ASSESSMENT OF WATER RESOURCE POTTENTIAL AND ALLOCATION IN MUVUMBA CATCHMENT

A Thesis Submitted and Presented to Arba Minch University

In partial Fulfillment of the requirements for the Degree of Master of Science in Hydrology and water resource management.

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DECLARATION

I, Edward Bagumira, declare that this thesis is my original work and it has not been presented by me or any university for similar or any other degree award.

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Signature

Date…………………………………………

CERTIFICATION

The undersigned certify that they have read and hereby recommend for the acceptance by the Arbaminch University the thesis entitled: 'ASSESSMENT OF WATER RESOURCE POTENTIAL AND ALLOCATION OF WATER IN MUVUMBA CATCHMENT' in partial fulfillment of the requirements for the Degree of Master of Science in Hydrology and Water Resource Management.

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Dr.-Ing. Yonas Michael

Advisor

Date: …………………..

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Last but not least, I extend my thanks to the family of Mr. Chris Glaser for their continuous support and advice during my study.

Dedication

The Thesis is dedicated to my mother Mukangarambe Paskazia.

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List of Abbreviations

AIDS	Acquired Immune Deficiency 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
ha	Hectars
HPP	Hydro Power Plant
ISTEER	Institut des Statistiques Economiques du Rwanda
KW	Kilo-Watt
MW	Mega-Watt
NEL	Nile Equatorial Lake
NIWR	Net Irrigation Water Requirement
NNW	North-North-West (Direction)
EG	Electrogaz
GPS	Satellite Positioning System
MM	Millimeter
WMO	World Meteorological Organization

Abstract

Water Resources in Rwanda is not uniformly distributed as a result of climate variability and rugged relief. The uneven distribution of the water resource in Rwanda is also exacerbated by serious land and environment degradations. The understanding of such dire situations requires a scientific water resources assessment, allocation and improved planning.

This research work has deliberated study on the assessment of water resource potential of the Muvumba Catchment and its allocation for water supply, irrigation and hydropower generation. The SWAT model has been applied for estimating the water resources potential of the catchment. The catchment was calibrated and the model was validated employing the limited secondary data source. The irrigation potential of the catchment was assessed setting established criteria such as land slope, soil texture and water availability.

The modeling result shows that the annual runoff volume from the Muvumba catchment is 531 Million cubic meter (MCM). The specific yield of the catchment is 1.911 l/s km^2 or 0.019 l/s/ha. The potentially irrigable land is estimated at 9908.4 hectares. The amount of water allocated for irrigation is 114 Million cubic meters (MCM). Water supply accounts for 14 Million cubic meters. Hence, the consumptive uses are catered for by the catchment yield. Hence, there is enough water resources at the time for the stated purposes.

1 INTRODUCTION

1.1 Background

In Rwanda, the water resources are unequally distributed. Even though it has been considered as generally sufficient, there is shortage of water for diverse users in eastern part of the regions where Muvumba catchment is located. This is mainly due to increase in population size and increased use of water for various purposes in economic activities. The major economic activities leading to increased water demand are irrigation, domestic water supply and industrial water supply.

The socioeconomic activities rely currently heavily on rainfall. Agricultural production is mainly rain fed. Industrial water demand in the catchment is steadily increasing. Moreover, potable water supply is in dire situation in which the residents have to walk long distance to haul water.

Hence, water harvesting infrastructures are required in order to harness the water resources for various uses. This requires estimation of the water resources potential. Moreover, the water resources need to be allocated optimally and prioritized. Hence, this thesis tries to approach the problems of water resources assessment and allocation from hydrological perspective. Before delving into details, it is imperative to briefly highlight on the physical features, geography, climate and hydrology of Rwanda which is illustrated hereunder.

Rwanda is a small, mountainous country, lying in the extreme southwestern part of the Nile Basin and contributing flow to Lake Victoria. It lies on the watershed divide between the Congo and Nile Basins, with about 80 percent of the land area in the Nile Basin. Rwanda lies geographically between 2.0^0 S and 30^0 E as shown in Figure 1.

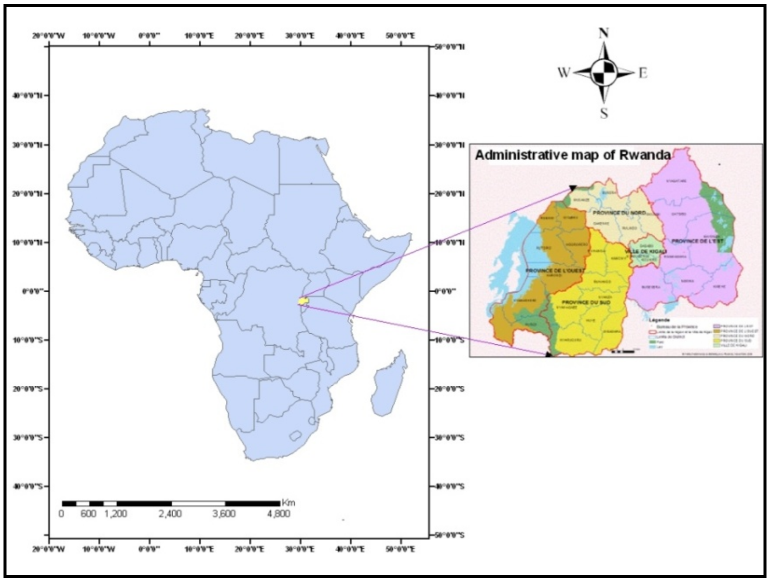


Figure 1: The location of Rwanda

The Republic of Rwanda is divided into Intara (provinces), Uturere (districts), Imirenge (sectors) and Utugari (cells). The Akarere (district) is the basic political-administrative unit of the country as shown in figure 2**Error! Reference source not found.**.

Figure 2: Administration of Rwanda

Altitudes are high across the whole country, between 1000 and 4500m with an average altitude of 1500m. Three different regions can be distinguished with increasing altitude from East to West.

- Low oriental lands in the East;
- the volcanic chain and the central plateau; and
- The Congo- Nile crest overhanging Lake Kivu in the West.

The altitude variation and the relief of the country bring about vast agro-bio-diversity.

Average annual rainfall in the whole of Rwanda is 1100 mm, but it varies from 700 mm in the North-East to 1600 mm/year in the South-West. There are two distinct rainy seasons:

- Short rainy season spanning from September to November; and
- Heavy rainy season from February till May.

Rwandan climate is tropical and its temperature is influenced by altitude. The average temperature in the whole country is 19^0C, with variations between 15^0C and 29^0 C., Temperature in the North- West are much lower than in the rest of the country.

Rwanda has two major river basins, namely the Congo Basin and the Nile Basin. The river basins exhibit dense river network. The Congo sub-basin consists of streams draining into Lake Kivu. Rusuzi River connects Lake Kivu and Lake Tanganyika. The Nile sub basin drains to Akagera River. The Akagera and Nyabarongo rivers cross a number of marshlands and lakes.

Rwanda is a country with about 90% of the population engaged in (mainly subsistence) agriculture. It is a densely populated country with a population size of about nine million. It is endowed with few natural resources and minimal industry. Primary foreign exchange earners are coffee and tea. Despite Rwanda's fertile ecosystem, food production often does not keep pace with population growth, requiring food imports. Rwanda continues to receive substantial aid money and obtained IMF-World Bank Heavily Indebted Poor Country (HIPC) initiative debt relief in 2005-06. Rwanda also received Millennium Challenge Account Threshold status in 2006. The government has embraced an expansionary fiscal policy to reduce poverty by improving education, infrastructure, and foreign and domestic investment and pursuing market-oriented reforms, although energy shortages, instability in neighboring states, and lack of adequate transportation linkages to other countries continue to handicap growth.

1.2 Study area

1.2.1 Location and administrative unit

The Study Area is located in the district of Nyagatare, which forms part of the current Eastern Province. The Eastern Province is bordered to the north by Uganda and to the East by Tanzania and to the South by both Tanzania and Burundi. The other districts within the Eastern Province are Bugesera, Gatsibo, Kayonza, Rwamagana, Kirehe and Ngoma. The area extent of the catchment is 1018.7 Km^2. Geographical extent of the area is -1^0 29' up to -1^0 34' south latitude, 30^0 6' up to 30^0 25' east longitude as shown in Figure 3.

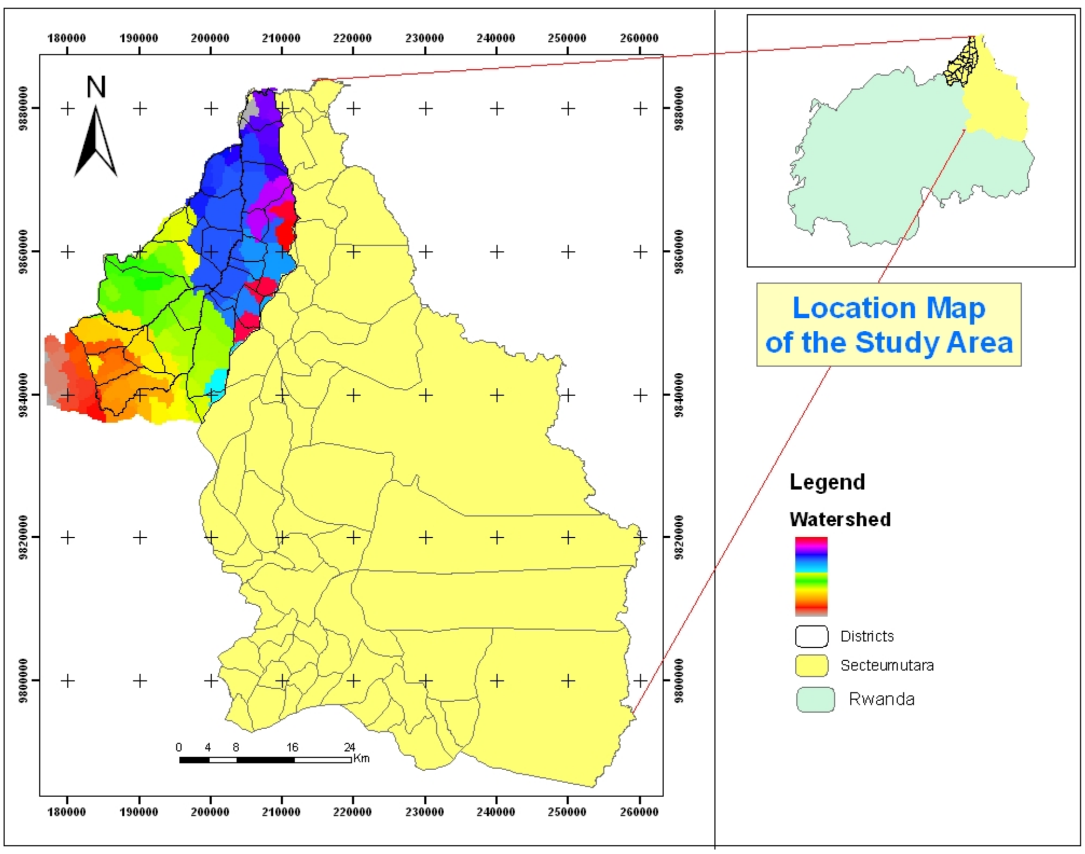


Figure 3 Location Map of the Study Area

1.2.2 Altitude and Topography setting of Muvumba catchment

The relief of Muvumba catchment is characterized by ridges and plains. The relief of the eastern region is predominantly collinear, having altitude which varies between 1300 m.a.s.l and 2200 m.a.s.l. as showed in figure 4. The general slope of the area is gentle from the south towards the north. The river bed slope as well as the valley shapes are the basic topographic feature in the area observed from west towards the east.

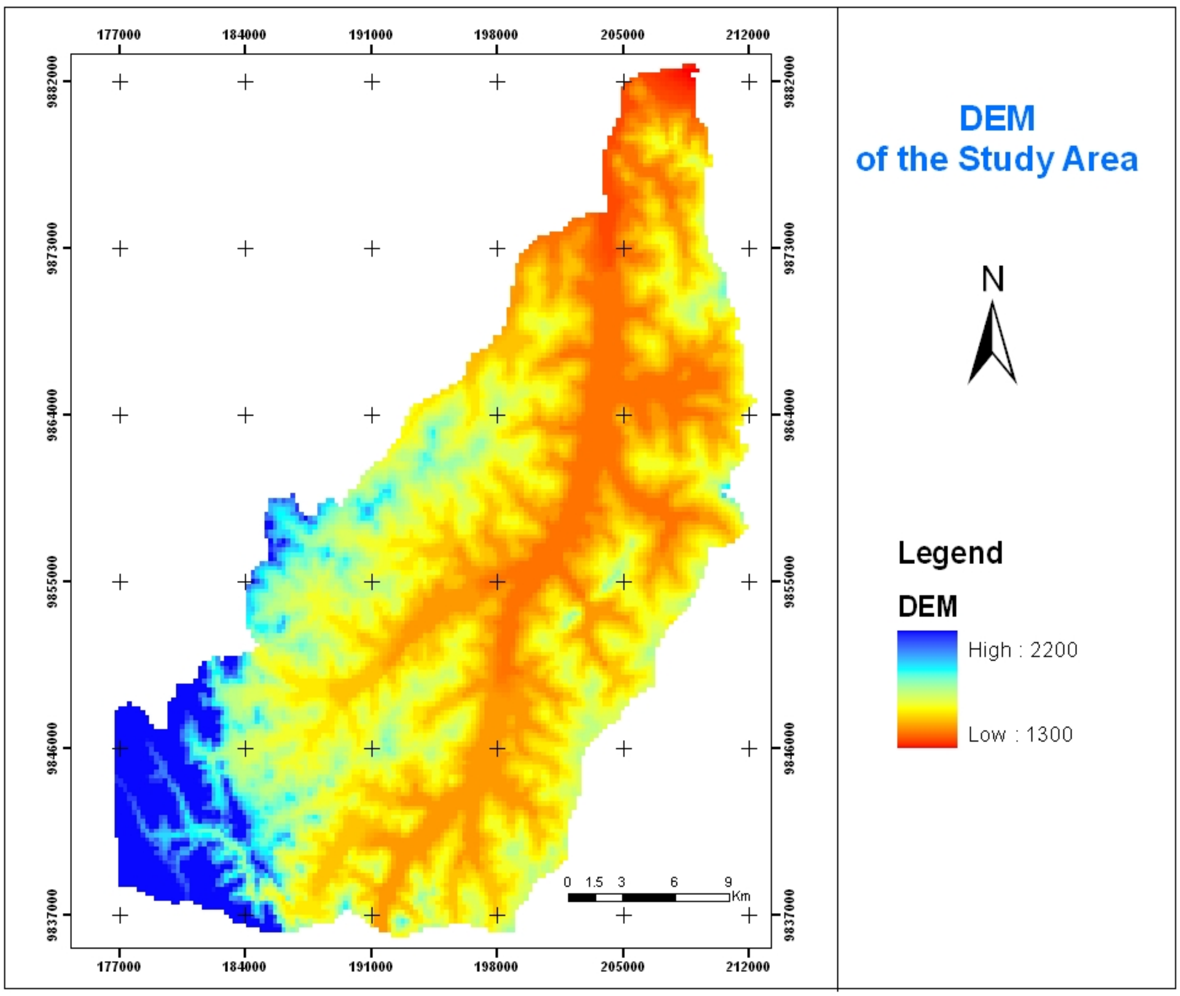


Figure: 4 Topographic Map of the Catchment

1.2.3 Climate

The region is characterized by reduced and rather capricious rainfall. Annual average rainfall is between 650 mm and 800 mm, but in the peripheral areas, in the Districts of Murambi and Rukara, it can reach 1000 mm a year as shown in figure 5. The most rainy months are November and April; the driest ones are June, July and August. The annual average temperature is 21 ^{0}C.

