GIS BASED IRRIGATION SUITABILITY ANALYSIS:

A CASE STUDY IN MALAGARAZI RIVER BASIN IN BURUNDI

A THESIS PRESENTED

BY

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3. "Contribution to the study of adaptability of eight potato genotype from CIP in three different agro-ecological areas". (April 2001, Bujumbura)

4. "Product engineering of HUBBARD race of the zootechnical station Maramvya".

DECLARATION AND COPY RIGHT

I, Gerard MANIRAKIZA, declare that this dissertation is my own original work and that it has not been presented and will not be presented to any other University for similar or any other degree award.

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ABSTRACT

Title: GIS based irrigation suitability Analysis: A case study in Malagarazi river basin in Burundi

The agriculture in Malagarazi sub basin (Eastern part of Burundi) is currently dependent on rainfed system with limited use of irrigation. Highly variable and erratic rainfall and lake of means to store water in Malagarazi sub basin has contributed to drought and chronic food shortages. Declining productivity in rainfed agriculture and rapid increase of population, land degradation, and land scarcity problem are the factors contributing to food problems in the area. To reduce the current intensified food shortage and poverty in Malagarazi sub basin, there is a need of strategies that can support the efforts of ensuring food security in the basin. Irrigation development was found to be best strategic option to ensure food security. The aim of this research is therefore, to investigate and identify potential irrigable area using the existing resources such as land and water resources with the aid of geographic information system (GIS). The total identified irrigable area for Malagarazi sub basins is 651ha, 849.5ha, 750ha and 520 ha for Rukoziri, Muyovozi, Rumpungwe and Mukazye sub-basins respectively. The overall identified potentiial irrigable area in the basin is in the order of 829.5 ha. The total available irrigation potential can not be developed with the available water. Thus, storage is essential. It can be concluded that the identified suitable area for irrigation in Malagarazi sub basin is 2,770.5ha. This potential irrigable area, combining with development technology, can help the population of Malagarazi sub basin which is largely rural and dependent on agriculture for their livelihoods. It will reduce the chronic malnutrition, poverty, hunger and increase agricultural production.

Key words: GIS; Irrigation; Malagarazi, Burundi

LIST OF ABBERVIATION AND ACRONYMS

ATP	Applied Training Project
°C	Degree centigrade
CROPWAT	Crop Water (FAO Software)
CWR	Crop Water Requirement
DEMs	Digital Elevation Model
ETo	Reference Evapotranspiration
ETm	Maximum Evapotranspiratin
ESP	Exchangeable Sodium Percentage
FAO	Food and Agricultural Organisation
FDC	Flow Duration Curve
GIS	Geographic Information System
GIWR	Gross Irrigation Water Requirement
GTZ	German Technical Co-operation
IGEBU	Institut Géographique du Burundi
ISABU	Institut des Sciences Agronomiques du Burundi
Km^2	Kilometers square
m	meter
M^3/s	Meter cube per second
mm	Millimeter
NBI	Nile Basin Initiative.
NIWR	Net Irrigation Water Requirement
PDNE	Plan Directeur National d 'Eau
REGIDESO	Régie de Distribution d'Eau et d 'Electricité
RAM	Readily Available Moisture
SOSUMO	Société Sucrière de Mosso
TAM	Total Available Moisture
TIN	Triangulated Irregular Network

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1. INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

Burundi is facing the problem with regards to increasing agricultural productivity so as to be able to nourish an unceasingly increasing population. The solution for this problem includes deep reforms of the traditional methods of agricultural production by introduction and popularization of the modern techniques. Agriculture engages 94% of the working population in Burundi. Agriculture is sedentary and relatively intensive in work. The farmers exploit in an individual way the private landholdings, which are allotted to them according to the common law.

The Burundian agriculture is currently dependent on rain fed system with limited use of irrigation. Highly variable and erratic rainfall and lake of means to store water put Burundi at risk of drought and chronic food shortages. Declining productivity in rain fed agriculture due to the rapid increase of population, land degradation, and land scarcity problem are the factors contributing to food problems in the country. Therefore, to alleviate the above problems and to increase food production in the future, effective and efficient irrigation development will be needed (Nsanzumuganwa, 1988)

Generally, to reduce the current intensified food shortage and poverty in the country and graduate from food aid, with the rapid increase of population and land scarcity problem, there is a need of strategies that can place food security as top priority. One of the strategies for food security is agricultural production growth in general and irrigation development in particular. Irrigation is inventively the most appealing solution of crop production by supplementing rain fed agriculture in marginal and drought prone areas of the country. On the other hand, planning for the development of irrigation requires the knowledge of the available potential irrigable areas in the country. So far there is no such detail information in some regions of the country.

Hence, the purpose of this research is primarily to fill the information about irrigation potential through qualitative and quantitative assessment of the existing physical resources, land and water resources with respect to irrigation suitability and to estimate the irrigation potential of the Malagarazi sub basins using geographic information system (GIS).

1.2. General introduction of Burundi

Burundi is located between 2°20 ' and 4°27 ' S latitude and between 28°50 ' and 30°53 ' E longitude. Total surface of Burundi is 27,834 km^2. Administratively, the country is subdivided in 17 provinces and 114 districts (communes). Four provinces form part of the basin of the Malagarazi are Cankuzo, Ruyigi, Rutana and Makamba (Bidou, 1991)

The Burundian borders have a characteristic that correspond to limits natural, especially made up by lakes and rivers. In the west, the Lake Tanganyika separates Burundi and the democratic Republic of Congo, in the North, the Kanyaru River and the lakes Cohoha and Rweru play the same part of separation with Rwanda. In the south East, the Malagarazi River separates from Tanzania. Figure1.1

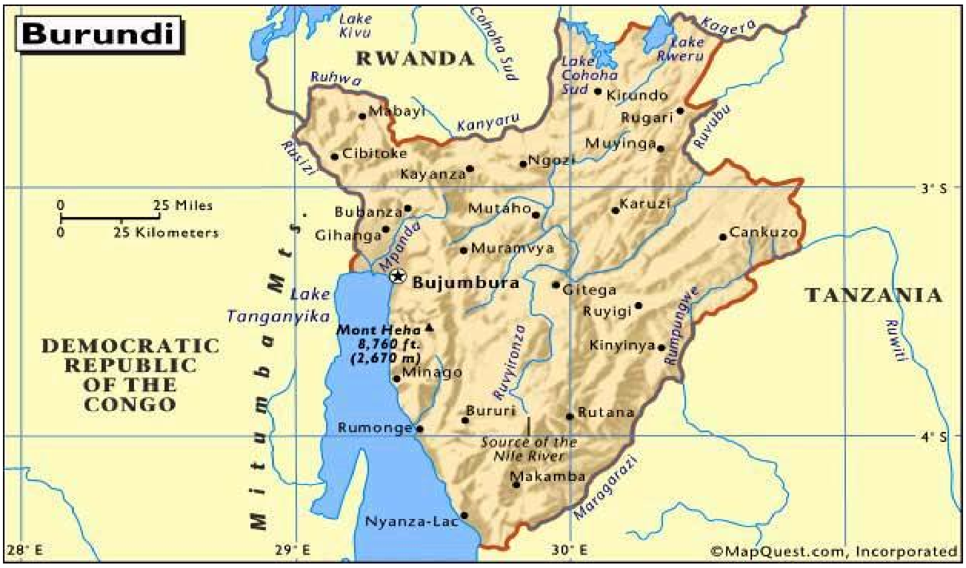

Figure 1.1.Localisation of Burundi

According to Bidou (1991), Burundi enjoys a tropical climate moderate by the altitude which varies from 773 m to 2,670 meter above sea level. Average annual rainfall is between 800 mm in the plain of Imbo and 2000 mm on the Congo-Nile Peak. The lowest area hottest and are sprinkled with rainfall in the West plain of Imbo and in north of the depression of Bugesera (1000mm/a). The highest areas (highlands) have rainfall that range from 1400 - 2000 mm. The distribution of the temperature in Burundi follows that of the catchments, the annual average temperature of 23°C in the plain of Imbo, lower area and 16°C on the Congo-Nile Peak.

Seasons: The country knows a pluviometric alternation at 4 times, marked by 2 maximum and 2 minima.

- The small rain season is from mid-September to mid-December, that corresponds to the first agricultural season known as season A
- The small dry season is from mid-December to mid-February,
- The great rainy season is from mid-February at May that corresponds to the second agricultural season known as season B
- The great season, i.e., dry season is from June- September

The soil: The soil is overall ferralsols or ferrisols in altitude (Mumirwa-Mugamba). It also meets, on the slopes and the peaks, the lithosols which are tropical brown soil not very advanced. In the funds of the marshy valleys (basin of Malagarazi) one finds grounds organic boggy, while the plain of Rusizi is characterized by its tropical black cotton soils (régogleys and regogleys saline). More than 36 % of the soil is acid and have an aluminic toxicity (Ntiburumunsi, 2000).

Hydrography: According to Nsanzumuganwa (1988), from its geographical position and of its relief, Burundi belongs to two principal catchment areas. The watershed separates the hydrographic system from the West, the South and the South -East country which feeds the Lake Tanganyika (basin of Congo) of the center and of the North which flows in Kagera (basin of the Nile). The total surface of the basin of Congo is 14,034 km² while that of the basin of the Nile (Kagera) is 13,800 km², it means that 50% of the own territory. These two basins hydrographic are divided into 6 sub-basins slopes (Malagarazi, Ruvubu, Tanganyika, Rusizi, Kanyaru and Kagera) (Figure1. 2)

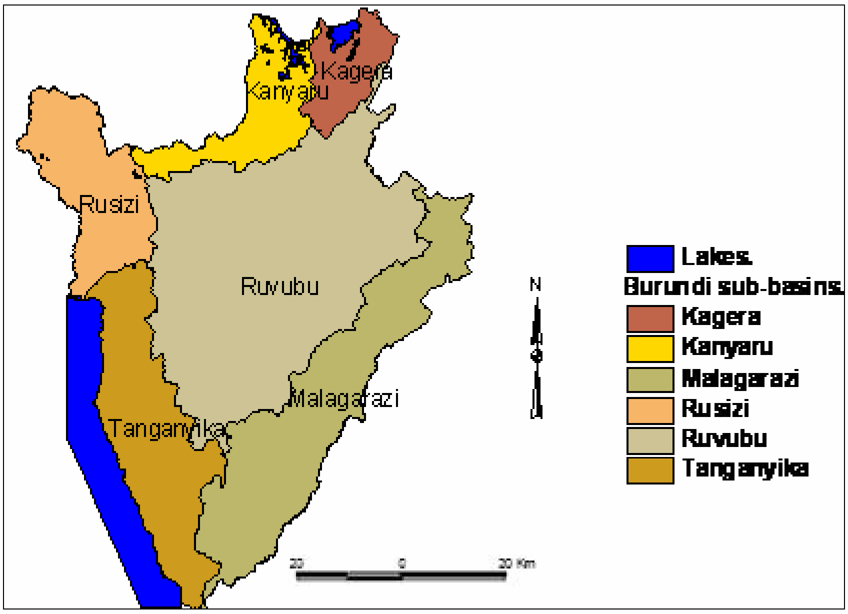

Figure 1.2: Burundi sub basin map

1.3. Problem statement

The population of Malagarazi sub basin is largely rural and dependent on agriculture for their livelihoods. But with the last decade of socio-political crisis, agricultural production has not kept place with population growth, leading to sever chronic malnutrition and hunger, and periodic crisis induced by consecutive drought (1984, 1987, 1993, 1998, 2004 and 2006). The irrigation potential is estimated about 8,223 hectares of arable land, only 1,594.08 hectares is currently under irrigation for sugarcane in SOSUMO, which plays insignificant role in the regional agricultural production.

Many factors (the hot climate, long season dries, the irregular rains, the endemic diseases striking the people, malaria....) prevented the immigration of the population in spite of the existence of vast vacant area. The population (especially men) of the natural area of Buyogoma, travels long way to go to make small-scale farming during the farming season and return over on their premises during the summer because of 80 percent from Buyogoma region cultivated less than 3 acres per household. At this period, it is the turn of the stockbreeders of the natural area of Bututsi, to keep their cow there.

However, another part of the population crosses the borders to go to Tanzania where there is the marsh prepared. High rate of infant mortality, limited access to potable water and low nutritional level of food in calories are common indicators of poverty in Malagarazi sub basin like as many parts of rural Burundi.

Transformation of existing traditional system in general and the potential irrigation systems particularly into modern irrigation and increasing agricultural production by more than two folds in a year is one of the main objectives of the country for food security and poverty alleviation. The adoption of appropriate irrigation method and improved agricultural water management system in the Malagarazi sub basin has been unimpressive. Irrigation development has been constrained by limited number of technologies available. Besides, unreasonably varying per hectare cost for small scale irrigation project development from time to time and from place to place, lack of well developed and organized irrigation infrastructures, provision of suitable agricultural inputs such as selected seeds, plant nutrients, pesticides and insecticides to increase agricultural productivity are among the areas that still need strong focus and improvement.

In order to provide alleviative measures for these and other bottlenecks on the sector, one important aspect is provision of well developed irrigation suitability database for the region in general and for the basin under consideration in particular. This database would help decision makers, investors, planners and policy makers at the local, regional and national levels to better identify profitable and sustainable irrigation investment opportunities.

1.4. Objective of the study

The general objective of the study is to identify potential irrigable area in the basin and to provide GIS based irrigation suitability criteria through the assessment of the natural physical resources such as land and water. The specific objectives of the study are:

- To map the existing and potential identified irrigable areas based on the soil, terrain feature and surface water availability in the sub basin of Malagarazi.
- To estimate the total irrigation water requirements for the identified irrigable land by taking in to account the surface irrigation method.
- To provide an integrated, geo-referenced irrigation suitability database with the aid of GIS that can be used for identifying potential irrigable areas in the basin.

- To compare potential irrigation water requirement of provisional irrigable land with the available surface water resources potential
- To estimate the storage requirements to irrigate the potential irrigable area.

CHAPTER TWO: LITERATURE REVIEW

2.1. THE WATER BUDGET

The Hydrologic cycle considers the global hydrologic system as a closed system with a fixed finite quantity of water transferred from one form to another. The hydrologic system at a local level (such as watersheds, regional groundwater aquifers, surface water reservoirs, etc) is usually an opened system with inputs (inflows), output (outflows) and local storage. These components of the hydrologic system may even vary with time and space within the studied regime. For surface water reservoir, the inputs are the steam inflows, and the outputs are the reservoir releases and evaporation from the reservoir. The difference between the inflows (I) and outflows (O) at any time interval will be equal to the change in the storage(S), which may be represented in a water budget form as follows (Eagleson, 1970):

$$I - O = \frac{dS}{dT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

For a watershed, the inflow is the precipitation (P), the outflow are the surface runoff and groundwater outflow (G), while the storage will be in the form of soil moisture and groundwater. The water budget may be even applied at a regional level, with several inflows and outflows, including precipitation, and surface water and groundwater runoffs. The stored water may account for surface water reservoirs, groundwater aquifers and the soil moisture. A general form of equation (1) may be written as:

$$(P + Ri + Gi) - (Ro + Go + E + ET) = \frac{d(Sm + Sg + Ss)}{dT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where i denote the inflow and o denotes the outflows, E is the evaporation, ET is the evapotranspiration, and Sm, Sg, and Ss are the stored water as soil moisture, groundwater and surface water, respectively. Evapotranspiration is the combined process of evaporation from the soil and transpiration by the plants in the vegetated areas (Mohamed, 2004).

2.2. IRRIGATION WATER DEMAND ASSESSMENTS

2.2.1. General

Water is one of the most important agricultural inputs that play crucial role in the process of plant growth. Crops need water right from the time of sowing to maturity. However the rate of use of water is affected by type of soil, type of plant, length of growing season, meteorological variables like temperature, humidity, rainfall, and wind. Irrigation water is a major source of water supply that ensures enough moisture for the plant life when there is inadequate rain fall. Thus irrigation water requirement is the total quantity of water required to be supplied by irrigation to meet crops need for consumptive use and additional needs like leaching, cultural operation, and unavoidable losses.

2.2.2 Crops and land allocation

When available water supply is adequate and fully meets crop water requirement, the productivity is maximum and the required supply depends on the growing season, and the irrigated area. In selecting the type of crop to be grown on given command area with given adequate water supply, the following variables should be studied thoroughly (Baharat, 1998)

- Climate
- Water requirement: sources of water should be adequate
- Soil requirements: selected crops should yield maximum production with minimum and provide adequate drainage facility during high impoundment
- Method of irrigation depends on soil type, topography, water sources
- Farmers preference
- Availability of labor and farm machineries
- Market and profit

Cropping pattern is the sequence in which plants are grown on the total area. The cropping pattern of the study (e.g. crops, crop rotation, and crop intensity) is essential input consideration in the overall study planning. The over all objective of cropping pattern is maximizing the utilization of land water in order that the beneficiaries are capable of implementing the proposed program in terms of supplying the labor and other inputs required to increase the percentage of the total cropped area. Cropping pattern depends on the availability of water, type of soil, climatic conditions, value of crops, socio-economic aspect,

2.2.3. Irrigation Requirement

a. Irrigation Water Requirement (IWR)

Water requirement is the amount of irrigation water required in order to meet the evapotranspiration need of the crop during its full growth. It is therefore the consumptive use itself, but exclusive of effective rainfall (Re), stored soil water (SW) or ground water contribution (GW) (Michael, 1979).

$$IWR = ETc - (Re + GW + SW) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

b. Effective rainfall (Re)

In view of the term water requirement of a crop, it follows that from the production point of view, the annual or seasonal effective rainfall as far as the water requirement of crops is concerned, should be interpreted as that portion of total annual or seasonal rainfall which is useful directly and /or indirectly for crop production at the site where it falls but without pumping. It therefore includes water intercepted by living or dry vegetation that is lost by evapotranspiration from the soil surface. The effective rainfall (Re) is taken as a fixed percentage of the total monthly rainfall. Re = % of total rainfall (Michael, 1979)

c. Ground Water contribution (GW)

The contribution from the ground water is determined by its depth below the root zone, the capacity of the soil and the water content in the root zone. As a very detailed experiment is need to estimate this variable it is often neglected.

d. Stored Soil Water (SW)

Rain or the flooding may cause the soil profile near or at field capacity at the start of growing season which may be equivalent to one full irrigation. However it could be neglected in the planning stage as it is difficult to estimate and its contribution is not generally significant. Hence we remain with the following result which is also called net irrigation requirement (Linsley, 1979):

$$NIR = ETc - Re \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

2.3. Soil and terrain suitability for irrigation

In order to compare soil and terrain conditions with specific crop requirements for optimum growth and production, soil and terrain qualities or characteristics, are derived from the FAO - UNESCO soil map of the world.

Soil requirements for irrigation

Referring to FAO 1997, the qualitative land evaluation for irrigation is generally based on interpretation of environmental characteristics, of which slope, soil and groundwater are the most important. The evaluation criteria adopted here consider surface irrigation using water of good quality (Table 2.1).

These criteria are used in this study for estimating the soil requirement for irrigation. The attributes of the FAO-UNESCO Soil Map of the World which were used for irrigation appraisal are: topography, drainage, texture, surface and subsurface stoniness, depth, calcium carbonate level, gypsum status salinity and alkalinity conditions. Criteria were established for evaluating each of these characteristics in relation to the specific requirements for upland crops and flooded rice. As the above criteria stated, two main land uses have been considered "Upland crops and flooded rice".

