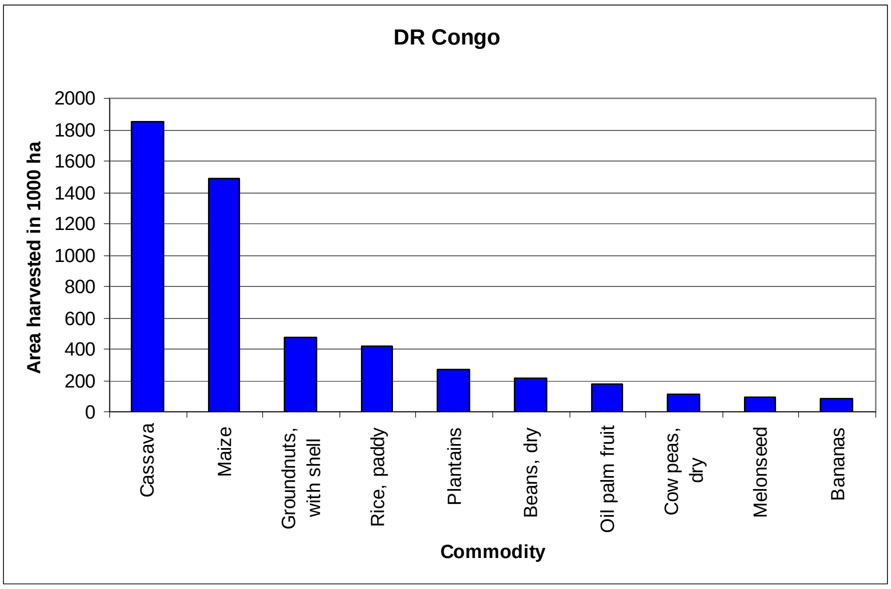


Figure 24: Agricultural production in DR Congo.

Table 11: Area equipped for irrigation in DR Congo.