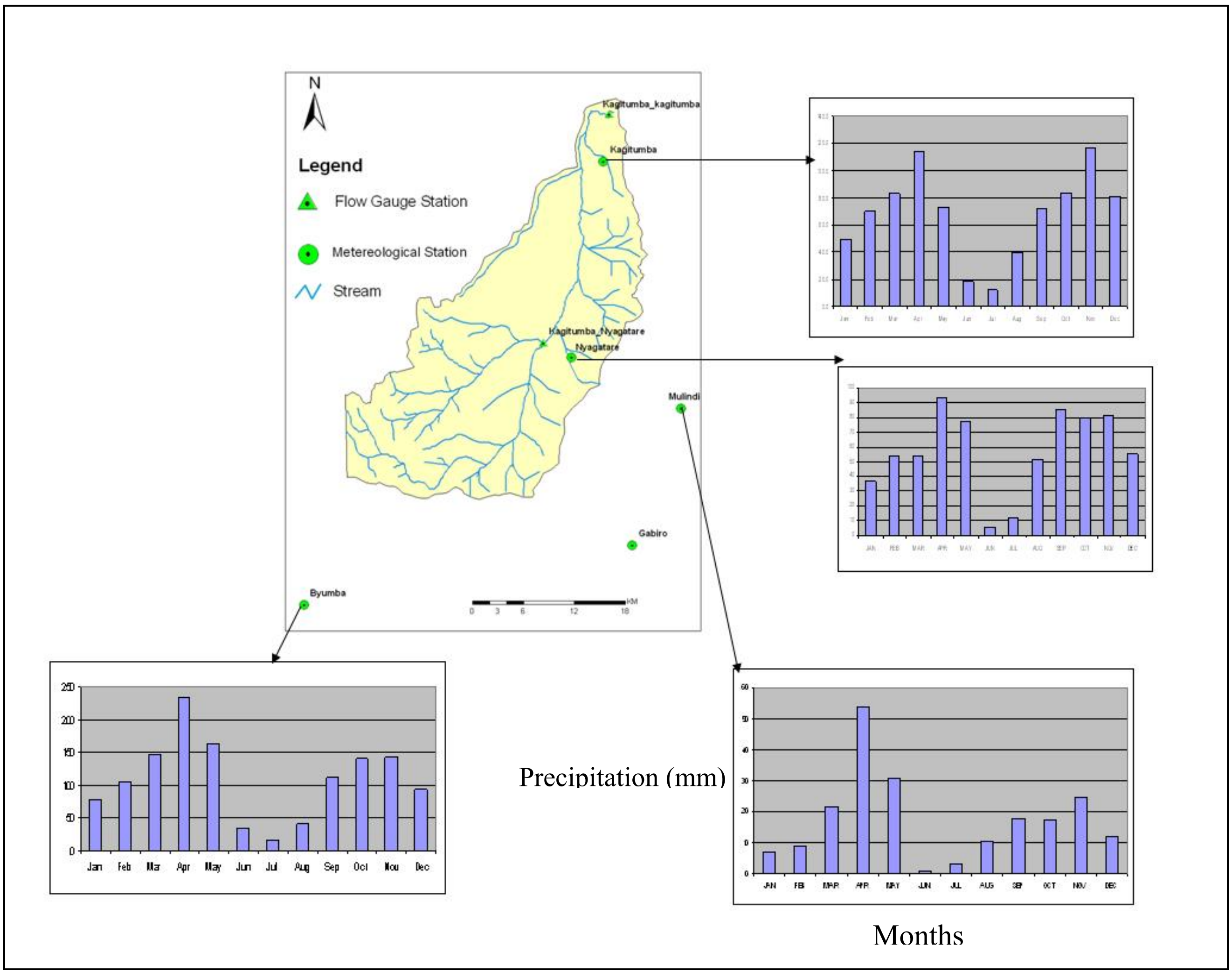


Figure 5 Meteorological Map of Muvumba Catchment

1.2.4 Rainfall

Annual rainfall amount is distributed during two rainy seasons as depicted in Figure 6. Short rainy season from Sept till Nov/ Long rainy season from February till May; Short dry season lasting from December till January/ Long dry season from June till September. The hydrological response of the catchment is generally low.

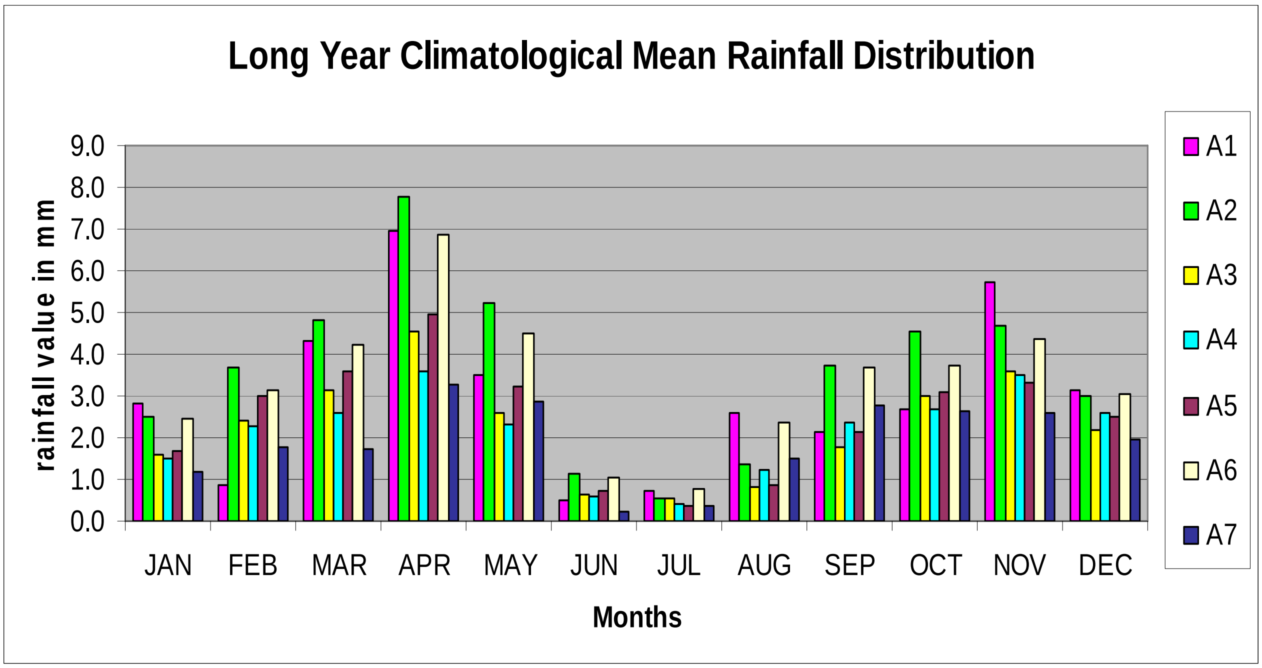


Figure 6 Annual Rainfall Distribution at different stations (Byumba Meteo-A1, Byumba Pref-A2, Gabiro-A3, Kagitumba-A4, Kiziguro-A5, Mulindi Usine-A6 and Nayagatare-A7)

1.2.5 Water resource

The river network of Muvumba catchment forms part of the basin of the Nile. Its principal drain, the Akagera river, after having received the contribution of its tributaries, from within and outside the country, finally discharges into the waters of the large lake Victoria. The general direction of the water run-off of surface of the area is directed towards the north.

The eastern province is compartmentalized by the broad valleys of the basin of the Akagera, and by their sub-systems. Among the most important rivers of the region is the Muvumba river as shown in Figure 7.

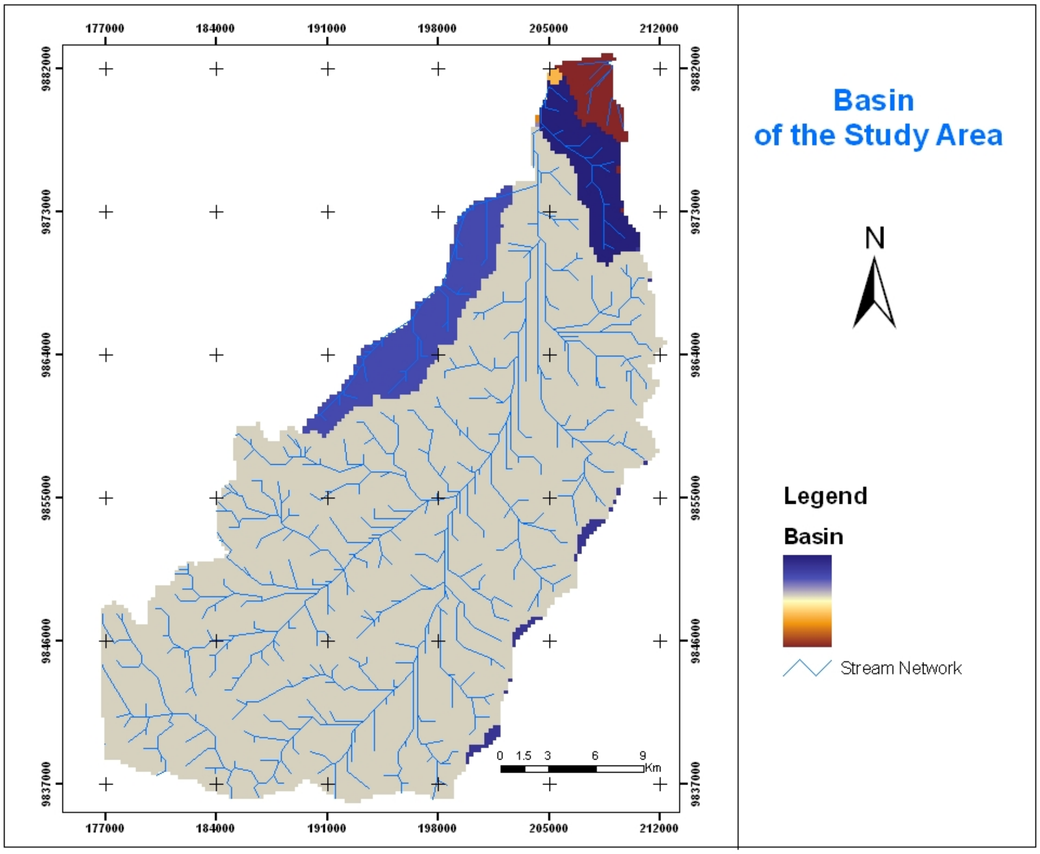


Figure 7 : River Network of Muvumba Catchment

1.2.6 Socio-economy setting of the study area

The majority of the populations of Muvumba catchment are farmers. That is due to the fact that the population of the Province is concentrated in the agricultural regions. Stock breeders also have in their families employed persons in agriculture. A more detailed analysis shows that 82,5% are farmers, 10,8% are stock breeders and 6.7% do miscellaneous jobs. There is no significant difference between men and women. That means that if the population has to take part in the payment of water, one can count that on the income from agriculture and from the livestock-farming who are exerted by more than 90% of the heads of household. Thus more than 90% of the assets are in agriculture and the livestock-farming.

1.3 Problem Statement

No detailed water resource potential assessment of the Muvumba Catchment has been carried out whereas there is a problem of shortage in potable water for human consumption. In addition to this problem the livestock also face a problem scarcity of water during dry seasons periods. However, the government is determined to conserve water for utilization through all seasons by establishing Dams in the country. Hence, the water resource potential of the watershed needs to be assessed and its management be scientifically addressed.

1.4 Objective of the Research

1.4.1 General objective

The overall objectives of the research are to estimate the water resources potential of the Muvumba Catchment, and to observe how the distribution of water resource match with the water demand to optimally allocate the water resource for various uses and propose for the decision makers to take mitigation measures .

1.4.2 The specific objectives:

i) To Develop the methodologies for assessing water resources potential for Muvumba Catchment

ii) To quantify the possible water resources availability for potable water, irrigation potential and hydropower potential in the catchment, and

iii) Identify type of structure and project needed and evaluation of the baseline water allocation for the identified sites

1.5 Structure of the Thesis

The Thesis is divided into five chapters. Chapter one covers the background information on Rwanda and its water resources. Chapter two outlines the literature review reflecting on previous efforts in water resources assessment and reports on the state-of-the-art in the same area. Chapter three deliberates on data collection, data analysis required for model development whereas, the methodology employed, the model development and the results obtained. The results and interpretation of the modeling are discussed at length in Chapter four. The last chapter, Chapter five, deliberates on conclusions and recommendations.

LITERATURE REVIEW

2. 1 Previous Studies

Khare, et. Al (2006), have shown that the quantity and quality of available water resources have been recognized as limiting factors in development of most of the arid and semi arid regions. Optimal use of available surface and groundwater, in any canal command area would result in their better utilization by maximizing the benefits from the crop production. Shortages of surface water supplies have increased the need of groundwater development in many canal commands. The potential of groundwater can be used to develop conjunctive use water management plans for supplementing canal water supplies and to increase agricultural productivity the results indicate that conjunctive use options are feasible and can be easily implemented in the area, which would enhance the overall benefits from cropping activities.

According to Takeo et. Al (2004) the potential water resources availability (PWRA) in an area is assessed in terms of disorder in intensity and over-a-year apportionment of monthly rainfall.

Petra Do¨ll et. Al (2002) referred the quantification water potential should estimated not only in individual river basins but also at the global scale is required to support the sustainable use of water. The Global Hydrology Model, which is a sub-model of the global water use and availability model, able to computes surface runoff, groundwater recharge and river discharge at a fine spatial resolution. Hydrology Mode mostly kept the accuracy based on the best global data sets currently available, and simulates the reduction of river discharge by human water consumption.

D.G. Jamieson et.Al (1995) Having outlined the conceptual design and planning capability in the previous two papers, the final contribution in this trilogy describes the application of Water Ware to the River Thames basin in England and Rio Lerma in Mexico. Examples are given of the real-world problems that can be addressed using this system. These include water-resource assessment, reservoir site selection, and decontamination of groundwater, estimation of sustainable irrigation abstractions and derivation of required effluent-quality standards. The requirement in both cases is to provide the analytical tools to be used by the agency staff themselves for planning purpose.

2. 2 The Concept of Watershed

A watershed is an area of land in which all rain and runoff and small tributaries drain into a common outlet. Watersheds are usually delineated from surface topography unlike catchments, which include area that provide water to the point through lateral flow over the surface and underground. Watershed is the most acceptable units for the purpose of planning for optimum use and conservation of natural resources (Verma et al 1995). It is also appropriate for most hydrological studies (Mulligan, 2004) and is widely used by many scientists.

Scientific management of soil, water and vegetation resources on watershed basis is, very important to arrest erosion and rapid siltation in rivers, lakes and estuaries. It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Prioritization of watersheds on the basis of those sub-watersheds within a watershed which contribute maximum sediment yield obviously should determine our priority to evolve appropriate conservation management strategy so that maximum benefit can be derived out of any such money-time-effort making scheme.

Sharma et al (2003); Ravishankar et al (1994); Sharma et al (2001) and Suresh et al (2004) have found watersheds as appropriate units for prioritizing their study areas based on the soil erosion indexes.

Rosental et al (1995); Gangodamage and Aggarwal (2001); Tripathi et al (2002) and Jasrotia et al (2002) have used watersheds as the unit for hydrological modeling by using remote sensing and GIS for data acquisition and processing.

2. 3 The use of hydrological model for water resource

SWAT is a physically based basin-scale continuous time distributed parameter hydrologic model that uses spatially distributed data. SWAT can simulate surface runoff using either the modified SCS curve number (CN) method (USDA Soil Conservation Service 1972) or the Green and Ampt infiltration model based on infiltration excess approach depending on the availability of daily or hourly precipitation data, respectively. The SCS curve number method was used in this study with monthly precipitation data. Based on the soil hydrologic group, vegetation type and land management practice, initial CN values are assigned from the SCS hydrology handbook (USDA Soil Conservation Service 1972).

2. 4 Classification of Hydrologic Simulation Models

Hydrological modeling is a great method of understanding hydrologic systems for the planning and development of integrated water resources management. The purpose of using a model is to establish baseline characteristics whenever data is not available and to simulate long-term impacts that are difficult to calculate, especially in ecological modeling (Lenhart et al. 2002).

There are many classification schemes of hydrologic models, such as, short term vs. long term, small scale vs. large scale, forecasting vs. predicting, physical vs. mathematical, continuous vs. discrete, descriptive vs. conceptual, lumped vs. distributed, and deterministic vs. stochastic models. Classifications are generally based on the method of representation of the hydrologic cycle or a component of the hydrologic cycle. Hydrologic simulation models use mathematical equations to calculate results like runoff volume or peak flow.

In Mathematical models, the model would be physically based. However, all existing theoretical models simplify the physical system and often include obviously empirical components, so they are considered conceptual models. An empirical model omits the general laws and is in reality a representation of data (Lenhart et al. 2002.). Physically based models are based on our understanding of the physical of the hydrological processes which control catchment response and use physically based equations to describe these processes. Generally, physically based models are used to simulate a wide range of complex aspects (Lenhart et al. 2002).

The stochastic versus deterministic classification of models depends on the character of the results obtained. If one or more of the variables in a mathematical model are regarded as random variables having distributions in probability, then the model is stochastic. If all the variables are considered to be free from random variation the model is deterministic. Using long data series, process-based deterministic models can compute the great number of calculations required to describe the complexity of a system. They can provide reliable information on the behavior of the system.

Deterministic hydrologic models can be classified into 3 main categories (Cunderlik 2003):

Lumped Models: parameters of lumped models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting forth response of individual sub basins. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. Lumped models are not applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven 2000)

Semi-distributed Models: parameters of semi-distributed models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. There are two main types of semi-distributed models: kinematics wave theory (KW) models and probability distributed (PD) models. The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven 2000). In the PD models spatial resolution is accounted for by using probability distributions of input parameters across the basin. The main advantage of semi-distributed models is their more physically based structure than that of lumped models, and their less input data demand than fully distributed models.

Distributed Models: parameters of distributed models are allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and hence can provide the highest degree of accuracy.

2. 5 Hydrologic Model Selection Criteria

There are numerous criteria which can be used for choosing the right hydrologic model. These criteria are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user depended, such as personal preference for GUI, computer operation system, input/output management and structure, or users add on expansibility. Among the various project-depended selection criteria, there are four main common, fundamental ones that must be always considered (Cunderlik 2003):

Required model outputs important for the needed purpose and therefore to be estimated by the model – does the model predict the variables required by the project such as peak flow, event volume and hydrograph, long term flows, etc

Hydrologic processes that need to be modeled to estimate the desired outputs adequately – is the model capable of simulating regulated reservoir operation, single event or continuous processes, Availability of input data – can all the inputs required by the model be provided within the time and cost constraints of the project Price – does the investment appear to be worthwhile for the objectives of the project for the project needing to asses the potential of water resource on a wide range of hydrological processes and existing water management practices, the following hydrologic model outputs are required (Cunderlik, 2003): Simulated flow peaks (stage, discharge), volumes and hydrographs at the outlets of sub basins, and in the profiles of special interest within the main basin .