Table 2.1: Criteria used in the evaluation of soil and terrain suitability for irrigation

CRITERIA	CONDITION	UPLAND CROPS	FLOODED RICE
Topography: slope	Optimum	< 2%	< 2 %
		2-8%	2-8%
Drainage	Optimum	Well drained	Poorly drained
	Marginal/Range	Moderately Well drained –Imperfectly drained	Very poorly drained – Well drained
Texture	Optimum	Loamy –Silty Clay Loam	Clay Loam - Clay
	Range	Sandy Loam – Clay sandy	Sandy Loam - clay
Soil depth	Optimum	> 100 cm	> 50 cm
	Marginal	50 - 100 cm	20 - 50 cm
Surface stoniness	no stones are acceptable	no stones are acceptable	no stones are acceptable
Sub surface stoniness	Optimum	< 40 %	< 40 %
	Marginal	40- 75 %	40- 75 %
Calcium carbonate	Optimum	< 30 %	< 15 %
	Marginal	30- 60 %	15 - 30 %
Gypsum	Optimum	< 10 %	< 3 %
	Marginal	10 - 25 %	3 - 15 %
Salinity	Optimum	< 8 mmhos/cm	< 2 mmhos/cm
	Marginal	8 - 16 mmhos/cm	2 - 4 mmhos/cm
Alkalinity	Optimum	< 15 ESP[1]	< 20 ESP
	Marginal	15 - 30 ESP	20 - 40 ESP

Source: http://www.fao.org/docrep/W4347E/w4347e0b.htm, consult April, 27, 2008

Noted that the main priority have been given to flooded rice where there is suitability for both crops in order to avoid counting twice the same potential land. Within this context, the following result has been estimated (table 2.2)

[1] ESP: Exchangeable Sodium Percentage

Table 2.2: Situation of irrigation suitability (FAO, 1997)

Country	Total area of the country (ha)	Soil suitable for rice (ha)	Soil suitable for irrigation of upland Crops (ha)	Total area of soils suitable for surface irrigation (ha)	As %of total area country [(5/2)*100]
Col (1)	Col (2)	Col (3)	Col.(4)	Col (5)	Col (6)
Burundi	2 783,400	302,100	286,700	588,800	21%

The table 2.2 shows that 21% of the Burundi area constitutes potential irrigable land by the stated criteria.

2.4. Irrigation development in Burundi

2.4.1. Water resources potential of Burundi

The water resource of the country is found in lakes, rivers, streams and of course groundwater. Based on its topography, Burundi is subdivided into six sub-basins as represented in figure 1.2. The summarized surface water resources potential is given in the table 2.3 and shows the total available discharge per basin and the importance of Malagarazi basin (about 10.12% of the total available discharge for the country) among others

Table 2.3: Summary of surface water resource potential in Burundi (PDNE, 1998)

Basin name	Surface area in Burundi (km^2)	Mean discharge			Base flow discharge
		Discharge (m^3/sec)	Runoff depth (mm)	Total annual volume (*$10^6 m^3$)	Discharge (m^3/sec)
Rusizi	2682	53	623	1672	43
Lac Tanganyika	3871	78	633	2450	60
Malagarazi	**5262**	**51**	**305**	**1607**	**37**
Congo	11817	182	483	5729	139
Ruvubu	10063	108	340	3 420	79
Kanyaru	1938	21	338	655	14
Kagera	1217	8	212	257	5
Nile	13524	137	890	4332	98
Total	25035	319	402	10061	237

Table 2.4 shows the imported, exported and total available discharge per basin in Burundi. There is no available information about groundwater potential. But it has been considered that groundwater resources with specific discharge above 0.3 l/s*km^2 are economically exploitable. Based on the sample spring flow, Burundi has more than 6,600 litters/sec for groundwater (PDNE, 1998)

Table 2.4: Surface water balance for Burundi (PDNE, 1998)

River name	Imported discharge (m^3/sec)[2]			Exported discharge (m^3/sec)[3]			Total available discharge per basin
	RDCongo	Rwanda	Tanzania	RDCongo	Rwanda	Tanzania	m^3/sec
Rusizi	129	10	0	- 180	0	0	40
Lac Tanganyika	0	0	0	-66	0	0	66
Malagarazi	**0**	**0**	**10**	**0**	**0**	**-37**	**27**
Rumpungwe	**0**	**0**	**72**	**0**	**0**	**-81**	**10**
Ruwiti	0	0	0	0	0	-1	1
Mweruzi	0	0	1	0	-	-4	3
Ruvubu	0	0	0	0	0	-95	95
Kanyaru	0	23	0	0	-39	0	16
Kagera	-	6	0	0	-14	0	8
sum	129	39	83	-246	-54	-218	267
Total	**251**			**-518**			**267**

Considering FAO (1997) report, the internal renewable water resources are estimated to be 3.6 km^3/year with 3.5 km^3/year as surface water, 2.1km^3/year of groundwater and 2 km^3/year of overlap. Considering the surface water balance budget, Burundi receives 251m^3/sec as imported discharge and 267m^3/sec are produced inside the country and summing to a total of 518m^3/sec for the outgoing discharges (table 2.4)

[2] Imported discharge would mean river flows that enter to the country from elsewhere
[3] Exported discharge means the rate of flow that is going out for the country (in Tanzania) through Transboundary rivers

2.4.2 Irrigation development in Burundi and in Malagarazi sub basin

According to Kabundege (2007), the irrigated land development in Burundi will be increasing from 1990 up to 2010 by 75.2% (table 2.5).

Table 2.5: Irrigated land development as projected to 2010 for Burundi (Kabundege, 2007)

Year	1990	2000	2010
Irrigated area	194.2 km^2	296.5 km^2	340.2 km^2

The table 2.6 shows the cropping pattern in Burundi during a particular year.

Table 2.6: Cropping pattern in Burundi (MINAGRI, 2007)

Cropping season	main crops	Cropping calendar											
		J	F	M	A	M	J	J	A	S	O	N	D
Throughout the year	Vegetables/sweet potatoes	-	-	-	-	-	-	-	-	-	-	-	-
Wet I	maize/sorghum				p	-	-	-	h				
Wet II	maize/sorghum	h								p	-	-	-
Wet I	Rice		p	-	-	-	-	h					
Wet II	Rice	h								p	-	-	-

Note:h:"harvesting"and p:"planting"

Based on the above analysis, it have been reported that the total irrigation potential in Burundi is estimated to be some 185,000 ha of which 105,000 ha lies in the Congo- basin and the remaining 80,000 ha in Nile basin (FAO,1997).

The table 2.7 provided the area under irrigation and the water demand in Malagarazi sub basin in the period of 15 years. There is no variation of area under irrigation from 1995 up to 2010. This means that there is no irrigation plan in Malagarazi sub basin. There is no modern irrigation development with fully or partial water control system. The use of water for agricultural productivity in the study area is mainly dominated by furrow irrigation method.

Table 2.7: Irrigation area and water demand in Malagarazi sub basin (PDNE, 1998)

Basin	**Area in ha**			**Maximum water demand (l/sec)**		
Year	**1995**	**2000**	**2010**	**1995**	**2000**	**2010**
Risizi	1,304	5,995	5,995	2,891	7,969	7,969
Tanganyika	1,941	1,941	1,941	2,280	2,280	2,280
Malagarazi	**1,941**	**1,941**	**1,941**	**2,280**	**2,280**	**2,280**
Ruvubu	1,000	500	500	2,000	1,000	1,000
Total	12,161	21,217	23,302	14,153	22,274	24,024

2.5. GIS Software for defining irrigation suitability parameters

Geographic Information System (GIS) is computer based-tools to capture, manipulate process, analyse and display spatial or geo-referenced data. They contain both geometry data (coordinates and topographical information) and attribute data, that is, information describing the properties of geometrical objects, such as points, lines, and areas. GIS are quite common and generally accepted in mapping as well as assessing soil and land use units and creating attributes that define the different features (Wayand, 1999).

In recent years, GIS have emerged as major spatial data handing tools and have been applied in hydrological and associated fields world wide (Negash, 2004). The incorporation of digital elevation data and terrain attributes, such as slope and aspect, are given increasing emphasis to determine spatially variable hydrological process occurring in a catchment at relatively fine resolution (Heuvelink, 1998). The Arc View /GIS are used to include the input parameters for determination of terrain feature and to display a variety of resolution in map form.

GIS is seen as a general purpose technology for handling geographic data in digital form and satisfying the following specific needs, among others (Goodchild, 1993):

- The ability to pre-process data from large stores into a form suitable for analysis, including such operations as reformatting, change of projection, re-sampling and generalization;
- Direct support for analysis and modelling such that forms of analysis, calibration of models, forecasting and prediction are all handled through instructions to GIS;
- Post-processing of results, including such operations are reformatting, tabulation, report generation and mapping.

Investigation of irrigable land by remote sensing and GIS techniques has evident advantages as objectivity, time saving and low cost. A lot of auxiliary information, which can help designers, planners and decision makers to generate new idea to improve irrigation system, can be obtained.

Once the Digital Elevation Models (DEM) is developed from the contour map of the basin, the other characteristic derivates and attributes can easily be derived using the broad based options in the Arc View/GIS environment.

The different physical variables (soil, land use, water, climate, terrain feature) used to define the suitability criteria made available and incorporated into a single unit with the aid of Arc View/GIS environment. In order to establish the terrain and soil suitability parameters various attributes of elevation, soil, land use/ cover condition and existing surface water resources are included into GIS and respective interpretation can be made.

CHAPTER THREE: METHODOLOGY

3. 1. Study area

The Malagarazi sub basin is at altitude varying between 1125 m (at the exit of the Malagarazi river of Burundi) to 1400 m (with the Rukoziri River). It extends on 160 km length (Northern to south). Its width varies between 10 km (with the foot of Nkoma) and 30 km (in Kinyinya). It is limited to the East by the rivers Maragarazi and Rumpungwe (Burundi-Tanzania border). In the West, it is limited by solid masses like Inanzerwe and the heights of Buyogoma going from the South to North. Under basin pouring of Malagarazi has 8,223 km^2. Four provinces form part of under basin of the Malagarazi (Cankuzo, Ruyigi, Rutana and Makamba). Figure1. 3

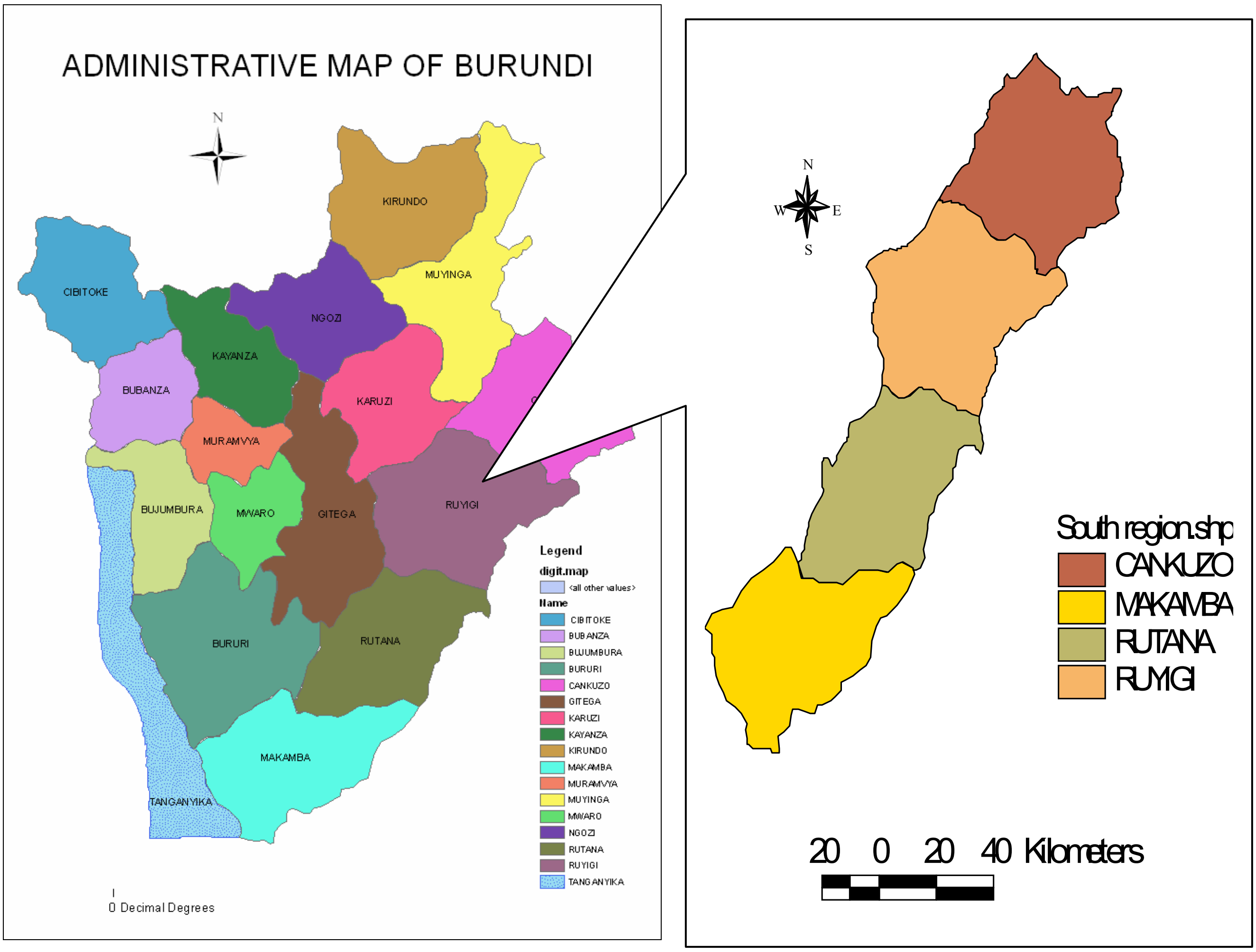

Figure 3.1: Study area

3. 1.1. Climate

The succession of the seasons in the basin of Malagarazi is the same as everywhere in Burundi: one dry season of June until September and a wet season which goes from October to May, with a small bending in January. The average temperature is about 21.83°C and rainfall is 1155.01 mm (IGEBU, 2007). The Malagarazi sub basin is gauged with about 4 functional meteorological stations and distributed throughout the sub-basin. Details on climate data and filling for the missing rain fall values in different stations are presented in data analysis section 3.2. Figure 3.1 shows localisation of meteorological station in Malagarazi sub basin.

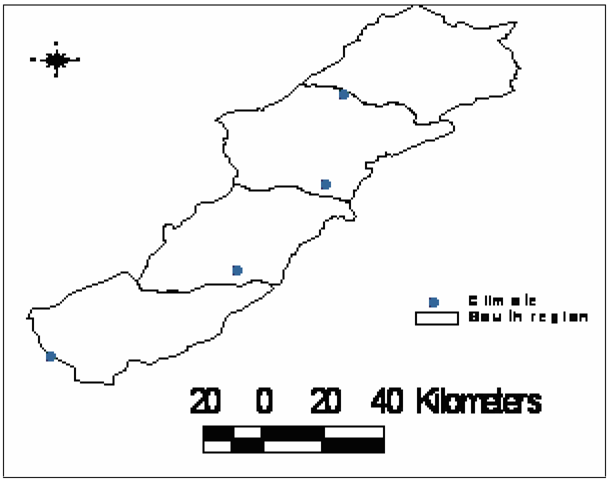

Figure 3.2: Coordinates of Meteorological station of Malagarazi sub basin

3.1.2. Hydrology

The Zaire-Nile dividing range determines the line between waters flowing into the Nile and those flowing into the Zairian basin thereafter into the Atlantic Ocean. From the northern tip in the virunga (volcanoes) mountains, Rwanda with an altitude reaching 2990m , then 2650m, then 2670m in up to the tip south of Burundi where the chain culminates at 1852m only (Kabundega , 2007). The hydrological data for major river basins in the catchments is obtained from Geographic Institute of Burundi (IGEBU). Maximum, minimum and annual average magnitudes of river discharge from the basin are estimated. This will be helpful in determination of potential irrigation capacity of surface water. The hydrological network of the basin is worked out with the aid of GIS environment and is marked by Muyovozi, Mukazye, Rumpungwe, Rukoziri and others attributes.

The river Maragarazi froms the under basin that receives water from Kumoso and of Buragane regions. It takes its source with Mugina, 1650 m of altitude, 30 km of the Lake Tanganyika and makes a long course before draining the Lake Tanganyika via Tanzania. Malagarazi forms the border between Burundi and Tanzania on 156 km.

Recorded annual flow of Muyovozi is 12.85m^3/s. Muyovozi River is utilized for irrigation purpose in Makamba province. Mukazye is a very small river which is not gauged. It is extensively utilized by the farmers in the village of Mabanda. The annual flow of Rumpungwe River at lower valley is about 7.8 m^3/s. Rukoziri River is estimated to3.55 m^3/s. A portion of Muyovozi River is used to irrigate the sugar cane in SOSUMO (Société Sucrière du Moso).

3.1.3. Topographical features

From the geomorphological point of view, two sets of paysagic can be distinguished in the natural area from Moso –Buyogoma: (1) one is associated with the formations of plain, general altitude bordering 1250 m. The greatest part of the area is traversed by the hydrographic network of Rumpugugwe and Malagarazi. These two rivers and their effluents traverse vast marshy extents. (2)the other landscape is characterized by four solid masses following one another of the South- North and culminating respectively to 1600 m and 1700 m (GTZ, 1984).

3.1.4. Geology

The geological field identified in Malagarazi sub basin by ISABU-Station Moso (1981) is Malagarazien or super group of Malagarazi. It acts of higher Preterozonic and levels in south-east. The malagarazien consists of rocks with weak metamorphism including of the sandstones, quartzite, conglomerates, basalts and limestones dolomitic. The latter are currently exploited on certain sites for the production of lime on a small scale. ISABU-Station Moso (1981) subdivides Malagarazien in four units of which succession of oldest towards most recent:

- "Mutsindozi": conglomerates, quarzites, sandstone, schists, limestones, dolomitic limestones with basalt intercalations;
- "Nkoma": conglomerates, quarzites, phyllites;
- "Moso": amygdaloid lava, silicified limestones;
- "Kibago": quarzites, sandstones, read schists.

3.1.5. Soil of the Malagarazi sub basin

A good knowledge of the grounds is essential for the development of an area whose economic life is on the whole tributary of agriculture. The soil studies in Burundi by the ISABU institute cuts revealed several major groups of soils. The basic soil group identified in the basin is that the basin of Malagarazi presents a mosaic of different grounds. We can however distinguish between:

- mollic xerokaolisols, xeroferasols and xeroferrisols on the hills and marsh.
- entisols and lithosols on the peaks of old surfaces of erosion or quartzitic.
- No hydromorphic or hydromorphic recent alluvial of depth, hydromorphic alluvial (minerals and organics) on the plains and marshes (Bidou *et al*., 1991)

Soil textures vary according to parent material from clay loam and clay in some parts to loamy sand and sandy loam which is susceptible to soil erosion due to their low bulk density even in gentle slopes.

3.1.6. Suitability Criteria for irrigation

Qualitative land evaluation for irrigation is generally based on interpretation of environmental characteristics, of which slope, soil drainage class, soil texture, soil depth, salinity and alkalinity of soil and groundwater are the most important in the study area. According to ISABU (Agronomics Sciences Institute of Burundi), the Malagarazi sub basin soil is categorized as Silty loam. The pH of the soil ranges between 5.8 and 7.2. The salinity of the soil is 0.09 mmhos/cm. The Cation Exchange Capacity (CEC) of soil of Malagarazi sub basin ranges between 23.6 and 39 meq/100gm (Ntiburumunsi, 2000). Water quality of Malagarazi's rivers is not checked. But from the farmers' experience, using the river water at the banks of the stream for some seedling of very small plot and traditional irrigation, one can deduce that this is an indicator of good quality water as it has no negative effect on their crops, but to be scientific , to test the water in laboratory is advisable.

3.1.7. Cropping pattern

The Malagarazi sub basin is characterized with highlands to low land semi-arid agro climatic regions. Different types of crops are supposed to be raised in different parts of the basin based on their climatic suitability through out the year. In most parts of the basin crops are grown four times in the same plot of land as the total growing duration of the crops do not exceed from three months. This is so in the areas where the soil fertility is well maintained and the soil moisture deficit is low enough and do not cause damage to crops. The common types of crops cultivated in some of the areas are listed in table 3.1.

Table 3.1: Major crops cultivate in selected areas of the basin:

Area	Types of crops grown
RUTANA (MUSASA)	Cotton, maize, banana, sugar cane, s.potato, etc
CANKUZO	Rice, maize, s.potato, Soya bean, Cotton, banana, Date Palm, Tobacco, etc
KINYINYA (RUYIGI)	Cassava, haricot bean, banana, Soya bean, cotton, Maize, Tomato, etc
NYANZA-LAC(MAKAMBA)	Cassava, banana, maize, Cotton, potato, citrus, Mango, etc

The cropping date is so selected in such a way that adequate growth and physiological development of the plant is maintained.

3.1.8. Socio economic situation

In the Malagarazi sub basin, the majority of the economically active groups are self employed or unpaid family workers group. The natural regions falling in Malagarazi sub basin (Kumoso, Buyogoma, Buragane) are the most productive for Cotton, Banana, Cassava, Sugar cane, etc. The major cash crop as well as for the other food stuff. Formally, the agricultural activities were carried out on rotational basis between the hill sides and the valleys according to the rain seasons. During wet seasons that are October to December and February to May, agriculture is practiced on hillsides. During the dry seasons that are January to February and June to September the agricultural activities were carried out in the valleys.