DR Congo	ha
1965	N/A
1975	N/A
1985	9,000
1995	11,000
2005	11,000

Kenya

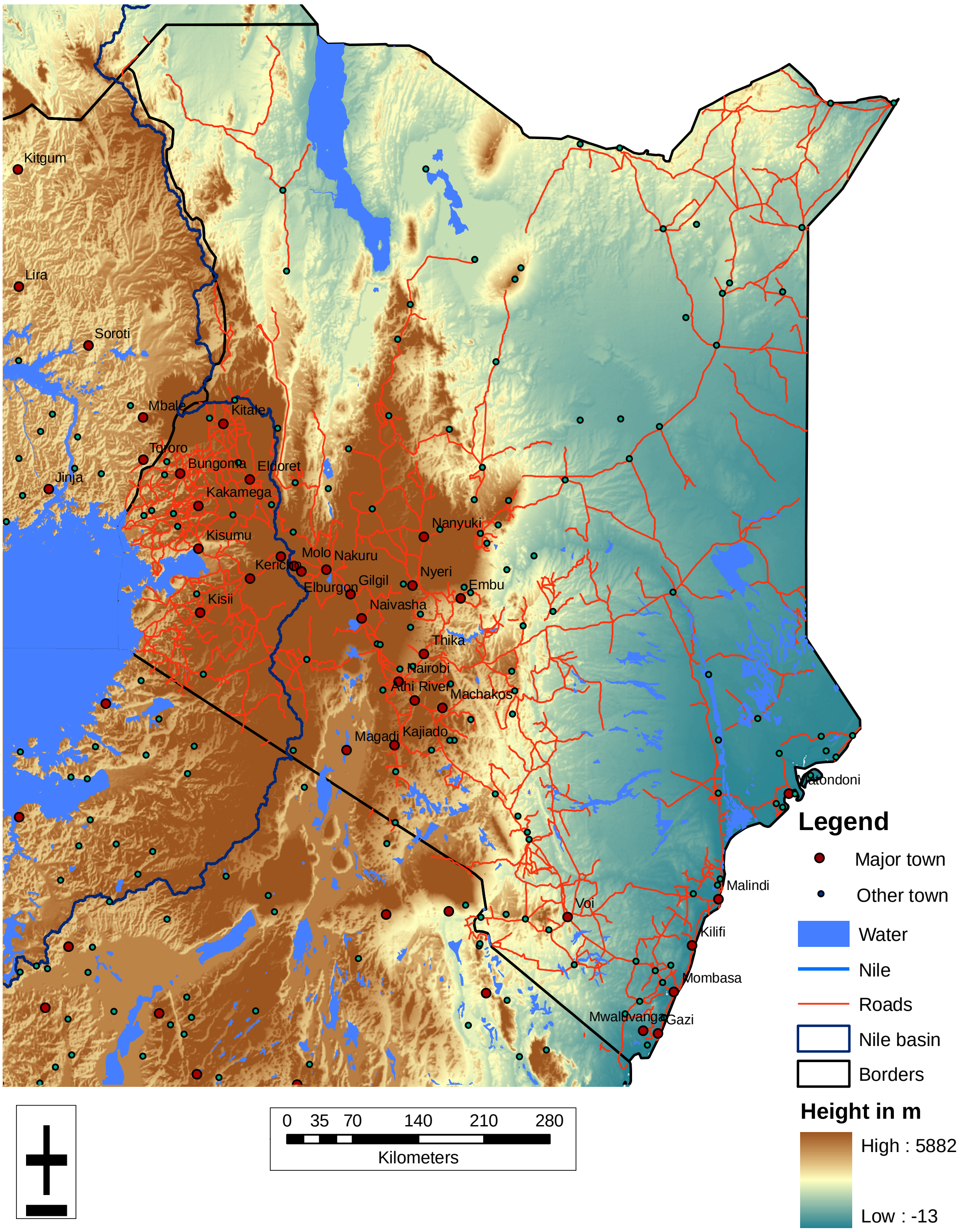


Figure 25: Map of Kenya with the Nile basin.

The following Figures and Table give a quick overview of some key facts regarding agriculture and irrigation in the country. All data are based on FAOstat and AquaStat.

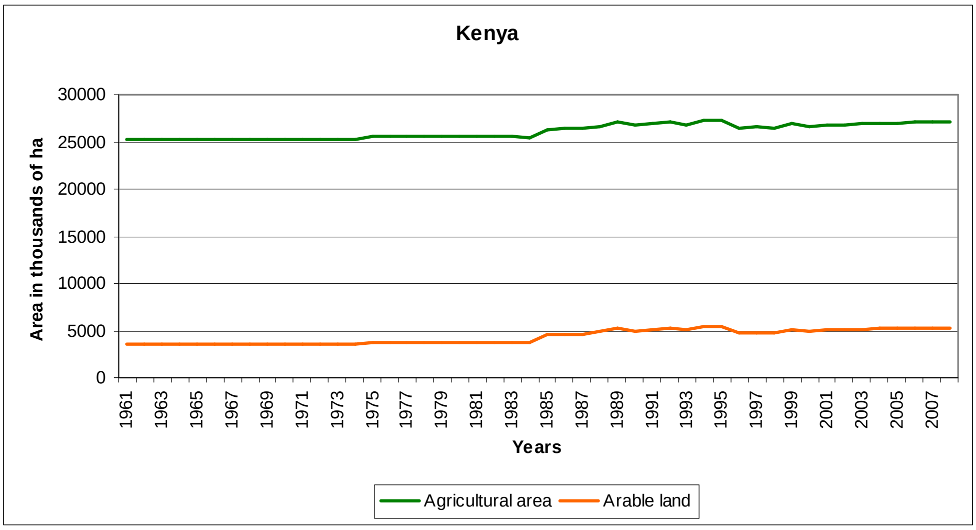


Figure 26: Agricultural area and arable land in Kenya.

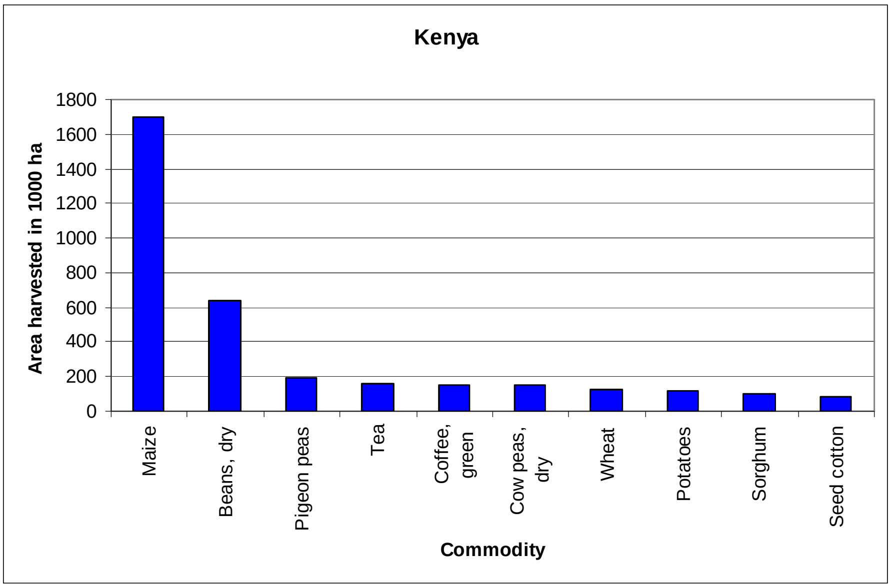


Figure 27: Agricultural production in Kenya.

Table 12: Area equipped for irrigation in Kenya.

