ASSESSMENT OF WATER RESOURCES POTENTIAL IN RUVUBU RIVER BASIN (BURUNDI EQUATORIAL NILE LAKES BASIN)

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IN PARTIAL FULFILMENT OF REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN HYDROLOGY AND WATER RESOURCES MANAGEMENT

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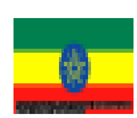

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The undersigned certify that they have read the thesis entitled « **ASSESSMENT OF WATER RESOURCES POTENTIAL OF RUVUBU RIVER BASIN** » and hereby recommended for the acceptance by the Arba Minch University in partial fulfillment of the requirements for the Degree of Master of Science in Hydrology and Water Resources Management.

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DEDICATION

To

MY LOVELY WIFE & OUR CHILDREN

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ABBREVIATIONS AND ACRONYMS

AIDS: Acquired ImmunoDeficiency Syndrome
CLIMWAT: Climatic Water (FAO-Software)
CROPWAT: Crop Water (FAO-Software)
CWR: Crop Water Requirement
ETO: Actual Evapotranspiration
ETP: Potential Evapotranspiration
ESP: Exchangeable Sodium Percentage
FAO: Food and Agriculture Organization
GDP: Gross Domestic Product
GIS: Geographic Information system
GIWR: Gross Irrigation Water Requirement
GW: Giga-Watt
GWh: Giga-Watt-hour
HPP: Hydro-Power Plant
IGEBU: Institut Geographique du Burundi
ISABU: Institut des Sciences Agronomiques du Burundi
ISTEEBU: Institut des Statistiques Economiques du Burundi
KW: Kilo-Watt
MW: Mega-Watt
NEL: Nile Equatorial Lake
NIWR: Net Irrigation Water Requirement
NNW: North-North-West (Direction)
PDNE: Plan Directeur National d'Eau
REGIDESO: Regie de Distribution d'Eau et d'Electricite
SOSUMO: Societe sucriere de Mosso

ABSTRACT

Water not only survives life on our Planet, but also provides populations comforts and luxuries, owing to its various uses. The natural resources of Burundi have been seriously degraded since the beginning of the socio-political crisis which the country has been experiencing for one decade. The overexploitation of arable lands, overgrazing, tilling of steep slopes and the phenomena of erosion in various forms account for the degradation of natural resources which are the basis of its economy.

The undertaken study tries to document the main basin of Nile basin part of Burundi, Ruvubu basin, in terms of water resources potential development for irrigation and hydropower.

Therefore, the potential irrigable area and potential hydropower sites have been assessed for future development and thereby contributing to alleviate the current deteriorating situation. The availability of surface water to balance demand and supply for irrigation development and the theoretical potential power has been estimated for the identified sites.

Accordingly, about 51,768 ha are identified as developable areas using river runoff irrigation system based on land slope criteria (≤ 10%). The total required gross water for developing such areas considering 0.74l/sec/ha as field water supply is evaluated at 0.602 km^3/ year. Based on natural inflow discharge and the natural river bed altitude (river bed altitude ≥ 1500m) to supply by gravity the command area, the available surface water for the above issue is about 32.6 m^3/sec which can satisfy about 85% of the irrigation water required for the potential irrigable areas.

However the estimate available discharge of 32.6 m^3/sec can satisfy the gross irrigation water requirement for irrigation development of the entire potential areas using reservoir storage system. In this manner a total of about 1.028 km^3 of water which greater than the required 0.602 Km^3/year can be stored per year in upstream site.

Using the collected and compiled data of natural inflow discharge (baseflow) and the natural gross head and topography features derived from topographic map, about 80 sites with a total potential theoretical power of about 400 MW are identified in different sub-basins of Ruvubu.

The adopted procedures and obtained results show that there is sufficient flow for implanting surface irrigation system in the basin. However, for sustainable water resources development for both irrigation and hydropower and others multi-purpose usage, it needs the implementation of water storage system which is not practiced nowadays. With this regard, based on unique criteria of topography feature of the area, about 20 sites are assessed potentially suitable for reservoir building for one or both purpose depending upon the location.

Furthermore, based on the prevailing conditions, suggestions measures are highlighted at the end of the work how to reverse the current deteriorating situation.

However, the adopted procedures and methodologies and the obtained results in this study are based on limited data and information and therefore involved a systematic study for validation. But, the results of this study can be used at preliminary stage for decision-makers and updated with field investigations and Environmental assessment aspects of basin.

CHAPITER ONE

1.0 INTRODUCTION

1.1. Preamble

“Africa must govern itself better and manage its natural resources better”
[KOFI Annan, 2000].

Water is the most precious natural resource and a universal asset. Man and living nature can neither develop nor survive without water. Man has been concerned with water from the beginning of his existence. In addition to water’s being essential to his diet, it is also the means by which he can banish hunger, develop energy, drive industry, enjoy recreation, promote trade and transport.

The Ruvubu basin which is the concerned study area is leading in terms of severe chronic hunger and crisis induced by civil war and aggravated by a periodic drought.

Since agriculture and economic development depend on rainfed water supply, rainfall variability and scarcity affect much crop yield, slow down developments, threaten food supplies and aggravate rural poverty. Thus, to bring food security in the national as well as in household level, implementation and expansion of irrigated agriculture must be resorted.

This requires an understanding of potential areas for irrigation development and the availability of water to satisfy the irrigation water requirements.

Furthermore, the absence of renewable energy supply and use of wood for constructing house force the population to uncontrollable exploitation of natural forest to meet the demand. Deforestation, soil erosion and soil fertility reduction are the enemies of agriculture production observed in study area.

Unless the minimum required energy supply is assured, the increasing energy demand with the increase of population has adverse consequence on ecological balance, which results in reduction of crop yield.

This study is intended to present the overall irrigation scheme and hydropower energy situation in Ruvubu basin. Its aim is to assess the availability of irrigation potential with respect to both land and water resources for future development issues with support of GIS. The needs of energy supply for a sustainable development and for environmental protection require identification of the potential site for power generation.
With this regard, the present study is structured in following manner:

The first chapter is an overview of the country background for the main aspects of development as well as the influencing factors.
The second chapter concerns the literature review of the theories and methods related to water resources assessment for both irrigation and hydropower. It gives also the high light of criteria and results of similar study which have been undertaken in the country if there is any.
The third chapter presents the overall characteristics of the Ruvubu basin as an interest area and provides analysis of some parameters which have more relationship to the objectives of the study and so far are used for achieving the main goal.

The fourth chapter is focused on pre-existing development of both irrigation and hydropower plants. From the general points of view to details information for better understanding the current status and hence be able to justify the necessity of the present study. The results obtained in this chapter are indicators to foresee the degree of water resources development in the study area and their analysis can indicate the positive impacts of new resources development.

Chapter five threats the non developed resources, land and water, for an eventual future irrigation development project. The methodology and criteria defined in the previous sections are applied to identify the developable areas for surface irrigation, quantify and balance the availability of water with the demand requirement for irrigation. The availability of water is once again estimated for potential power generation.
In chapter six, the estimated results are presented and discussed for a preliminarily critical future usage.
The last section, chapter seven, is reserved for conclusion and recommendations.

1.2. Problem statement

Socio-economic development and civilization of human being is closely associated to ability to utilize and control water resources. Burundi, once known to be relatively abundant in water resources, is now confronted with formidable water and sustainable development problem.

Population of Burundi is largely rural and dependent on agriculture for their livelihoods. Agriculture is the leading economic activity of the country. But with the last decade of socio-political crisis, agricultural production has not kept pace with population growth, leading to severe chronic malnutrition and hunger, and periodic crisis induced by consecutive drought (1983, 1987, 1993, 1998, 2004and 2006). The current cultivated land is estimated to be about 800,000 ha and it represents more than 33% of arable land. Despite irrigation potential estimate of about 215,000 hectares which represent about 26.9% of actual cultivated area, only about 20,000 hectares (2.5% of the potential) is currently under irrigation, which plays insignificant role in the country's agricultural production. Thus to bring food security in the nation as well as in household level, improvement and expansion of irrigated agriculture must be resorted.

The Ruvubu basin, which is case of study, is affected by the phenomenon of degradation of soil resources and vegetation cover and where endemic drought has prevailed for many years (North-eastern part). The lack of farm land, on the one hand, and the strong demographic pressure in rural areas, on the other hand, has led to intense land use resulting in severe soil impoverishment and insufficient fallowing and pastures. Farming methods are traditional and based almost exclusively on manual work. There is little use of agricultural inputs. Current outputs are still low per unit land and are estimated at 0.6 t/ha for beans, 1.4 t/ha for maize, 6.88 t/ha for potatoes, 20 t/ha for tomatoes, 4.5 t/ha for onions, 6 t/ha for bananas, 3.5 t/ha for citrus fruits and 8.25 t/ha for avocado.

Appropriate assessment and development of both water resources and irrigable land is a prerequisite factor for ensuring the problem which undermine the agriculture in such part of the country.

Furthermore, the forest resources of Burundi have been seriously degraded since the beginning of the socio-political crisis which the country has been experiencing for one decade. Thus, more than 30,000 ha of woodlots and 10,000 ha of natural forests have been destroyed during the quest for farmlands and new pastures and by uncontrolled felling meet households' fuelwood and lumber needs, reducing the country's forest cover rate from 8% to 5%. The main sources of energy are classified as following:

- ✓ Fuelwoods (95% of the total energy consumption)
- ✓ Kelosene: 10 kg/family/year,
- ✓ Biogaz: 13,000 M^3

The populations' fuelwood and lumber needs will grow substantially with refugees returning from neighbouring countries following the restoration of peace.

Today, the populations are well aware of the state of degradation of their productive capital. They realize that the absence of urgent interventions could affect the few remaining resources and will only heighten the phenomenon of erosion of watersheds, thus causing risks of landslides, significant losses of farmlands and soil fertility. The biodiversity which is already threatened will also be affected. In this regard, satisfying the energy needs of the population through sustainable hydropower energy is quite important. This approach helps to avoid deforestation and improvement of living standard in developing country like Burundi.

1.3. Objective of the Study

The goal of the project study is to contribute to food security by suggesting the use of irrigation water for increasing the productivity. More specifically, the purpose of the present study is to provide the planners, designers and decision- makers the detailed information for sustainable agriculture based on Irrigation practice where drought has prevailed for many years. Moreover, the hydropower potential is considered with vital importance in maintaining ecological and hydrological balances to supplement households' fuelwood once developed

Specific objectives include:

- ✓ To estimate the available surface water resources ;
- ✓ To provide meaningful guide to actions related to expansion of agricultural land and productivity by identifying the potential irrigable land;
- ✓ To combat the socio-economic effect of endemic drought by proposing irrigation practice to stabilize and increase the crop yield during the period of low rainfall;
- ✓ To identify the availability of hydropower energy to satisfy energy needs and hence avoid deforestation and improve living standard of the people;
- ✓ Identify the reservoir site based on physical criteria to store surface water for dual purpose of Hydropower generation and irrigation in period of water scarcity;
- ✓ To contribute to knowledge of water resources potential in the study area for effective and efficient use without causing harm to downstream users.

This study will assess the water resources potential at basin level while others have generally considered the administrative boundary level.

1.4. Methodology of the Study

As stated above, the aims and objectives of the research in this thesis are multiple. A great deal of the research would be undertaken to arrive at useful results at various stages. The methodology can be summarized as:

- discussion on the background theories,
- reviews the previous studies, reports and articles,
- data collection from institutions such as Ministry of geology and Mines, Ministry of Land, Tourism and Environment, Geographical institute of Burundi (IGEBU), ISABU, ISTEEBU, REGIDESO, etc; with this regard, 23 years monthly data of 7 meteorological station and 10 years monthly data of 12 hydrological stations have been used [see Appendix A1 and B1].
- Data processing and analysis using statistical packages and GIS to hydrological and physical parameters and spatial information;
- Interpretation and analysis of results.

In certain aspects, the research also retains originality, because the stated objectives are first endeavor to be tackled in the country by targeting a unit area as a basin.

CHAPITER TWO

2.0 LITERATURE REVIEW

2.1. Water resources assessment for Irrigation

2.1.1. Methods of estimating irrigation water demand and use.

The irrigation water demand and use can be established from:

- Estimates using empirical formula;
- Measurements of water consumption from flow gauging devices;
- Field measurements of the consumptive use of crops.

  - Field measurements of water use by crops are complex, time consuming and expensive. Generally irrigation water demands and use are estimated from empirical equations or calculated from readings from flow measurements located on irrigation schemes.

A. Use of empirical equations

There are two main methods that can be used to establish irrigation demand and use using empirical equations. These are:

- Approximate estimates;
- Detailed estimates.

For most water resources management applications at a basin and sub-basin level approximate estimates of irrigation water demand and use should suffice. However, there may be some cases that warrant more detailed estimates. The approximate and detailed procedures for estimating irrigation water demand and use are shown in Figures 2.1 and 2.2 respectively below.

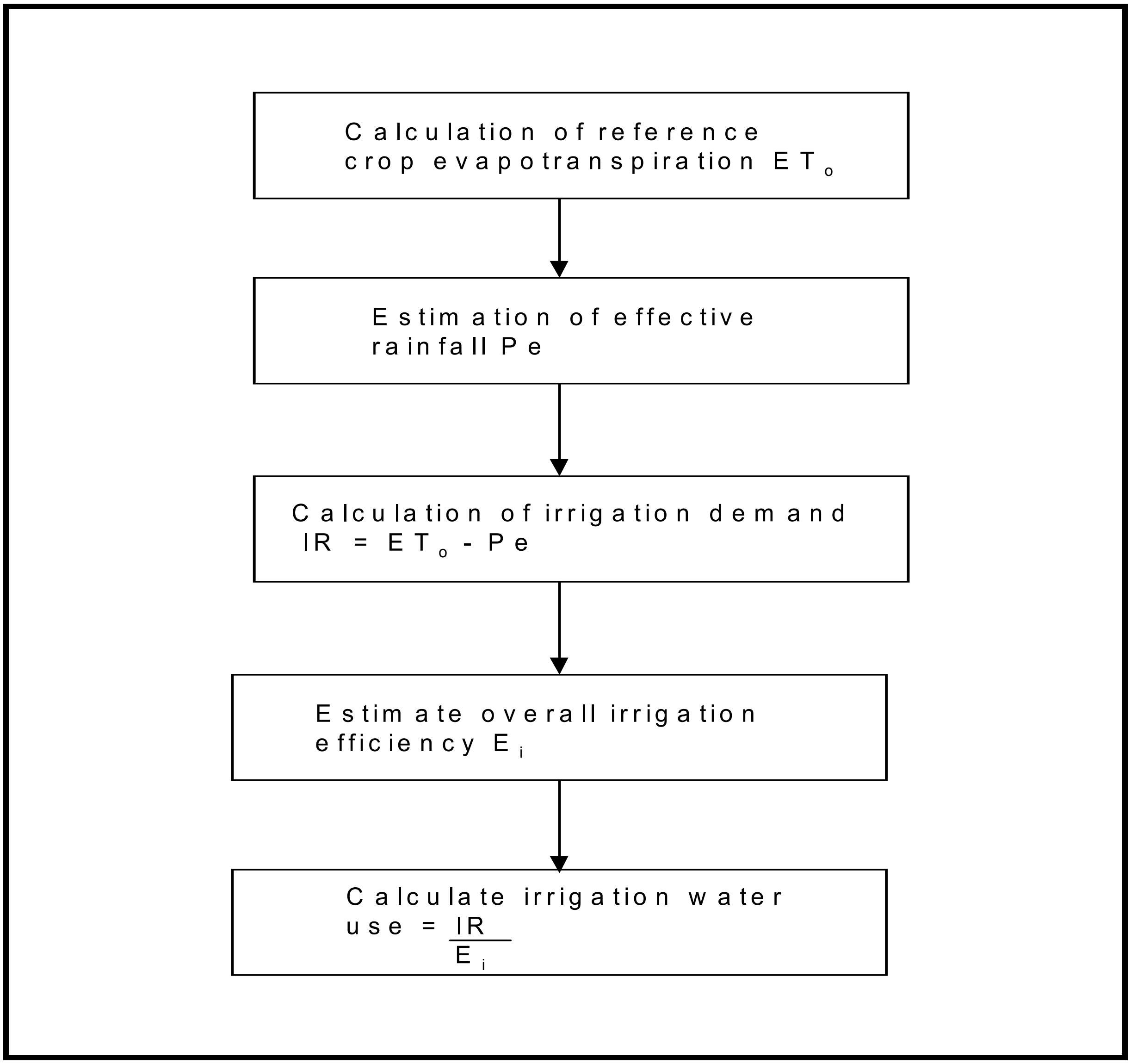


Figure.2.1: Approximate method for estimating irrigation demand and use [HR Wallingford, 2007].

It should be noted that often the greatest uncertainty in determining irrigation water use is the estimation of irrigation efficiency. The overall irrigation efficiency is defined as the ratio of water consumed by crops to the water diverted from the source (e.g. a river or reservoir). The overall irrigation efficiency can vary from 10% to 90% and is heavily dependent on the irrigation technology used, and the operation and maintenance of the irrigation scheme. Figures for irrigation schemes can be estimated from literature or from similar schemes where there are measuring devices.

B. Approximate method parameters estimation:

The irrigation water demand and use can be estimated approximately at a basin and sub-basin level using the following equations:

Irrigation water demand

$$IR = (ET_o - Pe) * A \text{ .... } \mathbf{2.1}$$

Where: ET_o is the Reference Crop Evapotranspiration for grass;

P_e is the effective rainfall;

A is the area under irrigation.

Irrigation water $\text{use} = \frac{\text{IR}}{\text{E}_\text{i}}$, where: IR is the irrigation water demand;

E_i is the overall irrigation efficiency.

Using the potential evapotranspiration for a reference crop (grass) may cause an upward bias in the estimates of irrigation water demand and use.

However, for estimating irrigation water demand and use at a basin and sub-basin level it provides a rapid and simple method.

Values of reference crop evapotranspiration estimated using the Penman-Monteith method and effective rainfall are available as part of CLIMWAT.

CLIMWAT is a climatic database produced by the Food and Agriculture Organization (FAO).

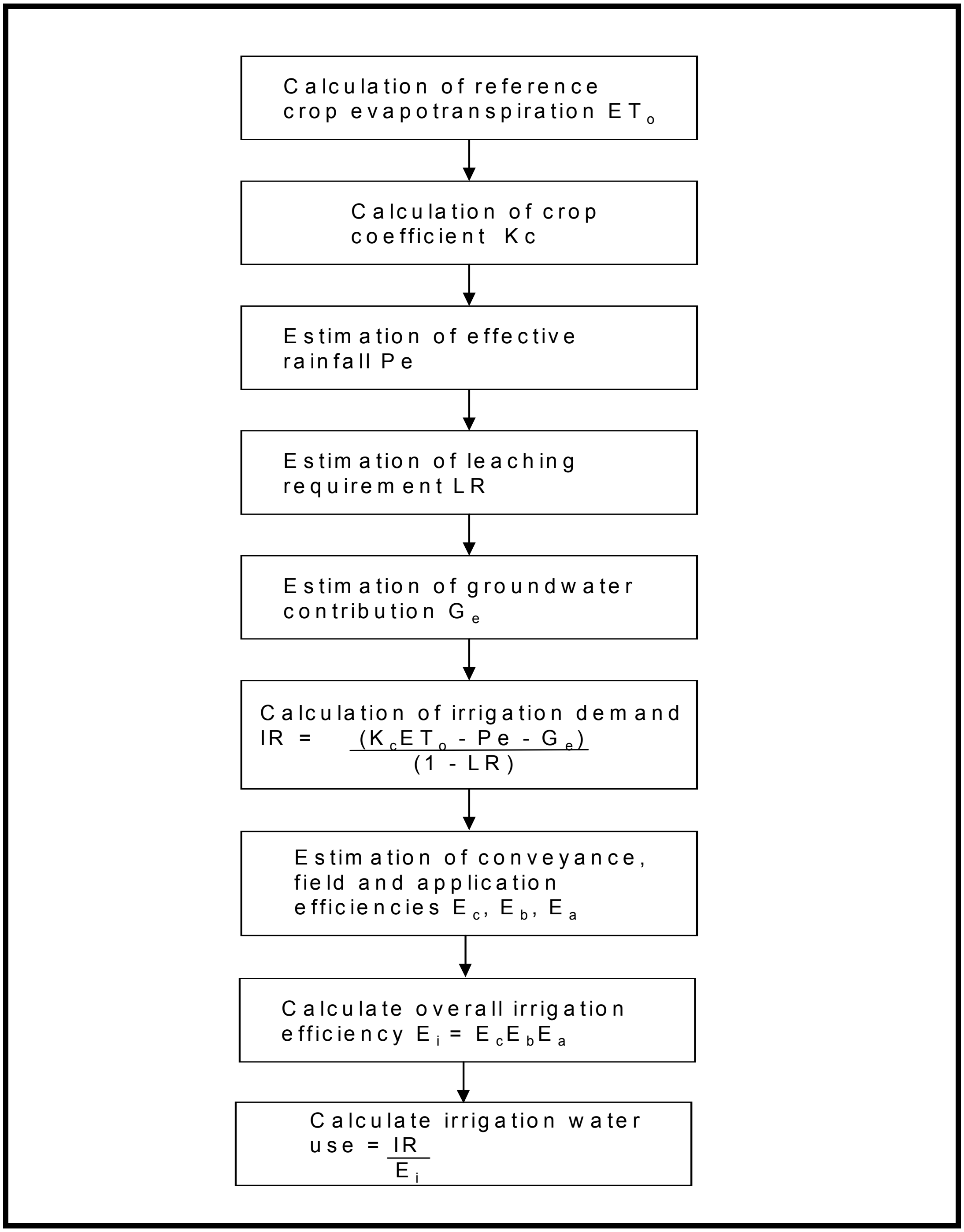


Figure.2.2: Detailed method for estimating irrigation water demand and use [HR Wallingford, 2003].

C. Detailed method parameters estimation

In order to carry out a detailed estimate of irrigation water demand and use, using empirical formulae, the following information is required:

- Reference crop evapotranspiration;
- Crop type and crop evapotranspiration;
- Cropped area;
- Effective rainfall;
- Soil type and leaching requirements;
- Irrigation efficiencies.

Overall irrigation efficiency

$$E_i \bullet \frac{V_c}{V_w} \quad \text{..} \mathbf{2.2}$$

Where: E_i is the irrigation efficiency;

V_c is the water consumed by the crops;

V_w is the water diverted from the source (e.g. a river or reservoir)

The FAO has produced a piece of software known as CROPWAT which in conjunction with CLIMWAT can be used to carry out detailed calculations to estimate irrigation water demand and use.

In Burundi, the water resources are unequally distributed in time and space. Even though it has been considered as generally abundant, there is shortage of water for diverse users in some natural regions like Bugesera and Mosso. This is mainly due to long duration of dry season occurring between six and seven months in the year for the aforementioned regions.

However, the water resources remain underused for socio-economic development purpose and the consequences are also present in regions with abundant rainfall but less distributed over time.

For instance, utilization of non potable water is shared between agriculture (irrigation, wetland, and cattle), industry and hydroelectricity.

In this thesis our attention is more focused on use of water for two main purpose irrigation and power generation.

2.1.2. Estimation of Irrigation Potential based on Physical Criteria

There are three main methods that can be used to establish irrigation potential using physical criteria.
These are:

- ✓ Soil and terrain suitability for surface irrigation;
- ✓ water availability for irrigation;
- ✓ Irrigation water requirement.

2.1.2.1. Soil and terrain suitability for surface irrigation method

The evaluation of soil qualities and terrain conditions to predict the performance for specific crops is an essential part of a land evaluation and land use planning exercise applied to agriculture. In the framework of this study, emphasis is more placed on the physical criteria terrain suitability soils and less to soil quality because of shortage of data.

2.1.2.2. Soil requirement 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 factors.

Accordingly, hereby we present the criteria selected in the evaluation of soil and terrain suitability for irrigation. These criteria are used in this study for estimating the irrigable land in Ruvubu basin.

Table 2.1: Soil and terrain suitability criteria [FAO, 1997]

Criteria	Condition	Upland crops	Flooded rice
Slope	Optimum	< 2%	< 2%
		2%-8%	2%-8%
Drainage (1)	Optimum	W	P
	Marginal/Range	MW-I	VP-W
Texture (2)	Optimum	L-SiCL	CL-MCim
	Range	SL-MCs	SL-MCm
Soil depth	Optimum	> 100 cm	> 50 cm
	Marginal	50 - 100 cm	20 - 50 cm
Surface stoniness		no stones are acceptable	no stones are acceptable
Subsurface 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 (3)	Optimum	< 8 mmhos/cm	< 2 mmhos/cm
	Marginal	8 - 16 mmhos/cm	2 - 4 mmhos/cm
Alkalinity (3,4)	Optimum	< 15 ESP	< 20 ESP
	Marginal	15 - 30 ESP	20 - 40 ESP

Note**:** Explanation of the symbol used

- Drainage: W = Well drained; MW = Moderately Well drained;
  I = Imperfectly drained; P = Poorly drained;
  VP = Very Poorly drained.
- Texture: L = Loamy; SiCL = Silty Clay Loam;
  SL = Sandy Loam; CL = Clay Loam.

- Salinity and alkalinity: The criteria refer to salinity and alkalinity conditions that can be accepted for irrigation and possibly improved by irrigation management. The choice of crops has to be made with regard to the local salinity and alkalinity situation.

- Alkalinity: ESP = Exchangeable Sodium Percentage.
- As the above criteria stated, two main land uses have been considered "Upland crops and Flooded rice". 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: Situation of soil suitability for irrigation [FAO, 1997]

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

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

2.1.2.3: Water resources availability as criteria for estimating irrigation potential.

Assessment of water resources can only be done at basin level. At country level it is possible to assess that part of the water resources which is generated inside the borders of the country. However, exchanges of water through international rivers represent a significant part of the water balance for several countries. In extreme cases, an arid country may depend almost entirely on water produced outside its borders. This explains the necessity to compute irrigation potential on the basis of river basins rather than countries [FAO, 1997].

A first estimate of water resources by basic unit can be obtained by multiplying annual precipitation P by a runoff coefficient c.

$$Q = c * P \quad \text{......} \quad 2.3$$

where **Q** is the average annual flow produced inside the basic unit; **Q** and **P** are expressed in mm/year and **c** is dimensionless.

This approximation has been done at country level as well as at basin. The internal renewable water resources have been 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 (runoff). There was no data about the incoming water.

2.1.2.4: Irrigation Water requirements

The assessment of irrigation potential, based on soil and water resources availability together, can only be done by simultaneously assessing the irrigation water requirements (IWR).

Based on water losses, irrigation water requirements are categorized into two:

- Net irrigation water requirement (NIWR), which is the quantity of water necessary for crop growth. It is expressed in millimeters per year or in m^3/ha per year (1 mm = 10 m^3/ha). It depends on the cropping pattern and the climate.
- Gross irrigation water requirement (GIWR), which is the quantity of water to be applied in reality, taking into account water losses.

GIWR can be obtained by multiplying Net irrigation water requirement (NIWR) by irrigation efficiency (E_i).

Multiplying GIWR by the area that is suitable for irrigation gives the total water requirement for that area.

A. Procedures of calculating irrigation water requirements

a. Classifying crops into types and calculate Crop water requirements (CWR) or Irrigation Water demand (IR) in millimeters.

For a given crop type i,

$$IR_i = \sum_{t}^{T} \left(k_{c_{it}} * ET_{o_t} - P_{eff_t} \right) \quad \text{.......2.4,}$$

Where $k_{c_{it}}$ is the crop coefficient of a given crop type i during the growth stage t and where T is the final growth stage.

Each crop type (i) has its own water requirements. Net irrigation water requirements (NIWR) in a specific scheme for a considered year are thus the sum of individual crop water requirements (CWR_i) calculated for each irrigated crop i.

Multiple cropping (several cropping periods per year) is thus automatically taken into account by separately computing crop water requirements for each cropping period.

By dividing by the area of the scheme (S. in ha), a value for irrigation water requirements is obtained and can be expressed in mm or in m^3/ha (1 mm = 10 m^3/ha).

b. Compute NIWR (mm).

$$NIWR = \frac{\sum_{i=1}^{n} CWR_i * S_i}{S} \quad \text{.......2.5,}$$

where S_i is the area cultivated with crop type i in ha. The cropping intensity of the scheme can be defined as the ratio

$$\frac{\sum_{i=1}^{n} S_i}{S} \quad \text{.......2.6,}$$

c. Compute GIWR (mm)

$$GIWR = NIWR * \frac{1}{E} \quad \text{.......2.7,}$$

where E is the global efficiency of the irrigation system.

Table 2.3: Irrigation cropping patterns for Burundi, [FAO, 1997].

Cropping season	main crops	Cropping calendar												cropping intensity	
		J	F	M	A	M	J	J	A	S	O	N	D	Actual	potential
all year	vegetables/sweet potatoes	-	-	-	-	-	-	-	-	-	-	-	-	30	30
Wet I	maize/sorghum				p	-	-	-	h					25	25
Wet II	maize/sorghum	h								p	-	-	-	15	15
Wet I	rice		p	-	-	-	h							20	40
Wet II	rice	h								p	-	-	-	20	50
														110	160

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 as stated early [FAO, 1997].

Table 2.4: Summary of irrigation potential and water requirements, water availability and area under irrigation in Nile basin [FAO, 1997].

Country area within Nile basin	Irrigation potential	Gross Irrigation water requirement		Actual flows		Flows after deduction for irrigation and losses		Area under irrigation
(ha)	(ha)	per ha (m^3/ha.yr)	total (km^3/yr)	inflow (km^3/yr)	outflow (km^3/yr)	inflow (km^3/yr)	outflow (km^3/yr)	(ha)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1,326,000	80,000	13,000	1.04	0.00	1.50	0.00	0.46	0

Because of limited data our work will be driven by the two first methods; soil and terrain suitability for surface irrigation and water availability for irrigation in accordance with FAO, 1997 "Report".

2.2. Water resources Assessment for Hydropower

2.2.1. Energy supplies in rural areas

The main requirement for socio-economic development in an area is the acquisition of economical and reliable energy. According to statistics from the United Nations, a total installed capacity of 85 GW should be newly added in the world's rural areas so that the unelectrified rural areas inhabited by 1.7 billion people will have electricity for basic needs (exclusive of industrial and agricultural loads). However, due to the limitations of conventional energy resources and a shortage of funds and expertise, etc. only a few millions of rural people in the world can be energized in a year. Therefore, the lack of electricity becomes a great constraint to the rural and even the national economic development of a country.

At the heart of rural electrification is the development of commercial energy. Owing to some historic factors, vast rural areas are completely cut off from the natural economy. Most energy consumption in rural areas is still from the biomass and electricity occupies only a small portion of the energy consumed. Especially for many developing countries, about more than 80% of the population is scattered in the countryside. On the one hand, around 60% of the commercial energy is imported, imposing seriously on the financial balance of the country, whilst on the other hand, cities and industrial centers are over using large amounts of energy. Such disproportionate energy allocation leads to an increase in firewood consumption and large-scale deforestation in rural areas, resulting in soil erosion and loss as well as a decrease in soil fertility and damage to the environment. Therefore, the promotion on rural commercial energy is a critical decision in developing countries [JOHN WILEY&SONS, 1997].

2.2.2. Current Status of power sector

The key facts on electric power status pertaining to the year 2001 for Rwanda, Burundi and Tanzanien shows the electricity balance within in comparison of others Great Lakes regions.

Table 2.5: Electricity balance of Great Lakes countries
[US Department of Energy, EIA/DOE, 2003]

Country	Installed capacity (MW)	Total Net Generation (GWh)	Consumption (GWh)	Import (GWh)	Exports (GWh)
Burundi	**49**	**155**	**170**	**30**	**0**
Kenya	934	4,033	3,980	230	0
Rwanda	31	96	140	50	0
Tanzania	620	2,905	2,750	50	0
Uganda	280	1,928	1,620	1	174
Total	1,914	9,117	8,660	361	174

The projected energy demand gives the following feature (table 2.6) and figure.2.3.

Table 2.6: Projected energy demand for Burundi (Upto year 2020)
[US Department of Energy, EIA/DOE, 2003]

year	High (GWh)	Medium (GWh)	Low (GWh)
2002	133.5	133.5	133.5
2005	156.7	153.5	147.8
2010	207.1	196.6	179
2015	267.8	246.7	213.2
2020	340.4	304	249.6

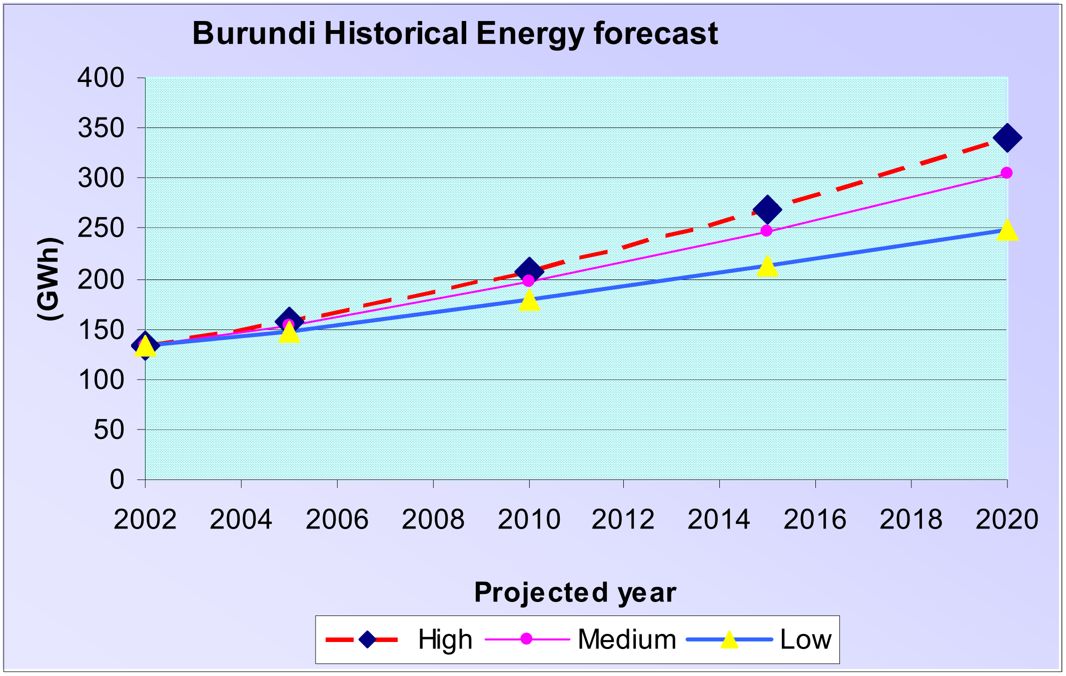


Figure.2.3: Burundi historical energy forecast (year 2020)

On average, the population with access to electricity in Nile equatorial Lake (NEL) region countries including Burundi is only about 5% to 10%; in many areas it is even less than 5%. The NEL region is characterized by constraint isolated power systems where demand exceeds present generation capacity. As can be seen from the above table 2.5, Burundi, Rwanda and Tanzania import power to meet the electricity demand of their countries. The increasing in energy demand is well expressed on figure.2.3, with historical energy forecast pattern.

The overview of energy situation and development are summarized by basin in the following table.

2.2.3. The Hydroenergy power Equation

Hydroenergy is known as a traditional renewable energy resource, and is based on the flow of natural circulating water and its drop from a height to a lower land surface. This constitutes its potential energy. In order to convert this potential energy into applicable electric energy, the water flow must enter and drive a hydraulic turbine, transforming the hydroenergy into mechanical energy. In this part of the work, the most important parameter in assessing hydropower potential of the river basin is the available flow and head.

2.2.4. Theoretical available Power (P_t): Is the amount of power in which the product of the available head, discharge and the specific gravity of water, and in this condition the overall efficiency considered as 100%. The general relationship can be expressed by the Water power equation:

$$P_t = \rho * g * Q * H. \qquad \textbf{2.8,}$$

where: - P_t: express Theoretical available Power,

- Q: Discharge in m^3/sec
- H: the available Head in meter,
- ρ: Specific Gravity of water mostly it is 10 KN/m^3

Hereby, the calculated power (P_t) is theoretical. In natural circumstances, when water flows down a river course by gravity, the hydroenergy is lost in overcoming the resistance and scouring of the river bed. Moreover there are also losses due to turbine-generator combinations, which are characterized by the efficiency (η), the ratio of power output to power input.

Considering this overall efficiency (η), the technically available Power can be estimated in following expression:

$$P_t = \eta * \rho * g * Q * H \qquad 2.6,$$

where η: is the overall efficiency.

2.2.5. Hydropower plants classification

Hydropower plants may be classified according to different criteria, such as head, powerhouse layout, and installed capacity. But habitually, hydropower stations are classified in terms of their capacity. The hydropower capacity may vary at different times and indifferent countries but it has no strict definition. Different methods of classification only reflect the degree of industrial development of a country at a certain period and the proportion of hydropower in whole power sector of a country. Therefore different countries have different definitions.

For convenience of the discussion in present study, the classification of hydropower plants is referred to their size: Large, Medium and Small hydropower plants.
In accordance with the UN definition, the Small hydropower means the installed capacity of the station is from 100 to 1000 MW.

Table.2.7: Classification of Hydropower Plants [Dereje Tadesse, 2005]

Size of HPP		Plant Capacity
Small Scale	Micro	up to 100 KW
	Mini	101 – 1,000 KW
	Small	1,001 – 10,000 KW
Medium Scale		10 – 200 MW
Large Scale		> 200 MW

Referring to this classification, the analysis of information collected from ministry of Energy and Mines shows that many of hydropower plant fall in Small Scale Hydropower in Burundi, because their capacity are less than 10,000 KW. Two Hydropower plant only can be considered in Medium Scale with capacity greater than 10 MW but less than 20 MW. The detail is discussed later.

By considering only the hydropower site with power greater than 1 MW, the feasible theoretical potential is estimated at 6000 GWh/year. This is equivalent to a total capacity of 1200 MW out of which 300 MW is economically feasible. The flow required for this potential is about 61.62 m^3/sec which represent one tenth of total nationally available discharge (518 m^3/sec).

The present study is focused on theoretical hydropower potential on the basis of available Ruvubu river flow data and the physical topographic feature determining the available head.

CHAPTER THREE

3.0 ANALYSIS OF PHYSIOGRAPHIC AND HYDROLOGIC CHARACTERISTICS

3.1. Physiographic and hydrologic characteristics of Burundi

3.1.1. Location

Burundi is located at the interface of the East Africa and Central Africa, between latitudes 2°15’ and 4°30 south, longitudes 28°50’ and 30°55’ East. Overall, Burundi covers a total area of 27,834 km^2 with 24,871 km^2 of land area and 2,963 km^2 of lakes. It borders with Rwanda in the North, with Tanzania in the East, with Lake Tanganyika in the Southwest, and with Congo (Kinshasa) in the West.

Bujumbura is the capital and largest city; the country being divided into 17 provinces.

Figure.3.1: Burundi location map [Microsoft ® Encarta ® 2007].

3.1.2. Topographical features

Burundi's landscape is characterized by a nearly unbroken series of mountains and hills. Although Burundi sits just south of the Equator, the higher elevations afford a cool and pleasant climate. The country experiences two wet and two dry seasons each year. Woodland once covered most of Burundi's central and eastern plateaus, but farmers have cleared almost all the trees in order to plant crops.

Figure.3.2: Burundi's Steep Terrain and Tea cultivation [Microsoft ® Encarta ® 2007]

3.1.3. Climate

The climate is tropical, moderated in most places by altitude variation between 2,670 m on Heha Mountain and 774 m on Lake Tanganyika level. The average annual temperature varies from 15°C on the highland to 23°C in west Great Rift Valley (Imbo). The climate is characterized by two main alternative seasons. Dry seasons are from June to September and rainy season is from October to May. There is a small dry season between December and February. The average annual precipitation is estimated to be more than 1300 mm, but can vary significantly year to year. Lack of rain periodically causes droughts, and excessive rainfall can cause floods and landslides.

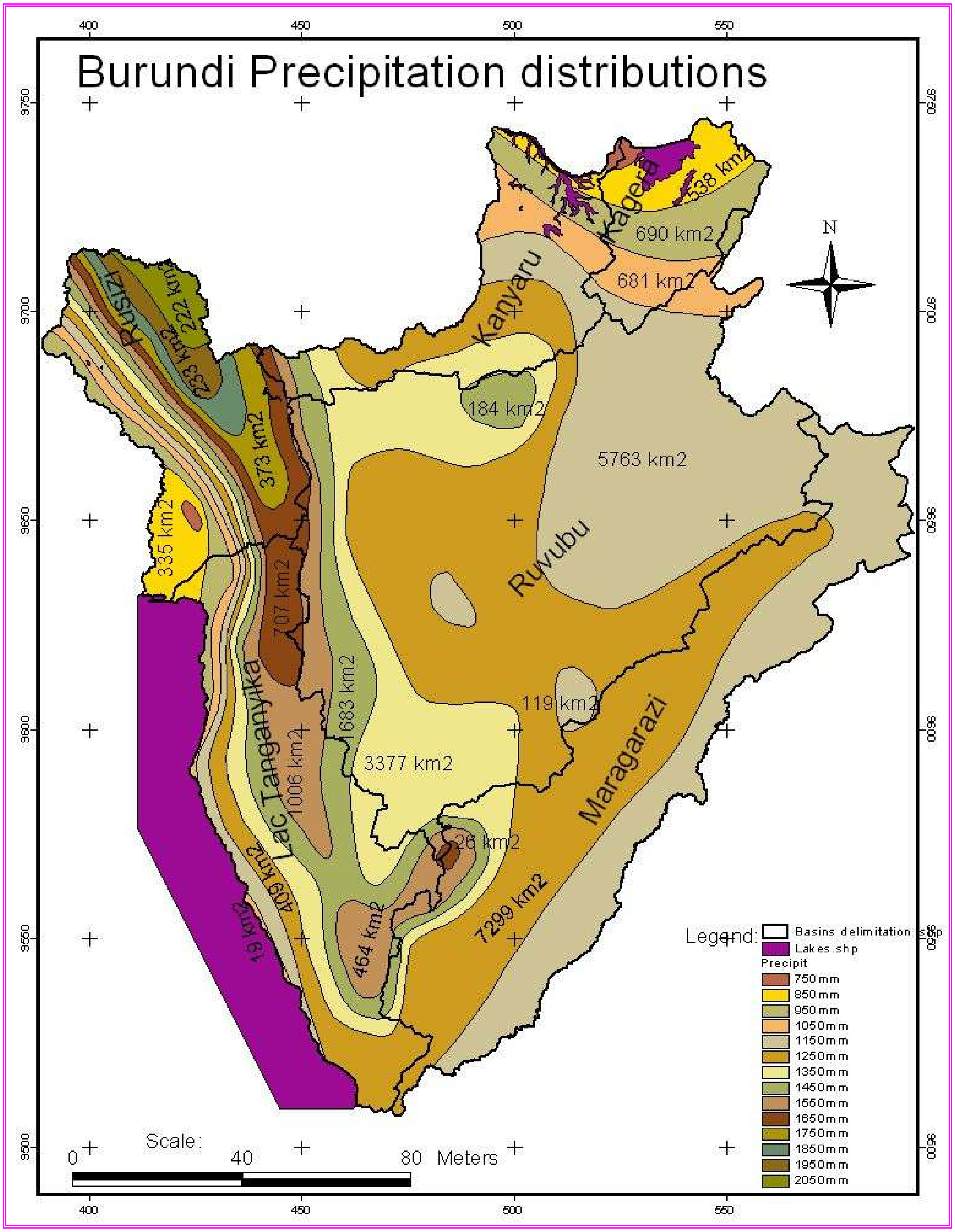


Figure.3.3: Distribution pattern of precipitation of Burundi [PDNE,1998]

3.1.4. Hydrography and drainage basin

Hydrographically, Burundi has a very dense network of rivers and perennial streams which can be subdivided into two main watersheds namely the Congo and the Nile watersheds (Bidou et al. 1991). The Nile River spreads over ten countries by two main river systems: the White Nile and Blue Nile. About 47.6 % of country area is found in the Nile basin. While the sources of Blue Nile are located in the Ethiopian highlands, the White Nile takes its most distant source in Burundi on Ruvyinzora River rising in the present study basin. Ruvubu basin drains all water into Kagera River and travels the border between Rwanda and Tanzania, then between Uganda and Tanzania and thereafter flows into Lake Victora. It constitutes the main tributary of Nile for the country with 112.16 m^3/sec (about 3.5 Km^3/year) of baseflow and mean annual discharge of 152.5 m^3/sec (4.74 Km^3/ year) in wet year**.** Ruvubu basin covers 10,063 km^2 which represents more than 72% of the Nile basin part of the country.

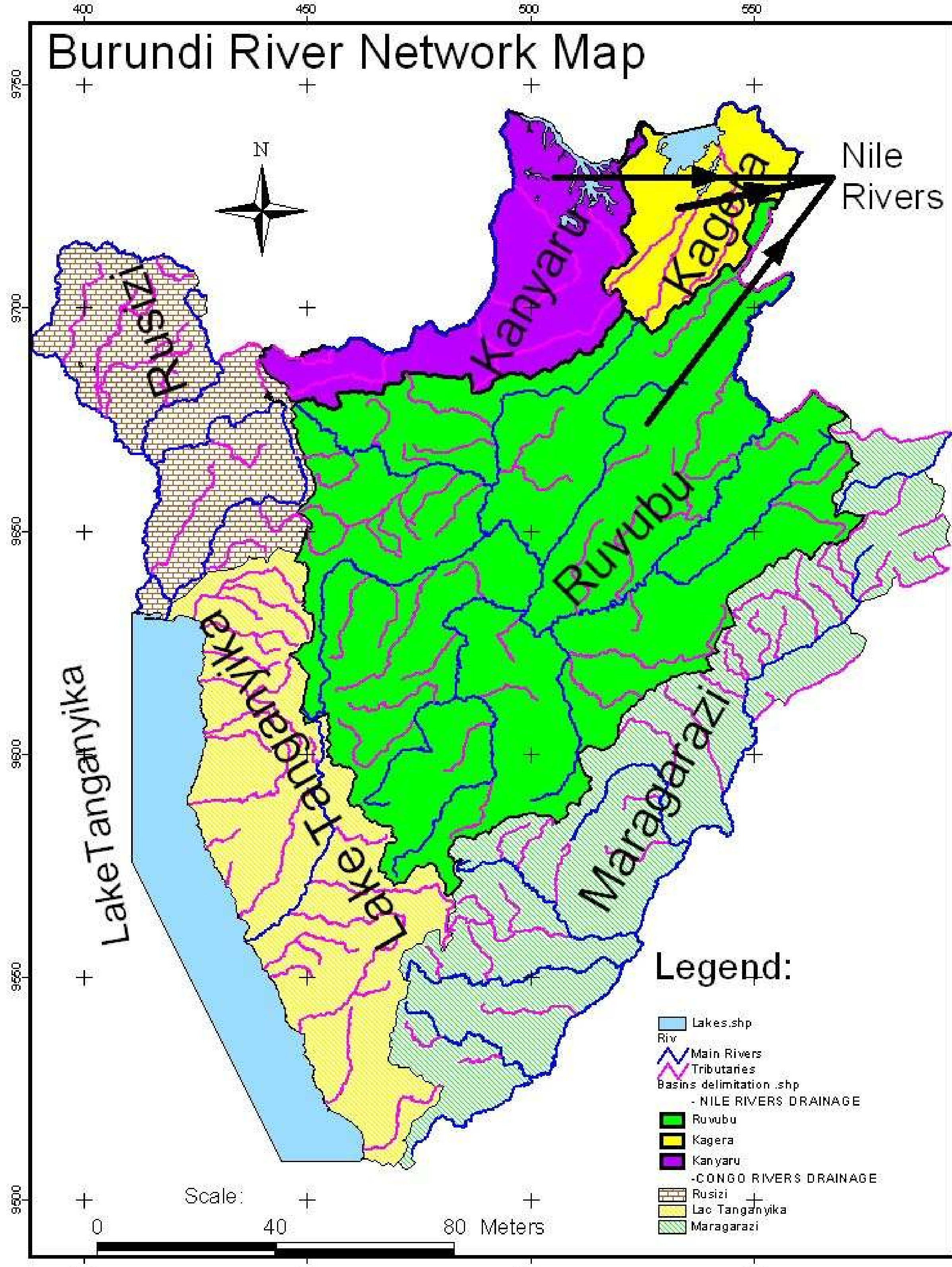


Figure.3.4: River Network of the Burundi basins

Burundi is subdivided into six sub-basins in which Ruvubu is the largest (40.2% of the total land area). A comparison of Ruvubu basin and others sub-basins with respect to coverage area are indicated in table below.

Table 3.1: Burundi sub-basins and coverage area

Sub-basins	Congo basin (11,817 km^2)			Nile basin (13,524 km^2)		
	Rusizi	*Lake Tanganyika*	*Malagarazi*	***Ruvubu***	*Kanyaru*	*Kagera*
Surface area into Burundi	*2,682*	*3,871*	*5,262*	***10,063***	*1,938*	*1,217*
As % 0f the total area	*10.7%*	*15.4%*	*21.02%*	***40.2%***	*7.7%*	*4.8%*

3.1.5. Socio-Economy situation and Agriculture

The socio-economic development of a country is related to its water Resources management. Therefore, the population health, economy development and water resources usage in agriculture are the interconnected factors for human being indicators.

A. Population Health

The population of Burundi (2006 estimate) is 8,090,068. The overall density of 315 persons per km^2 is one of the highest in Africa. The population is 90 percent rural. Most Burundians live in family groupings dispersed throughout the highlands, and villages are uncommon. Instability due to violence between the Hutu and Tutsi ethnic groups in both Burundi and Rwanda has led to mass migrations. Burundi’s life expectancy at birth is 51 years, among the lowest in the world, due to poverty, ethnic strife, and numerous diseases, including one of the highest incidences of acquired immunodeficiency syndrome (AIDS) in the world. The population growth rate in 2006 was an estimated 3.7

percent. The country's capital and most important city is Bujumbura, on the northeastern shore of Lake Tanganyika [Nile Conference Report, Feb.2002]. Since the water demand increase with population growth, the table below shows the projected population into 2010 for Burundi.

Table 3.2: Projected population to 2010

Year	1995		2000		2010
Population	Total	Growth rate (%)	Total	Growth rate (%)	Projected population
	6 156 243	3,34 %	7 253 655	3,07 %	9 814 082

B. Economy situation

a. Revenue and poverty

Over the past ten years, the socio-economic situation has steadily deteriorated due to disruption brought about by military conflict, and the social and political crisis which caused a freeze in international cooperation, as well as by drought that extended over several years. All of these factors have contributed to an increase in consumer prices (inflation tripled from 1993 to 1997), while salaries have not increased (in the case of civil servants) or have even been cut back (in the case of employees of many private enterprises). Meeting basic needs in terms of food, clothing and housing has become a problem for a large portion of the population. The percentage of poor people went from 34.8% in 1992 to 69% in 2002. Smaller families and families with educated head of households tend to do better than other families. The crisis increased the vulnerability of the households headed by women (22% of all households). The most excluded groups are street children, war refugees, the disabled and members of the Batwa social group. The access to water usage has been also deteriorated due to this socio-political cris and is linked to the poverty of the people.

b. Country Resources and Revenue

Income per capita stood at about US$100 in 2002, which makes Burundi one of the poorest countries in the world. Burundi has a predominantly agricultural economy and its Gross Domestic Product (GDP) was estimated at US$657 million in 2004. Export earnings are dominated by a single crop: "coffee" and little "tea".

Mining includes the small-scale exploitation of gold and peat. Important reserves of uranium and nickel (estimated at 5 percent of the world's reserves) remain to be exploited. Test drilling has indicated the presence of oil under Lake Tanganyika, but petroleum exploitation has not yet proved significant.