Now days the irregularity in rainfall patterns such as late onset and early cessation of rain as well as the little know how of farmers have made farming activities very complicated in the valleys. Coming to land use and environment, the study area comprise kumoso national reserve with various species of animals and trees. But, with the demographic pressure, the extension of agriculture into marginal lands, brush fires deforestation by uncontrolled cutting of trees, causes soil erosion and habitat loss threatens wildlife population. The table3.2 shows the population of Malagarazi sub basin and occupied area.

Table 3.2: Population in Malagarazi sub basin

Provinces	Population	Area (Km^2)
CANKUZO	214,837	1,965
RUTANA	309,767	1,959
RUYIGI	388,474	2,339
MAKAMBA	493,602	1,960
Total	**1,406,680**	**8,223**

3.2. Materials and Methods

To assess and estimate the irrigation potential in the basin and provide the useful results according to the stated objectives, different materials and methods are used. The procedures to be followed include among others:

- Collect spatial database of the soil, topography, land use
- Scanning and geo-referencing of the spatial data (map)
- Estimate the gross water requirement of the identified land, using CROPWAT and based selected crops
- Assess the available runoff or stream flow in the river across the surface irrigation area
- Identify and use appropriate suitability criteria to delineate potential irrigable areas by surface irrigation method
- Compare the gross water requirement and the available water. If the available water is less than the gross irrigation requirement, the storage is required for surface irrigation method

3.2.1. Data collection and checking for its consistency

Generally, the study involves the following procedures:

- ❖ collection of hydrological and meteorological data, topographical map and digitized map of the basin,
- ❖ filling and extension of data,
- ❖ checking of data for consistency,

For the purpose of this work, 20 years of climate and hydrological data have been collected. These include monthly rainfall, mean maximum and mean minimum temperature, monthly relative humidity, wind speed at two meter height, sunshine hours for 4 stations were collected from the Geographic Institute of Burundi (IGEBU). The summary information is given in table 3.3

Table 3.3: Summary information of agro-meteorological stations in Malagarazi

Stations name	Location			Type of data	Annual values	Period	Percentage of missing data
	Elevation (m)	Latitude (degree) S	Longitude (degree)				
MUSASA	1260	4.00	30.10	Rainfall (mm)	1126.2	1986-2006	0.0
				Air temperature (°)	21.97	1986-2006	2.14
				Relative humidity (%)	71.21	1999-2003	1.3
				Sunshine (hour)	4.3	1987-1990	0.58
				Wind speed (m/s)	0.7	1996-2004	0.05
CANKUZO	1652	3.28	30.38	Rainfall (mm)	1161.9	1986-2006	0.0
				Air temperature (°)	19.4	1986-2006	1.2
				Relative humidity (%)	69.5	1997-2004	0.16
				Sunshine (hour)	1.29	1996-2004	0.4
				Wind speed (m/s)	1.27	1997-2004	0.18
KINYINYA	1450	2.58	30.08	Rainfall (mm)	1145.2	1986-2006	0.0
				Air temperature (°)	22.12	1986-2006	0.05
				Relative humidity (%)	70.8	2000-2005	0.26
				Sunshine (hour)	2.00	1994-2000	0.13
				Wind speed (m/s)	0.62	1982-1999	1.21
NYANZA-Lac	792	4.35	29.60	Rainfall (mm)	1186.75	1986-2006	0.0
				Air temperature	23.8	1986-2006	4.53
				Relative humidity (%)	87.6	2001-2005	1.42
				Sunshine (hour)	1.93	1993-2003	0.29
				Wind speed (m/s)	0.84	1991-2004	2.36

In the catchment, the percentage of missing data is described in table 3.3 and the results show that the missing data percentage is very less as compared to the availability of year's data.

To estimate the areal rainfall for Malagarazi sub basin, different stations were selected, which are inside of the catchment (Cankuzo, Musasa, Kinyinya and Nyanza-lac).
The missing data was estimated using the normal ratio method (equation 7) of average annual values from the record of surrounding stations.
Therefore, the missing precipitation data Px, will be given by:

$$Px = \frac{Nx}{M}\left[\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3}\right] \quad \text{.............................. (5)}$$

Where N1, N2, N3, and Nx representing the average annual rainfall at stations 1, 2, 3 and X respectively P1, P2, P3 and Px representing their respective precipitation data of the annual for which the data is missing at station X. M is the number of surrounding stations.

3.2.2: Determination of areal rainfall

It is important that the point rainfall data obtained from each station be converted to areal rainfall. The rainfall over the study area was determined using Theissen-Polygon method because, it provides for the nonuniform distribution of gages by determining a weighting factor for each gage. The weighted mean of the precipitation values can then be computed. In this method lines are drawn to connect reliable rainfall stations and the connecting lines are bisected perpendicularly to form a polygon around each station. To determine the mean, the rainfall amount of each station is multiplied by the area of its polygon and the sum of the products is divided by the total area. If P1, P2, …Pn are the rainfall magnitudes recorded by the station 1,2, …n respectively and A1,A2, ….An are the respective areas of Thiessen polygon, then the average rainfall over the catchment P is given by:

$$P = \frac{P1A1 + P2A2 + ... + PnAn}{A1 + A2 + ... An} \quad \text{.................. (6)}$$

$$P = \sum_{i=1}^{m} P1 \frac{Ai}{A}$$

Where m is the number of stations

The ratio Ai/A is called the weighting factor for each station and Thiessen polygon constructed by Arc map software is presented in annex B

3.2.3. Hydrological data

The main purpose of studying hydrology is to assess water availability for irrigation development and planning the existing water. The source of water for the proposed irrigation is Perennial River. The farms mainly utilize water from Muyovozi, Rumpungwe, Rukoziri and Mukazye rivers, which are located at north part of the farm and flow from north along the Ouestern and Eastern part of the farm boundary to wards south and join Malagarazi River which is located at Southern -East part of the Malagarazi sub basin. The rivers are perennial and supply water for irrigation.

The Mukazye River is ungauged. The amount of its discharge in both summer and winter seasons was not measured. Therefore, there is no river discharge data. The discharge can be estimated or generated by area ratio method of estimating the discharge of ungauged rivers from that of near by gauged river discharge. From the catchment area ratio of Mukazye and Rumpungwe rivers and discharge of Rumpungwe, the discharge of Mukazye River is estimated as follows.

$$Q_{MUKAZYE} = \frac{(A_{MUKAZYE})^n * Q_{RUMPUNGWE}}{A_{RUMPUNGWE}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where:

$Q_{Mukazye}$ = generated flow of mukazye (cumecs)

$A_{mukazye}$ = catchment area of mukazye(sq.km)

$Q_{rumpungwe}$ = measured discharge of rumpungwe (cumecs)

$A_{rumpungwe}$ = catchment area of Rumpungwe River (sq.km)

n = power relating the area rations to the discharge and it varies from 0.6 to 1.2

Double mass curve analysis was also used to check the consistency of data flow series for selected gauged stations and the result is in annex C. Other secondary data such as soil and land use maps of the study area have been collected from soil and land use maps produced by the Agronomic Institute of Sciences in Burundi (ISABU) in collaboration with Geographic Institute of Burundi (IGEBU). The cropping pattern is so selected to fit with the local cropping calendar and the respective crop coefficient for the initial, mid and let seasons is identified based on the FAO guidelines. The intermediate Kc value is linearly interpolated between the pre-identified kc values for different stages.

Thus, data analysis was done using different material such as GIS Software, CROPWAT 4.3, hard copies of topographical map, soil maps, scanner and tracing papers

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Determination of reference evapotranspiration

The governing equation of Penman Montieth is used for determination of reference evapotranspiration in cropwat 4 window version 4.3, because it takes into account the various elements of the climatic and aerodynamic components in determining reference evapotranspiration (ETo) and it is also recommended by FAO, and widely used to calculate reference evapotranspiration.

Climatic data used and the amount of reference evapotranspiration (mm/day) determined by CROPWAT software 4 window version 4.3 are show in table 4.1 for Musasa station. The reference evapotranspiration is ranged from 3.3 to 4.2 mm/day.

Table 4.1: Meteorological data and reference evapotranspiration at Musasa station
(Altitude 1260 m above sea level, Latitude 4° S and Longitude 30.10° E) (1986-2006)

Months	Max Temp(°c)	Min Temp(°c)	Humidity (%)	Wind speed (km/d)	Sunshine (hours)	Solar radiation ($MJ/m^2/d$)	ETo (mm/d)
January	27.8	16.2	78.0	0.5	9.0	23.3	4.2
February	29.2	15.9	75.5	0.6	8.0	22.2	4.1
March	28.5	16.0	76.3	0.6	7.0	20.6	3.8
April	27.8	16.5	77.3	0.5	7.0	19.6	3.5
May	28.3	15.8	75.3	0.4	9.0	21.0	3.6
June	28.4	13.1	67.5	0.6	10.0	21.4	3.3
Jully	29.0	12.1	64.0	0.7	11.0	23.2	3.5
August	30.9	13.4	59.5	0.8	11.0	24.7	4.0
September	32.0	15.4	59.3	0.9	10.0	24.7	4.2
October	30.6	16.5	66.0	1.0	9.0	23.6	4.2
November	28.9	16.6	76.3	1.0	9.0	23.3	4.2
December	28.1	16.3	79.7	0.6	8.0	21.5	3.9
Average	29.1	15.3	71.2	0.7	9.0	22.4	3.9

The result shows that the mean daily reference evapotranspiration rate (ETo) is more or less equal most months of the year. The lowest is in June. The same procedure is used for other stations in Malagarazi sub basin and detail is in annex D. With this regard, the mean daily and annual reference evapotranspiration estimated for the stations in Malagarazi sub basin is given in table 4.2.

Table 4.2: Mean daily and annual evapotranspiration rates

Stations	Average ETo (mm/d)	Annual ETo (mm)	Rainfall (mm)
Musasa	3.9	1404	1126.2
Cankuzo	1.4	504	1161.9
Kinyinya	2.7	972	1145.2
Nyanza-lac	2.3	828	1186.7

The resultants show that the annual reference evapotranspiration (ETo) is high in Musasa than others locality because of rainfall is less and it is very hot in that zone.

4.2. Crop water requirement

The depth of soil water which can be used effectively by the crop, readily available soil moisture (RAM), depending directly on the rooting depth of the crop. The rooting depth varies from 0.25-0.30 m at initial stage to 1.40 m for fully matured crop. Vegetable crops 0.50-1.00

The critical soil moisture level where the first drought stress occur affecting evapotranspiration and crop production, stated as allowable depletion. It is a fraction of the total available soil moisture and normally varies from 0.60 to 0.90. To estimate yield reduction due to drought stress, yield response factor, ky, is given as input variable in the crop data option. Table 4.3 shows the crop coefficient (kc) for cotton at Musasa and details can be obtained from FAO 24 and 56 paper.

Table 4.3: Crop coefficient (kc) of Cotton at Musasa for different growth stages

Station: Musasa Crop: Cotton Planting date:1 March					
	Growing stages				
	I	II	III	IV	Total
Length of days	30	50	60	55	195
Kc	0.35	1.2	1.2	0.60	
Root depth (m)	0.30	-	-	-	1.40
Depletion	0.60	-	0.60	0.90	
Ky	0.40	0.40	0.50	0.40	0.85

The same procedure is used for other cropping patterns at Musasa, Cankuzo, Kinyinya and Nyanza lac and detail is in annex E.

The irrigation scheme tries to fit the cropping pattern of the area taking into account to the rainfall distribution of the area. The cropping pattern in the Musasa area is given in appendices G2. From cropping pattern, it can be observed that, banana grows throughout the year. The plantation of cotton starts at beginning of March and ends at the middle of September. Maize starts at beginning of October and ends at the middle of February.

The calculation of crop water requirements is carried out per decade. Crop evapotranspiration per decade is calculated by multiplication of the number of effective crop days. This will normally be 10, except in the first and last decade when planting date and harvest date do not necessarily coincide with the beginning or the decade.

Irrigation requirements are determined by the equation (4). The estimated crop water requirement value, effective rainfall and irrigation requirement were calculated by using cropwat 4 window version 4.3, for selected crops in Malagarazi sub basin and the results are shown in figure 4.1

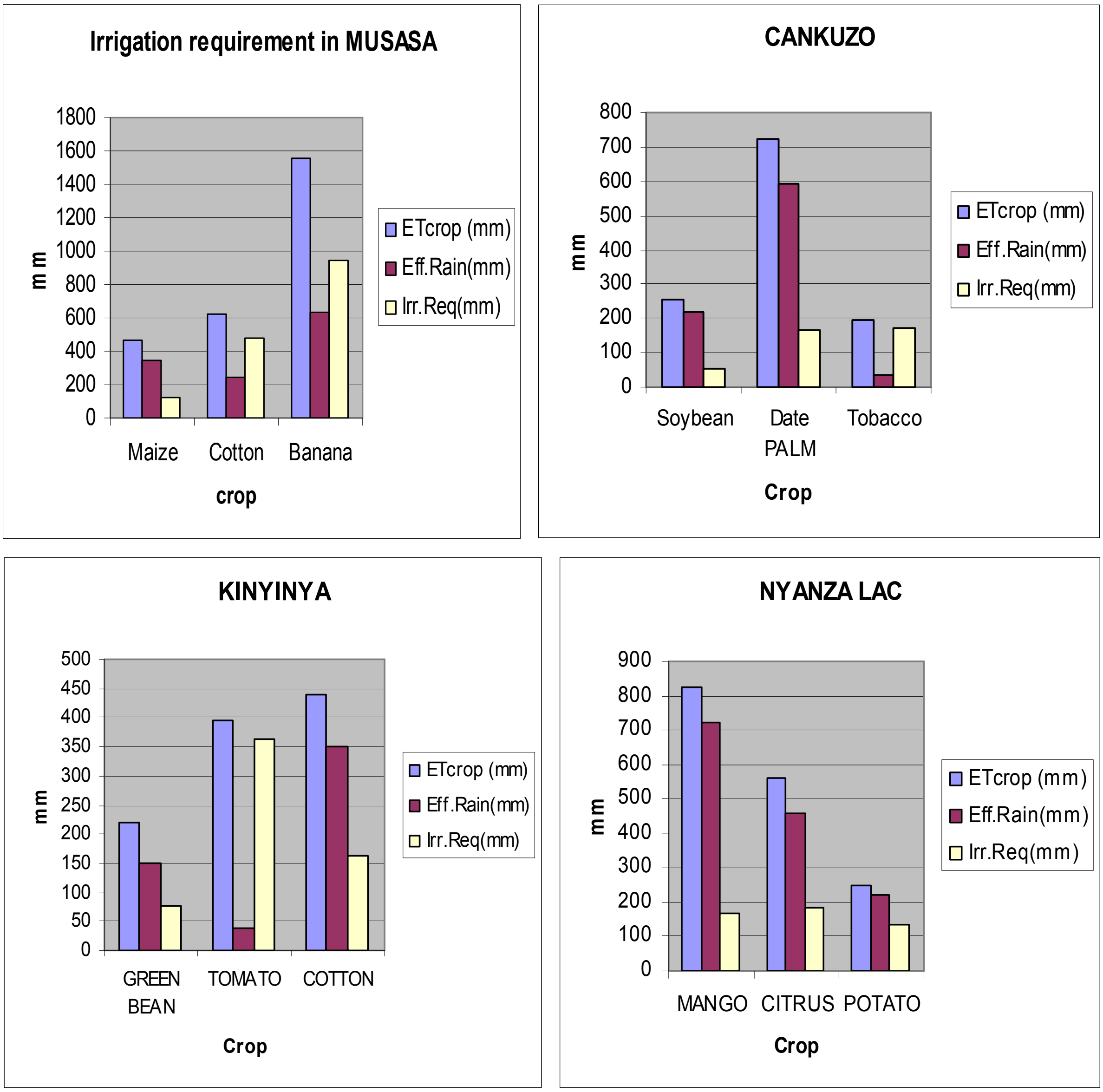

Figure 4.1: Irrigation requirement

The results show that cotton, banana and tomato in different zone needed more water supply for irrigation than others crops. Some crops as maize, soy bean, green bean and potato require relatively less irrigation water. Not only the irrigation water requirements of these crops are less but also their water requirement is lower. This may be due to their shorter growing period compared to other perennial crops.

4.3. Irrigation Scheduling

The irrigation scheduling program provides the possibility to develop and plan indicative irrigation schedules adapted to field operational conditions; evaluate field irrigation programs in terms of efficiency of water use and yield production and simulate field irrigation programs under water deficiency conditions, rain fed conditions, supplementary irrigation.

The input data are crop water requirements, rain fall, crop data and soil data (soil type description, Total Available Soil Moisture, Maximum Rain infiltration Rate, Maximum Rooting Depth, and Initial Soil Moisture Depletion). In our case, the soil is loamy soil with Total Available Moisture (TAM) 140 mm/m.

The irrigation scheduling program allows a range of options, depending on the specific application the user is aiming at and the conditions and restrictions the field irrigation system imposes. The scheduling option refers to timing option which related to when irrigation is to be applied and application options which related how much water is to be given per irrigation turn. In our case, irrigate when a specified 100% of readily soil moisture depletion occurs and refill to a specified 100% of readily available soil moisture. The irrigation schduling for the select crops in the Malagarazi sub basin is showen in appendix G1

The budget calculation in CROPWAT assumes soil moisture content at field capacity at planting period. The rainfall data are given as monthly values and the program converts the monthly values into 10 daily values (see CWR calculation in appendix F). The actual evapotranspiration is equal to the calculated crop evapotranspiration as long as soil moisture content has not reached the critical level as given by the allowable depletion (P). Beyond this level actual crop evapotranspiration is reduced proportionally to soil moisture depletion.

Values for total and readily available soil moisture, as determined by root depth, allowable depletion and total available soil moisture, are calculated on a monthly basis. The net irrigation requirement is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. Therefore, the net irrigation requirements are 481.72mm, 118.67mm and 940.91mm for cotton, maize and banana in Musasa respectively. The irrigation requirements per ha are 4,817.2m (481.72*10000)/1000, 1186.7m and 9409.1m for cotton, maize and banana respectively. The application of irrigation is 100% of readily soil moisture and the field water supply is 0.43l/s/ha for banana, 0.41 l/s/ha for cotton and 0.15 l/s/ha for Maize.

4.4. Surface water potential of major streams in the Malagarazi sub basin

The surface water potential of major streams situated in the basin is considered. Here the estimation is based to perennial rivers (Q_{100} = 100%) whose flow records are available. With this regard, Muyovozi, Rumpungwe, Rukoziri and Mukazye streams dry period flows as well as maximum run off magnitude is estimated from the available time series data.

Flow Duration Curve: FDC

Flow –duration curves find considerable use in water resources planning and development activities. Flow-duration –carve of a stream is a plot of discharge against the percentage of the time the flow was equalled or exceeded. The curve is known as discharge-frequency curve. It is not a probability curve because discharge is correlated between successive time intervals and discharge characteristics are dependent on season of the year. Flow duration curve provides a compact graphical summary of stream flow variability. Figure 4.2 shows the Flow Duration Curve of Mukazye River.

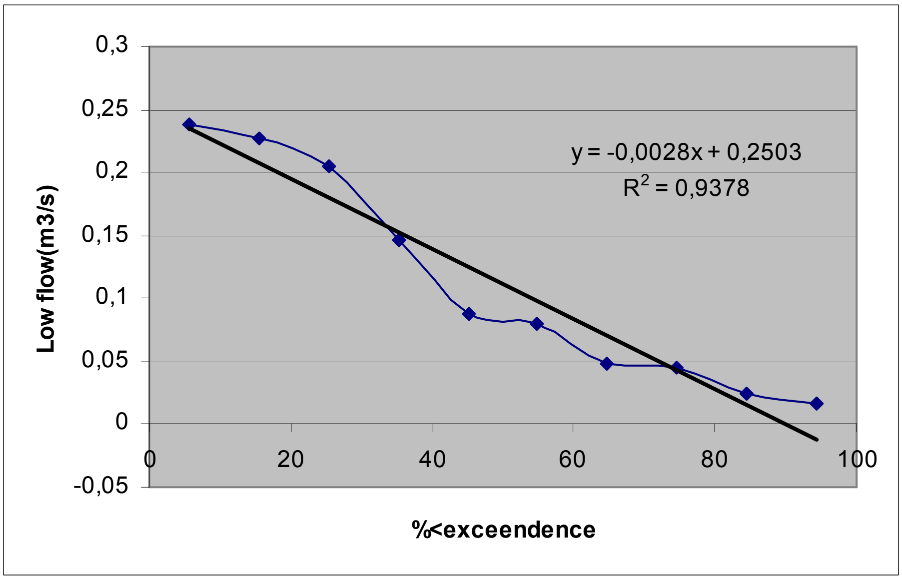

Figure4.2: Flow Duration Curve for Mukazye River

The trend line shows that the low flow at 100% exceendence is lower than 0 m^3/s. There is no water available in the river. The maximum flow is less than 0.25 m^3/s during the season. The figure 4.3 shows the percentage exceedence low flow of streams in Malagarazi sub basin.