2. 6 GIS techniques for water resource potential assessment

Geographical information system is a process that contains a set of procedures that facilitate the data input, data storage, data manipulation and analysis and data output for both spatial and attribute data to support decision making activities (Grimshaw, 1994). .

GIS has two major functions namely fundamental (or basic) advanced. Fundamental functions are functions like measurement, re-classification, overlay operations, connectivity operations and neighborhood operations. Advanced functions are statistical and mathematical modeling functions (Malezewaski, 1999).

In this study, both the fundamental and advanced capabilities of the GIS system were utilized. to conduct data analysis, perform l modeling to categorize the study area based on the water resource potential, and produce output thematic layers like irrigable potential site, potable water potential area and preliminary dam site location.

1. METHODS AND MATERIALS

3.1 Hydrological model selection

SWAT has been employed for assessment of water resources. SWAT has found popularity these days because it nearly simulates all hydrological processes to an acceptable degree of accuracy. In this research, SWAT has been employed to generate flow series and perform water allocation in the Muvumba catchment. It is also hypothesized that SWAT could be applied to catchments in Rwanda. SWAT is a comprehensive model that requires intensive data to run.

3.2 Data Collection

Primarily Data were collected during field visit. Using Global positioning system (GPS) Meteorological data were obtained from Meteorological Organization of RWANDA. Topographic maps, soil maps, land use/land cover map were obtained from GIS centre of Rwanda and statistical data from the Statistics organization of Rwanda.

3.3 Model Set up

3.2.1 SWAT (Soil and Water Assessment Tool)

SWAT is a physically based basin-scale continuous time distributed parameter hydrologic model that uses spatially distributed data on soil, land use, Digital Elevation Model (DEM), and weather data for hydrologic modeling and operates on a daily time step.

Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. A complete description of the SWAT model components (Version 2003) is found in Arnold et al. (1998) and Neitsch et al. (2002).

SWAT employs the concept of hydrological response unit abbreviated HRU. SWAT computations are carried out in three steps. In a first step, the program calculates the fluxes of each HRU, these outputs will be aggregated to a sub basin output, in accordance with the fractions of the HRU's. The sub basin outputs will then be routed through river reaches according to the river network.

Storage volumes represent the water balance in each HRU in the watershed and the soil profile can be subdivided into multiple layers. Soil water processes include surface runoff, infiltration, evaporation, plant water uptake, inter (lateral) flow, and percolation to shallow and deep aquifers.

SWAT can simulate surface runoff using either the modified SCS curve number (CN) method (USDA Soil Conservation Service 1972) or the Green and Empt infiltration model based on infiltration excess approach depending on the availability of daily or hourly precipitation data, respectively. The SCS curve number method was used in this study with monthly precipitation data. Based on the soil hydrologic group, vegetation type and land management practice, initial CN values are assigned from the SCS hydrology handbook (USDA Soil Conservation Service 1972). SWAT updates the CN values daily based on changes in soil moisture.

The excess water available after accounting for initial abstractions and surface runoff, using SCS curve number method, infiltrates into the soil. A storage routing technique is used to simulate the flow through each soil layer. SWAT directly simulates saturated flow only and assumes that water is uniformly distributed within a given layer. Unsaturated flow between layers is indirectly modeled using depth distribution functions for plant water uptake and soil water evaporation. Downward flow occurs when the soil water in the layer exceeds field capacity and the layer below is not saturated. The rate of downward flow is governed by the saturated hydraulic conductivity. Lateral flow in the soil profile is simulated using a kinematics storage routing technique that is based on slope, slope length and saturated conductivity. The upward flow from the lower layer to the upper layer is regulated by the soil water to field capacity ratio of the two layers. Percolation from the bottom of the root zone is recharged to the shallow aquifer.

SWAT has three options for estimating potential ET, namely, Hargreaves (Hargreaves and Samani, 1985), Priestley-Taylor (Priestley and Taylor 1972), and Penman-Monteith (Monteith 1965). The Penman-Monteith method was used in this study. SWAT computes evaporation from soils and plants separately as described by Ritchie (Ricthie, 1972). Soil water evaporation is estimated as an exponential function of soil depth and water content based on potential ET and a soil cover index based on above ground biomass. Plant water evaporation is simulated as a linear function of potential ET, leaf area index (LAI), root depth (from crop growth model), and soil water content.

The crop growth model used in SWAT is a simplification of the EPIC crop model (Williams et al. 1984). A single model is used for simulating both annual and perennial plants. Phonological crop growth from planting is based on daily-accumulated heat units above a specified optimal base temperature for each crop, and the crop biomass is accumulated each day based on the intercepted solar radiation until harvest. The canopy cover, or LAI, and the root development are simulated as a function of heat units and crop biomass.

3.2.2 Watershed delineation

A digital elevation model used in this study has a 1km resolution which is obtained from the GIS center. The DEM of Muvumba River catchment shows the source of Muvumba River, located in the eastern region of the Rwanda as shown in Figure 8.

The DEM is employed to generate the stream network as shown in Figure 8. The size and number of sub basins were determined after processing the DEM by defining a threshold area.

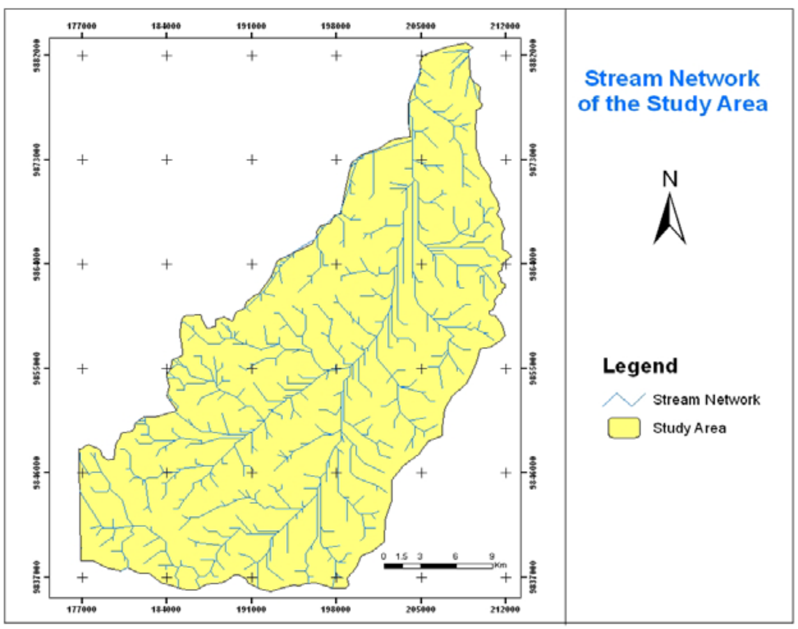


Figure 8: Drainage Map of the Study Area

In this section additional outlet points were added at the place where stream flow measured data are available. The two most important ones are at Uganda border at Kagitumba and Nyagatare station, where flow is monitored. These outlets enable finally to calibrate and validate the model output. Unnecessary outlet points were also removed to obtain better sub basin classification. In this study there was no inlet definition made in the catchment. Finally, after sub basin parameter calculation, the whole catchment is subdivided into 67 sub basins as shown in Figure 9.

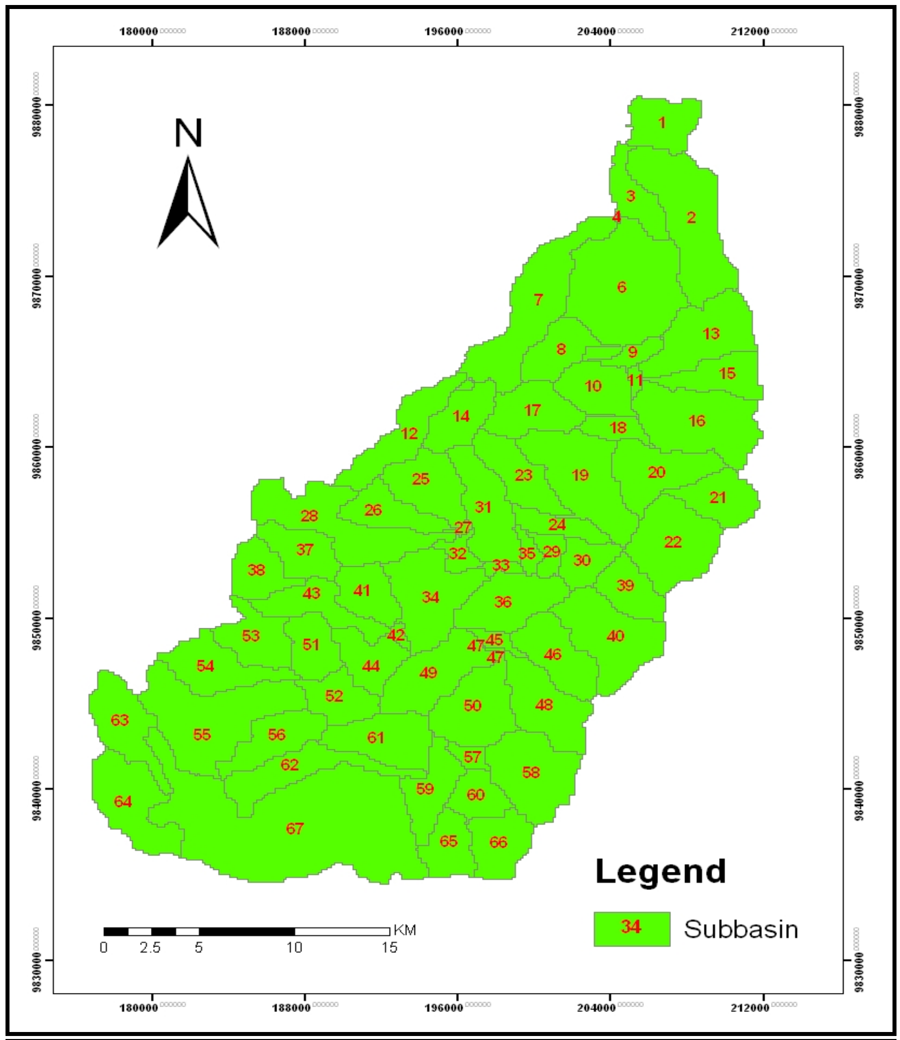


Figure 9 Muvumba catchment sub basins

3.2.3 Land use and Soil Characterization

The movement of water in the land phase of hydrological cycle depends on the soil type and vegetation cover. In order to simulate the land phase of hydrological cycle right, the resolution land use and soil map and their database should be at finer spatial resolution. The more detailed database we build for both, the easier to simulate the physical phenomenon in a meaningful way. The available data from previous study on Akegera River Basin were used in this study. This includes Land use grid data of Africa at 1km resolution and Soil grid data of Africa at 10km resolution.

3.2.4 Land use Definition

The information contained in the land use map tells how the different uses of the surface are distributed inside the area under study. In Figure below and Table below it can be seen that the basin is mainly occupied by Savanna with more than 67% of the basin area. There is also a 20% of the area covered by dry land cropland and pasture.The rest is mainly woodland and grassland**.**

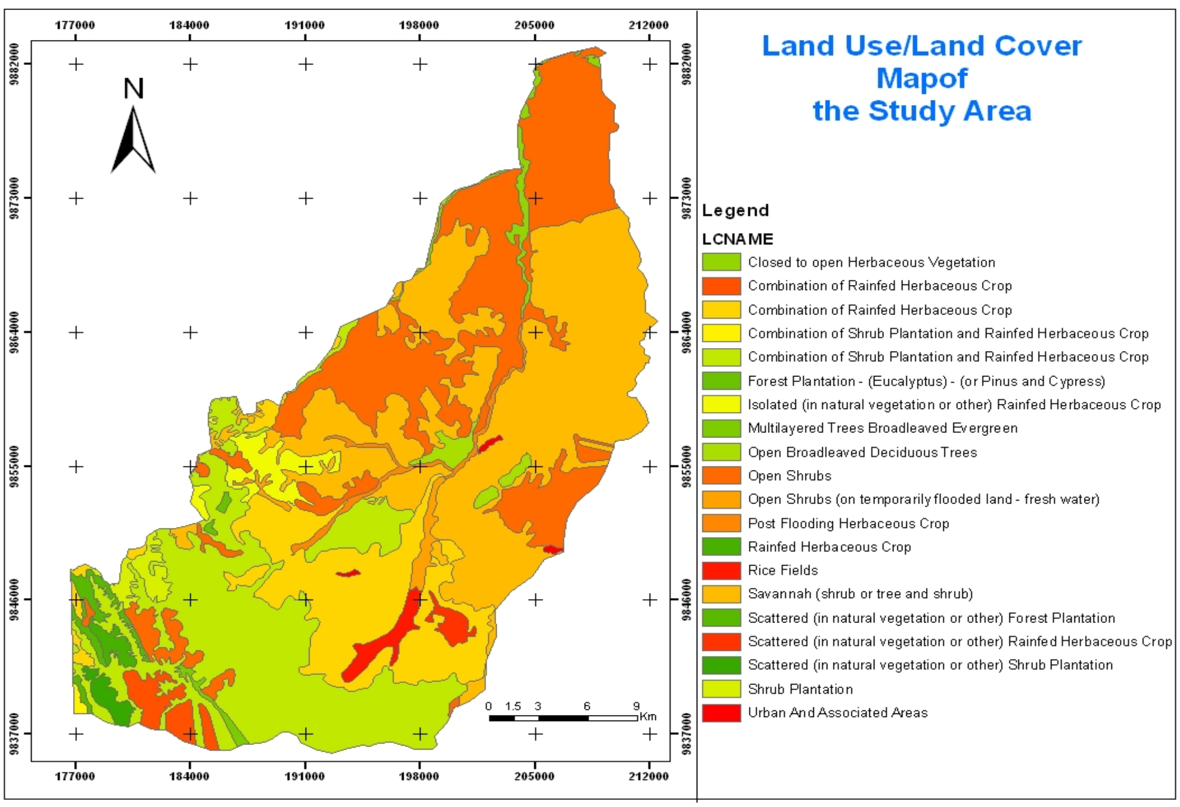


Figure 10 Land use/ Land cover Map of Muvumba catchment

Table 1 Area covered by different land use (with SWAT Code)

Land Cover	Area (km2)	% of total area	swat code
Mixed wetlands	82.6	0.78	WETL
Herbs	7580.7	37.41	POTA
Savannah	3.9	30.55	RNGE
Evergreen broadleaf forest	13.1	2.45	FRSE
Deciduous broad leaf forest	4784.4	1.22	FRSD
Range bush	1765.1	24.52	RNGB
Range bush	594.4	0.18	RNGB
Forest mixed	4053.3	2.89	FRST

3.2.5 Soil Definition

The Muvumba basin is mainly formed from clay and clay-loam soil type, but the riverbed has a loam and sandy-loam type of soil. The infiltration capacity of the soil depends, among others, on the porosity of the soil, which determines its storage capacity and affects the resistance of the water to flow into deep layers. Since the soil infiltration capacity depends on the soil texture, the highest infiltration rates are observed in sandy soil. This shows that, surface runoff is higher in heavy clay and loamy which has low infiltration rate. Throughout the basin the soils are generally vetisols or latosols. The soil map of the catchment is shown in Figure 11. The drainage system is well defined, the gradient of most tributaries is steep. Flood water quickly collect in the drainage channels (Hurst et al., 1959) and the loss to overflowing on flood plains or to evaporation is small over much of the basin. Because of the sparse growth of trees, steep slopes, and the shallow and often denuded soil, runoff is rapid and a relatively small amount of rainfall is retained deep percolation or absorption.

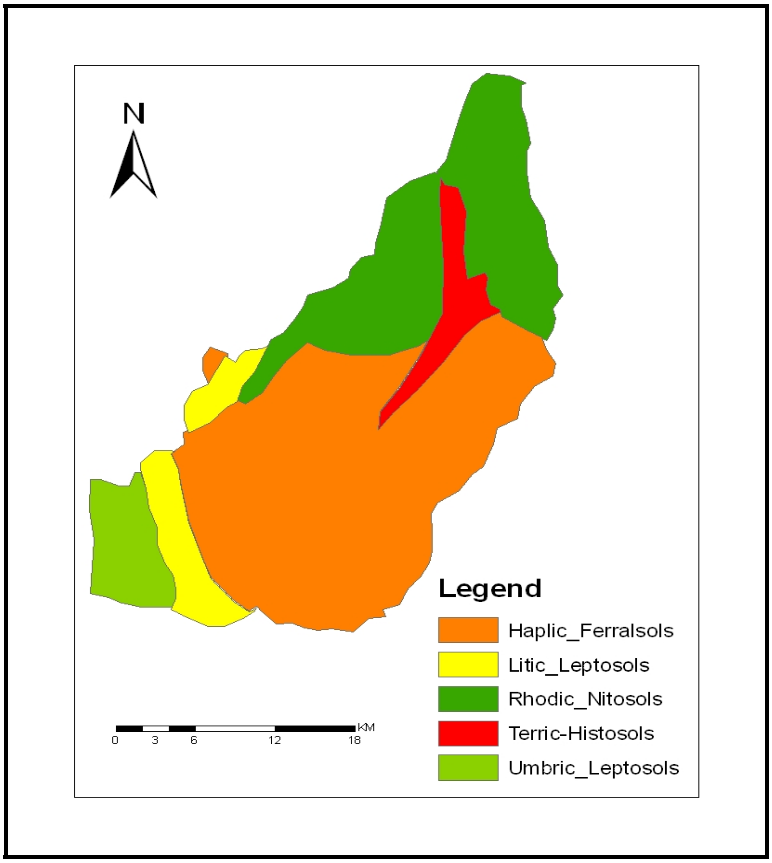


Figure 11: Soil Map of the Catchment

Table 2 Area covered by different soil layers in Muvumba Catchment

Soil layers	**Area (km^2)**	**Percent of total area (%)**
Terric Histosola	45417.9	5.48
Rhodic Nitosols	239598	26.24
Haptic Ferrasols	462344.8	54.86
Lithic Leptosols	65825.64	7.41
Umbric Leptolsa	53376.4	6.01

3.2.6 Hydrologic Response Units Distribution (HRU)

Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land cover/ crops and soils (Neitsch, 2002).