National budget figures for 1999 showed a large deficit, with $128 million in revenues and $167 million in expenditures. The government and foreign companies dominate the export sector of the economy.

Burundi is heavily dependent on foreign aid, principally from Western Europe. Past austerity measures have added to ethnic tensions. In turn, ethnic and political instability has severely affected Burundi's production capacity. Export earnings have fallen from a peak of US$ 132 million in 1988 to an estimated US$30 million in 2001. Burundi's labor force numbers 3.7 million people, of which 15 percent are engaged in agriculture, 22% in industry, and 59% in services.

C. Agriculture

More than 90% of the population is depending on subsistence farming. Agriculture accounts for 49% of the Gross Domestic Product. In 2002, cash crops such as coffee, cotton, tea, rice and sugar accounted for more than 80% of export receipts, but agriculture remained mainly subsistence-based.

The most important cash crop is coffee. Cotton and tea are also grown for export and local consumption. Cash crops revenues are dependant upon international market factors and suffer from inappropriate infrastructure (lack of warehouses, weakness of road and communication systems). Chief food crops are beans, bananas, sweet potatoes, cassava, and maize.

In 2005 livestock numbered 325,000 cattle, 750,000 goats, and 230,000 sheep. Social and cultural importance is attached to the ownership of large cattle herds. Although cattle are raised primarily for subsistence, the customary importance of owning large herds as a symbol of wealth and status (and keeping them rather than selling or butchering them) has caused overgrazing of available pastures lands. They are, however, economically underutilized and overgrazing has contributed to soil erosion.
Furthermore, farm size is shrinking because of demographic pressure. The average farm size is very small (0.5 ha) in most regions. This has led to over-exploitation and degradation of arable land. Soil fertility has declined mainly because of erosion and improper farming practices and many fields are contaminated with iron and aluminum based toxins.
Although, commercial fisheries and subsistence fishing around Lake Tanganyika, supply domestic demand.

3.1.6. Analysis of Water resources distribution and usages

A. Water resources distribution

The distribution and quantity of water has strong relationship with topography and rainfall distribution. The water resource of the country is found in lakes, rivers, streams and of course groundwater. Based on this topography, Burundi is subdivided into six sub-basins as represented early with figure.3.4. The summarized surface water resources potential is shown in the table below (table 3.3 and 3.4).

The table below highlights the importance of Ruvubu basin in term of mean discharge, runoff, total annual water volume and baseflow contribution in Burundi Nile basin part as well as in whole country. Its contribution to Nile basin part of the country is about 78%, 38%, 78% and more than 80% respectively for mean discharge, runoff, annual water volume and baseflow.

The table 3.4.is provided to compare the total available discharge per basin and show the importance of Ruvubu basin (about 35% of the total available discharge for the country) among others.

To compare the homogeneity pattern of Ruvubu and others main rivers of the country, monthly flow of each basin vs. months of the year have been plotted and the fig.3.5 shows similar trends for all with peak observed in April.

Table 3.3: Summary of surface water resource potential in Burundi [PDNE, 1998].

Basin name	Surface area into Burundi (km^2)	Mean discharge				Base flow discharge		Guaranteed discharge (Q95%)	
		Discharge (m^3/sec)	Spec.disch (l/sec*km^2)	Runoff depth(mm)	Total annual volume (*10^6 m^3)	Discharge (m^3/sec)	Spec.disch. (l/sec*km^2)	Discharge (m^3/sec)	Spec.disch (l/sec*km^2)
Rusizi	2682	53	19.8	623	1672	43	15.9	34	12.6
Lac Tanganyika	3871	78	20.1	633	2450	60	15.4	40	10.2
Malagalazi	5262	51	9.7	305	1607	37	7.0	18	3.3
Congo	11817	182	15.4	483	5729	139	11.8	91	7.7
Ruvubu	**10063**	**108**	**10.8**	**340**	**3,420**	**79**	**...........**	**52**	**5.2**
Kanyaru	1938	21	10.7	338	655	14	7.2	11	5.4
Kagera	1217	8	6.7	212	257	5	4.5	4	3.2
Nile	**13524**	**137**	**28.7**	**890**	**4332**	**98**	**.............**	**72**	**13.8**
Total of Burundi	25035	319	12.7	402	10061	237	9.5	157	6.3

Table 3.4: Surface water balance for Burundi [PDNE, 1998]

River name	Imported discharge (m^3/sec)			Exported discharge (m^3/sec)			Total available discharge per basin
	Zaire	Rwanda	Tanzania	Zaire	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
Kanzigiri (kagera)		6	0	0	-14	0	8
Sum	129	39	83	-246	-54	-218	267
Sum	**251**			**-518**			**267**

In term of groundwater no detailed information is available. However it have been considered that groundwater resources with specific discharge above 0.3 l/sec*km^2 are economically exploitable. Based on the sample springs flow, Burundi has more than 6,600 liters/sec which means about 574,240 m^3/day [PDNE, 1998].

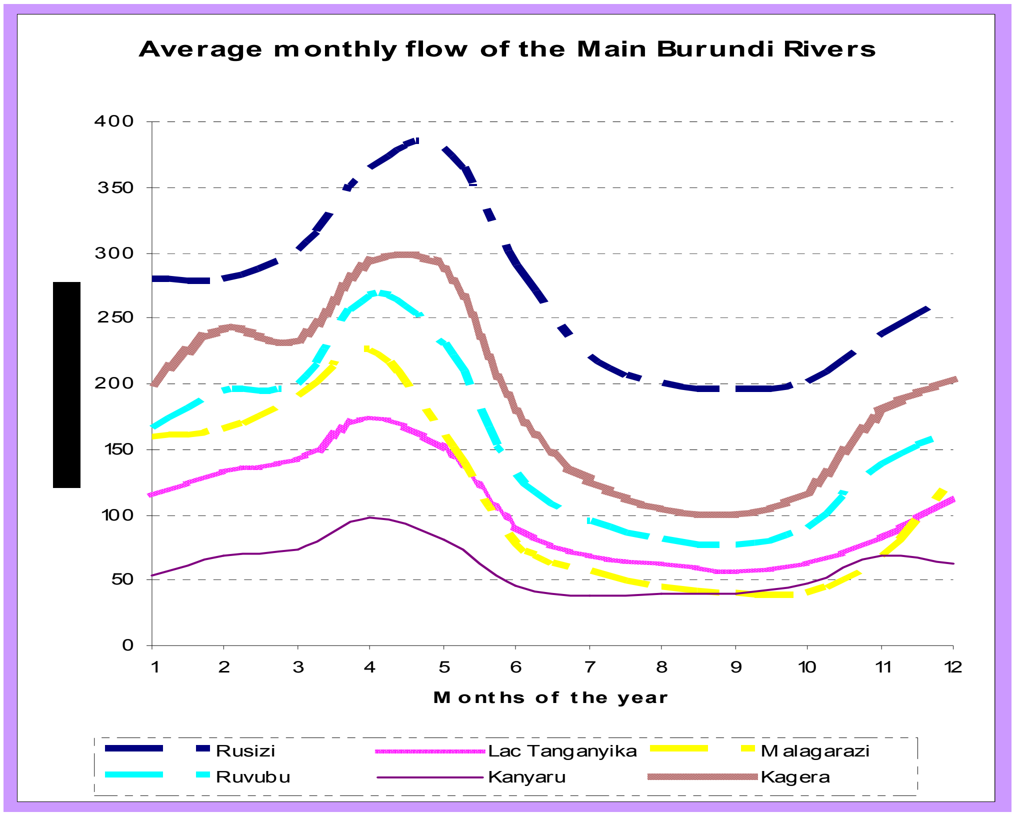


Figure 3.5: Sub-basin Monthly flow pattern

The above graphic schemes show clearly that the maximum mean discharge is observed in mid-April in most of the rivers and the minimum mean discharge is reached in September which corresponds respectively with maximum rainfall and minimum rainfall in the year.

The yearly distribution of the flow of river is highly dependent on rainfall pattern.

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 over lap.

Considering the surface water balance budget, Burundi receives 251 m^3/sec as imported discharge and 267 m^3/sec are produced inside the country and summing a total of 518 m^3/sec for the outgoing discharges (PDNE, 1998).

B. Water utilization situation

Coming to water utilization, the water demand is increasing with respect to population growth. In rural area the water demand has increased from $173*10^6$ m^3 in 1990 to $293*10^6$ m^3 in 2000. In urban, it has increased from $22*10^6$ m^3 in 1990 to $40*10^6$ m^3 in 2000, it means two times each 10 years.

Table 3.5: Drinking water demand forecast ($*10^6$ m^3/sec)

Year	1990	2000	2010
Urban water demand	22.77	40.99	70.42
Rural water demand	173.45	292.6	433.87
Total water demand for the country	196.34	333.59	504.29
Total water demand within Nile basin	102.1	173.47	262.23

Coming to water usage, the economy of the country is based on traditional agriculture and does not satisfy the food security demand. Almost 90 % of the population are farmers and depend on water resources utilization. However, it is necessary to mention that the water use in agriculture is essentially rainfall. Hence, the productivity is still insufficient and when drought occurs even for a short period of time (say 2 or 3 months) it constitutes a calamity for the people.

Currently the water supply is estimated at 94.5 % for domestic, 5.22% for public's infrastructures (schools, health center, hospital, market, etc.) and 0.22% for industries.

In Rural area, 51% of the population is supplied from developed springs and 49% remaining takes water from natural rivers and lakes which are less potable.

The Ministry of rural development report indicates that only 50.6% of the rural people are supplied in potable water.

In Burundi the organization responsible for urban water supply and quality control is REGIDESO a semi government own firm. The urban area is supplied by gravity water supply system but it is subjected to shortage of water due to excessive increasing water demand.

The usage of water for Electricity is dated from 1940 and there are actually 27 hydropower plants stations in the whole country. The hydropower potential with power greater than 1MW is estimated at 6000 GWh/year with 61.62 m^3/ sec of water demand (10% of the available discharge for the country).

Burundi expects to have more energy supply with two hydroelectric generation plants on Rusumo River (in Tanzania) and Rusizi River together with cooperation of Congo, Rwanda and Tanzania through Nile Basin Initiative Projects.

Generally, lack of details information on water resources of the country is one of the disadvantage factors for its multiple usage development.

3.2. Analysis of Physiographic and Hydrologic characteristics of the study area.

3.2.1. General View.

As said above, 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. The mountain is lying NNW/SSW. From the northern tip in the virunga (volcanoes) mountains, Rwanda with an altitude reaching 2990 m, then 2650 m then 2670 m in up to the tip south of Burundi where the chain culminates at 1852 m only. The chain is asymmetric with the western side being much steeper than the eastern side that leans slightly towards the central plateau of Burundi within the Ruvubu hence the Nile basin within Burundi [Nile Conference Report, Feb.2002].

3.2.2. Ruvubu location

The Ruvubu sub-basin, considered here after as a basin is a sub-basin of the Nile. The location of Ruvubu basin on Burundian map is shown on figure 2.6 below. The Ruvubu river basin is located in Center-East of the country between 2° 30’ and 3° 55’ North latitudes, and 29°30’ and 30° 45’ East longitudes. It covers 10063 km^2 as derived from ArcView3.3 and represents about 40.2 % of Burundi’s land area. It is the largest sub-basin among the six in the country. The study area extends through 11 provinces which are among the most populated of the country such as Muyinga, Muramvya, Kayanza, Ngozi, and Gitega with mean density between 300 and 400 inhab/km^2 [ISTEEBU, 1990]

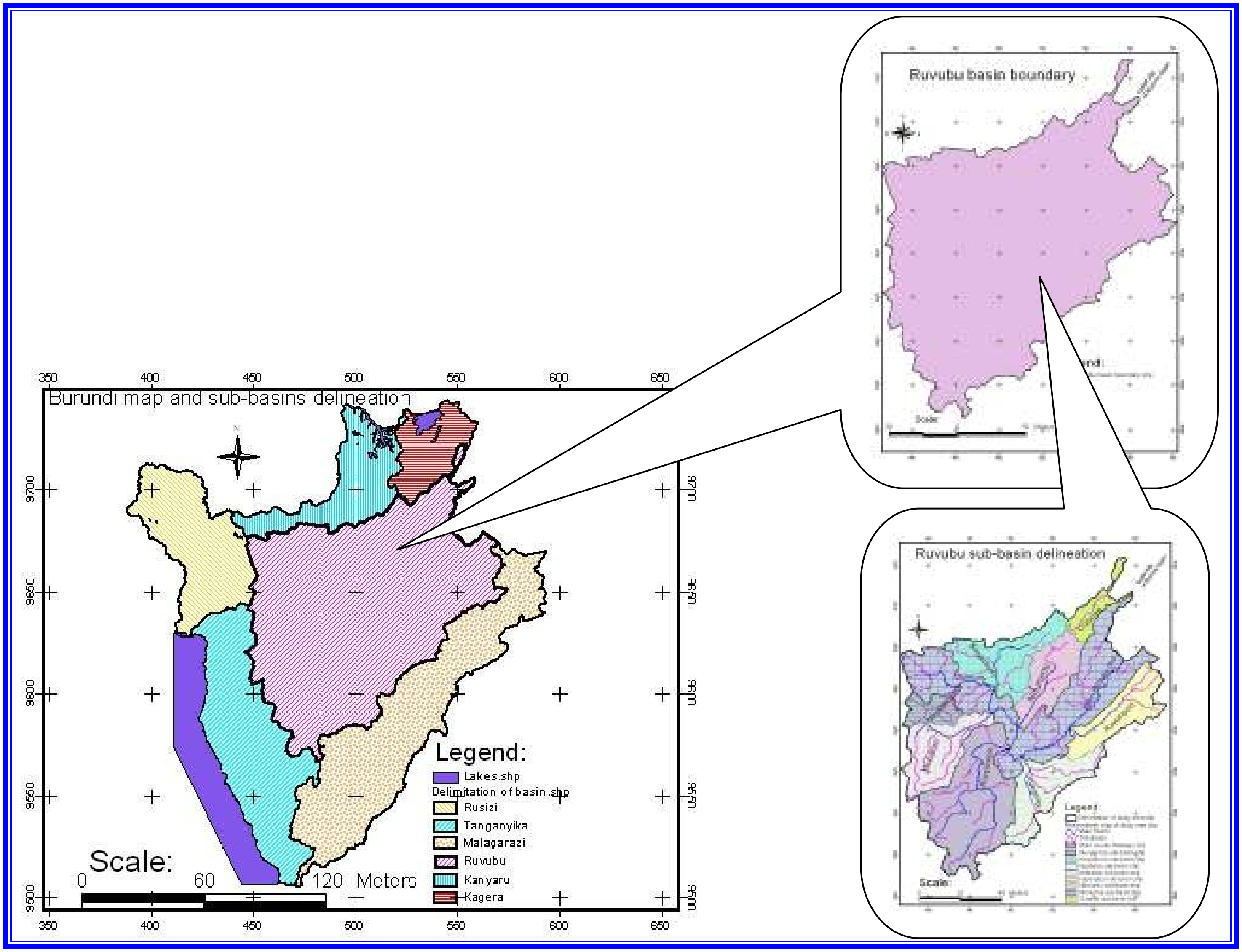


Figure 3.6: Location of Ruvubu basin on Burundi map.

The water resources system of Ruvubu basin is not well-studied and documented basin; hence calls for a study starting from basic characteristics of the basin.

3.2.3. Topographical and hydrographical features

A. Topographical features.

The Ruvubu River originates from the mountains forest "KIBIRA". The physiographic information of the country, which is according to GIS Data, shows that the topography of the basin ranges between 1500 m up to 2750 m above mean sea level respectively from Eastern lowland to South-Western highland.

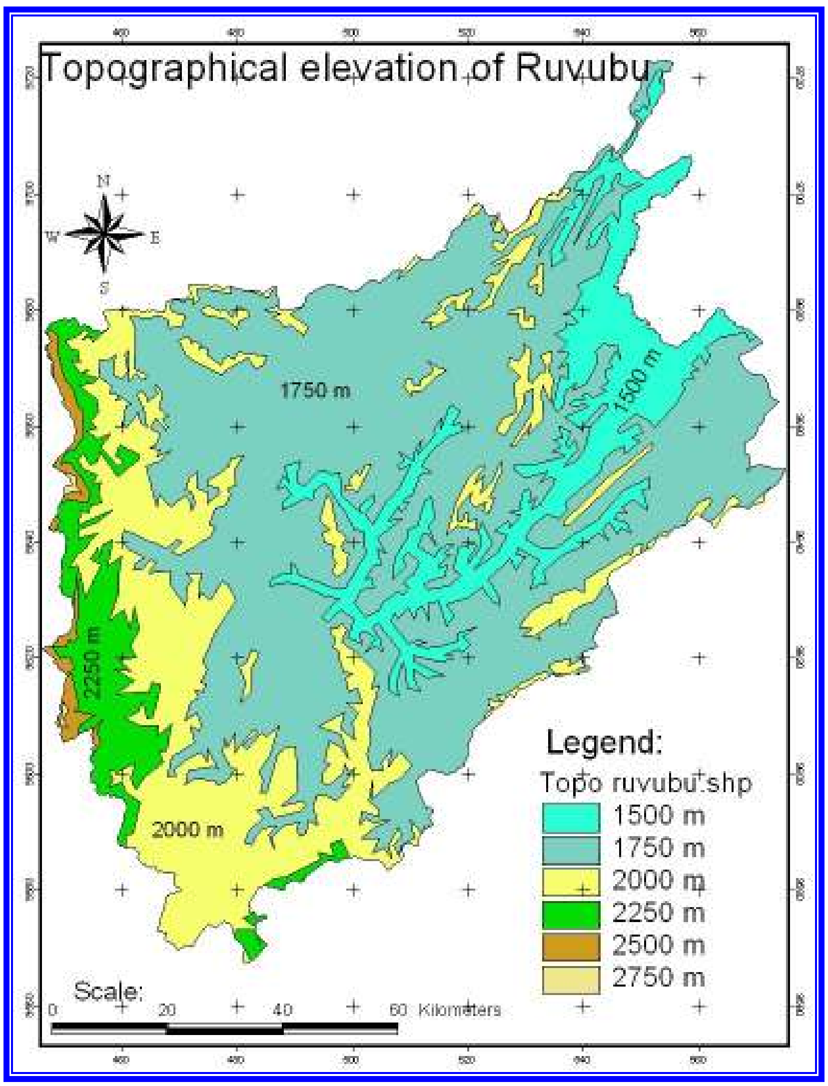


Figure.3.7: Ruvubu topographic feature

The physiographic information of the basin indicates that most of the terrain has slopes oriented in two direction, West-East direction and North-South directions. The slope with West-East direction is more steeper than North-South direction slope.

B. Hydrographical feature analysis

Burundi owns the most southern source of the river Nile which is located near Rutovu in the south of the country. We thereafter shall consider the Nile to be represented in Burundi by the tributaries of the Kagera River that are those of the Ruvubu River as well as part of the kanyaru shared by both Rwanda and Burundi countries. The Kanyaru River collects the remaining tributaries within the Nile basin in Burundi and some from southern Rwanda. The hydrographic network of the Kagera River is marked by a multitude of lakes some of them located in Burundi. These are: cohoha, Rwihinda, Rweru and kanzigiri. The total area of the Ruvubu basin is about 10063 km^2 made of a series of small size sub-catchments whose areas vary from 300 km^2 to 2,838 km^2. It represents alone about 40.2% of Burundi's land area and more than 75% of total Nile basin part of the country. Their compactness indices is estimated to be 1.6, shown that all these sub-catchments are quite homogeneous.

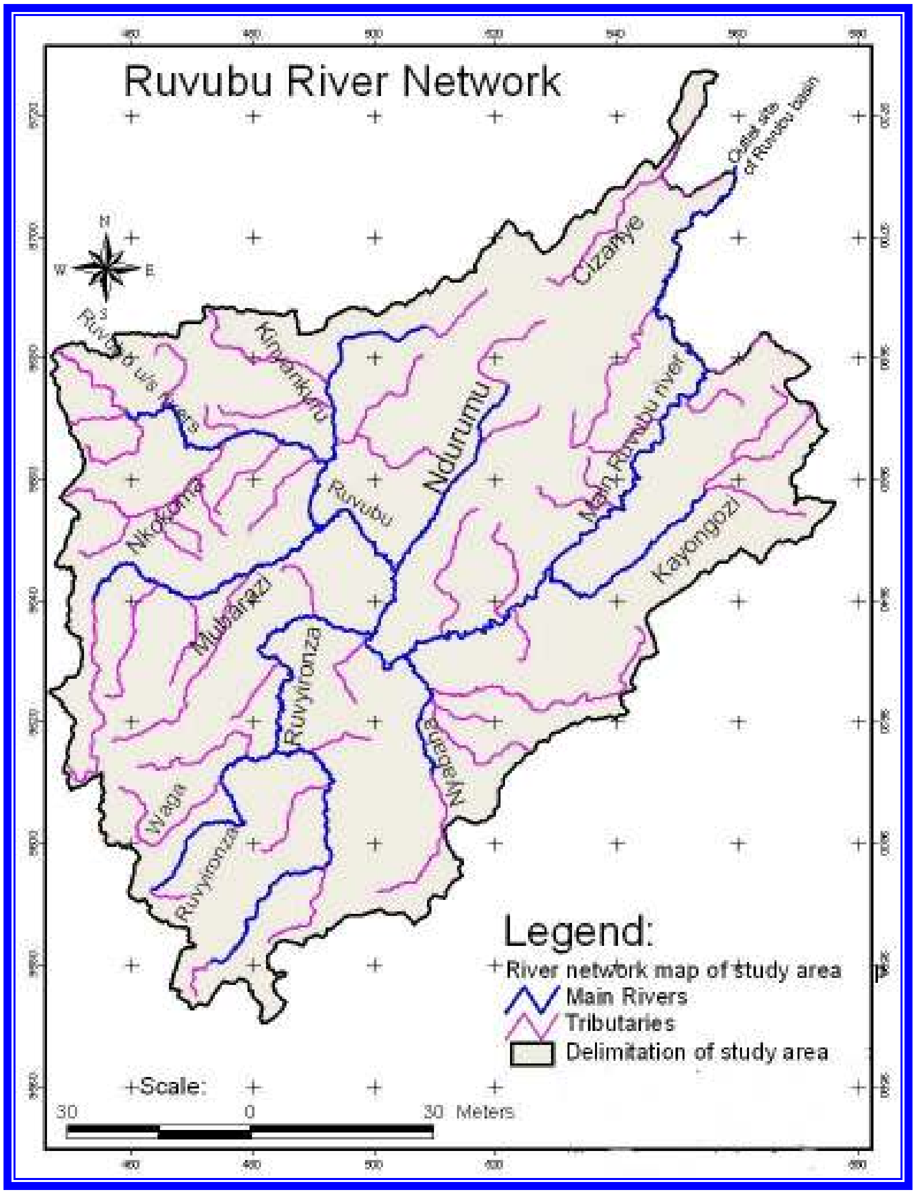


Figure.3.8: River Network of Ruvubu basin

Taking into account the length and the area as criteria for importance, we may consider the major tributaries of the Ruvubu to be: Ruvyironza, Kinyankuru, Nyabaha and Mubarazi. Taking into account the water discharge criterion alone, the major tributaries of the Ruvubu River will be Ruvyironza and Nyabaha which collect essentially the water from the southern part of the basin.

Analyzing the river network of the basin, the combined effects of climate and geology on the basin topography yield an erosion pattern which is characterized by a network of dendritic stream pattern. The basin is homogeneous, offering no variation in the resistance to the flow of water. The resulting streams run in all directions with no define preference to any one particular direction.

C. Climate

The Ruvubu is gauged basin with about 23 functional meteorological stations out of 32 distributed throughout the sub-basins. The meteorological stations distributions are shown in the figure 3.9 below.

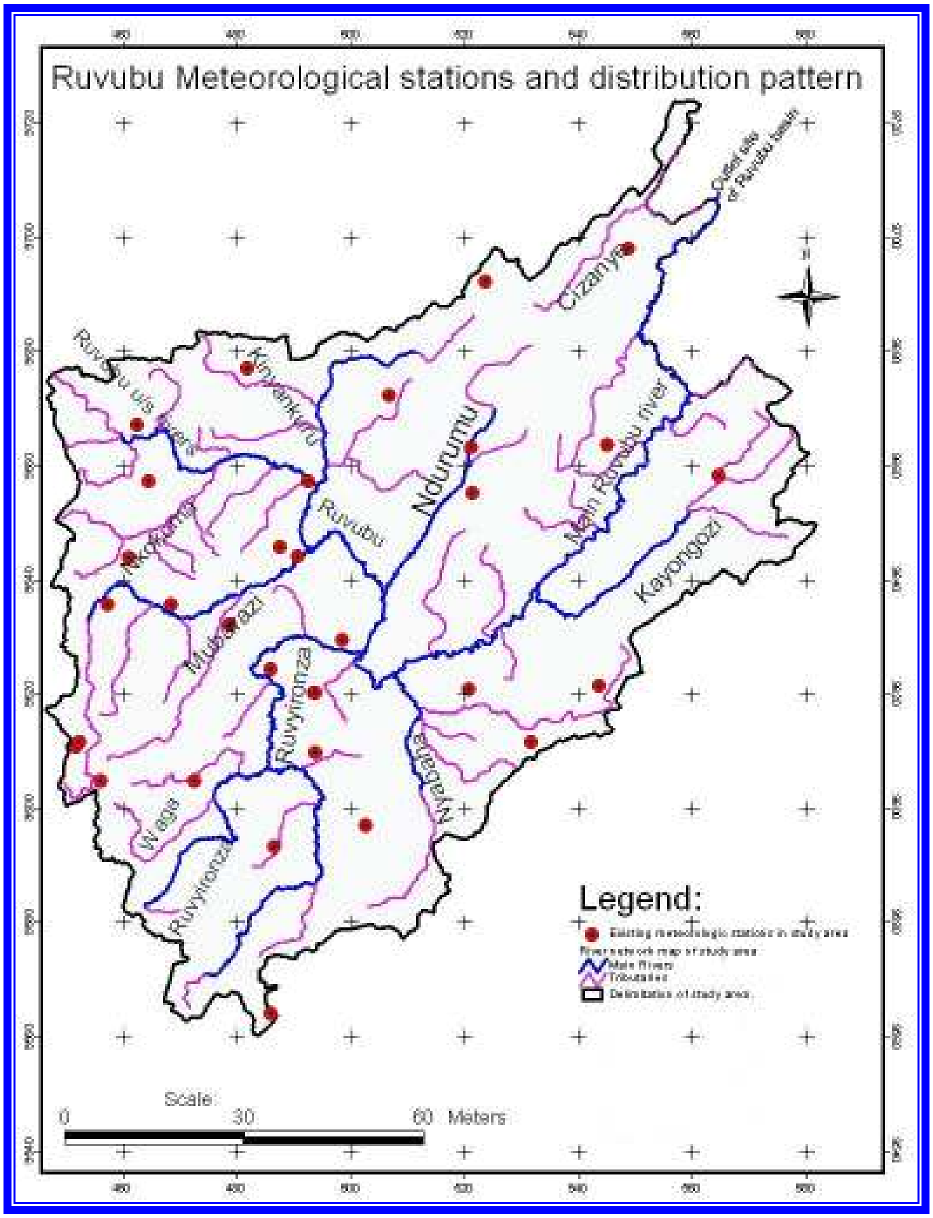


Figure 3.9: Location of Meteorological Station in Ruvubu basin

The rainfall is well distributed over the Ruvubu basin with a slight variability due to the land shape. The maximum rainfall over the basin occurs during the rainy months from

March to April while the dry months are those of from June to August. The total rainfall for these three dry months combined have been estimated at 85mm, 33 mm and 0.5mm for three considered scenarios wetted, moderated and dry years. The long term mean rainfall calculated by the Theisen spatial method over the Ruvubu catchments is found to be 1485mm, 1258 mm and 87mm respectively for Wetted, moderated and dry long term year scenarios (1970-1993).

Table 3.6: Meteorological stations and data record availability

N0	Name of station	Coordinate			Record period
		X	Y	Altitude (m)	
1	Gisozi	464	9606	2097	1970-1990
2	Gitega Airport	464	9606	2097	1970-1990
3	Muriza	515	9605	1616	1970-1990
4	Muyinga	538	9686	1756	1970-1990
5	Nyamuswaga	504	9680	1980	1970-1990
6	Ruvyironza	475	9579	1980	1970-1990
7	Teza	451	9645	1965	1970-1990

Table 3.7: Ruvubu Monthly Mean precipitation for three different scenarios,[PDNE,1998]

Month	Jan	Feb	Mar.	Ap.	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Mean ann prec. (mm)	Sum of 3 dry months	Monthly mean
Wetted year prec.	217.6	193.0	241.9	283.2	142.9	22.1	12.7	50.8	97.7	153.3	241.5	216	1485.6	85.6	123.8
Moderated year prec.	151.2	132.0	169.2	203.5	89.4	9.5	4.6	19.5	57.9	103.0	162.7	154.7	1258.4	33.6	104.9
Dry year prec.	88.9	85.7	109.7	129.2	35.5	0.2	0.0	0.3	22.7	55.4	96.5	97.6	1045.5	0.5	87.1

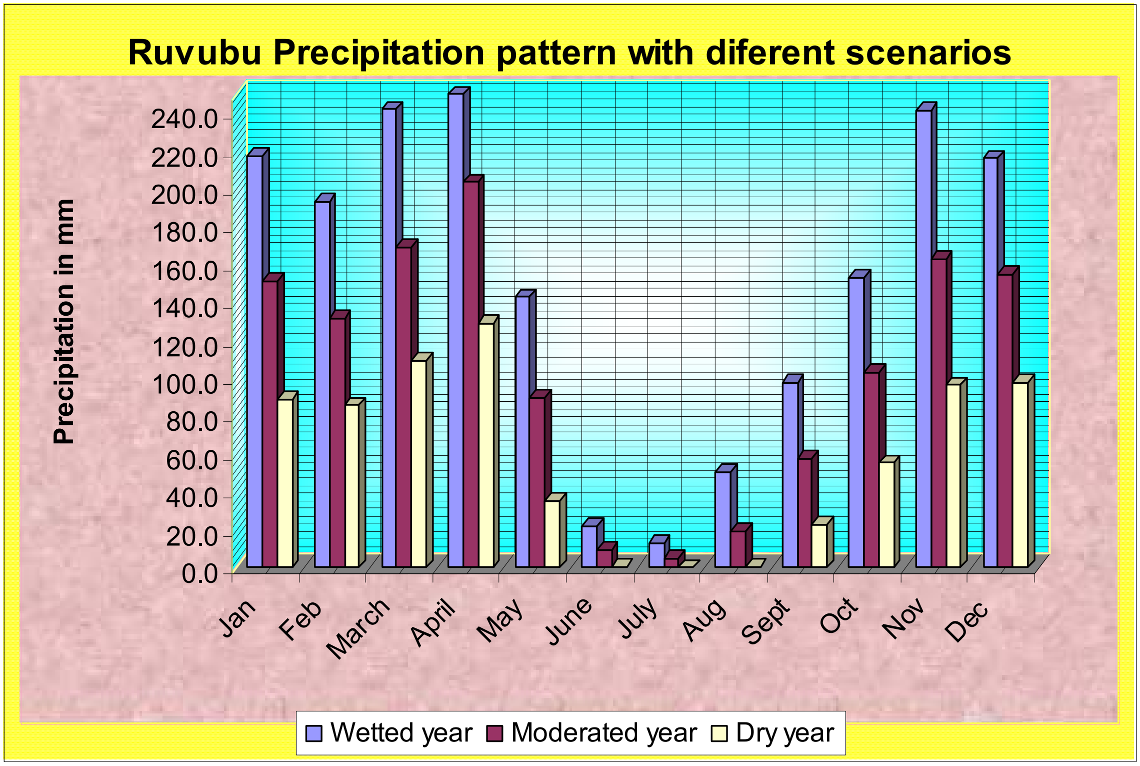


Figure 3.10: Ruvubu Precipitation pattern with three different scenarios

Table 3.8: Ruvubu monthly precipitation-ETP and discharge (wet year),[PDNE,1998]

Mean annual value		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prec (mm)	1485.6	217.6	193.0	241.9	283.2	142.9	22.1	12.7	50.8	97.7	153.3	241.5	216.0
ETP (mm)	1364.9	105.7	99.7	110.9	96.4	106.0	118.3	136.6	142.7	131.0	123.5	96.2	97.9
Discharge (m3/sec)	1511.1	139.5	165.1	157.4	197.1	196.0	125.2	84.8	70.20	59.5	70.4	107.6	137.7

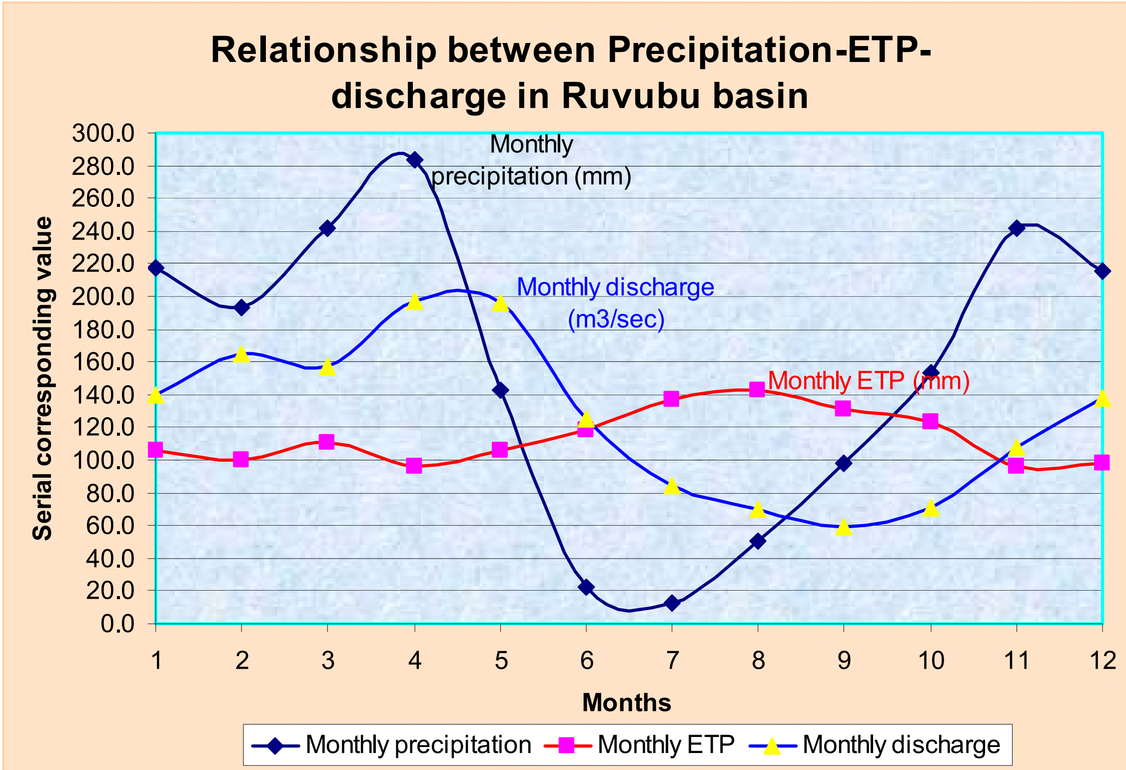


Figure 3.11: Relationship between Monthly Precipitation-ETP-Discharge (Wet year)

Table 3.9: Ruvubu monthly precipitation-ETP and discharge for Moderate year, [PDNE,1998]

Mean annual value		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prec (mm)	1258.4	151.2	132.0	169.2	203.5	89.4	9.5	4.6	19.5	57.9	103.0	162.7	154.7
ETP (mm)	1364.9	105.7	99.7	110.9	96.4	106.0	118.3	136.6	142.7	131.0	123.5	96.2	97.9
Discharge (m3/sec)	1118.0	93.8	112.6	120.2	144.8	145.6	89.7	63.6	54.8	52.1	60.3	82.1	98.5

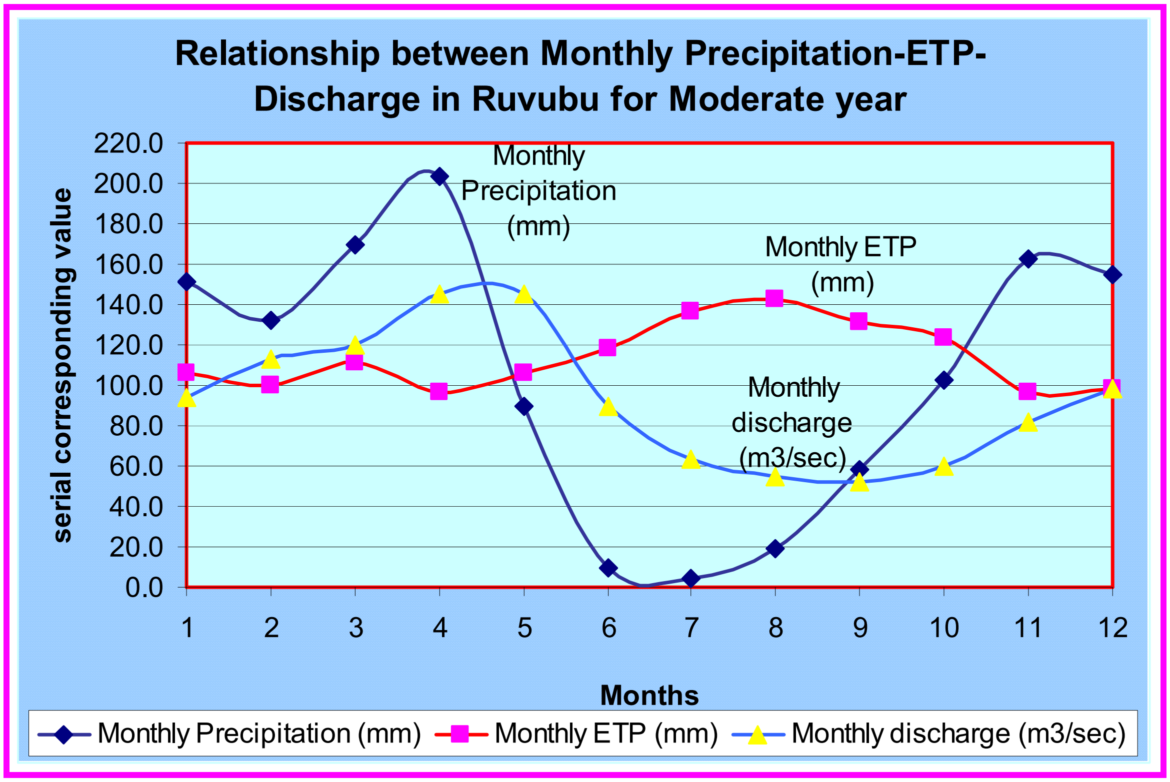


Figure 3.12: Relationship between Monthly Precipitation-ETP-Discharge (Moderate year)

Table 3.10: Ruvubu monthly precipitation-ETP and discharge (Dry year) [PDNE,1998]

Mean annual value		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prec (mm)	1045.5	88.9	85.7	109.7	129.2	35.5	0.2	0.0	0.3	22.7	55.4	96.5	97.6
ETP (mm)	1364.9	105.7	99.7	110.9	96.4	106.0	118.3	136.6	142.7	131.0	123.5	96.2	97.9
Discharge (m3/sec)	760.5	72.9	84.0	94.9	86.6	56.2	45.0	39.5	41.3	48.2	55.7	68.1	68.1

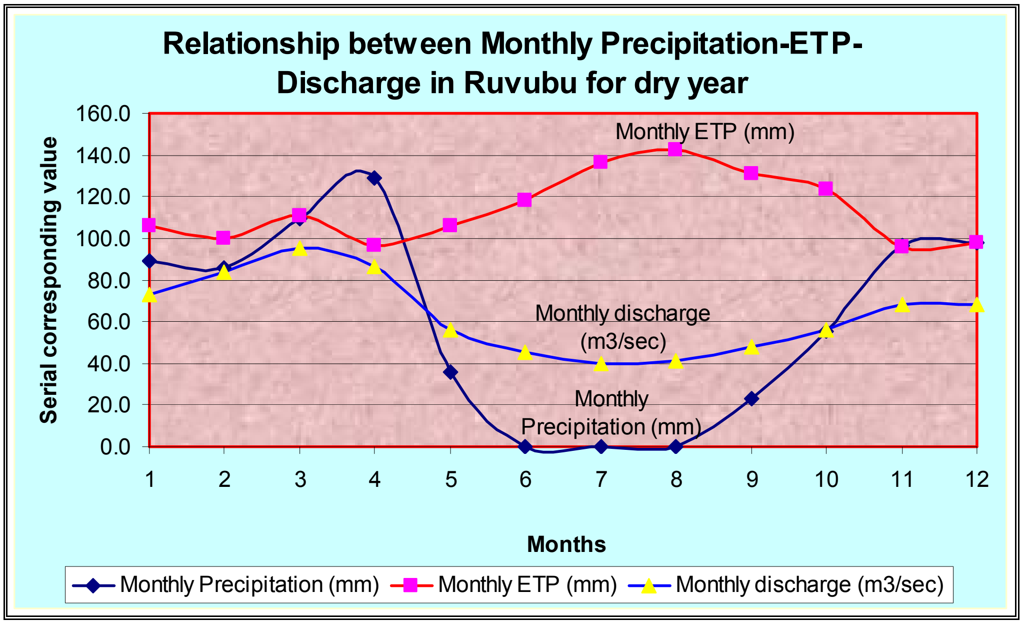


Figure 3.13: Ruvubu monthly precipitation-ETP and discharge (Dry year)

As it can be seen on the above figures, the average monthly precipitation does not satisfy the evapotranspiration demand from May to October in case of wetted and moderate year. In the case of dry year, the monthly evapotranspiration demand is almost greater than the monthly precipitation in the year except April and between November-December. It has to be mention that these months where ETP demand is greater than the Precipitation correspond to the period where precipitation could not satisfy Crop water demand. Hence irrigation system is required for growing crops.

The rainfall regime in the area is characterized by short duration showers and thunderstorms especially during the months of December and February to such extent that it was established that 80% of the daily rainfall events last less than 3 hours.

The other major difficulties are:

- flooding as early as the first rains;
- low crop yield due to water shortage in some years;
- heavy loss of organic soil by erosion;
- heavy deposit of soil in the valley.

According to the GIS data analysis the average annual rainfall varies from the maximum of 1650 mm to a minimum of 950 mm in basin. It can be noted that the precipitation are decreasing with respect to altitude from Western highland to Eastern lowland of study area with average altitude of 1690 m.

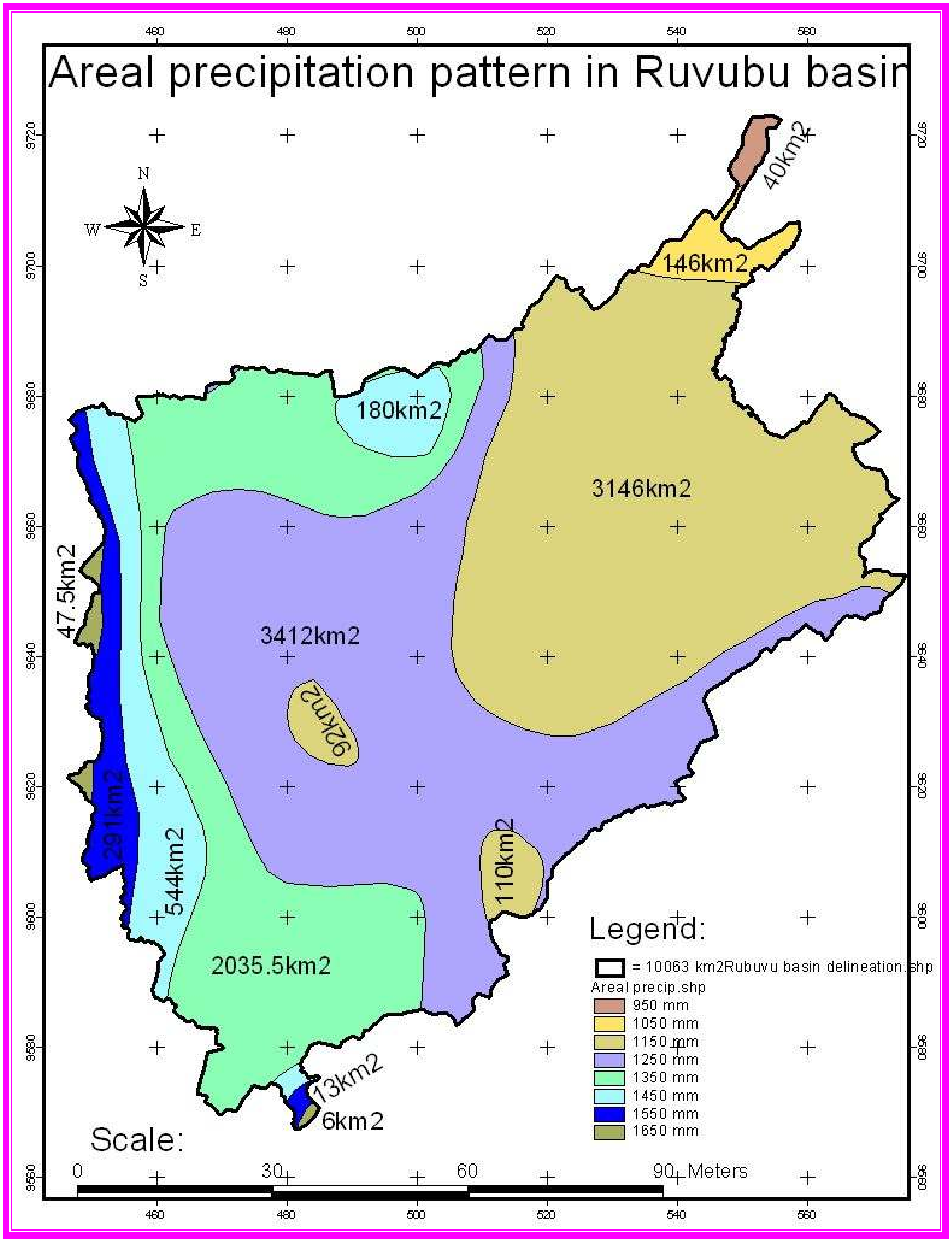


Figure 3.14: Areal precipitation pattern of Ruvubu basin.

Using ArcView 3.3 software, the obtained average annual precipitation is equal to 1334 mm.

Converted to average annual precipitation volume, the results are presented in the table below.

Table 3.11: Average annual precipitation volume in Ruvubu

Precipitation depth (mm)	Wetted area in km^2	Wetted perimeter (km)	Wetted area in ha	Precipitation volume ($*10^3m^3$)
950	39.79	30.86	0.004	37800
1050	145.94	80.90	0.015	153237
1150	3348.25	364.33	0.335	3850483
1250	3411.89	508.23	0.341	4264863
1350	2035.51	433.18	0.204	2747932
1450	723.80	273.23	0.072	1049507
1550	303.96	202.88	0.030	471136
1650	53.57	83.98	0.006	88386
Sum	**10,062.69**	**1,977.60**	**1.007**	**12,663,344**

Here by summing the areal precipitation volume the result show that Ruvubu basin receives about 12.66 km^3 of precipitation every year.

2.2.4. Lithology and Geology.

The lithology and geology of Burundi are made of the oldest series of strata of the African pedestal (socle). Burundi belongs to a vast Precambrian geosynclinals in which huge and tick sediments collected over ages. Two major lithological and geological systems surfaced in Burundi namely the RUSIZIAN in the western part and the BURUNDIAN in the central, north and east of the country. The tectonic falt, the Graben represents the south-western bow type branch of the Rift-valley of the east Africa.

The mineral resources of Burundi are relatively scarce. A few alluvial gold deposits are extracted with cassiterite and bastnaisite. Recent findings have brought up a very important nickel deposit in the South-Eastern (Musongati) part to Burundi.

Burundi landshape is one of the most complex in the whole east Africa if we consider the small size of this country. It comprises four types of land features namely:

- The imbo plain in the west,

- The Zaire-Nile basin dividing range,
- The central plateaus
- And Moso depression.

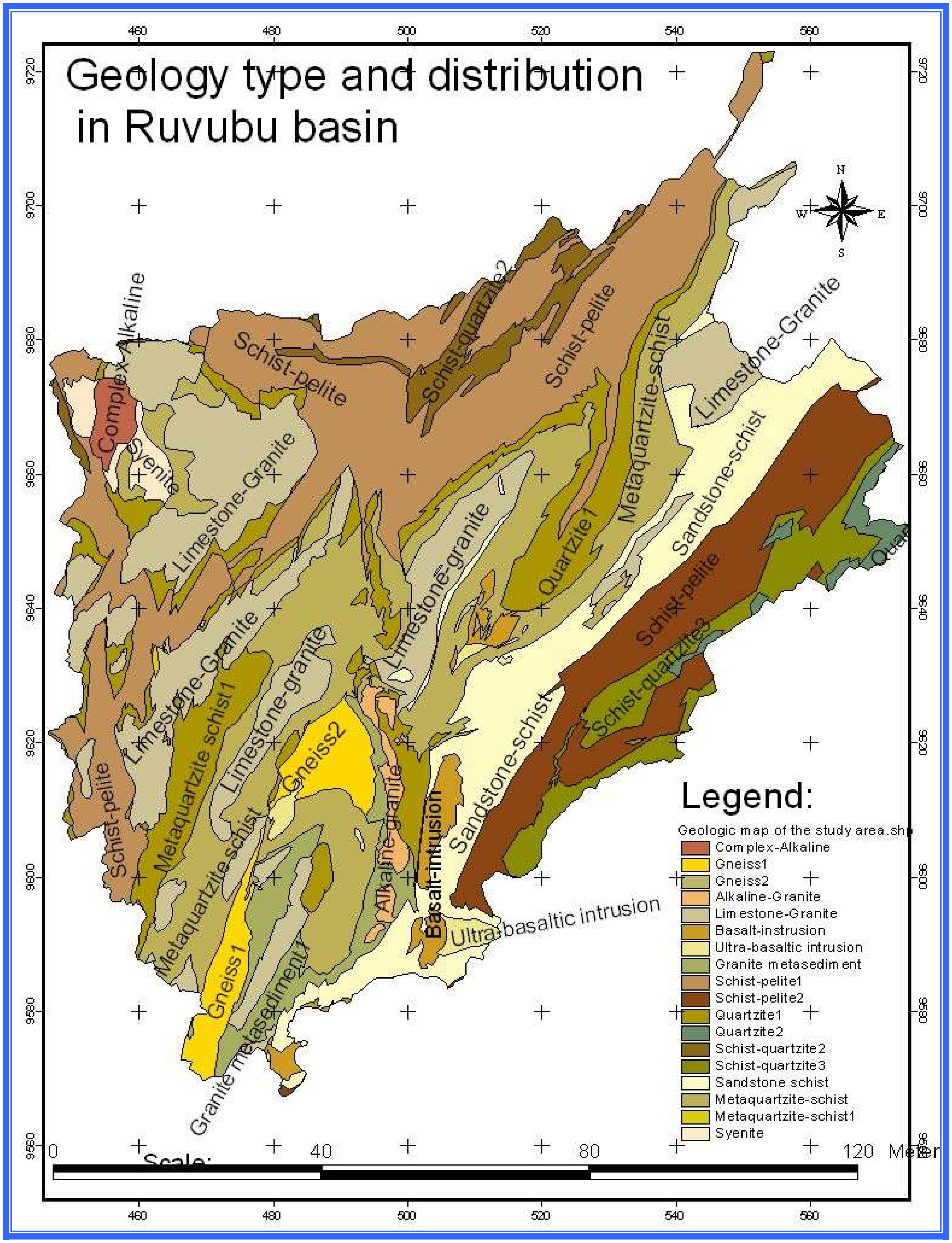


Figure 3.15: Ruvubu basin Geologic Map [PDNE, 1998]

Based on the GIS, the generated results are presented in the above map. The geology of the Ruvubu reflects a complex feature in lithology nature. Considering the criteria of hardness of the lithology, the western and northern zone of the basin is dominated by Schist-pelite, Limestone granite with some intercalation of Metaquartzite-schist. The South and eastern zone are dominated by the extending of Quartzite, schist-quartzite, sandstone schist with some basaltic and ultra-basaltic intrusion. One can also mention a relative alternance between the type of quartzite and type of schist in geology of the study area. The geologic context described here can be referred for reservoir site investigation.