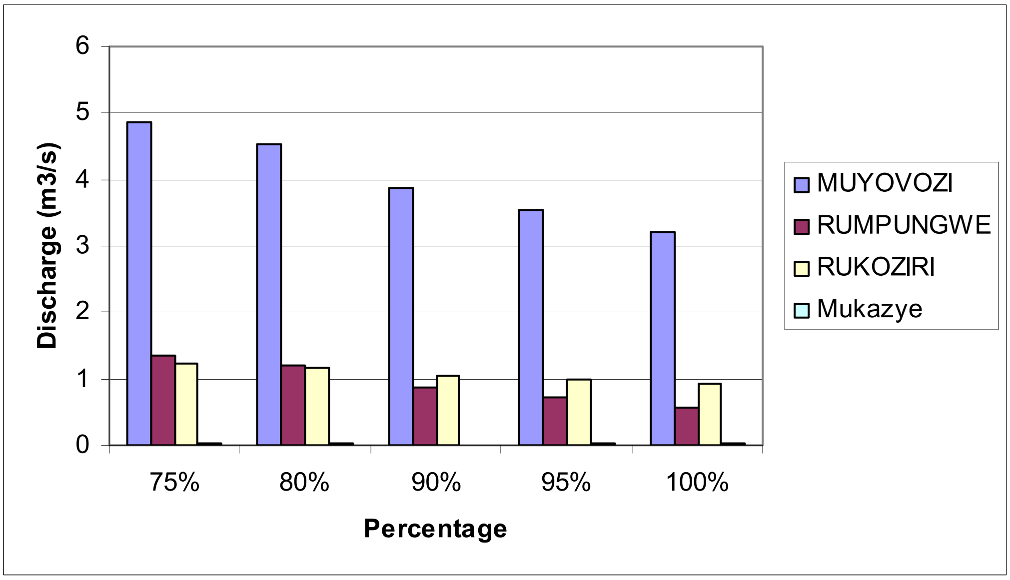

Figure4.3: Percentage exceedence low flows

Comparing the stream flow regimes of rivers, Muyovozi River has big discharge for all percentage exceedence low flows considered in figure 4.3 and Mukazye is the last. The results show that at any time, water is available in each river except Mukazye River during season.

4.5. Comparison of land and water potentials available in the sub basin

The water potential of the basin was determined and the potential irrigable area was estimated in the respective catchments taking into account the available minimum flow in the study area. Thus the total discharge and the area to be irrigated during the irrigation period are presented in table 4.4. The available minimum flow of rivers can irrigate about 156.20km2; 2.0913Km2; 35.83km2 and 114.06Km2 of land for Muyovozi, Mukazye, Rumpungwe and Rukozire rivers, respectively.

Table 4.4: Potential irrigable area with available water

Catchments	Low flow of Rivers (m3/s)	Crop	Length of days	Irrigation requirement (IR) (mm)	Annual Discharge (10^3m3/year)	Area can be irrigated (km^2)
RUTANA (MUSASA	Muyovozi(1.78)	Cotton	195	469.4	12, 495.6	26.62
		Maize	135	85.3	8, 650.8	101.42
		Banana	365	830.4	23, 389.2	28.17
Sub-total						156.20
CANKUZO	Mukazye (0.016)	Soyen Bean	135	77.5	77.76	1.004
		DatePalm	365	307.2	210.24	0.685
		Tobacco	110	157	63.36	0.404
Sub-Total						2.0913
RUYIGI	Rumpungwe(0.30)	Green Beans	90	49.4	972	19.68
		Tomato	145	343.2	1, 566	4.56
		Cotton	195	181.7	2, 106	11.59
Sub -Total						35.83
MAKAMBA	Rukozire(0.90)	Mango	365	360.2	11, 826	32.83
		Citrus	365	219.0	11, 826	54.00
		Potato	130	154.7	4, 212	27.23
Sub -Total						114.06
Total						**308.182**

The total area that can be irrigated using the available low flow is about 308.182Km2 in the basin. The potential maximum flow of Muyovozi, Mukazye, Rumpungwe and Rukozire rivers has the capacity to irrigate about 3,537.73Km^2; 818.89km^2; 3,475.83 km^2; 1,256.93 km^2, respectively during the growing seasons of the crops. Computation is also done using the

75%, 80%, 90%, 95%, 100% exceeded low flow out the recorded low flows and the respective areas to be irrigated with this different scenario is summarized in table 4.5

Table 4.5: Area that can be irrigated with different percentage exceedence flow

River	Area irrigated (km2)with ….percent reliability level of flow				
	75%	80%	90%	95%	100%
Muyovozi	117.042	113.6	102.24	94.33	81.93
Mukazye	3.95	3.88	2.75	1.99	1.90
Rumpungwe	110.96	104.02	84.53	71.96	54.53
Rukoziri	111.03	109.56	108.25	106.41	92.77
Total	**342.03**	**329.93**	**297.01**	**274.65**	**231.13**

The results show that the area irrigated with 75%, 80%, 90%, 95%, and 100% exceedence flow is decreased. It means that the area irrigated with 75% exceedence flow is higher than the area irrigated with 100% exceedence flow. Taking account 25% of water in down stream for maintaining ecological equilibrium, the area irrigated with 100% is 231.13 km2 for the total potential irrigable area with available water (308.182 km2)

4.6 Soil and Land use data

4.6.1. Mapping soil units using GIS environment

People are dependent on soil and, conversely good soils are dependent on people and the use they make of the land. Soil provides the room for water to be used by plants through the roots present in the same medium, as a habitat for soil organisms. Malagarazi sub basin is characterized with diversified geomorphology and soil patterns. However, the identification of representative soil textures and their physical as well as chemical properties is based on the FAO/UNDP's classification. The map use is developed from 1:250,000 scale topographical maps of Burundi. The figure 4.4 shows the attributes soil map unit of Malagarazi sub basin.

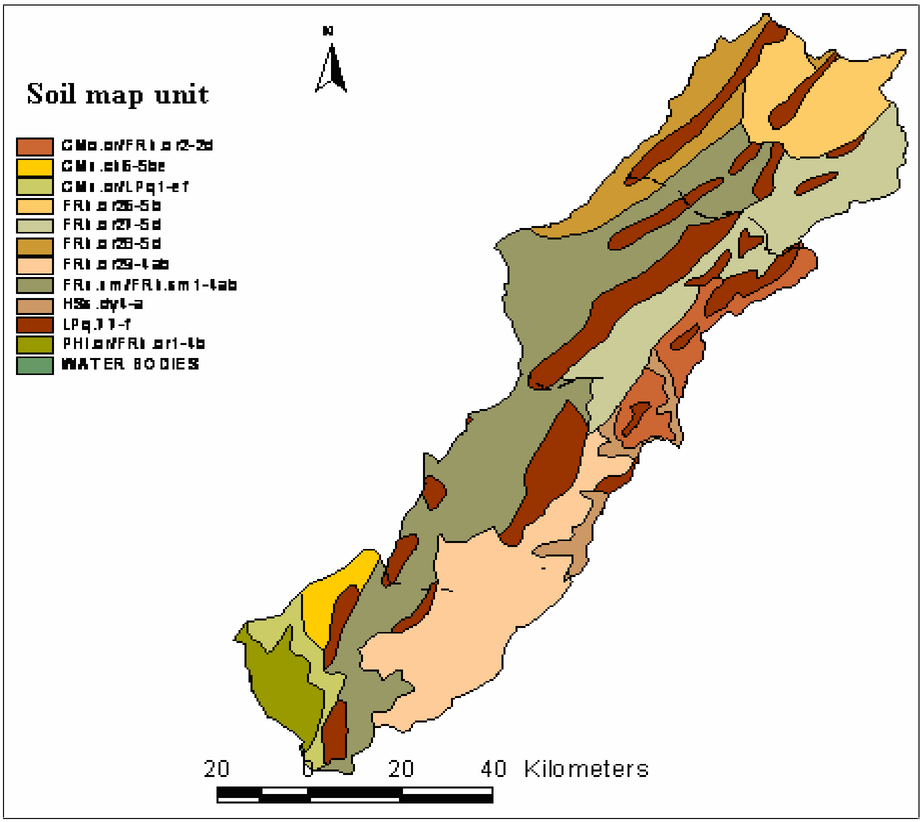

Figure 4.4: Attributes soil map unit of the study area

Table 4.6: mapping unit and corresponding geomorphic types

Mapping Unit	Geomorphic types
CMo	Organic Cambisols
CMu	Humic Cambisols
FRh	Haplic Ferrasol
HSs	Histosol
LPq	Lithic Leptosol
PHL	Phaeozems

Source: FAO/UNDP soil map of Burundi and its inclusive legend.

The Organic Cambisols and Haplic Ferrasol are distributed through the study area. The humic cambisoils are located only in south west and histosols are situated in eastern party of Malagarazi sub basin. Phaeozems are found in south west region and in the North West zone.

4.6.2. Mapping land use /cover conditions

Land use/ Land cover is the result of the interaction on man and land. Land use/land cover is the use of land for different purposes in order to meet the basic needs of human being. The most important uses include housing, cultivation grazing, and fuel wood. Vegetation is that the cover land consists of (composed of) grasses, shrubs and trees of various types of species. The species, sites and patterns of vegetation are due to the environmental factors (soils, climate, and topography) and biological factors.

The factors of vegetation could have influence directly or indirectly. The factors that affect directly are radiation, soil moisture and humidity since the effects can be recognized. The indirect effects include slope and flora in soil. The effects of the scale of factors could be extended at large such as by temperature and also limited locally by soil moisture and soil composition. Generally, the factors are classified into four: (1) climate, (2) edaphic factor, (3) physical factor, and (4) biological factor (Toumy, 1958).

Vegetation is affected by different interacting environmental factors, and thus difficult to distinguish the dominant factor that exerts strong influences upon forest. Due to this, complex relationship of vegetation and environmental factors, there are different basis for classification.

Based on the criteria of classification of land use/land cover by FAO, the main land use/ land cover units distinguished in the watershed are forestland(least disturbed, highly disturbed), woodland, bush land, shrub land, cultivated land, swampy (wetland), bare land(degraded land) and others. Figure 4.5 shows the attributes land use /land cover for Malagarazi sub basin

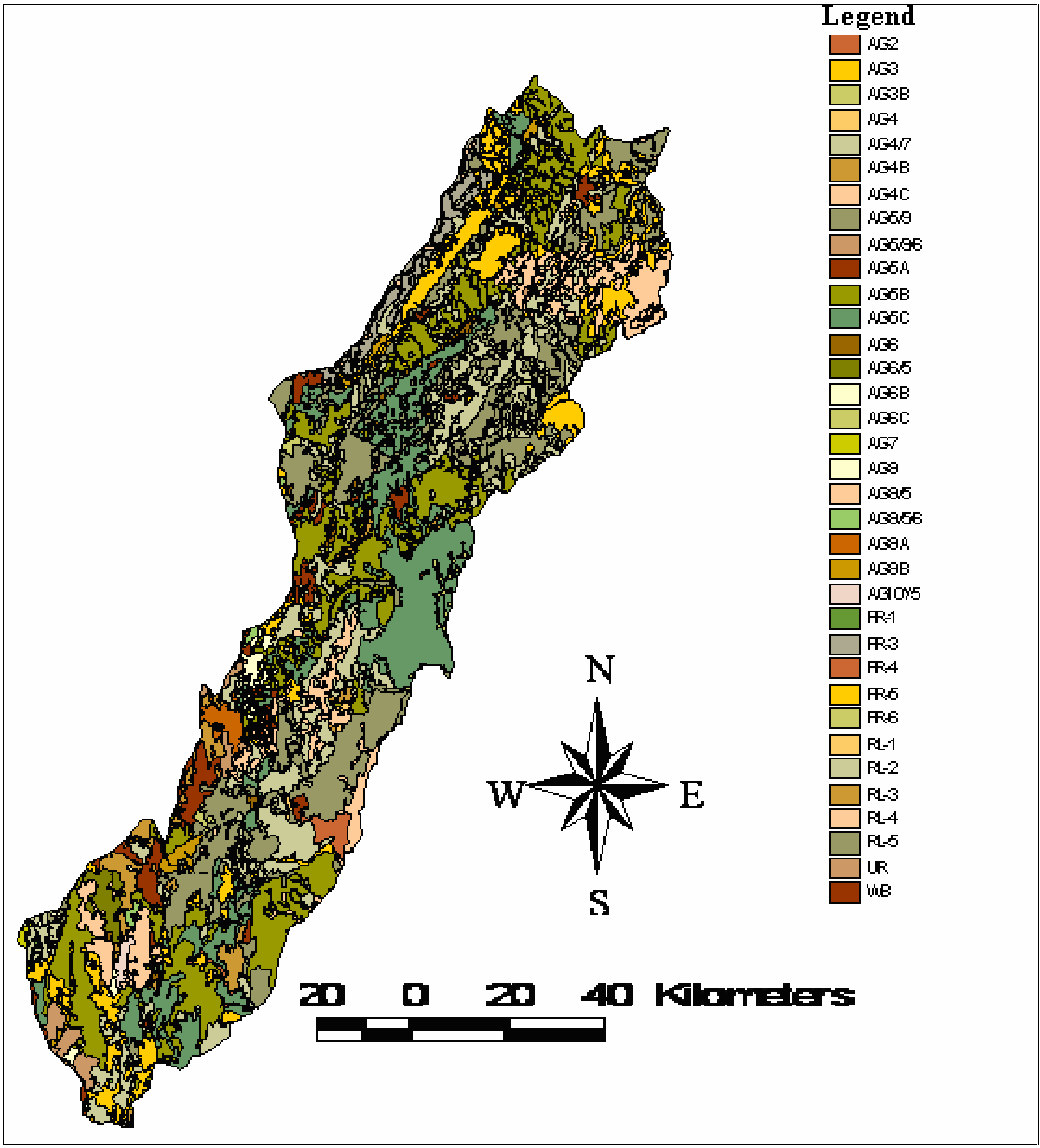

Figure4. 5: Land use/ land cover of Malagarazi sub basin (FAO, 1984)

The land cover/land use condition for the basin is extracted from the land use/land cover map of Burundi, which was developed by Ministry of Territory, Tourism and Environment. Diversified land use and land cover patterns are summarized in the table 4.7

Table 4.7 Malagarazi land use classification

Land cover ID	Descriptions of land cover names
AG-2	Closed herbaceous vegetation
AG-3	Closed herbaceous vegetation on Permanently Flooded Land - Fresh Water
AG-3B	Closed herbaceous vegetation with Sparse trees in Temporarily Flooded Land - Fresh Water
AG-4	Closed Shrubs
AG-4/7	Closed trees
AG-4B	Combination of banana Plantation and Rainfed Herbaceous Crop -Two crop per year (approx.60- 70% and 30- 40%)
AG-4C	Combination of Forest Plantation and Rainfed Herbaceous Crop -Two crop per year (approx.40- 60% and 20 40%); Remaining natural vegetation)
AG-6/9	Combination of Rainfed Herbaceous Crop -Two crop per year and Shrubs Plantation (approx.40- 60% and 20 40%); Remaining Forest Plantation)
AG-6/9/6	Combination of Rainfed Herbaceous Crop -Two crop per year and Shrubs Plantation (approx.40- 60% and 20 40%); Remaining natural vegetation)
AG-6A	Combination of Rainfed Herbaceous Crop and Rainfed tree crop or Palm Plantation (approx.40- 60% and 20 40%); Remaining natural vegetation)
AG-6B	Combination of Shrubs Plantation and Rainfed Herbaceous Crop -Two crop per year (approx.40- 60% and 20 40%); Remaining Forest Plantation)
AG-6C	Combination of Shrubs Plantation and Rainfed Herbaceous Crop -Two crop per year (approx.40- 60% and 20 40%); Remaining natural Plantation)
AG-6	Forest Plantation -(Eucalyptus)or Pinus and Cypress
AG-6/6	Irrigated Herbaceous Crop
AG-6B	Isolated (in natural vegetation or other) Forest Plantation (Eucalyptus) or Pinus and Cypress (field density 10 -20% polygon area)
AG-6C	Isolated (in natural vegetation or other) Rainfed Herbaceous Crop -Two crop year (field density 10 -20% polygon area)
AG-7	Isolated (in natural vegetation or other) Rainfed Herbaceous Crop (field density 10 -20% polygon area)
AG-9	Open Broadleaved Deciduous Trees
AG-9/6	Open shrubs
AG-9/6/6	Open Shrubs (on temporarily flooded land - fresh water)
AG-9A	Post Flooding Herbaceous Crop
AG-9B	Rainfed Herbaceous Crop
AG10"/6	Rainfed Herbaceous Crop-Two Crop year (mixed unit with natural vegetation or other)(field area approx.60%polygon area)
FR-1	Rainfed tree crop or Palm plantation
FR-3	Savannah (shrub or tree and shrub)
FR-4	Scattered (in natural vegetation or other) Forest Plantation (Eucalyptus) or Pinus and Cypress (field density 20 -40% polygon area)
FR-6	Scattered (in natural vegetation or other) Post Flooding Herbaceous Crop (field density 20 -40%polygon area)
FR-6	Scattered (in natural vegetation or other) Rainfed Herbaceous Crop-Two Crop year (field density 20 -40% polygon area)
RL-1	Scattered (in natural vegetation or other) Rainfed Herbaceous Crop (field density 20 -40% polygon area)
RL-2	Scattered (in natural vegetation or other) Shrub Plantation Undifferentiated (field density 20 - 40% polygon area) (field density 20 -40% polygon area)
RL-3	Shrub Plantation -Undifferentiated
RL-4	Shrub Plantation Undifferentiated (mixed unit with natural vegetation or other) (field area approx.60% polygon area)
RL-6	Sparse Herbaceous Vegetation
UR	Urban And Associated Areas
WB	Water Bodies

The land use data analysis shows that combination of shrub plantation and herbaceous crop with two crops per year is dominant in the study area. The South East is more covered with open shrubs along the Malagarazi River, open broadleaved deciduous trees and savannah located in East reserve national. The agriculture in this zone is scattered and mixed with shrubs plantation and rainfed herbaceous Crop. The irrigation schemes are observed in the individual farming with the flooding irrigation system with Malagarazi River and its tributaries. As we can see, the study area is suitable for irrigation with growing crop vegetation.

However, the respective land use and cover conditions have been mapped many years ago and need to be updated. With this respect, areas covered with Bad Lands, swampy areas, restricted/controlled areas are not clearly visible to be excluded from potential capacity estimation. The irrigable area has also increase now.

4.6.3. Landscape of Malagarazi

The figure 4.6 shows the attributes of landscape of Malagarazi sub basin.

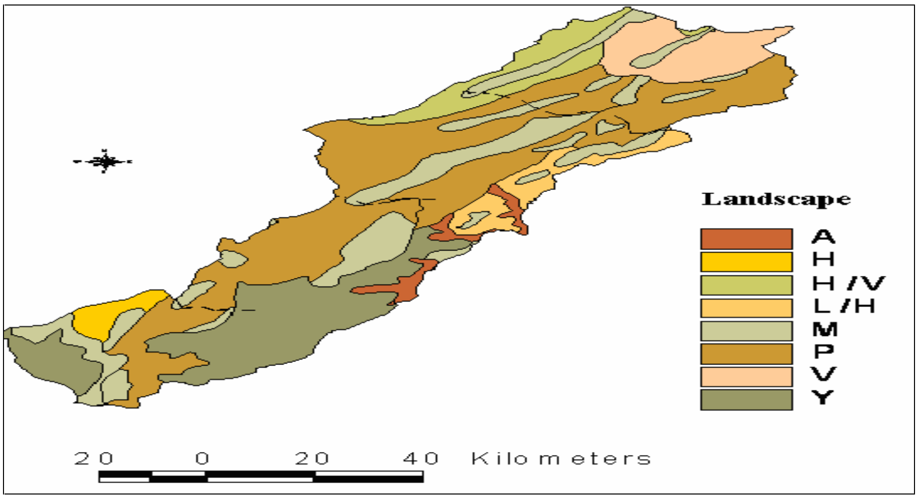

Figure 4.6: Landscape of Malagarazi sub basin

The major landform identified within the basin consists of the alluvial landform (A), Valley (V), Mountains (M), Plain (P), Hill (H), and Valley with hill (H/V). From this result one can consider that plane and relatively valley area could be considered as suitable areas for agriculture from topography point of view, the soil suitability, the water availability and the land use/ land cover (figure 4.5).

