## COLLEGE OF SCIENCE AND TECHNOLOGY
## SCHOOL OF ENGINEERING

***Department of Civil, Environmental and Geomatics Engineering***

**MSc in Water Resources and Environmental Management (WREM)**


# DESIGN OF A SUSTAINABLE HYDRAULIC STRUCTURE FOR FLOOD CONTROL IN RUBYIRO CATCHMENT WITH FOCUS ON KATABUVUGA SUB CATCHMENT

A Thesis done by:


**UWAREMWE Jean Marcel**

**University of Rwanda**

**College of Science and technology**

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**Year 2022**

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A Thesis done by:

**UWAREMWE Jean Marcel**

**Registration Number: 214003578**

Under the guidance of

**Prof. Dr. UMARU Garba Wali( PhD)**

Submitted in partial fulfillment of the requirements for the award of the degree of

**MSc in Water resources and Environmental Management (WREM)**

In the

**University of Rwanda**

**College of Science and technology**

**School of Engineering**

**Department of Civil, Environmental and Geomatics Engineering**

**Nyarugenge, April 2022**

**DECLARATION**

I hereby declare that the thesis entitled **"Design of a sustainable hydraulic structure for flood control in Rubyiro catchment with focus on Katabuvuga sub catchment"** submitted for the Degree of Master of Science is my original work and the thesis has not formed the basis for the award of any Degree, Diploma, Associateship, Fellowship of similar other titles. It has not been submitted to any other University or Institution for the award of any Degree or Diploma.

Date: The 24th April 2022

UWAREMWE Jean Marcel Signature:

Registration Number: 214003578

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**BONAFIDE CERTIFICATE**

Certified that this thesis titled **"Design of a sustainable hydraulic structure for flood control in Rubyiro catchment with focus on Katabuvuga sub catchment"** is the bonafide work of **UWAREMWE Jean Marcel (Reg. Nº: 214003578)** who carried out the research under my supervision. Certified further that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier for this or any other candidate.

Signature of the Supervisor: …………………………………………….

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## ACKNOWLEDGEMENT

First of all I thank the almighty God who helped me during my studies with his powerfully hand. I want to express my sincere thanks to Prof. Dr. UMARU Garba Wali, who has accepted in ensuring monitoring and evaluation of this project. His assistance and relevant remarks have been crucial for the improvement of this work.

Sincere thanks to my family, for love and moral from the beginning of my studies up to now.

To the University of Rwanda through its College of science and technology, school of engineering, department of civil engineering, Master of Science in Water Resources and Environmental Management (WREM) that kindly assisted me on finding useful knowledge for this research project, their assistance is greatly appreciated.

Special thanks also to DAAD Scholarship for your full support during my studies.

Thanks to all those who have contributed directly or indirectly to the realization of this project. May God bless you so much!

**ABSTRACT**

Floods are natural events that mainly happen when the river catchment receives greater water than usual amounts (for example through rainfall or melting snow). The river cannot cope and this extra water causes the level of the water in the river to rise and a flood to take place. This flooding may take place at any point along the river course and not necessarily at the place where the extra water has entered. Most of countries in Africa are regularly affected by severe and often multi-year disasters including landslides and floods. Rwanda is among countries which face floods disasters because of its topography.

Rubyiro catchment especially Katabuvuga sub catchment is not left out of the effect of this global disaster and it is located in south-west of Rusizi District Western Province. The Katabuvuga sub catchment (39.68 $Km^2$) through its main river Katabuvuga (21.67 Km) is one of the major flood prone areas in the country, where almost every year flood events are recorded and its consequences have been evaluated in Bugarama Valley especially on rice farming.

The aim of this study is to design a sustainable hydraulic structure for flood control in Rubyiro catchment with focus on Katabuvuga sub catchment.

Daily rainfall data from January 2011 to December 2019 have been collected from two meteorological stations; the Kamembe airport station and Bugarama station. The maximum rainfall intensity was found to be 2.3 mm per hour which was observed on the 07$^{th}$ March 2016. The peak runoff water discharge has been calculated by using the rational method and its prediction in 30 years has been calculated by using the linear model (Q= 10.093 $m^3/s$). For a long term sustainable flood control solution for the Katabuvuga River of the Katabuvuga sub catchment as well as in the Bugarama Valley, a multipurpose embankment dam have been proposed.