3.2.5. Soils map analysis

The soil studies in Burundi by the ISABU Institute have revealed several major groups of soils within the Nile basin the most encountered being:

- Ferralsoils-orthotype located in the mildly ondulated landscape,
- Ferralsoils-anthropic located within accidented landscape,
- Ferrisoils-intergrades found with recent tropical soils over very steep terrain;
- Ferrisoils-anthropic found with ferrisoils-orthotype in high recent accidented terrain;
- Ferrisoils-intergrade to recent tropical soils and ferrisoils-orthotype found in large plateaux,
- Ferrisoils-intergrade to recent tropical soils and ferrisoils-antthropic found in very accidented high terrain;
- Ferrisoils- intergrade to the recent tropical soils associated with very accidented landscape running from the Zaire-Nile range towards the bottom of the Graben;
- Gravelly ferralsoils with surfacings are found on tops of laterised peneplains of mean altitudes.

Many other soils encountered in the Nile basin are of organic composition associated with the very rich soils bedding the banks of the numerous tributaries of the Ruvubu. The exploitation of these rich agricultural lands supposes mastering water table control during cultural seasons.

Additional information on soil type in study area has been sought using the GIS ArcView 3.3 software analysis and six class of soil are identified. 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 tables below summarize the identified soils class and their physical characteristics (Table 3.11) and Landuse in Ruvubu basin (Table3.12).

Table 3.12: Ruvubu soil classification and characteristics.

Soil type		**Identified soil Characteristics**					
FAO CLASS1	**SLOCLASS1**	**Slope**	**Condition**	**Drainage**	**Texture**	**Soil depth**	**Surface stoniness**
		0%-2%	Optimum	Well		0- 150 cm	
Fru.um	**ab**	2%-8%	Marginal	Well		-	0
		0%-2%	Optimum	Well		100-150 cm	
FRh.or	**b**	2%-8%	Marginal	Well	4	-	0
		0%- 2%	Optimum	Well		50-100 cm	
		2%-8%	Marginal	Well			
Alu.um	**ad**	8%-16%	Inadequate	Well	5		0
		0%-2%	Optimum	Well		0- > 150 cm	
		2%- 8%	Marginal	Well			
Cmu.ch	**be**	> 8%	Inadequate	Well	5		0
		0%-2%	Optimum	Well		100-150 cm	
		2%-8%	Marginal	Well			
FR.or	**d**	> 8%	Inadequate	Well	5		0
		0%- 2%	Optimum	Well			
		2%-8%	Marginal	Well			
LPq	**f**	> 8%	inadequate	Well	5	0-10 cm	0

The following map presents the soil types distribution (figure 3.16) and Landuse map (Figure 3.17).

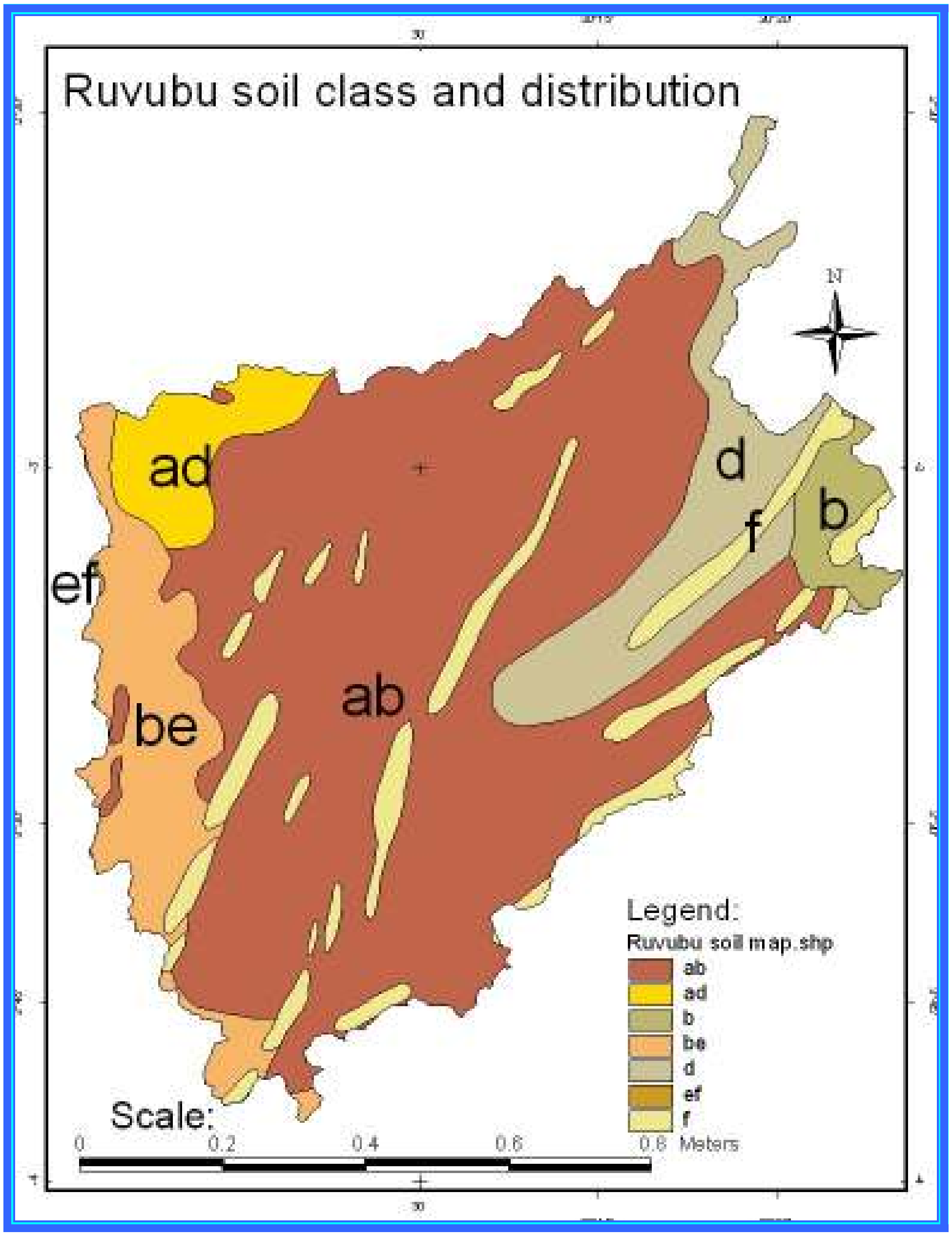


Figure 3.16: Ruvubu Soil map,[FAO, 1974].

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 in general and irrigation appraisal such as topography, drainage, texture, surface stoniness and depth conditions. With these criteria, identified soil classes (ab) is the dominant and with (ad) are fully adequate for agriculture. Soil class (b) and (be) are partially suitable for agriculture with some inadequate because of soil slope (> 8%). The soil class (f) is the less dominant and totally unsuitable for agriculture because of low soil depth (0-10cm).

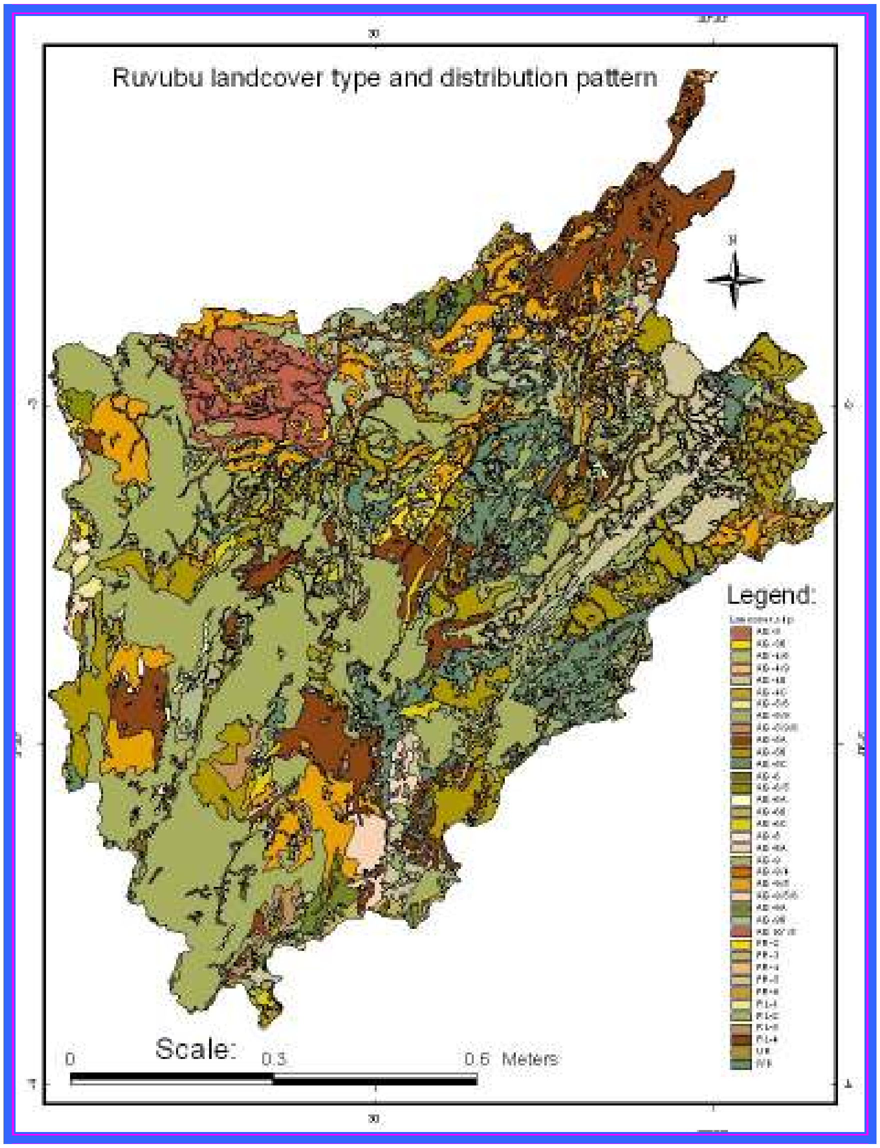


Figure 3.17: Ruvubu Landuse map, [FAO, 1974]

The landuse and cover units are identified and criteria will be set in chapter four for their suitability for irrigation. The landcover and use condition for the basin is extracted from the landcover and use map of Burundi, which was developed by Ministry of Territory, Tourism and Environment. Diversified landuse and cover patterns have been identified and are summarized in the following table (Table 3.13).

Table 3.13: Ruvubu Landuse Classification

Land cover ID	Landcover name
AG-3	Post Flooding Herbaceous Crop
AG-3B	Scattered (in natural vegetation or other) Post Flooding Herbaceous Crop (field density 20-40% of polygon area)
AG-4B	Scattered (in natural vegetation or other) Rainfed Herbaceous Crop (field density 20-40% of polygon area).
AG-4/6	Combination of Rainfed Herbaceous Crop and Forest Plantation (approx. 40-60% and 20-40%; remaining natural vegetation)
AG-4/9	Combination of Rainfed Herbaceous Crop and Shrub Plantation (approx. 30% each; remaining natural vegetation)
AG-4B	Scattered (in natural vegetation or other) Rainfed Herbaceous Crop (field density 20-40% of polygon area).
AG-4C	Isolated (in natural vegetation or other) Rainfed Herbaceous Crop (field density 10-20% polygon area)
AG-5/6	Combination of Rainfed Herbaceous Crop - Two crop per year - and Forest Plantation (approx. 40-60% and 20-40%; remaining natural vegetation)
AG-5/9	Combination of Rainfed Herbaceous Crop - Two crop per year and Shrub Plantation (approx. 40-60% and 20-40%; remaining natural vegetation)
AG-5/9/6	Combination of Rainfed Herbaceous Crop - Two crop per year and Shrub Plantation (approx. 40-60% and 20-40%; remaining Forest Plantation)
AG-5A	Rainfed Herbaceous Crop - Two Crop Year (mixed unit with natural vegetation or other) (field area approx. 60% polygon area)
AG-5B	Scattered (in natural vegetation or other) Rainfed Herbaceous Crop - Two Crop Year - (field density 20-40% of polygon area)
AG-5C	Isolated (in natural vegetation or other) Rainfed Herbaceous Crop - Two Crop Year - (field density 10-20% polygon area)
AG-6	Forest Plantation - (Eucalyptus) - (or Pinus and Cypress)
AG-6/5	Combination of Forest Plantation and Rainfed Herbaceous Crop - Two crop per year (approx. 40-60% and 20-40%; remaining natural vegetation)
AG-6A	Forest Plantation (Eucalyptus) or Pinus and Cypress (mixed unit with natural vegetation or other) (field area approx. 60% polygon area)
AG-6B	Scattered (in natural vegetation or other) Forest Plantation (Eucalyptus) or Pinus and Cypress (field density 20-40% polygon area)
AG-6C	Isolated (in natural vegetation or other) Forest Plantation (Eucalyptus) or Pinus and Cypress (field density 10-20% polygon area)
AG-8	Tea Plantation
AG-8A	Tea Plantation (mixed unit with natural vegetation or other) (field area approx. 60% polygon area)
AG-9	Shrub Plantation - Undifferentiated
AG-9/4	Combination of Shrub Plantation and Rainfed Herbaceous Crop (approx. 40-60% and 20-40%; remaining natural vegetation)
AG-9/5	Combination of Shrub Plantation and Rainfed Herbaceous Crop - Two crop per year (approx. 40-60% and 20-40%; remaining natural vegetation)
AG-9/5/6	Combination of Shrub Plantation and Rainfed Herbaceous Crop - Two crop per year (approx. 40-60% and 20-40%; remaining Forest Plantation)
AG-9A	Shrub Plantation - Undifferentiated (mixed unit with natural vegetation or other) (field area approx. 60% polygon area)
AG-9B	Scattered (in natural vegetation or other) Shrub Plantation - Undifferentiated (field density 20-40% polygon area)
FR-2	Multilayered Trees Broadleaved Evergreen
FR-3	Open Broadleaved Deciduous Trees
FR-4	Closed Shrubs
FR-5	Open Shrubs
FR-6	Open Shrubs (on temporarily flooded land - fresh water)
RL-1	Closed Herbaceous Vegetation
RL-2	Savannah (shrub or tree and shrub)
RL-3	Sparse Herbaceous Vegetation
RL-4	Closed Herbaceous Vegetation On Permanently Flooded Land - Fresh Water
UR	Urban And Associated Areas

3.2.6. Analysis of water resources distribution and drainage sub-basins

The distribution and quantity of water has strong relationship with the topography and rainfall distribution. The water resources of the basin are totally found in rivers, streams and groundwater.

Based on the topography, Ruvubu is subdivided into nine catchments and 14 hydrological stations are distributed within the basin (Figure 3.18).

The figure shows these catchments and is developed by manual delineation and steams network with ArcView 3.3 software.

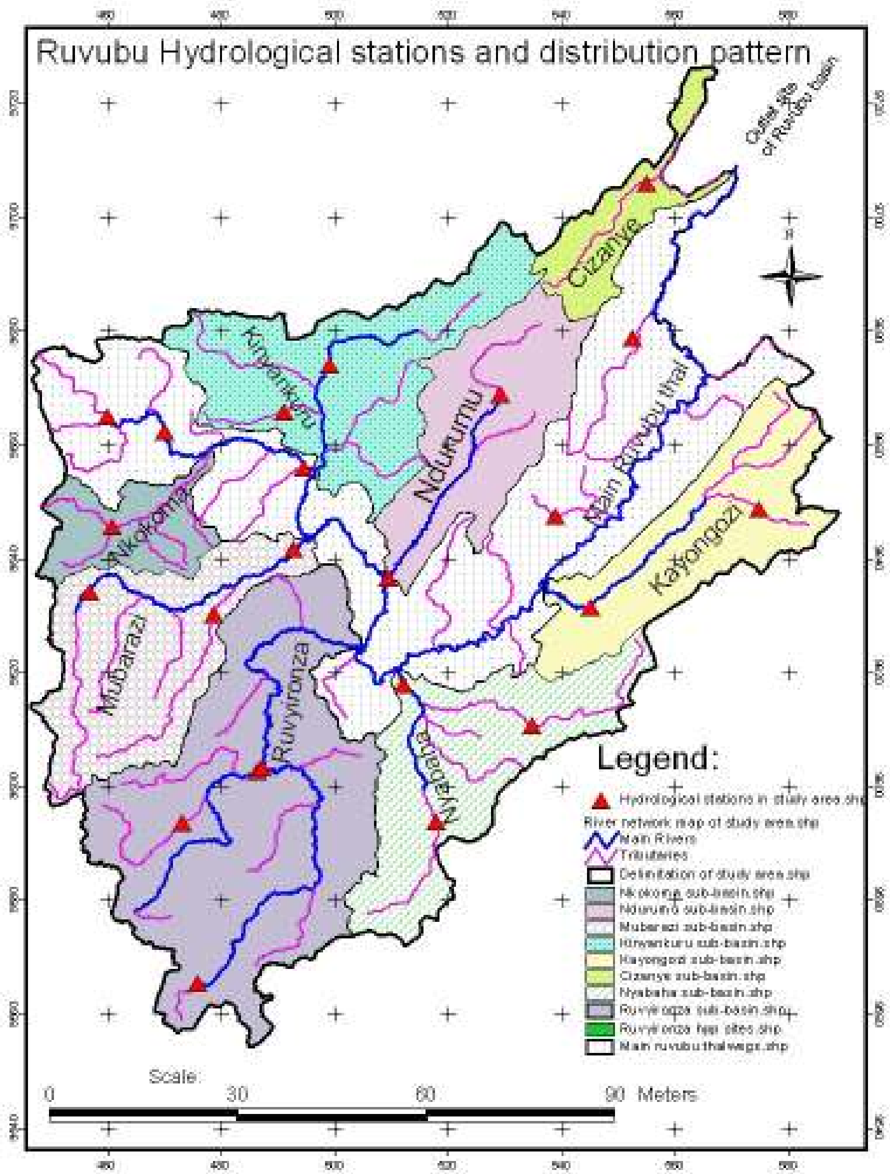


Figure 3.18: Drainage Sub-basin of Ruvubu River.

Table 3.14: Discharge generated throughout the sub-basin

sub-basin name	Area (km^2)	Discharge in m^3/sec	Annual water volume in $*10^6 m^3$
Ruvubu bac	2,838	101,98	3,172.0
Ruvyironza	2,047	24.8	771.4
Kinyankuru	1,059	17.11	532.2
Nyabaha	939.7	8.49	264.1
Mubarazi	926	12.29	382.3
Kayongozi	818	6.12	190.4
Ndurumu	779	9.67	300.8
Nkokoma	341	5.24	163.0
Cizanye	308.5	3.14	97.7

The annual water budget can be calculated using the Empirical formula expressed as:

$$P_t = ET_o + Q_b + R_{off} + I + \Delta S \quad \textbf{...3.1}$$

Table 3.15: Ruvubu annual water budget [PDNE, 1998]

Basin	Area (km^2)	Prec.		ET_0		Q_b		R_{off}		Infiltration		Mean discharge
		mm	%	mm	%	mm	%	mm	%	mm	%	m^3/sec
Ruvubu	10063	1213	100	947	78	237	20	50	4	-21	-2	95.3

The report show that in Ruvubu basin, the available yearly surface water is estimated at over 53.6 million cubic meters and there no information about groundwater resources. It contributes somewhat 32% of national yearly inflow and on the other side, the total flow is trans-boundary and nothing remains in the country.

The yearly distribution inflow of the rivers is highly dependent on rainfall. For example, derived form indicated gauge stations data, 38% of the flow occurs between March and May (3 months). In association of with this pattern, various report show that the river carry heavy sediment load during this period of heavy rainfall. Every year the Ruvubu basin carries between 300 and 700 tons/ha/year of sediment in the last two decade.

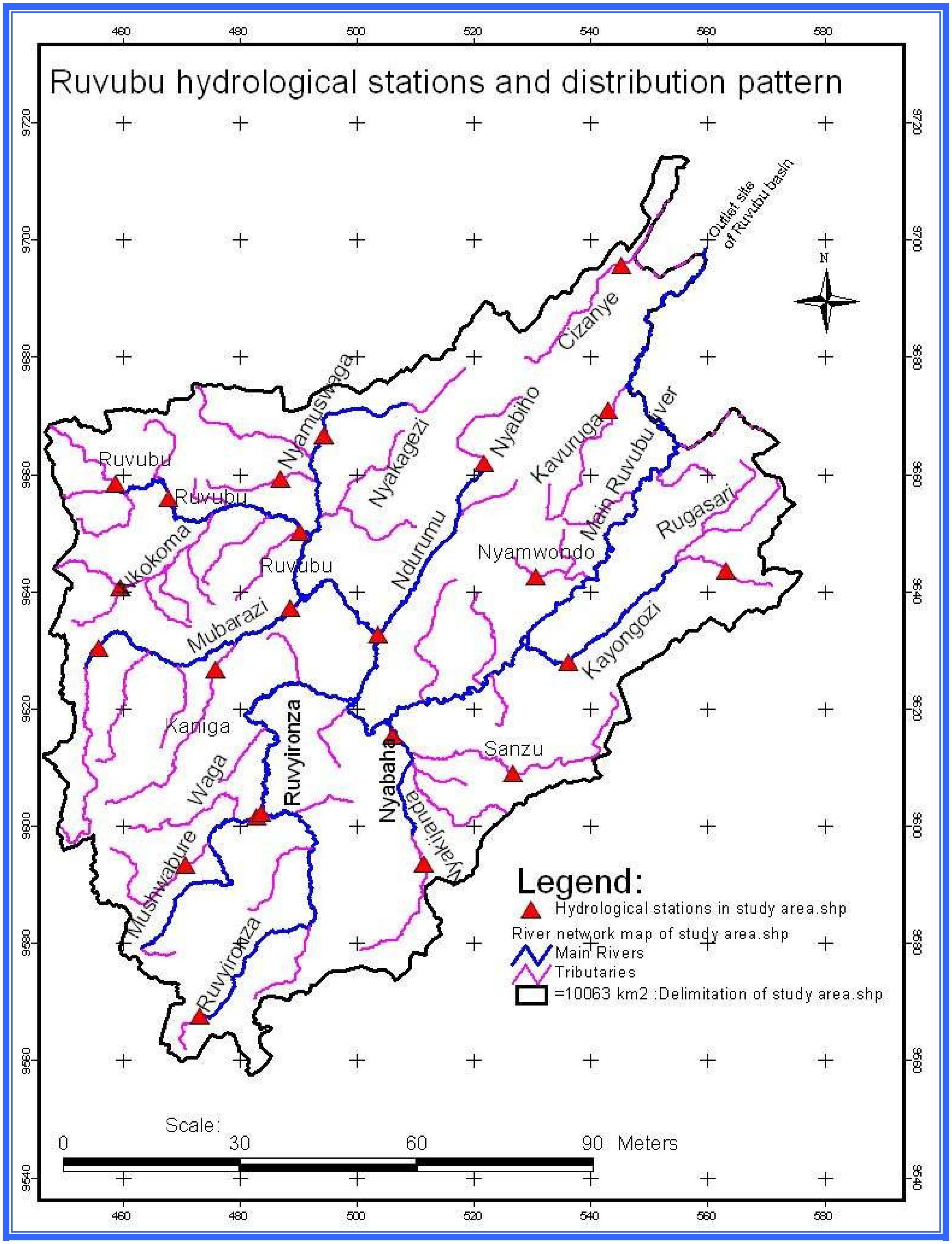


Figure 3.19: Ruvubu sub-basin and drainage pattern

3.2.7. Hydrological regime

Some report shows that the lowest annual flow value of Ruvubu occurs in August, September or October month with a more frequently occurrence in September. It can vary from 30 to 50 m^3 per sec. Soon after this month of September, the flow begins to increase and reach the maximum value in December. This maximum value may become the annual maximum.

The water level decreases during the December-January small dry season. It then restarts to rise soon in February to reach the annual maximum value in April although this may sometimes occur in May. The March and April monthly maxima are very close to the main maximum which often becomes the annual maximum value. It varies from 120 m^3s^{-1} to 250 m^3s^{-1} from year to year.

Analyzing the monthly water flow of the Ruvubu river before its exit out of the Burundi territory provides a figure on which for a dry year, the mean monthly discharge is exceeded only in the first four month from January to April. The mean monthly discharge for a dry year is plot on the below figure.

Table 3.16: Mean monthly flow of Ruvubu river

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean monthly disch. (m^3/sec)
Discharge (m^3/s)	112.6	120.2	144.8	145.6	89.7	63.6	54.8	52.1	60.3	82.1	98.5	80.2	93.8

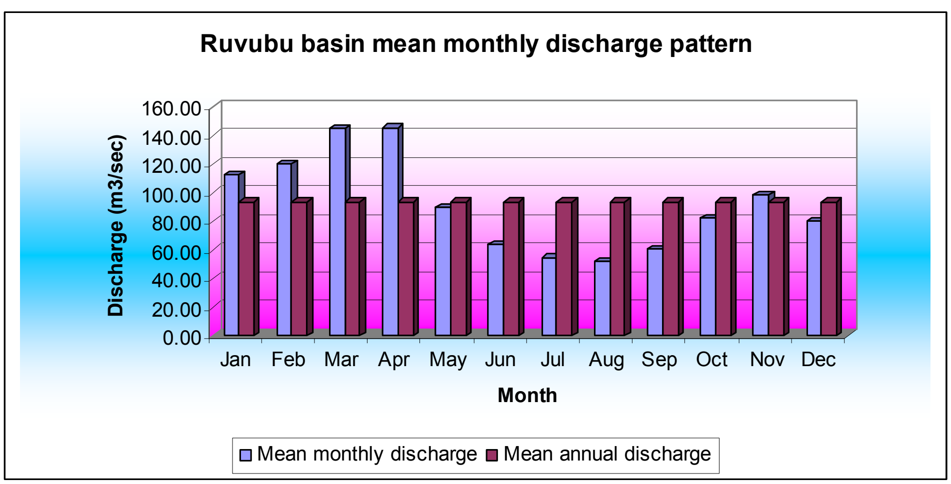


Figure 3.20: Ruvubu mean monthly discharge pattern (Dry year)

When we tried to plot the 120 monthly mean values from September 1974 to August 1984 on a Gauss probability paper, we found that the values belonged not to a unique population but too many of them.

3.2.8. Socio-economic situation and infrastructures

We have already said that the Nile Basin is represented by the Ruvubu catchments with in Burundi with 97% of the entire population living in the country side. The majority of the economically active groups are self-employed or unpaid family workers group. The basin practices varied farming activities thanks to its mild climate and the variability of the landscape.

The natural regions falling in Ruvubu basin (Kirimiro and Bugesera) are the most productive for coffee, the major cash crop as well as for the other food stuff. Rice production is catching up especially in the valleys of the major tributaries of the Ruvubu including the swampy areas where rotational agriculture of rice and beans is practiced.

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 Ruvubu National Park 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 figure below provides the provinces and their population density in the study area.

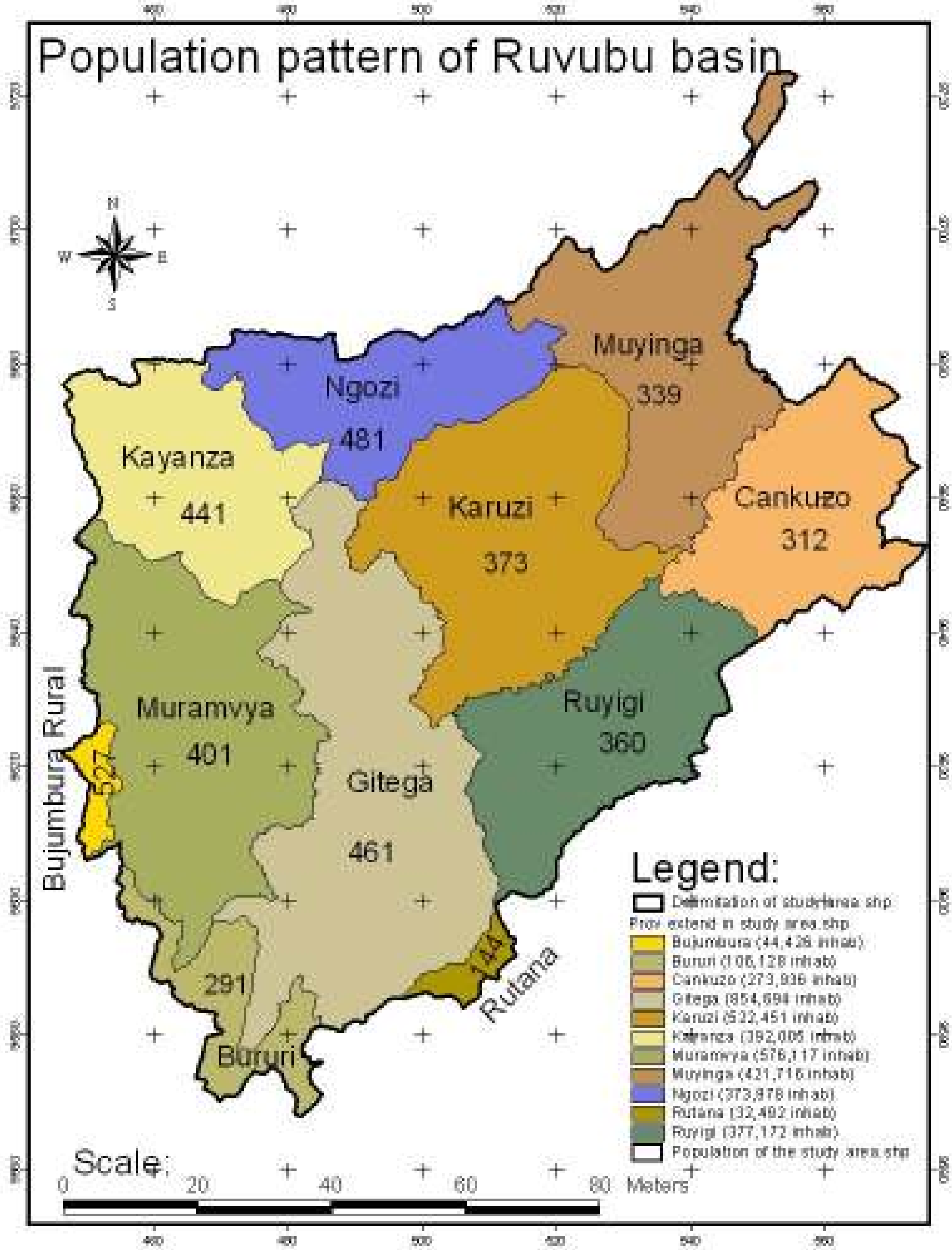


Figure 3.21: Summary of Ruvubu basin population projection to 2010 [PDNE, 1998]

The Ruvubu basin is a home of 3,972,437 people as it has been derived with Arcview 3.3 tool based on database collected from Energy and Water department [PDNE, 1998]. It constitutes about 55% 0f the total National population as it has been projected in PDNE, 1998 report.

Development potential in Ruvubu basin rests largely on the abundant natural resources like a Ruvubu national park with a protected area estimated at 468 km^2 and 111 km^2 of military reserve area. The population is majority of workforce, with major economic challenges coming from rapid population growth, high level poverty and inequality and low productivity.

Per capita income figure shows disparity in wealth and development distribution, with urban town residents earning much more than the peasants in rural area.

In terms of infrastructure development, nine urban town centers are located in Ruvubu basin and all are supplied in electric power and water supply but with regulation system due to shortage of supplying and non updated structures. On average, the population with access to electricity in Burundi is only about 5% to 10%; in Ruvubu basin areas it is even less than 5%.

Rural water distribution is done by the ministry of rural development and recently the local community authorities have been involved. The water supply coverage is actually still low in rural areas: it is estimated to be 40% although considerable efforts are being deployed in the field with the help of foreign assistance.

CHAPITER FOUR

4.0 EXISTING WATER RESOURCES USES AND DEMAND ANALYSIS

This section has aim in understanding the degree of water usages and demand from the general overview of irrigation and hydropower in the country to the specific study area. It analyzes briefly the progress within basin water resources development in order to justify finally the needs of new development resources.

4. 1. Concepts of water demand and use

The terms water use and water demand are often used interchangeably. However, these terms have different meanings.

a. **Water use**

Water use can be distinguished into three different types. These are:

- **Withdrawals (or abstractions):** where water is taken from a surface or groundwater source and after use returned to natural water body (e.g. water used for cooling in industrial processes). Such return flows are particularly important for downstream users in the case of water taken from rivers;
- **Consumptive water use** (or water consumption): that starts with a withdrawal (or an abstraction) but in this case without any return flow. Water consumption is the water abstracted that is no longer available for use because it has evaporated, transpired, been incorporated into products and crops, consumed by man or livestock or otherwise removed from freshwater resources.
- **Non-consumptive water use:** the in situ use of a water body for navigation, instream flow requirements for fish, recreation, effluent disposal and hydroelectric power generation.

b. **Water demand**

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption.

Table 4.1: Total Potable Water demand forecast (*10^6 m^3/sec)

Year	1995		2000		2010	
	Population	Demand (l/sec)	Population	Demand (l/sec)	Population	Demand (l/sec)
Drinking water	**6 156 243**	**1798.27**	**7 253 655**	**2342.4**	**9 814 082**	**3784.91**
Industries		**5.10**		**5.19**		**5.22**
Sum		**1,803.48**		**2,347.50**		**3,790.13**

4.2. Review of existing Irrigation

a. Definition of irrigation:

Irrigation is artificial watering of land to sustain plant growth. Irrigation is practiced in all parts of the world where rainfall does not provide enough ground moisture. In dry areas, such as the southwestern United States, irrigation must be maintained from the time a crop is planted. In areas of irregular rainfall, irrigation is used during dry spells to ensure harvests and to increase crop yields. Irrigation has greatly expanded the amount of arable land and the production of food throughout the world.

b. Irrigation methods: There are four main methods used today to irrigate fields:flood irrigation,

- furrow irrigation,
- sprinkler irrigation,
- and drip or trickle irrigation.

A. Flood irrigation is used for close-grown crops such as rice and where fields are level and water is abundant. A sheet of water is allowed to advance from ditches and remain on a field for a given period, depending on the crop, the porosity of the soil, and its drainage. Basin flooding is used in orchards, with basins built around trees and filled with water.

Figure 4.1: Picture of flood irrigation by simple drawing Water from a Canal

B. Furrow irrigation is employed with row crops such as cotton and vegetables. Parallel furrows, called corrugations, are used to spread water over fields that are too irregular to flood. One disadvantage to the furrow method of irrigation is that plants nearer to the water source may receive much more water than those farther away.

C. Sprinkler irrigation. The principle consist of each sprinkler, spaced along a pipe, sprays droplets of water in a continuous circle until the moisture reaches the root level of the crop. Center-pivot irrigation uses long lines of sprinklers that move around a circular field like the large hand of a clock. It is used especially for feed crops such as alfalfa, which, when irrigated, furnish several mowings a year.
Sprinkler irrigation uses less water and provides better control.

Figure 4.2: Picture of sprinkler method.

D. Drip, or trickle, irrigation delivers small but frequent amounts of moisture to the root area of each plant by means of narrow, plastic tubes. This method, which is used with great success in the United States, Israel, and Australia, ensures a minimum loss of water through evaporation or percolation into the ground.
With this regard, water has always been, and will remain an essential natural resource in the development of the country specially developing countries which depend on agriculture.

However, the use of water for irrigation has been recently introduced in Burundi and then the agriculture sector continues to suffer in cases of water shortages or droughts.

4.2.1. Existing water uses for irrigation

As it has been early stated, almost agricultural productivity depends on rainfall water in Burundi. As the farmers practice the traditional techniques, they grow crop on the upland during the rainy season and crop benefits from rain water requirement. On the other hand, crops are grown in wetland (Marshes) during dry season where flooding irrigation system is applied without using any technique. The water use for growing crop in this manner has not been considered in irrigation water use.

Furthermore, the land on which water is used primarily for the purpose of agriculture production has been named with two terminologies ***"water managed areas"*** and***" irrigated areas or land".***

In this work ***"water managed areas or land"*** represent the land where on crops are grown by simply flooded irrigation system without any control system of water.

The term ***"irrigated areas or land"*** has been limited to that part of the water managed areas equipped with hydraulic structures: full or partial control irrigation, equipped wetland or valley bottoms and areas equipped for spate irrigation.

The difference between the two categories comprises cultivated wetland and valley bottoms without irrigation equipment and recession cropping areas.

The first category concern more crop of rice. For instance, the irrigated agriculture is practiced in Rusizi valley, Tanganyika valley mainly for rice and in Malagarazi valley for growing sugarcanes (SOSUMO "Society sugar plant of Mosso").

Flooding irrigation for rice and furrow irrigation for sugar cane are the mostly practiced techniques.

The tables 4.2 and its relevant figures 4.3, 4.4 and 4.5 gives a general view on water demand per sector to have an idea on how irrigation and hydropower water demand is expected to vary in the period of 20 years (1990-2010). The table 4.3 below is provided to compare the area under irrigation and the corresponding water demand in Ruvubu basin with others sub-basins again in the period of 20years so one can understand the irrigation projection for the study area.

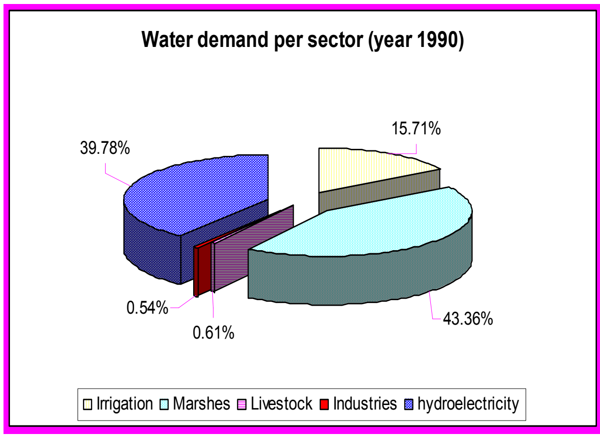
Table 4.2: Summary of non potable water demand per sector in Burundi

Year	***Year 1990***		***Year 2000***		***Year 2010****	
Sector	***demand (l/sec)***	***As % of the total***	***demand (l/sec)***	***As % of the total***	***demand (l/sec)***	***As % of the total***
Irrigation	14,153	15.7	22,274	16.3	24,024	15.9
Marshes	39,054	43.3	45,275	33.2	57,717	38.2
Livestock	546	0.6	683	0.5	958	0.6
Industries	488	0.5	544	0,4	545	0.4
hydroelectricity	35,830	39.7	67,380	49.4	67,380	44.7
Total Demand	**90,071**	**100**	**136,156**	**100**	**150,624**	**100**

Table 4.3: Irrigation water demand projected into 2010

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
Taganyika	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***
Sum	**12,161**	**21,217**	**23,302**	**14,153**	**22,274**	**24,024**

The GIS analysis has been applied on collected data and displayed the general overview of water use at national level as well as at Ruvubu basin level. The table below provides details of the quantity and percentage of water use per sector including irrigation.



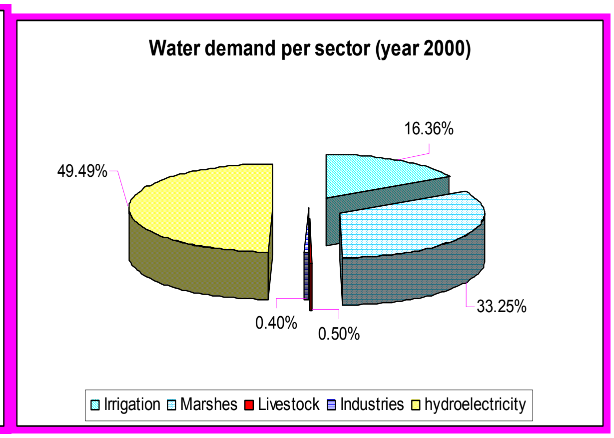


Figure 4.3: Water demand (year 1990)

Figure 4.4: Water demand (year 2000)

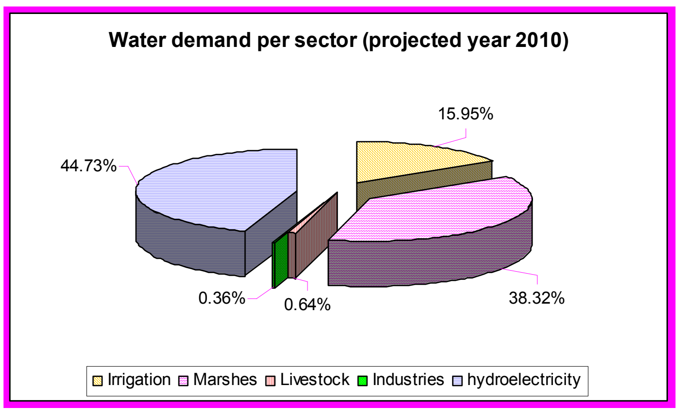


Figure 4.5: Projected water demand in year 2010

Table.4.4: Summary of non potable Water use per sector in Ruvubu basin

year	2000	*2010	2000	*2010	2000	*2010	2000	*2010	2000	2010	2000	*2010	2000	*2010
sector	Potable water		Wetlands		Irrigation		Hydropower		Livestock		Industry		Total use	
water use (m^3/sec)	**1.46**	**3.79**	**32.5**	**32.6**	**0.00**	**0.00**	**15.10**	**19.9**	**0.42**	**1.88**	**0.20**	**0.21**	**52.8**	**54.39**
% of the total	**2.94**	**6.50**	**65.4**	**55.8**	**0**	**0**	**30.4**	**34.1**	**0.84**	**3.22**	**0.4**	**0.36**	**100**	**100**

**means the projected scenario*

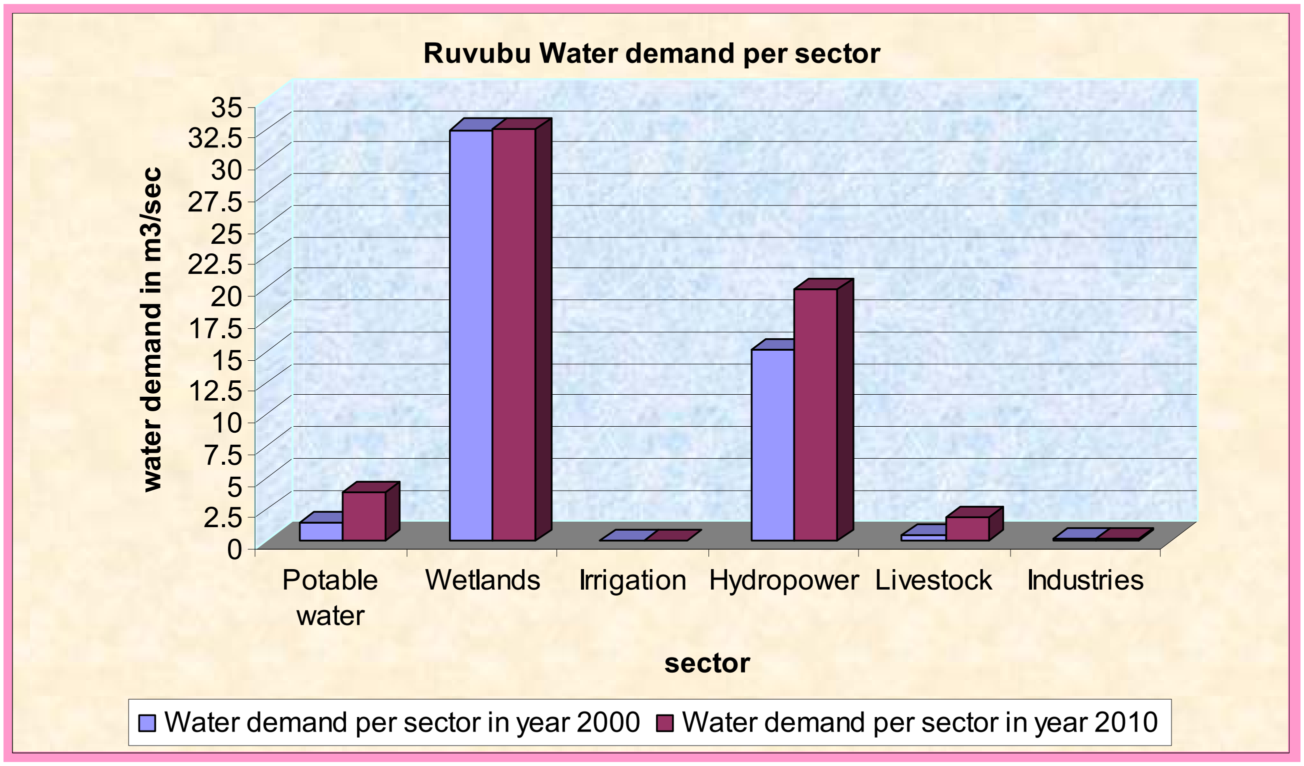


Figure 4.6: Ruvubu Water demand pattern per sector (Between 2000 and 2010)

Tables 4.4 and 4.5 and the associated above diagrams gives broad patterns of water demand in Burundi as well in Ruvubu basin for different sectors. Whilst the absence of data on the total volumes of water used in the country prevents detailed comparisons from being made, agricultural water use in the country clearly is dominated compared to hydropower and wetland water use sectors.

In this regards total non potable water use in Ruvubu basin; represents 32% of the national use. And there is no significance variation in quantity of use from 2000 up to 2010.

It is currently estimated null in the study basin. The low proportion of water used for agriculture suggests that how crops may fail when drought occurs. And further, express low agricultural productivity which is heavily driven by scarce or undistributed rain over time. Hence there is highly opportunity of increasing productivity by irrigation practice.

However, the water managed areas are presented with unknown scale along the Ruvubu wetland and its tributaries.

4.2.2. Overview of irrigation development in Burundi

It is difficult to find reliable estimates of the irrigation potential of the humid country, like Burundi. In fact, neither water nor land is a limiting factor to agricultural development in the country and others factors have to be taken into account in other to have some kind of realistic estimates of potential [FAO, 1997].

4.2.2.1. Identification of irrigation development in Burundi

Considering the PDNE 1998 database, and using GIS software to display the information on irrigated area we have derived the projected irrigation area into 2010. For visual understanding and spatial interpretation, the projected scenarios have been plotted (figure 4.7) and then located irrigation development with respect to different sub-basins of the country. This helps quickly foreseen in irrigation development of interest basin compare to others.

Table 4.5: Irrigated land projected in 2010

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

* *means projected scenario*

The major irrigated crops are rice and sugar cane. The irrigation area has increased by some 102.3 km^2 between 1990 and 2000 and by 43.7 km^2 from 2000 to 2010. Note that only irrigated area with full or partial irrigation techniques have been considered but water managed areas also exist.

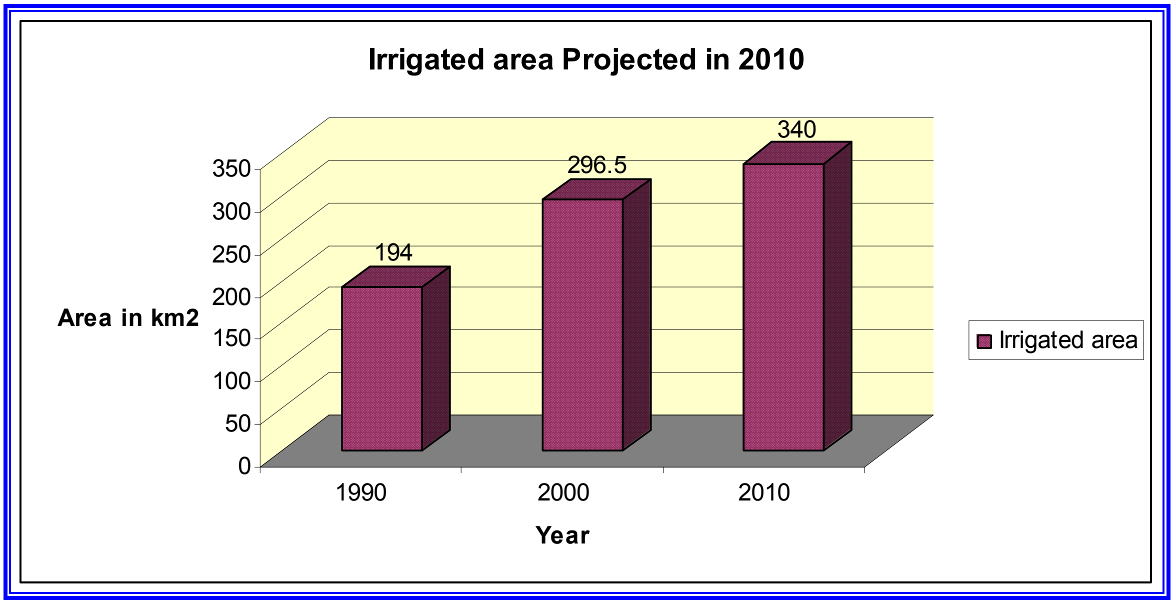


Figure 4.7: Irrigation development pattern (projected year 2010)

The following maps show the location of the irrigated area throughout the Burundi map.

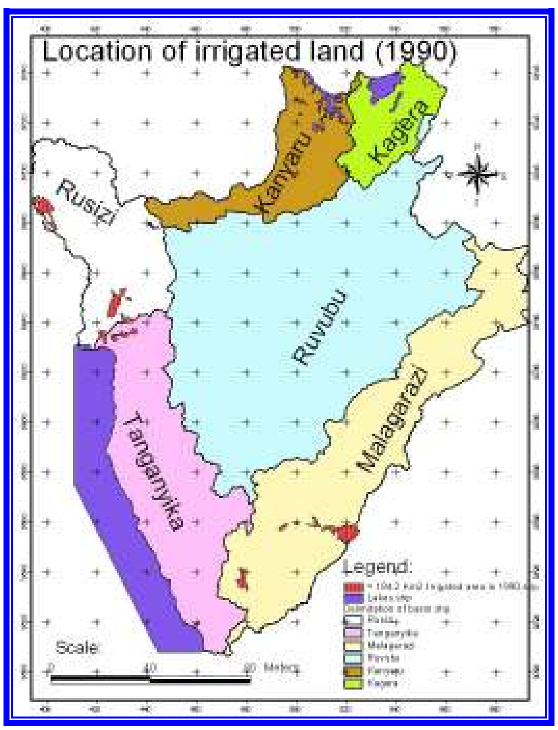


Figure 4.8: Location of irrigated land (year 1900)

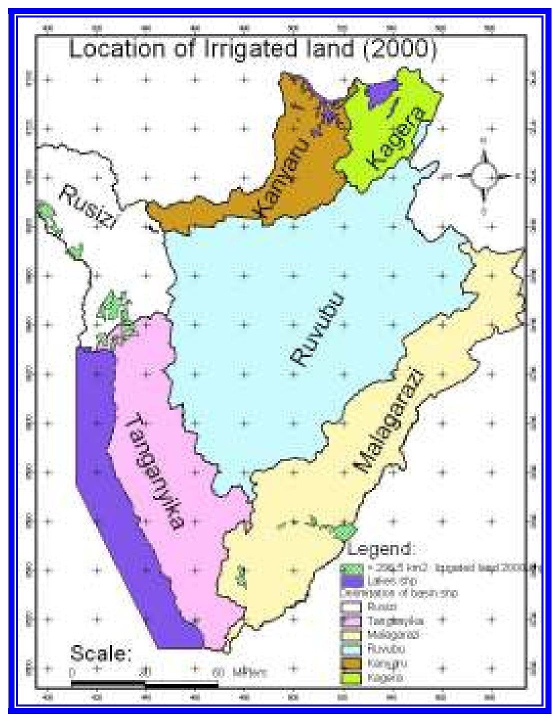


Figure 4.9: Location of irrigated land (year 2000)

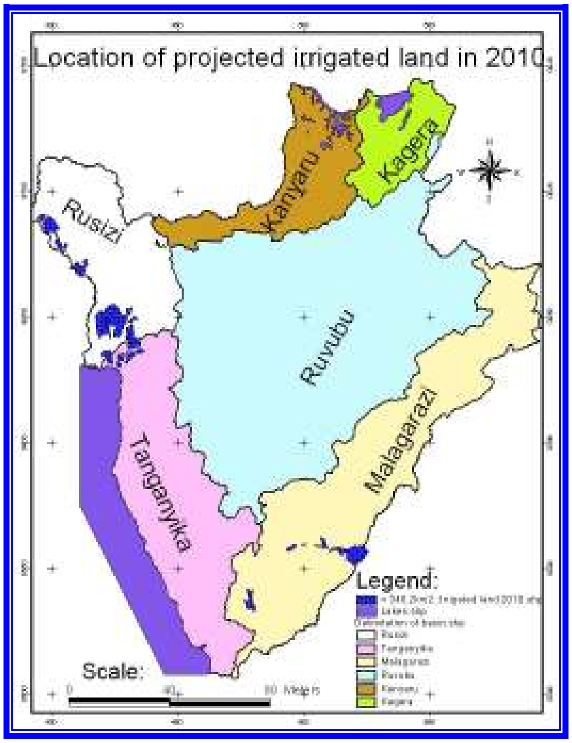


Figure 4.10: Location of irrigation area projected (year 2010)

4.2.2.2: Identification of irrigation development per basin

After identifying and locating irrigated land in the country from 1990 to 2010, we would like to show the change in irrigation development throughout each basin. The results are illustrated in the table below.