4.6.4 Soil class

Qualitative land evaluation for irrigation is generally based on interpretation of environmental characteristics, of which slope and soil type are the most important factors. The attributes of the FAO-soil map of Burundi are used for agricultural land use in general and irrigation appraisal such as topography, drainage, texture, surface stoniness and depth conditions. With these criteria, an identified soil class (ab) is the dominant soil class (figure 4.7).

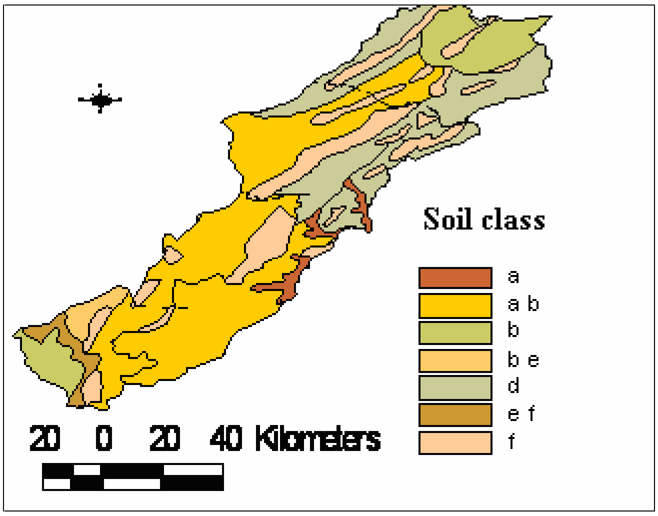

Figure 4.7: Soil class

Additional information on soil type in the Malagarazi sub basin has been sought using the GIS ArcView 3.3 software analysis and seven class of soil are identified (figure 4.7). The basin is characterized with diversified geomorphology and soil patterns. However, the identification of representative soil textures and their physical properties are based on the FAO's classification. The table 4.8 summarizes the identified soils class and their physical characteristics in Malagarazi sub basin.

Table 4.8: Malagarazi soil classification and characteristics

Soil type		Identified soil characteristics			
FAO class1	Soil class1	Slope	Condition for irrigation	Drainage	Surface stoniness
CMo.or	a	0%-2%	Optimum	Poor	0
		2%-8%	Marginal	Well	
CMu.ch	ab	0%-2%	Optimum	Poor	0
		2%-8%	Marginal	Well	
		8%-16%	Inadequate	Well	
CMu.or	b	0%-2%	Optimum	Poor	0
		2%-8%	Marginal	Well	
		>8%	Inadequate	Well	
FRh.or	be	0%-2%	Optimum	Poor	0
		2%-8%	Marginal	Well	
		8%- 16%	Inadequate	Well	
FRu.um	d	0%-2%	Optimum	Poor	0
		2%-8%	Marginal	Well	
		>8%	Inadequate	Well	
HSs.dy	ef	0%-2%	Optimum	Poor	0
		2%-8%	Marginal	Well	
		>8%	Inadequate	Well	
LPq	f	>30	Marginal	Well	0

Soil data results revealed topography (slope), drainage and surface stoniness conditions favourable for agricultural purposes. With FAO classification criteria, seven soil classes have been identified in Malagarazi sub basin. Soil class (ab) is the dominant with characteristics fully suitable for agriculture. It covers more than 70% of Malagarazi land from southern to Northern part of the basin. Soil class (d) is also fully adequate for agriculture and is observed in North West of the basin. Soil class (a) is present in small portion in Western party of the basin. Soil class (b) and (be) are partially suitable for agriculture with some inadequate portion because of soil slope (>10%). Soil class (b) is present in small portion of Eastern and Northern boarder of the basin and soil class (be) is observed in small Eastern portion of the basin. The soil class (f) is found on small portion throughout the dominant soil and is totally unsuitable for agriculture because it is dominated by mountains. The soil (ef) is located in Southern Eastern party of the basin and is not suitable for agriculture.

4.7. Analysis of Hydrological Characteristics Generated From DEM of MALAGARAZI sub basin

4.7.1. Digital Elevation Model (DEM)

Problems in interpolating a digital elevation model (DEM) from topographic maps have been invoked in the literature (e.g. Burrough and McDonnell, 1998; Wilson and Gallant, 2000): elevation values are explicitly available only along contour lines. DEMs and DEM-derivatives have been often used as explanatory variables in continuous soil attributes mapping. However, in many instances the amount of error propagation cannot be neglected and should be accounted for when using these regression-based techniques (Burrough, 2000).

The Digital Elevation Models (DEMs) are point elevation data stored in digital computer files. These data consists of x, y grid location and point elevation data or z variables. They are generated in a variety of ways for a variety of map resolution or scales. The most widely used data structures for elevation values of square-grid cell net works. A DEM is a raster-based depiction of the earth surface and assigns each cell an elevation value, which is represented by a color. The accuracy of such data depends on the size of the grid mesh and on the applied data types. For the implementation of hydrological calculations on the basis of the DEM, a surface free, called sink is necessary. A sink is usually an incorrect value which is lower than the values of its surrounding. Hydrological information can not be derived from DEM until the sinks have been identified and filled afterwards because any water which flows into them cannot flow out and would therefore cause incorrect results. The DEM of Malagarazi sub basin is showed in figure 4.8

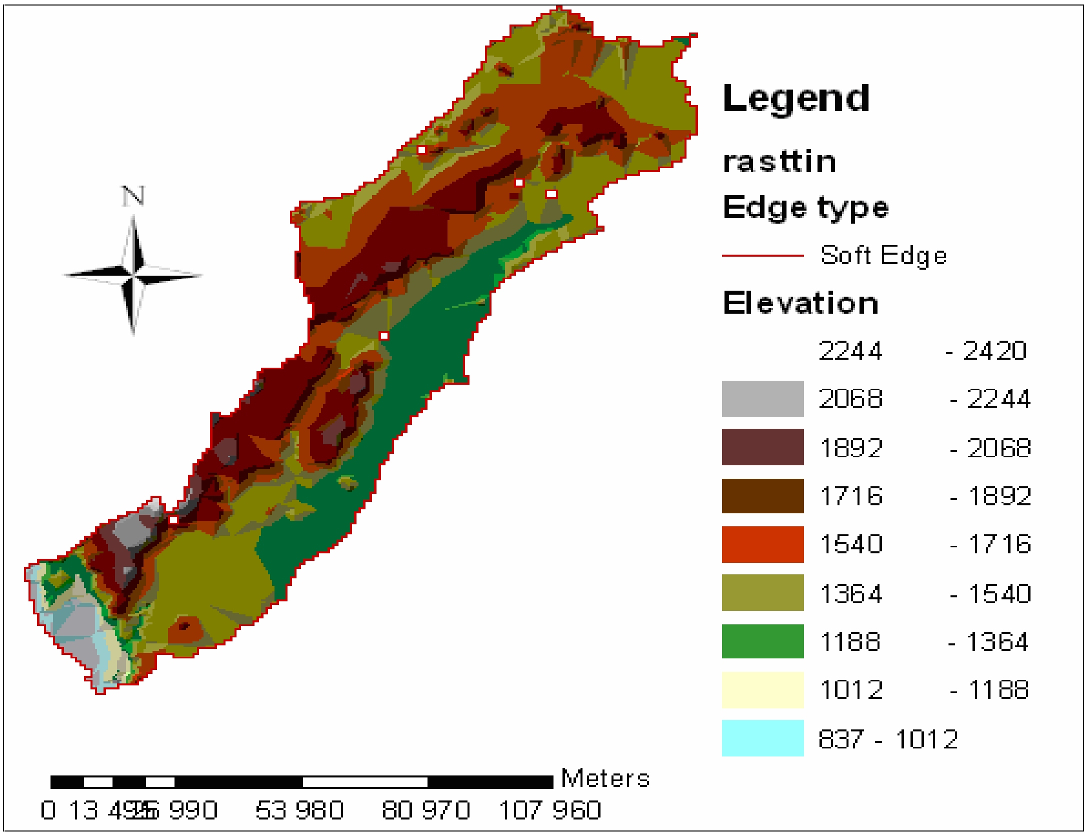

Figure 4.8: Elevation of Malagarazi sub basin

Figure 4.8 shows the elevation of Malagarazi sub basin. As it can be seen, the elevation ranges from 837 to 2420 m. The upper areas of Muyovozi river basin (Rutana), the North East of Rumpugwe (Mpungwe Mountain range in Ruyigi), North Eastern escarpments of Cendajuru (Cankuzo) depression and highland are characterized with rugged topography and elevation range of 1540m- 2420m above sea level. The rapid increase in elevation for this range shows the variation in slope within short distance interval. These areas have not been considered as potentially suitable for agriculture nor for irrigation. Potential irrigable sites which theoretically could be developable are identified with altitude range below 1540m based on slope and water availability. GIS tools, contours lines and map information are used to locate areas with small slopes (≤ 10%). Detail description can be obtained from slope map derived from DEMs.

4.7.2 Analyzing surface of DEM

There are two groups of surface functions in Arc-View GIS, a category for creating surfaces and a category for analyzing surface. The function of the first category, called surface interpolators, creates a continuous surface from sampled input point values. Surfaces are represented by continuous variables whereas map features mostly taken from print outs such as administrative area boundaries are represented by discrete variables. One creates a surface by interpolating values of cells. The values each cell is the value of the point at the center of the cell, and the value of other locations within the same cell is interpolated from the cell center and the centers of neighbouring cells.

The second category uses a continuous grid theme to perform a specified calculation, which results in different representations of the surface. It derives patterns which are not visible in an original surface. The following functions in Arc-GIS were applied:

- Contours
- Aspect
- Slope

A. Contours

The base map has been translated from a topographical map of Burundi at scale of 1:250,000. A manual digitizing procedure at 25 m interval was adopted to generate the contour map of the watershed which will further be used to generate important derivative products such as slope, aspect, flow accumulation, flow direction , etc. This analysis is also a major tool to indicate the appropriate method of irrigation to be adapted on a specific area once the slope of the watershed is identified. The result for contour map of Malagarazi sub basin is in annex H.

B. Slope:

Slope is defined by a plane tangent to the surface as modelled by the DEM for all grid cells. The slope gradient can be understood as the maximum rate of change of altitude. The calculation of slope from DEMs is particularly important for derivation of flow direction, flow accumulation, slope length, terrain units and estimation of potential gravitational energy, etc

The output slope grid theme represents the degree of slope for each cell location. Data on slope is provided as floating data. The main significance of developing slope map of the Malagarazi sub basin is to observe how flat, mild and steep the slope is. Observing the derived slope of the sub basin, different methods of irrigation, with the suitable soil can be suggested. Figure 4.9 shows the slope of Malagarazi sub basin derived from DEM

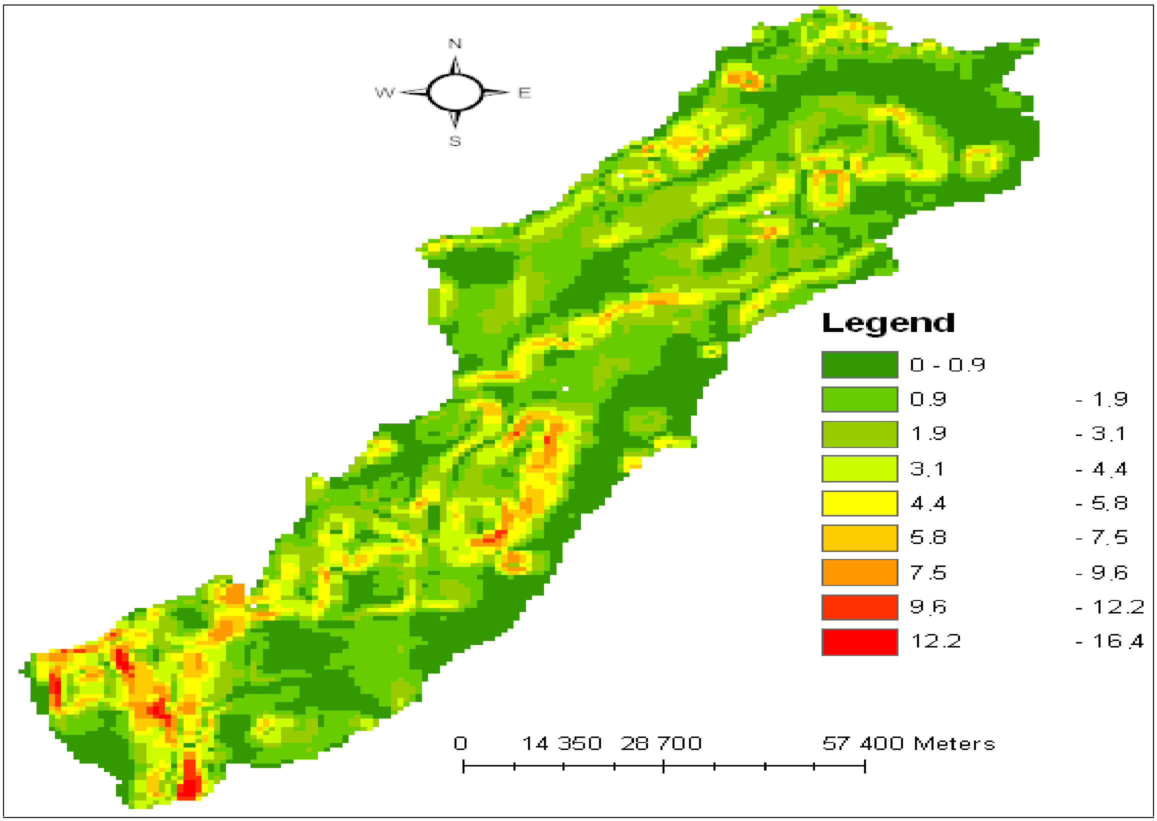

Figure 4.9: Slope of Malagarazi sub basin derived from the DEMs

Figure 4.9 shows that the slope of the study area is less than 16.5 % and the values range from 12.2 to 16.4 shows the area which is occupied by the mountains. That part of the study area is not suitable for surface irrigation method according to FAO criteria.

C. Aspect

The aspect function identifying the steeps down slope direction from each cell to its neighbours. This helps in identifying to which direction does the slope takes place that the direction of the runoff can be estimated prior to the development of the flow direction. Data on flow direction are provided as integers. The result is shown in annex H.

4.7.3. Overview of Hydrological Parameters

The following parameters can be generated from the DEM of the Malagarazi watershed with the hydrological functions of ArcView extended with the spatial analyst and hydrological functions:

- Flow direction
- Flow accumulation

- Sub-basin delineation

A. Flow Direction and Flow accumulation

The function Flow Direction computes the flow direction for each cell in the DEM. The direction in which water will flow out of each cell is encoded to correspond with the orientation of one of the eight cells which surround the cell. The flow direction is delineated by the steepest gradient between the neighboring cells. In flat areas the flow directions are iteratively calculated so that the flow path traverses the flat and continues downhill at one of the flat's spill points. Flow directions are thus quantified into eight possibilities, and cannot represent large facets oriented towards angles other than these eight. The hill-shed is used to enhance the relief of the surface. This map was combined with the main river network of the Malagarazi watershed to represent how the rivers flow through the developed valley (fig 4.10).

The second conditioning step is the computation of flow accumulation value for each cell. This is the count for each cell of how many upstream cells contribute to it based on their flow directions. The delineation of sub-basins, hence, is done on the result of the flow accumulation (figure 4.10)

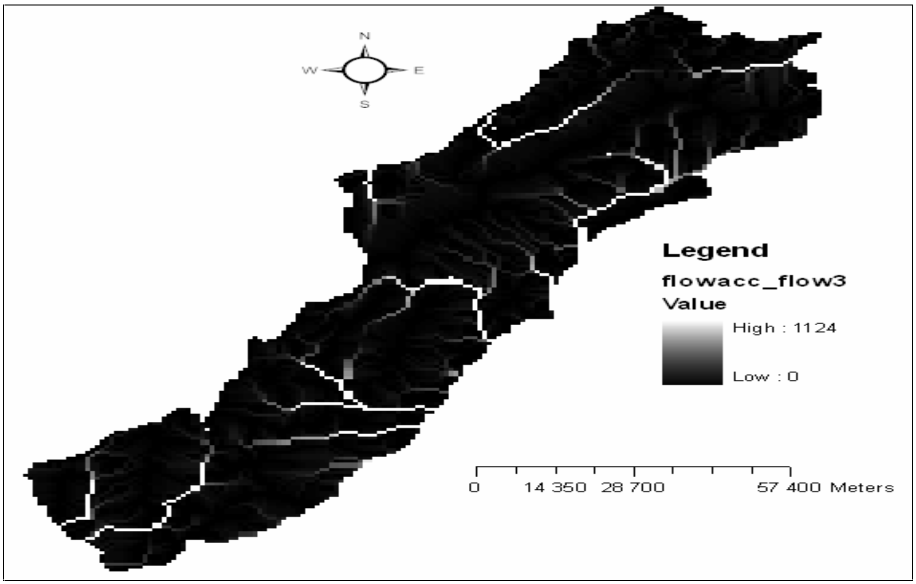

Figure 4.10: Flow accumulation and flow direction of Malagarazi sub basin

The results (figure 4.10) shows that the major rivers (Muyovozi, Rumpungwe, Mukazye and Rukoziri) and their tributaries flow from the North Eastern party to Sousth Ouestern party of

Malagarazi sub basin before traversing in Tanzania. The flow accumulation value is range from 0 to 1124.

B. Sub-basin Delineation

After the conditioning phase, the database can be further processed to delineate watershed from the DEM. Sub basin generation can be proceeded manually with the pre-requisite that the delineation goes hand in hand with study under consideration. Four sub-basins were identified for these study based on the threshold of their contribution to flow.

The flow which will be generated from these sub-basins will be one of decision parameter weather the area at the outlets of the sub-basins can benefit from the use of irrigation. This being only one parameter, other parameters like the irrigable land availability should also be considered. Taking into account the land use/ land cover, the topography (slope), the soil class, the landscape, the elevation, the attributes soil units and the available water, the study area is suitable for irrigation.

Identification of potential irrigable areas in Malagarazi sub basin is referring to the area which can potentially be irrigated. It depends on the physical resources "soil" and "water". The potential cultivable areas are delineated from Malagarazi sub basin contour map based on slope which is assumed to be less than 10%. The contour lines with 25 m intervals have been created and slope can then be estimated by dividing the differences between two altitude levels by the measured distance between two consecutive contour lines. The sub basins, in which these potential areas lie, have been identified and the results are given in table 4.9

Table 4.9: Irrigable area in the Malagarazi sub basin (based on slope as criteria for surface irrigation method)

ID Number	Sub-basin name	Area (sq.km)	Perimeter (Km)	% Area
1	Rukoziri	5.27	5.52	23.86
2	Muyovozi	9.85	9.47	31.64
3	Rumpungwe	8.59	8.28	27.58
4	Mukazye	7.43	7.41	16.92
TOTAL		**31.14**		100.00
Existing irrigable area		19.41		

In this regard, the potential irrigable areas are estimated to be 31.14 km^2, this doesn't exclude the residential areas or natural reserves such as natural reserves of Murore and Moso. It represents about more than 2 % of the total Malagarazi land. From the above irrigable area of 31.14 Km^2, we have to set the criteria for estimating which area can be developed using surface irrigation.

Thus for evaluating the approximate potential irrigable areas, the residential areas have to be excluded. To estimate these residential areas considering the current potential result a certain assumption should be made regarding the average house area occupied, the number of persons per family in order to estimate total number of house within the identified area.

Assumption statements:

- ⇒ Number of person per family (one house) =6
- ⇒ Total Population in the study area =1 406,680 (within area of 8,223 km^2),
- ⇒ Residential area size per family (one house)=300 m^2/house

Then we calculate number of population in identified potential irrigable area = (31.14 km2*1,406,680 persons)/8,223 km2 = 5,327persons.