Kenya	ha
1965	14,000
1975	40,000
1985	42,000
1995	70,000
2005	103,000

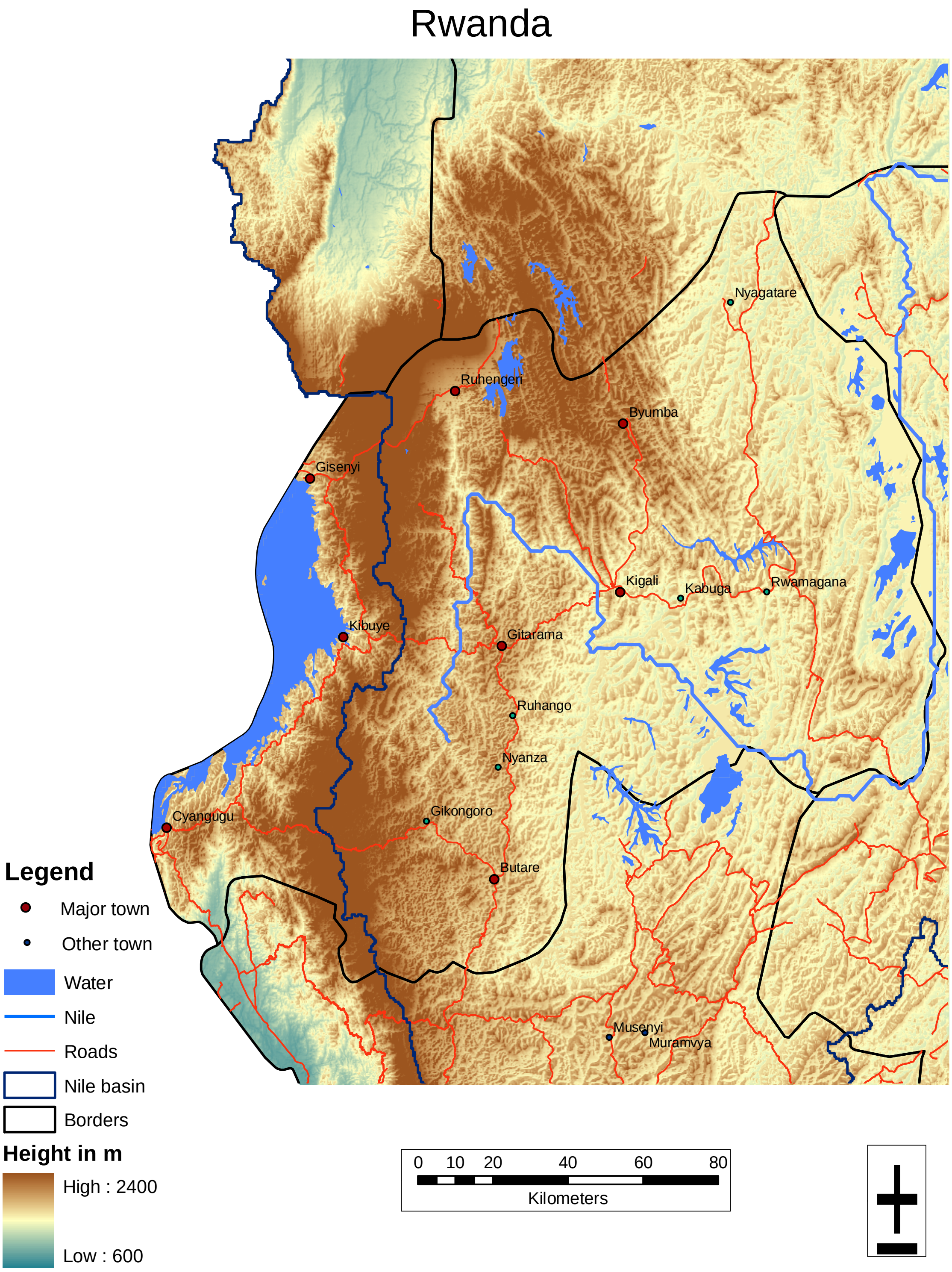


Figure 28: Map of Rwanda with the Nile basin.

The following Figures and Table give a quick overview of some key facts regarding agriculture and irrigation in the country. All data are based on FAOstat and AquaStat.

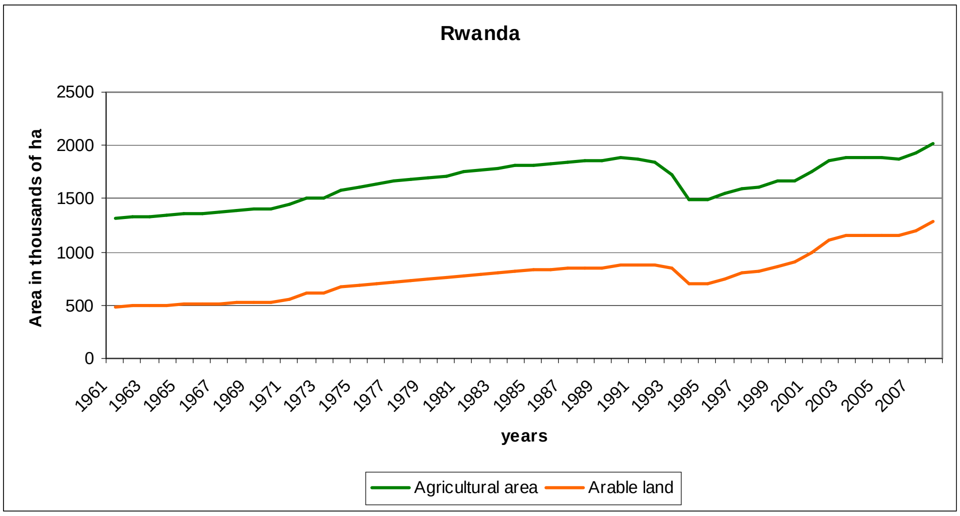


Figure 29: Agricultural area and arable land in Rwanda.