Table 4.6: Irrigated land per basin

Basin		Rusizi	Lac Tanganyika	Malagarazi	**Ruvubu**
Year	1990	84.6 km^2	27 km^2	82.5 km^2	**0 km^2**
	2000	164.6 km^2	49.3 km^2	82.5 km^2	**0 km^2**
	*2010	208.3 km^2	49.3 km^2	82.5 km^2	**0 km^2**

A. Irrigation development pattern per year

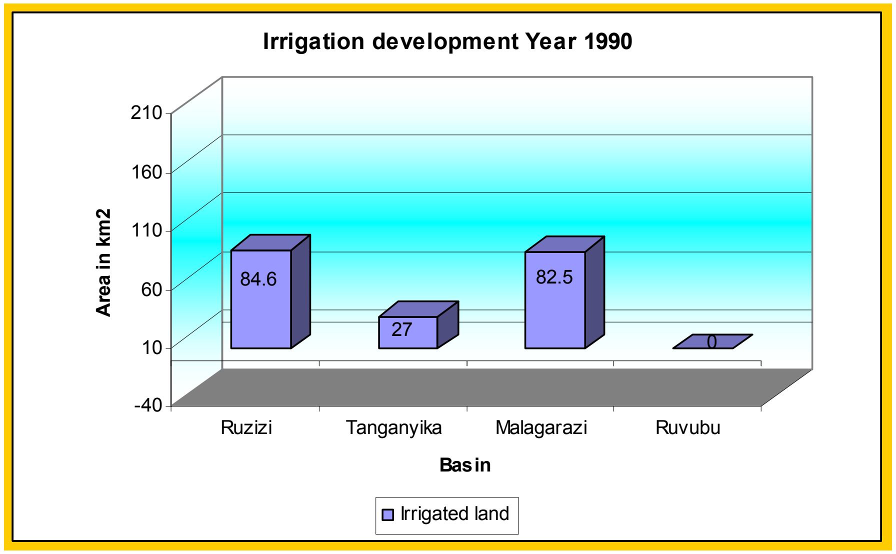


Figure 4.11: Irrigation development pattern year 1990

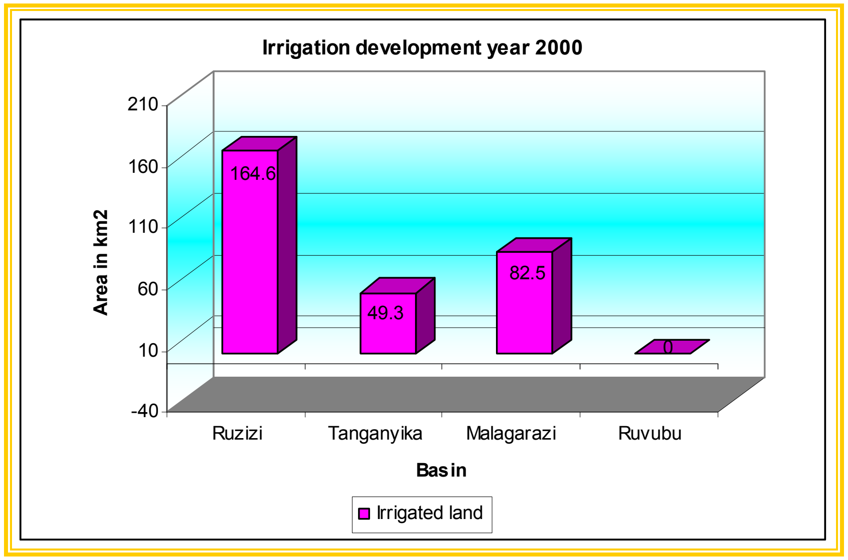


Figure 4.12: Irrigation development pattern year 2000

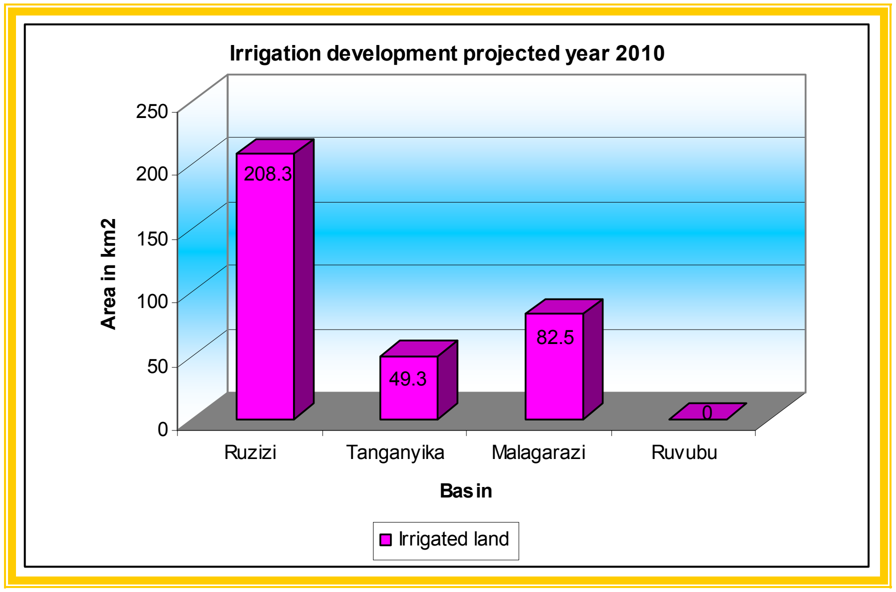


Figure 4.13: Irrigation development pattern projected year 2010

B. Irrigation development pattern projected to 2010 within the basin

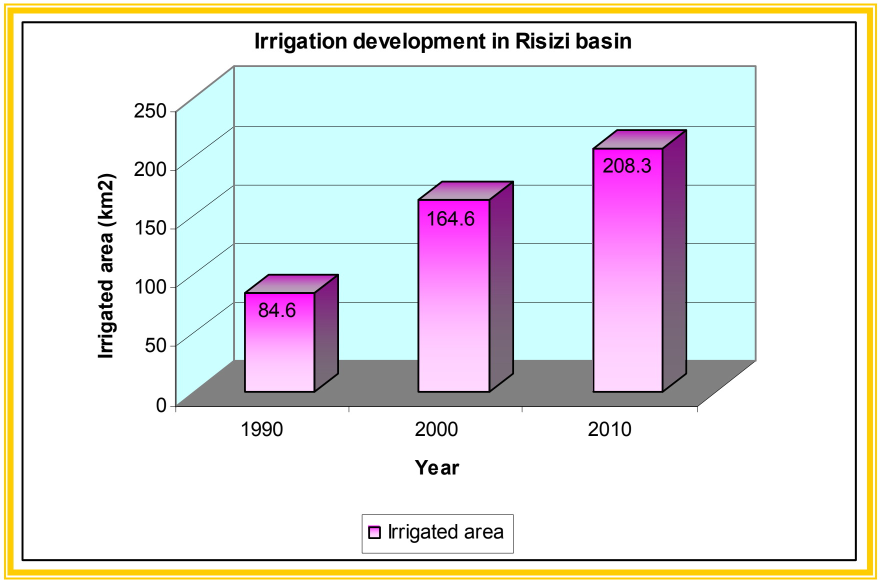


Figure 4.14: Irrigation development pattern in Rusizi.

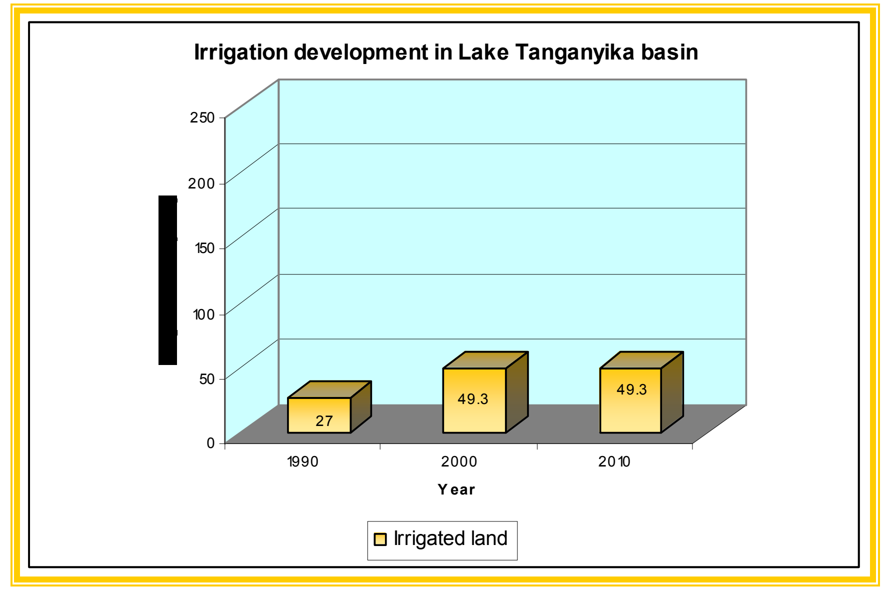


Figure 4.15: Irrigation development pattern in Lake Tanganyika

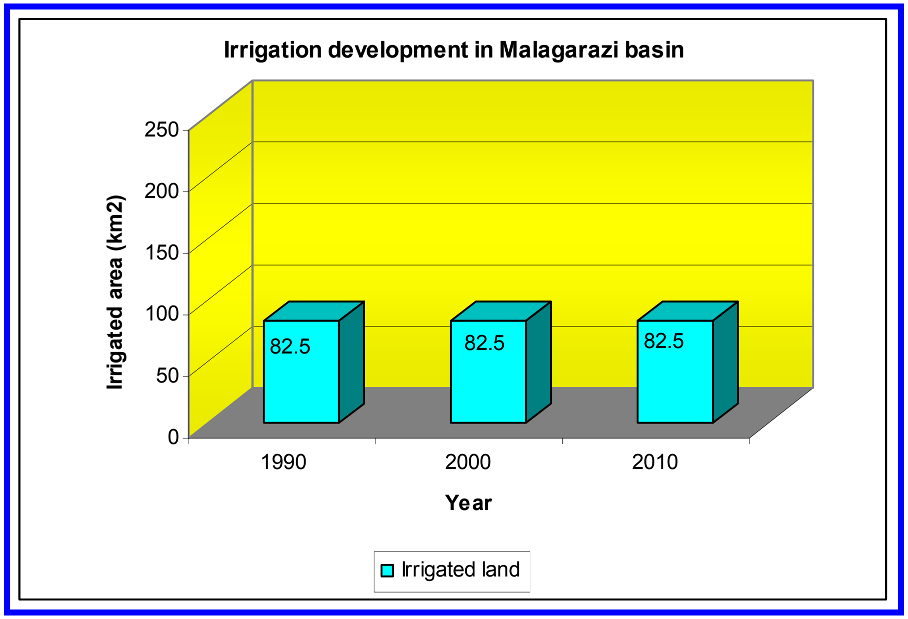


Figure 4.16: Irrigation development pattern in Malagarazi basin

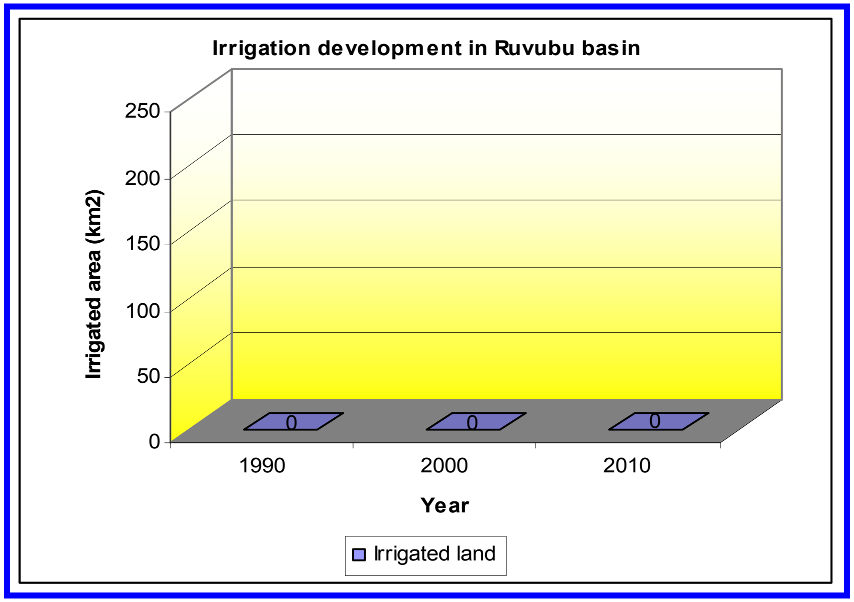


Figure 4.17: Irrigation development pattern in Ruvubu basin

Analyzing the derived results, one can conclude that irrigation development have been highly active in Rusizi basin more than the others basins. The irrigated area has been twice increased from 1990 to 2000 in Rusizi and Lake Tanganyika and has been constant for others. From year 2000 to too 2010, 26 % increase has been projected for Rusizi while there will be no change at all for others basin.

4.2.3. Existing irrigation development in the study area

As stated at early stage, there is no modern irrigation development with fully or partial water control system. The use of water for agricultural productivity concern in the study the flooded rice and is defined hereby as water managed areas. There is no details information on exploited land with the stated scheme.

4.3. Existing hydropower development

At the heart of rural electrification is the development of commercial energy. Owing to some historic factors, the Ruvubu basin like other rural areas is completely cut off from the natural economy. Most energy consumption in the Ruvubu basin is still from the biomass (> 95%) and electricity occupies only a small portion (< 5%) of the energy consumed. The study of energy demand in relation to the environment in Burundi reveals alarming situations of fire wood shortage in some rural areas. We also notice that hydroelectricity is taking up from the traditional wood energy. Wood resources are naturally diversified and quite abundant in Burundi. Wood is collected from natural forests, artificial and agricultural farming.

Recent data estimate the actual wood demand to 2.4 millions tons per year while the total availability not exceeds 1.7 millions tons per year. Or more than 90% of Burundians live in rural with no electricity. This means still they have to satisfy their need in fire and construction wood while the stock deficit runs over 0.7 millions tons a year. The populations' fuelwood and lumber needs will grow significantly with refugees returning from neighbouring countries following the restoration of peace.

It is clear, therefore, that the supply in energy has an important role to play, both in terms of living standard, protecting and maintaining ecological and hydrological balances.

4.3.1. Overview of energy situation, development and exploitation in Burundi.

The recent information on hydroelectric power situation and development shows that about 35 hydropower plants have been developed up to year 2003 in the whole country with more than 52,481.2 KW estimated power generation. These are distributed throughout the country basin and the total water needs can be estimated at 125m^3/sec and more in order to produce the above quantity of power. Some of these hydroelectric plants (6 stations) have been abandoned and others need rehabilitation and maintenances. The majority of the sites (almost 80%) have capacities less than 1 MW (classified as Mini Hydropower). The following tables describes the developed (or) and investigated hydropower sites in Burundi basins. It highlighted for each basin the location, capacity power generated and the required discharge for better understanding the future development. The explained figure below from tables and later with the compiled and plotted power capacity per basin shows the comparison of hydropower development in Ruvubu and others basins.

The figure (Figure 4.18) is an overview of the distribution sites throughout the country and also basin while the figure 4.21 represents the hydropower plant located in the study area.

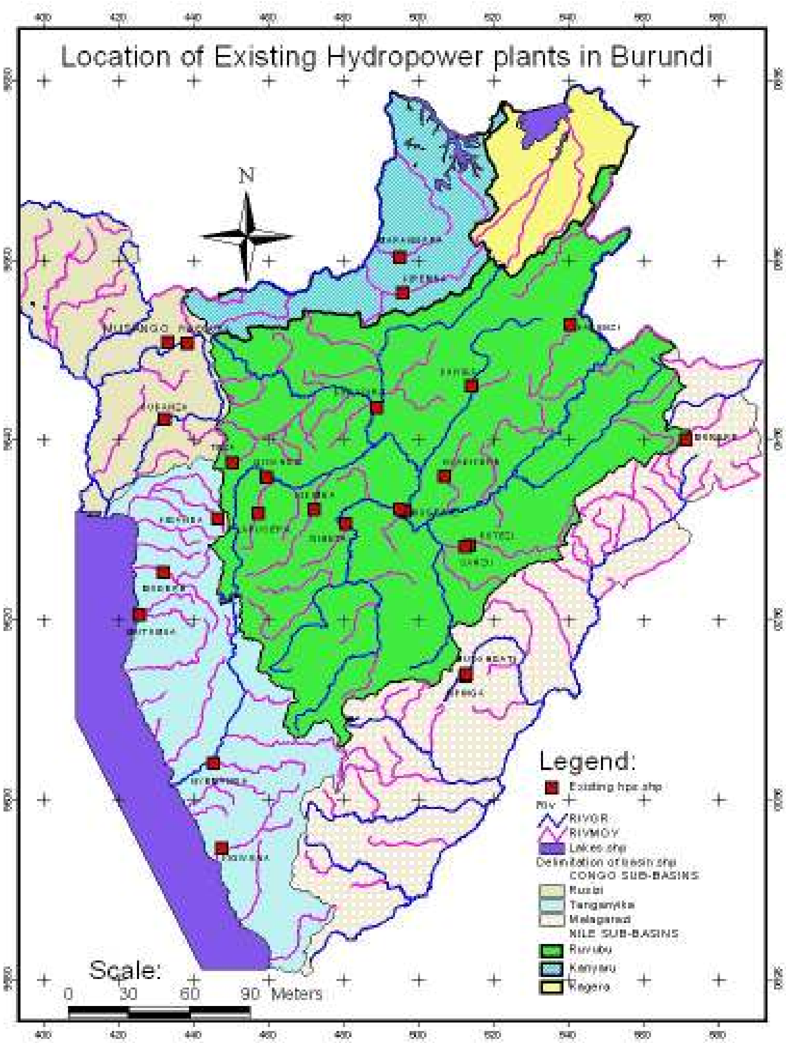


Figure 4.18: Location of existing main hydropower plants.

The hydropower developments per basin have been derived from collected database by using Arcview software and are hereby presented in the tabular form.

Table.4.7: Hydroelectric Station located in Rusizi basin

Name of the HP site	River name	River source	Basin	X-Coord	Y-coord	Natural head	Year of const.	Design period life	Disc for power generation (m^3/sec)	Min avail disharge (m^3/sec)	Garanteed power in Kw
RUSIZI 2	RUSIZI		Rusizi	-	-	28.5	1989	2029	70.61	0	**16100**
RUSIZI 3	RUSIZI		Rusizi	-	-		-	-	-	0	
BUBANZA	Mpanda	Mpanda3	Rusizi	435	9655	17.3	-	1990	0.98	4.03	136
MASANGO	GITENGE	Gitenge3	Rusizi	437	9675	-99	1997	2037		32.55	
MUSANGO	Nanderama	Gitenge3	Rusizi	436	9676	20	1984	2024	0.19	3.83	30
RWEGURA	Gitenge	Gitenge3	Rusizi	441	9676	426	1986	2026	1.53	2.16	**4070**
MPANDA 2195 m	MPANDA	Mpanda1	Rusizi	449	9655	464.3	1997	2037	1.4	0.66	**5200**
RUSHIHA	GITENGE	Gitenge4	Rusizi	428	9672	-	2003	2043	-	6.48	12.7
KABU 23	KABURANTWA	Kaburantwa3	Rusizi	418	9677	130	2003	2043	15	12.38	**15600**
Total Power Generation											**41,148.7**

Table 4.8: Hydroelectric plant located in Lake Tanganyika basin

Name of the HP site	River name	River source	Basin	X-Coord	Y-coord	Natural head	Year of const.	Design period life	Disc for power generation (m^3/sec)	Min avail disharge m^3/s	Garanteed power in Kw
MUTUMBA	Kirasa	Kirasa	Lake Tanganyika	428	9603	20	1980	2020	0.31	3.42	50
RYARUSERA	Kagogo	Murago1	Lake Tanganyika	449	9629	40	1984	2024	0.08	0.27	25
MUGERE	Mugere	Mugere2	Lake Tanganyika	435	9614	290	1982	2022	0.94	3.81	**2200**
NYEMANGA	Siguvyaye	Siguvyaye2	Lake Tanganyika	448	9563	226	1988	2028	0.77	3.87	**1400**
KIGWENA	Nzibwe	Nyengwe2	Lake Tanganyika	450	9541	141	1984	1997	0.06	5.57	64
MULE 34	MULEMBWE	Murembwe8	Lake Tanganyika	445	9563	-	2003	2043	-	19.2	
JIJI 03	JIJI	Jiji1	Lake Tanganyika	468	9569	404	2003	2043	2.3	2.86	**3300**
Total power generation											**7,039**

Table 4.9: Hydroelectric plant located in Malagarazi basin

Name of the HP site	River name	River source	Basin	X-Coord	Y-coord	Natural head	Year of const.	Design period life	Disc for power generation (m^3/sec)	Min avail disharge in m^3/sec	Garanteed power in Kw
MURORE	GISUMA?	Murusumo	Malagarazi	574	9650	40	1988	2028	0.06	0.07	20
MPINGA	Nyamabuye	Nyamabuye1	Malagarazi	515	9587	40	1984	2024	0.02	0.72	6
MUSONGATI	Nyamabuye	Nyamabuye1	Malagarazi	515	9587	60	-	-	0.02	0.86	10
Total Power Generation											**36**

Table 4.10: Hydroelectric plant located in Ruvubu basin

Basin site	Hydroel. Stat. name	River name	river name at diversion site	X-coord	Y-coord	Net head	Const. year	Design period	Mean avail.disch. (m^3/sec)	Garanteed power gen. (KW)
Ruvubu	**BURASIRA**	Ruvubu	Ruvubu11	492	9659	20	1984	2024	25.47	30
	TEZA	Nyabigondo	Nyabihondo	453	9644	20	1970	2010	0.64	360
	GIKONGE	Mubarazi	Mubarazi2	462	9640	27.3	1982	2022	5.3	240
	KIGANDA	Mucece	Mucece	460	9630	16	1988	2028	.43	44
	KIBIMBA	Kaniga	Kaniga1	475	9631	28			2.65	16
	BUHIGA	Ndurumu	Nyabiho	517	9664	26	1984	2024	6.86	240
	MUGERA2	Ruvyironza	Ruvyironza11	499	9631	17.4	1980	2020	**25.39**	**1,200**
	MUGERA1	Ruvyironza	Ruvyironza11	498	9631	17.4			**25.33**	**1,200**
	GIHETA	Ruvyironza	Ruvyironza9	483	9627	5.30		1990	22.71	33
	BUTEZI	Sanzu	Sanzu2	516	9622	9.60	1988	2028	2.4	240
	SANZU	Sanzu	Sanzu2	515	9621	7.70	1982	2022	2.4	70
	NYABIKERE	Nyabizi	Nyabizi	510	9640	20	1989	2029	0.44	140
	KAYENZI	Kavuruga	Kavuruga2	543	9681	30	1984	2024	1.6	150
Sum	**13 sites**								**121.6**	**3,962.5**

Table 4.11: Hydroelectric plant located in Kanyaru basin

Name of the HP site	River name	River source	Basin	X-Coord	Y-coord	Natural head	Year of const.	Design period life	Disc for power generation (m^3/sec)	Min avail disharge (m^3/ s)	Garanteed power in Kw
KIREMBA	Buyongwe	Buyongwe2	Kanyaru	499	9689	20	1984	2024	0.47	3.2	75
MARANGARA	Ndurumu	Ndurumu2	Kanyaru	498	9699	60	1986	2026	0.46	1.39	220
Total Power Generation											**295**

By summing up the power development in each basin, the results are presented in the table below:

Table 4.12: Developed power capacity per basin

Basin	Total Power Capacity in Kw
Rusizi	41,148.7
Tanganyika	7,039
Maragarazi	36
Ruvubu	**3,962.5**
Kanyaru	295
Kagera	0
Sum	**52,481.2**

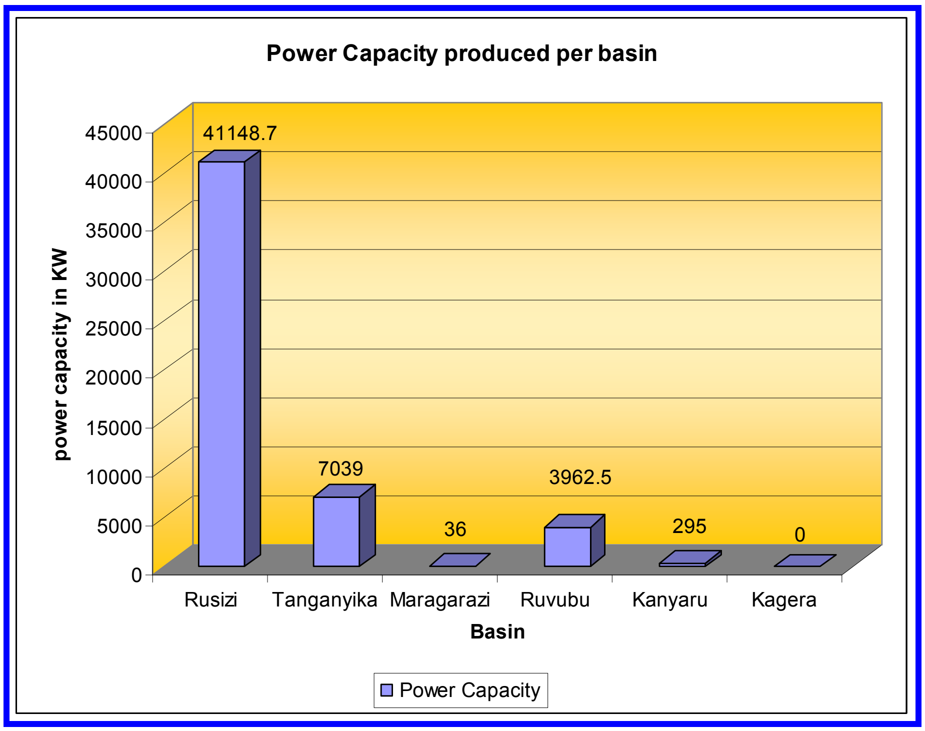


Figure 4.19: Existing power development pattern per basin

The general view of the above trends indicates that almost 80% of the total Hydropower energy developed in the country is produced in Risizi basin. Only 7.5 % of the total Hydropower capacity is developed in Ruvubu basin.The table below indicates the location sites with power generation greater than 1 Mw.

Table 4.13: Hydropower plants with capacity greater than 1MW.

Hydroel site name	River name	river name at deversion site	Basin	X-coord	Y-coord	Net head	Construction year	Design period life	Disch.for power gener.(m^3/sec)	Garanteed capacities (KW)
RWEGURA	Gitenge	Gitenge3	Rusizi	441	9676	426	1986	2026	1.53	4,070
Rusizi 2	KABURANTWA	Rusizi 2 (Kaburantwa4)	Rusizi	414	9672	181.3	2001	2041	12.85	16,100
KABU 23	KABURANTWA	Kaburantwa3	Rusizi	418	9677	130	2003	2043	15.00	15,600
MPANDA 2195m	MPANDA	Mpanda1	Rusizi	449	9655	464.3	1997	2037	1.40	5,200
MUGERE	Mugere	Mugere2	Lake Tanganyika	435	9614	290	1982	2022	0.94	2,200
NYEMANGA	Siguvyaye	Siguvyaye2	Lake Tanganyika	448	9563	226	1988	2028	0.77	1,400
JIJI 03	JIJI	Jiji1	Lake Tanganyika	468	9569	404	2003	2043	2.30	3,300
Total power Rusizi and Tanganyika basins										**47,870**
MUGERA2	**Ruvyironza**	**Ruvyironza11**	**Ruvubu**	**499**	**9631**	**17.40**	**1980**	**2020**	**8.62**	**1,200**
MUGERA1	**Ruvyironza**	**Ruvyironza11**	**Ruvubu**	**498**	**9631**	**17.40**	**-**	**-**	**8.62**	**1,200**
Total power for Ruvubu basin									**17.24**	**2,400**
Total capacity with power generation > 1 MW										**50,270**

A total of 9 sites have been evaluated at more than 1 MW power production each. The majority of the plants are classified as Small Scale Hydropower with capacities less than 10 MW (Small HPP) referred to the early stated criteria in the table 2.7. However, Kaburantwa 3 and Rusizi 2 are estimated to generate power capacity greater than 10 MW, but less than 20 MW. They are classified as Medium Scale hydropower plant.

4.3.2. Existing hydropower development in the study area

As it has been shown above 13 hydroelectric power generation have been developed in Ruvubu basin. One is abandoned while we don't have information on two sites whether they are functional or not.

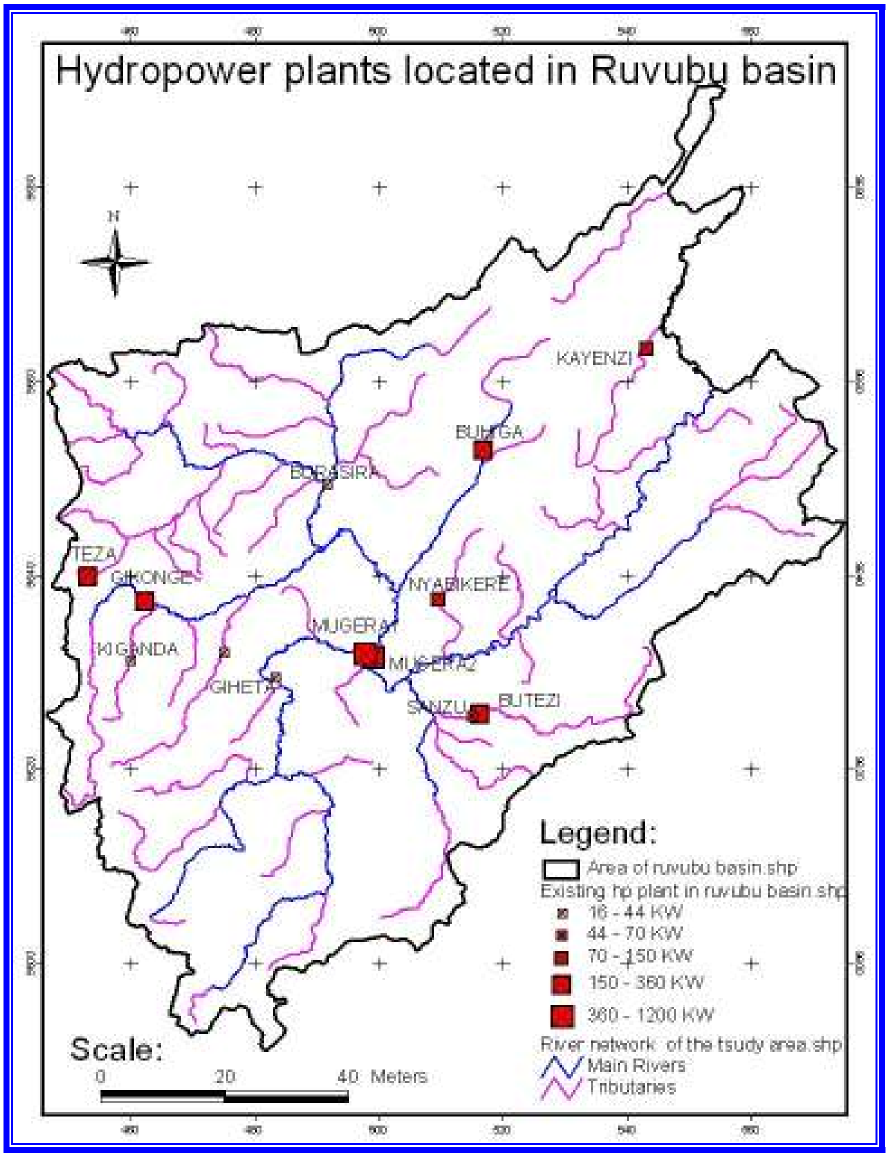


Figure 4.20: Location of hydroelectric sites in Ruvubu basin.

The total power generation within the basin is estimated at about 3,963 KW with about 29.94 m^3/sec total discharge requirement. Only two sites out of 13 identified sites can generate more than 1000 KW each (total of 2,400 KW for both).

The overview of energy situation and development within Ruvubu basin have been summarized in the table 4.12 with available information regarding hydropower sites coordinates, estimated required discharge and power capacity generated.

Analyzing the hydropower sites exploitation we can mention that almost all the sites are overexploited. In many cases the discharge requirement for power generation is less than the available mean discharge that is the main statement which indicates overexploitation of hydropower plant.

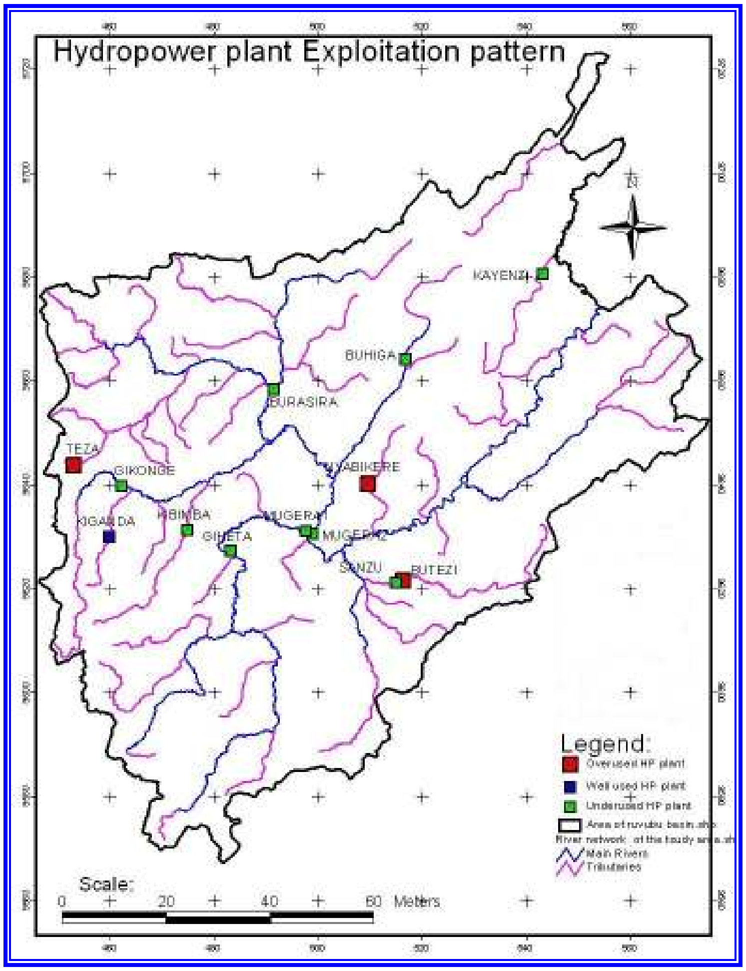


Figure 4.21: Degree of existing hydropower exploitation in Ruvubu

As regards to hydropower plants exploitation in Ruvubu basin, 3 out of 12 HPP (25% of the total HPP) are overexploited, 7 HPP are underexploited and only 1 HPP is well exploited. Hence, there are possibilities of extending the 7 HPP which are currently underused in order to increase the power generation.

CHAPITER FIVE

5.0 THE WATER RESOURCES POTENTIAL ASSESSMENT IN RUVUBU BASIN

5.1. Irrigation potential assessment

5.1.1. Guidelines to estimate irrigation potential

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

The area which can potentially be irrigated depends on the physical resources “soil” and “water”, combined with the irrigation water requirements as determined by the cropping patterns and climate. In this study it is called “physical irrigation potential”.

5.1.2: Theoretical Potential Irrigable Areas and Water Demand Assessment

5.1.2.1. Identification of potential irrigable areas in Ruvubu basin

A. Pre-identified potential areas

There are areas that have been indicated by some irrigation project plan, but their preliminary study has not been done and does not exist. This includes areas located in natural regions of Nile basin. The table below provides the summary of size of land and the corresponding irrigation water demand for upland crops and lowland crops without certain details.

Table 5.1: Areal distribution of potentials irrigation in Burundi Nile Basin [KABWA Agapit, 2003]

Natural region of Nile basin	Mugamba	Kirimiro	Buyenzi	Bugesera	Bweru	Buyogoma	Total
Upland crops with slope =0% (ha)	81,032	95,434	67,974	47,554	94,675	158,528	**545,197**
NIWR (m^3/sec)	95.1	112	79.8	55.8	111.1	186.1	**640**
Upland crops with slope ≤ 30% (ha)	65,600	102,390	59,610	79,610	100,250	172,520	**579,980**
NIWR (m^3/sec)	77	120.2	70	93.5	117.7	202.5	**681**
Marshes (lowland) areas (ha)	8,608	16,801	25,496	24,871	485	6,787	**83,048**
NIWR (m^3/sec)	6.4	12.4	18.9	18.4	0.4	5	**62**
Available discharge (m^3/sec)	5.3	25.2	8.1	2	6.9	40	**88**

Note: *Considered water duties for estimating NIWR are:

- For upland crops, FWS = 1.174 l/sec/ha
- For lowland crops, FWS = 0.74 l/sec/ha

Analyzing the above table, it can be mentioned that the NIWR for upland crops irrigation project with slope equal to 0% or greater than 30% cannot be satisfied with available discharge. The available discharge can totally satisfy only the NIRW for lowland crops irrigation Project within Nile Basin.

B. identification of cultivable areas

For simplification, the potential cultivable areas are delineated from Ruvubu contour map based on slope which is assumed to be less than 10%.

From the topographic map of the study area, we have converted it into grid features, and then transform the grid map into Tin features with help of GIS tools.
The contour lines with 50 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. If the ratio $\frac{\text{[illegible]}}{\text{[illegible]}}$ [illegible] 10%, the area is assumed to be potentially suitable for irrigation.

Therefore, as discussed early in third chapter the topography of Ruvubu basin has been ranged into six altitude range level [Figure 3.7].

The slope variability is the first used criteria and hence potential cultivable areas can be located at altitude level ranged as following:

- Topography with altitude equal or less than 1500 m;
- Topography with altitude between 1500 m and 1750m;
- And Topography with altitude between 1750m and 2000 m.

For convenience the potential cultivable areas have been delineated from these three altitude ranges and to exclude some portions with slope greater than 15% and altitude greater than the predefined contour line.

The sub-basins, in which these potential areas lie, have been identified and the results are discussed in table below.

Table 5.2: Identified potential cultivable areas

Scenarios	**High contour altitude (m)**	**Lower contour altitude (m)**	**Delineated area (km^2)**	**Sub-basin within the area**
Scenarios$_1$	1500	≤ 1500	526.04	Main Ruvubu, Ndurumu, Ruvyironza, Kayongozi, Cizanye and Mubarazi
Scenarios$_2$	1750	1500	4,875.7	Main Ruvubu, Ruvyironza, Nyabaha, Kayongozi, Ndurumu, Kinyankuri, Mubarazi, nkokoma Cizanye
Scenarios$_3$	2000	1750	1,502	Mubarazi, Nkokoma, Main ruvubu, Ruvyironza
Total identified cultivable area			**6,903.74**	

In this regard, the potential cultivable areas are estimated at 6,903 km^2, this doesn't exclude the residential areas or natural reserves such as Ruvubu National Park. It represents about more than 68% of the total Ruvubu land. From the above cultivable area of 6,903 Km2, we have to set the criteria for estimating which area can be developed using surface irrigation.

5.1.2.2. Theoretical Potential Irrigable areas

To identify the potential irrigable land based on GIS is sought out by following procedures:

1. *delineate the total area of the below given contour;*
2. *calculate the total area in the delineated part;*
3. *delineate the areas which are not suitable for agriculture such as residential area, islands, and cliffs etc.*
4. *calculate the net irrigable land by subtracting the total unsuitable area for agriculture from the total delineated area.*

The figure 5.1 below represent a contour map with the stated procedures for delineating potential irrigable areas just for a simple demonstration to provide to the readers a comprehensive manner on how has been identified the areas highlighted on the figures 5.2 and figure 5.3.

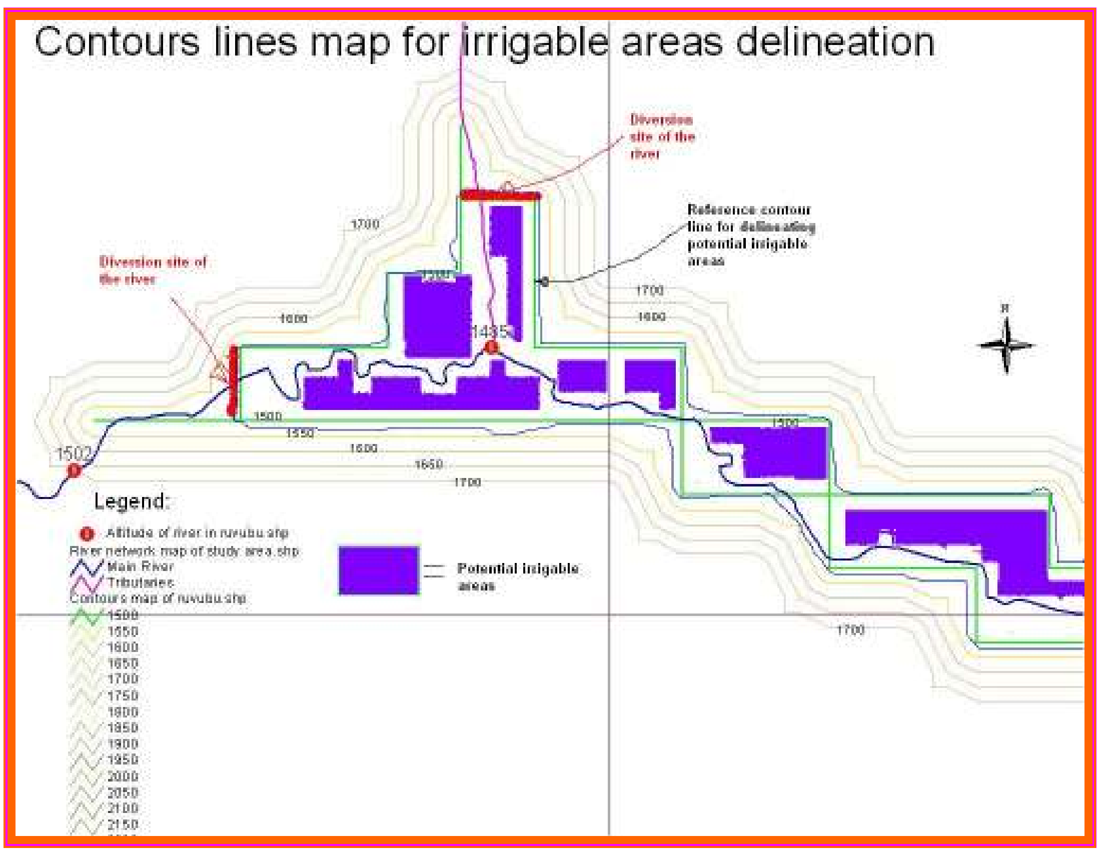


Figure 5.1: Demonstration of potential irrigable areas delineation

From the contour map, the irrigable area is delineated by following a predefined contour line where the diversion of river flow is expected to be implemented. The delineated area below this contour line is taken as the potential irrigable land by any river which originates above the altitude of identified contour line.

By analyzing the surrounding rivers bed altitude, the potential irrigable land by gravity system is delineated along the contour line of 1500m altitude. The contour lines with respect to topographical altitude ranges are very closely. It means that there is a high variation of the slope at each transition zone from one range altitude level to the other. The general feature of contour lines is shown on figure 5.2 with the identified potential irrigable areas.

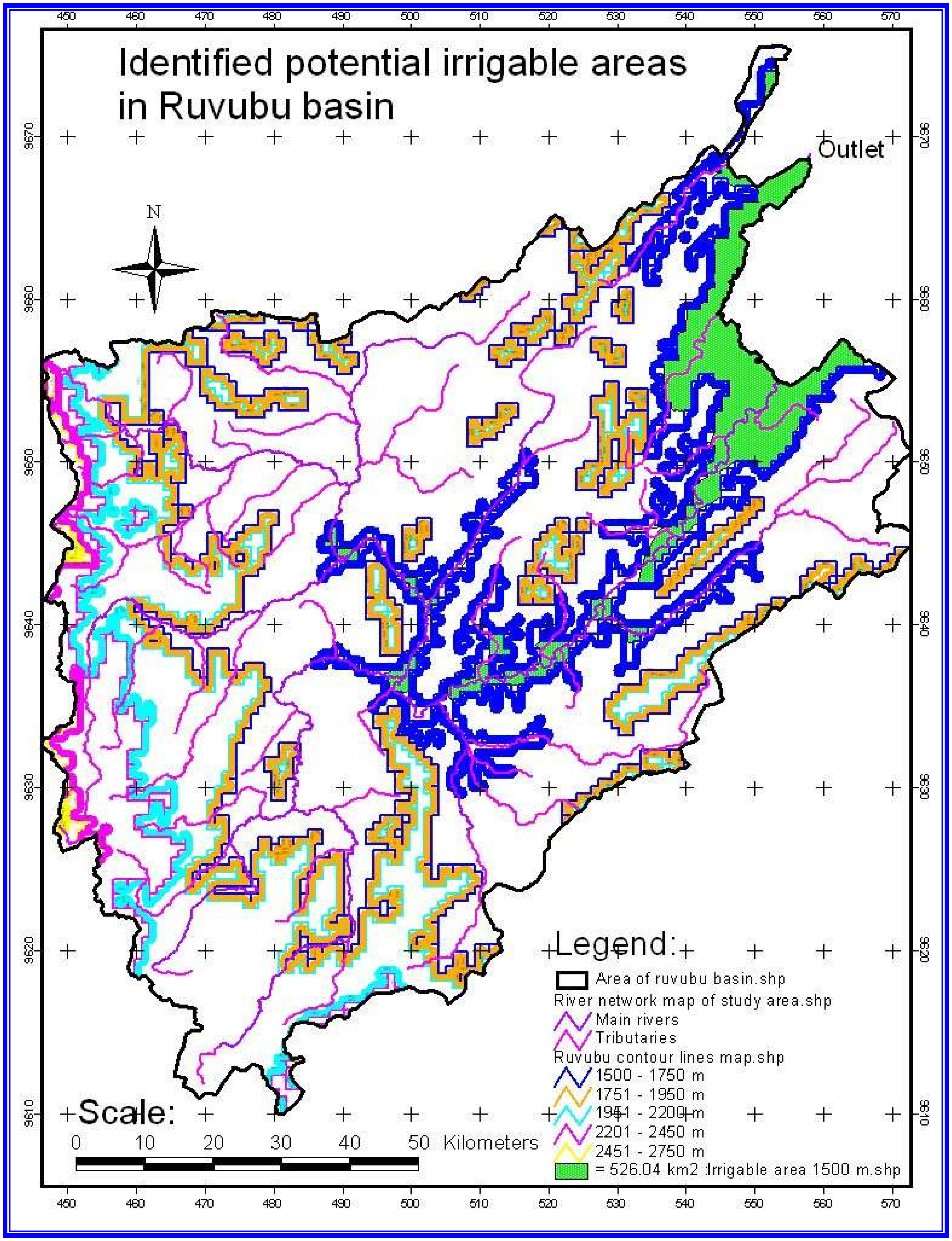


Figure 5.2: Map of identified potential irrigable areas in Ruvubu.

To show the probable location of the identified potential irrigable areas throughout the the delineated sub-basins, the overlapping system on Arcview tools has be used and then one can identify which sub-basin may have more probable potential irrigable areas at sub-basins level. The figure 5.3 provides a highlight of extension pattern with respect to delineated sub-basins of Ruvubu.

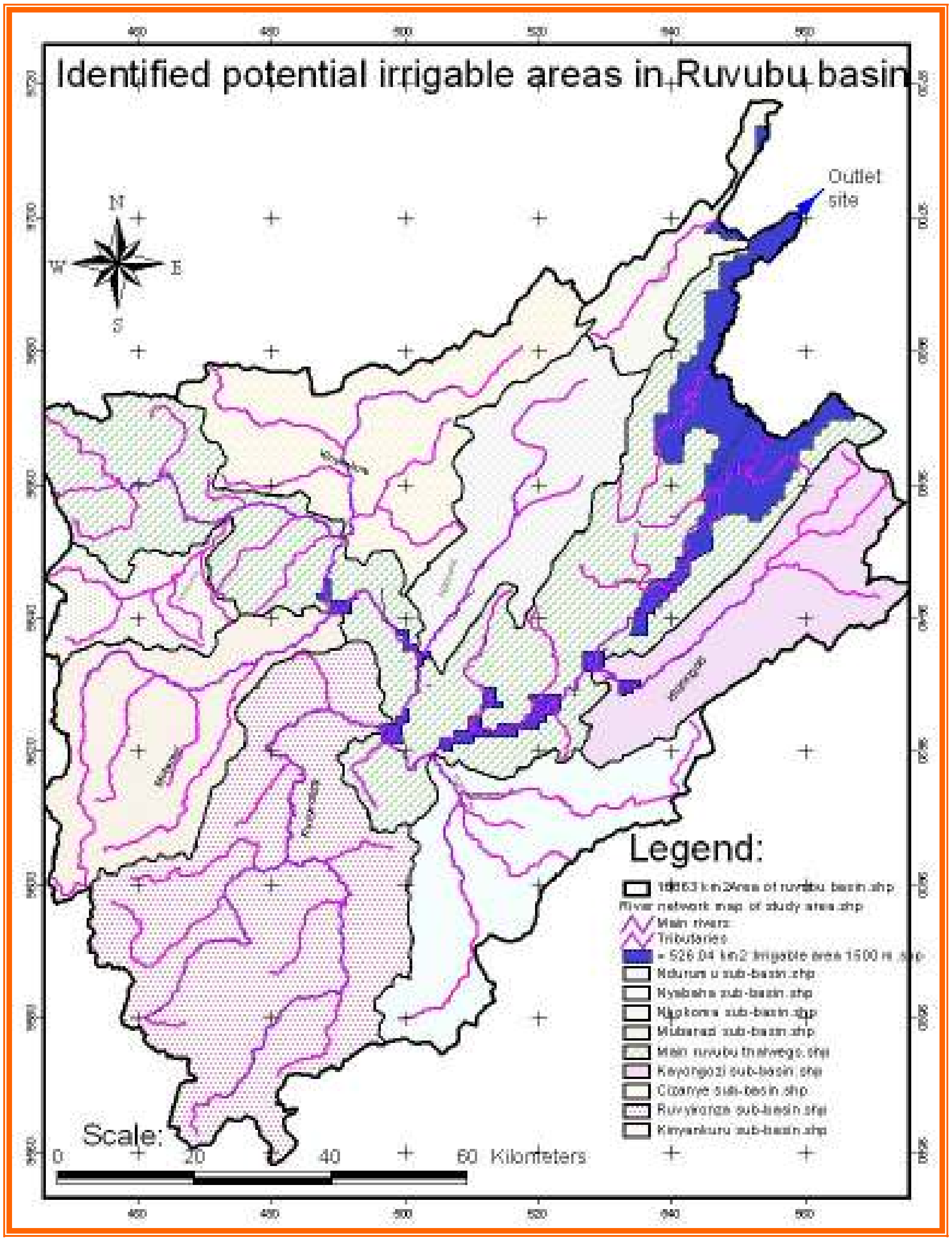


Figure 5.3: Extension pattern of identified irrigable areas throughout the Ruvubu sub-basins

By overlapping the sub-basins and the identified potential irrigable areas, the figure shows that the irrigable areas are located within the six sub-basins. The major extend areas is found in the the main Ruvubu valley while only a small portion can be found within others sub-basins.