An HRU represents a sub-division in the sub-basin that is characterized by a unique combination of land use and soil type. The HRU has no location in the sub-basin model, but is only defined as a fraction of the sub-basin that can be represented by a unique combination of soil and land use. HRUs are used in most SWAT runs since they simplify a run by lumping all similar soil and land use areas into a single response unit.

HRUs can be defined in two ways namely: the dominant approach and the virtual basin approach (Sirinivasn, 1998). The dominant approach creates one HRU for each sub basin based on the most prevailing land use class and the soil class. The virtual approach creates one or more HRUs for each sub basin based on dominant of land use and soil. In this study 67 HRUs are generated.

3.2.7 Weather Data Definition

The size and complexity of the Muvumba Catchment, together with the lack of meteorological and hydrological data, is a major constraint to the application of sophisticated hydrological models. In this study, data from Metrological organization of Rwanda was used in weather data definition in SWAT. The observed grids are based exclusively on meteorological measurements from individual stations.

In order to make use of the CRU half-degree climate grids in SWAT that require station data as weather input, it is first necessary to overlay the climate grids with a SWAT sub basins shape file and then to aggregate the values in order to obtain one value per month per each sub basin. The overlay and the creation of the sub basin averages of monthly precipitation, minimum and maximum temperature as well as the number of wet days per month, were performed using a semi-automated program within ArcGIS (Schuol, 2005). This program is basically made up of the creation of Thiessen polygons around each value point representing the center of the grid cell, the overlay and intersection of the subbasin layer with the climate grids and finally the computation of the area-weighted average which is then assigned to each subbasin centroid.

The weather input files were generated at Swiss Federal Institute of Aquatic Science and Technology (Eawag) using the daily weather generator explained in the previous paragraph and are made available for this study. The climatic data required for SWAT simulation are: daily precipitation, daily maximum and minimum air temperature, daily solar radiation, daily wind speed, and daily relative humidity. If any of these data is not available, which is very likely, SWAT can generate data using a weather generator. The later three are simulated using the WXGEN in SWAT due to the absence of data. Daily precipitation and temperature data are available for each of the subbasins. To do so, monthly values are needed to generate daily ones. The rest of the required data will have to be generated from monthly data included in userwgn database included in AVSWAT databases.

3.2.8 Sensitivity analysis

Sensitivity is measured as the response of an output variable to a change in an input parameter with the greater the change in output response corresponding to a greater sensitivity. Sensitivity analysis evaluates how different parameters influence a predicted output. Parameters identified in sensitivity analysis that influence predicted outputs are often used to calibrate a model.

Sensitivity tests and preliminary model run were carried out in order to identify the most sensitive model parameters. To avoid over parameterization, only the most sensitive parameters were adjusted in model calibration. Seven sensitive parameters were identified as shown in **Table 4**. Five of these mainly affect the surface runoff (CN2, SLOPE, Sol_K, Soil_Z and Sol_AWC), the remaining two affect base flow generation (GWQMN and ALPHA_BF).

Sensitivity analysis at sub basin 30 and sub basin 1 has been carried out to get the most sensitive parameters for calibration.

During the manual calibration, range of values for some sensitive parameters has been identified without losing their physical meaning in reality. These parameters are CN2, Slope, ALPHA_BF and GWQMN.

Table 3 Sensitivity Analysis Result

Parameters	Ranking
SMFMX	28
SMFMN	28
ALPHA_BF	12
GWQMN	3
GW_REVAP	28
REVAPMN	28
ESCO	7
SLOPE	5
SLSUBBSN	13
TLAPS	28
CH_K2	14
CN2	1
SOL_AWC	2
surlag	10
SFTMP	28
SMTMP	28
TIMP	28
GW_DELAY	15
rchrg_dp	8
canmx	9
sol_k	4
sol_z	6
sol_alb	16
epco	11
ch_n	18
blai	28
BIOMIX	17

Table 4 Most sensitive parameters

SWAT Parameter Name	Description	Calibration Range	Change Option
CN2	Antecedent Moisture Condition II Curve Number	+/- 25%	3
SLOPE	Average Slope Steepness	+/- 15%	3
SOL_K	Saturated Hydraulic Conductivity (mm/hr)	+/- 50 %	3
SOL_AWC	Available Water Capacity (mm/ mm soil depth)	+/- 50 %	3
GWQMN	Threshold water level in shallow aquifer for baseflow	0 - 500 mm	1
ALPHA_BF	Baseflow Alpha Factor (days)	0 - 0.8	1
ESCO	Plant Evaporation Compensation Factor	0 - 1	1

3.2.9 Base Flow Separation

Base flow separation is the process of separating total gauged flow data into surfaceand base flow parts (fig. 12). The main aim of separating stream flow is for the purpose of calibrating estimated surface flow data. Accordingly simple base flow separation technique was used. The technique is developed on Microsoft Excel program. The base flow separation implemented in program TIMESPLOT is based on a recursive filter commonly used in signal analysis. This filter has been described by Nathan and McMahon (1990).

3.2.10 Flow Calibration and Validation

Calibration is a process of model testing with known input and output used to adjust or estimate factors. It is the process of adjusting or estimating adjustment factor by comparing simulated data with the measured ones. In this study manual calibration was used with many trial of adjusting the most sensitive parameters. Accordingly the most sensitive parameter were the curve number (CN), and the soil evaporation compensation factor (ESCO).

Validation is the Process of comparing model results with and independent data set without further adjustment of parameters. This validation process was applied after every calibration process. For evaluating the simulation result, SWAT has two approaches. These approaches are the statistical and the graphical one. The statistical are coefficient of determination (R^2), Nash-Suttcliffe simulation efficiency (E), mean and standard deviation of the simulated and measured data and slope, intercept and regression. The graphical are time step, shape, peak comparison between simulated and measured data. In this study coefficient of determination form the statistical approach and time step, shape, peak comparison between simulated and measured data form graphical approach were used.

Flow calibration was performed for a period of five years from January 1st, 1954 to December 31st, 1959. Parameters used for calibration are curve number (CN) and soil evaporation compensation factor (ESCO). First of all the total river flow was separated into surface and base flow. Then the simulated flow was calibrated manually using the separated observed surface flow gauged at the outlet of the sub watershed. It was calibrated temporally by making delicate adjustments to ensure best fitting of the simulated flow curves with the gauged flow curves. Manipulation of the parameter values were carried out within the allowable ranges recommended by SWAT developers. The initial/default and finally adjusted parameter values are shown in Table 5.

Table 5 Initial and final adjusted parameter value of flow calibration

No.	*Parameters*	*Description*	*Effect on simulation when parameter values increase*	*Range*	*Initial Value*	*Adjusted Value*
1	CN2	Initial SCS CN II value	Increase surface runoff	+/- 25%	Default.	-25%
2	ESCO	Soil evaporation compensation factor	Decrease evaporation	0-1	0.95	0.1

After Calibration the surface runoff volume was validated. The purpose of the validation was to observe visually how much the simulated pattern seems to be the measured one based on monthly basis. Besides the visual observation, statistical investigation was done to see the correlation between the two. According to the statistical result the R^2 is 0.9. This indicated that the simulation is positively and highly correlated with the measured one. As depicted in

Figure 12 , that the simulated runoff line similarly follows the pattern of the measured runoff line except deviation in some points.

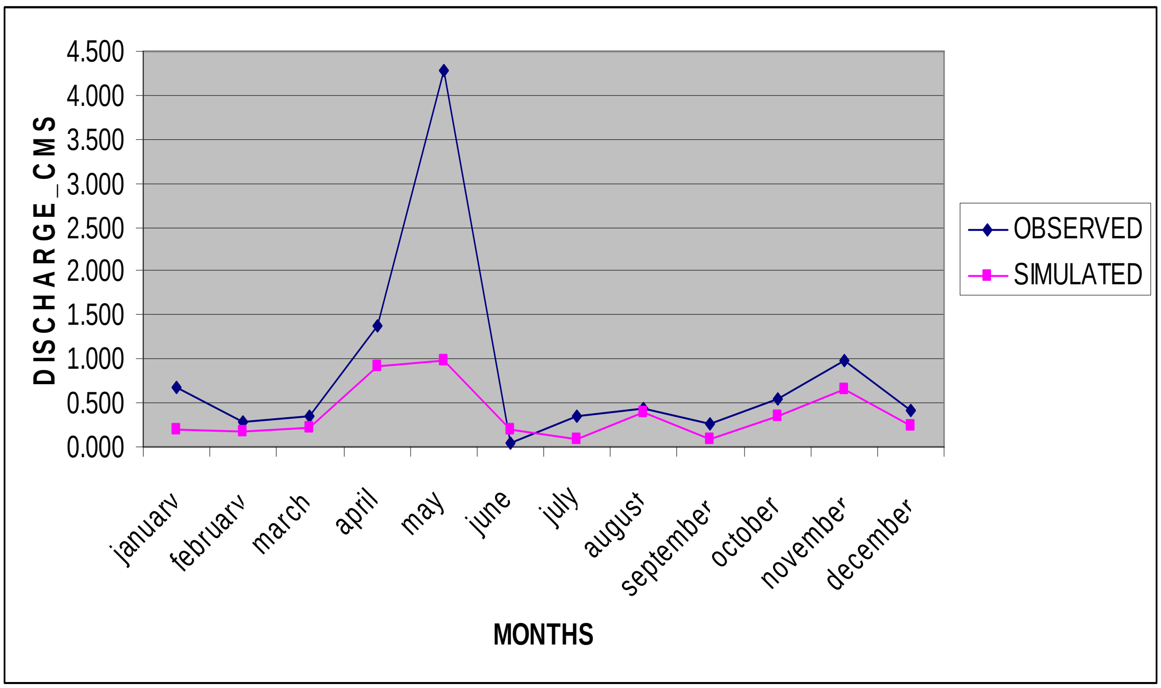


Figure 12 : Comparison of measured and simulated runoff volume

3.2.11 Validation of discharge

Discharge was simulated on monthly basis using SWAT. Hence it is necessary to validate the runoff discharges to have a better estimation of the model. The validation was done based on monthly basis from 1959 to 1960. Validation was done to observe how much the simulation similar to the measured one. Statistical analysis was also made to see the degree of correlation between the simulated and the measured one. Accordingly the correlation coefficient (R^2) is 0.7 as sis shown in Figure 13.

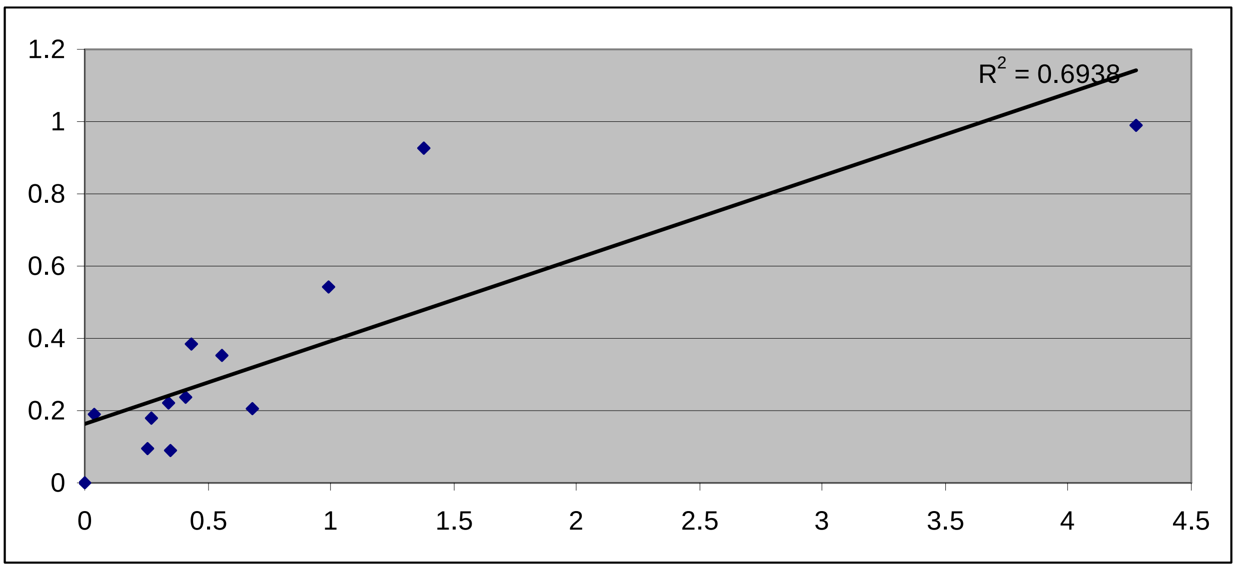


Figure 13 : Relationship between measured and simulated discharge

2. THE WATER RESOURCES POTENTIAL ALLOCATIONS IN MUVUMBA CATCHMENT

In the previous chapter, it was shown that a flow series could de generated for the Muvumba catchment using SWAT. The flow series will be generated using the calibrated and validated model of Muvumba catchment. The irrigation potential and hydropower generation capacity of the catchment are assessed in this chapter. The demand for potable water supply and demand for irrigation are computed and compared with the water available.

4.1 Water Resources Potential of Muvumba Catchment

It is computed that the annual water resources potential of the Muvumba catchment is estimated at 0.53 km^3 as shown in Table 6 according to the calibrated SWAT model for the catchment. The catchment yield given here is the sum of the contributions from all sub catchments.

Table 6 Swat output for water flow in Muvumba catchment sub basins

Sub-basin	Area_(ha)	Discharge (cubic meter/second)	Q (Km^3 /Year)
3	1975904	0.17	0.0053
6	1504757	2.20	0.0688
9	1457138	2.04	0.0638
13	494676	0.07	0.0022
11	497477	0.19	0.0059
16	8143392	0.09	0.0028
15	3792705	0.04	0.0012
18	1864420	1.76	0.0550
20	188467	0.17	0.0053
19	3089818	1.59	0.0497
24	523001	1.50	0.0469
29	1048042	1.32	0.0413
35	1970942	0.77	0.0240
36	7125052	0.60	0.0186
46	1447031	0.05	0.0016
45	1120676	0.50	0.0157
48	3582098	0.06	0.0019

50	6532741	0.38	0.0117
58	5686707	0.07	0.0022
57	1606458	0.25	0.0078
59	6307668	0.15	0.0047
60	2694818	0.10	0.0033
67	20279530	0.71	0.0221
31	1429126	0.06	0.0019
32	718804	0.19	0.0060
27	554086	0.09	0.0029
33	246937	0.70	0.0219
34	1759072	0.51	0.0159
44	754368	0.31	0.0097
51	1646845	0.11	0.0035
53	1694212	0.04	0.0013
55	3783806	0.08	0.0026
62	3048693	0.05	0.0017
61	514316	0.06	0.0017
Total	**99083781.87**	**16.98**	**0.53**

Hence, the next subsections discuss the allocations possible for various uses in the basin.

4.2 Estimation of Irrigation Potential based on physical Criteria

GIS techniques were used to establish the probable location of the identified potential irrigable areas throughout the delineated sub-basins, the overlapping system on ArcGIS tools has be used and then one can identify which sub-basin may have more probable potential irrigable areas at sub-basins level (figure 9). 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, Irrigation water requirement and water availability for irrigation.