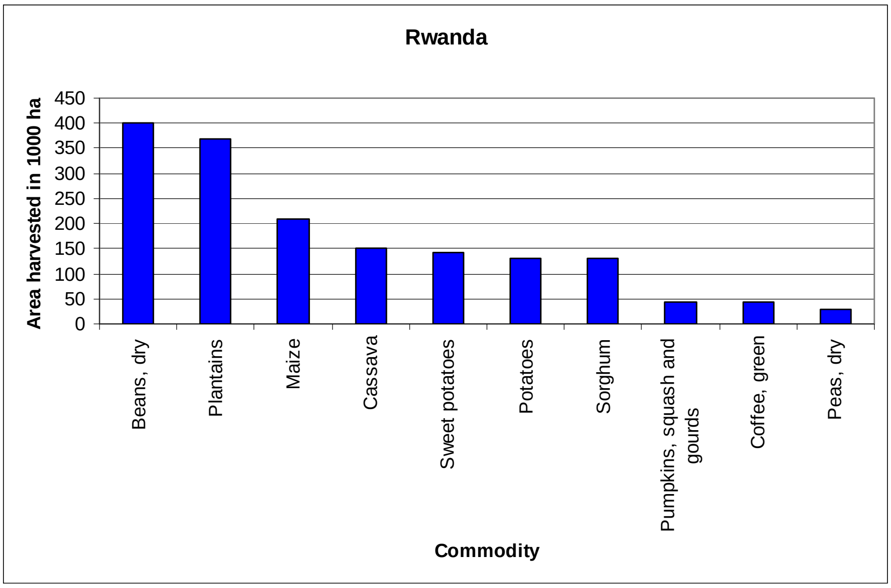


Figure 30: Agricultural production in Rwanda.

Table 13: Area equipped for irrigation in Rwanda.