Table 5.3: Sub-basins within the potential areas

Considered contour line	Potential irrigable land by gravity system (ha)	Sub-basin within identified area
1500 m	52,604	Main Ruvubu Valley, Ruvyironza, Ndurumu, Kayongozi ,Cizanye and Mubarazi
As % of the total of the basin	5.2%	

Thus for evaluating the approximate potential irrigable areas, the residential areas have to be excluded. To estimating 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.

Assumptions statement:

- Number of person per family = 5,
- Total Population in the study area = 4,000,000 (within area of 10063 km^2),
- Residential area size per family (one House) = 200 m^2 / house

Then we calculate number of population in identified potential irrigable area = (526.04 km^2 *4000000 persons) / 10063 km^2 = 209,099 persons.

Number of house within identified potential irrigable area = 209,099 persons/5 = 41,820 houses

Residential area= 41,820 houses * 200 m^2 / house = 836,394 m^2 = 8.36 km^2

Hence, the potential irrigable area is approximated to be:

526.04 k m^2 -8.36 km^2 = 517.68 km^2

Note that, the considered potential irrigable areas does not exclude the others probable restricted areas located in the Ruvubu basin. It is theoretical estimated at 51,768 ha and represent about 5% of the total area of the Ruvubu basin.

5.1.2.3. Theoretical estimation of Gross irrigation water requirement for the identified potential areas

In order to assess the water demand for the exploitation of irrigation potential of the identified areas, the existing information have been reviewed to assume the gross irrigation water requirement (GIWR) or Field Water supply per unit area (FWS). The table below shows the assumed values by different Authors.

Table 5.4: Gross irrigation water requirement used by Author

Authors	Study area	Type of crops	FWS	
			l/sec/ha	m^3/ha/year
FAO, 1997	Whole Burundi	Upland crop		13,000
		Lowland crop		
PDNE, 1998	Whole Burundi	Upland crop	2	31,450(*)
		Lowland crop		
KABWA. A, 2003	Nile Basin zone	Upland crop	1.174	18,460(*)
		Lowland crop	**0.74**	**11,636(*)**

(*) Note that these values are estimated from the field water supply in liter per second per hectare and converted into m^3/ha/year taking account the considered growing season (two crops per year) and by estimated the irrigation duration period in each growing season.

As it appears in the above table, there is a large disparity in considered values between Authors. One may have overestimated while others underestimate the applicable field water supply per unit area value.

For convenience of theoretical estimating irrigation water demand for the identified potential land, we simple consider the water duty value which can be found in range of applicable value from literature review and other research studies. Therefore, in this study, we refer to the recent report and estimate the Gross irrigation requirement per ha per year using the 0.74l/sec/ha for lowland crops, [KABWA, 2003]. The procedures and factors used in estimating water duty in km^3/year and the GIWR for the potential irrigable area such as cropping calendar and assumed irrigation period per year are presented in the table below.

Table 5.5: Main crops types and Growth duration for estimating water duty in Km^3/ha/year

Crops type	Growing season	Planting date	Harvesting date	estimated irrigation period		Water duty or FWS (0.74l/sec/ha)		GIWR for 51,768 ha (km^3/year)
				irrigation/ season	Irrig. Period /year	m^3/sec/ha	Km^3/ha/Year	
Rice	Wet I	Feb/March	June/July	3 months	6 months/year	11,636 m^3/ha/year	$1.163*10^{-5}$	**0.602**
	Wet II	Sep/Oct	Jan/Feb	3 months				
Maize	Wet I	Feb/March	June/July	3 months	6 months/year			
	Wet II	Sep/Oct	Jan/Feb	3 months				
Sorghum	Wet I	Feb/March	June/July	3 months	6 months/year			
	Wet II	Sep/Oct	Jan/Feb	3 months				
Beans	Wet I	March/Apr	June/July	3 months	6 months/year			
	Wet II	Oct/Nov	Jan/Feb	3 months				
Vegatable and Sweet Potato	Wet I	Feb/March	June/July	3 months	6 months/year			
	Wet II	Sep/Oct	Jan/Feb	3 months				

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 water duty in m^3 /ha/unit of time or km^3/ha/unit of time and using the value as:

$$D_i \bullet A * I_A \quad \ldots\ldots 5.1$$

where D_i = irrigation demand [km^3/year],

A = Potential irrigable area [ha],

I_A = water applied per unit area [km^3/ha/year]

Based on the assumed value of I_A = $11.076*10^{-6}km^3$/ha/year and the resulting total theoretical irrigation demand in the identified potential area is estimated as:

$$D_i \bullet 51{,}768\,ha * 11.636 * 10^{-6}\,Km^3/ha/year \bullet 0.602\,Km^3/year \quad \ldots\ldots 5.2$$

The total Gross irrigation requirement for 517.68 km^2 is estimated at **0.602 km^3/year**.

5.1.3. Theoretical Surface Water Potential Assessment for irrigation

The theoretical surface water potential for irrigation is estimated by taking account the mean minimum annual flow of rivers draining the identified potential irrigable areas.

We consider only the surface water and the river bed elevation feature which ducted the location of the diversion point for gravity supply. In this study we consider the minimum flow for dry year then evaluate the water availability for irrigation for only the selected rivers.

A sample of summary of availability of water that should be taken out of river, based on topography of the river bed are presented in the table below.

Table 5.6: Summarized Estimate of Total Water Availability and Demand under Mean discharge for Exploitation of Identified irrigable land.

River name		Estimated diversion point coordinates			Min Mean annual discharge for dry year		Potential area to be irrigated	GIWR for 51,768 ha
		x	y	Altitude (m)	m^3/sec	km^3/year	ha	Km^3/year
Kayongozi*(3)		534	9637	1500	1.44	0.045	**44,054**	**0.602**
Ruvyironza*(11)		496	9631	1500	8.62	0.272		
Mubarazi*(6)		489	9647	1500	3.87	0.122		
Ndurumu*(2)		504	9642	1500	2.26	0.071		
Nyambiga		523	9633	1500	0.09	0.003		
Ruvubu*(11)	Ruvubu*(14)	500	9634	1500	16.32	0.515		
Ruvubu*(13)								
Ruvubu*(14)								
Sub-total 1					**32.6**	**1.028**		
Nyambizi		512	9637		0.5	0.036	**70,649**	
Nyamigina		544	9664		0.19	0.010		
Kavuruga*(1)		538	9671		0.35	0.034		
Cizanye*(1)		542	9704		0.89	0.047		
Nyamisuma*(3)		535	9652		0.83	0.044		
Kayongozi*(4)		529	9637		1.78	0.135		
Nyakigizi		520	9635		0.24	0.017		
Mutwenzi		497	9629		0.24	0.017		
Ruvubu*(18)	Ruvubu*(22)-Ruvubu*(14)	532	9645		14.66	0.676		
Ruvubu*(21)								
Ruvubu*(22)								
Sub-Total 2					**52.28**	**1.648**		
Ruvubu Mean Min annual discharge					**54.70**	**1.726**	**73,919**	

Note: *these numbers state the concerned river for irrigation in a given sub-catchments.

** these discharge value are for the main river which have been used in upstream site and are further not considered to avoid a double counting of the same river discharge.

In order to determine the total available water to be diverted and supplied the irrigation project once developed in the identified area, three scenarios have been considered. And the obtained total quantity of water is compared to the theoretical GIWR for potential irrigable area.

- Scenario $_1$:only rivers with bed altitude at diversion point greater than contour line of 1500m are considered. The estimated discharge is 32.6 m^3/sec.
- Scenario $_2$: Exploitation of main rivers and main tributaries throughout the potential

zone without considering their bed level altitude. Estimated discharge in this manner is about 52.28 m^3/sec

- Scenario $_3$: water availability based on the total minimum annual discharge at Ruvubu- bac. It is estimated at 54.70 m^3/sec.

The theoretical potential irrigable areas can be estimated by dividing the available discharge by the FWS. The results are presented in above table can be in the following manner:

The total surface available water for first scenario is estimated at 32.6 m^3/sec and can only irrigate about 44,054 ha without storage which represents about 85% of the theoretical identified potential irrigable areas. However, about 1.028 Km3/year can be provided using a reservoir storage system and can therefore sufficiently satisfy the total GIWR (0.602 km^3/year) for developing surface irrigation in the potential area of 51,768 ha.

The second scenario estimates the potential water available to 52.28 m^3/sec and this amount of water can potentially irrigate about 70,649 ha which greater than the identified potential areas. A storage system should provide about 1.648 km^3/year.

Scenario $_3$ provides about 54.7 m^3/sec which theoretically should irrigate more than 73,919 ha of land. About 1.726 km^3 should be stored per year. But this scenario may not be physically feasible for surface irrigation due to constraints of topography feature.

However, environmental and socioeconomic constraints also have to be taken into consideration in order to guarantee a sustainable use of the available physical resources.

This means that in most cases the possibilities for irrigation development would be less than the physical irrigation potential.

Then, as conclusion, the scenario1 is considered to be economically practicable with simply diversion of river runoff to supply the command area identified below the contour line of 1500m altitude. However, this scenario does not satisfy the GIWR and hence a reservoir storage system in upstream site has to be implemented.

5.2. Assessment of Hydropower Potential in Ruvubu basin

Substituting electricity for fire wood gives positive effects by reducing deforestation and, hence, conserving the ecological environment as well as improving the hygiene of people. According to China's statistics, one household with five persons needs to burn 2500-3000 kg of firewood in a year, which is approximately equivalent to 2.5-3 m^3 of timber. As there are about 4,000,000 people in Ruvubu basin which means about 800,000 households, it may be expected that about 20– 24 million m^3 of timber would be burnt in the study area, which would lead to environmental catastrophy for the country. Reportedly, in the Ruvubu basin the forest cover have been reduced from 8% to 5% for firewood supply, even charcoal is chopped rampantly, supplied up to Bujumbura, the capital city. Its water and land resources are thus destroyed and the villagers compelled to move elsewhere. Human beings damage the environment and are likewise punished by the environment.

Electricity should meet the basic demands for the country side and township-run enterprises and private consumptions.

5.2.1. Guidelines to estimate Hydropower potential

In Burundi, one of the energy policy objectives should be to ensure a reliable supply of energy at the right time and at affordable price, particularly to support the countries agricultural and industrial development strategies. Enhancing and expending the development and utilization of hydropower is one of the priorities of the energy policy. Hydropower, a renewable energy, ranks high compared to others in Burundi's power sector. Its continued development is perceived as essential given the extremely low level of current electricity generation, demand forecasts at one hand, and the abundance of water resources. In this background, considering the vast available water resources, this work envisages the assessment of hydropower potentials for selected rivers encompassing two options; one without reservoir storage and other with reservoir storage. The first option involving the natural flow to utilize the perennial discharge in the river, based on flow duration curves constructed taking into account the discharge data available. The second option will not be developed because of missing information and characteristics of the area. However, based on the physical features like topography developed from GIS tools, the reservoirs sites will be identified in different sub-basins.

For identification of potential hydropower in using runoff of natural streams as it comes without storage, the minimum available discharge and the gross natural head of water have been used at identified potential site.

5.2.2. Procedures for data generation at the potential site

The site of water resources development in any of the uses can be at gauged or ungauged site. As stated earlier, the Ruvubu basin is gauged. Therefore, to estimate the hydropower potential at any particular point along the river reach, flow data can be transferred to the site of interest using Area Ratio Methods.

The guidelines for Area Ratio Methods for assessing available dependable flow for the potential site are estimated by:

$$Q_{site} = \left(\frac{A_{site}}{A_{gauge}}\right)^{n} * Q_{gauge} \quad \text{...5.3}$$

Where: - Q_{site} represents discharge at the selected site

- Q_{gauged} =discharge at the gauge site.
- A_{site} = drainage area at identified site
- A_{gauged} = drainage area at the gauge site
- n varies between 0.6 and 1.2.

If the A_{site} is within 20% of the A_{gauged} $\left(0.8 \le \frac{A_{site}}{A_{gauged}} \le 1.2\right)$ then n= 1 is used. The estimated discharge at the selected site will be with in 10% of actual discharge [Awulachew, 2000].

When A_{site} is within 50% of the A_{gauged}, transferred data refers to the Weighted average flow developed from two nearest stations between Upstream and Downstream gauges [Gulliver and Roger, 1991]. Using the following equation:

$$Q_{site} = \frac{(A_{gauge1} - A_{site}) * Q_{gauge1} + (A_{site} - A_{guage2}) * Q_{gauge2}}{(A_{gauge1} - A_{gauge2})} \quad \text{..............................5.4}$$

Where: $gauge_1$: upstream gauging site and $Agauge_2$ downstream gauging site.

5.2.3. Stream Flow Data Computation and Analysis at Potential sites.

The aim is to estimate how much flow is available at a particular site and how much reliable. The Flow Duration Curve provides useful information on the availability of flow and reliability and enables defining the available water for power production. Note that daily or monthly flow data can be used to develop Flow Duration Curve.

Due to the missing data in daily flow data, the Flow Duration Curve is derived from monthly flow data for the particular potential site.

The Duration Curve has been constructed by ranking all the discharge data for the 12 months in a year regardless of the sequence in which they occurred. The percentage of the data equal to or exceeding a given flow value, termed as percentage of exceedance, is calculated. The ranked discharge is plotted versus the corresponding % of exceedance to obtain Flow Duration Curve.

For the selected hydrological site, the mean monthly flow data has been analyzed. For convenience some 10 stations are considered. Rank the data in descending order (see table 5.1) us example. Compute for each year the probability of exceedance using Weibull's Formula**:** $P = \frac{m}{n+1}$ **,…………………………………………………………………………5.5,**
where n is the number of months of record and m is the rank number of the event. Equation (5.5) is also known as plotting position.

The available discharge for power generation is determined from the Flow Duration curve and 50% dependable flow is employed for storage type of Hydropower sites and 95% dependable flow for the case of runoff river type. The Flow Duration Curve is hereby constructed for simple demonstration for Ruvubu-bac site and the plotting position is shown in figure5.4.

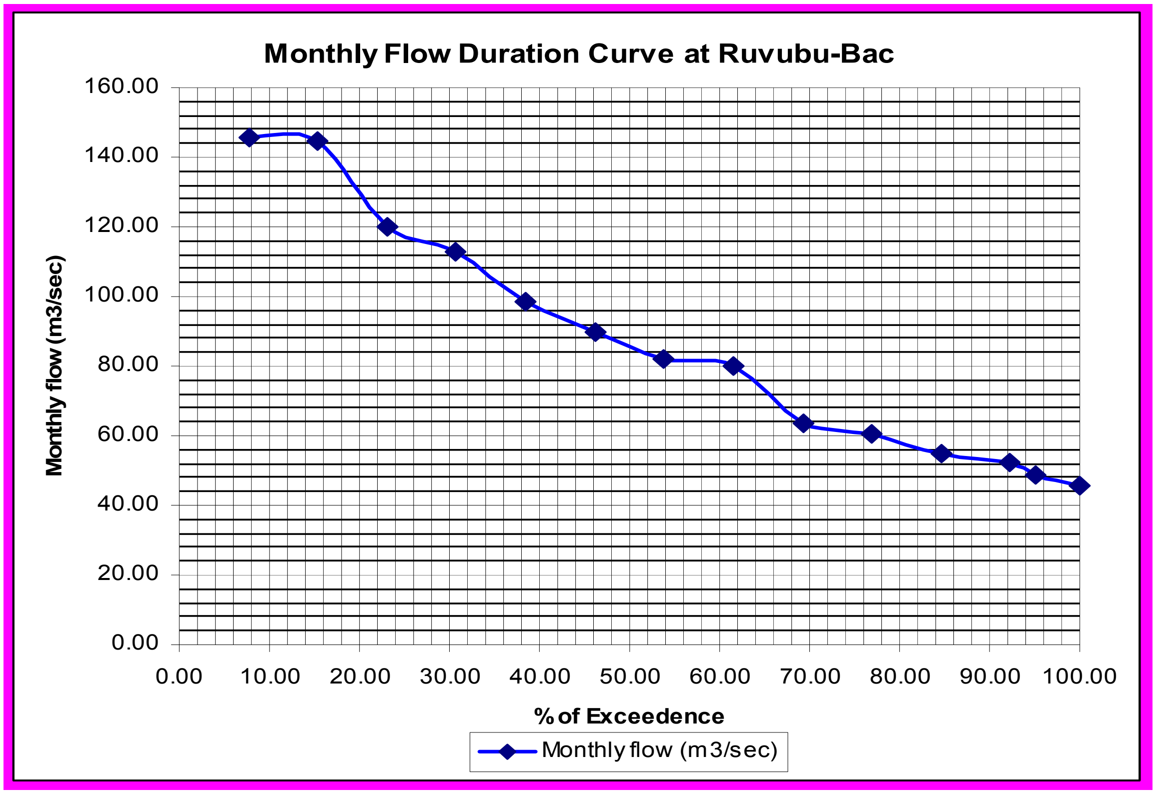


Figure 5.4: Monthly Flow Duration Curve at Ruvubu-Bac site

Table 5.7: Dependable flow estimation at the site of interest from FDC for site Ruvubu-bac.

% of Exceedence	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	100%
Q in m^3/sec	145.33	130.04	113.37	95.68	85.30	80.53	63.28	58.11	52.89	48.61	45.58

5.2.4: Hydropower site selection criteria

The general criteria to be employed for estimating the hydropower potential and identifying the sites are:

1. As far as possible, harness the available head on the site optimally or maximize the use of the available head. There should be also adequate discharge on the site for the developed hydropower,
2. for storage type hydropower development the submergence and water surface area should be minimum, narrow gorge areas are advantageous,
3. in case there is a confluence of two rivers in the identified reach, the site should be located on downstream of the confluence point to take the advantageous of the flow of both rivers,
4. the site should be easily accessible, accessibility from the viewpoint of transportation,
5. Distance from the load centre should be short.

Any combination of head and flow can be used to develop a hydropower, and more important will be given to these two main factors.

In this study, for the purpose of assessing hydropower potential site in Ruvubu basin, we employ the GIS approach. For convenience of discussion, the topographical and hydrological data are hereby used and only Runoff River and natural head have been the main directive criteria. The analysis of natural river bed together with topographical map through GIS environment gives information about the gross head and the analysis of hydrological data provides us the available potential theoretical discharge. Both Gross Head and estimated discharge are thereafter utilized for estimating Potential power capacity at the selected site. Note that if the maximum altitude is not know, the maximum altitude have been used and this normally is subjected to overestimation of Potential power at the location site.

5.2.5. Theoretical Hydropower Potential Assessment of the Ruvubu sub-basins

The Ruvubu basin, which is the largest drainage basins of the country, has been subdivided into 9 sub-basins. The Topography and natural drainage network of the sub-basins of Ruvubu are such that limited types (storage, runoff/diversion, small scale, medium scale, and low, medium head) of hydropower development options are available. And also, the distribution of the site is not uniform in all sub-basins. As a result, it is necessary to discuss information concerning with potential of the sub basins, number of sites and categorizing the sites depending on available head, and plant potential of each sub-basin and the following section address these.

By taking, the above site selection criteria, into account site selection have been carried out and the hydropower potential based on the available discharge and natural head for each sub-basins have been computed. The identified attractive hydropower potential sites and the estimated potential power are summarized in table form and mapped in the respective delineated sub-basin.

The summarized forms of identified site includes site designation related directly to name of the river, the coordinate location, bed level altitude of the river just at site, the possible available head, the available discharge and the potential power.

The results per sub-basin are discussed in the below tables and figures from table 5.8 to 5.16 and figure 5.5 to 5.14 and then summarized for whole Ruvubu basin in the table 5.17 and figure 5.15.

Table 5.8: Ruvyironza identified site and estimated hydropower potential

Sub-basin	S.N^0	Name of the HP site	Coordinates		bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
			X	Y						
Ruvyironza	1	Ntaruka	489	9633	1485		1800	315	0.35	1,082
	2	Ruvyironza11	499	9630	1406	1480		74	25.10	18,221
	3	Ruvyironza10	491	9633	1480	1485		5	24.77	1,215
	4	Ruvyironza 9	489	9633	1485	1536		51	23.38	11,697
	5	Ruvyironza12	484	9626	1536	1565		29	21.34	6,071
	6	Ndaberi	484	9626	1536		2092	556	0.37	2,018
	7	Mubongwe	489	9611	1572		2053	481	0.41	1,935
	8	Kayokwe	478	9610	1595		2259	664	0.89	5,797
	9	Waga 3	482	9611	1570	1595		25	10.63	2,607
	10	Waga 2	478	9610	1595	1615		20	8.31	1,630
	11	Mushwabure	474	9606	1615		2229	614	2.10	12,649
	12	Waga 1	474	9606	1615		2210	595	1.96	11,440
	13	Ruvyironza 3	492	9605	1585	1642		57	6.29	3,517
	14	Ruvyironza 2	491	9592	1642	1735		93	3.59	3,275
	Total potential HPP in Ruvyironza sub-basin									**83,155**

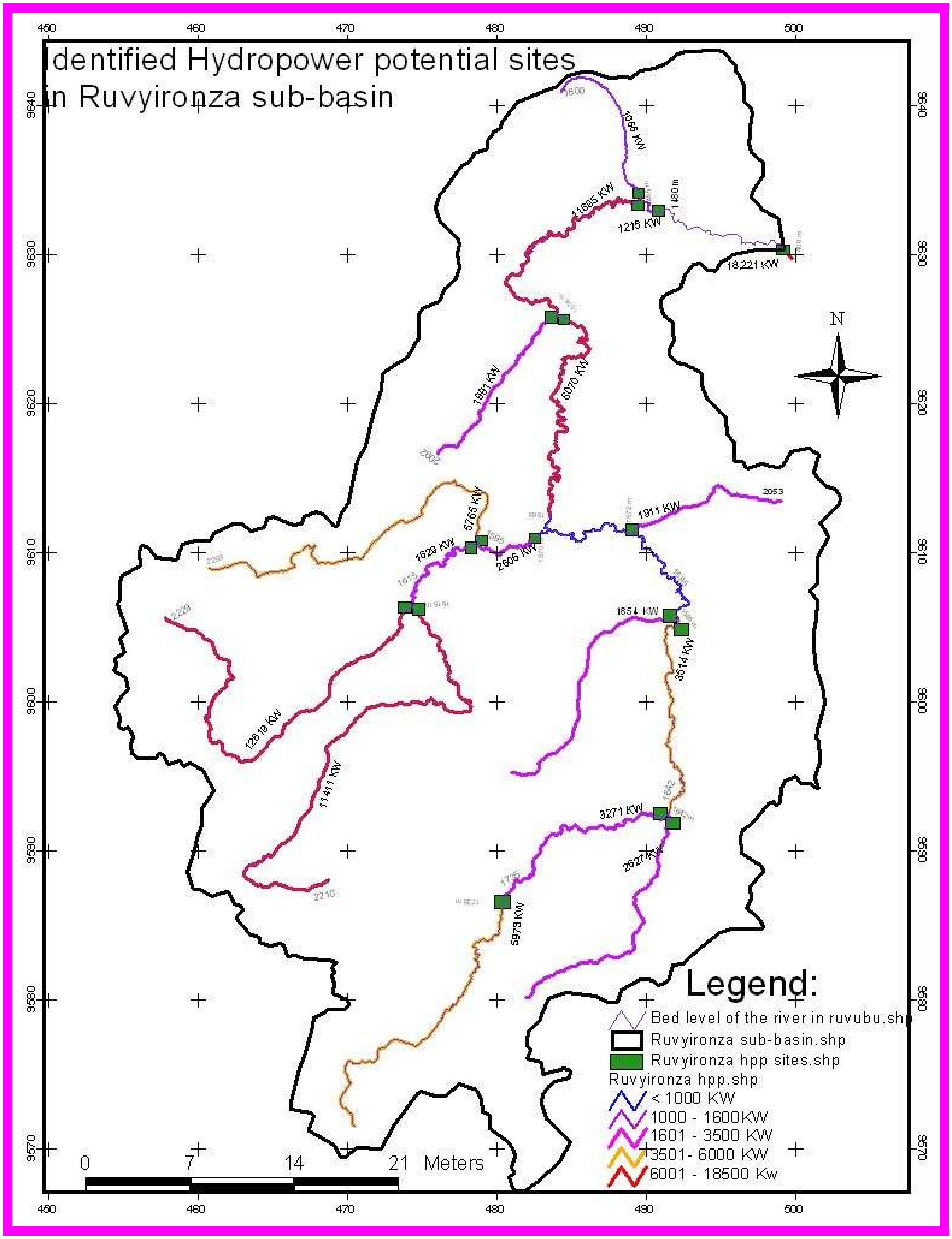


Figure 5.5. Hydropower potential distribution in Ruvyironza sub-basin

Table 5.9: Main Ruvubu identified site and estimated hydropower potential

Sub-basin	S.N^0	Name of HP site	Coordinates		Bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin (m)	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
			X-coord	Y-coord						
Main Ruvubu River basin	1	Ruvubu 28	558	9706	1325	1343		18	108.90	19,230
	2	Ruvubu 13	503	9641	1434	1483		49	38.92	18,708
	3	Ruvubu 18	504	9627	1384	1403		19	76.27	14,216
	4	Ruvubu 14	499	9630	1406	1434		28	49.49	13,594
	5	Ruvyironza 9	489	9633	1485	1536		51	23.38	11,697
	6	Ruvubu 19	520	9633	1366	1379		13	87.45	11,152
	7	Ruvubu 1	459	9667	1670		2554	884	1.18	10,233
	8	Ruvubu 23	546	9665	1347	1355		8	99.63	7,819
	9	Ruvubu 22	538	9651	1355	1361		6	96.80	5,698
	10	Cigazure	554	9674	1345		1826	481	1.13	5,332
	11	Ruvubu 11	489	9649	1485	1505		20	25.62	5,027
	12	Mucece	464	9636	1670		2377	707	0.71	4,924
	13	Nyamisesera	460	9665	1657		2450	793	0.55	4,279
	14	Ruvubu 18	510	9630	1379	1384		5	85.39	4,188
	15	Kavuruga 1	541	9679	1360		1838	478	0.75	3,517
	16	Ruvubu 21	528	9641	1361	1365		4	89.07	3,495
	17	Nyakabindi	459	9667	1670		2533	863	0.31	2,624
	18	Nyamwondo1	530	9651	1500		1901	401	0.60	2,360
	19	Ruvu 25	466	9668	1604	1657		53	4.25	2,210
	20	Ruvubu 7	484	9661	1525	1546		21	10.70	2,204
	21	Mutwenzi	498	9629	1403		2026	623	0.35	2,139
	22	Ruvubu 26	466	9668	1604		1943	339	0.63	2,095
	23	Ruvubu 27	545	9684	1343	1345		2	105.20	2,064
	24	Nyakigezi	520	9633	1366		1948	582	0.36	2,055
	25	Ruvubu 5	474	9662	1551	1581		30	6.02	1,772
	26	Ruvubu 15	498	9629	1404	1406		2	75.16	1,475
	27	Ruvub 8	489	9659	1513	1525		12	11.39	1,341
	28	Ruvubu 4	467	9665	1581	1604		23	5.72	1,291
	29	Nyagisuma 3	538	9651	1355	1424		69	1.74	1,178
	30	Kagoma	489	9659	1513		1974	461	0.25	1,131
	31	Ruvubu 26	554	9674	1345	1346		1	102.06	1,001
	Total potential in Main Ruvubu sub-basin									**170,049**

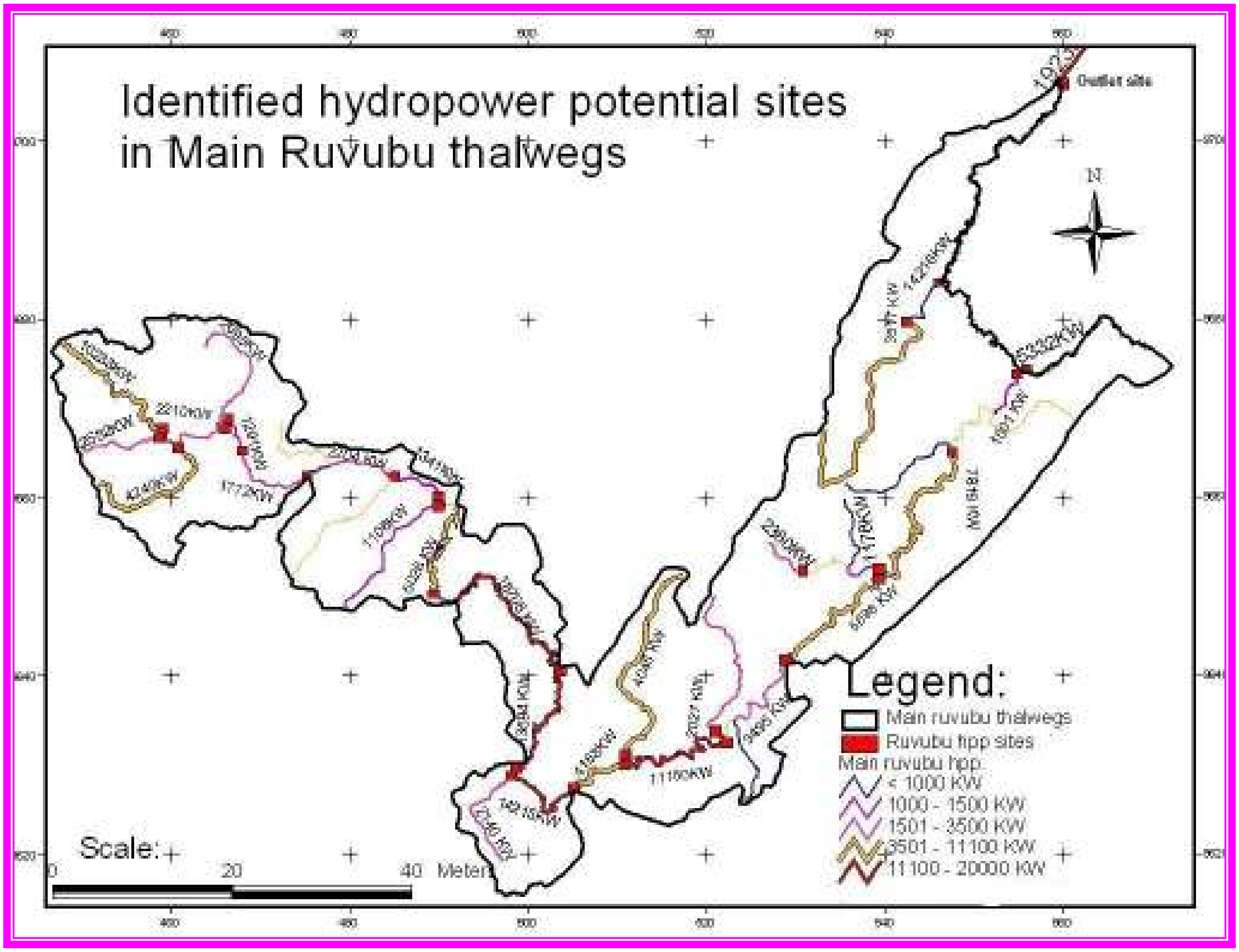


Figure 5.6: Hydropower potential distribution in Main Ruvubu Thalwegs

Table 5.10: Kinyankuru identified site and estimated hydropower potential

Sub-basin	S.N^0	Name of HP site	Coordinates X-coord	Coordinates Y-coord	Bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
Kinyankuru	1	Nyamuswaga1	494	9676	1540		1859	319	2.05	6,415
	2	Nyacizima	492	9672	1527		2022	495	1.78	8,644
	3	Nyakagezi	492	9667	1524		1901	377	0.28	1,036
	4	Kinyankuru 4	493	9662	1511	1524		13	9.29	1,185
	5	Nyabusyo 1	496	9663	1520		1855	335	1.17	3,845
	6	Tambi	496	9663	1520		1820	300	0.55	1,619
	Total potential in Kinyankuru sub-basin									**22,642**

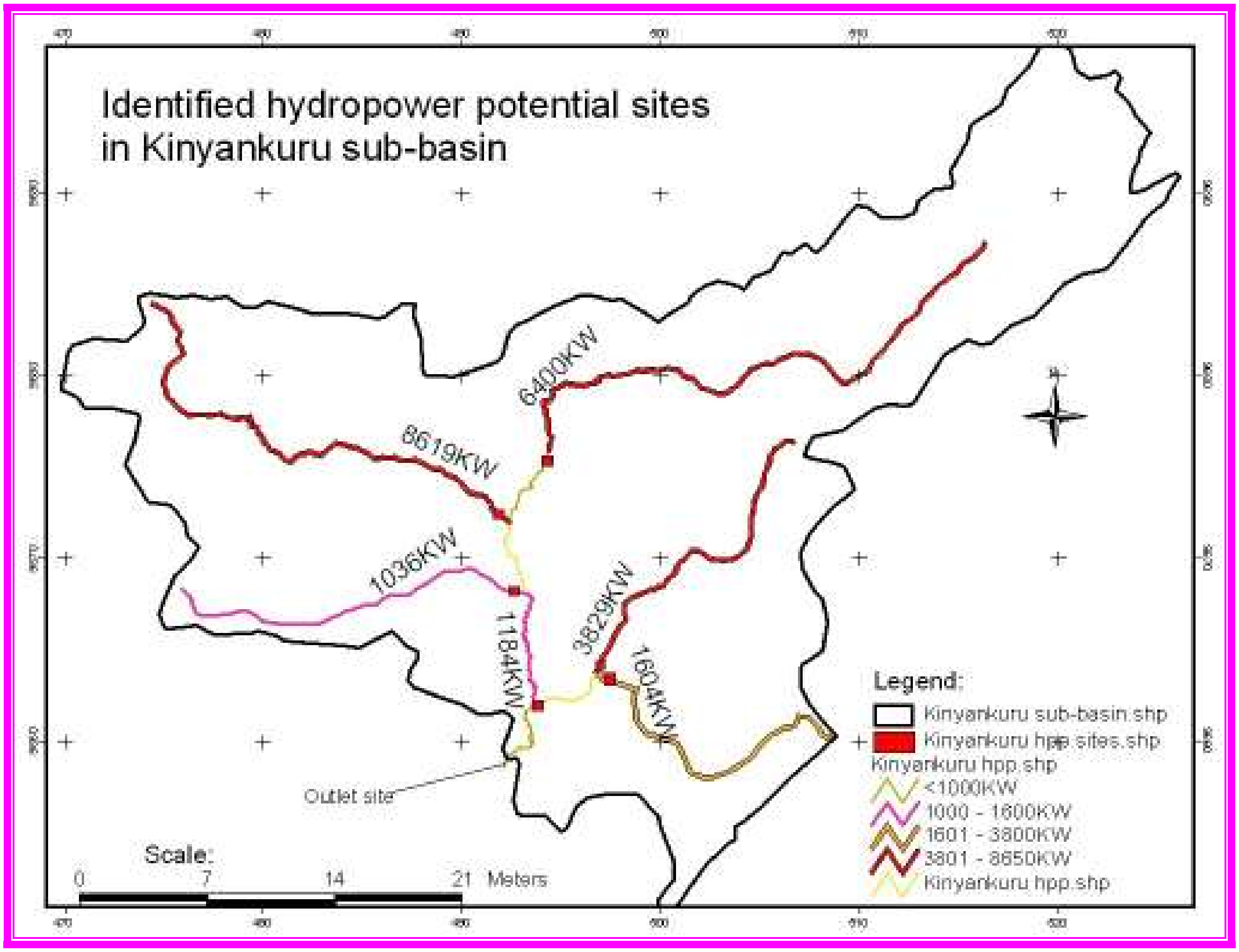


Figure 5.7: Hydropower potential distribution in Kinyankuru sub-basin

Table 5.11: Mubarazi identified site and estimated hydropower potential

Sub-basin	S.N⁰	Name of HP site	Coordinates		Bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
			X-coord	Y-coord						
Mubarazi	1	Mubarazi 5	488	9646	1486	1519		33	11.92	3,859
	2	Mubazi 2	464	9639	1670	1820		150	5.09	7,490
	3	Mubarazi 3	469	9636	1615	1670		55	7.03	3,793
	4	Mubarazi 4	478	9640	1519	1615		96	7.98	7,515
	5	Mubarazi 1	455	9639	1820		2522	702	2.41	16,597
	6	Kaniga	478	9640	1519	1560		41	3.37	1,355
	7	Nyabuyumpu	469	9636	1615		2000	385	0.28	1,058
	8	Mucece	464	96387	1670		2377	707	0.71	4,924
	9	Kaniga 1	476	9636	1560		2259	699	1.66	11,383
	Total potential in Mubarazi sub-basin									**57,974**

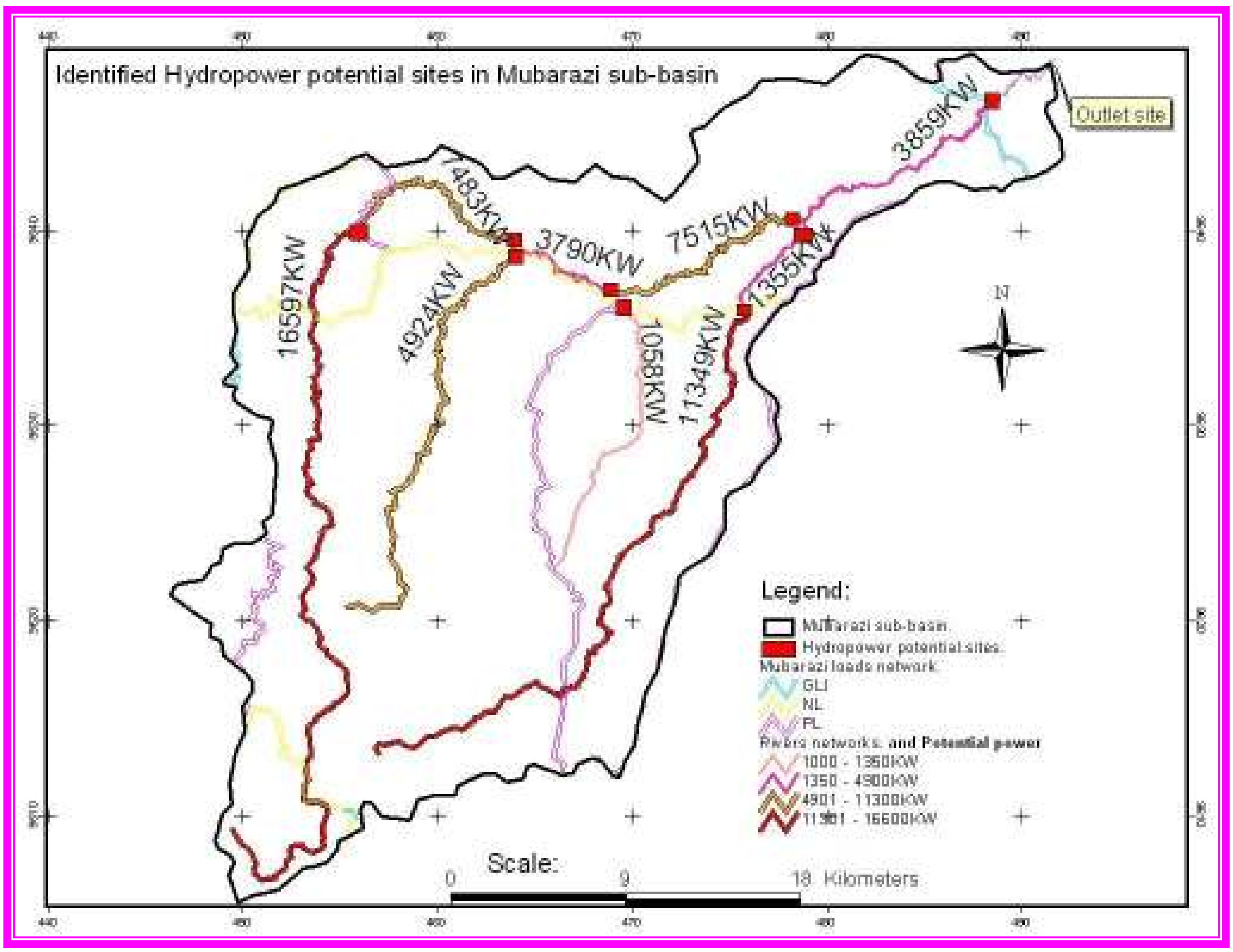


Figure 5.8: Hydropower potential distribution in Mubarazi sub-basin

Table 5.12: Ndurumu identified site and estimated hydropower potential

Sub-basin	S.N0	Name of HP site	Coordinates X-coord	Coordinates Y-coord	Bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
Ndurumu	1	Nyabiho	503	9641	1483		1888	405	3.43	13,628
	2	Ndurumu2	516	9662	1437	1483		46	8.40	3,791
	Total potential in Ndurumu									**17,418**

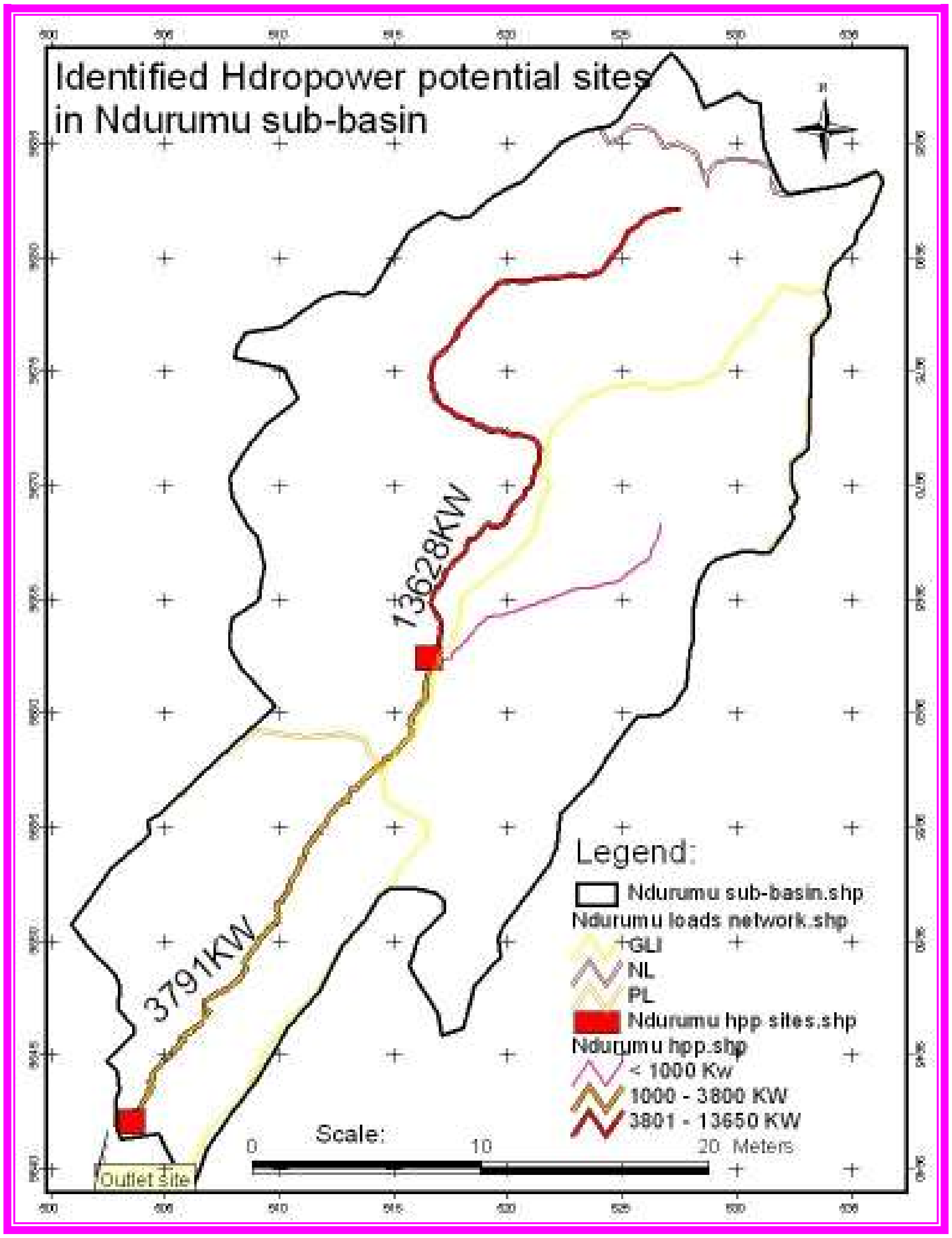


Figure 5.9: Hydropower potential distribution in Ndurumu sub-basin

Table 5.13: Nyabaha identified site and estimated hydropower potential

Sub-basin	S.N⁰	Name of HP site	Coordinates		Bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
			X-coord	Y-coord						
Nyabaha	1	Nyabizi			1379		1948	569	0.73	4,075
	2	Nyabaha 5	506	9625	1393	1425		32	8.41	2,640
	3	Sanzu	509	9621	1425	1540		115	2.08	2,347
	4	Nyakijanda 3	509	9620	1439	1475		36	3.68	1,300
	5	Sanzu 1	526	9618	1540		2055	515	0.64	3,233
	6	Kamiranzovu1	509	9620	1448		1943	495	0.52	2,525
	7	Nyakijanda 2	506	9615	1475	1555		80	2.90	2,276
	8	Nyakijanda 1	511	9602	1555		2000	445	1.23	5,370
	Total potential in Nyabaha									**23,765**

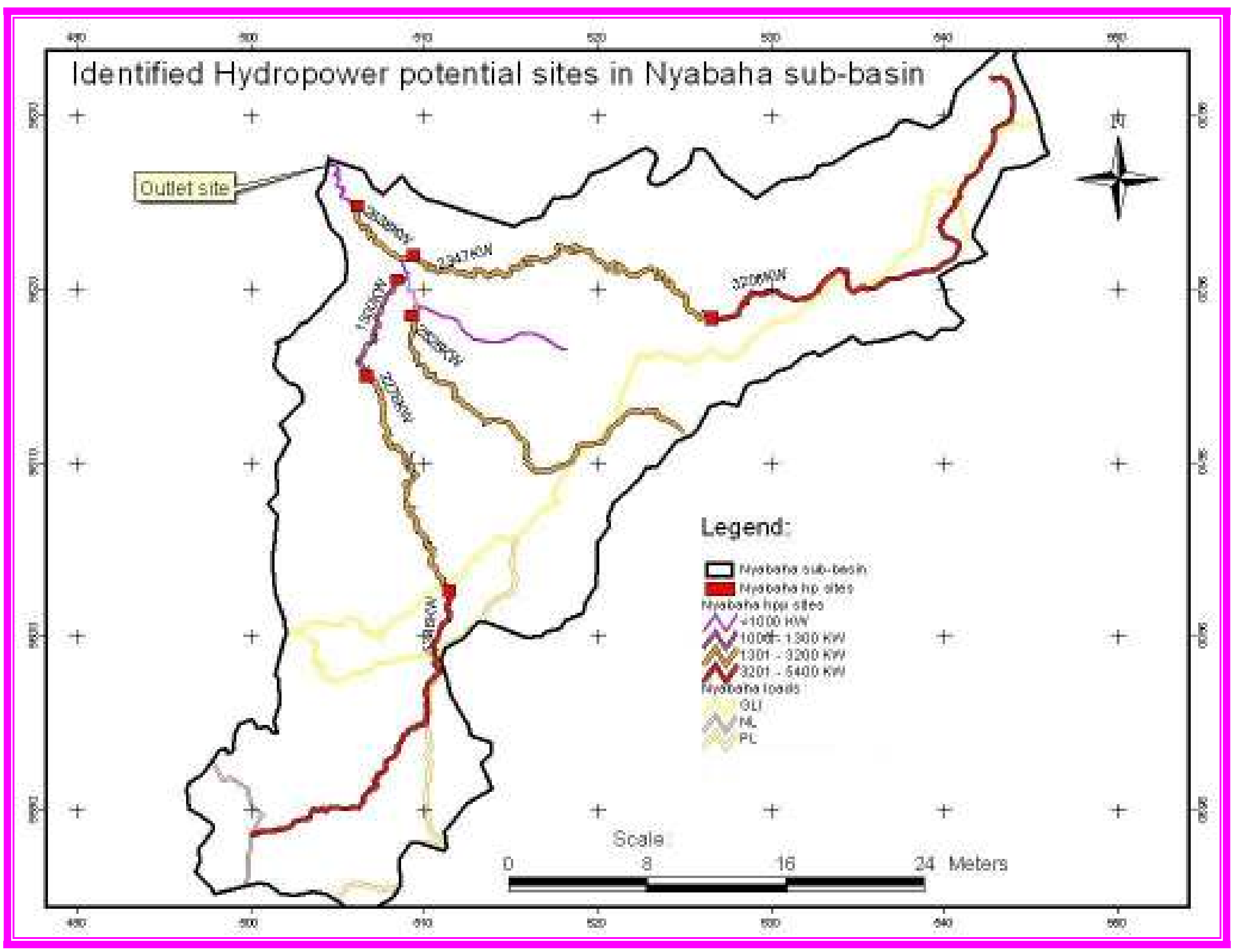


Figure 5.10: Hydropower potential distribution in Nyabaha sub-basin

Table 4.14: Kayongozi identified site and estimated hydropower potential

Sub-basin	S.N^0	Name of HP site	Coordinates X-coord	Coordinates Y-coord	Bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
Kayongozi	1	Kayongozi 1	558	9659	1520		1826	306	0.42	1,261
	2	Rugasari	554	9654	1498		1908	410	0.58	2,333
	3	Kayongozi3	535	9637	1465	1498		33	4.57	1,479
	4	Kayongozi6	528	9641	1361	1465		104	6.53	6,662
	Total potential in Kayongozi									**11,735**