The proposed multipurpose embankment dam, once applied will contribute not only to the flood control observed in this sub catchment but also in other purposes like fishing, support existing irrigation systems, recreation among others for the development of that area.

**Keywords**: Sustainable flood control, Katabuvuga sub-catchment, Katabuvuga River, multipurpose embankment dam.

## LIST OF ACRONYMS

REMA: Rwanda Environmental Management Authority

MINEMA: Ministry in Charge of Emergency Management

ARF: Area Reduction Factor

RLMUA: Rwanda Land Management and Use Authority

RNRA: Rwanda Natural Resources Authority

GDP: Gross Domestic Product

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# CHAPTER 1: INTRODUCTION

## 1.1. Background

Floods are natural events that mainly happen when the river catchment receives greater water than usual amounts (for example through rainfall or melting snow). The river cannot cope and this extra water causes the level of the water in the river to rise and a flood to take place. This flooding may take place at any point along the river course and not necessarily at the place where the extra water has entered. Cities are more prone to floods than rural areas because of high population densities and concentration of economic activities.

The negative consequences of floods on the socio-economic welfare of the global society cannot be over emphasized. Flood causes loss of lives, properties and destruction of environment, deaths of people, destruction of infrastructures and other many unwanted effects.

The Katabuvuga sub catchment of Rubyiro catchment which is the target in this research has suffered from the flooding problem for several times. This is mainly due to its altitude which is very low at the outlet compared to other surrounding areas of the catchment. Katabuvuga River flooding effects can be classified as follows: (1) Primary effects: Physical damage which can damage any type of structure including bridges, cars, buildings, sewerage systems, roadways and canals (Brammer, 1990); (2) Secondary effects: Water supplies, diseases, crops, tress, vegetation and transport; (3) Tertiary and long-term effects: Economic (Rozens, 1994).

High floods that have been observed in Katabuvuga river which is the target in this research can be classified among flash floods which are quick floods caused by a sudden cloudburst or thunder storm. Huge amounts of water fall in a short time and in cities and towns the drains overflow and roads become flooded. Flash floods also happen in mountainous areas, where steep slopes cause the water to travel at high speeds. The rushing water erodes the soil, washing it away down the slopes. Flash floods often occur rapidly and with little warning.