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

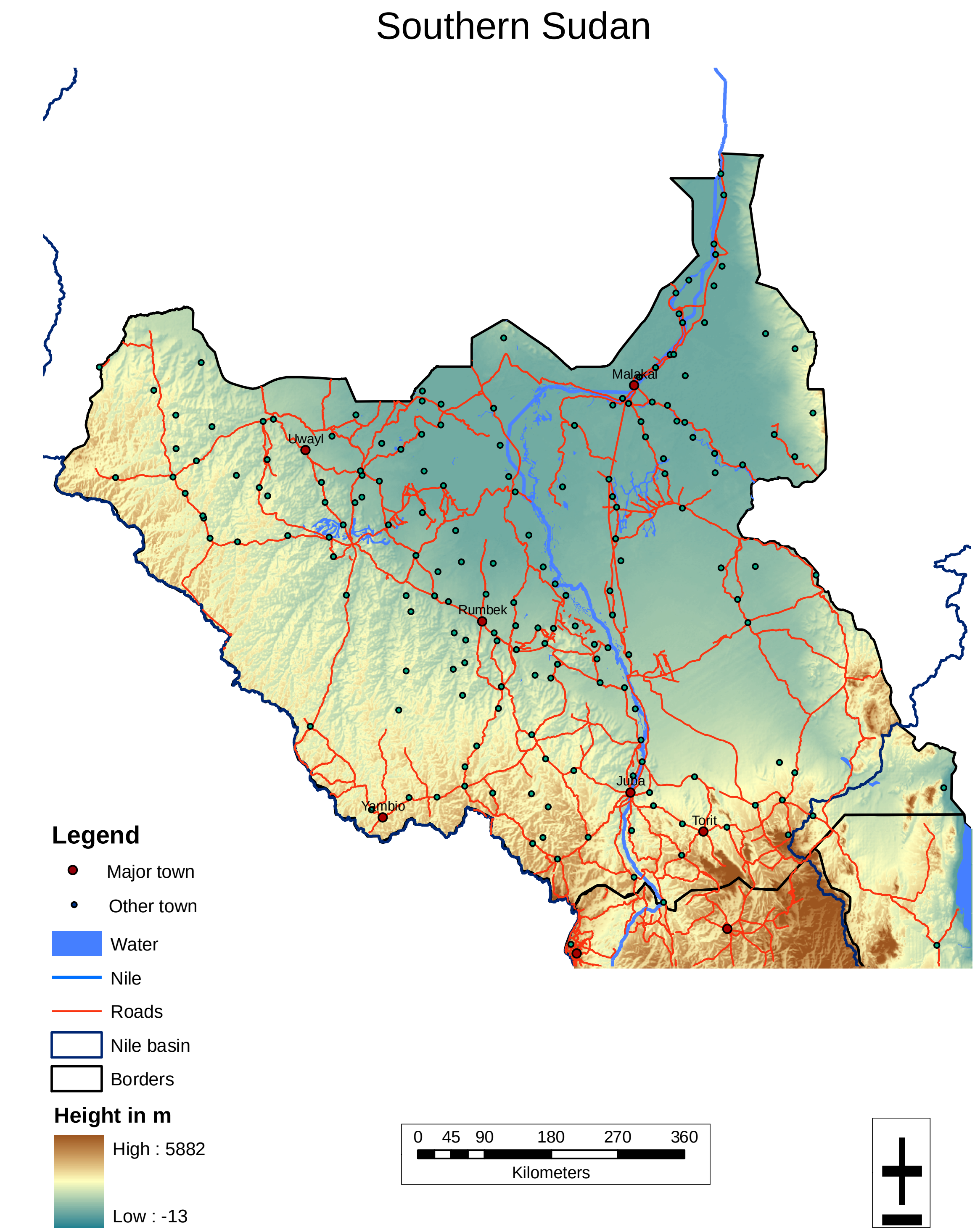


Figure 31: Map of Sudan with the Nile basin.

The following Figures and Table give a quick overview of some key facts regarding agriculture and irrigation in the country. All data are based on FAOstat and AquaStat.

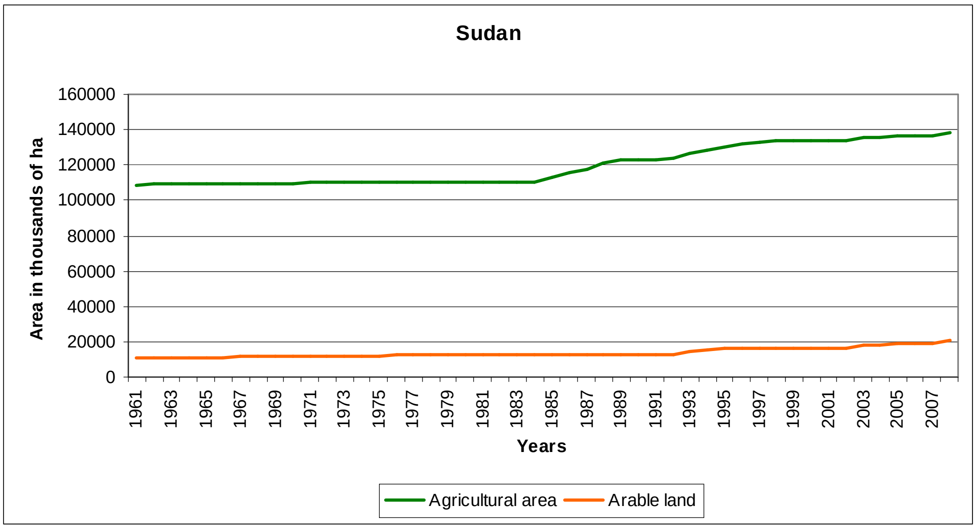


Figure 32: Agricultural area and arable land in Sudan.

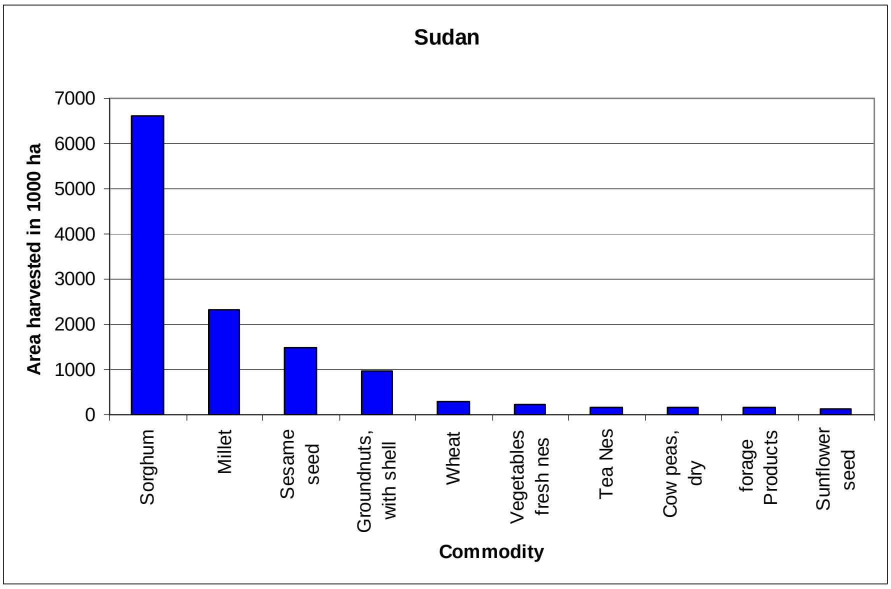


Figure 33: Agricultural production in Sudan.

Table 14: Area equipped for irrigation in Sudan.