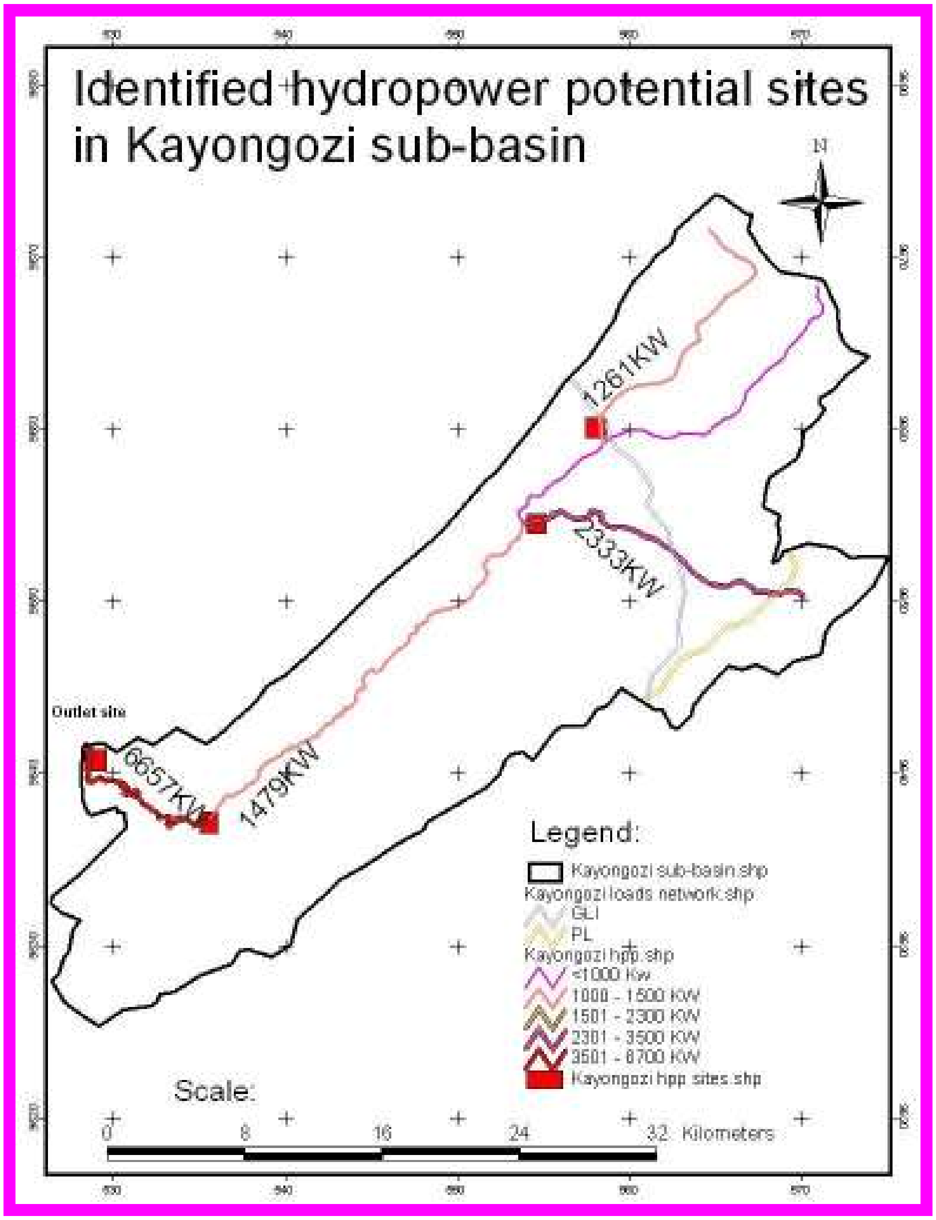


Figure 5.11: Hydropower potential distribution in Kayongozi sub-basin

Table 5.15: Nkokoma identified site and estimated hydropower potential

Sub-basin	S.N^0	Name of HP site	Coordinates X-coord	Coordinates Y-coord	Bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
Nkokoma	1	Nkokoma3	468	9654	1582	1630		48	3.24	1,526
	2	Nkokoma1	459	9650	1777		2666	889	0.69	6,018
	3	Nkokoma2	464	9651	1630	1777		147	2.79	4,023
	4	Nkokoma4	459	9649	1777		2600	823	0.64	5,167
	Total potential in Nkokma									**16,734**

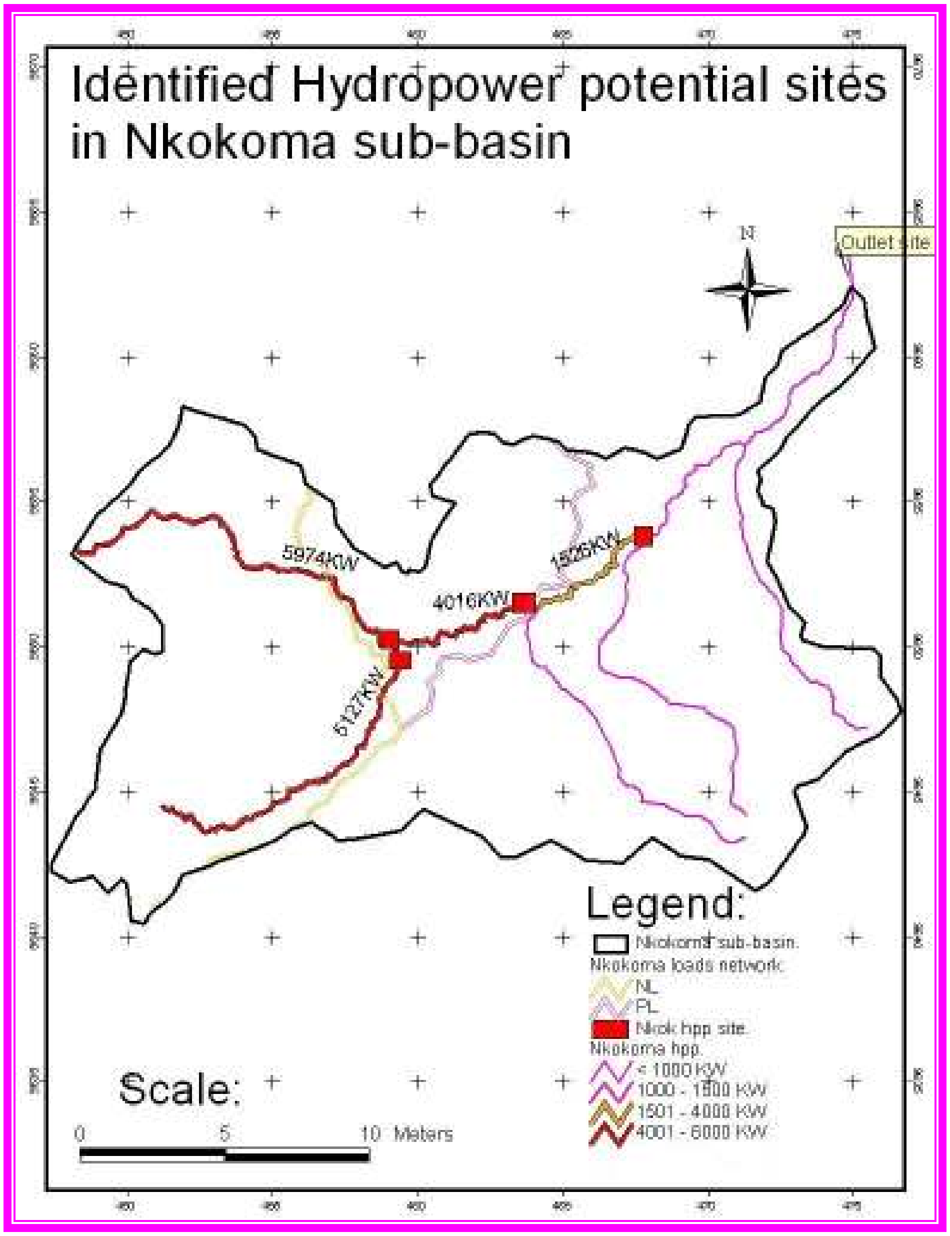


Figure.5.12: Hydropower Potential distribution in Nkokoma sub-basin

Table 5.16: Cizanye identified site and estimated hydropower potential

Sub-basin	S.N^0	Name of HP site	Coordinates		Bed level of the river (m)	Max. altitude (m)	Max. Altitude of the basin	Gross Head (m)	Available discharge (m^3/sec)	Power potential (KW)
			X-coord	Y-coord						
Cizanye	1	Cizanye1	544	9704	1385		1868	483	0.96	4,549
	2	Cizanye3	558	9706	1325	1375		50	2.28	1,116
	Total potential in Cizanye									**5,665**

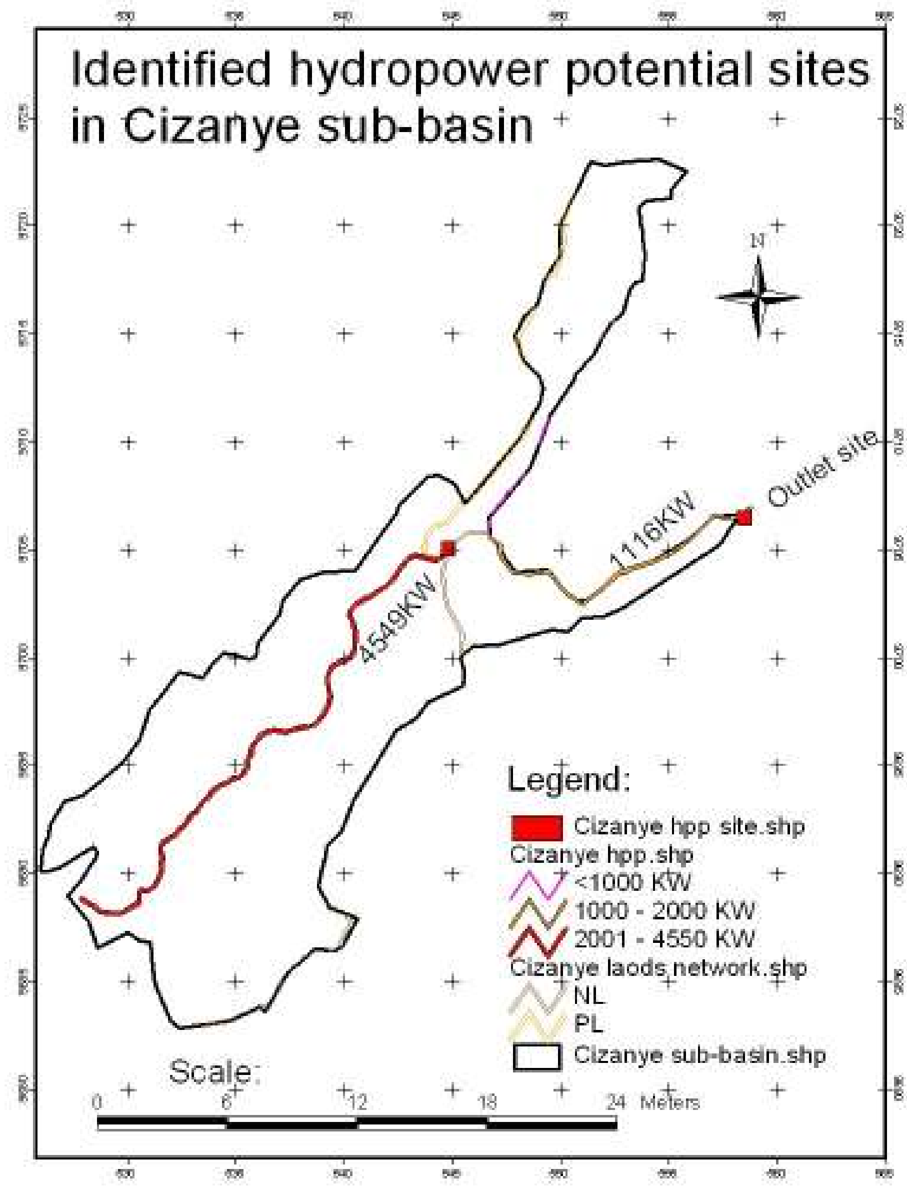


Figure 5.13: Hydropower potential distribution in Cizanye sub-basin

Table 5.17: Summary of the estimated potential hydropower in Ruvubu basin.

Sub-basin name	Area of the sub-basin in km^2	number of identified sites with power potential >1000 KW	Estimated total power potential (KW)	As % of total hydropower potential
Main Ruvubu Thalwegs	2,833	31	170,049	41.6 %
Ruvyironza	2,047	14	83,155	20.3 %
Mubarazi	926	9	57,974	14.2 %
Nyabaha	939.7	8	23,765	5.8 %
Kinyankuru	1,059	6	22,642	5.5 %
Ndurumu	779.2	2	17,418	4.2 %
Nkokoma	341	4	16,734	4.1 %
Kayongozi	818.6	4	11,735	2.8 %
Cizanye	308.5	2	5,665	13.8 %
Total hydropower potential	**10,063**	**80**	**409,137**	**100 %**

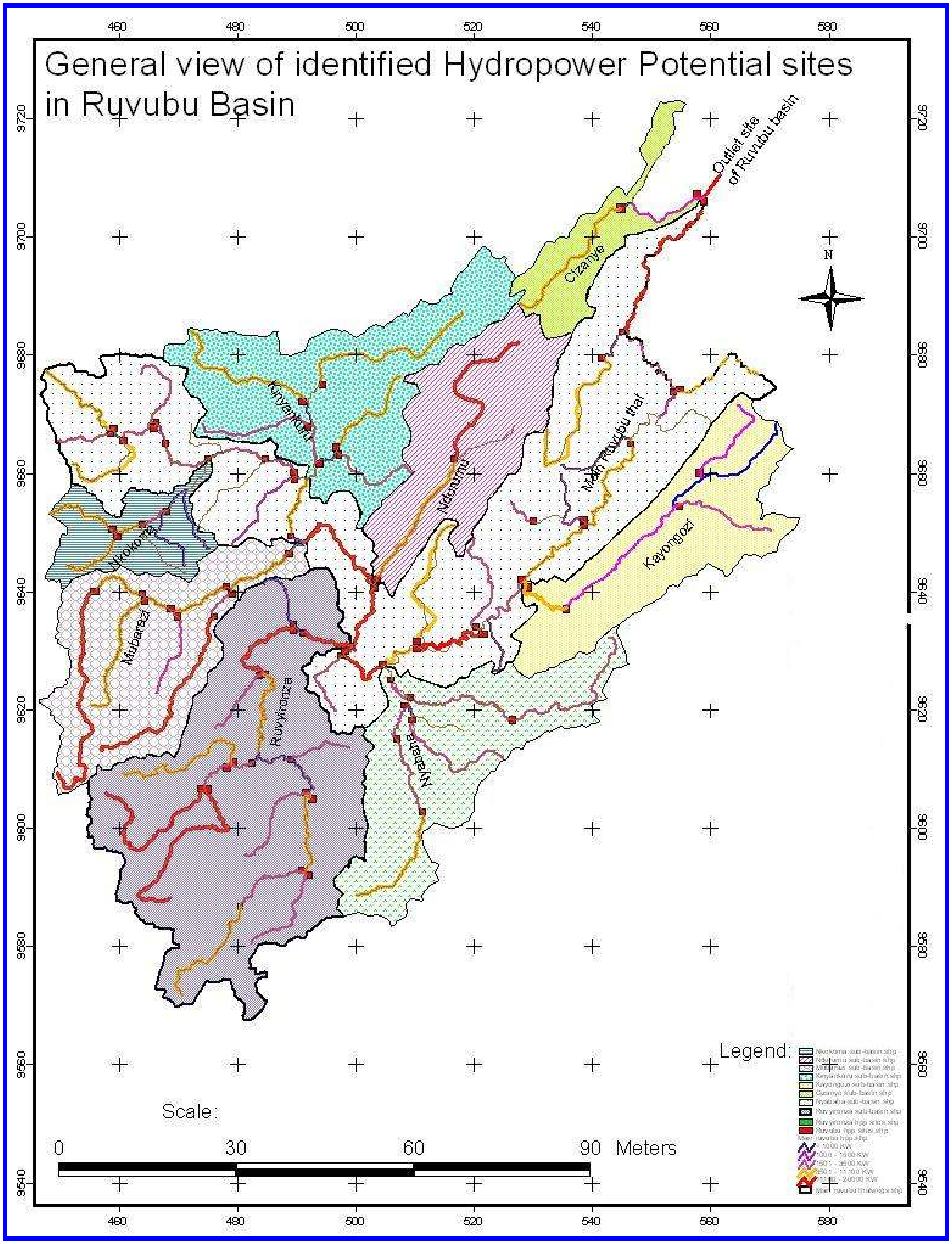


Figure 5.14: General Map of the potential hydropower sites in Ruvubu

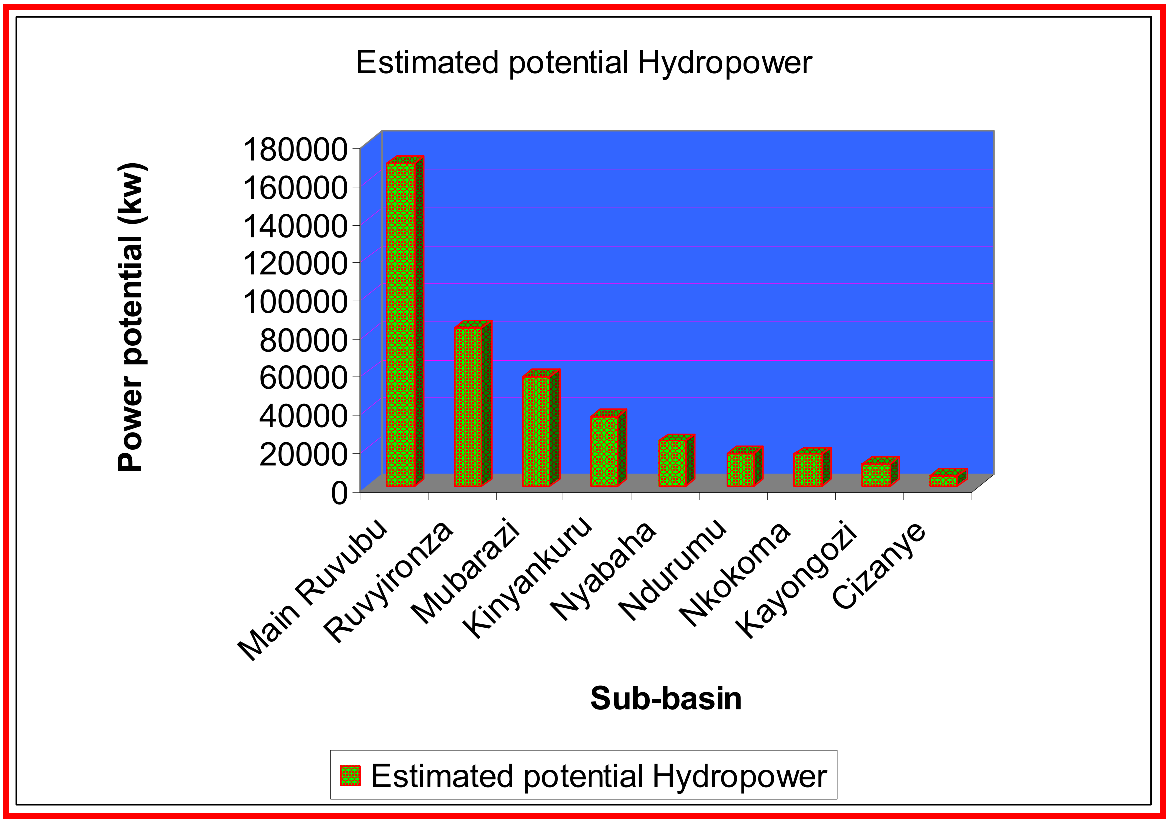


Figure 5.15: Hydropower potential distribution pattern per sub basin

Considering an average natural fall along the river reach and the average available mean discharge in each sub-basin, a total of 80 sites have been identified to generate a total of 409,137 KW potential power. The Main Ruvubu thalwegs (170,049 KW) and Ruvyironza (83,155 KW) accounts more than 60% of the total estimated Hydropower potential. The remaining seven sub-basins contribute less than 40% with less than 15% of potential contribution for each.

5. 3. IDENTIFICATION OF RESERVOIR POTENTIAL SITE

Reservoirs are constructed across rivers and streams to create an artificial lake behind it. Reservoirs and dams are the most important and expensive elements in multi-purpose river basin management. They require very careful planning, design and operation. A number of problems arise in design, construction and operation of the reservoirs, for example, selection of site, the relative merits of different types of dams, storage capacity and optimum yield and coordinated use of storage for different purposes.

Storage works are constructed to serve many purposes, which include:

- Storage and control of water for irrigation;
- Storage and diversion of water for domestic uses;
- Water supplies for Industrial uses;
- Development of Hydroelectric power;
- Increasing water depths for navigation;
- Storage space for flood control;
- Reclamation of low-lying lands;
- Debris control;
- Preservation and cultivation of useful aquatic life;
- Recreation.

Depending upon the purposes served, reservoirs may be classified as under:

- Storage or conservation reservoirs;
- flood protection reservoirs;
- Distribution reservoirs;
- Multi-purpose reservoirs.

In this research, the aim is to identify the potential reservoir site for dual purposes such as Irrigation and Hydroelectric purposes.

The investigations for reservoir planning are a hard task which required Engineering surveys, Geological investigations and Hydrological investigations.

5.3.1: Criteria for Reservoir site selection

The final selection of site for reservoir depends upon the following factors:

- The geological condition of the catchment area should be such that percolation losses are minimum and maximum run-off is obtained.
- The reservoir site should be such that quantity of leackage through it is a minimum. Reservoir site having the presence of highly permeable rocks reduce the water tightness of the reservoir. Rocks which are not likely to allow passage of much water include shales and slates, schists gneisses, and crystalline igneous rocks such as granite.
- Suitable dam site must exist. The dam should be founded on sound watertight rock base, and percolation below the dam should be minimum. The cost of the dam is often a controlling factor in selection of site.
- The reservoir basin should have narrow openings in the valley so that the length of the dam is less.
- the cost of real estate for the reservoir, including road, rail road, dwelling re-location etc. must be as less as possible.
- The topography of the reservoir site should be such that it has adequate capacity without submerging excessive land and other properties.
- The site should be such that a deep reservoir is formed. A deep reservoir is preferable to a shallow one because of (i) lower cost of land submerged per unit of capacity, (ii) less evaporation losses because of reduction in the water spread area, and (iii) less likelihood of weed growth.
- The reservoir site should be such that it avoids or excludes water from those tributaries which carry a high percentage of silt.
- The reservoir site should be such that the water stored in it is suitable for the purpose for which the project is undertaken. The soil and rock mass at the reservoir site must not contain any objectionable minerals and salts.

In the present study, three main theoretical criteria have been considered for selecting potential reservoir sites. There are:

1. *based on closed contours lines from the topographic map;*

2. *based on narrow openings in downstream valley so that the cross-section of the dam to the river reach is expected to be less;*
3. *based on the presence of perennial river in the valley.*

Hereby, a schematic map (figure.5.16) is represented to demonstrate the case of reservoir identification considering the three above stated criterion.

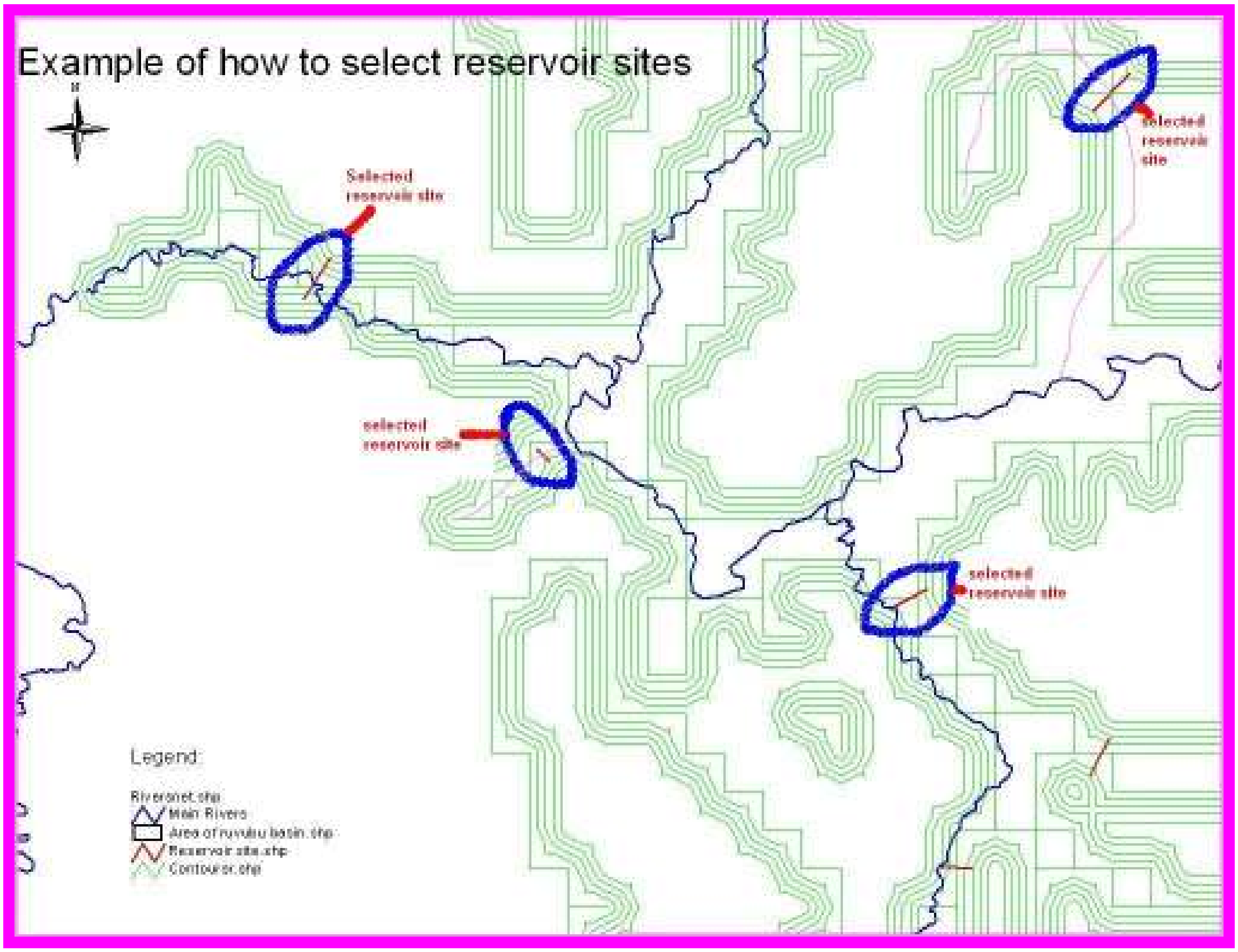


Figure 5.16: Example of how to select reservoir potential based on contour lines map

Finally, the identified potential reservoir sites are located on Ruvubu basin map (figure5.17) and the relevant information (rivers, coordinates and minimum contour lines) are presented in the tabular form below (table 5.18).

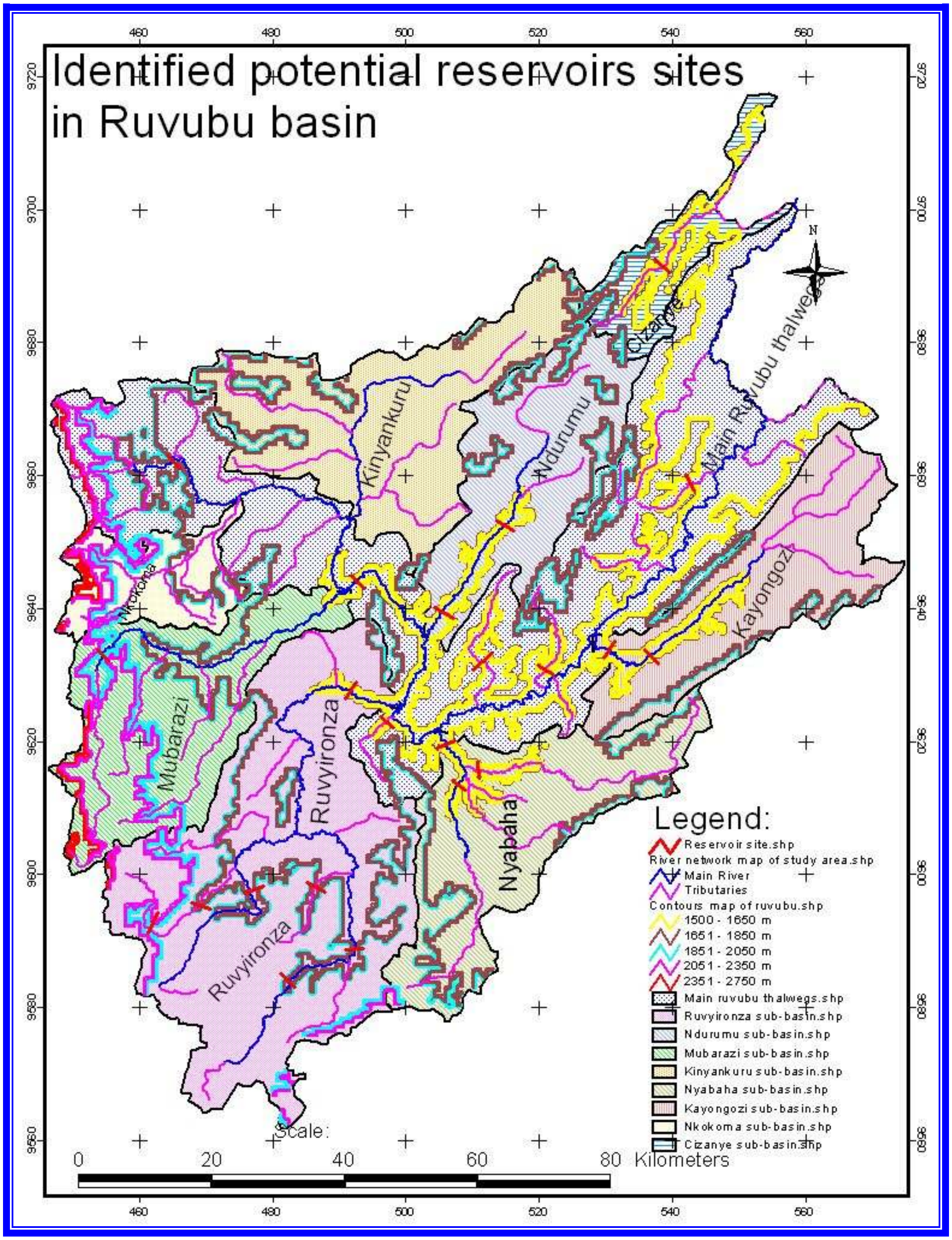


Figure 5.17: Location of identified potential reservoir sites in Ruvubu basin.

Table 5.18: Identified Potential Reservoir site and their location

Reservoir N^0	Name of the sub-basin	Name of the river across	Inflow Discharge (m^3/sec)	Location			Purpose of the reservoir
				X-coord	y-coord	Minimum contour altitude (m)	
R1	Ruvyironza	Ruvyironza2	2.97	482	9586	1750	HP and Irrigation
R2		Ruvyironza3	5.19	492	9594	1750	HP and Irrigation
R3		Kanyangwa	0.77	486	9603	1750	HP and Irrigation
R4		Waga1	3.91	476	9603	1750	HP and Irrigation
R5		Mushwabure1	0.001	461	9597	1750	HP and Irrigation
R6		Mushwabure2	0.89	468	9600	1750	HP and Irrigation
R7	Nyabaha	Nyakijanda3	3.35	508	9619	1500	Irrigation and HP
R8		Sanzu2	1.27	510	9621	1500	Irrigation and HP
R9		Nyabaha5	8.32	506	9625	1500	Irrigation and HP
R10	Main Ruvubu Thalwegs	Mutwenzi	0.7	497	9628	1500	Irrigation and HP
R11		Ruvubu13	38.25	492	9649	1500	Irrigation and HP
R12		Nyakigezi	0.71	520	9636	1500	Irrigation and HP
R13		Nyabizi	1.45	511	9637	1500	Irrigation and HP
R14		Nyamigina	0.4	542	9664	1500	Irrigation and HP
R15	Kayongozi	Kayongozi3	3.16	536	9638	1500	Irrigation and HP
R16		Kayongozi4	5.96	530	9639	1500	Irrigation and HP
R17	Mubarazi U/S	Mubarazi1	1.2	454	9638	2000	Irrigation and HP
R18	Ndurumu	Ndurumu2	7.2	514	9658	1500	Irrigation and HP
R19		Ndurumu3	9.6	505	9645	1500	Irrigation and HP
R20	Cizanye	Cizanye1	0.001	538	9696	1500	Irrigation and HP

The analyses of topographical map and river flow data through each sub-basin have permitted us to select the potential reservoir sites in the study area. A total of 20 sites have been identified for potential reservoir site based on narrow openings in downstream valley so that the cross-section of the dam to the river reach is expected to be less. The purposes of the reservoirs depend upon of the location. It is advisable to locate reservoir for hydropower generation in the upstream site so that the water can then be utilized in downstream site for others purposes such as irrigation. The reservoir site for irrigation purpose has to be located in near the command area. However, the reservoir for dual purposes Hydropower and irrigation purposes may be implemented at any site depending on available head for hydropower and nearness to the command area.

CHAPITER SIX

6.0 RESULTS AND DISCUSSION

The collected and compiled data have been used to apply theories and concepts for achieving to set objectives. The achieved results are discussed and summarized with this chapter.

6.1. Identified potential irrigable land

Qualitative land evaluation for irrigation is generally based on interpretation of physical characteristics of which slope, soil, land use and the available water resources are the most important parameters. 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 dense forest, Bad Lands, swampy areas, restricted/controlled areas are not clearly visible to be excluded from potential capacity estimation.

A. Soil Data results

Soil data results revealed topography, drainage, texture, surface stoniness and depth conditions favorable for agricultural purposes. With FAO classification criteria, six soil classes have been identified in Ruvubu. Soil class (ab) is the dominant with characteristics fully adequate for agriculture. It covers more than 80% of Ruvubu land from central plateau to Northern part of the basin. Soil class (ad) is also fully adequate for agriculture and is observed with small portion in North-West 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 boarder of the basin and (be) is observed along the western boarder with Congo crest (highland part). The soil class (f) is found on small portion throughout the dominant soil and is totally unsuitable for agriculture because of low soil depth (0-10cm).

B. Land use Data analysis.

The land use data analysis shows that combination of shrub plantation and herbaceous crop with two crops per year is dominant from west to North-East. The South-East is more covered with open shrubs along the Ruvubu river, open broadleaved deciduous trees and savannah located in Ruvubu national park. The agriculture in this zone is scattered and mixed with shrubs plantation. No irrigation schemes are observed except the individual farm flooded rice system along the Ruvubu valleys and its tributaries.

C. DEMs and Terrain feature

The upper areas of Ruvubu river basin, West hill and highland are characterized with rugged topography and elevation range of 1750m-2750m above sea level. The rapid increase in elevation for this range shows the variation in slope within short distance interval. These have not been considered as potentially suitable for agriculture nor for irrigation.

Potential irrigable sites which in theory could be developable are identified with altitude range below 1750m based on slope and water availability. GIS tools, contours lines and map information are used to locate areas with small slopes (≤ 10%) taken as physical criteria keeping in mind that the possible irrigation scheme is by gravity furrow/flood irrigation type. The nearness to the rivers is useful to reduce the conveyance system (irrigation canals length) and thereby to develop the irrigation system economically.

With this respect, the potential irrigable land has been identified below 1500m altitude and is estimated at 51,768 ha.

However, it has to be mentioned that other areas with altitude of 1750 m revealed suitable based on slope criteria but even if water is available can not be supplied by gravity system to the potential area due to lower river bed level altitude.

6.2. Estimated water resources and demand for the identified potential irrigable area

Gross Irrigation Water Requirement over the entire identified potentially irrigable area is estimated and compared with the existing river flow. The total GIWR is estimated based on assumption of Field Water Supply per unit area of 0.74l/sec/ha which represent $11.636*10^{-6}km^3$/ha/year. Then the total theoretical Gross Irrigation water demand for entire potential area of 51,768 ha is estimated at 0.602 km^3/year.

For estimation of water availability to satisfy the theoretical water demand three scenarios have been considered.

- the baseflow discharge of rivers with river bed altitude greater than 1500m in the upstream of the command area (on diversion point);
- the baseflow discharge of all rivers and tributaries draining the identified potential area;
- The baseflow discharge at Ruvubu-Bac.

As a result, first scenario gives a possibility of diverting a total discharge of 32.60 m^3/sec which can irrigate about 85% (44,054 ha) of the identified potential areas of 51,768 ha 44,054 ha. A storage system should provide about 1.028km^3/year and is estimated to satisfy the total theoretical Gross irrigation Water demand of 0.602 Km^3/year for developing surface irrigation of the total identified potential area.

The second alternative gives 52.28 m^3/sec of discharge and can potentially satisfy the required quantity of water for surface irrigation development of about 70,649 ha.

The third alternative provides a minimum total discharge of 54.7 m^3/sec to satisfy surface irrigation of 73,919 ha and about 1.726 km^3 can be stored per year. This scenario can not be however physically feasible for diversion type of irrigation development in the identified areas due constraints of topography.

The table below shows the first scenario using storage system and provides the quantity of water remaining after satisfying the water required for irrigation development of 51,768 ha.

Table 6.1: Summary of irrigation potential and water requirements, water availability in Ruvubu basin (for scenario$_1$).

Ruvubu basin area	Irrigation potential	Gross Irrigation water Requirement		Actual flow		storage after deduction for irrigation and losses
ha	ha	per ha (m^3/ha.Year	Total (Km^3/Yr)	inflow (m^3/sec)	Storage (Km^3/Yr)	Outflow (Km^3/Yr)
1,006,300	51,768	11,636	0.602	32.6	1.028	0.426

6.3. Estimated potential hydropower in Ruvubu basin

For the purpose of assessing the Hydropower potential in Ruvubu basin, GIS approach have been used based on monthly stream flow and estimate at site potential and produce potential hydropower map for each sub-basin. In order to identify the attractive hydropower head, tabular values of elevations, against coordinates have been derived from topographic map of 1: 50,000 scale. Monthly discharges have been computed and then hydropower potential estimated. In Ruvubu basin, based on this approach, a total of 80 sites are identified that produce potential power equal or greater than 1000 KW each. The direct tributaries of main Ruvubu thalwegs is found to dominate in the number of potential sites (31 sites) with estimated theoretical potential power of 170,049 KW (41% of the total potential). Ruvyironza basin is the second in the number of sites (14 sites) as well as the estimated potential power of about 83,155 KW (20% of the total potential power). With estimate of about 400,000 KW total potential for the Ruvubu basin, the most attractive locations, from the magnitude of power potential points of view, are high head locations which are accompanied by large discharges. However, for economical feasibility in addition to the obvious discharge and available head, other factors such as demand center and associated transmission cost, etc., come into consideration.

Based on the information developed in this research, one can obtain accurate sub-basins and basin characteristics for the identified sites. Be able to undertake accurate survey for knowing the available heads at the preliminarily identified sites as above and estimate the hydropower potential and its feasibility combining with other economic parameters.

6.4. Identified reservoir sites.

Based on the results developed in this research, at least two water uses have been treated and the associated water demand. These, among others, are useful basis for resource development and exploitation as well to devise strategies for integrated planning of basin development. The available surface water resource at a particular development site or demand area may or may not be adequate. The irrigation water demand for developing irrigation project in the entire identified potential areas indicates that there is water deficit in supply site. Hence, to substantially improve the resource exploitation, it is mostly important to provide reservoir.

In order to suggest such concepts, a number of 20 sites have been identified as reservoir potential sites based on topography. The information provided for identified reservoir sites include river name and available inflow discharge, the estimated coordinate location. It is advisable that for hydropower purpose, reservoir storage has to be implemented just in upstream site of the identified hydropower locations. In case of irrigation purpose, the reservoir storage may be located any where at the vicinity of the command area. The potential reservoir site is identified based on narrow openings in downstream valley so that the cross-section of the dam to the river reach is expected to be less.

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7.0 CONCLUSION AND RECOMMENDATIONS

In this study, it has been aimed to assess the water resources potential for irrigation and the water resources potential for hydropower. The study area is one of the most undocumented and non-investigated basin despite being inhabited by more than 55% of the national population and rapidly growing population under vulnerable environment.

Under the support of the main objective a number of status have been setout and briefly described to contribute to the aim of the prime goal.

General analyses of physiographic and hydrologic characteristics of Ruvubu basin have been provided. General reviews of socio-economic situation and infrastructures development with particular detail information on water resources development of the study area have been made.

Furthermore, the analyses of the Ruvubu drainage basin under GIS environment has been derived from the previously existed information system and are further enhanced such as by integrating infrastructure, population, soil map, landcover, some of the development potentials, etc.

With this regard, GIS environment tools enabled to establish nine sub-basins in Ruvubu with extensive and relatively accurate drainage information. For visual and spatial presentation of results, various maps have been provided to locate the potential identified irrigable areas, potential hydropower sites and potential reservoir sites.
Summing up, the set objectives at the beginning of this thesis have been successfully tackled and enabled comprehensive understanding of potential water resources availability in Ruvubu basin for the set objectives. The outcomes contained in this study provide:

- About 51,768 ha of potential irrigable land with estimated GIWR of 0.602 km^3/year ;
- 32.6 m^3/sec (1.028 km^3/year) of estimated available surface water developable for supplying the demand in this identified irrigable areas;

- about 400,000 KW of estimated hydropower potential in 80 identified sites;
- and 20 selected reservoir potential sites.

In view of the results, the Ruvubu basin has an estimated potential irrigable area of about 5% of the total area. The water availability from river runoff exploitation can satisfy about 85% of the GIWR for the identified theoretical potential irrigable site. This means there is the need of implementing a storage system for balancing supply and demand for irrigation projects. The Ruvubu basin has also an appreciable hydropower potential and only about 1% is currently developed. For sustainable water resources development and multi-purpose usages, a number of sites are identified to be potentially favorable for reservoir storage based on topography and the presence of river in upstream sites.
However, the results obtained in this study are subject to uncertainty and can be taken as preliminary indicator tools for first stage of implementation of any project related to water resources development.

Some parameters are based on simple assumptions and need to be adjusted by field and Engineering surveys to understand more the behavior of area characteristics.

As recommendations, there is a pressing need to utilize the land and water resources potential of the basin due to growing population. If the available water resources in the system are properly managed, it could be effectively utilized for basin development as well as for national development and preservation of environment. The suggested measures to reverse or improve the existing detrimental situation and yet utilize the water resources more effectively are:

- ✓ Increase of agricultural productivity through small to large scale irrigation schemes and thereby enable food self-sufficiency of the region and enhance socio-economic development.
- ✓ In irrigation development, existing practice of water misuse and poor management should be corrected through proper training of the users ;
- ✓ Program of erosion control measures in the entire basin system such as avoidance of poor farming practices, forestation, terracing, prevention of overgrazing, etc.
- ✓ Development of water structures by constructing reservoirs in upstream sites of the basin. By doing so, the water can be stored and used to supplement the water demand at critical period for irrigation and for hydropower development on regular basis.

- ✓ Use of renewable and sustainable energy sources such as development and use of Hydropower instead of wood as source of energy for cooking and lighting, and thereby reduce deforestation of the basin and soil erosion ;
- ✓ Replacement of wood construction material with other sources such as clay-bricks, soil-cement blocs and stones, thereby reducing deforestation and its consequences.
- ✓ Environmental education of community through various associations, organizations, schools, etc, is an urgent task to be implemented.

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APPENDIX

APPENDIX

Appendix.A.1: Meteorological Station in Ruvubu basin

N0	Station name	X	Y	ALT	Starting year	Stoped year	Mesured parameter	Managed by
1	Bugarama	449	9636	2203	1962	1987	P	IGEBU
2	Buhinyuza	540	9666	1553	1983		P	IGEBU
3	Bukeye	460	9647	1849	1958	1986	P	IGEBU
4	Burasira	490	9660	1536	1961		PTI	IGEBU
5	Butezi	517	9625	1680	1982		PT	IGEBU
6	Gatara	462	9669	1806	1930		PT	IGEBU
7	Giheta	484	9628	1624	1931		P	IGEBU
8	Gisanze	520	9693	1716	1935	1987	P	IGEBU
9	Gishubi	485	9599	1735	1983		P	IGEBU
10	Gisozi	464	9606	2097	1931		PGTHVEBI	IGEBU
11	Gitega aéro	490	9623	1645	1964		PGTHVBI	IGEBU
12	Gitega agri	491	9624	1721	1922	1986	P	IGEBU
13	Gitega zege	491	9624	1663	1972		PTI	IGEBU
14	Gitongo	486	9649	1603	1934	1987	P	IGEBU
15	Ijenda mission	452	9615	2191	1971	1980	P	IGEBU
16	Karuzi	518	9658	1600	1953		PT	IGEBU
17	Kibimba	477	9636	1726	1935		P	IGEBU
18	Kibumbu	471	9610	1814	1933		PT	IGEBU
19	Kiganda E.F.I.	559	9660	1930	1974		P	IGEBU
20	Makebuko	500	9602	1770	1934		P	IGEBU
21	Mugera paroisse	496	9633	1757	1930		P	IGEBU
22	Muramvya	457	9639	1989	1927		P	IGEBU
23	Muriza	515	9605	1616	1977		PGTHVBI	IGEBU
24	Murongwe	489	9647	1500	1962		PT	IGEBU
25	Musema	464	9660	1845	1930		P	IGEBU
26	Musenyi par.	504	9674	1684	1935		P	IGEBU
27	Musongati	511	9588	1770	1976		P	IGEBU
28	Muyinga	538	9686	1756	1927		PGTHVEI	IGEBU
29	Mweya	492	9614	1735	1976		PT	IGEBU
30	Ngozi ocibu	480	9678	1831	1927		P	IGEBU
31	Nyakararo	456	9610	2228	1962		P	IGEBU
32	Nyamuswaga	504	9680	1720	1980		PGTHVBI	IGEBU
33	Rugari paroisse	544	9698	1650	1930		PT	IGEBU
34	Rusengo	539	9625	1660	1930	1983	PT	IGEBU
35	Rutovu	484	9571	2013	1958	1987	PT	IGEBU
36	Ruvyironza	475	9579	1822	1960		PGTHVEBI	IGEBU
37	Ruyigi agri	527	9616	1610	1928		P	IGEBU
38	Teza	451	9645	2166	1965		PGTVEBI	IGEBU

Explaination

p: Precipitation
T: Temperature
I: Sunshine duration
G: Humnigraph
H: Humidity
V: Wind speed
B: Pan Evaporation
E: Piche Evaporation

No1. Gisozi Station: X= 464, Y= 9606, Altitude = 2097 m													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Prec mm**
1970	233.3	220.7	334.4	227.8	97.0	4.3	6.2	12.2	27.1	64.2	118.5	168.0	1513.7
1971	226.8	106.4	111.9	323.7	276.2	3.3	22.5	8.9	70.4	108.8	108.0	229.5	1596.4
1972	129.4	261.1	223.2	169.5	124.9	64.7	0.0	57.2	116.0	140.2	256.8	168.0	1711.0
1973	248.8	76.8	78.5	127.9	144.6	19.1	0.0	0.0	108.0	184.1	191.5	189.6	1368.9
1974	163.6	80.8	185.6	212.0	146.0	18.7	31.6	3.1	56.7	114.4	116.8	62.6	1191.9
1975	104.2	159.8	184.3	161.2	95.4	0.1	23.6	0.0	40.8	132.8	136.7	125.4	1164.3
1976	91.5	158.6	196.9	168.1	107.3	1.1	0.8	52.9	69.3	97.4	149.9	100.4	1194.2
1977	211.6	165.8	203.1	287.3	121.5	6.4	0.0	29.4	106.0	24.1	292.0	144.5	1591.7
1978	124.3	181.0	301.3	215.4	37.4	9.8	0.0	27.8	96.7	190.7	192.6	183.3	1560.3
1979	126.5	290.3	186.6	293.5	102.7	20.7	0.0	0.0	8.1	118.7	214.7	184.8	1546.6
1980	83.8	150.1	141.9	147.0	154.4	2.1	0.0	0.3	60.1	51.9	178.7	191.3	1161.6
1981	189.8	119.9	267.9	172.9	98.2	1.3	1.4	46.1	52.3	91.1	59.1	249.2	1349.2
1982	136.7	94.0	208.5	335.5	208.2	10.7	0.0	0.0	39.8	99.9	255.2	282.1	1670.6
1983	80.1	218.5	220.0	178.3	109.5	1.0	6.1	24.9	26.2	203.4	154.2	147.5	1369.7
1984	180.8	156.0	169.9	155.1	76.2	0.0	37.4	35.1	26.9	152.9	206.9	186.0	1383.2
1985	134.5	257.0	237.0	418.3	56.5	4.2	0.0	0.0	82.9	110.9	213.2	166.6	1681.1
1986	251.0	246.7	155.2	316.4	140.8	0.3	0.0	0.6	81.1	93.6	271.7	246.8	1804.2
1987	298.3	157.2	160.7	188.6	73.4	1.4	0.0	4.3	137.4	79.7	181.0	133.3	1415.3
1988	237.7	224.3	230.5	288.0	29.8	0.0	10.5	33.9	96.7	127.9	121.5	159.9	1560.7
1989	223.0	124.2	363.5	203.6	106.6	15.3	0.4	0.0	101.9	115.1	217.8	312.5	1783.9
1990	110.2	265.9	223.0	127.7	96.6	0.0	6.8	28.4	113.0	112.7	156.0	98.9	1339.2
1991	197.6	221.9	108.0	207.4	217.0	41.2	9.0	0.6	43.8	219.2	146.8	181.5	1594.0
1992	138.8	225.4	145.1	159.4	88.1	8.4	0.0	0.0	36.4	177.3	174.2	79.5	1232.6
1993	140.9	122.2	141.4	155.6	175.7	0.8	0.0	15.7	0.4	119.6	120.6	100.1	1093.0
Monthly Mean	**169.3**	**178.5**	**199.1**	**218.3**	**120.2**	**9.8**	**6.5**	**15.9**	**66.6**	**122.1**	**176.4**	**170.5**	**1453.2**

No2. Gitega airport Station: X= 490, Y= 9623, Altitude = 1645 m													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Prec mm**
1970	146.1	162.2	238.8	243.1	44.1	10.0	0.7	17.8	15.8	37.2	152.4	206.7	**1274.9**
1971	221.7	90.5	134.7	252.3	127.5	0.2	3.2	42.7	33.7	86.5	119.2	130.3	**1242.5**
1972	82.7	212.6	205.9	103.8	98.1	49.2	0.0	4.2	93.7	115.5	156.8	155.2	**1277.7**
1973	228.4	177.1	69.5	125.7	66.4	17.2	0.0	0.0	72.3	106.9	144.3	104.6	**1112.4**
1974	166.8	76.7	219.8	233.9	121.0	14.3	17.2	0.1	80.3	83.6	132.0	111.4	**1257.1**
1975	97.9	140.0	175.6	130.9	54.9	0.0	13.0	0.0	124.9	85.4	94.0	189.6	**1106.2**
1976	100.1	152.5	158.9	152.3	117.5	1.2	1.5	4.5	86.9	127.9	113.0	242.9	**1259.2**
1977	205.1	160.1	103.1	207.3	116.0	0.5	0.0	39.1	62.4	61.5	176.1	155.0	**1286.2**
1978	127.3	134.3	281.7	188.5	54.8	0.0	0.0	4.8	62.6	136.7	146.1	180.3	**1317.1**
1979	140.1	218.8	225.3	313.5	41.3	9.0	0.0	0.1	2.1	69.7	218.4	141.1	**1379.4**
1980	128.2	85.8	117.9	96.3	95.0	0.0	0.0	0.5	56.7	33.4	257.7	163.9	**1035.4**
1981	121.8	113.1	153.4	120.3	115.5	0.0	0.0	48.8	143.9	85.8	56.0	192.6	**1151.2**
1982	138.0	146.6	138.3	226.7	146.3	5.1	0.0	0.0	47.5	148.4	275.5	148.9	**1421.3**
1983	97.5	88.1	106.5	171.7	58.7	0.1	0.0	8.9	23.6	163.1	126.2	143.6	**988.0**
1984	161.7	153.7	70.8	109.1	3.9	0.0	38.5	28.9	22.6	151.9	208.7	204.6	**1154.4**
1985	96.5	225.2	167.4	250.1	20.6	0.0	0.0	0.0	86.5	172.2	129.1	103.6	**1251.2**
1986	233.4	205.1	171.7	255.2	131.1	0.8	0.0	0.3	29.0	70.7	223.7	147.1	**1468.1**
1987	286.0	84.3	44.5	128.6	115.0	0.0	0.0	0.3	137.1	86.8	166.3	78.4	**1127.3**
1988	303.1	138.8	178.4	302.7	24.0	0.0	30.9	27.8	63.4	106.2	122.4	177.1	**1474.8**
1989	154.9	144.4	322.9	223.2	73.3	18.8	0.5	10.8	50.0	98.2	118.5	132.4	**1347.9**
1990	37.5	217.0	186.1	136.9	54.3	0.0	0.0	0.9	90.5	79.2	144.0	121.4	**1067.8**
1991	154.2	43.5	135.8	135.9	175.5	14.4	1.1	0.0	51.0	125.0	151.6	120.7	**1108.7**
1992	88.3	128.0	167.2	194.2	47.4	1.6	0.0	0.0	13.1	125.4	176.6	142.4	**1084.2**
1993	122.8	173.2	146.2	95.8	63.3	0.0	0.0	14.0	0.0	87.2	150.0	134.4	**986.9**
Monthly M	151.7	144.7	163.4	183.3	81.9	5.9	4.4	10.6	60.4	101.9	156.6	151.2	1215.8