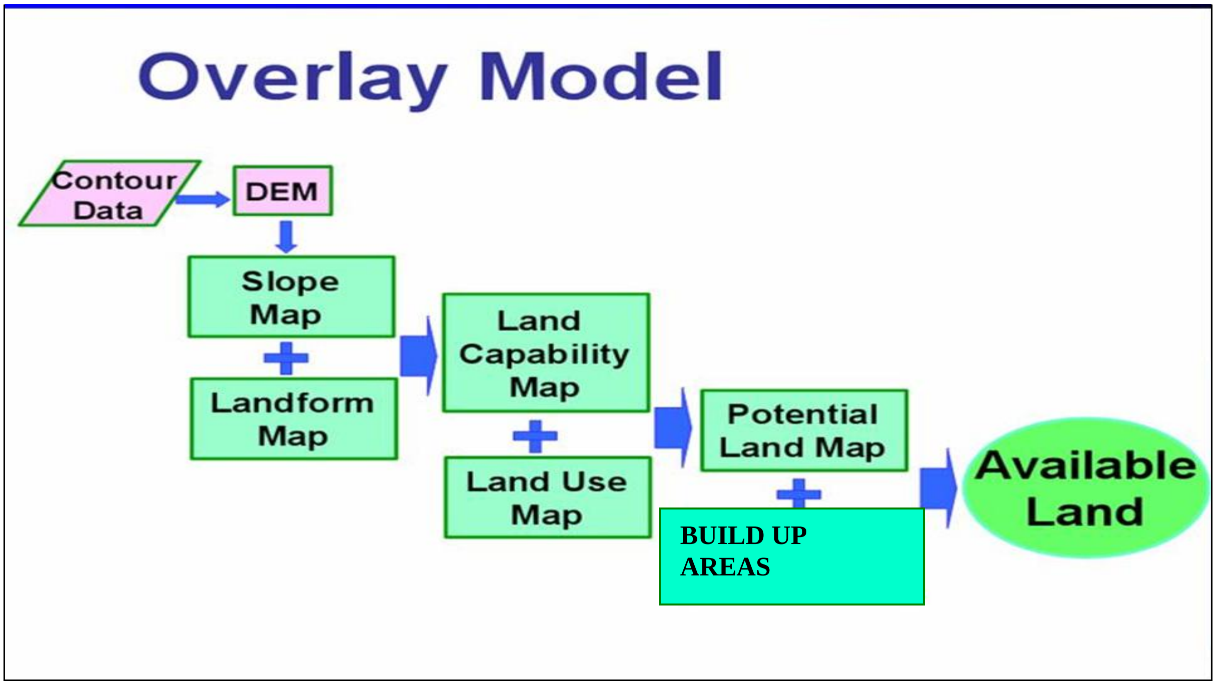


Figure 14: Schematic diagrams of GIS overlay model analysis

4.2.1 Soil and terrain suitability for surface irrigation method

The evolution 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.

4.2.2 Soil suitability for irrigation

Referring to FAO1997, the qualitative land evolution for irrigation is generally based on interpretation of Environmental characteristics, of which slope, soil and groundwater are the most important factors.

Accordingly, the criteria selected in the evaluation of soil and terrain suitability for irrigation are presented herein. These criteria are used in this study for estimating the irrigable land in Muvumba basin.

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 is made with regard to the local salinity and alkalinity situation using the following criteria such as alkalinity.

Table 7 Soil and Terrain Suitability

Criteria	Condition	Upland crops
Slope	Optimum	< 2%
	Mariginal	2%-8%
Hill side irrigation	range	<5%
Drainage(1)	Optimum	W[1]
	Marginal/Range	MW[2]-1
Texture (2)	Optimum	L[3] - SiCL[4]
	Range	SL[5]-MC[6]s
Soil depth	Optimum	> 100cm
	Marginal	50-100cm
Surface stoniness		No stones are acceptable
Subsurface stoniness	Optimum	< 40 %
	Marginal	40-75 %
Calcium carbonate	Optimum	< 30 %
	Marginal	30-60 %

Gypsum	Optimum	< 10 %
	Marginal	10-25 %
Salinity(3)	Optimum	< 8 mmhos/cm
	Marginal	8-16 mmhos/cm
Alkalinity	Optimum	< 15 ESP
	Marginal	15-30 ESP

[1] Exchange of sodium percentage

[2] W indicates a well drained soil.

[3] MW indicates moderately well drained.

[4] L = loamy soil

[5] SiCL = Clay Loam

[6] SL = Sandy loam

[7] MC = Silty Clay

Factors Determining Surface irrigation potential

Factors which were considered for evaluation of irrigation potential are.

1. Slope
2. Soil texture
3. Soil depth
4. Soil drainage(permeability)
5. Soil type
6. Land use/Land cover
7. Water resource
8. Climate (temperature &Rainfall)

Slope

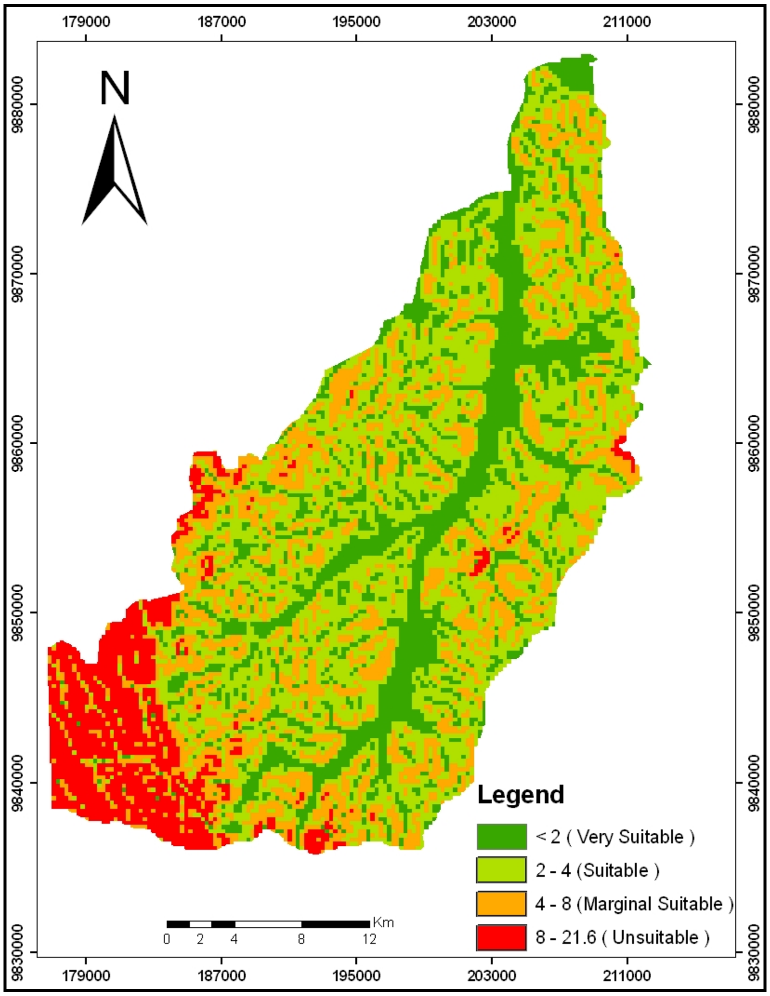


Figure 15 Reclassified slope map of Muvumba catchment.

- is the incline (gradient) of a surface and is commonly expressed in percent
- Influences on:
  - the length of the irrigation run
  - erosion control practices
  - irrigation method
  - crop adaptability
- After evaluation, Slope map was reclassified
- Slope suitability map was developed after Factor rating was given

[< 2 = Very Suitable, 2-4 = Suitable, 4-8 = Marginally Suitable, >8 =Unsuitable]

Soil Texture

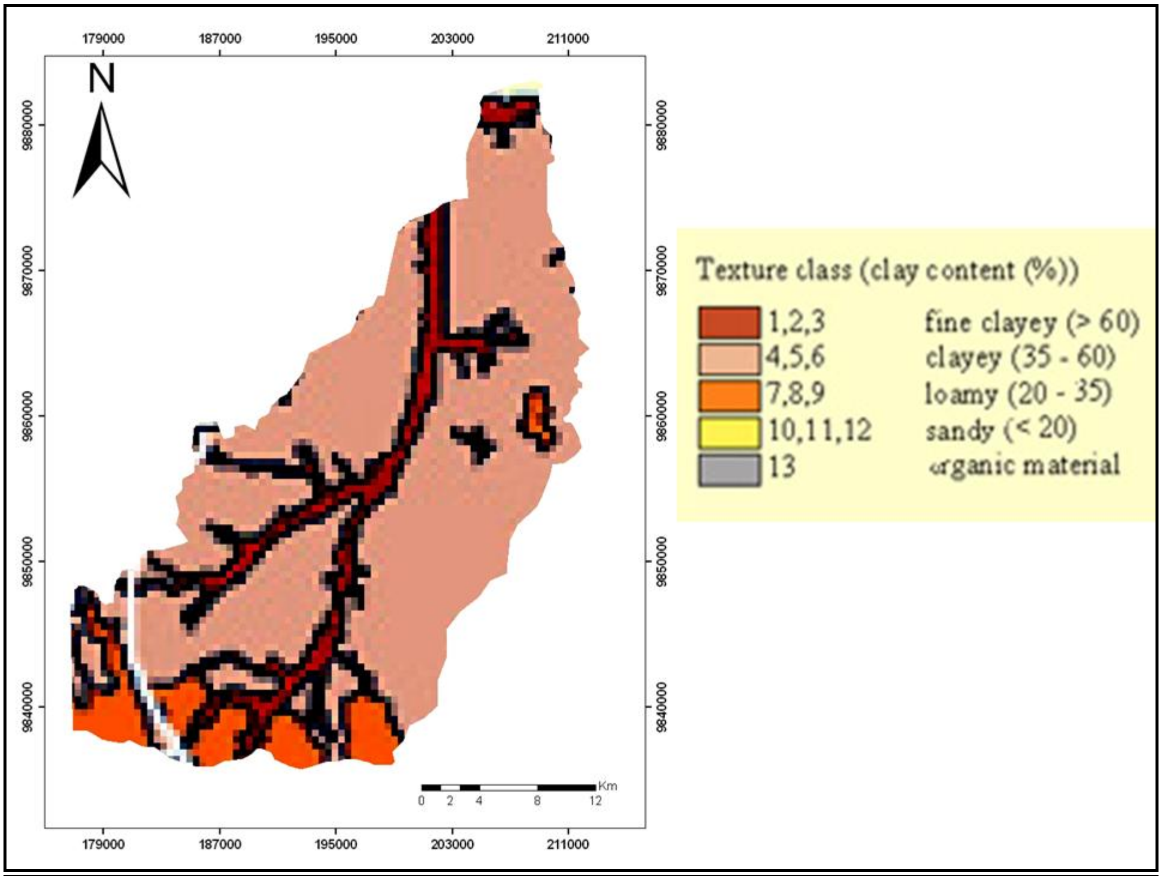


Figure 16 soil texture map of Muvumba catchment

- Based on its particles size, soils are divided in to

Clay, Silt and Sand (major one)

- Determine infiltration rate

Fine-textured soils	clay, clay loam and silty clay loam
Medium-textured	sandy clay loam, loam, and silt loam
Coarser-textured	sandy soils

Soil textures of the study area were characterized by

- Clay loam
- Clay

Soil Depth

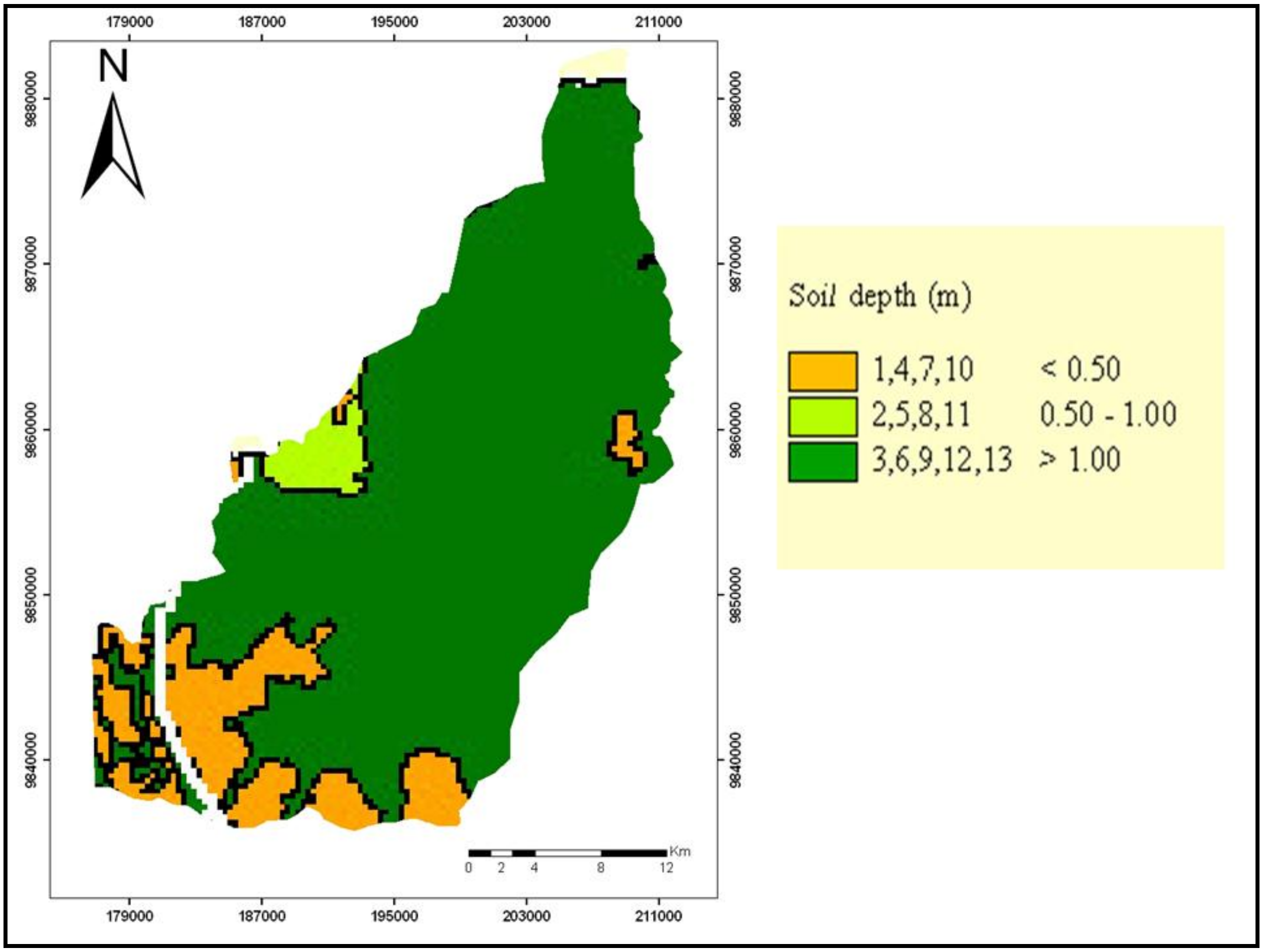


Figure 17 soil depth map of Muvumba catchment

- Refers to the thickness of the soil materials.
- provides structural support, nutrients, and water for plants
- affect irrigation management decisions
- Plants can extract only the soil water that is in contact with their roots.
- In the study area soil depth varied from place to place from<50cm up to > 150cm.
- Suitability of soil depth map was reclassified based on the requirement of irrigation using FAO guideline (FAO, 1991)

Soil Drainage

- permits normal plant growth
- is essential to ensure sustained productivity
- allow efficiency in farming operations
- the study area was reclassified in to well, moderately well and imperfectly drained land
- Haplic_ferrasols, litic_leptols, rhodic_nitosols,Terric_histosols,umbric_leptosols, were the major types of soils
- Vector format of soil type map of the study area was rasterized.

Land use/ land cover

- Influences on the cost of irrigation practice to prepare the land for agriculture.

- Includes grasses, shrub land, cultivation, woodland, bare land, wetland, plantation, natural forest.
- Rank was given to develop LU/LC suitability map based on costs to remove or change for cultivation and environmental impacts under the basin.

- For cultivation, plantation, bare land, =1(very suitable)

For grasses, =2(suitable)

For shrub land, woodland highland bamboo =3(marginal suitable)

For natural forest, wetland, =4(unsuitable)

Water Resource & Climate

Rainfall

- Muvumba River is grouped under the main rivers found in the country.
- Large area of the basin is characterized by well external drainage.
- Climate of the study area was characterized by semi arid.
- The basin has two rainy seasons.

  Av.T0 = 21c0

Average RF of 800mm

Temperature &Rainfall map were developed using IDW (Inverse Distance Weighted) techniques

Multi-Criteria Decision Evaluation (MCDE) Method

- After evaluation of the physical land capability of the basin, physical land suitability map for irrigation was developed.

- MCDE method was used to develop irrigation suitability map. This method has procedures.

Procedures

- Establishing the Criteria:

Factors considered for the physical land suitability for irrigation are:

- Slope gradients
- Soil texture
- Soil depth
- Soil drainage
- land use/land cover of the basin
- Soil type of the basin

Constraints:

- limit the alternatives
- are excluded from consideration
- road and built up area (town) were considered as constraints
- Standardizing the Factors
- Pair wise technique was used for standardizing the factors.
- Ratings were given for all factors on a 9-point continuous scale
- by taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria, weights were given for all factors.

If the consistency ratio is < 0.1 it is acceptable for weighting the factors

Table 8: Weighting Factor

Factors	Slope	Soil Drainage	Depth	Texture	Soil type	Land use
Slope	1					
Soil Drainage	1/3	1				
Depth	1/3	1/3	1			
Texture	1/5	1/3	1/5	1		
Land use	1/5	1/3	1/3	3	1	
Soil type	1/5	1/5	1/3	1/3	1/3	1

- <u>Weighting the Factors:</u>

Eigenvector of the pair wise comparison matrix

Factors	Wi
Slope	0.42
Soil drainage	0.21
Soil depth	0.14
Soil texture	0.10
Land use	0.08
Soil type	0.05
CR	0.04

Undertaking the Multi-Criteria Evaluation:

After criteria maps (factors and constraints) had been developed, an evaluation (or aggregation) stage was undertaken to combine the information from the factors and constraints.

-Weighted Linear Combination (WLC) technique was used to develop the physical land suitability map of the basin.

-Multiply standardized factors map by its factor weight and then sum the results

$$S = \sum Wi\ Xj$$

S = 0.42 **SP**+ 0.21**SD**+ 0.14 **D**+0.10 **T**+0.08 **L.U**+0.05 **S.T**

Where:

S is the irrigation suitability land

SP is the Slope

SD is Soil drainage

D is the soil depth

T is the texture

L.U is the land use

S.T is the soil type

As per the above criteria two main land uses have been considered. These are “Upland crops and flooded rice”. Priority is given to flooded rice where both crops are found to be suitable in order to avoid double counting.