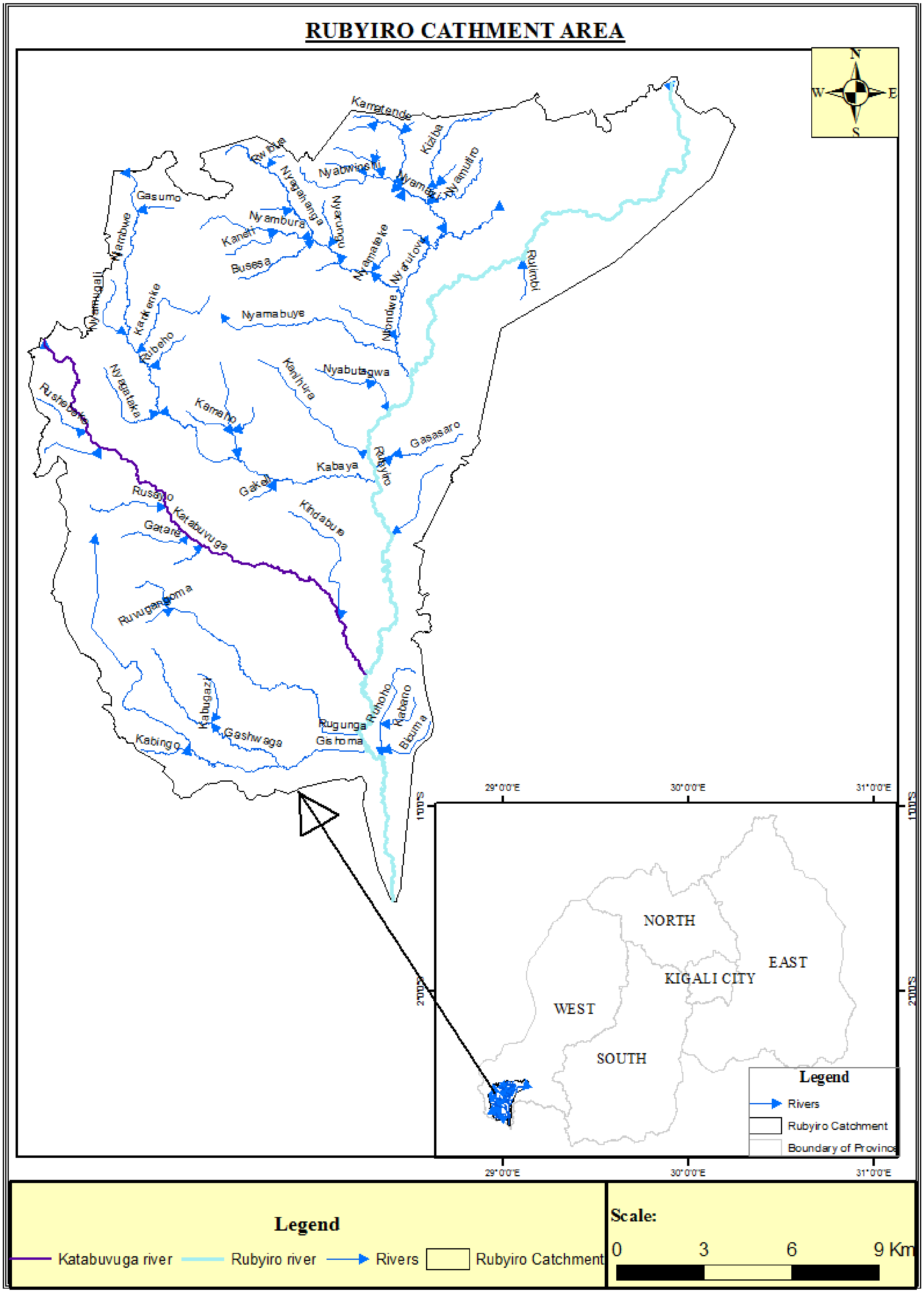


**Figure 1:** Location of Rubyiro catchment

## 1.2. Problem statement

Rwanda is vulnerable to a range of disasters and emergency situations. Floods is one of many key disasters that frequently affect localized areas of the country (*MIDIMAR, 2001*) and most of the affected people do not have efficient mechanisms to cope with natural hazards. In addition, the hilly topography and high annual precipitation rates with overexploitation of the natural environment such as deforestation, inappropriate farming and poor housing techniques accelerate the disaster risks and hence result into losses of lives and damages to property from the community exposed to these flooding.

Rubyiro catchment especially Katabuvuga sub catchment is not left out of the effect of this global disaster and it is located in south-west of Rusizi District Western Province. This catchment is one of the major flood prone areas in the country, where almost every year flood events are recorded and its consequences have been evaluated: (1) Flood damages property and endangers the lives of humans and other species; (2) Its rapid water runoff causes soil erosion and concomitant sediment deposition elsewhere (such as further downstream or down a coast); (3) Some prolonged high floods can delay traffic in areas which lack elevated road ways and they can also interfere with farming; (4) Structural damage can occur in bridge abutment, backlines and other structures;(6) Financial losses due to floods are typically evaluated;(7) Urban damage, effects on Gross Domestic Product (GDP), Population at risk.

Conducting a research on flooding and design an appropriate hydraulic structure for flood control will help the population around to improve their economic activities.

**Figure 2 :** Katabuvuga river banks destroyed and local people’s houses and fields flooded

## 1.3. General Objective

This research aims to design a sustainable hydraulic structure for flood control in Rubyiro catchment with focus on Katabuvuga sub catchment.