No3. Muriza Station: X= 515, Y= 9605, Altitude = 1616 m													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Prec mm**
1970	231.1	202.3	219.9	258.5	51.8	16.0	0.4	11.6	13.4	38.3	135.5	171.1	1349.9
1971	68.1	103.4	258.8	91.4	0.4	1.1	18.2	28.3	66.6	122.3	137.4		896.0
1972	179.3	200.2	121.9	147.6	96.3	95.2	0.0	21.3	53.6	141.0	201.6	155.5	1413.5
1973	178.7	97.0	48.0	192.7	80.9	29.2	0.0	0.0	51.6	80.7	192.9	119.8	1071.5
1974	159.1	61.6	126.6	231.5	74.7	23.8	2.5	0.7	30.2	53.0	125.3	74.2	963.2
1975	58.3	69.2	143.9	153.6	80.1	0.1	2.1	0.0	26.4	71.5	109.5	140.7	855.4
1976	92.6	115.1	86.1	183.1	79.0	1.7	0.2	6.6	34.0	14.0	132.9	141.7	887.0
1977	192.7	107.7	83.5	191.7	99.5	0.0	0.0	23.4	27.2	79.6	190.0	109.9	1105.2
1978	169.7	255.0	252.0	200.3	55.5	2.2	0.0	8.4	39.2	135.7	212.9	270.6	1601.5
1979	194.7	216.2	124.0	288.3	97.5	10.2	0.0	0.0	3.2	50.6	89.1	129.5	1203.3
1980	81.7	80.7	76.3	182.8	115.4	0.0	0.0	0.0	43.4	43.8	168.0	118.7	910.8
1981	110.2	42.7	208.9	174.5	35.1	0.0	0.0	48.5	23.2	52.9	116.8	234.0	1046.8
1982	83.5	81.9	86.1	283.2	163.0	7.2	0.0	0.4	17.2	98.4	294.3	257.4	1372.6
1983	63.9	123.4	102.9	240.5	39.3	0.0	0.0	31.4	20.7	95.1	112.7	167.8	997.7
1984	167.9	121.1	181.4	138.4	16.3	0.0	16.6	36.6	16.8	71.2	174.0	91.3	1031.6
1985	199.2	211.3	234.3	259.4	72.6	0.0	0.0	0.4	52.4	67.0	105.9	86.3	1288.8
1986	172.4	94.2	155.2	271.6	95.2	3.7	0.0	0.9	25.3	141.9	197.6	137.2	1295.2
1987	235.9	131.4	154.0	209.5	82.9	0.8	0.0	0.0	144.6	20.6	205.1	79.6	1264.4
1988	188.6	92.4	185.1	260.6	48.7	0.1	0.0	49.9	33.6	61.6	173.5	226.0	1320.1
1989	373.3	125.7	269.6	229.9	107.6	53.1	0.0	1.3	42.1	63.9	141.2	211.7	1619.4
1990	29.8	283.1	205.6	170.4	47.6	0.0	0.0	2.8	46.8	122.8	129.8	84.9	1123.6
1991	113.8	104.0	98.4	187.0	206.3	26.8	0.0	0.0	14.5	110.5	99.5	150.1	1110.9
1992	126.6	218.5	210.9	201.8	54.2	0.0	0.0	0.0	9.7	77.0	190.9	111.6	1201.2
1993	132.3	115.4	69.1	85.3	106.0	0.0	0.0	13.1	0.0	39.7	111.8	102.1	774.8
Monthly M	**150.1**	**135.6**	**154.3**	**201.4**	**79.4**	**11.3**	**1.7**	**11.9**	**34.8**	**77.2**	**156.2**	**140.5**	**1154.4**

No4. Muyinga Station: X= 538, Y= 9686, Altitude = 1756 m													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Prec mm**
1970	104.1	206.3	166.7	214.4	65.7	4.1	10.7	22.3	18.0	55.5	97.3	211.8	1176.9
1971	174.9	104.3	120.2	207.1	76.4	0.0	1.8	62.7	50.7	68.0	91.5	96.3	1053.9
1972	154.5	213.8	94.6	119.8	88.0	14.5	0.0	34.7	61.2	162.7	150.9	126.9	1221.6
1973	89.1	155.0	104.6	198.7	245.8	0.5	0.0	0.0	69.7	88.7	112.8	42.2	1107.1
1974	100.3	103.2	290.3	243.7	114.1	25.9	28.1	1.1	19.9	35.7	86.1	59.6	1108.0
1975	119.3	89.4	121.1	174.3	74.9	0.0	13.1	1.3	161.9	123.0	73.4	143.8	1095.5
1976	54.2	87.1	92.3	145.7	47.8	0.2	11.6	21.0	52.7	66.4	133.3	131.6	843.9
1977	182.1	75.4	146.9	328.7	125.7	2.0	0.0	36.3	61.4	46.4	173.4	110.5	1288.8
1978	146.3	99.4	250.4	193.8	64.0	2.6	0.0	24.5	48.6	117.4	74.5	116.1	1137.6
1979	262.6	144.0	105.8	205.4	75.1	23.6	0.0	0.0	28.2	63.8	135.1	142.8	1186.4
1980	82.6	78.7	114.1	114.7	70.5	22.2	0.0	12.5	58.0	108.8	153.1	136.7	951.9
1981	76.8	72.4	156.6	127.7	82.0	0.0	0.0	101.3	61.6	88.2	92.0	59.4	918.0
1982	117.5	24.5	114.2	215.2	121.0	11.8	3.2	0.1	62.3	84.3	39.3	148.9	942.3
1983	40.5	167.1	148.1	228.9	68.2	0.1	0.0	57.0	74.8	101.7	97.7	81.4	1065.5
1984	72.1	67.1	121.9	70.6	9.4	0.0	37.1	112.4	65.7	171.6	291.9	66.6	1086.4
1985	113.5	209.0	77.4	248.5	78.6	0.0	0.0	5.6	103.0	127.6	196.7	147.0	1306.9
1986	116.3	100.1	159.1	341.7	57.5	43.7	0.0	1.4	30.1	182.4	164.0	51.8	1248.1
1987	145.3	66.9	236.6	211.0	184.0	26.8	0.0	1.6	141.9	97.9	332.0	64.9	1508.9
1988	331.1	172.7	152.9	134.7	36.8	6.2	0.0	63.8	30.3	192.5	110.5	125.6	1357.1
1989	31.6	170.4	119.6	115.2	143.2	57.5	0.0	26.3	62.3	94.4	87.9	195.8	1104.2
1990	72.6	193.8	147.0	111.4	64.6	0.0	0.0	17.8	79.7	105.0	110.9	152.5	1055.3
1991	90.5	86.7	78.5	148.2	162.5	39.2	0.4	23.3	15.7	143.1	106.3	79.7	974.1
1992	108.4	137.1	103.1	303.5	43.1	7.6	0.0	0.5	56.8	117.2	71.3	143.9	1092.5
1993	221.1	46.2	150.5	263.2	78.5	0.3	0.0	56.0	0.3	88.5	84.9	144.6	1134.1
Monthly	125.3	119.6	140.5	194.4	90.7	12.0	4.4	28.5	59.0	105.5	127.8	115.9	1123.5

No5. Nyamuswaga Station: X= 504, Y= 9680, Altitude = 1980

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Prec mm
1970	162.1	171.0	206.4	249.5	80.0	16.6	0.5	20.3	30.3	75.6	176.4	190.4	1379.1
1971	163.8	105.3	152.6	314.5	151.2	4.1	3.9	49.6	52.1	126.9	151.6	128.2	1403.8
1972	112.2	216.7	157.0	144.4	93.2	146.0	0.1	11.0	114.8	152.2	193.6	143.2	1484.4
1973	195.3	178.5	118.7	239.3	111.4	30.0	0.1	0.2	101.7	139.1	175.4	69.9	1359.6
1974	154.1	98.4	252.2	224.0	130.2	41.6	11.1	0.7	97.4	114.6	159.1	90.8	1374.2
1975	122.2	130.7	165.6	233.1	76.7	1.8	12.2	0.6	140.3	129.1	127.4	146.5	1286.2
1976	111.3	164.0	144.0	187.5	123.6	6.4	1.5	9.3	107.0	157.3	157.1	140.6	1309.6
1977	189.3	147.4	153.0	236.9	105.8	1.0	0.1	38.3	82.6	96.6	212.0	184.5	1447.5
1978	147.2	141.8	255.6	235.8	71.5	4.7	0.1	10.2	79.5	165.5	164.4	179.9	1456.2
1979	138.1	194.5	168.7	236.3	90.6	17.6	0.1	0.3	7.4	109.3	229.5	155.7	1348.1
1980	270.0	174.0	153.6	128.2	117.3	1.1	0.0	0.6	127.2	192.2	278.7	91.6	1534.5
1981	133.6	65.4	137.0	194.4	106.7	7.1	0.0	61.4	94.7	126.7	89.4	190.8	1207.2
1982	207.4	122.7	132.8	284.5	188.9	6.9	0.0	0.0	67.3	203.4	284.1	154.1	1652.1
1983	63.0	198.4	215.1	230.5	164.8	4.3	4.2	32.0	23.7	205.1	328.8	161.5	1631.4
1984	212.4	112.2	150.4	151.1	20.2	0.0	22.3	77.6	25.1	177.3	282.8	113.2	1344.6
1985	110.7	162.3	132.8	320.9	84.3	15.0	0.0	17.3	129.8	150.7	211.7	169.6	1505.1
1986	172.5	205.5	217.3	330.0	166.7	0.0	0.0	4.6	38.7	117.3	109.7	114.6	1476.9
1987	211.9	96.8	134.5	323.9	75.3	39.8	0.0	0.0	183.9	128.6	336.6	76.4	1607.7
1988	143.2	121.9	204.8	179.9	30.3	0.0	5.0	29.1	92.0	202.7	112.4	143.7	1265.0
1989	118.6	132.4	210.9	165.0	85.8	144.5	2.5	11.1	58.1	146.8	156.6	223.3	1455.6
1990	96.0	282.6	250.1	89.7	42.7	0.0	0.0	0.0	188.1	106.9	105.3	191.4	1352.8
1991	156.1	45.1	128.3	303.8	166.8	27.9	1.0	4.2	55.5	137.3	213.3	113.6	1352.9
1992	69.9	111.9	129.7	198.7	77.5	7.8	0.0	0.0	35.9	121.7	171.4	158.1	1082.6
1993	110.3	150.8	95.8	165.6	76.6	2.1	0.0	34.9	2.9	46.1	144.7	124.9	954.7
Monthly Mean	**148.8**	**147.1**	**169.5**	**223.6**	**101.6**	**21.9**	**2.7**	**17.2**	**80.7**	**138.7**	**190.5**	**144.0**	**1386.3**

No6. Rivyironza Station: X= 475, Y= 9579, Altitude = 1960

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Prec mm
1970	248.6	197.7	244.0	257.6	42.3	33.4	25.2	0.0	19.4	71.7	187.5	232.6	1560.0
1971	210.4	100.2	110.3	269.1	73.7	0.0	6.1	15.1	44.1	71.6	328.8	259.1	1488.5
1972	195.5	218.4	164.9	117.5	79.7	54.2	0.0	15.7	77.1	148.8	181.8	172.2	1425.8
1973	209.8	79.4	86.6	202.0	64.5	8.3	0.0	0.4	103.0	170.2	172.0	144.7	1240.9
1974	163.3	133.9	104.5	252.6	56.3	18.3	42.2	1.3	42.9	59.6	113.2	124.0	1112.1
1975	107.5	113.4	259.3	126.3	81.8	2.2	30.3	0.0	63.2	108.4	133.1	93.9	1119.4
1976	204.7	194.1	104.1	190.8	67.1	0.4	0.0	9.6	38.7	66.8	97.9	112.1	1086.3
1977	241.4	181.0	188.0	260.7	55.7	0.6	0.0	30.2	43.1	54.8	262.6	148.4	1466.5
1978	137.9	169.2	252.1	193.1	40.0	0.4	0.0	17.9	35.4	114.4	243.4	216.1	1419.9
1979	183.7	282.0	120.7	338.4	102.5	15.8	0.0	0.0	0.0	71.2	99.0	177.4	1390.7
1980	119.4	191.9	175.9	63.5	125.8	7.0	0.0	0.0	51.7	131.5	168.8	163.8	1199.3
1981	141.2	157.3	209.5	149.8	67.8	0.0	0.2	19.0	82.6	64.2	195.8	157.3	1244.7
1982	204.3	150.2	171.0	211.6	125.9	9.0	0.0	0.0	12.0	147.6	186.6	170.7	1388.9
1983	102.1	279.4	113.9	182.5	48.8	1.8	0.0	38.0	29.3	118.2	150.5	137.4	1201.9
1984	201.7	190.7	98.7	161.2	20.3	0.0	3.6	30.7	11.7	128.8	169.5	218.3	1235.2
1985	167.9	154.6	271.3	295.8	51.9	0.4	0.0	0.0	45.0	124.5	151.3	128.4	1391.1
1986	217.6	171.0	171.3	212.3	72.5	0.0	0.0	6.0	63.7	207.0	51.1	130.3	1302.8
1987	214.9	127.9	112.5	64.0	89.1	4.3	0.0	4.2	70.0	89.5	119.0	119.4	1014.8
1988	289.2	139.8	228.7	208.3	28.6	2.5	0.0	48.3	35.0	51.3	181.2	154.4	1367.3
1989	157.3	234.6	295.1	95.1	101.9	71.7	0.6	35.3	72.8	103.3	126.1	180.8	1474.6
1990	73.8	271.5	231.5	174.7	52.5	0.0	0.0	15.2	31.0	101.5	87.9	118.7	1158.3
1991	169.8	181.9	95.3	169.4	96.6	31.2	0.0	19.5	55.8	130.6	138.4	136.3	1224.8
1992	129.9	292.9	93.2	141.6	56.3	7.1	0.9	0.0	1.1	132.0	202.5	163.5	1221.0
1993	180.0	129.8	201.9	119.9	103.5	0.1	0.0	3.0	2.0	28.7	144.6	122.7	1036.2
Monthly Mean	178.0	181.0	171.0	185.7	71.0	11.2	4.5	12.9	42.9	104.0	162.2	157.6	1282.1

No7. Teza Station: X= 451, Y= 9645, Altitude = 1965													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Prec mm**
1970	206.7	178.7	360.7	301.7	124.9	3.1	1.1	6.4	53.1	110.5	173.0	280.3	1800.2
1971	216.5	93.3	132.0	314.9	193.9	7.5	19.2	19.6	107.0	182.1	178.5	142.1	1606.6
1972	229.5	233.7	152.8	148.4	117.3	60.9	0.0	48.8	169.9	187.1	237.9	226.9	1813.2
1973	163.6	203.6	52.3	152.5	169.1	26.5	0.2	0.0	246.8	141.2	317.6	121.2	1594.6
1974	132.8	115.7	128.0	286.0	223.0	80.5	37.2	9.9	109.7	102.3	143.5	157.1	1525.7
1975	161.4	186.4	168.4	227.7	106.7	3.1	24.9	1.2	105.9	234.9	149.3	168.8	1538.7
1976	61.8	168.0	153.4	221.4	102.2	27.8	1.7	52.9	200.9	167.1	178.0	176.6	1511.8
1977	191.7	131.1	156.2	229.5	116.7	18.2	4.7	47.5	73.2	55.2	336.2	169.3	1529.5
1978	112.2	199.0	326.5	337.6	58.4	29.0	0.0	53.9	152.6	117.4	156.5	232.3	1775.4
1979	158.0	293.5	152.3	392.7	115.0	37.8	0.0	2.5	0.0	93.0	252.1	250.8	1747.7
1980	174.0	191.5	162.3	176.4	177.6	3.2	0.0	1.5	91.7	254.8	215.0	184.4	1632.4
1981	147.8	120.9	234.2	203.1	182.0	11.1	7.0	68.8	121.0	210.0	99.9	175.1	1580.9
1982	165.5	101.5	277.6	272.7	120.9	14.0	0.0	0.1	107.3	157.6	356.9	151.7	1725.8
1983	100.4	153.6	214.9	245.7	81.9	8.7	0.5	62.8	67.1	204.4	191.0	157.6	1488.6
1984	225.0	142.7	182.8	135.5	64.5	0.0	16.4	47.8	78.1	140.5	215.5	201.0	1449.8
1985	210.5	145.1	260.4	358.0	62.8	3.7	0.0	1.2	119.5	119.7	285.9	210.7	1777.5
1986	191.5	119.4	167.9	283.5	189.0	11.1	0.0	4.0	41.4	219.0	245.7	159.3	1631.8
1987	241.0	211.4	172.3	269.9	177.7	12.2	1.4	0.4	175.7	136.4	335.8	113.2	1847.4
1988	190.6	213.7	300.2	293.1	46.1	0.0	2.7	94.2	68.3	168.8	238.9	217.5	1834.1
1989	180.3	205.8	222.4	148.9	140.1	44.5	21.6	26.1	69.5	115.9	131.6	171.6	1478.3
1990	103.5	213.1	220.1	207.4	107.5	0.0	0.0	53.0	121.6	112.7	169.1	153.4	1461.4
1991	130.4	126.4	184.3	273.8	182.0	46.7	0.0	13.6	55.8	203.5	124.0	174.8	1515.3
1992	160.7	169.2	127.7	267.5	132.4	20.0	0.0	0.0	31.7	196.9	152.5	178.1	1436.7
1993	198.4	150.4	196.8	152.5	156.9	6.5	0.0	11.3	3.8	36.9	156.1	73.8	1143.4
Monthly Mea	**168.9**	**169.5**	**196.1**	**245.9**	**131.2**	**19.8**	**5.8**	**26.1**	**98.8**	**152.8**	**210.0**	**177.0**	**1602.0**

Appendix. A.3: Monthly Precipitation per basin (mm)

Basin name	Mean ann prec (mm)	Jan	Feb	Mar	Ap	May	June	July	Aug	Sept	Oct.	Nov.	Dec.
Ruvubu	1485.6	217.6	193.0	241.9	283.2	142.9	22.1	12.7	50.8	97.7	153.3	241.5	216.0
Ruvubu1	1700.2	249.0	220.8	276.9	324.1	163.6	25.3	14.5	58.2	111.8	175.4	276.4	247.3
Nyakabindi	1743.0	255.3	226.4	283.8	332.3	167.7	25.9	14.9	59.6	114.6	179.9	283.4	253.5
Ruvubu2	1596.4	233.8	207.4	260.0	304.3	153.6	23.7	13.6	54.6	105.0	164.7	259.6	232.2
Nyamisesera	1632.4	239.1	212.0	265.8	311.2	157.1	24.3	13.9	55.9	107.3	168.4	265.4	237.4
Ruvubu3	1593.7	233.4	207.0	259.5	303.8	153.3	23.7	13.6	54.5	104.8	164.4	259.1	231.8
Kinyangona	1593.7	233.4	207.0	259.5	303.8	153.3	23.7	13.6	54.5	104.8	164.4	259.1	231.8
Ruvubu4	1593.2	233.3	206.9	259.4	303.7	153.3	23.7	13.6	54.5	104.8	164.4	259.0	231.7
Ruvubu5	1481.2	216.9	192.4	241.2	282.4	142.5	22.0	12.6	50.7	97.4	152.8	240.8	215.4
Nkokoma	1604.8	235.1	208.4	261.3	305.9	154.4	23.9	13.7	54.9	105.5	165.6	260.9	233.4
Ruvubu6	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Kawalembe	1551.9	227.3	201.6	252.7	295.9	149.3	23.1	13.2	53.1	102.0	160.1	252.3	225.7
Ruvubu7	1534.7	224.8	199.3	249.9	292.6	147.7	22.8	13.1	52.5	100.9	158.4	249.5	223.2
Nyarubanda	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Ruvubu8	1513.9	221.7	196.6	246.5	288.6	145.7	22.5	12.9	51.8	99.5	156.2	246.1	220.2
Kagoma	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Ruvubu9	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Ruvubu10	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Kinyankuru	1554.6	227.7	201.9	253.2	296.4	149.6	23.1	13.2	53.2	102.2	160.4	252.8	226.1
Ruvubu11	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Ruvubu12	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Mubarazi	1626.0	238.2	211.2	264.8	310.0	156.4	24.2	13.9	55.6	106.9	167.8	264.4	236.5
Ruvubu13	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Ndurumu	1368.2	200.4	177.7	222.8	260.8	131.6	20.3	11.7	46.8	90.0	141.2	222.5	199.0
Ruvubu14	1474.6	216.0	191.5	240.1	281.1	141.9	21.9	12.6	50.5	97.0	152.2	239.8	214.4
Ruvyironza	1556.8	228.0	202.2	253.5	296.8	149.8	23.1	13.3	53.3	102.4	160.6	253.1	226.4
Ruvubu15	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Ruvubu16	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Mutwenzi	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Ruvubu17	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Nyabaha	1465.7	214.7	190.4	238.7	279.4	141.0	21.8	12.5	50.2	96.4	151.2	238.3	213.2
Ruvubu18	1475.6	216.1	191.7	240.3	281.3	142.0	21.9	12.6	50.5	97.0	152.3	239.9	214.6
Nyabizi	1368.5	200.4	177.8	222.9	260.9	131.7	20.3	11.7	46.8	90.0	141.2	222.5	199.0
Ruvubu19	1414.6	207.2	183.7	230.4	269.7	136.1	21.0	12.1	48.4	93.0	146.0	230.0	205.7
Nyakigezi	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Ruvubu20	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Nyambiga	1371.4	200.9	178.1	223.3	261.4	131.9	20.4	11.7	46.9	90.2	141.5	223.0	199.4
Ruvubu21	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Kayongozi	1384.8	202.8	179.9	225.5	264.0	133.2	20.6	11.8	47.4	91.1	142.9	225.2	201.4
Ruvubu22	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Nyagisuma	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Ruvubu23	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Nyamigina	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Ruvubu24	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Nyongera	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Ruvubu25	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Ruvubu26	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Cigazure	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Ruvubu27	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Kavuruga	1357.6	198.8	176.3	221.1	258.8	130.6	20.2	11.6	46.5	89.3	140.1	220.7	197.4
Ruvubu28	1321.2	193.5	171.6	215.1	251.9	127.1	19.6	11.3	45.2	86.9	136.3	214.8	192.1
Cizanye	1287.3	188.5	167.2	209.6	245.4	123.8	19.1	11.0	44.0	84.6	132.8	209.3	187.2

Appendix A.3,(cont'…): Mean Precipitation per basin (Wet year)

Basin name	Annual prec	Jan	Feb	Mar	Ap	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
Ruvubu	1258.4	151.2	132.0	169.2	203.5	89.4	9.5	4.6	19.5	57.9	103.0	162.7	154.7
Ruvubu1	1440.2	173.0	151.1	193.6	232.9	102.3	10.9	5.2	22.3	66.3	117.8	186.2	177.1
Nyakabindi	1476.5	177.4	154.9	198.5	238.8	104.9	11.2	5.4	22.9	68.0	120.8	190.9	181.5
Ruvubu2	1352.3	162.5	141.9	181.8	218.7	96.1	10.2	4.9	21.0	62.3	110.6	174.8	166.3
Nyamisesera	1382.8	166.1	145.1	185.9	223.6	98.3	10.5	5.0	21.4	63.7	113.1	178.8	170.0
Ruvubu3	1350.0	162.2	141.6	181.5	218.3	95.9	10.2	4.9	20.9	62.2	110.4	174.5	166.0
Kinyangona	1350.0	162.2	141.6	181.5	218.3	95.9	10.2	4.9	20.9	62.2	110.4	174.5	166.0
Ruvubu4	1349.6	162.1	141.6	181.4	218.3	95.9	10.2	4.9	20.9	62.1	110.4	174.5	165.9
Ruvubu5	1254.7	150.7	131.6	168.7	202.9	89.2	9.5	4.6	19.4	57.8	102.7	162.2	154.3
Nkokoma	1359.4	163.3	142.6	182.7	219.9	96.6	10.3	5.0	21.1	62.6	111.2	175.8	167.2
Ruvubu6	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Kawalembe	1314.6	157.9	137.9	176.7	212.6	93.4	9.9	4.8	20.4	60.5	107.6	170.0	161.6
Ruvubu7	1300.0	156.2	136.4	174.7	210.2	92.4	9.8	4.7	20.2	59.9	106.4	168.1	159.8
Nyarubanda	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Ruvubu8	1282.4	154.1	134.5	172.4	207.4	91.1	9.7	4.7	19.9	59.1	104.9	165.8	157.7
Kagoma	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Ruvubu9	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Ruvubu10	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Kinyankuru	1316.9	158.2	138.2	177.0	213.0	93.6	10.0	4.8	20.4	60.6	107.7	170.3	161.9
Ruvubu11	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Ruvubu12	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Mubarazi	1377.4	165.5	144.5	185.1	222.8	97.9	10.4	5.0	21.4	63.4	112.7	178.1	169.4
Ruvubu13	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Ndurumu	1159.0	139.2	121.6	155.8	187.4	82.4	8.8	4.2	18.0	53.4	94.8	149.8	142.5
Ruvubu14	1249.1	150.1	131.1	167.9	202.0	88.8	9.4	4.6	19.4	57.5	102.2	161.5	153.6
Ruvyironza	1318.7	158.4	138.4	177.3	213.3	93.7	10.0	4.8	20.4	60.7	107.9	170.5	162.1
Ruvubu15	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Ruvubu16	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Mutwenzi	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Ruvubu17	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Nyabaha	1241.6	149.2	130.3	166.9	200.8	88.2	9.4	4.5	19.2	57.2	101.6	160.5	152.7
Ruvubu18	1250.0	150.2	131.1	168.0	202.2	88.8	9.5	4.6	19.4	57.6	102.3	161.6	153.7
Nyabizi	1159.3	139.3	121.6	155.8	187.5	82.4	8.8	4.2	18.0	53.4	94.8	149.9	142.5
Ruvubu19	1198.3	143.9	125.7	161.1	193.8	85.2	9.1	4.4	18.6	55.2	98.0	154.9	147.3
Nyakigezi	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Ruvubu20	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Nyambiga	1161.7	139.6	121.9	156.2	187.9	82.6	8.8	4.2	18.0	53.5	95.0	150.2	142.8
Ruvubu21	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Kayongozi	1173.0	140.9	123.1	157.7	189.7	83.4	8.9	4.3	18.2	54.0	96.0	151.7	144.2
Ruvubu22	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Nyagisuma	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Ruvubu23	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Nyamigina	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Ruvubu24	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Nyongera	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Ruvubu25	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Ruvubu26	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Cigazure	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Ruvubu27	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Kavuruga	1150.0	138.1	120.7	154.6	186.0	81.7	8.7	4.2	17.8	53.0	94.1	148.7	141.4
Ruvubu28	1119.2	134.4	117.4	150.4	181.0	79.5	8.5	4.1	17.3	51.5	91.6	144.7	137.6
Cizanye	1090.5	131.0	114.4	146.6	176.4	77.5	8.2	4.0	16.9	50.2	89.2	141.0	134.1

Appendix A.3 (cont'…): Mean Precipitation per basin (dry year)

Basin name	Mean annual prec (mm)	Jan prec.	Feb	Mar	Ap	May	Jn	July	Aug	Sept	Oct.	Nov.	Dec.
Ruvubu	1045.5	88.9	85.7	109.7	129.2	35.5	0.2	0.0	0.3	22.7	55.4	96.5	97.6
Ruvubu1	1196.5	101.7	98.1	125.5	147.9	40.7	0.3	0.0	0.3	26.0	63.4	110.4	111.7
Nyakabindi	1226.6	104.3	100.5	128.7	151.6	41.7	0.3	0.0	0.3	26.7	65.0	113.2	114.5
Ruvubu2	1123.4	95.5	92.1	117.9	138.9	38.2	0.3	0.0	0.3	24.4	59.6	103.7	104.9
Nyamisesera	1148.8	97.7	94.2	120.5	142.0	39.0	0.3	0.0	0.3	25.0	60.9	106.0	107.3
Ruvubu3	1121.5	95.4	91.9	117.7	138.6	38.1	0.3	0.0	0.3	24.4	59.5	103.5	104.7
Kinyangona	1121.5	95.4	91.9	117.7	138.6	38.1	0.3	0.0	0.3	24.4	59.5	103.5	104.7
Ruvubu4	1121.2	95.3	91.9	117.6	138.6	38.1	0.3	0.0	0.3	24.4	59.4	103.5	104.7
Ruvubu5	1042.4	88.6	85.4	109.4	128.9	35.4	0.2	0.0	0.3	22.6	55.3	96.2	97.3
Nkokoma	1129.4	96.0	92.6	118.5	139.6	38.4	0.3	0.0	0.3	24.5	59.9	104.2	105.5
Ruvubu6	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Kawalembe	1092.1	92.9	89.5	114.6	135.0	37.1	0.2	0.0	0.3	23.7	57.9	100.8	102.0
Ruvubu7	1080.0	91.8	88.5	113.3	133.5	36.7	0.2	0.0	0.3	23.5	57.3	99.7	100.9
Nyarubanda	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Ruvubu8	1065.4	90.6	87.3	111.8	131.7	36.2	0.2	0.0	0.3	23.1	56.5	98.3	99.5
Kagoma	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Ruvubu9	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Ruvubu10	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Kinyankuru	1094.0	93.0	89.7	114.8	135.2	37.2	0.2	0.0	0.3	23.8	58.0	101.0	102.2
Ruvubu11	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Ruvubu12	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Mubarazi	1144.3	97.3	93.8	120.1	141.5	38.9	0.3	0.0	0.3	24.9	60.7	105.6	106.9
Ruvubu13	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Ndurumu	962.9	81.9	78.9	101.0	119.0	32.7	0.2	0.0	0.3	20.9	51.1	88.9	89.9
Ruvubu14	1037.7	88.2	85.1	108.9	128.3	35.3	0.2	0.0	0.3	22.5	55.0	95.8	96.9
Ruvyironza	1095.5	93.2	89.8	114.9	135.4	37.2	0.2	0.0	0.3	23.8	58.1	101.1	102.3
Ruvubu15	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Ruvubu16	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Mutwenzi	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Ruvubu17	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Nyabaha	1031.5	87.7	84.5	108.2	127.5	35.1	0.2	0.0	0.3	22.4	54.7	95.2	96.3
Ruvubu18	1038.5	88.3	85.1	109.0	128.4	35.3	0.2	0.0	0.3	22.6	55.1	95.8	97.0
Nyabizi	963.1	81.9	78.9	101.0	119.1	32.7	0.2	0.0	0.3	20.9	51.1	88.9	89.9
Ruvubu19	995.5	84.7	81.6	104.4	123.1	33.8	0.2	0.0	0.3	21.6	52.8	91.9	93.0
Nyakigezi	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Ruvubu20	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Nyambiga	965.1	82.1	79.1	101.3	119.3	32.8	0.2	0.0	0.3	21.0	51.2	89.1	90.1
Ruvubu21	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Kayongozi	974.5	82.9	79.9	102.2	120.5	33.1	0.2	0.0	0.3	21.2	51.7	89.9	91.0
Ruvubu22	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Nyagisuma	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Ruvubu23	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Nyamigina	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Ruvubu24	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Nyongera	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Ruvubu25	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Ruvubu26	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Cigazure	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Ruvubu27	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Kavuruga	955.4	81.2	78.3	100.2	118.1	32.5	0.2	0.0	0.2	20.8	50.7	88.2	89.2
Ruvubu28	929.8	79.1	76.2	97.6	114.9	31.6	0.2	0.0	0.2	20.2	49.3	85.8	86.8
Cizanye	905.9	77.0	74.2	95.0	112.0	30.8	0.2	0.0	0.2	19.7	48.0	83.6	84.6

Appendix A.4: Monthly Temperature (^0C) per basin

Basin Name	Basin area	Mean annual T°	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12
Ruvubu	10063	18.9	19.0	19.3	19.6	20.0	19.9	18.9	17.9	18.0	18.6	19.1	18.9	18.8
Ruvubu1	129.7	17.3	17.4	17.7	18.0	18.3	18.2	17.3	16.4	16.5	17.0	17.5	17.3	17.2
Nyakabindi	32.09	16.7	16.8	17.1	17.4	17.7	17.7	16.8	15.9	15.9	16.5	17.0	16.7	16.7
Ruvubu2	6.49	17.2	17.4	17.6	17.9	18.3	18.2	17.3	16.4	16.4	17.0	17.5	17.3	17.2
Nyamisesera	98.11	17.6	17.8	18.0	18.4	18.7	18.6	17.7	16.8	16.8	17.4	17.9	17.7	17.6
Ruvubu3	22.99	17.5	17.6	17.9	18.2	18.5	18.4	17.5	16.6	16.7	17.2	17.7	17.5	17.4
Kinyangona	119.4	18.5	18.6	18.9	19.2	19.6	19.5	18.6	17.6	17.6	18.2	18.7	18.5	18.4
Ruvubu4	17.41	17.8	17.9	18.2	18.5	18.9	18.8	17.9	16.9	17.0	17.5	18.0	17.8	17.7
Ruvubu5	66.95	17.9	18.1	18.3	18.7	19.0	18.9	18.0	17.0	17.1	17.6	18.2	17.9	17.8
Nkokoma	341.2	17.5	17.7	17.9	18.3	18.6	18.5	17.6	16.7	16.7	17.3	17.8	17.6	17.5
Ruvubu6	7.63	17.8	17.9	18.2	18.5	18.9	18.8	17.9	16.9	17.0	17.5	18.0	17.8	17.7
Kawalembe	45.26	19.0	19.1	19.4	19.8	20.1	20.0	19.1	18.0	18.1	18.7	19.3	19.0	18.9
Ruvubu7	35.77	17.9	18.1	18.3	18.7	19.0	18.9	18.0	17.0	17.1	17.6	18.2	17.9	17.8
Nyarubanda	84.23	18.8	18.9	19.2	19.6	19.9	19.8	18.9	17.9	17.9	18.5	19.1	18.8	18.7
Ruvubu8	14.86	18.0	18.1	18.4	18.8	19.1	19.0	18.1	17.1	17.2	17.7	18.3	18.0	17.9
Kagoma	80.4	18.8	18.9	19.2	19.6	19.9	19.8	18.9	17.9	17.9	18.5	19.1	18.8	18.7
Ruvubu9	1.18	18.1	18.2	18.5	18.8	19.2	19.1	18.2	17.2	17.2	17.8	18.3	18.1	18.0
Ruvubu10	3.33	18.1	18.2	18.5	18.8	19.2	19.1	18.2	17.2	17.2	17.8	18.3	18.1	18.0
Kinyankuru	1060	19.1	19.2	19.5	19.9	20.3	20.2	19.2	18.2	18.2	18.8	19.4	19.1	19.0
Ruvubu11	53.17	18.6	18.7	19.0	19.4	19.7	19.6	18.7	17.7	17.7	18.3	18.9	18.6	18.5
Ruvubu12	5.59	18.6	18.7	19.0	19.4	19.7	19.6	18.7	17.7	17.7	18.3	18.9	18.6	18.5
Mubarazi	926.6	17.2	17.4	17.6	18.0	18.3	18.2	17.3	16.4	16.4	17.0	17.5	17.3	17.2
Ruvubu13	159.5	18.3	18.4	18.7	19.0	19.4	19.3	18.4	17.4	17.4	18.0	18.5	18.3	18.2
Ndurumu	779.7	19.2	19.4	19.7	20.0	20.4	20.3	19.3	18.3	18.3	18.9	19.5	19.3	19.2
Ruvubu14	69.47	18.5	18.6	18.9	19.2	19.6	19.5	18.5	17.5	17.6	18.2	18.7	18.5	18.4
Ruvyironza	2048	18.2	18.3	18.6	18.9	19.3	19.2	18.3	17.3	17.3	17.9	18.4	18.2	18.1
Ruvubu15	2.72	18.4	18.5	18.8	19.1	19.5	19.4	18.5	17.5	17.5	18.1	18.6	18.4	18.3
Ruvubu16	1.74	18.8	18.9	19.2	19.6	19.9	19.8	18.9	17.9	17.9	18.5	19.1	18.8	18.7
Mutwenzi	67.48	18.4	18.5	18.8	19.1	19.5	19.4	18.5	17.5	17.5	18.1	18.6	18.4	18.3
Ruvubu17	72.63	18.4	18.5	18.8	19.2	19.5	19.4	18.5	17.5	17.5	18.1	18.6	18.4	18.3
Nyabaha	940	19.0	19.1	19.4	19.8	20.1	20.0	19.1	18.0	18.1	18.7	19.3	19.0	18.9
Ruvubu18	41.41	18.5	18.6	18.9	19.2	19.6	19.5	18.6	17.6	17.6	18.2	18.7	18.5	18.4
Nyabizi	172.6	19.7	19.9	20.2	20.5	20.9	20.8	19.8	18.7	18.8	19.4	20.0	19.8	19.6
Ruvubu19	86.13	18.5	18.7	18.9	19.3	19.6	19.6	18.6	17.6	17.7	18.2	18.8	18.6	18.4
Nyakigezi	86.22	19.2	19.4	19.7	20.0	20.4	20.3	19.3	18.3	18.3	18.9	19.5	19.3	19.2
Ruvubu20	5.27	18.5	18.7	18.9	19.3	19.6	19.6	18.6	17.6	17.7	18.2	18.8	18.6	18.5
Nyambiga	31.05	19.5	19.6	19.9	20.3	20.7	20.6	19.6	18.5	18.6	19.2	19.8	19.5	19.4
Ruvubu21	53.02	18.6	18.7	19.0	19.3	19.7	19.6	18.6	17.6	17.7	18.3	18.8	18.6	18.5
Kayongozi	818.6	19.5	19.6	19.9	20.3	20.7	20.6	19.6	18.5	18.6	19.2	19.7	19.5	19.4
Ruvubu22	109.2	18.7	18.8	19.1	19.4	19.8	19.7	18.7	17.7	17.8	18.4	18.9	18.7	18.6
Nyagisuma	192.2	19.3	19.4	19.7	20.1	20.4	20.3	19.3	18.3	18.4	18.9	19.5	19.3	19.2
Ruvubu23	141	18.7	18.8	19.1	19.5	19.8	19.7	18.8	17.8	17.8	18.4	18.9	18.7	18.6
Nyamigina	48.98	20.1	20.2	20.5	20.9	21.3	21.2	20.2	19.1	19.1	19.7	20.3	20.1	20.0
Ruvubu24	106.4	18.7	18.9	19.1	19.5	19.8	19.8	18.8	17.8	17.8	18.4	19.0	18.7	18.6
Nyongera	59.44	20.3	20.4	20.7	21.1	21.5	21.4	20.4	19.3	19.3	20.0	20.6	20.3	20.2
Ruvubu25	0.57	18.7	18.9	19.1	19.5	19.8	19.8	18.8	17.8	17.8	18.4	19.0	18.7	18.6
Ruvubu26	18.7	18.7	18.9	19.1	19.5	19.9	19.8	18.8	17.8	17.9	18.4	19.0	18.8	18.6
Cigazure	70.55	20.1	20.2	20.5	20.9	21.3	21.2	20.2	19.1	19.1	19.8	20.4	20.1	20.0
Ruvubu27	38.47	18.8	18.9	19.2	19.6	19.9	19.8	18.9	17.9	17.9	18.5	19.0	18.8	18.7
Kavuruga	245.9	20.0	20.2	20.4	20.8	21.2	21.1	20.1	19.0	19.1	19.7	20.3	20.0	19.9
Ruvubu28	133.7	18.9	19.0	19.3	19.6	20.0	19.9	18.9	17.9	18.0	18.6	19.1	18.9	18.8
Cizanye	310.4	19.8	19.9	20.2	20.6	21.0	20.9	19.9	18.8	18.9	19.5	20.1	19.8	19.7

Appendix 5: Potential Evapotranspiration per Basin

Basin Name	Basin area	Ann. ETP	ETP1	ETP2	ETP3	ETP4	ETP5	ETP6	ETP7	ETP8	ETP9	ETP10	ETP11	ETP12
Ruvubu	10063	1364.9	105.7	99.7	110.9	96.4	106.0	118.3	136.6	142.7	131.0	123.5	96.2	97.9
Ruvubu1	129.71	1274.2	98.6	93.1	103.5	90.0	99.0	110.4	127.5	133.2	122.2	115.3	89.8	91.4
Nyakabindi	32.09	1243.3	96.2	90.8	101.0	87.8	96.6	107.8	124.4	130.0	119.3	112.5	87.6	89.2
Ruvubu2	6.49	1272.0	98.5	92.9	103.4	89.8	98.8	110.2	127.3	133.0	122.0	115.1	89.7	91.3
Nyamisesera	98.11	1295.1	100.3	94.6	105.2	91.5	100.6	112.3	129.6	135.4	124.3	117.2	91.3	92.9
Ruvubu3	22.99	1285.6	99.5	93.9	104.5	90.8	99.9	111.4	128.6	134.4	123.3	116.3	90.6	92.2
Kinyangona	119.38	1342.9	103.9	98.1	109.1	94.8	104.3	116.4	134.4	140.4	128.8	121.5	94.7	96.4
Ruvubu4	17.41	1304.7	101.0	95.3	106.0	92.1	101.4	113.1	130.5	136.4	125.2	118.1	92.0	93.6
Ruvubu5	66.95	1311.7	101.5	95.8	106.6	92.6	101.9	113.7	131.2	137.2	125.8	118.7	92.5	94.1
Nkokoma	341.22	1289.6	99.8	94.2	104.8	91.1	100.2	111.8	129.0	134.9	123.7	116.7	90.9	92.5
Ruvubu6	7.63	1304.0	100.9	95.3	106.0	92.1	101.3	113.0	130.5	136.4	125.1	118.0	91.9	93.6
Kawalembe	45.26	1372.3	106.2	100.2	111.5	96.9	106.6	118.9	137.3	143.5	131.7	124.2	96.7	98.5
Ruvubu7	35.77	1311.3	101.5	95.8	106.6	92.6	101.9	113.7	131.2	137.1	125.8	118.7	92.4	94.1
Nyarubanda	84.23	1361.3	105.4	99.4	110.6	96.1	105.8	118.0	136.2	142.4	130.6	123.2	96.0	97.7
Ruvubu8	14.86	1316.8	101.9	96.2	107.0	93.0	102.3	114.1	131.8	137.7	126.3	119.2	92.8	94.5
Kagoma	80.4	1361.3	105.4	99.4	110.6	96.1	105.8	118.0	136.2	142.4	130.6	123.2	96.0	97.7
Ruvubu9	1.18	1320.1	102.2	96.4	107.3	93.2	102.6	114.4	132.1	138.1	126.7	119.5	93.1	94.7
Ruvubu10	3.33	1320.5	102.2	96.5	107.3	93.3	102.6	114.5	132.1	138.1	126.7	119.5	93.1	94.8
Kinyankuru	1060.5	1378.9	106.7	100.7	112.0	97.4	107.1	119.5	138.0	144.2	132.3	124.8	97.2	98.9
Ruvubu11	53.17	1350.6	104.5	98.7	109.7	95.4	104.9	117.1	135.1	141.2	129.6	122.2	95.2	96.9
Ruvubu12	5.59	1350.6	104.5	98.7	109.7	95.4	104.9	117.1	135.1	141.2	129.6	122.2	95.2	96.9
Mubarazi	926.6	1272.7	98.5	93.0	103.4	89.9	98.9	110.3	127.3	133.1	122.1	115.2	89.7	91.3
Ruvubu13	159.51	1331.5	103.1	97.3	108.2	94.0	103.4	115.4	133.2	139.2	127.7	120.5	93.9	95.5
Ndurumu	779.71	1386.3	107.3	101.3	112.6	97.9	107.7	120.2	138.7	145.0	133.0	125.4	97.7	99.5
Ruvubu14	69.47	1342.5	103.9	98.1	109.1	94.8	104.3	116.4	134.3	140.4	128.8	121.5	94.6	96.3
Ruvyironza	2047.7	1326.7	102.7	96.9	107.8	93.7	103.1	115.0	132.7	138.7	127.3	120.1	93.5	95.2
Ruvubu15	2.72	1337.4	103.5	97.7	108.7	94.5	103.9	115.9	133.8	139.9	128.3	121.0	94.3	96.0
Ruvubu16	1.74	1361.3	105.4	99.4	110.6	96.1	105.8	118.0	136.2	142.4	130.6	123.2	96.0	97.7
Mutwenzi	67.48	1337.8	103.5	97.7	108.7	94.5	103.9	115.9	133.8	139.9	128.3	121.0	94.3	96.0
Ruvubu17	72.63	1338.5	103.6	97.8	108.8	94.5	104.0	116.0	133.9	140.0	128.4	121.1	94.3	96.0
Nyabaha	939.95	1372.7	106.3	100.3	111.5	96.9	106.6	119.0	137.3	143.5	131.7	124.2	96.8	98.5
Ruvubu18	41.41	1343.3	104.0	98.1	109.1	94.9	104.4	116.4	134.4	140.5	128.9	121.5	94.7	96.4
Nyabizi	172.63	1414.2	109.5	103.3	114.9	99.9	109.9	122.6	141.5	147.9	135.7	128.0	99.7	101.5
Ruvubu19	86.13	1345.8	104.2	98.3	109.4	95.1	104.6	116.7	134.7	140.7	129.1	121.8	94.9	96.6
Nyakigezi	86.22	1387.0	107.4	101.3	112.7	98.0	107.8	120.2	138.8	145.0	133.1	125.5	97.8	99.5
Ruvubu20	5.27	1346.2	104.2	98.3	109.4	95.1	104.6	116.7	134.7	140.8	129.2	121.8	94.9	96.6
Nyambiga	31.05	1401.7	108.5	102.4	113.9	99.0	108.9	121.5	140.2	146.6	134.5	126.8	98.8	100.6
Ruvubu21	53.02	1347.3	104.3	98.4	109.5	95.2	104.7	116.8	134.8	140.9	129.3	121.9	95.0	96.7
Kayongozi	818.6	1400.2	108.4	102.3	113.8	98.9	108.8	121.4	140.1	146.4	134.3	126.7	98.7	100.5
Ruvubu22	109.16	1353.2	104.7	98.8	110.0	95.6	105.1	117.3	135.4	141.5	129.8	122.4	95.4	97.1
Nyagisuma	192.2	1387.4	107.4	101.3	112.7	98.0	107.8	120.2	138.8	145.1	133.1	125.5	97.8	99.6
Ruvubu23	140.97	1355.0	104.9	99.0	110.1	95.7	105.3	117.4	135.6	141.7	130.0	122.6	95.5	97.2
Nyamigina	48.98	1433.3	110.9	104.7	116.5	101.2	111.4	124.2	143.4	149.9	137.5	129.7	101.0	102.8
Ruvubu24	106.37	1356.5	105.0	99.1	110.2	95.8	105.4	117.6	135.7	141.9	130.1	122.7	95.6	97.3
Nyongera	59.44	1445.8	111.9	105.6	117.5	102.1	112.3	125.3	144.7	151.2	138.7	130.8	101.9	103.7
Ruvubu25	0.57	1356.9	105.0	99.1	110.3	95.8	105.4	117.6	135.8	141.9	130.2	122.8	95.6	97.4
Ruvubu26	18.7	1357.2	105.1	99.1	110.3	95.9	105.4	117.6	135.8	141.9	130.2	122.8	95.7	97.4
Cigazure	70.55	1434.7	111.1	104.8	116.6	101.3	111.5	124.4	143.6	150.0	137.6	129.8	101.1	103.0
Ruvubu27	38.47	1360.9	105.3	99.4	110.6	96.1	105.7	118.0	136.2	142.3	130.6	123.1	95.9	97.7
Kavuruga	245.87	1430.0	110.7	104.5	116.2	101.0	111.1	123.9	143.1	149.5	137.2	129.4	100.8	102.6
Ruvubu28	133.65	1364.6	105.6	99.7	110.9	96.4	106.0	118.3	136.5	142.7	130.9	123.5	96.2	97.9
Cizanye	310.4	1417.5	109.7	103.5	115.2	100.1	110.1	122.9	141.8	148.2	136.0	128.3	99.9	101.7

Appendix B.1: Hydrogical Station in Ruvubu basin

N0	Station ID (IGEBU)	National Station ID	Station site name	Long	Lat	HFBase Point	HFStart Date	HFRiver
1	11031	21000	RUVUBU (MUYINGA)	30.5	-3.0	1350	09-Jul-74	RUVUBU
2	11032	21030	RUVUBU (KANABUSORO)	29.7	-3.0	1580	01-Sep-79	RUVUBU
3	11033	21070	RUVUBU (BURASIRA)	29.7	-3.1	1513	01-Jan-82	RUVUBU
4	11034	21080	NYAMUSWAGA (GISHA)	29.9	-2.9	1550	01-Sep-89	NYAMUSWAGA
5	11035	21090	MUBARAZI (MURONGWE)	29.9	-3.2	1486	01-Sep-76	MUBARAZI
6	11036	21091	KANIGA (DISPENSAIRE)	29.8	-3.3	1570	24-Feb-75	KANIGA
7	11037	21100	RUVUBU (GITONGO)	29.9	-3.2	1489	01-Feb-75	RUVUBU
8	11038	21101	RUVUBU (GITEGA)	30.0	-3.4	1402	20-Jul-73	RUVUBU
9	11039	21110	NDURUMU (SHOMBO)	30.0	-3.2	1448	03-May-74	NDURUMU
10	11040	21120	RUVYIRONZA (MUYANGE)	29.8	-3.5	1565	01-Sep-85	RUVYIRONZA
11	11041	21121	WAGA (MUYANGE)	29.8	-3.5	1575		WAGA
12	11042	21122	RUVYIRONZA (KIBAYA)	29.9	-3.3	1482	08-May-74	RUVYIRONZA
13	11043	21123	RUVYIRONZA (NYABIRABA)	29.9	-3.5	1578	22-Oct-88	RUVYIRONZA
14	11044	21130	NYABAHA (MUBUGA)	30.1	-3.4	1393	23-Jul-73	NYABAHA
15	11045	21132	NYAKIJANDA (BUHORO K10)	30.1	-3.5	1518	16-Jul-73	NYAKIJANDA
16	11046	21133	NYAKIJANDA (BUHORO K10)	30.1	-3.6	1556	06-Jun-74	NYAKIJANDA
17	11047	21140	KAYONGOZI (NYANKANDA)	30.3	-3.3	1458	07-May-74	KAYONGOZI

Appendix B.2:Mean Minimum Discharge (m3/sec)