Sudan	ha
1965	1,550,000
1975	1,700,000
1985	1,763,000
1995	1,946,000
2005	1,863,000

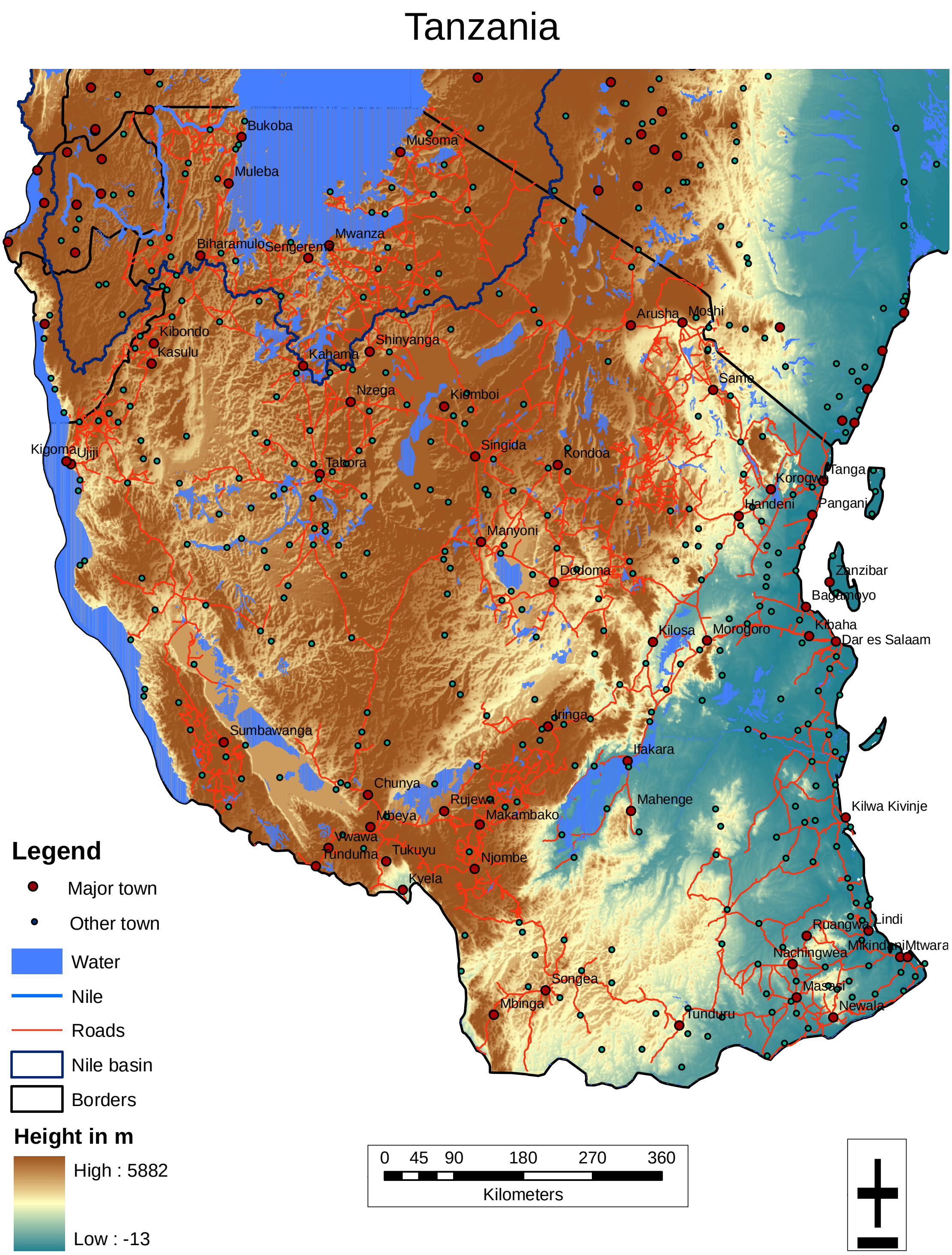


Figure 34: Map of Tanzania with the Nile basin.

The following Figures and Table give a quick overview of some key facts regarding agriculture and irrigation in the country. All data are based on FAOstat and AquaStat.

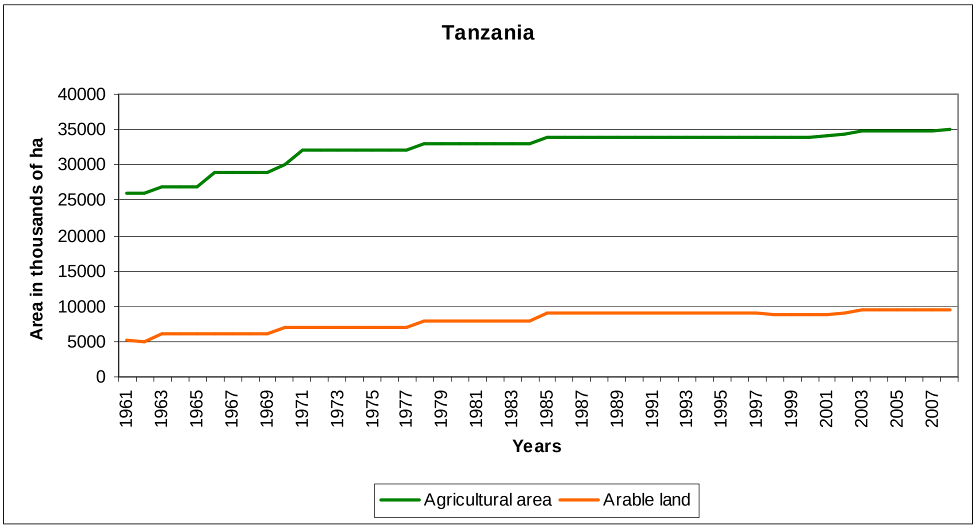


Figure 35: Agricultural area and arable land in Tanzania.