Number of house within identified potential irrigable area 5,327 persons/6 per house = 887.8 houses

Residential area= 887.8 houses *300 m^2/house = 266340m^2 = 0.266340 km^2

Hence, the potential irrigable area is approximated to be:

31.14 Km2 - 0.266340 km2 =30.87366 km^2

During the creation of SOSUMO in 1982, a concession of 5,800 ha was gracefully put under his procession. It is however seen that a part of this concession (2.5ha) is in marshy zone and thus little or not exploitable. Thus, potential irrigable area is 30.87366 km^2 – 0.025km^2 = 30.84866km^2.

The mountains are occupied in 1.25km^2, 0.83 km^2, 1.02km^2, and 0.04km^2 for Rutana, Makamba, Ruyigi and Cankuzo respectively. The potential irrigable area is now 30.84866km^2- 3.14km^2 = 27.70866 km^2

Note that, the considered potential irrigable areas does not exclude the others probable restricted areas located in the Malagarazi basin. The potential irrigable area is theoretical estimated at 27.709km^2 and represent about 0.38% of the total area of the Malagarazi basin.

Table 4.10: Potential irrigable areas in the catchments of Malagarazi sub basin (based on the slope, soil, water availability as criteria)

Catchment	Potential irrigable (km^2)	Potential irrigable (ha)
Rukoziri	6.51	651
Muyovozi	8.495	849.5
Rumpungwe	7.50	750
Mukazye	5.20	520
Total	**27.705**	**2,770.5**

The actual irrigated area in Malagarazi sub basin is only 1,941 ha or 19.41km^2 (PDNE, 1998). These irrigated areas include the area with slope greater than 10%. The approximated potential irrigable area (27.705km^2) is greater than the actual irrigable area. It means that there is 8.295km^2 which is not identified using the FAO criteria. This shows that the irrigable area which is not cultivated, can help to reduce the system to cross the borders to go to Tanzania where there is the marsh prepared. It can help also to reduce the current intensified food shortage and poverty in the Malagarazi sub basin.

4.8 Irrigable area and storage requirement for different scenarios of water availability

Crop water demand for common crops in Malagarazi sub basin is estimated using the available climatic, soil and cropping pattern data. The crop water demand over the entire identified potentially irrigable area is calculated and computed with the existing flow. The monthly low flow as well as the 75%, 80%, 90%, 95%, 100% time of exceedence low flow is calculated and compared to the total water requirement of the crop over the irrigable area. Table 4.11 shown the storage at 100% exceedence flow.

Table 4.11: Irrigable area and storage requirement needed considering low flow (100% exceedence)

River	Available discharge (10^3 m^3)	Irrigable area with 100% flow (ha)	Potential irrigable area (ha)	Volume of water required for potential irrigable area (10^6 m^3)	Storage requirement (10^6 m^3)
Muyovozi	101,240	81.93	849.5	1050,212	948,972
Mukazye	936.62	1.90	520	256,339	255,402
Rumpungwe	17,830.45	54.53	750	245,238	227,408
Rukoziri	29,306.40	92.77	651	205,653	176,347

There is storage requirement in order to meet the irrigation water requirement of potential identified area with different scenario (100%, 95%, 90%, 80%, and 75%) in each sub basin. It means that the flow available is not enough for the potential identified irrigable area.

Scenario 2: Irrigable area and storage requirement needed considering low flow (95% exceedence)

River	Available discharge (10^3 m^3)	Irrigable area with 95% flow (ha)	Potential irrigable area (ha)	Volume of water required for potential irrigable area (10^6 m^3)	Storage requirement (10^6 m^3)
Muyovozi	111,694.20	94.33	849.5	115,685	1,045.150
Mukazye	495.12	1.99	520	130.37	129.88
Rumpungwe	22,781.61	71.96	750	269.73	246.95
Rukoziri	31,277.40	106.41	651	215.75	184.47

Scenario 3: Irrigable area and storage requirement needed considering low flow (90% exceedence)

River	Available discharge (10^3 m^3)	Irrigable area with 90% flow (ha)	Potential irrigable area (ha)	Volume of water required for potential irrigable area (10^6 m^3)	Storage requirement (10^6 m^3)
Muyovozi	122,148.39	102.24	849.5	1,167.24	1,045
Mukazye	53.61	2.75	520	102.15	101.62
Rumpungwe	27,732.76	84.53	750	279.53	251.79
Rukoziri	33,248.4	108.25	651	225.44	192.196

Scenario 4: Irrigable area and storage requirement needed considering low flow (80% exceedence)

River	Available discharge (10^3 m^3)	Irrigable area with 80% flow (ha)	Potential irrigable area (ha)	Volume of water required for potential irrigable area (10^6 m^3)	Storage requirement (10^6 m^3)
Muyovozi	143,056.76	113.6	849.5	1,230.34	1,087.28
Mukazye	829.4	3.88	520	112	111.18
Rumpungwe	37,635.06	104.02	750	308.26	270.62
Rukoziri	37,190.4	109.56	651	249.16	211.97

Scenario 5: Irrigable area and storage requirement needed considering low flow (75% exceedence)

River	Available discharge (10^3 m^3)	Irrigable area with 75% flow (ha)	Potential irrigable area (ha)	Volume of water required for potential irrigable area (10^6 m^3)	Storage requirement (10^6 m^3)
Muyovozi	153,510.94	117.042	849.5	1,281.42	1,127.91
Mukazye	1,270.90	3.95	520	168.59	167.32
Rumpungwe	42,586.21	110.96	750	326.99	284.41
Rukoziri	6,538.07	111.03	651	43.22	36.68

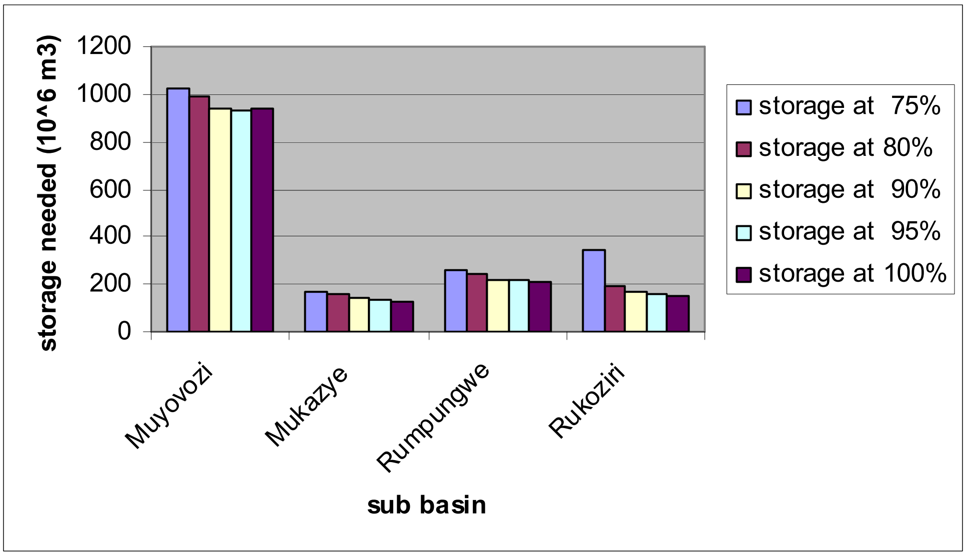

Figure 4.11: Storage requirement at different flow levels

Those five scenarios show that the storage requirement is high in Muyovozi river than others rivers in the basin. Muyovozi has a big discharge which can contribute much to the storage. In each river, the storage is descending at 75% to 100%. The figure 4.12 shows the irrigable area for different scenarios of availability water.

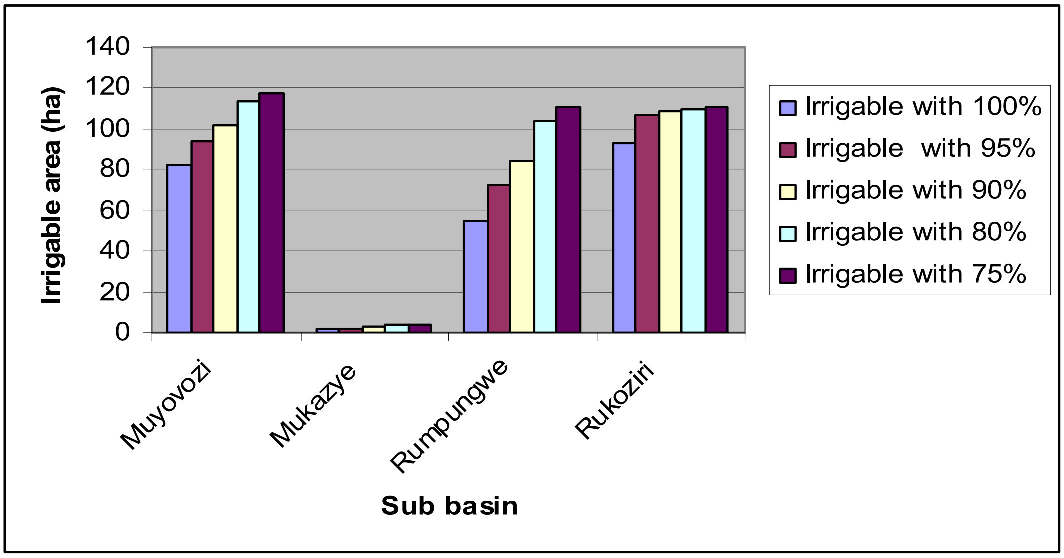

Figure 4.12: Irrigable area for different scenarios of availability water

The irrigable area is high in Muyovozi River basin when compared to other rivers. The lowest in the size of irrigable area is Mukazye River basin. Taking into account the available water in each river, the irrigable area is high by 75% exceendence flows than 100%.

4.9 Estimation of Gross irrigation water requirement for the identified potential areas

Table 4.12 shows the Gross irrigation requirement in Malagarazi sub basin with 70% of application efficiency.

Table 4.12: Field water requirement

Sub basin	Type of crop	Irrigation Water requirement (IWR) (mm)	Gross Irrigation requirement = IWR/ 0.70 (mm)	FWR (Field Water Requirement)	
				l/sec/ha	m^3/ha/season
1.MAKAMBA (NYANZA LAC)	MANGO	169.2	241.71	0.14	4415.04
	CITRUS	184.30	263.28	0.08	2522.88
	POTATO	136.83	195.47	0.17	5361.12
2.RUTANA (MUSSA)	Maize	118.67	169.53	0.15	4730.4
	Cotton	481.72	688.17	0.41	12929.76
	Banana	940.91	1344.16	0.43	13560.48
3.RUYIGI (KINYINYA)	GREEN BEAN	74.94	107.06	0.04	1261.44
	TOMATO	363.89	519.84	0.41	12929.76
	COTTON	160.85	229.78	0.14	4415.04
4.CANKUZO	Soybean	53.82	76.88	0.07	2207.52
	Date PALM	165.28	236.12	0.12	3784.32
	Tobacco	172.12	245.89	0.26	8199.36

Note that these values are estimated from the field water supply in liter per second per hectare and converted into m^3/ha/year.

Hence, for a number of purposes such as irrigation potential assessment and estimating the number of total irrigation demand, it is often sufficient to adopt a Field water Requirement in m3/ha/unit of time or km3/ha/unit of time. The total Gross irrigation requirement for Malagarazi sub basin shows that big gross irrigation water requirement was found for banana and the small quantity is for soybean. This is because the banana crop has longer growing period than the others.

CHAPTER FIVE: SUMMARY, CONCLUSION AND REMMENDATION

5.1. Summary and conclusion

The objective of this study was to identify potential irrigable area in the Malagarazi sub basin and to provide GIS based irrigation suitability criteria through the assessment of the natural resources such as soil, land use and water availability.

The GIS environment was used to identifying potential suitable areas for irrigation. Suitability criteria were set based on parameters such as slope, soil, land use/land cover and water availability for irrigation. General reviews on characteristics and detail information on water resources available in the study area have been also made.

Furthermore, analyse of climatic and hydrology data and checking for there consistency by using mass curves method have been done. Adjusting for the incorrect records for some of the stations were also done before estimating ETo and crop water requirement. The analysis of the crop water demand was made to evaluate whether irrigation is required or not. Assisted by the CROPWAT software, the water requirements of different crops in the respective sub basins were made.

The available surface water potential and the potential irrigable area were estimated for each river in the basin in order to have reliable low flow. Flow Duration Curve (FDC) was developed and different percentage of exceedence low flow were estimated. The total crop water requirement and irrigable area were estimated under the scenarios of 75%, 80%, 90%; 95% and 100% river flows, i.e exceedence flow.

In the present work, criteria used for the evaluation of soil and terrain suitability for irrigation are topography (slope), soil classification, land use/land cover, drainage condition for irrigation and surface stoniness. With this regard, the DEMs show slope variation in the basin and the potential flow direction is easily observed from its derivatives (flow accumulation, flow direction). GIS based database that include soil classification in the basin, slope, land use land cover have been developed. The potential irrigable area identified using water availability criteria, slope, and soil is respectively 651ha; 849.5ha; 750ha; and 520ha for Rukoziri, Muyovozi, Rumpungwe and Mukazye rivers. The result showed that the total available irrigation potential can not be developed with the available water. Hence, storage is essential. The storage requirement was estimated based on 75%, 80%, 90%, 95% and 100% exceendence flow.

It can be concluded that the identified suitable area for irrigation in Malagarazi sub basin is 2,770.5ha whereas the existing irrigated area is about 1,914 ha only. This potential irrigable area can help the population of Malagarazi sub basin which is largely rural and dependent on agriculture for their livelihoods. It will reduce the chronic malnutrition, poverty, hunger, and periodic crisis induced by consecutive drought.

Furthermore, the population of Malagarazi sub basin which has less than 300m^2 per household can get more land and increase agricultural production by more than two times in a year. This database would help decision makers, investors, planners and policy makers at the local, regional and national levels to make informed decision and investment.

5.2 Recommendation

Based on the findings of this study the following recommendation can be given:

1. It is recommended to the planners and policy makers to exploit the identified irrigable area in Malagarazi sub basin in order to use the available resources and increase productivity

2. The present study used only surface water resource in the basin to estimate potential irrigable area. The obtained area could be much higher if conjunctive use of surface and groundwater resources is considered. Therefore, the groundwater contribution for irrigation development has to be assessed in the future works.

3. It is recommended to update the land use/land cover of the country because the data used is very old; the land cover might have change after 1984 due to many factors (climate, erosion, degradation, etc)

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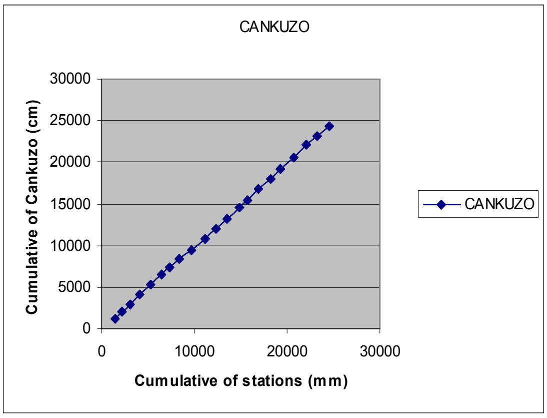
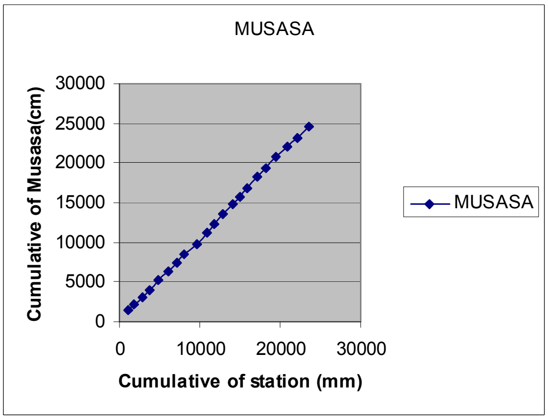
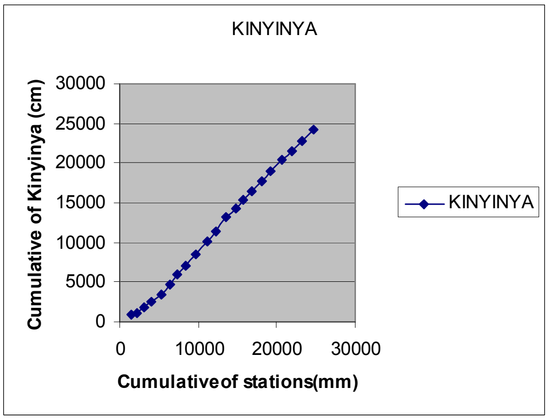
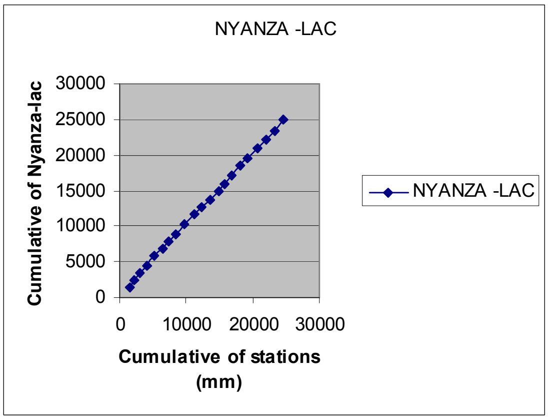
APPENDICES

APPENDICE -A. Double mass curve of rainfall data for Malagarazi sub basin









APPENDICE -B. Areal precipitation for Malagarazi sub basin

N°	Stations	Rainfall (mm) (B)	Thiessen polygon	Area of polygon (km2) (Ai)	Total Area (km2) (A)	Weighting factor Ai/A =C	Areal precipitation (mm) (B)*(C)
1	CANKUZO	1161.9	1	362.64	3247.35	0.11167259	129.75
2	RUTANA (Musasa)	1126.2	2	990.19	3247.35	0.30492248	343.41
3	RUYIGI (Kinyinya)	1145.2	3	1340.77	3247.35	0.41288127	472.83
4	MAKAMBA (Nyanza-lac)	1186.75	4	553.75	3247.35	0.17052366	202.37
Sum							1148.36

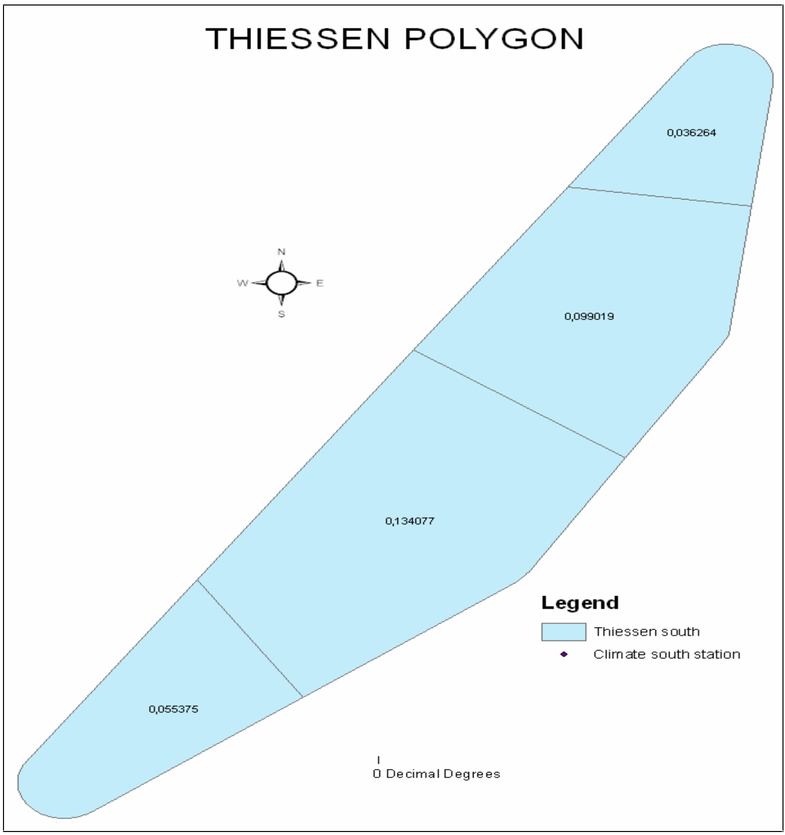
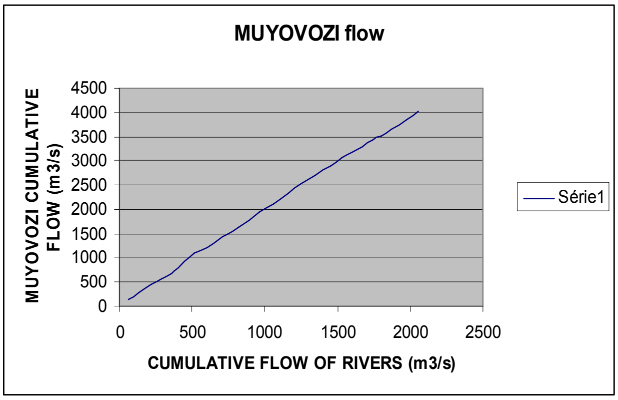
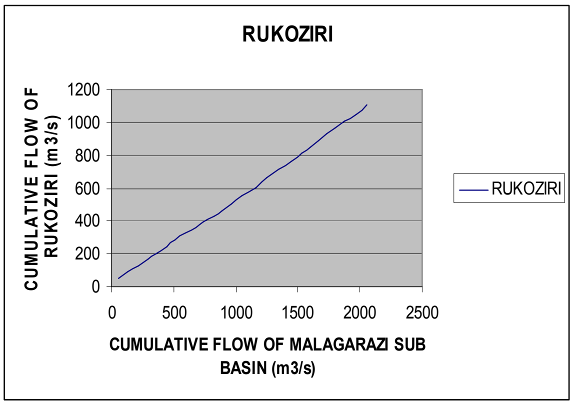
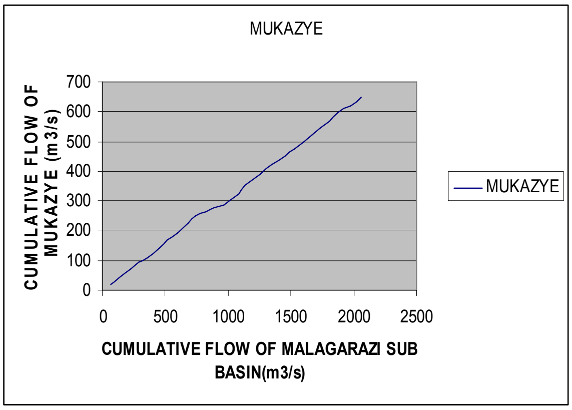