With in this context**,** 9908.4 hectors potential irrigation area was delineated in the basin. As shown in figure 15, most of the irrigation area is located at the right bank of the river and follows the main stream.

The modeling results shown in table 6 that the annual runoff volume from selected sub basin in Muvumba catchment is 531 Million cubic meter (MCM). The specific yield of the catchment is 1.911 $l/s/km^2$ or 0.019 l/s/ha. The potentially irrigable land is estimated at 9908.4 hectares. The amount of water allocated for irrigation is 114 Million cubic meters (MCM).

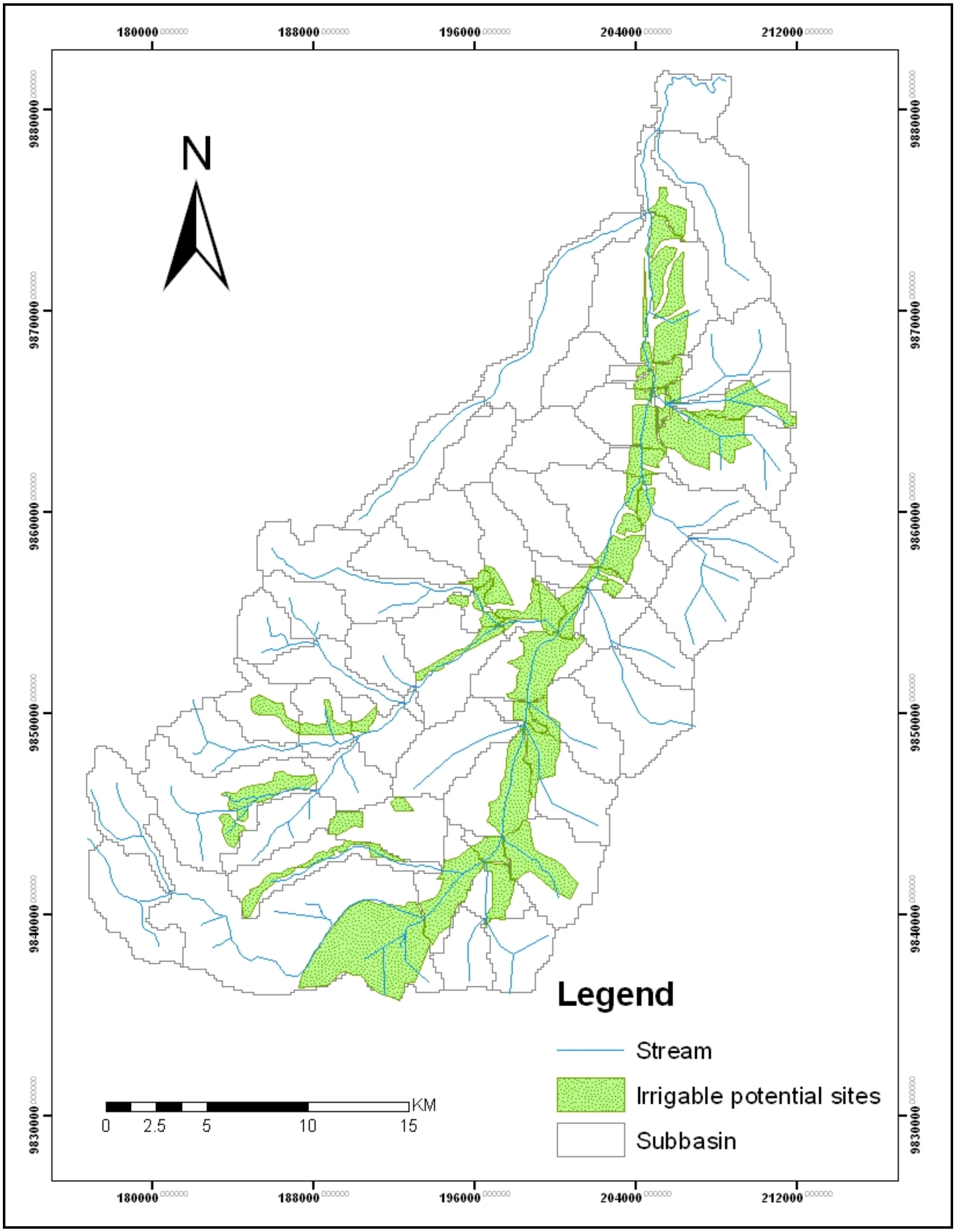


Figure 18   Potential Irrigation sites in Muvumba catchment

4.2.3 Irrigation water requirements

The irrigation water demand can be established from estimates using empirical formula. Generally, irrigation water demands and use are estimated from empirical equations or calculated from readings of flow measurements located on irrigation schemes. Herein the crops are classified into FAO defined types and the Crop water requirements (CWR) or Irrigation Water demand (IR) is computed in millimetres using CROPWAT (FAO, 1997).

Each crop type has it 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 (CWRI) calculated for each irrigated crop. Multiple cropping (several cropping 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[7] or in m^3 / ha.

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 values by Author.

Table 9: **Gross irrigation water requirement used by Autho**r

Authors	Study area	Type of crops	FWS	
			l/sec/ha	m^3/ha/year
KABWA. A, 2003	Nile Basin zone	Upland crop	1.174	18,460(*)
		Lowland crop	0.74	11,636(*)

.

Table 10: Irrigation Cropping Patterns for Rwanda (FAO, 1997)

Cropping season	**Main crops**	**Cropping calendar**												**Cropping intensity**	
		J	F	M	A	M	J	J	A	S	O	N	O	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
														70	70

Note:

h stands for harvesting

p stands for planting

In order to assess the water demand for the exploitation of irrigation potential of the identified areas, the existing information have been reviewed to compute the gross irrigation water requirement (GIWR) or Field Water supply per unit area (FWS).

The table below shows the assumed values by different Authors. FAO CROPWAT were used also to carry out detailed calculations to Estimate irrigation water demand and use for specified crop type as showed in table 3. In the use of the model in the thesis is more focused to lump the result on SWAT model final output in table 4.

Table 11: Crop water requirements for selected crops

Crops Type	**Growing Season**	**Planting Date**	**Harvesting Date**	**Estimated irrigation Period**		**Water Duty or FWS (0.74L/SEC/ha)**		**GIWR for 9908.4ha (km^3/year)**
				Irrigation/ season	Irrig. Period /year			
Sorghum	Wet I Wet II	Feb/March Sep/Oct	June/July Jan/Feb	3 month 3 months	6 months/year	**11636 (m^3/ha/year**	**$1.163*10^{-5}$ (Km^3/ha/year)**	**0.115**
Maize	Wet I Wet I	Feb/March Sep/Oct	June/July Jan/Feb	3 month 3 months	6 months/year			
Tomato	Wet I Wet II	Feb/March Sep/Oct	June/July Jan/Feb	3 month 3 months	6 months/year			
Dry beans	Wet I Wet II	March/Apr Oct/Nov	June/July Jan/Feb	3 month 3 month	6 months/year			

Hence, from Table , it can be shown that there is sufficient water for irrigation and the whole irrigation requirement could be satisfied.

4.3 Delineation of potable water potential

The use of hydrological models for the evaluation of surface and groundwater resource in conjunction with ancillary ground information in GIS environment is becoming an effective method for the improvement of groundwater development success rate. In order to arrive at the groundwater prospect map raster based GIS modeling was conducted using Weighted Linear Combination (WLC) method considering different parameters including drainage density, slope, lithiology and lineaments.

4.3.1 Drainage system and slope

Drainage

The drainage that develops in a given area depends on slope, the composition of the underlying bedrock and patterns of geologic structures such as faults/fractures, joints, olds, etc. Drainage network can be described according to its pattern and texture. Drainage pattern is the design formed by the aggregate of drainage ways in an area regardless of whether they are occupied by permanent or perennial stream (Ali, 2006).

The drainage texture that develops in an area gives important clues of the subsurface conditions, which help in deciphering groundwater conditions of the area. Fine drainage texture develops on bedrock where surface runoff exceeds infiltration and coarse drainage develops on permeable bed rock where infiltration exceeds surface runoff. In porous geologic formation surface drainage will be less developed or completely missing. (Figure 19).

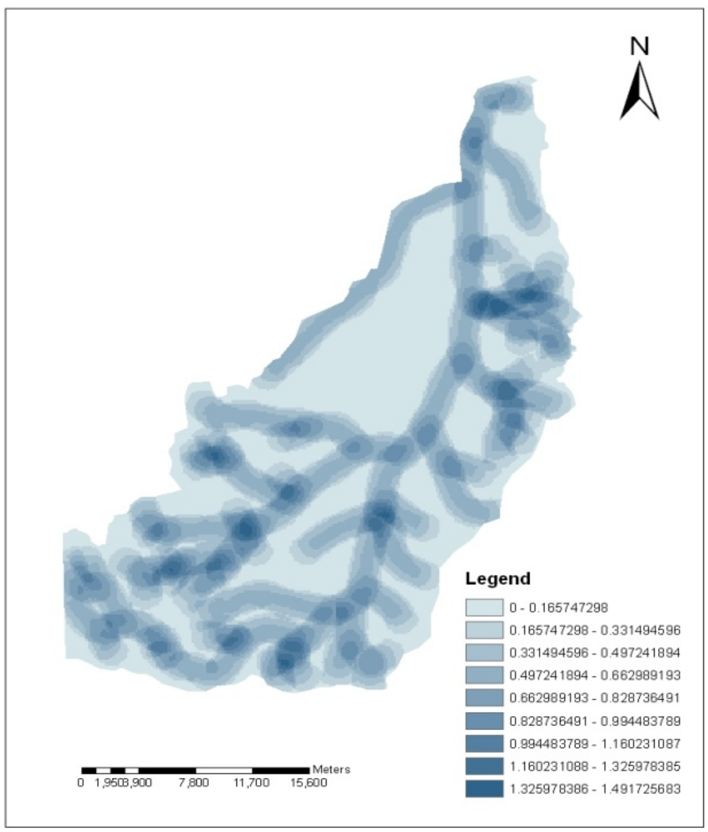


Figure 19: Drainage density map

Slope

Slope determines the hydrological characteristics of the catchment. Higher slope results in higher hydraulic gradient which favors overland flow than percolation by reducing residence time of the precipitation.

In order to generate slope map, contour lines were digitized from the mosaic of topographic map. The digitized contours were used to generate Triangulated Irregular Network (TIN) from which the slope map of the study area was generated (Figure 20).

The generated slope map was reclassified into 5 classes (flat, gentle, moderate, steep and very steep) and assigned class weight based on degree of importance calculated using pairwise comparison matrix with CR of 0.05 (Table7). The classification result revealed that most part of the study area is flat and gentle with weighted percentage of about 51 and 26 respectively.

Table 12: Class weight of slope

	Slope Degree	Weight	Weight percentage
Flat	0 - 2.94	0.5128	51.3
Gentle	2.94 -9.49	0.2615	26.3
Moderate	9.49 -18.64	0.129	12.9
Steep	18.64- 30	0.0967	9.5

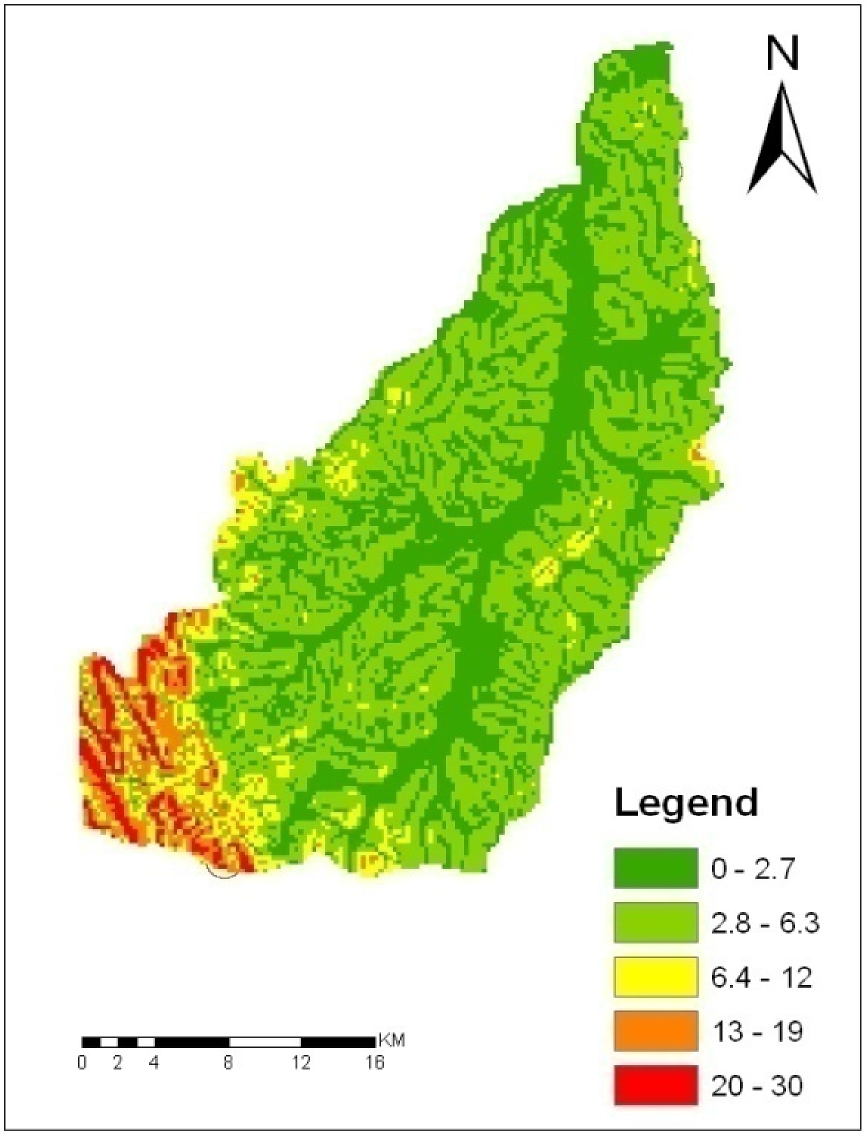


Figure 20: Slope map

4.3.2 Lithology

Lithiology is one of the factors that indicate the groundwater prospect of an area. Different lithologic units have distinct porosity and permeability. The porosity determines the amount of water which can be held in storage and the permeability determines the ease of withdrawing the water for use (Stanley et al., 1966).

Lithology determines the type of porosity that the rock possesses. The dominant porosity that exists in unconsolidated sediments is intergranular, fracture porosity in consolidated rocks and double porosity in some consolidated volcanic and sedimentary rocks as shown in figure 21.

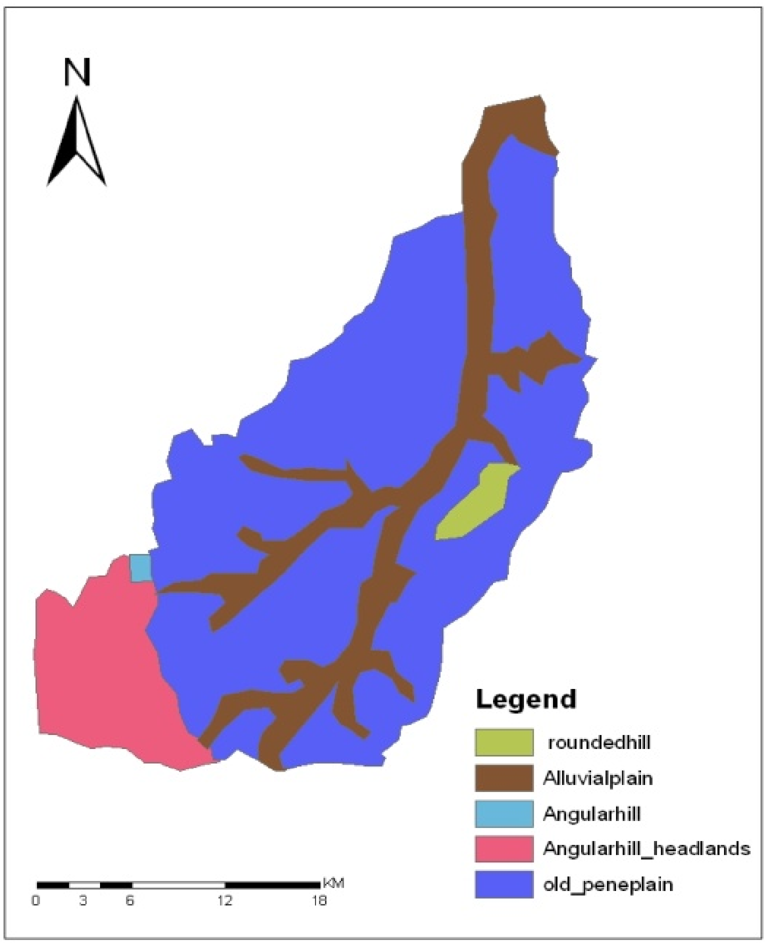


Figure 21: Lithiology Map

Lineaments are significant lines of landscape caused by joints and faults revealing the architecture of rock basement (Hobbs, 1904) as cited in Sander, 2007. Lineaments are zones of increased porosity and permeability in hard rocks. Mapping of lineaments is one of the key factors in understanding groundwater occurrence and movement in hard rock terrain.
Mapping of lineaments, as shown in

Figure 14, can be carried out from topographic maps and digital elevation models (DEM).