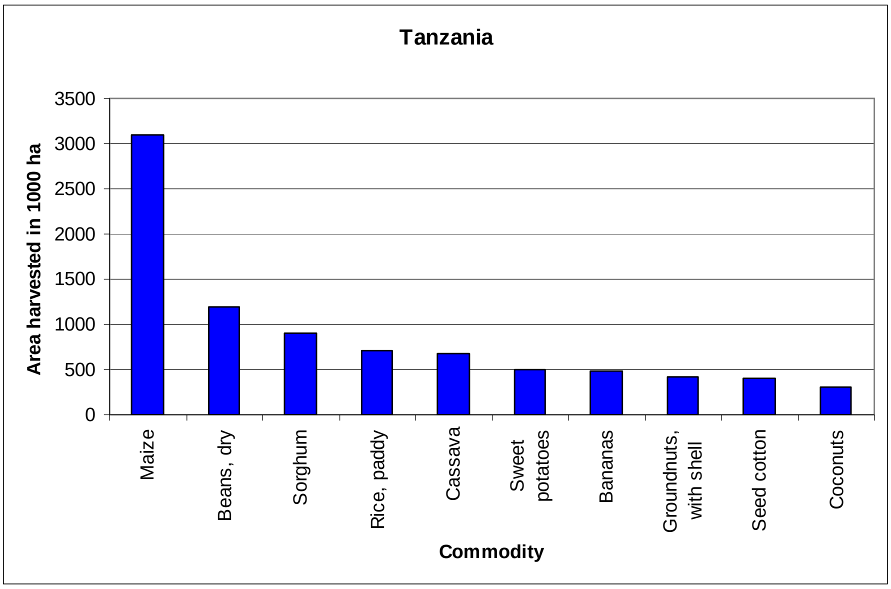


Figure 36: Agricultural production in Tanzania.

Table 15: Area equipped for irrigation in Tanzania.