Figure 1: Thiessen polygon

APPENDICE -C. Double mass curve of flow data







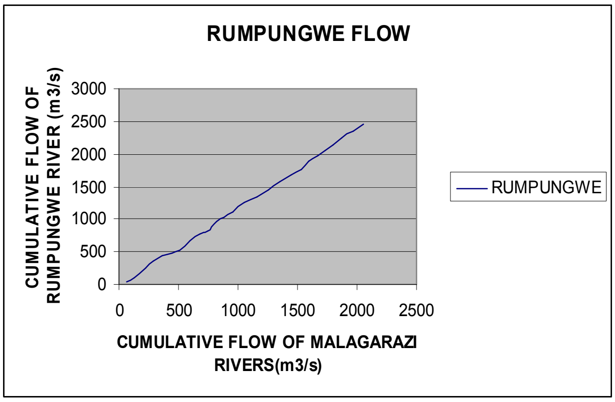
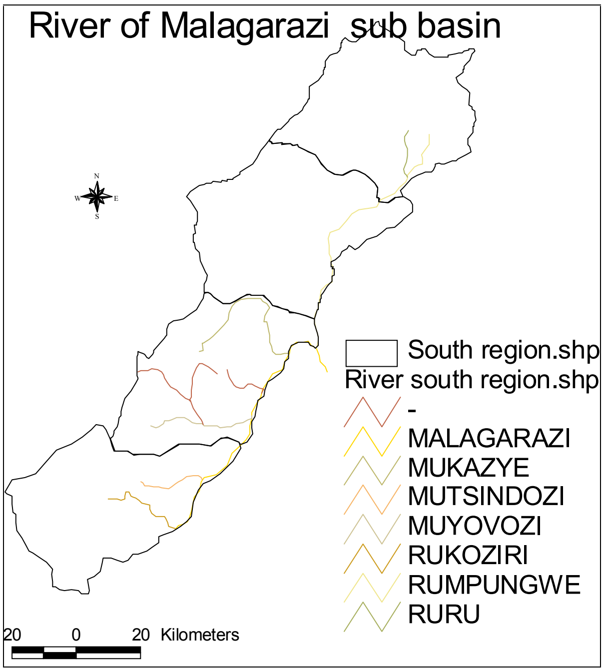
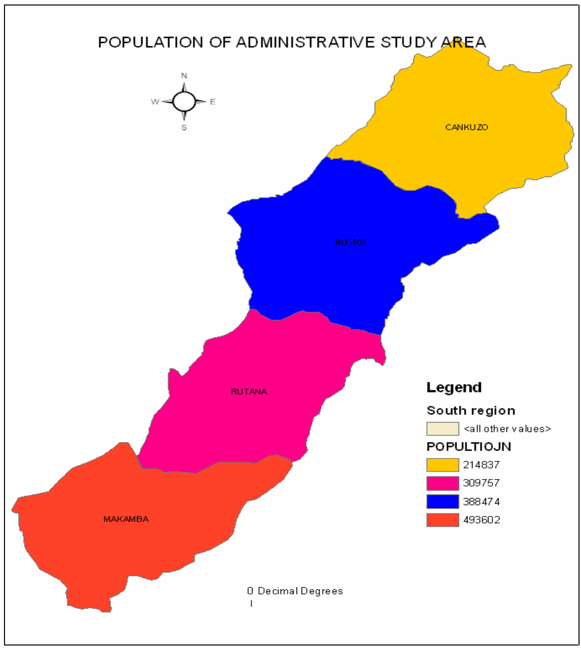


Figure2: Major rivers and population in Malagarazi sub basin





APPENDICE -D. Climatic data and estimated ETo for different stations

Table D.1. Climatic data and estimated ETo values of Musasa station

Country: BURUNDI Station : Musasa : Altitude : 1260 m Long : 30°6' E Latitude : 4° S								
Month	Max Temp °©	Min Temp ° ©	Avg	Relative Humidity (%)	Wind speed (Km/d)	Sunshine (Hrs)	Solar Radiation ($MJ/m^2/d$)	ETo Pen-Moniteith (mm/d)
Jan	27.8	16.2	21.7	78.0	0.5	9.0	23.3	4.2
Feb.	29.2	15.9	21.9	75.5	0.6	8.0	22.2	4.1
Mar.	28.5	16.0	22.1	76.3	0.6	7.0	20.6	3.8
Apr.	27.8	16.5	22.1	77.3	0.5	7.0	19.6	3.5
May	28.3	15.8	21.6	75.3	0.4	9.0	21.0	3.6
June	28.4	13.1	20.9	67.5	0.6	10.0	21.4	3.3
Jul.	29.0	12.1	20.7	64.0	0.7	11.0	23.2	3.5
Aug	30.9	13.4	22.1	59.5	0.8	11.0	24.7	4.0
Sept.	32.0	15.4	23.7	59.3	0.9	10.0	24.7	4.2
Oct.	30.6	16.5	23.1	66.0	1.0	9.0	23.6	4.2
Nov.	28.9	16.6	22.0	76.3	1.0	9.0	23.3	4.2
Dec	28.1	16.3	21.7	79.7	0.6	8.0	21.3	3.9
AVG	29.1	15.3	21.9	71.2	0.7	9.0	22.4	3.9

Table D.2 Climatic data and estimated ETo values of Cankuzo station

Country: BURUNDI

Station : Cankuzo : Altitude : 1652 m

Longitude : 30°22'48'' E

Latitude : 3°16'48'' S

Month	Max Temp °©	Min Temp ° ©	Avg	Relative Humidity (%)	Wind speed (Km/d)	Sunshine (Hrs)	Solar Radiation ($MJ/m^2/d$)	ETo Pen-Moniteith (mm/d)
Jan	24.7	13.1	18.8	74.2	0.9	1.1	11.0	2.2
Feb.	25.3	13.1	19.2	73.9	1.0	1.2	11.4	2.3
Mar.	25.2	13.3	19.2	76.3	1.0	1.3	11.6	2.3
Apr.	24.9	13.7	19.2	80.6	1.5	1.3	11.0	2.2
May	24.7	13.6	19.2	79.7	1.3	1.4	10.4	2.0
June	25.0	12.5	18.7	66.2	1.6	1.4	9.9	1.9
Jul.	25.4	12.6	19	55.5	1.8	1.4	10.1	1.9
Aug	26.7	13.7	20.2	49.9	1.2	1.4	10.8	2.1
Sept.	27.6	14.1	20.8	56.7	1.2	1.5	11.6	2.3
Oct.	27.0	13.8	20.4	66.0	1.2	1.3	11.5	2.3
Nov.	25.0	13.2	19.1	77.9	1.3	1.1	11.0	2.2
Dec	24.7	13.0	18.8	76.6	1.3	1.1	10.9	2.2
AVG	25.5	13.3	19.4	69.5	1.3	1.3	10.9	2.1

Table D.3 Climatic data and estimated ETo values of Kinyinya station

Country: BURUNDI

Station : Kinyinya: Altitude : 1450 m

Longitude : 30°04'48'' E

Latitude : 2°34'48'' S

Month	Max Temp °©	Min Temp ° ©	Avg	Relative Humidity (%)	Wind speed (Km/d)	Sunshine (Hrs)	Solar Radiation ($MJ/m^2/d$)	ETo Pen-Moniteith (mm/d)
Jan	27.8	16.2	22.0	75.2	0.6	1.1	11.0	2.3
Feb.	28.3	16.1	22.2	72.3	0.7	1.2	11.4	2.4
Mar.	27.8	16.2	22.0	75.3	0.6	1.3	11.6	2.4
Apr.	27.4	16.6	21.9	76.3	0.6	3.4	14.2	2.8
May	27.5	16.1	21.7	72.9	0.5	4.3	14.6	2.7
June	27.8	14.3	21.1	68.8	0.6	5.6	15.7	2.7
Jul.	28.3	13.3	20.8	63.8	0.6	5.9	16.4	2.8
Aug	29.8	14.8	22.2	62.5	0.8	6.2	17.9	3.1
Sept.	30.8	16.1	23.4	69.4	0.6	5.1	17.2	3.3
Oct.	30.2	16.7	23.4	68.5	0.6	4.2	16.0	3.1
Nov.	28.3	16.5	22.4	70.6	0.6	3.1	14.0	2.7
Dec	27.6	16.4	21.9	73.8	0.6	3.5	14.4	2.8
AVG	28.5	15.8	22.1	70.8	0.6	3.7	14.5	1.7

Table D.4 Climatic data and estimated ETo values of Nyanza -lac station

Country: BURUNDI

Station : Nyanza –lac : Altitude : 792 m

Longitude : 29°36'E

Latitude : 4° 21' S

Month	Max Temp °©	Min Temp ° ©	Avg	Relative Humidity (%)	Wind speed (Km/d)	Sunshine (Hrs)	Solar Radiation ($MJ/m^2/d$)	ETo Pen-Moniteith (mm/d)
Jan	28.2	19.2	23.7	96.0	0.6	1.1	11.1	2.4
Feb.	28.7	19.2	23.9	100.0	0.6	1.2	11.5	2.5
Mar.	28.3	19.3	23.8	89.0	0.5	1.3	11.6	2.5
Apr.	28.6	19.4	24.0	78.0	0.7	1.3	10.9	2.3
May	29.3	19.0	24.2	85.0	0.8	1.4	10.3	2.1
June	29.4	17.6	23.4	82.0	0.9	1.4	9.8	2.0
Jul.	29.7	16.4	23.1	59.0	1.0	1.4	10.0	1.9
Aug	30.3	16.8	23.5	51.0	1.1	1.4	10.7	2.1
Sept.	31.1	18.0	24.5	52.0	1.0	1.5	11.6	2.3
Oct.	29.6	19.3	24.4	57.0	0.9	1.3	11.5	2.4
Nov.	28.1	19.3	23.7	76.0	1.1	1.1	11.1	2.3
Dec	27.8	19.1	23.4	97.0	0.9	1.1	11.0	2.3
AVG	29.1	18.6	23.8	76.8	0.8	1.3	10.9	2.3

APPENDICE- E: Cropping pattern, crop data and CWR

Table E.1 Cropping pattern, crop data for cotton, maize and banana in Musasa

Station: Musasa Crop: Cotton Planting date:1 March					
	Growing stages				
	I	II	III	IV	Total
Length of days	30	50	60	55	195
Kc	0.35	1.2	1.2	0.60	
Root depth (m)	0.30	-	-	-	1.40
Depletion	0.60	-	0.60	0.90	
Ky	0.40	0.40	0.50	0.40	0.85

Station: Musasa Crop: Maize Planting date:1 oct					
	Growing stages				
	I	II	III	IV	Total
Length of days	25	40	40	30	135
Kc	0.30	1.20	1.20	0.50	
Root depth (m)	0.30	-	-	-	1.0
Depletion	0.50	-	0.50	0.80	
Ky	0.40	0.40	1.30	0.50	1.25

Station: Musasa Crop: Banana Planting date:1 Dec					
	Growing stages				
	I	II	III	IV	Total
Length of days	135	60	140	30	365
Kc	1.0	1.20	1.20	1.0	
Root depth (m)	0.80	-	-	-	0.80
Depletion	0.35	-	0.35	0.35	
Ky	1.30	1.30	1.30	1.30	1.30

I= initial stage, II= development stage, III= mid stage , IV = Late stage

Table E.2 Cropping pattern, crop data for Tobacco, DatePalm and Soyabean in Cankuzo

Station: Cankuzo Crop: Tobacco Planting date:1 May					
	Growing stages				
	I	II	III	IV	Total
Length of days	20	30	30	30	110
Kc	0.50	1.15	1.15	0.80	
Root depth (m)	0.25	-	-	-	0.80
Depletion	0.40	-	0.50	0.65	
Ky	0.40	1.00	1.00	1.50	1.90

Station: Cankuzo Crop: Date PALM Planting date:1 September					
	Growing stages				
	I	II	III	IV	Total
Length of days	140	30	150	45	365
Kc	0.90	0.95	0.95	0.90	
Root depth (m)	2.00	-	-	-	2.00
Depletion	0.50	-	0.50	0.50	
Ky	0.80	0.80	0.80	0.80	0.80

Station: Cankuzo Crop: Soya bean Planting date:1 February					
	Growing stages				
	I	II	III	IV	Total
Length of days	20	30	60	25	135
Kc	0.40	1.15	1.15	0.50	
Root depth (m)	0.30	-	-	-	1.00
Depletion	0.50	-	0.60	0.90	
Ky	0.40	0.80	1.00	0.40	0.85

Table E.3 Cropping pattern, crop data for Green bean, Tomato and Cotton in Kinyinya

Station: Kinyinya Crop: Green bean Planting date:15 September					
	Growing stages				
	I	II	III	IV	Total
Length of days	20	30	30	10	90
Kc	0.50	1.05	1.05	0.90	
Root depth (m)	0.30	-	-	-	1.00
Depletion	0.45	-	0.45	0.60	
Ky	0.20	0.60	1.00	0.40	1.15

Station: Kinyinya Crop: Tomato Planting date:1 May					
	Growing stages				
	I	II	III	IV	Total
Length of days	30	40	45	30	145
Kc	0.60	1.15	1.15	0.80	
Root depth (m)	0.25	-	-	-	1.00
Depletion	0.30	-	0.40	0.50	
Ky	0.50	0.60	1.10	0.80	1.05

Station: Kinyinya Crop: Cotton Planting date:1 January					
	Growing stages				
	I	II	III	IV	Total
Length of days	30	50	60	55	195
Kc	0.35	1.20	1.20	0.60	
Root depth (m)	0.30	-	-	-	1.40
Depletion	0.60	-	0.60	0.90	
Ky	0.40	0.40	0.50	0.40	0.85

Table E.4 Cropping pattern, crop data for Mango, Citrus and Potato in Nyanza lac

Station: Nyanza -lac Crop: Mango Planting date:15October					
	Growing stages				
	I	II	III	IV	Total
Length of days	90	90	90	95	365
Kc	0.90	1.10	1.10	0.90	
Root depth (m)	2.00	-	-	-	2.00
Depletion	0.60	-	0.60	0.60	
Ky	0.80	0.80	0.80	0.80	0.80

Station: Nyanza lac Crop: Citrus (70% Cover) Planting date:1 December					
	Growing stages				
	I	II	III	IV	Total
Length of days	150	90	90	35	365
Kc	0.70	0.65	0.65	0.70	
Root depth (m)	1.40	-	-	-	1.40
Depletion	0.50	-	0.50	0.50	
Ky	1.00	1.00	1.00	1.00	1.00

Station: Nyanza lac Crop: Potato Planting date:15 March					
	Growing stages				
	I	II	III	IV	Total
Length of days	25	30	45	30	130
Kc	0.50	1.15	1.15	0.75	
Root depth (m)	0.30	-	-	-	0.60
Depletion	0.25	-	0.30	0.50	
Ky	0.45	0.80	0.80	0.30	1.10

APPENDICE- F: Crop water requirement

Table F.1 Crop water requirement estimated for cotton, banana, maize (Musasa)

Station:Musasa Crop: Maize				Planting date: 1 October Irrigation Efficiency: 70%				
Date	ETo(mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1Oct	41.56	100.00	0.30	12.47	18.68	11.17	1.29	0.02
11 Oct	42.05		0.30	12.62	24.45	13.35	0.00	0.00
31Oct	42.68		0.54	22.89	39.17	19.98	2.91	0.05
10Dec	42.24		1.20	50.69	57.06	40.50	10.19	0.17
30Dec	40.75		1.20	48.90	52.26	34.31	14.58	0.24
29Jan	39.88		0.72	28.79	32.10	17.45	11.34	0.19
8 Feb	19.79		0.55	10.82	15.70	8.44	2.38	0.08
TOTAL	**561.97**			**461.90**	**561.15**	**345.39**	**118.67**	**0.15**

Station:Musasa Crop: Cotton				Planting date: 1 March Irrigation Efficiency: 70%				
Date	ETo(mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1Mar	38.36	100.00	0.35	13.43	43.17	26.45	0.00	0.00
21Mar	37.22		0.35	13.03	58.77	39.09	0.00	0.00
30Apr	35.40		0.95	33.75	38.04	22.98	10.77	0.18
20 May	35.00		1.20	42.00	3.54	0.27	41.74	0.69
29Jun	35.62		1.20	42.75	0.00	0.00	42.75	0.71
9 Jul	36.06		1.20	43.27	0.00	0.00	43.27	0.72
18 Aug	38.59		0.81	31.35	0.25	0.00	31.35	0.52
7Sept	19.93		0.62	12.39	4.97	0.00	12.39	0.41
TOTAL	**714.06**			**620.18**	**402.58**	**248.74**	**481.72**	**0.41**

Station:Musasa Crop: Banana				Planting date: 1 December Irrigation Efficiency: 70%				
Date	ETo (mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1Dec	42.54	100.00	1.00	42.54	55.90	38.39	4.14	0.07
31 Mar	36.68		1.00	36.68	62.71	42.26	0.00	0.00
10 Apr	36.18		1.00	36.36	61.14	41.01	0.00	0.00
20 May	35.00		1.13	39.73	3.54	0.27	39.46	0.65
9Jun	35.08		1.20	41.97	0.00	0.00	41.97	0.69
29 July	37.21		1.20	44.65	0.00	0.00	44.65	0.74
17 Oct	42.30		1.20	50.69	28.60	14.48	36.27	0.60
26 Nov	21.35		1.01	21.64	26.79	17.47	4.17	0.14
TOTAL	**1415.81**			**1557.95**	**1044.73**	**629.14**	**940.91**	**0.43**

Table F.2 Crop water requirement estimated for Soya bean, DatePALM, Tobacco (Cankuzo)

Station:Cankuzo Crop: Soybean				Planting date: 1 february Irrigation Efficiency: 70%				
Date	ETo(mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1Feb	22.63	100.00	0.40	9.05	46.07	28.51	0.00	0.00
11Feb	22.56		0.40	9.03	46.28	28.76	0.00	0.00
21 Feb	22.43		0.54	12.05	47.86	30.18	0.00	0.00
23 Marc	21.67		1.15	24.92	54.54	35.88	0.00	0.00
12 May	20.13		1.15	23.15	22.54	10.59	12.56	0.21
11Jun	9.83		0.55	5.42	0.00	0.00	5.42	0.18
TOTAL	**286.57**			**254.72**	**516.68**	**219.16**	**53.82**	**0.07**