To achieve this general objective, the specific objectives were summarized as follow:

### 1.3.1. Specific Objectives

In line with the research hypothesis, the following specific objectives have been outlined:

- To analyze the causes and impacts of flood in the catchment,
- To quantify flood and estimation of flood of different recurrent interval,
- To propose appropriate measures for flood control and its design

## 1.4. Research question

The following hypotheses were made before undertaking the study:

- Is the high flow velocity from upstream of Katabuvuga River and its flow channel which is not deep the causes of flooding?
- Are Solid materials (stones, gravels, etc) flowing downstream during heavy rain also the cause of flooding in the valley and households along the river sides?

## 1.5. Scope of the research

Regarding the main objective of this research, the design of a sustainable hydraulic structure for flood control will be limited on Katabuvuga river which is the main flooding river in the Katabuvuga sub catchment.

## 1.6. Outline of the research

The proposed research will be organized into six chapters including chapter one of introduction; Chapter two will provide a review of related literature; Chapter three will discuss the methodology employed for the research; chapter four will deal with data analysis, empirical results and discussions of the findings of the research conducted and Chapter five will cover the proposed measures for flood control and the design of a multipurpose Dam on Katabuvuga river and then Chapter six will be the conclusion of the research, and appropriate recommendations.

## CHAPTER 2: LITERATURE REVIEW

### 2.1. Catchment

A catchment is a basin shaped area of land, bounded by natural features such as hills or mountains from which surface and sub-surface water flows into streams, rivers and wetlands. Water flows into, and collects in, the lowest areas in the landscape. The system of streams which transport water, sediment and other material from a catchment is called a drainage network. The drainage network channels the water from throughout the catchment to a common outlet. The outlet of a catchment is the mouth of the main stream or river. The mouth may be where it flows into another river or stream, or the place where it empties into a lake, estuary, wetland or ocean.

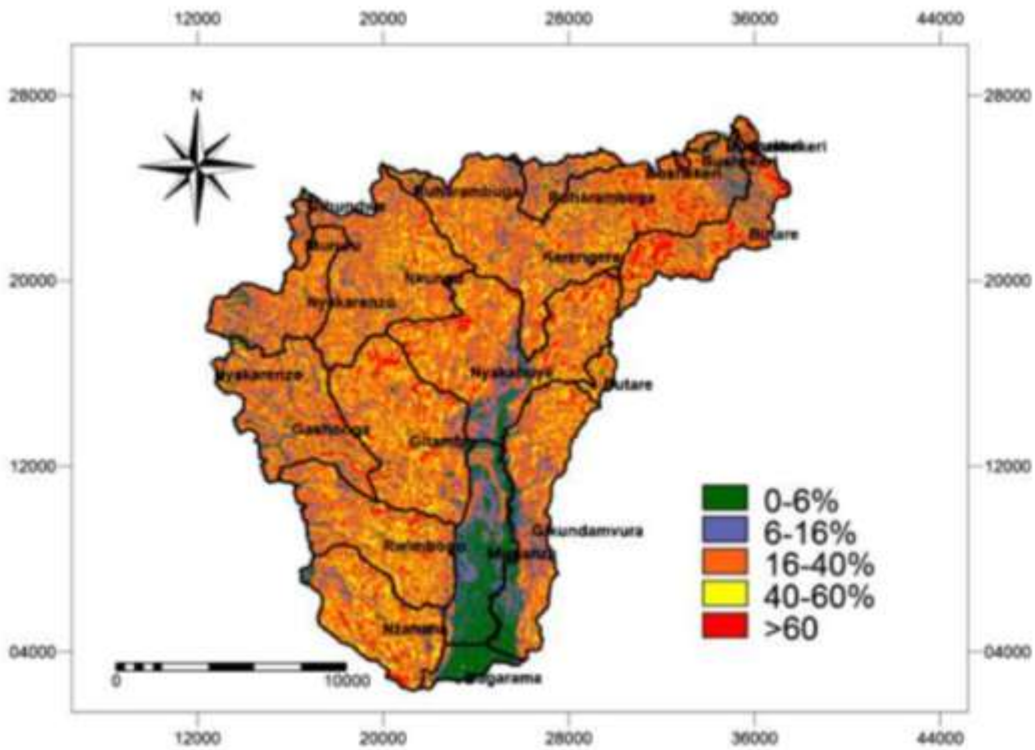


**Figure 3:** Slope classes of Rubyiro catchment

#### 2.1.1. Streams of the catchment

Tributaries are small feeder streams that empty into larger streams or rivers in the catchment. Streams begin their journey to the sea in the upper reaches of the catchment. Some may appear briefly, flowing only during periods of intense rainfall. Some are intermittent, flowing during the wet seasons of the year. Others are more permanent, having year-round flow. If the stream is steep it will be fast-flowing and energetic. This means that it has the energy to carry large amounts and large-sized pieces of rock and gravel which have been eroded from stream beds and banks.