Tanzania	ha
1965	28,000
1975	52,000
1985	127,000
1995	150,000
2005	184,000

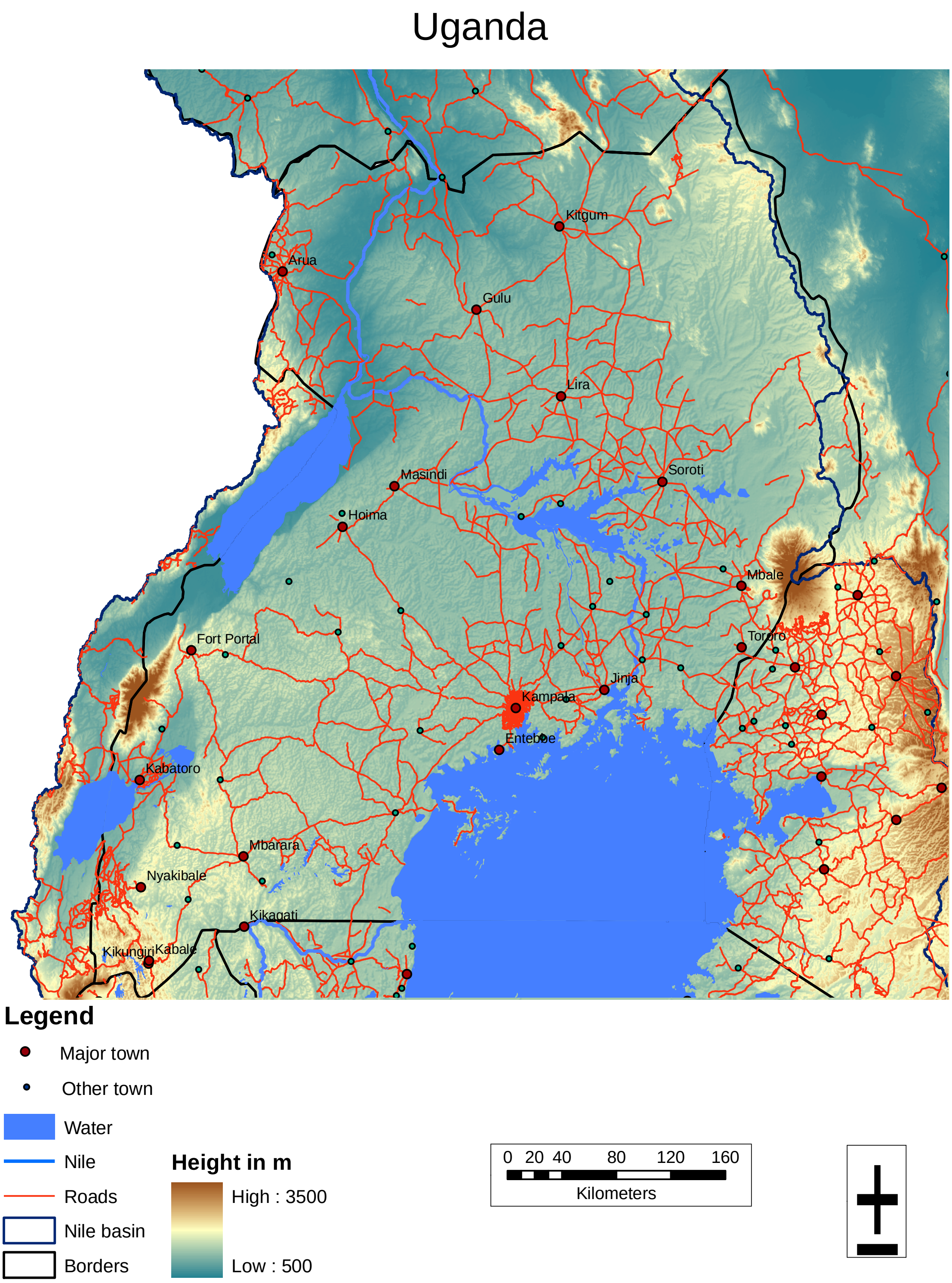


Figure 37: Map of Uganda with the Nile basin.

The following Figures and Table give a quick overview of some key facts regarding agriculture and irrigation in the country. All data are based on FAOstat and AquaStat.

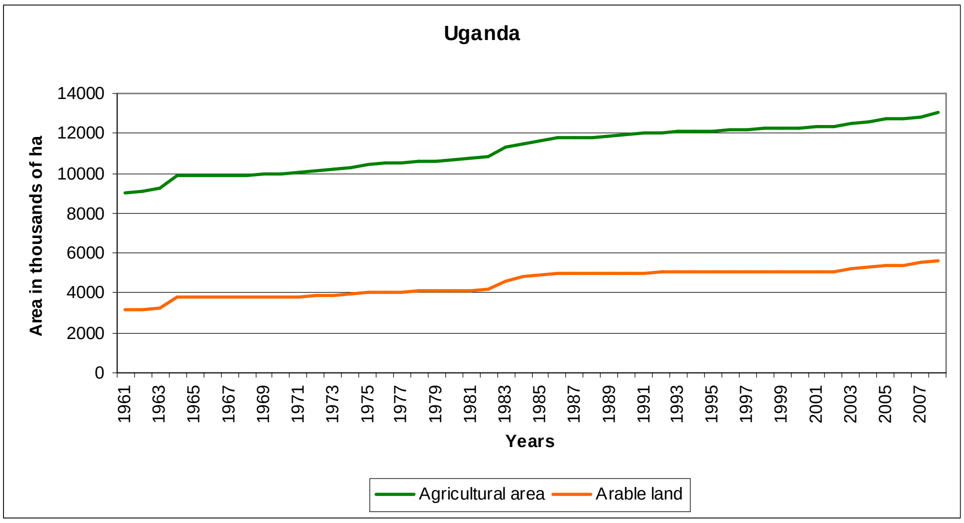


Figure 38: Agricultural area and arable land in Uganda.

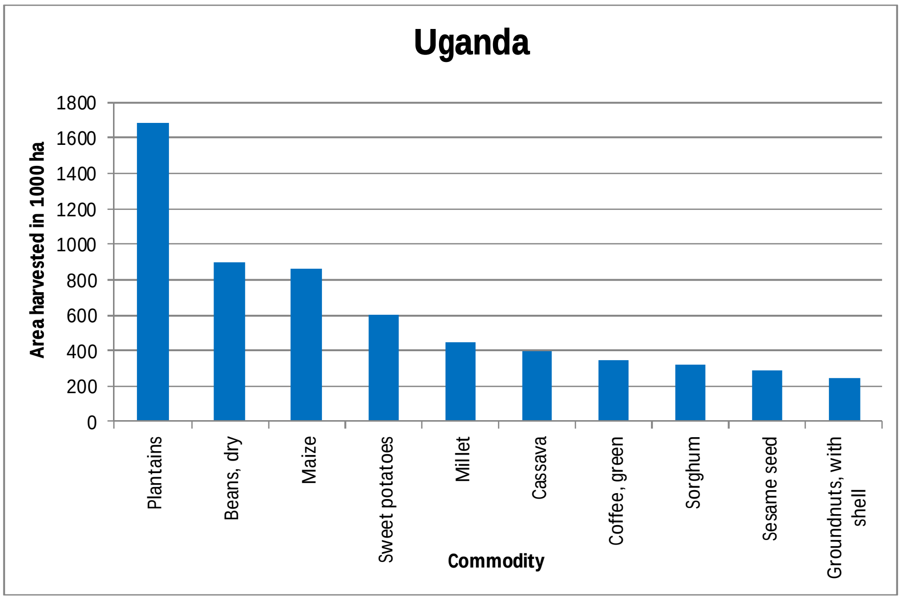


Figure 39: Agricultural production in Uganda.

Table 16: Area equipped for irrigation in Uganda.

Uganda	ha
1965	3,000
1975	4,000
1985	9,000
1995	9,000
2005	9,000

Appendix 3: Stream map with different thresholds.