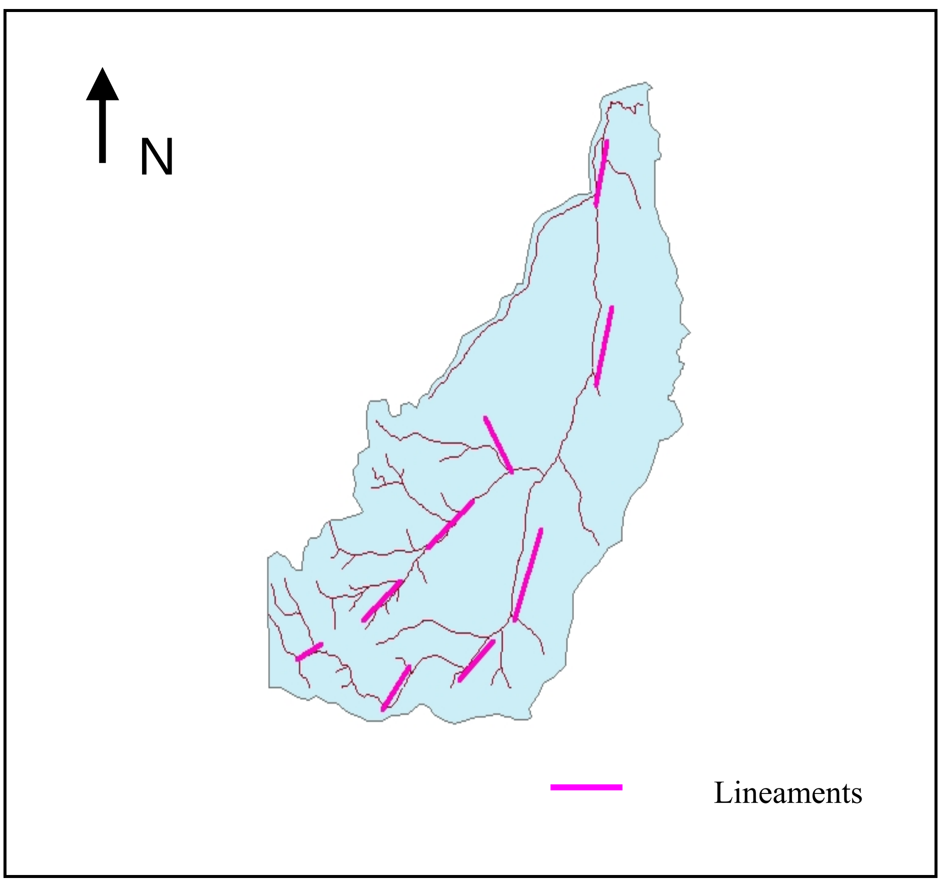
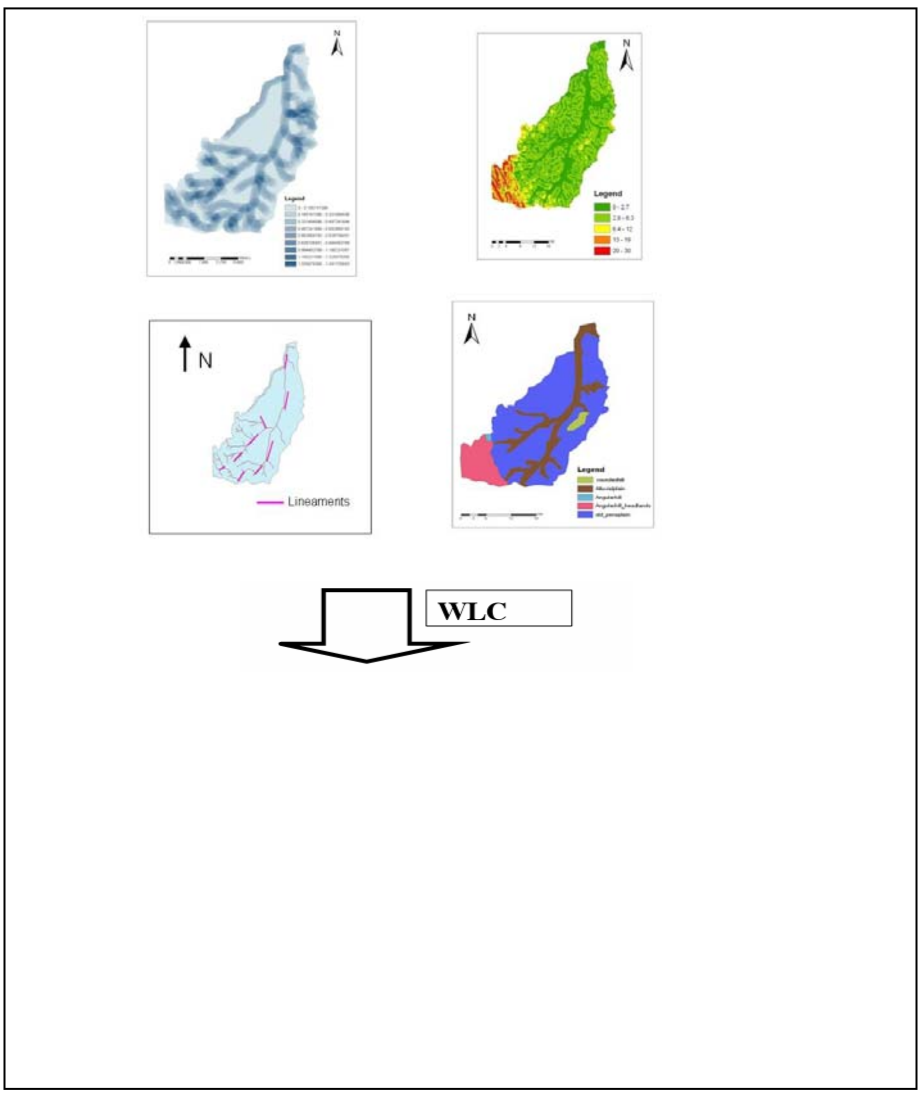


Figure 14: Linements Map

Based on different parameters in GIS overlay analysis the final Potential potable water map were produced as showed in Figure 2 . For this, the vector thematic layers generated from topographic maps and geologic map were converted to raster layer. All factor maps were reclassified and class weight determined through multi-criteria evaluation technique using pair wise comparison matrix. The weight of each factor map was determined through similar procedure CR for the matrix is 0.10. Accordingly thermal lineaments which were assumed to be tectonic lineaments and having groundwater manifestation were given a higher degree of influence as compared to the remaining seven factors.

Aggregation of the class and factor map weight was done using WLC whereby the class weights were multiplied with the factor weight and the products were summed over all attributes (figure 23).



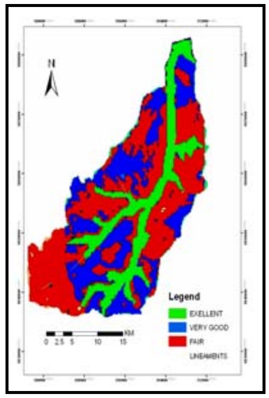


Figure 23: Surface and Ground water prospect map

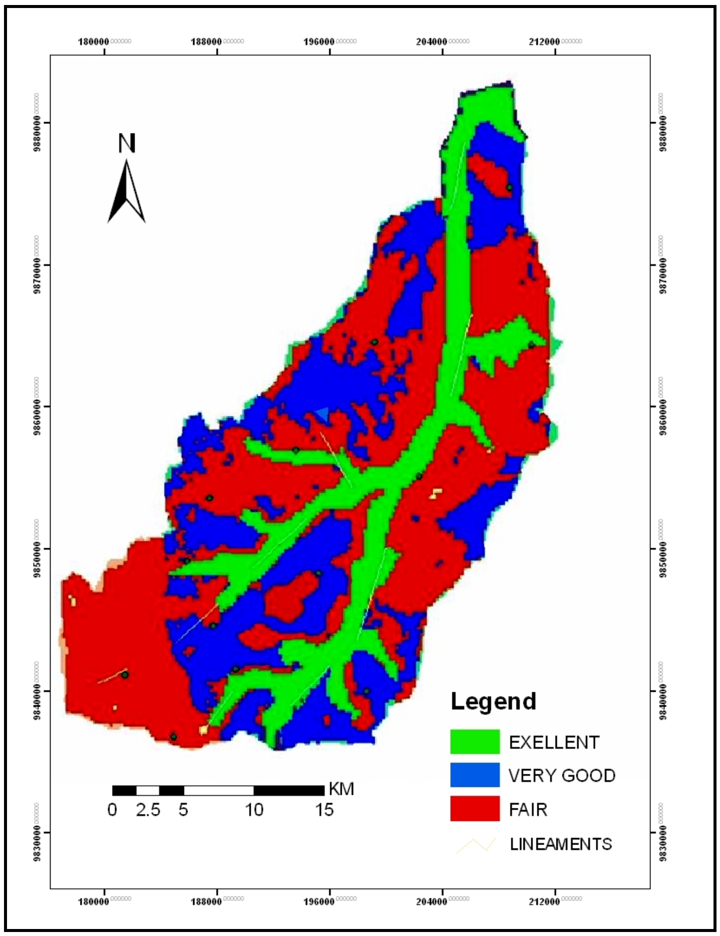


Figure 24: Potential potable water extraction sites

The green partner shows (figure 24) the excellence following the river patterns these sites a located along the river course.

Those site with very good potential for portable water supply are shown in blue, sites with marginal portable water are marked red .

The unit consumption rates, the levels of service and the consumer population 394217 with live stock demand 260,793 of Muvumba catchment have been used to calculate the domestic water demand as shown in appendix 1.

The result found to be 14 Million cubic meters (MCM) in the year 2022 as described in appendix 1**.** The total water demand for potable water can be fetched from the surface water of the catchment. Besides the usage of surface water potential can assist the projected growing population demand.

3. CONCLUSION AND RECOMMENDATIONS

In this study, it has been tried to assess the water resources potential using hydrological models and allocate the resource for potable water and irrigation. Under the framework of the main objective a number of statuses have been set out and briefly described to contribute to the aim of the prime goal.

General analyses of physiographic and hydrologic characteristics of Muvumba catchment have been provided. With this regard, SWAT MODEL is employed to establish 67 sub-basins in Muvumba with extensive and relatively accurate drainage information. For visual and spatial presentation of results, various maps have been provided to locate the potential irrigable areas, and potential sources of potable water.

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 Muvumba basin for the set objectives. The outcomes contained in this study provide:

About 9908.4 hectars of potential irrigable land with estimated GIWR of 0.115 km^3/year. The available surface water developable for supplying the demand in this identified irrigable areas is 0.53 km^3/year of estimated. Irrigation cropping patterns for the catchment are recommended.

In view of the results, the Muvumba basin has an estimated potential irrigable area of about 20% of the total area. The water availability from river runoff exploitation can satisfy the GIWR for the identified theoretical potential irrigable site.

It is recommended that a number of gauging stations are installed in order to better assess the water resources potential. Moreover, a detailed baseline survey should be carried out in order to assess the demand of water resources. Hence, further research is recommended identification of demand and supply of water.

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Appendix

Appendix 1 water demand in the catchment

Consumption Parameters

HC (l/h/d)		100	5%	Pop Growth Rate ('	2.2	Max Day Factor	0.2
YT		40	45%	Non-Domestic Der	0.15	Livestock Growth (%)	2
SP		20	30%	Losses	0.2	Livestock Demand (l/h/d)	50

Year	Nyagatare		Pop at Given Service Level			Average Demand (m3/d)							Max Day Demand (m3/d)	
	Human	Livestock	HC	YT	SP	HC	YT	SP	Non-Dom	Livestock	Losses	Net Demand	Max Day	Grand Total
2002	255,104	175,506	12,755	114,797	76,531	1,276	4,592	1,531	1,110	8,775	3,457	20,740	4,148	24,888
2003	260,716	179,016	13,036	117,322	78,215	1,304	4,693	1,564	1,134	8,951	3,529	21,175	4,235	25,410
2004	266,452	182,597	13,323	119,903	79,936	1,332	4,796	1,599	1,159	9,130	3,603	21,619	4,324	25,943
2005	272,314	186,249	13,616	122,541	81,694	1,362	4,902	1,634	1,185	9,312	3,679	22,073	4,415	26,487
2006	278,305	189,973	13,915	125,237	83,491	1,392	5,009	1,670	1,211	9,499	3,756	22,536	4,507	27,043
2007	284,428	193,773	14,221	127,992	85,328	1,422	5,120	1,707	1,237	9,689	3,835	23,009	4,602	27,611
2008	290,685	197,648	14,534	130,808	87,206	1,453	5,232	1,744	1,264	9,882	3,915	23,492	4,698	28,191
2009	297,080	201,601	14,854	133,686	89,124	1,485	5,347	1,782	1,292	10,080	3,998	23,985	4,797	28,782
2010	303,616	205,633	15,181	136,627	91,085	1,518	5,465	1,822	1,321	10,282	4,081	24,489	4,898	29,386
2011	310,295	209,746	15,515	139,633	93,089	1,551	5,585	1,862	1,350	10,487	4,167	25,003	5,001	30,003
2012	317,122	213,941	15,856	142,705	95,137	1,586	5,708	1,903	1,379	10,697	4,255	25,528	5,106	30,633
2013	324,099	218,220	16,205	145,844	97,230	1,620	5,834	1,945	1,410	10,911	4,344	26,064	5,213	31,276
2014	331,229	222,584	16,561	149,053	99,369	1,656	5,962	1,987	1,441	11,129	4,435	26,611	5,322	31,933
2015	338,516	227,036	16,926	152,332	101,555	1,693	6,093	2,031	1,473	11,352	4,528	27,170	5,434	32,603
2016	345,963	231,577	17,298	155,683	103,789	1,730	6,227	2,076	1,505	11,579	4,623	27,740	5,548	33,288
2017	353,574	236,208	17,679	159,108	106,072	1,768	6,364	2,121	1,538	11,810	4,720	28,323	5,665	33,987
2018	361,353	240,932	18,068	162,609	108,406	1,807	6,504	2,168	1,572	12,047	4,820	28,917	5,783	34,701
2019	369,303	245,751	18,465	166,186	110,791	1,847	6,647	2,216	1,606	12,288	4,921	29,525	5,905	35,429
2020	377,427	250,666	18,871	169,842	113,228	1,887	6,794	2,265	1,642	12,533	5,024	30,145	6,029	36,174
2021	385,731	255,679	19,287	173,579	115,719	1,929	6,943	2,314	1,678	12,784	5,130	30,778	6,156	36,933
2022	394,217	260,793	19,711	177,398	118,265	1,971	7,096	2,365	1,715	13,040	5,237	31,424	6,285	37,709

Appendix 2 Population Growth Rate

Year/District	Bugesera	Rwamagana	Kayonza	Ngoma	Kirehe	Gatsibo	Nyagatare
Population 2002	266,775	220,502	209,723	235,109	229,468	283,456	255,104
Population 2007	297,440	245,848	233,830	262,134	255,845	316,039	284,428
Population 2012	331,630	274,108	260,708	292,266	285,254	352,366	317,122
Population 2017	369,750	305,616	290,676	325,861	318,043	392,870	353,574
Population 2020	394,695	326,234	310,286	347,845	339,499	419,374	377,427
Population 2022	412,252	340,746	324,089	363,318	354,601	438,030	394,217

Appendix 3 River flow data MCM

yearly summary of daily discharge

discharge in cubic meters per second

JAN	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.83	5.04	7.83	5.92	23.16	12.7	11.7	4.76	8.37	6.56	7.65	9.47
4.9	5.18	7.65	5.84	22.68	12	11.4	4.76	7.47	6.96	7.04	8.64
6.88	5.25	6.8	5.76	24.25	12.1	10.71	4.69	6.4	6.24	6	7.92
6.48	5.68	6.88	5.6	28.06	14.16	10.05	4.62	5.68	5.46	5.53	7.29
6	5.46	7.65	5.32	27.02	14.16	9.28	4.55	5.39	5.11	5.46	7.04
5.76	5.32	7.12	5.11	25.75	1250	8.37	4.48	5.18	5.25	5.53	7.56
6.56	5.04	6.96	4.83	25.75	11.4	7.56	4.41	5.11	5.11	9.57	7.65
5.76	4.9	7.12	4.76	20.83	10.71	7.2	4.48	5.04	5.39	13.43	7.65
7.2	4.9	6.8	5.04	21.6	12	6.96	4.48	5.04	5.11	11.9	7.65
6.64	4.76	6.72	6.64	20.5	10.33	6.64	4.41	5.11	5.04	11.2	8.01
6.4	5.53	6.72	6.08	21.72	9.28	6.4	4.41	5.46	4.9	12.1	7.83
6.64	4.48	6.4	6.64	22.8	8.73	6.16	4.41	6	4.83	11.4	7.12
592	4.97	6.28	6.24	22.56	8.28	5.92	4.41	5.76	4.69	11.1	7.12
5.46	5.32	5.96	7.56	27.67	8.87	5.68	4.34	5.46	6.16	10.81	7.2
5.11	5.32	5.68	7.2	26.12	14.47	5.6	4.41	5.25	5.25	12.9	6.88
4.9	6.88	6.2	7.04	24.37	14.47	5.53	4.41	5.04	6	11.4	6.48
4.69	3.72	7.56	9	26	13.21	5.46	441	4.83	5.39	9.47	6.16
4.62	3.9	8.82	10.33	27.54	11.2	5.39	4.41	4.76	4.97	8.46	6.4
5.25	4.08	7.92	9.19	22.8	9.76	5.32	5.25	4.69	5.39	9	9
539	7.65	7.47	8.64	19.51	13.85	5.25	5.32	4.55	5.39	13	8.1
5.32	7.38	7.47	9.95	27.93	13.21	5.18	5.11	4.34	5.39	14.69	7.04
5.25	7.12	7.56	11.5	29.66	12.6	5.11	4.97	4.41	518	11.9	6.64
5.04	6.8	8.1	12.9	3215	12.4	5.04	504	4.41	6.32	10.9	6.08
4.9	6.64	810	17.2	27.8	11.6	5.04	504	4.48	5.92	12	5.6
490	7.2	9.76	20.94	23.76	11.5	504	8.82	7.56	624	14.79	5.25
490	6.8	8.91	19118	1874	12.8	4.97	8.82	6.32	6.4	14.26	5.04
4.69	6.48	7.65	1940	1863	1654	4.9	8.82	5.84	6.24	13.21	4.83
4.55	6.32	7.29	20.06	18.63	16.98	4.9	7.65	5.32	5.84	12.8	546
4.48	7.29	7.12	17.42	18.85	14.47	4.83	9.28	5.32	5.53	11.7	5.04
5.18		7.23	20.72	17.53	12.5	4.83	8.1	5.92	5.32	10.71	4.76
5.53		6.48		15.55		4.83	8.1		5.46		4.48