No1. Ruvubu-bac (Muyinga) Station: X= 550, Y= 9670, Altitude = 1338 m, Area = 9295.8 km²													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Ann disch**
1980	68.4	66.5	70.0	70.0	72.4	52.1	43.1	38.1	35.9	35.0	51.1	64.9	**667.4**
1981	72.0	69.6	75.2	112.9	93.0	60.8	50.1	45.7	44.7	44.1	45.7	53.9	**767.4**
1982	70.4	72.5	76.2	85.9	131.1	77.5	57.1	46.5	41.9	41.9	69.6	130.6	**901.1**
1983	85.5	83.8	94.4	82.1	100.5	66.3	49.6	46.5	44.2	56.4	55.2	74.4	**838.8**
1984	96.0	102.0	86.8	91.8	62.1	48.5	45.0	37.9	31.5	43.4	42.6	60.2	**747.8**
1985	54.3	109.6	77.7	151.1	112.2	80.1	61.7	50.8	50.8	48.4	60.5	70.6	**927.6**
1986	94.5	100.7	114.3	121.5	160.4	90.1		58.8	54.4	58.4	68.8	108.8	**1030.7**
1987	111.6	146.9	130.7	112.5	120.5	79.0	62.6						**763.8**
1988										67.4	85.7	88.2	**241.2**
1989	144.2	151.4	143.4	196.5	157.4	116.0	89.6	75.8					**1074.3**
1990													
Mean Monthly	**88.5**	**100.3**	**96.5**	**113.8**	**112.2**	**74.5**	**57.3**	**50.0**	**43.3**	**49.4**	**59.9**	**81.4**	**927.2**

No2. Ruvubu kanabusoro Stat: X= 468, Y= 9665, Altitude = 1585 m, Area = 426.2 km²													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	2.7	3.6	3.1	4.0	4.3	3.3	2.8	2.5	2.3	2.1	4.2	4.0	**38.8**
1981									2.5	2.5	2.8	2.8	**10.7**
1982	2.9	2.9	3.0	5.1	6.0	4.6	4.0	3.3	3.2	3.3	3.9	5.4	**47.7**
1983	4.2	4.1	4.4	4.9	5.5	4.3	3.8	3.4	2.9	3.2	3.4	4.5	**48.5**
1984	4.7	3.5	5.0	5.4	3.6	2.6	2.4	1.9	1.7	2.0	2.5	3.3	**38.4**
1985	3.5	5.5	4.5	9.0	6.3	5.1	3.9	3.4	3.4	3.0	4.0	4.7	**56.2**
1986	4.4	4.7	5.5	7.6	6.9	4.8	4.1	3.5	3.2	3.7	6.1	4.9	**59.4**
1987	5.1	4.4	4.7	4.7	5.3	4.2	3.5	3.1	3.0	3.1	3.4	3.5	**47.9**
1988	4.4	4.9	4.6	7.5	5.7	4.6	4.0	3.9	3.6	3.6	4.5	4.9	**56.1**
1989	5.7	5.4	5.1	6.0	6.4	5.5	4.7	4.0	3.8	4.0	4.1	4.5	**59.2**
1990	3.9	4.5	6.4	5.6	4.9	4.0	3.5	2.5					**35.2**
Mean Monthly	**4.1**	**4.3**	**4.6**	**6.0**	**5.5**	**4.3**	**3.7**	**3.1**	**3.0**	**3.0**	**3.9**	**4.2**	**45.3**

No3. Ruvubu Burasira Station: X= 490, Y= 9659, Altitude = 1513 m, Area = 1103.7 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	7.8	9.2	8.9	9.1	9.5	7.5	6.4	5.7	5.5	5.8	14.3	12.9	**102.6**
1981	8.8	8.1	12.5	10.2	7.9	7.1	5.7	5.5	6.2	6.5	7.2	7.2	**92.7**
1982	7.2	6.2	7.3	11.7	11.2	8.2	6.6	5.1	5.5	5.8			**75.0**
1983		7.3	9.0	8.7	10.4	7.5	6.1	5.4	4.5	5.5	7.0	8.8	**80.2**
1984	10.4	7.3	8.7	10.1	6.5	5.1	4.9	4.6	3.4	4.6	5.6	7.2	**78.4**
1985	7.0	9.1	6.2	18.5	10.6	8.5	6.6	5.5					**72.0**
1986									6.0	6.1	14.8	10.8	**37.7**
1987	11.5	8.9	11.0	10.9	11.6	8.8	7.3	6.4	6.8	6.9	9.0	8.0	**107.0**
1988	8.3	11.8	11.5	17.0	12.6	9.8	8.6	8.0	7.5	8.8	13.1	12.0	**129.0**
1989	12.8	12.9	11.4	14.2	14.1	11.8	10.7	9.6	8.4	8.7	8.9	10.7	**134.2**
1990	8.3	9.9	16.8	15.0	11.1	8.4	7.8	6.6					**83.9**
Mean Monthly	**9.1**	**9.1**	**10.3**	**12.5**	**10.6**	**8.3**	**7.1**	**6.2**	**6.0**	**6.5**	**10.0**	**9.7**	**105.4**

No4. Mubarazi-Murongwe Stat: X= 488, Y= 9647, Altitude = 1495 m, Area = 908.4 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	7.3	7.7	8.7	8.3	9.5	6.9	5.6	4.9	4.6	4.5	5.7	8.3	**81.8**
1981	11.4	11.2	11.2	16.3	14.7	10.1			6.9	7.4	7.2	6.9	**103.2**
1982	8.7	10.0	9.9	18.5	17.3	12.0	9.6	7.8	6.9	7.1	9.6	12.6	**129.9**
1983	9.7	9.3	10.7	10.7	11.5	9.2	5.8	5.1	3.6	5.3	5.2	6.1	**92.1**
1984	7.3	9.4	6.9	7.8	5.3	4.5	4.1	3.6	2.6	3.5	3.2	6.2	**64.3**
1985	5.1	7.3	6.7	22.3	10.8	7.7	5.8	4.9	4.7	4.1	5.3	5.7	**90.2**
1986	8.7	5.9	10.0	9.6	12.8	8.7	6.6	5.2	5.0	5.1	12.0	10.9	**100.5**
1987	12.7	15.6	14.9	13.2	13.3	11.1	8.8	7.5	7.4	7.5	8.2	10.4	**130.4**
1988	10.6	12.7	12.7	17.2	15.2	12.2	7.2	6.5	4.3	7.1	8.1	9.8	**123.5**
1989	11.0	17.1	14.3	20.7	17.4	12.0	8.4	7.8	7.2	6.4	7.6	12.0	**141.9**
1990	9.4	12.4	17.2	14.8	12.7	9.4	8.0	6.4					**90.2**
Mean Monthly	**9.3**	**10.8**	**11.2**	**14.5**	**12.8**	**9.4**	**7.0**	**6.0**	**5.3**	**5.8**	**7.2**	**8.9**	**104.4**

No5. Kaniga Dispensaire Station: X= 476, Y= 9636, Altitude = 1585 m, Area = 206.4 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	1.6	1.5	1.7	2.1	2.0	1.6	1.4	1.2	1.2	1.2	1.9	2.1	**19.5**
1981	2.5	2.1	2.4	2.9	2.6	2.0	1.5	1.5	1.5	1.5	1.5	1.6	**23.6**
1982	2.1	2.5	2.2	4.1	3.9	3.0	2.4	1.9	1.8	1.8	2.1	2.9	**30.7**
1983	2.5	2.2	2.4	2.2	2.7	2.1	1.7	1.4	1.4	1.6	1.9	2.1	**24.2**
1984	2.4	3.0	2.4	2.5	1.9	1.7	1.7	1.6	1.1	1.5	1.4	2.0	**23.1**
1985	1.8	2.6	2.5	6.5	3.7	3.0	2.4	2.1	1.7	2.5	2.2	2.0	**33.0**
1986	2.5	2.5	2.9	3.4	3.6	2.5	2.0	1.6	1.6	1.9	3.6	3.7	**31.6**
1987	3.9	4.4	3.5	3.1	3.0	2.5	2.0	1.8	1.7	1.6	1.8	2.0	**31.2**
1988	1.8	2.7	2.7	4.4	3.5	2.8	2.4	2.1	2.0	2.2	2.5	2.7	**31.7**
1989	3.0	6.0	4.1										**13.1**
1990													
Mean Monthly	**2.4**	**3.0**	**2.7**	**3.5**	**3.0**	**2.3**	**1.9**	**1.7**	**1.5**	**1.7**	**2.1**	**2.3**	**26.2**

No6. Ruvubu Gitongo Stat: X= 489, Y= 9650, Altitude = 1485 m, Area = 2220.7 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	26.4	21.0	16.5	19.6	11.2	14.3	12.1	10.9	10.7	10.7	15.8	24.1	**193.1**
1981	22.6	15.8	17.7	21.9	22.2	15.3	12.9	12.6	12.9	14.8	17.0	18.9	**204.4**
1982	16.6	18.8	22.2	22.4	23.3	15.6	14.3	13.5	12.4	16.6	16.6	22.6	**214.7**
1983													
1984	20.4	20.6	17.6	16.3	13.5	12.1	11.6	10.5	11.1	13.5	18.8	22.2	**188.2**
1985	22.4	24.5	17.3	29.2	22.6	18.0	12.7	11.4	12.2	17.3	24.2	21.4	**233.3**
1986	19.6	22.1			58.4	19.2	17.5	14.1	13.3	13.6	28.6	22.4	**228.8**
1987	22.9	20.3	22.8	22.3	26.0	17.4	14.3	12.4	12.2	17.5	17.9	20.9	**226.8**
1988	21.8	23.0	24.6	28.9	28.1	20.2	17.7	15.3	15.5	16.7	26.8	24.9	**263.5**
1989	23.9	24.8	23.0	23.5	26.0	22.0	18.3	15.5	14.9	17.3	23.0	24.6	**256.8**
1990	24.5	26.9	25.0	24.6	23.7	15.8	13.2	12.2					**165.8**
Mean Monthly	**22.1**	**21.8**	**20.7**	**23.2**	**25.5**	**17.0**	**14.5**	**12.8**	**12.8**	**15.3**	**20.9**	**22.4**	**217.5**

No7. Ruvubu Gitega Station: X= 498, Y= 9630, Altitude = 1408 m, Area = 6212 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	47.2	44.7	50.7	49.8	51.5	34.7	26.7	22.8	20.5	19.7	38.0	46.4	**452.6**
1981	48.9	51.5	55.9	79.4	65.7	42.1	35.5	31.4	30.6	29.8	33.0	34.7	**538.6**
1982	48.8	50.9	54.3	71.5	83.2	50.9	41.1	31.7	27.9	29.4	50.1	75.1	**614.9**
1983	53.4	49.3	57.7	54.3	61.1	41.9	34.8	30.2	25.6	28.5	37.8	52.0	**526.3**
1984	67.0	65.2	52.8	60.7	41.1	31.6	30.0	25.6	19.3	27.1	27.0	41.2	**488.6**
1985	41.1	61.1	54.4	132.1	71.9	52.6	41.9	32.4	32.8	34.0	44.2	66.2	**664.7**
1986	66.0	63.4	73.6	81.4	92.8	61.1	47.6	37.9	35.7	37.3	73.9	65.9	**736.6**
1987	85.8	87.4	74.8	69.5	75.2	49.3	38.7	32.4	31.6	37.8	45.2	46.0	**673.5**
1988	46.0	67.9	65.2	102.6	80.1	59.8	51.1	41.1	41.1	43.5	70.7	59.8	**728.8**
1989	93.6	92.6	77.2	119.0	105.6								**488.1**
1990													
Mean Monthly	**59.8**	**63.4**	**61.7**	**82.0**	**72.8**	**47.1**	**38.6**	**31.7**	**29.4**	**31.9**	**46.7**	**54.1**	**591.3**

No8.Ruvyironza-Kibaya Stat: X= 491, Y= 9633, Altitude = 1470 m, Area = 1978.4 km2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	16.7	15.6	17.0	16.0	17.0	13.4	10.6	9.1	8.5	8.1	9.8	12.9	**154.6**
1981	15.1	17.7	17.4	23.0	16.3	13.8	11.9	9.8	9.1	9.1	9.5	9.7	**162.4**
1982									10.0	9.3	15.7	31.2	**66.1**
1983	21.7	21.1	22.5	19.1	20.4	15.6	12.5	10.2	9.4	9.8	12.6	15.6	**190.5**
1984	20.3	27.2	22.7	24.6	17.2	13.3	11.9	9.6	8.0	9.0	9.0	13.5	**186.3**
1985	13.3	19.4	19.3	50.4	26.9	18.8	14.7	12.8	12.4	11.3	13.5	17.2	**230.1**
1986	22.5	24.7	26.0	25.9	31.5	19.8	16.3	12.7	12.4	12.0	21.7	23.6	**249.1**
1987	27.5	31.7	24.1	21.5	21.0	15.5	13.0	10.8	10.6	11.6	13.1	12.9	**213.2**
1988	13.1	22.9	20.5	28.8	22.8	17.0	14.8	13.1	11.2	12.6	12.6	14.4	**203.7**
1989	28.3	27.5	24.8	45.7	30.9	22.7	17.8	15.2	13.9	13.6	13.5	20.0	**273.9**
1990	16.3	17.9	37.6	29.7	23.7	17.9	14.8	12.3					**170.2**

No9. Nyabaha-Mubuga Station: X= 506, Y= 9625, Altitude = 1400 m, Area = 933.4 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	4.9	5.5	6.4	5.8	6.8	5.5	4.1	3.6	3.1	2.8	3.5	4.9	**56.9**
1981	4.5	4.4	4.5	8.8	8.8	6.4	4.7	3.6	4.0	3.3	2.8	3.9	**59.6**
1982									3.8	4.2	5.5	16.1	**29.5**
1983	11.9	11.4	8.5	7.5	10.8	7.7	5.0	4.4	3.4	4.2	4.5	6.3	**85.5**
1984	7.1	9.5	8.2	7.7					3.9	3.6	3.7	5.8	**49.3**
1985	5.4	7.8	8.0	21.0	11.8	8.8	6.2						**69.0**
1986													**0.0**
1987									3.3	3.3	3.2	3.5	**13.2**
1988	3.3	5.5	5.3	9.0	10.1	5.5	4.3	4.0	3.6	3.4	3.8	4.1	**61.7**
1989	6.8	11.2	9.6	21.2	12.9	7.7	5.6	4.8	4.4	4.2	3.8	5.0	**97.0**
1990	5.0	5.2	12.5	9.9	6.3	5.7	4.9	4.3					**53.8**
Mean Monthly	**6.1**	**7.5**	**7.9**	**11.3**	**9.7**	**6.7**	**5.0**	**4.1**	**3.7**	**3.6**	**3.8**	**6.2**	**52.3**

No10.Nyakijanda-Buhinda Stat: X= 511, Y= 9603, Altitude = 1608 m, Area = 216.8 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	1.1	1.2	1.6	1.4	1.8	1.5	1.2	0.8	0.8	0.7	0.8	0.9	**13.8**
1981	1.0	1.2	1.2	3.2	2.8	1.9	1.6	1.2	1.1	1.0	0.8	1.1	**18.0**
1982	1.1	1.5	1.3	1.8	3.6	2.1	1.5	1.2	1.1	1.0	1.2	4.3	**21.7**
1983	2.4	2.2	2.1	2.0	2.7	1.9	1.5	1.3	1.0	1.0	0.9	1.0	**19.9**
1984	1.4	2.3	2.1	2.2	1.9	1.5	1.3	1.1					**13.8**
1985									1.7	1.5	1.6	1.6	**6.4**
1986	2.0	2.1	2.0	2.3	4.3	2.5	2.1	1.7	1.5	1.4	2.0	2.2	**26.0**
1987	2.8	3.5	2.7	2.5	2.5	2.0	1.7	1.5	1.3	1.2	1.2	1.1	**24.0**
1988	1.1	1.8	1.7	3.2	3.0	2.2	1.9	1.7	1.4	1.3	1.2	1.2	**21.9**
1989	2.3	3.0	2.5	7.3	4.4	3.0	2.3	2.0	1.7	1.7	1.4	1.8	**33.3**
1990	1.8	1.8	3.6	3.2	2.5	2.0	1.8	1.5					**18.3**
Mean Monthly	**1.7**	**2.1**	**2.1**	**2.9**	**2.9**	**2.1**	**1.7**	**1.4**	**1.3**	**1.2**	**1.2**	**1.7**	**19.7**

No11. Kayongozi-Nyankanda Station: X= 536, Y= 9637, Altitude = 1498 m, Area = 682 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	4.8	3.5	3.1	3.1	3.1	2.2	1.8	1.5	1.4	1.5	1.6	3.2	**30.6**
1981	2.9	2.8	3.7	5.4	5.2	3.0	2.3	1.9	1.7	1.9	2.0	3.1	**35.9**
1982	4.3	3.3	3.4	3.6	6.2	3.6	2.7	2.0	1.7	1.7	3.5	5.0	**40.9**
1983	4.7	4.5	5.7	5.2	6.5	3.8	2.9	2.5	2.2	2.3	3.0	4.1	**47.1**
1984	5.9	5.1	3.6	5.0	2.9	2.3	2.2	1.8	1.4	1.8	1.7	3.0	**36.5**
1985	3.0	4.8	3.7	9.4	5.1	3.5	2.4	2.4	2.3	2.4	2.5	4.0	**45.3**
1986	5.7	7.0	6.5	6.4	9.2	5.4	4.2	3.3	2.9	2.7	5.2	9.7	**68.2**
1987	9.5	9.5	7.0	6.4	5.8	4.1	3.3	2.9	2.7	2.6	2.8	3.6	**60.3**
1988	3.5	6.1	4.9	8.9	8.5	5.3	4.3	3.9	3.2	3.6	4.5	4.3	**61.0**
1989	10.1	10.7	10.4	11.4	8.6	6.1	4.7	4.1	3.9	3.6	3.9	5.7	**83.2**
1990	4.5	5.1	11.7	11.0	7.1	5.1	4.1	3.5					**52.1**
Mean Monthly	**5.3**	**5.7**	**5.8**	**6.9**	**6.2**	**4.0**	**3.2**	**2.7**	**2.3**	**2.4**	**3.1**	**4.6**	**51.0**

No12. Kavuruga-Kayenzi Stat: X= 543, Y= 9680, Altitude = 1360 m, Area = 185.1 km^2													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual disch**
1980	0.7	0.7	0.9	1.0	0.9	0.6	0.4	0.4	0.3	0.4	0.7	0.9	**7.8**
1981	0.9	0.8	0.8	1.8	1.3	0.7	0.6	0.5	0.6	0.5	0.5	0.7	**9.4**
1982	0.7	0.5	0.5	0.5	0.9								**3.1**
1983													
1984													
1985													
1986													
1987													
1988													
1989													
1990													
Mean Monthly	**0.8**	**0.6**	**0.7**	**1.1**	**1.0**	**0.6**	**0.5**	**0.4**	**0.4**	**0.4**	**0.6**	**0.8**	**6.8**

Appendix B3: Minimum available discharge per rivers for Dry year in Ruvubu

Station code	River name	Min. ann.disch m3/sec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
21000	Ruvubu25	54.70	60.06	58.38	69.73	74.50	70.69	55.67	46.56	40.61	37.34	39.85	43.74	59.34
21030	Ruvubu4	1.89	2.86	3.42	3.12	4.44	4.20	3.22	2.78	2.44	2.28	2.09	2.83	3.14
21070	Ruvubu9	4.00	7.07	5.98	6.27	8.56	6.56	5.17	4.61	4.68	4.46	4.72	5.69	7.20
21090	Mubarazi	3.77	6.77	6.70	7.12	8.18	7.73	6.14	5.18	4.48	3.81	4.23	4.85	5.95
21091	Kaniga	1.05	1.65	1.48	1.78	1.90	1.72	1.62	1.30	1.16	1.12	1.17	1.30	1.62
21100	Ruvubu11	9.59	15.26	13.91	15.21	18.17	15.16	12.72	11.28	10.51	10.20	11.00	12.85	16.60
21101	Ruvubu15	22.65	41.03	41.29	49.81	54.64	50.02	34.77	29.53	25.69	23.03	26.90	29.13	39.17
21110	Ndurumu2	2.26	4.71	4.55	5.19	6.14	5.11	3.75	3.18	2.48	2.32	2.44	2.80	4.91
21120	Ruvyironza7	12.70	17.74	20.98	24.88	25.13	23.38	18.79	15.19	12.03	12.89	12.77	14.00	17.27
21121	Waga	5.95	8.24	9.62	11.89	12.40	11.40	8.89	7.27	6.16	6.01	6.22	6.60	7.85
21122	Ruvyironza10	8.09	12.51	12.80	17.30	13.99	16.53	12.91	10.39	8.97	8.09	8.64	8.75	11.06
21130	Nyabaha	2.08	4.19	4.52	4.67	6.12	6.36	4.37	4.16	3.46	3.06	2.54	2.88	3.38
21132	Nyakijanda	0.59	0.93	1.01	1.25	1.35	1.72	1.26	1.04	0.79	0.70	0.63	0.61	0.82
21140	Kayongozi3	1.41	2.95	2.83	3.25	3.88	3.21	2.33	1.98	1.55	1.46	1.50	1.76	3.03
21160	Kavuruga1	0.31	0.67	0.50	0.57	0.62	0.91	0.60	0.38	0.36	0.32	0.37	0.47	0.69
21170	Cizanye	0.81	1.05	1.03	1.22	1.41	1.28	0.97	0.80	0.72	0.64	0.72	0.76	1.08
21080	Nyamuswaga	1.95	3.05	2.59	3.09	3.28	2.65	2.39	2.13	1.97	1.96	2.25	2.47	3.40
21123	Ruvyironza4	2.90	4.45	4.49	6.20	5.02	5.90	4.57	3.69	3.20	2.90	3.10	3.11	3.92
21133	Nyakijanda	0.81	1.35	1.43	1.79	1.94	2.37	1.73	1.44	1.13	1.02	0.88	0.90	1.10
21220	Ruvubu13	13.88	22.70	21.19	23.27	27.22	23.58	19.54	17.01	15.49	14.59	15.87	18.29	23.42
21240	Ruvubu14	16.32	27.75	26.09	28.88	33.81	29.10	23.58	20.41	18.18	17.09	18.53	21.33	28.65
21310	Ruvubu18	27.62	45.92	44.62	53.54	55.69	54.22	43.15	36.05	31.58	29.22	30.85	34.01	44.78
21320	Nyabizi	0.50	0.80	0.78	0.93	1.07	0.96	0.74	0.61	0.54	0.48	0.54	0.53	0.82
21340	Nyakigezi	0.24	0.39	0.38	0.45	0.52	0.47	0.36	0.30	0.27	0.24	0.27	0.23	0.40
21360	Nyambiga	0.09	0.14	0.14	0.17	0.19	0.17	0.13	0.11	0.10	0.09	0.10	0.10	0.15
21370	Ruvubu21	28.89	47.95	46.60	55.91	58.41	56.66	45.02	37.60	32.97	30.45	32.24	35.43	46.87
21390	Ruvubu22	30.98	51.98	50.50	60.40	63.69	61.13	48.35	40.42	35.28	32.55	34.50	38.00	51.04

Appendix.C.1: Population number of Burundi

	Year 1995			Year 2000			Projected Year 2010		
Province name	Population number	Pop.density (inhab/km2)	Growth rate (%)	Population number	Pop.density (inhab/km2)	Growth rate (%)	Population number	Pop.density (inhab/km2)	Growth rate (%)
Muyinga	422025	239	2.58	481706	271	2.58	602568	339	2.26
Kirundo	498869	281	4.53	624319	350	4.52	791170	444	2.40
Cibitoke	321056	207	2.84	370161	238	2.84	469894	302	2.41
Ngozi	523526	377	1.70	570823	410	1.70	669753	481	1.61
Kayanza	452436	383	0.51	466044	393	0.51	522698	441	1.15
Cankuzo	205081	110	7.64	298273	159	7.64	585725	312	6.98
Karuzi	326999	234	2.58	372339	266	2.58	522451	373	3.45
Bubanza	264346	252	3.53	315353	300	3.53	394323	375	2.26
Gitega	630986	335	2.31	710477	375	2.31	873293	461	2.08
Muramvya	481632	324	1.76	525720	353	1.76	597074	401	1.28
Ruyigi	313314	139	5.68	414463	184	5.68	812895	360	6.97
Bujumbura Rural	449826	387	3.82	543278	466	3.82	614754	527	1.24
Bujumbura Capital	274266	3108	3.10	319497	3620	3.10	421113	4772	2.80
Bururi	453137	189	3.35	535979	223	3.35	699812	291	2.70
Rutana	266448	145	6.48	367055	198	6.48	682779	368	6.40
Makamba	272483	147	4.21	338168	180	4.21	553780	295	5.06
Total population	**6,156,430**			**7,253,655**			**9,814,082**		
Source: PDNE, 1998									

Appendix C.2: Derived Estimated population number in Ruvubu

Province extent within Ruvubu basin	Area (km2)	population density (inhab/km2)	Population per province
Muyinga	1244	339	**421,716**
Cankuzo	878	312	**273,936**
Ruyigi	1047.7	360	**377,172**
Karuzi	1400	373	**522,200**
Ngozi	777.5	481	**373,978**
Gitega	1854	461	**854,694**
Rutana	88.3	368	**32,494**
Kayanza	888.9	441	**392,005**
Muramvya	1436.7	401	**576,117**
Bururi	364.7	291	**106,128**
Bujumbura rural	84.3	527	**44,426**
Total	10063		**3,974,865**

Appendix D: Irrigation development

Appendix D.1: Irrigation development area (year 1990)

Site name	Irrigated area (km2)	River name	FWS 1 (l)	FWS 2 (l)	FWS 3 (l)	FWS 4 (l)	FWS 5 (l)	FWS 6 (l)	FWS7 (l)	FWS 8 (l)	FWS 9 (l)	FWS1 0 (l)	FWS1 1 (l)	FWS1 2 (l)
BUKEMBA	0.85	MUSASA	170	170	170	170	170	170	170	170	170	170	170	170
BUGIGA	0.5	MUSASA	100	100	100	100	100	100	100	100	100	100	100	100
BIGINA	1.6	MUSASA	320	320	320	320	320	320	320	320	320	320	320	320
MPARAMBO, MUNYIKA, CIBITOKE, L.DOGODOGO	8.04	NYAMAGANA; NYAKAGUNDA	558	166	294	558	1468	1791	1791	1272	1018	421	421	421
RUKANA	5	NYAKAGUNDA	343	102	180	343	902	1100	1100	781	625	258	258	258
KIDWEBIZI	0.85	KIDWEBIZI	23	39	8	28	38	23	40	59	26	38	25	25
BUHINYUZA	2.25	GIKOMA	61	102	22	74	101	62	107	156	67	99	65	65
KIYANGE	2.35	GIKOMA	63	107	22	77	105	64	111	162	71	104	68	68
MUGERERO I	24.9	MPANDA	669	1130	240	816	1116	682	1183	1723	749	1099	721	721
RANDA	4	MPANDA	29	214	155	156	423	517	407	343	149	57	36	36
RUKARAMU I	9.2	MPANDA	192	440	169	319	581	533	586	682	296	324	211	211
BURAGANE SUD	2.75	MUGOMBWA	550	550	550	550	550	550	550	550	550	550	550	550
KIBONE	0.6	MUGWEJI	120	120	120	120	120	120	120	120	120	120	120	120
MUGWEJI	1.4	MUGWEJI	280	280	280	280	280	280	280	280	280	280	280	280
PLANT.CAFE	4.7	MURAGO	34	251	182	183	497	608	478	403	175	67	42	42
RUBIRIZI	1.75	MURAGO	47	79	17	57	78	48	83	121	53	77	51	51
NYAMABERE I	2	MUSENYI	54	91	19	66	90	55	95	138	60	88	58	58
SOSUMO	14.16	MUTSINDOZI	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230
BURAGANE NORD	2.25	MUYOGO, RUKOZIRI	450	450	450	450	450	450	450	450	450	450	450	450
BUGOMA	1.45	MUZAZI	39	66	14	48	65	40	69	100	44	64	42	42
KABAMBA I	4.35	MUZAZI	117	198	42	143	195	119	207	301	131	192	126	126
MARAMVYA	1.95	MUZAZI	52	89	19	64	87	53	93	135	59	86	57	57
RUGWE	2.3	MUYOVOZI	460	460	460	460	460	460	460	460	460	460	460	460
Total area	99.2													

AppendixD.2: Irrigation development area (year 2000)

Site name	Irrigated area (km^2)	River name	FWS 1 (l)	FWS 2 (l)	FWS3 (l)	FWS 4 (l)	FWS 5 (l)	FWS 6 (l)	FWS7 (l)	FWS 8 (l)	FWS 9 (l)	FWS 10 (l)	FWS 11 (l)	FWS 12 (l)
MBAZA-MIDUHA	8	RUHWA	473	473	141	249	473	1246	1520	1520	1080	864	357	357
MURAMBI	2.65	MUHIRA	136	136	40.6	71.6	136	358	437	437	310	248	103	103
CIBITOKE	5.1	NYAMAGANA	274	274	81.7	144	274	720	879	879	624	500	207	207
GASENYI	17.18	KABURANTWA	508	508	152	268	508	1338	1632	1632	1159	927	383	383
MPARAMBO,MUNYIKA, RUJEMBO,L. DOGODOGO	22.02	NYAMAGANA; NYAKAGUNDA	748	748	223	394	748	1968	2401	2401	1706	1365	564	564
RUKANA	5	NYAKAGUNDA	343	343	102	180	343	902	1100	1100	781	625	258	258
KIDWEBIZI	0.85	KIDWEBIZI	32	23	39	8	28	38	23	40	59	26	38	25
BUHINYUZA	2.25	GIKOMA	85	61	102	22	74	101	62	107	156	67	99	65
BUTERERE	3.9	GIKOMA	0	28	208	151	152	413	504	396	334	145	56	35
KIYANGE	2.35	GIKOMA	88	63	107	22	77	105	64	111	162	71	104	68
GIFURWE	2.15	MPANDA	0	15	114	83	83	228	278	218	184	80	31	19
GIHANGA I	13.65	MPANDA	273	306	802	636	636	985	1096	1022	648	779	434	213
GIHANGA II	5.75	MPANDA	115	129	338	268	268	415	461	430	273	328	183	90
MUGERERO I	24.9	MPANDA	658	521	1190	457	863	1572	1443	1586	1847	801	876	571
NYAMABERE II	13.1	MPANDA	334	381	746	581	589	869	917	837	444	835	479	252
RANDA	4	MPANDA	0	29	214	155	156	423	517	407	343	149	57	36
RUKARAMU I	11.05	MPANDA	292	231	528	202	383	697	640	704	819	356	389	253
RUSIZI I	3.65	MPANDA	69	56	242	207	202	240	275	310	208	193	113	40
BURAGANE SUD	2.75	MUGOMBWA	550	550	550	550	550	550	550	550	550	550	550	550
KIBONE	0.6	MUGWEJI	120	120	120	120	120	120	120	120	120	120	120	120
MUGWEJI	1.4	MUGWEJI	280	280	280	280	280	280	280	280	280	280	280	280
PLANT.CAFE	4.7	MURAGO	0	34	251	182	183	497	608	478	403	175	67	42
RUBIRIZI	1.75	MURAGO	66	47	79	17	57	78	48	83	121	53	77	51
NYAMABERE I	2	MUSENYI	75	54	91	19	66	90	55	95	138	60	88	58
SOSUMO	14.16	MUTSINDOZI	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230
BURAGANE NORD	2.25	MUYOGO, RUKOZIRI	450	450	450	450	450	450	450	450	450	450	450	450
BUGOMA	1.45	MUZAZI	55	39	66	14	48	65	40	69	100	44	64	42
KABAMBA I	4.35	MUZAZI	164	117	198	42	143	195	119	207	301	131	192	126
KABAMBA II	6.75	MUZAZI	177	228	351	254	264	477	494	386	185	449	251	151
MARAMVYA	1.95	MUZAZI	73	52	89	19	64	87	53	93	135	59	86	57
RUGWE	2.3	MUYOVOZI	460	460	460	460	460	460	460	460	460	460	460	460
BUKEMBA	0.85	MUSASA	170	170	170	170	170	170	170	170	170	170	170	170
BUGIGA	0.5	MUSASA	100	100	100	100	100	100	100	100	100	100	100	100
BIGINA	1.6	MUSASA	320	320	320	320	320	320	320	320	320	320	320	320
Total area	196.91													

Appendix.D.3: Projected irrigation area (in year 2010)

Site name	Projected Irr. area (km2)	River name	FWS 1(l)	FWS2 (l)	FW S 3 (l)	FWS4 (l)	FW S5 (l)	FWS6 (l)	FWS7(l)	FW S8 (l)	FWS9 (l)	FWS 10 (l)	FW S11 (l)	FW S12 (l)
BUKEMBA	0.85	musasa	170	170	170	170	170	170	170	170	170	170	170	170
BUGIGA	0.5	musasa	100	100	100	100	100	100	100	100	100	100	100	100
BIGINA	1.6	musasa	320	320	320	320	320	320	320	320	320	320	320	320
MBAZA-MIDUHA	8	ruhwa	473	473	141	249	473	1246	1520	1520	1080	864	357	357
MURAMBI	2.65	muhira	136	136	40.6	71.6	136	358	437	437	310	248	103	103
CIBITOKE	5.1	nyamagana	274	274	81.7	144	274	720	879	879	624	500	207	207
GASENYI	17.18	kaburantwa	508	508	152	268	508	1338	1632	1632	1159	927	383	383
MPARAMBO, MUNYIKA, RUJEMBO, L.DOGODOGO	22.02	nyamagana; nyakagunda	748	748	223	394	748	1968	2401	2401	1706	1365	564	564
RUKANA	5	nyakagunda	343	343	102	180	343	902	1100	1100	781	625	258	258
KIDWEBIZI	0.85	kidwebizi	32	23	39	8	28	38	23	40	59	26	38	25
BUHINYUZA	2.25	gikoma	85	61	102	22	74	101	62	107	156	67	99	65
BUTERERE	3.9	gikoma	0	28	208	151	152	413	504	396	334	145	56	35
KIYANGE	2.35	gikoma	88	63	107	22	77	105	64	111	162	71	104	68
GIHANGA III	11.55	kajeke	227	228	712	582	577	805	905	909	590	641	363	159
RUSIZI III	7.15	kajeke	140	141	441	361	357	499	561	563	366	397	225	98.7
GIFURWE	2.15	mpand	0	15	114	83	83	228	278	218	184	80	31	19
GIHANGA I	13.65	mpanda	273	306	802	636	636	985	1096	1022	648	779	434	213
GIHANGA II	5.75	mpanda	115	129	338	268	268	415	461	430	273	328	183	90
MUGERERO I	24.9	mpanda	658	521	1190	457	863	1572	1443	1586	1847	801	876	571
NYAMBERE II	13.1	mpanda	334	381	746	581	589	869	917	837	444	835	479	252
RANDA	4	mpanda	0	29	214	155	156	423	517	407	343	149	57	36
RUKARAMU I	11.05	mpanda	292	231	528	202	383	697	640	704	819	356	389	253
RUSIZI I	3.65	mpanda	69	56	242	207	202	240	275	310	208	193	113	40
BURAGANE SUD	2.75	mugombwa	550	550	550	550	550	550	550	550	550	550	550	550
KIBONE	0.6	mugweji	120	120	120	120	120	120	120	120	120	120	120	120
MUGWEJI	1.4	mugweji	280	280	280	280	280	280	280	280	280	280	280	280
PLANT.CAFE	4.7	murago	0	34	251	182	183	497	608	478	403	175	67	42
RUBIRIZI	1.75	murago	66	47	79	17	57	78	48	83	121	53	77	51
NYAMABERE I	2	musenyi	75	54	91	19	66	90	55	95	138	60	88	58
SOSUMO	14.16	mutsindozi	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230
BURAGANE NORD	2.25	muyog, rukoziri	450	450	450	450	450	450	450	450	450	450	450	450
BUGOMA	1.45	muzazi	55	39	66	14	48	65	40	69	100	44	64	42
KABAMBA I	4.35	muzazi	164	117	198	42	143	195	119	207	301	131	192	126
KABAMBA II	6.75	muzazi	177	228	351	254	264	477	494	386	185	449	251	151
MARAMVYA	1.95	muzazi	73	52	89	19	64	87	53	93	135	59	86	57
RUGWE	2.3	muyovozi	460	460	460	460	460	460	460	460	460	460	460	460
Total area	215.6													

Appendix E: Crop name and Growth duration

Crops type	Growing season	Planting date	Harvesting date	estimated irrigation period		FWS			Water duty in m3/ha/year	GIWR for 51,768 ha (km^3/year)
				irrigation/season	Irrig. Period /year	2l/s/ha	1.174 l/s/ha	0.74 l/s/ha	0.74l/s/ha	
Rice	Wet I	Feb/March	June/July	3 months	6 months/year	31,449 m^3/ha/year	18,460 m^3/ha/year	**11,636 m^3/ha/year**	**11,636 m3/ha/year**	**0.602**
	Wet II	Sep/Oct	Jan/Feb	3 months						
Maize	Wet I	Feb/March	June/July	3 months	6 months/year					
	Wet II	Sep/Oct	Jan/Feb	3 months						
Sorghum	Wet I	Feb/March	June/July	3 months	6 months/year					
	Wet II	Sep/Oct	Jan/Feb	3 months						
Beans	Wet I	March/Apr	June/July	3 months	6 months/year					
	Wet II	Oct/Nov	Jan/Feb	3 months						
Vegatable and Sweet Potato	Wet I	Feb/March	June/July	3 months						
	Wet II	Sep/Oct	Jan/Feb	3 months	6 months/year					
Manioc	Wet I									
	Wet II	Oct/Nov	Sep/Jan	1 year						

Table showing how to estimate Water duty

Appendix F: Maps

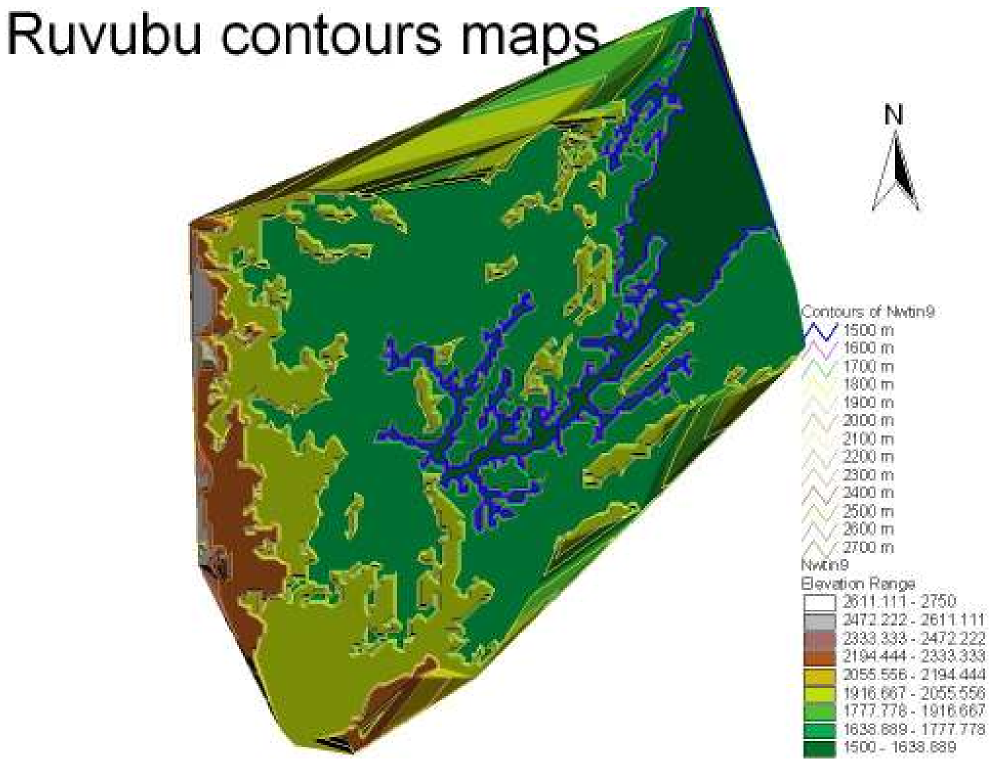

Figure.1: DEM Map derived for Ruvubu basin pattern

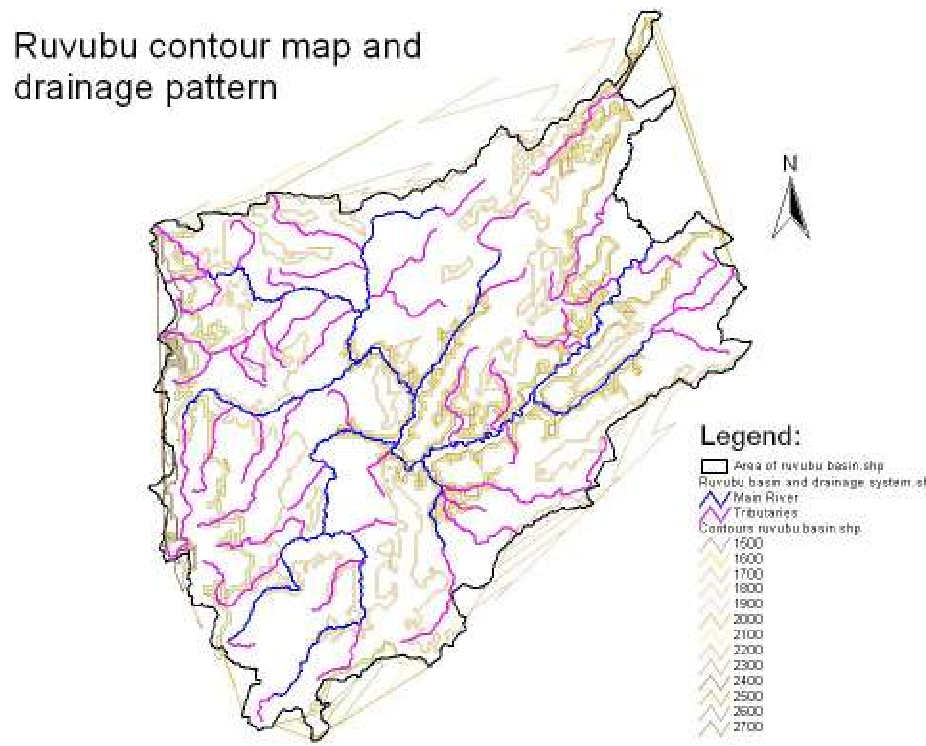

Figure.2: Ruvubu countour maps and drainage

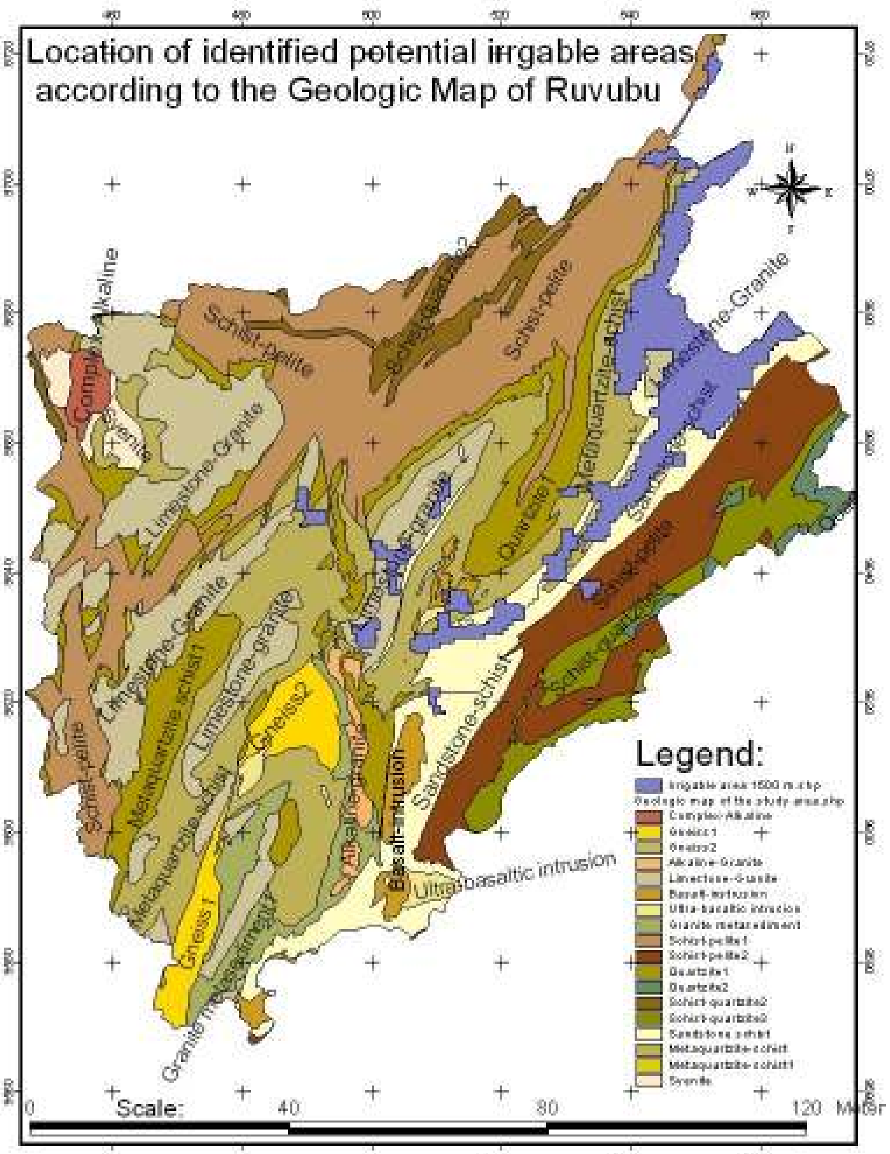

Figure 3. Location of identified irrigable areas in Geologic map

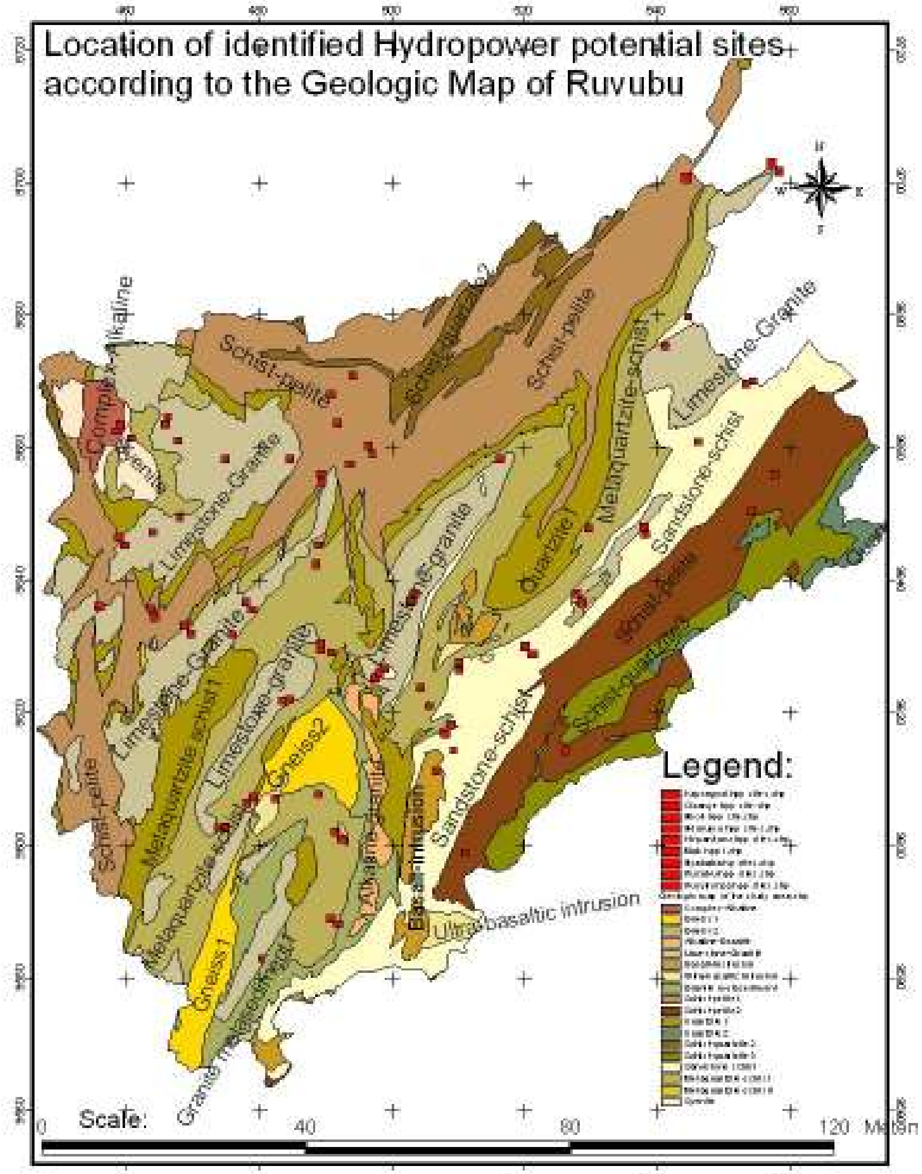

Figure 4 Location of Hydropower potential site in the Geologic map

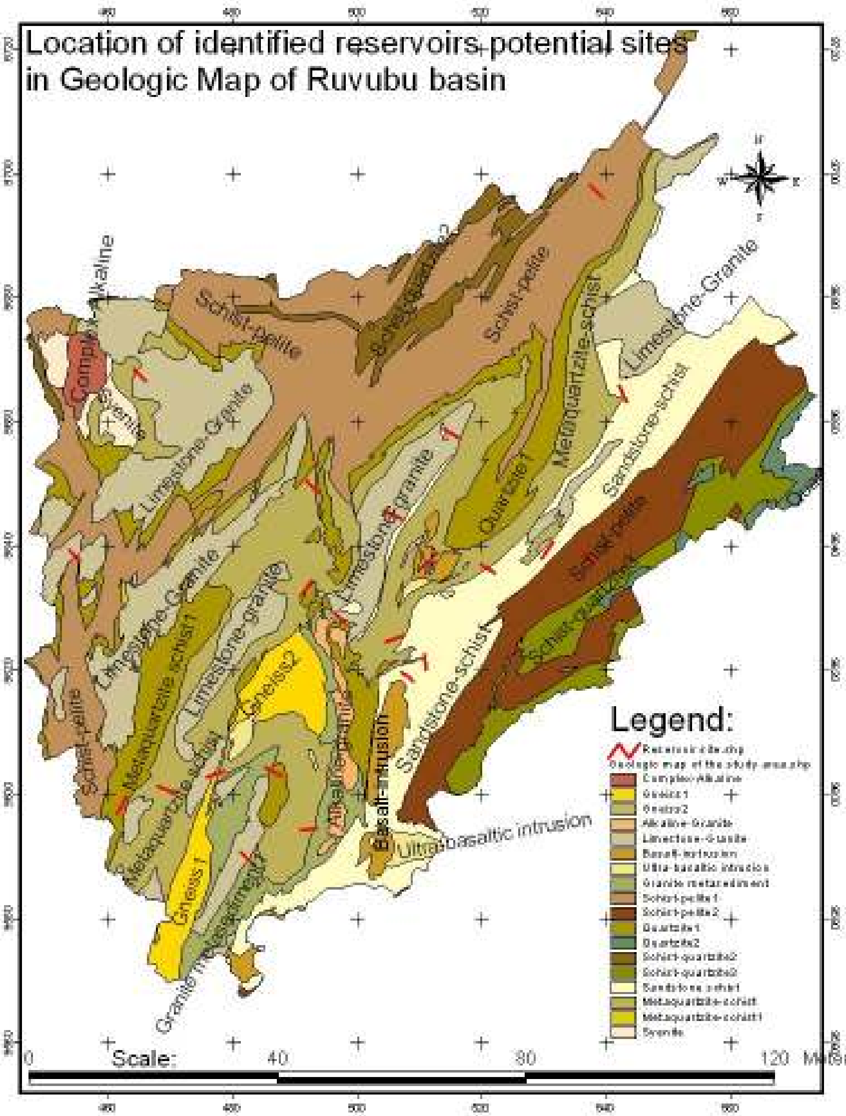

Figure 5. Location of selected potential reservoir site in Geologic map.

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