Station: Cankuzo	Planting date: 1 september

Crop: Date PALM				Irrigation Efficiency: 70%				
Date	ETo(mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1 sept	21.04	100.00	0.90	18.94	10.01	0.00	18.94	0.31
9 Jun	22.47		0.90	20.22	51.00	32.70	0.00	0.00
8Feb	22.59		0.94	21.29	46.06	28.55	0.00	0.00
18Feb	22.48		0.95	21.35	47.26	29.66	0.00	0.00
8Jul	19.68		0.95	18.69	0.00	0.00	18.69	0.31
27 Aug	10.40		0.90	9.38	2.95	0.00	9.38	0.31
TOTAL	**781.25**			**722.62**	**1141.39**	**590.20**	**165.28**	**0.12**

Station: Cankuzo Crop: Tobacco				Planting date: 1 May Irrigation Efficiency: 70%				
Date	ETo(mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1 May	20.43	100.00	0.50	10.21	36.02	20.52	0.00	0.00
11 May	20.16		0.50	10.08	23.83	11.49	0.00	0.00
20 Jun	19.59		1.15	22.53	0.00	0.00	22.53	0.37
10 Jul	19.70		1.15	22.65	0.00	0.00	22.65	0.37
9 Aug	20.32		0.85	17.32	0.00	0.00	17.32	0.29
TOTAL	**219.04**			**195.86**	**72.49**	**35.45**	**172.12**	**0.26**

Table F.3 Crop water requirement estimated for cotton, banana, maize (Kinyinya)

Station: Kinyinya Crop: Green bean				Planting date: 10september Irrigation Efficiency: 70%				
Date	ETo(mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
10Sept	31.21	100.00	0.50	15.60	10.75	0.00	15.60	0.26
20Sept	31.11		0.50	15.56	15.65	2.00	13.56	0.22
20 Oct	30.15		0.97	29.16	32.01	18.33	10.83	0.18
30 Oct	29.61		1.05	31.09	37.28	23.06	8.03	0.13
19Nov	28.23		1.05	29.64	45.91	29.14	0.50	0.01
29 Nov	27.43		0.97	26.55	48.93	30.88	0.00	0.00
TOTAL	**268.20**			**220.56**	**279.88**	**149.95**	**74.94**	**0.04**

Station: Kinyinya Crop: Tomato				Planting date: 1 May Irrigation Efficiency: 70%				
Date	ETo(mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1 May	25.77	100.00	0.60	15.46	39.61	23.50	0.00	0.00
21May	26.83		0.60	16.10	11.18	3.02	13.07	0.22
20 Jun	28.54		0.95	27.14	0.00	0.00	27.14	0.45
10Jul	29.60		1.15	34.04	0.00	0.00	34.04	0.56
9Aug	30.79		1.15	35.41	0.00	0.00	35.41	0.59
29Aug	31.17		1.03	32.03	5.18	0.00	32.03	0.53
18Sept	15.59		0.82	12.83	6.69	0.00	12.83	0.42
TOTAL	**421.81**			**394.89**	**100.40**	**39.04**	**363.89**	**0.41**

Station: Kinyinya Crop: Cotton				Planting date: 1 Junuary Irrigation Efficiency: 70%				
Date	ETo(mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1Juan	25.23	100.00	0.35	8.83	50.15	32.22	0.00	0.00
21Juan	24.51		0.35	8.58	45.78	28.36	0.00	0.00
20 Feb	24.00		0.95	22.89	54.69	35.78	0.00	0.00
1 Apr	24.55		1.20	29.46	62.21	41.93	0.00	0.00
11May	26.28		1.20	31.54	25.17	12.52	19.02	0.31
10 Jun	27.97		1.03	28.24	2.12	0.00	28.24	0.47
10 Jul	14.74		0.62	9.16	0.00	0.00	9.16	0.30
TOTAL	**500.68**			**439.13**	**712.74**	**450.10**	**160.85**	**0.14**

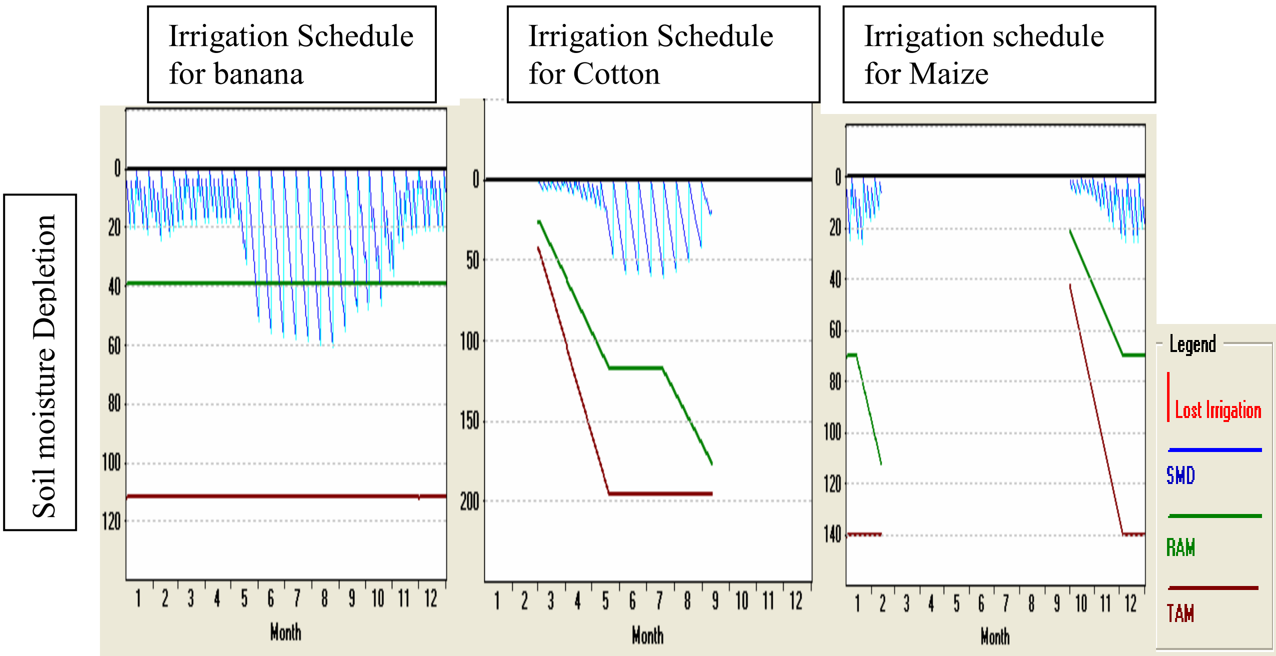
Table F.4 Crop water requirement estimated for Mango, Citrus, Potato (Nyanza -Lac)

Station: Nyanza lac Crop: Mango				Planting date: 10 October Irrigation Efficiency: 70%				
Date	ETo (mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
10 Oct	23.22	100.00	0.90	20.90	28.45	14.70	6.20	0.10
29Oct	24.21		0.90	21.79	56.51	37.32	0.00	0.00
7 Feb	24.57		0.98	24.05	42.26	25.52	0.00	0.00
8 Apr	22.66		1.10	24.93	58.62	38.94	0.00	0.00
7 Jun	20.56		1.10	22.61	0.00	0.00	22.61	0.37
27 Jun	20.33		1.10	22.37	0.00	0.00	22.37	0.37
16 Aug	21.12		1.00	21.21	0.00	0.00	21.21	0.35
5 Oct	11.47		0.90	10.37	10.79	4.37	6.00	0.20
TOTAL	**827.22**			**824.11**	**1168.87**	**722.87**	**169.2**	**0.14**

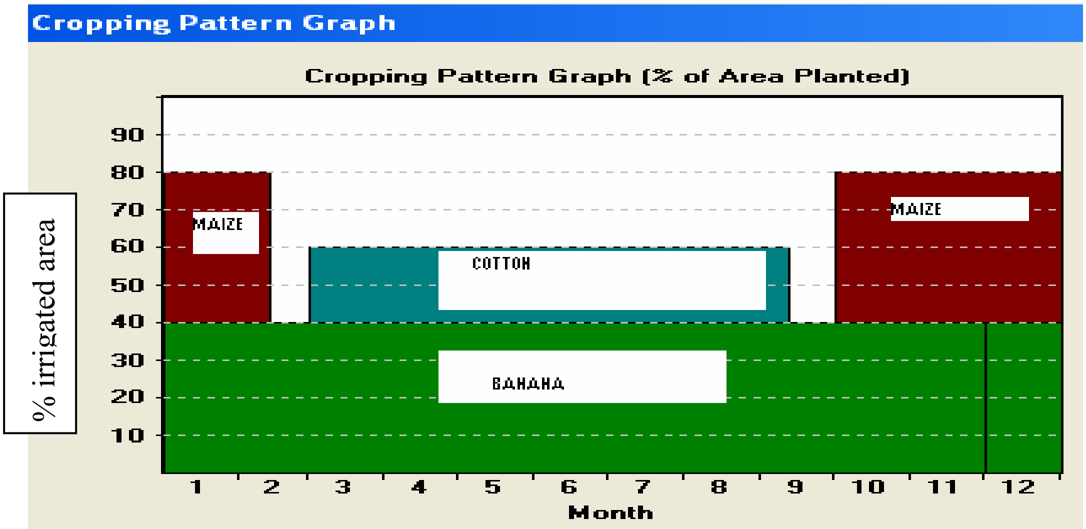
Station: Nyanza lac Crop: Citrus				Planting date: 1 december Irrigation Efficiency: 70%				
Date	ETo (mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
1Dec	24.26	100.00	0.70	16.98	61.94	41.49	0.00	0.00
31Dec	23.01		0.70	16.11	58.74	39.14	0.00	0.00
30 April	21.73		0.70	15.15	44.50	27.43	0.00	0.00
29 Jul	20.63		0.65	13.41	0.00	0.00	13.41	0.22
17 Oct	23.46		0.65	15.25	35.10	20.37	0.00	0.00
26Nov	12.12		0.70	8.45	30.37	20.35	0.00	0.00
TOTAL	**827.22**			**562.47**	**1168.87**	**460.1**	**184.30**	**0.08**

Station: Nyanza lac Crop: Potato				Planting date: 15March Irrigation Efficiency: 70%				
Date	ETo (mm/p)	Crop area (%)	Crop Kc	CWR (ETm) (mm/p)	Total Rain (mm/p)	Eff .Rain (mm/p)	Irr.Req (mm/p)	FWS (l/s/ha)
15 Marc	23.65	100.00	0.50	11.82	53.80	35.20	0.00	0.00
25 Marc	23.26		0.50	11.63	57.50	38.18	0.00	0.00
24 April	21.57		1.15	24.34	39.70	23.69	0.65	0.01
13 Jun	20.46		1.15	23.52	0.00	0.00	23.52	0.39
13 Jul	20.38		0.81	16.51	0.00	0.00	16.51	0.27
Total	**279.96**			**250.25**	**355.68**	**223.10**	**136.83**	**0.17**

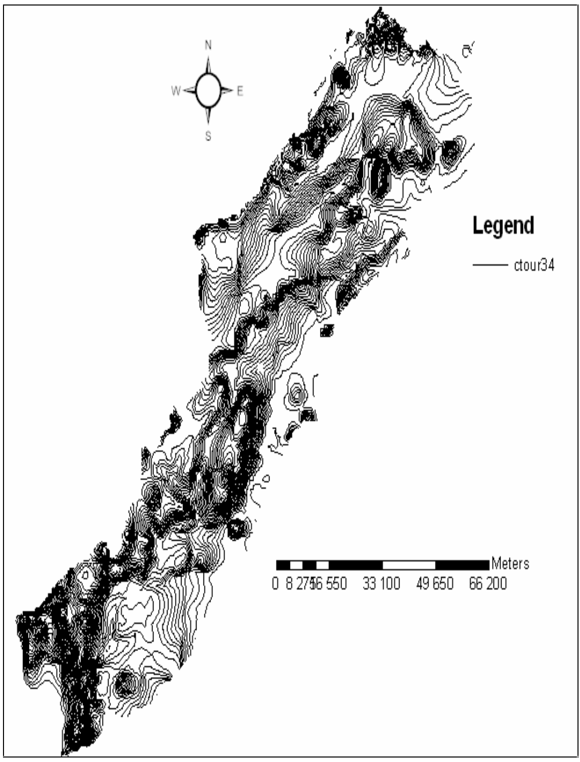
APPENDICE- G1: Irrigation schedule at Musasa

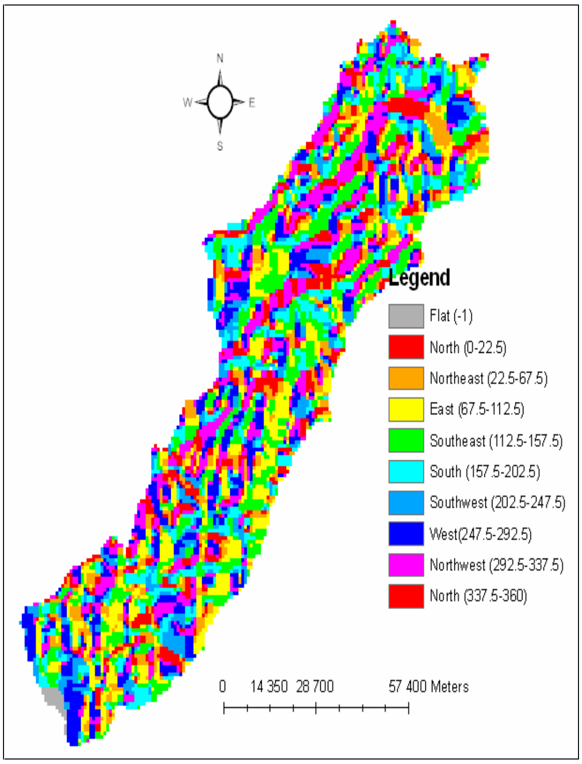


APPENDICE- G2: Crop pattern in Musasa



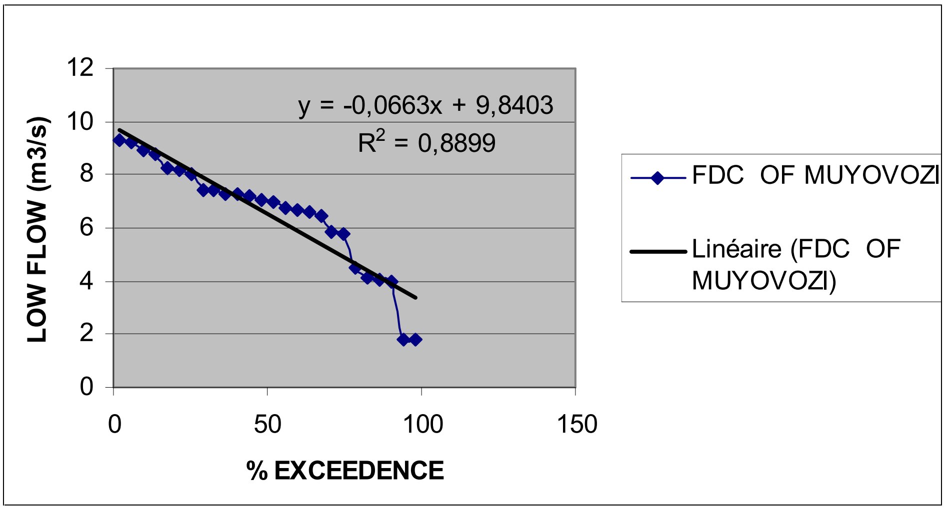
APPENDICE- H: Contour map and Aspect of Malagarazi sub basin



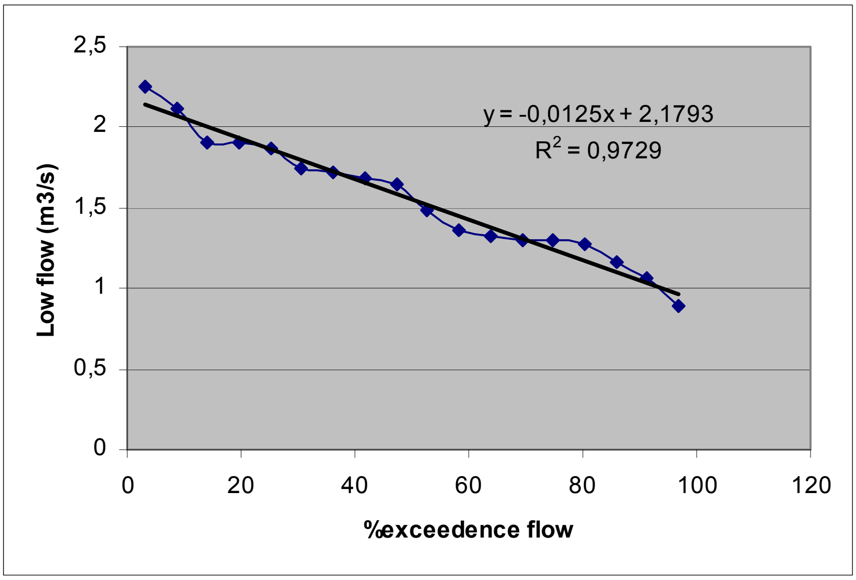


APPENDICE -I: Flow Duration Curve (FDC)

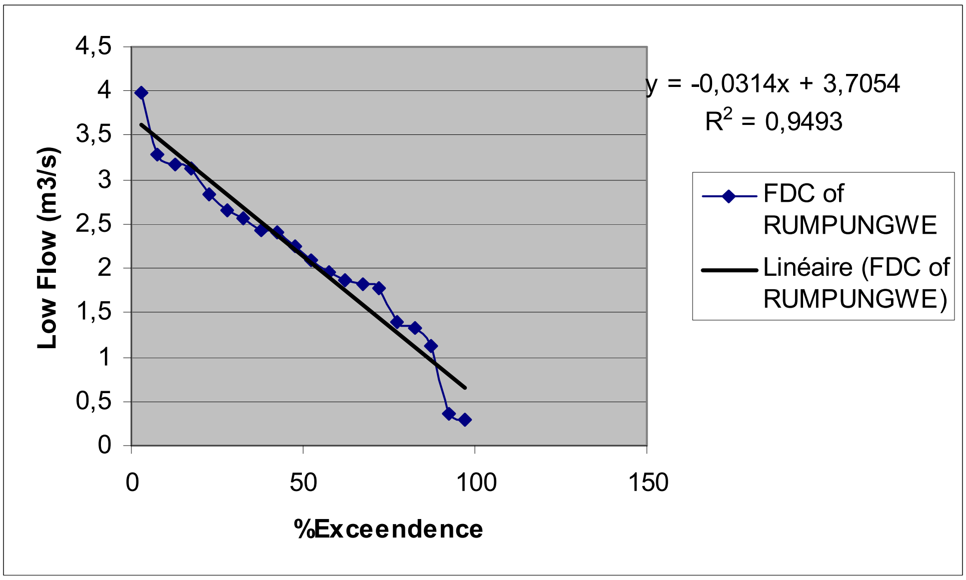
I. 1. Flow Duration Curve of Muyovozi



I. 2. Flow Duration Curve of Rukoziri



I. 3. Flow Duration Curve of Rumpungwe



Criteria used in the evaluation of soil and terrain suitability for irrigation

CRITERIA	CONDITION	UPLAND CROPS	FLOODED RICE
Topography: slope	Optimum	< 2%	< 2 %
		2-8%	2-8%
Drainage	Optimum	Well drained	Poorly drained
	Marginal/Range	Moderately Well drained –Imperfectly drained	Very poorly drained – Well drained
Texture	Optimum	Loamy –Silty Clay Loam	Clay Loam - Clay
	Range	Sandy Loam – Clay sandy	Sandy Loam - clay
Soil depth	Optimum	> 100 cm	> 50 cm
	Marginal	50 - 100 cm	20 - 50 cm
Surface stoniness	no stones are acceptable	no stones are acceptable	no stones are acceptable
Sub surface stoniness	Optimum	< 40 %	< 40 %
	Marginal	40- 75 %	40- 75 %
Calcium carbonate	Optimum	< 30 %	< 15 %
	Marginal	30- 60 %	15 - 30 %
Gypsum	Optimum	< 10 %	< 3 %
	Marginal	10 - 25 %	3 - 15 %
Salinity	Optimum	< 8 mmhos/cm	< 2 mmhos/cm
	Marginal	8 - 16 mmhos/cm	2 - 4 mmhos/cm
Alkalinity	Optimum	< 15 ESP[4]	< 20 ESP
	Marginal	15 - 30 ESP	20 - 40 ESP

Source: http://www.fao.org/docrep/W4347E/w4347e0b.htm, consult April, 27, 2008

[4] ESP: Exchangeable Sodium Percentage