Streams are often classified by size. Within any catchment the smallest streams that have year round flow and no tributaries are called first order streams. When two first order streams meet they form a second order stream. A third order stream is formed when two second order streams join, and so on. Stream order only changes when two streams with the same classification meet. For example, when a first order stream meets a second order stream the resulting stream remains a second order stream.

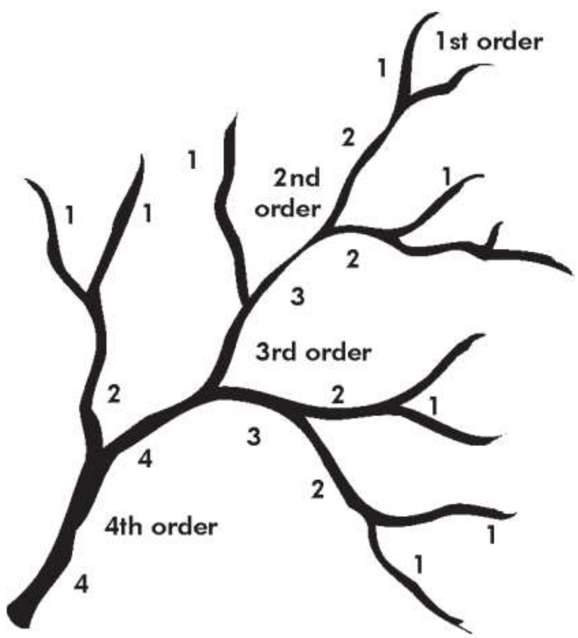


**Figure 4**: Stream order in the catchment

### 2.2. Precipitation

Rwanda receives an average annual precipitation of 1200 mm. Rainfall ranges from as low as 700 mm in the Eastern Province to about 2000 mm in the high altitude north and west. Precipitation is the main form in which Rwanda’s ground water aquifers and surface water bodies are recharged. Precipitation is the main source of water for agriculture, as more than 90% of Rwanda's agriculture is rain-fed.

As indicated in Table 1, about half of the total rainfall occurs in one season i.e. the March-May season. This natural flow of rainwater would dictate that half of the water-requiring activities (essentially farming) be done during this period, or that water is stored for use in time of shortage.

| **Period** | **Season description** | **Share of Total Annual Precipitation** |
|---|---|---|
| Feb – May | Long rains (April is the wettest month) | 48% |
| June – Mid-Sept. | Long dry spell. | Very little rains (25-50 mm especially in High altitude areas |
| Mid-Sept – Dec. | Short rains (November the wettest during this season) | 30% |
| Dec. – Jan. | Short rains with short dry spell | 22% |

**Table 1**: Temporal distribution of precipitation (Data source: UNEP (2009); Haguma et al (2008))

Besides temporal variations, rainfall in Rwanda exhibits wide geographical disparities. Virtually all of Rwanda's water towers are located in the Albertine region like Nyungwe Mountain forest, Volcanoes National Park and the Rugezi wetland. However, the dense drainage network is relatively even allowing most parts of the country to receive water.