Appendix 4 projected population of eastern province of Rwanda

Country	Installed capacity (MW)	Total Net Generation 9GWh)	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	360	174

Appendix 5 Crop Parameters-SWAT

Crop Parameters used by the SWAT model

1 AGRL 4 Agricultural Land-Generic true

33.50 0.45 3.00 0.15 0.05 0.50 0.95 0.64 1.00 2.00 30.00 11.00 0.0199 0.0032 0.0440 0.0164

0.0128 0.0060 0.0022 0.0018 0.250 0.200 0.005 4.000 0.750 8.500 660.000 36.000 0.050

2 AGRR 4 Agricultural Land-Row Crops true

39.00 0.50 3.00 0.15 0.05 0.50 0.95 0.70 2.50 2.00 25.00 8.00 0.0140 0.0016 0.0470 0.0177

0.0138 0.0048 0.0018 0.0014 0.300 0.200 0.007 4.000 0.750 7.200 660.000 45.000 0.050

3 FRSD 7 Forest-Deciduous false

15.00 0.76 5.00 0.05 0.05 0.40 0.95 0.99 6.00 3.50 30.00 10.00 0.0015 0.0003 0.0060 0.0020

0.0015 0.0007 0.0004 0.0003 0.010 0.001 0.002 4.000 0.750 8.000 660.000 16.000 0.050

4 FRSE 7 Forest-Evergreen false

15.00 0.76 5.00 0.15 0.70 0.25 0.99 0.99 10.00 3.50

30.00 0.00 0.0015 0.0003 0.0060 0.0020 0.0015 0.0007 0.0004 0.0003

0.600 0.001 0.002 4.000 0.750 8.000 660.000 16.000 0.050

5 FRST 7 Forest-Mixed false

15.00 0.76 5.00 0.05 0.05 0.40 0.95 0.99 6.00 3.50 30.00 10.00 0.0015 0.0003 0.0060 0.0020

0.0015 0.0007 0.0004 0.0003 0.010 0.001 0.002 4.000 0.750 8.000 660.000 16.000 0.050

6 PAST 6 Pasture false

35.00 0.90 4.00 0.05 0.05 0.49 0.95 0.99 0.50 2.00 25.00 12.00 0.0234 0.0033 0.0600 0.0231

0.0134 0.0084 0.0032 0.0019 0.900 0.003 0.005 4.000 0.750 10.000 660.000 36.000 0.050

7 RNGB 6 Range-Brush false

34.00 0.90 2.00 0.05 0.10 0.25 0.70 0.35 1.00 2.00 25.00 12.00 0.0160 0.0022 0.0200 0.0120

0.0050 0.0014 0.0010 0.0007 0.900 0.003 0.005 4.000 0.750 10.000 660.000 39.000 0.050

2 URMD Residential-Medium Density

0.380 0.300 0.240 0.180 225.000 0.750 550.000 232.000 7.200

Appendix 6: Weather Generator Parameters-SWAT

Weather generator (WGEN) parameters used by the SWAT model

Legend of the parameters used in the weather generation		
	Symbol	***Symbol Description***
A	TMPMX	Average or mean daily maximum air temperature for month (ºC).
B	TMPMN	Average or mean daily minimum air temperature for month (ºC).
C	TMPSTDMX	Standard deviation for daily maximum air temperature in month (ºC).
D	TMPSTDMN	Standard deviation for daily minimum air temperature in month (ºC).
E	PCPMM	Average or mean total monthly precipitation (mm H2O).
F	PCPSTD	Standard deviation for daily precipitation in month (mm H2O/day).
G	PCPSKW	Skew coefficient for daily precipitation in month.
H	PR_W1	Probability of a wet day following a dry day in the month.
I	PR_W2	Probability of a wet day following a wet day in the month.
J	PCPD	Average number of days of precipitation in month.
K	SOLARAV	Average daily solar radiation for month (MJ/m2/day).
L	DEWPT	Average daily dew point temperature in month (ºC).
M	WNDAV	Average daily wind speed in month (m/s).

Station Name	**Nyagatare**	**Byumba**	**Kagitumba**	**Mulindi**	**Gabiro**
X	203477	171855	207280	216486	210682
Y	9852493	9823273	9875710	9846489	9830278
Z	1450	2235	1280	2100	1472
TMPMX1	25.19	21.1	26.4	26.4	26.4
TMPMX2	25.54	20.9	26.1	26.1	26.1
TMPMX3	25.24	20.1	27.4	27.4	27.4
TMPMX4	24.78	19.8	27.2	27.2	27.2
TMPMX5	24.69	20.2	27.3	27.3	27.3
TMPMX6	25.05	20.5	26.9	26.9	26.9
TMPMX7	25.66	20.6	27.1	27.1	27.1
TMPMX8	26.56	20.7	27.5	27.5	27.5
TMPMX9	26	20.3	27.1	27.1	27.1
TMPMX10	25.12	20.2	27	27	27
TMPMX11	24.58	17.9	25.4	25.4	25.4
TMPMX12	24.86	18.7	25.3	25.3	25.3
TMPMN1	15.33	10.1	15	16.8	10.1
TMPMN2	15.47	10.8	14.7	16.7	10.8
TMPMN3	15.54	16.2	15.4	16.9	16.2
TMPMN4	15.77	15.7	16.2	16.8	15.7
TMPMN5	15.73	17.7	15.8	16.8	17.7

TMPMN6	14.84	14	14.2	16.8	14
TMPMN7	14.07	14.8	14.8	17.2	14.8
TMPMN8	14.94	14.5	15.3	16.7	14.5
TMPMN9	15.33	14	15.7	16.7	14
TMPMN10	15.48	14.2	16.3	16.7	14.2
TMPMN11	15.33	14.2	15.6	17.4	14.2
TMPMN12	15.36	13.8	15.2	16.2	13.8
TMPSTDMX1	1	0.91	1.17	0.84	0.92
TMPSTDMX2	2	0.89	1.71	8.52	0.88
TMPSTDMX3	1	0.95	1.47	1.33	0.88
TMPSTDMX4	1	0.65	0.71	6.19	0.85
TMPSTDMX5	1	0.69	1.29	8.36	0.79
TMPSTDMX6	1	0.58	0.69	1.09	0.69
TMPSTDMX7	1	0.37	0.71	8.76	0.62
TMPSTDMX8	1	0.41	0.94	8.82	0.73
TMPSTDMX9	1	0.29	0.93	8.82	0.84
TMPSTDMX10	1	0.39	0.92	1.13	0.75
TMPSTDMX11	5	0.35	1.21	1.38	0.67
TMPSTDMX12	5	0.63	0.71	6.14	0.76
TMPSTDMN1	7	0.33	0.97	0.97	8.75
TMPSTDMN2	8	0.27	0.87	0.87	9.43
TMPSTDMN3	1	0.27	0.69	0.69	1.67
TMPSTDMN4	1	0.39	0.3	0.3	0.83
TMPSTDMN5	3	0.33	0.39	0.39	4.04
TMPSTDMN6	1	0.31	1.17	1.17	1.28
TMPSTDMN7	0	0.32	0.79	0.79	0.43
TMPSTDMN8	2	0.25	0.63	0.1	2.65
TMPSTDMN9	3	0.23	1.36	1.36	3.71
TMPSTDMN10	2	0.42	2.59	2.59	2.11
TMPSTDMN11	2	0.23	0.38	0.38	2.39
TMPSTDMN12	1	0.38	1.07	1.07	1.69
PCPMM1	29.1	78.37	54.15	84.73	78.37
PCPMM2	43.6	74.84	64.05	125.3	74.84
PCPMM3	61.77	122.56	80.75	134.34	122.56
PCPMM4	92.81	208.3	115.93	196.21	208.3
PCPMM5	79.06	129.29	71.33	148.57	129.29
PCPMM6	6.13	22.63	26.77	42.6	22.63
PCPMM7	17.07	19.01	9.05	49.17	19.01
PCPMM8	50.53	44.13	36.05	79.1	44.13
PCPMM9	51.28	95.86	65.78	113.86	95.86
PCPMM10	74.91	134.11	84.1	103.16	134.11
PCPMM11	74.82	106.79	90.93	129.79	106.79
PCPMM12	50.75	104.99	65.16	118.18	104.99
PCPSTD1	14.9	31.62	32.37	50	31.62
PCPSTD2	28.75	31.43	25.78	50	31.43
PCPSTD3	26.12	50	0.1	50	50
PCPSTD4	16.01	49	0.1	32.64	50
PCPSTD5	33.42	50	38.05	50	50
PCPSTD6	11.15	29.89	37.2	47.74	29.89
PCPSTD7	11.54	16.1	11.85	50	16.1

PCPSTD8	35	22.14	48.99	32.64	22.14
PCPSTD9	42.54	50	26.53	40	50
PCPSTD10	25.01	39.57	29.71	43.52	39
PCPSTD11	22.08	44.14	34.79	49.9	44.14
PCPSTD12	34.39	44.21	31.83	48.9	44.12
PCPSKW1	-1.002	1.14	-0.33	-0.17	1.14
PCPSKW2	-0.33	-0.44	-0.53	2.01	-0.44
PCPSKW3	0.699	0.71	1.93	0.02	-0.71
PCPSKW4	-1.975	-0.03	0.8	0.44	-0.03
PCPSKW5	-1.349	0.03	-0.65	0.67	0.03
PCPSKW6	2.208	1.39	1.84	1.61	1.39
PCPSKW7	0.165	0.29	1.17	1.72	0.29
PCPSKW8	0.475	-0.65	1.99	-0.33	-0.65
PCPSKW9	0.141	0.86	-0.14	-0.39	0.86
PCPSKW10	0.257	0.07	0.75	-0.89	0.07
PCPSKW11	0.004	-0.95	-0.59	1.94	-0.95
PCPSKW12	0.174	-0.75	-0.1	0.64	-0.75
PR_W1_1	0.24	0.24	0.28	0.51	0.24
PR_W1_2	0.29	0.3	0.32	0.2	0.3
PR_W1_3	0.37	0.5	0.56	0.3	0.5
PR_W1_4	0.3	0.95	0.36	0.54	0.95
PR_W1_5	0.11	0.58	0.29	0.2	0.58
PR_W1_6	0	0.08	0.07	0.24	0.08
PR_W1_7	0.07	0.07	0.07	0.12	0.07
PR_W1_8	0.16	0.15	0.11	0.07	0.15
PR_W1_9	0.35	0.15	0.27	0.23	0.15
PR_W1_10	0.57	0.29	0.37	0.15	0.29
PR_W1_11	0.47	0.64	0.3	0.33	0.64
PR_W1_12	0.22	0.5	0.29	0.35	0.5
PR_W2_1	0	0.5	0.62	0.2	0.5
PR_W2_2	0.25	0.33	0	0.56	0.33
PR_W2_3	0.42	0.59	0.4	0.46	0.59
PR_W2_4	0.4	0.85	0.79	0.59	0.85
PR_W2_5	0	0.63	0.64	0.17	0.63
PR_W2_6	0	0.67	0	0.44	0.67
PR_W2_7	0.33	0.33	0	0.4	0.33
PR_W2_8	0.33	0	0	0.33	0.01
PR_W2_9	0.54	0	0.25	0.38	0.01
PR_W2_10	0.53	0.64	0.42	0.2	0.64
PR_W2_11	0.53	0.63	0	0.22	0.63
PR_W2_12	0.38	0.59	0.4	0.36	0.59
PCPD1	5	9	5	9.14	9
PCPD2	6	9	8	9.14	9
PCPD3	11	13	8	13.57	13
PCPD4	13	19	12	18	19
PCPD5	9	14	9	12.71	14
PCPD6	1	2	2	3.71	2
PCPD7	2	2	1	2.86	2
PCPD8	5	6	3	7.86	6
PCPD9	6	12	7	12.14	12

PCPD10	11	13	10	13.14	13
PCPD11	13	15	11	16.43	15
PCPD12	7	13	7	12.43	13
RAINHHMX1	6.75	10.66	7.72	9.61	10.66
RAINHHMX2	11.92	11.43	16.09	34.19	11.43
RAINHHMX3	5.85	11.56	15.49	18.55	11.56
RAINHHMX4	12.82	13.27	18.69	18.89	13.27
RAINHHMX5	2.14	9.45	12.6	14.4	9.45
RAINHHMX6	0	18.22	4.22	18.49	18.22
RAINHHMX7	7.15	6.52	5.57	35.56	6.52
RAINHHMX8	24.65	15.74	22.54	3.4	15.74
RAINHHMX9	6.47	6.3	8.1	17.2	6.3
RAINHHMX10	9.04	13.72	8.82	8.18	13.72
RAINHHMX11	6.75	7.24	4.81	8.78	7.24
RAINHHMX12	10.03	9.45	4.77	21.93	9.45
SOLARAV2	37.12	37	37	37	37
SOLARAV3	37.84	38	38	38	38
SOLARAV4	36.97	37	37	37	37
SOLARAV5	35.1	35	35	35	35
SOLARAV6	33.94	34	34	34	34
SOLARAV7	34.42	35	34	34	35
SOLARAV8	36.02	36	36	36	36
SOLARAV9	37.3	37	37	37	37
SOLARAV10	37.1	37	37	37	37
SOLARAV11	35.87	35.78	35.81	35.82	37.8
SOLARAV12	35.05	35	35	35	35
DEWPT1	15.4	19.7	16.1	16.3	15.1
DEWPT2	15.5	19.8	16	16.2	15
DEWPT3	15.4	20	16	16.1	15.4
DEWPT4	15.5	20	15.7	15.8	15.3
DEWPT5	15.7	19.8	15.7	15.7	15.4
DEWPT6	15.9	19.1	15.9	16.2	15.4
DEWPT7	16	18.7	16.4	16.7	-15.4
DEWPT8	16	19.1	16.6	16.7	15.6
DEWPT9	15.6	19.6	16	16.1	15.4
DEWPT10	15.4	19.8	15.8	15.9	15.5
DEWPT11	15.4	19.8	15.5	15.7	15.3
DEWPT12	15.5	19.7	15.8	15.9	15.2
WNDAV1	5	2.1	3.73	2.49	2.49
WNDAV2	5	2.2	3.79	2.2	2.2
WNDAV3	5	2.1	4	2.1	2.1
WNDAV4	5	1.9	3.66	1.9	1.9
WNDAV5	5	2.01	3.81	2.01	2.01
WNDAV6	5	2.4	4.04	2.4	2.4
WNDAV7	5	2.46	3.61	2.45	2.45
WNDAV8	5	2.46	3.56	2.46	2.46
WNDAV9	5	2.44	4.11	2.44	2.44
WNDAV10	4	2.04	3.71	2.04	2.04
WNDAV11	5	2.13	3.7	2.13	2.13
WNDAV12	5	2.35	3.91	2.35	2.35

Appendix 7: Soil parameters used by the SWAT mode

SOIL NAM	RHODICNITOSOLS	TERRIC HISTOSOLS	HAPLIC_FERRASOLS	LITIC LEPTOSOLS	UMBRIC LEPTOSOLS
HYDGRP	D	D	A	D	A
SOL_ZMX	100.00	100.00	100.00	100.00	100.00
TEXTURE	CLAY	CLAY LOAM	SAND CLAY	CLAY LOAM	CLAY
SOL_Z1	100	100	100	100	100
SOL_BD1	1.3	1.36	1.43	1.36	1.29
SOL_AWC1	0.18	0.78	0.18	0.78	0.18
SOL_K1	1.2	3	1.2	3	0.25
SOL_CBN1	2	0.05	2	0.05	2
CLAY1	40	30	30	30	40
SILT1	25	25	20	25	27
SAND1	35	45	50	45	33
SOL_ALB1	0.23	0.23	0.23	0.23	0.23
USLE_K1	0.3	0.56	0.23	0.25	0.2