Table 2 shows that higher altitude zones receive higher rainfall and have better moisture retention conditions than the low altitude Plains which tend to have semi-arid conditions.

| **Parameters** | **High Altitude zone (1800 – 3000 m)** | **Medium Altitude (central plateau) zone (1500–1800 m )** | **Low Altitude (Eastern plateau) (1250–1400 m )** |
|---|---|---|---|
| Rainfall (mm) | 1,300 – 2,000 | 1200 – 1,400 | 600 – 1,400 |
| Temperature (oC) | 16-17 | 18-21 | 20-24 |
| Evapo-transpiration (mm) | 1,000 – 1,300 | 1,300 – 1400 | 1,400 – 1,700 |
| Relative Humidity (%) | 80-95 | 70-80 | 50-70 |

**Table 2**: Precipitation and Influencing factors for rainwater moisture retention by Altitude zone (Source: UNEP (2009). Rwanda: From Post-conflict to Environmentally Sustainable Development)

From table 2, it can be observed that the high altitude North-West to South-West stretch of the country receives the largest share of annual precipitation, while the medium to low altitude North-East to South- East receives the least.

## 2.3. Floods

A flood is a great flowing or overflowing of water onto land that is not usually submerged. A flood happens when too much rain, brought by storms and strong winds, falls and cannot be absorbed by the soil. Rivers burst their banks and the water spills onto the land. Strong winds blowing across the sea make huge waves that surge onto the land and flood coastal areas. (Encyclopedia of natural disasters).

### 2.3.1. Types of floods

- **River Floods:** Rivers floods happen when rivers and streams cannot carry away all the extra water that falls as rain or comes from melting snow. The water rises in the rivers and streams and overflows onto normally dry land. Floods destroy farmland, wash away people's houses and drown people and animals. Towns and cities are flooded too.
- **Flash floods:** A flash flood is a quick flood caused by a sudden cloudburst or thunder storm. Huge amounts of water fall in a short time and in cities and towns the drains overflow and roads become flooded. Flash floods also happen in mountainous areas, where steep slopes cause the water to travel at high speeds. The rushing water erodes the soil, washing it away down the slopes. Flash floods often occur rapidly and with little warning.
- **Coastal flooding**: Can be caused by strong winds blowing waves onto the land. Hurricanes and major storms produce most coastal floods. Very high tides and tsunamis also flood the coasts. In many countries, large groups of people live along the coasts and for these people coastal flooding can be very serious. Thousands of people have been drowned in coastal flooding in many parts of the world.

### 2.3.2. Floods in Rwanda

Rwanda is vulnerable to a range of disasters and emergency situations. Floods and landslide are key disasters that frequently affect localized areas of the country and most of the affected people do not have efficient mechanisms to cope with natural hazards. In addition, the hilly topography and high annual precipitation rates with over exploitation of the natural environment such as deforestation, inappropriate farming and poor housing techniques accelerate the disaster risks and hence result into losses of lives and damages to property from the community exposed to these disaster risks. (Bizimana, 2010)

Therefore, in Rwanda, most vulnerable areas prone to landslides and floods are located in the Western part namely Nyabihu, Rubavu, Musanze, Burera, Gakenke, Rusizi and many others. This situation calls upon the Ministry of Disaster Management and Refugee to conduct a scientific field study to identify the areas mostly prone to floods and landslides all over the country and this will contribute a lot in the process of sustainable management of disaster risks. (Bizimana, 2010)

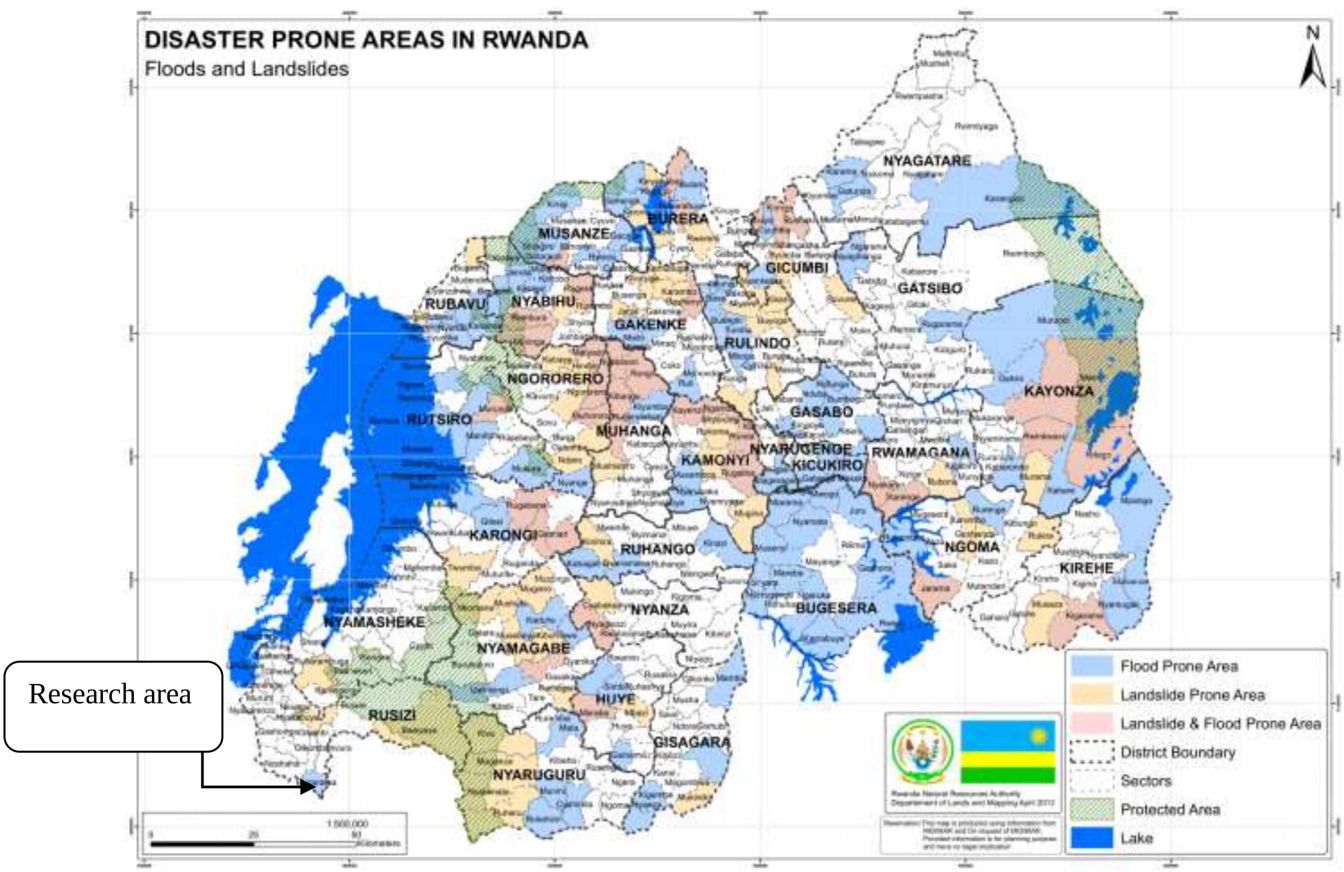


**Figure 5:** Disasters prone areas in Rwanda (floods and landslide) (RNRA, 2012)

### 2.3.3. Causes of flooding in Rwanda

The flood can be caused by various sources: high precipitation levels, not necessarily in the flooded area, or other causes such as melting snow, blockage of the flow. Flash floods occur after local rainfall with high intensity, which leads to a quick raise of water levels causing a threat to lives of the inhabitants. The time available to predict flash floods in advance is limited. Severe rainfall on the flood location may be used as indicator for this type of flood. This generally occurs in mountainous and urban areas because of its geographical features and climatic profile, Rwanda is prone to various hazards but especially localized floods and landslides (Douglas et al, 2008).

Due to its dense river network and large wetlands, the country is threatened mainly by riverine floods.

### 2.3.4. Impact of Flooding in Rwanda

Flood hazards affect people and activities located in flood prone areas across the country. The effects of flood hazards have worsen with recent increase of the population accompanied with the scarcity of land that have pushed people to settle in marginal land and flood prone areas. In general, the agriculture sector is the most affected by flood hazards. Only in 2017, a recording system of flood hazard events and its impacts has been installed. It showed that 15 people have been killed, 2 injured, 57 houses were damaged or completely destroyed and 1800.36 ha of land were affected. (MIDMAR, 2017)

### 2.3.5. Flood control structures and methods

Flood control structures are designed to protect coastal and river-bank areas, including urban and agricultural communities, homes, and other economically valuable areas, and the people located within them. These structures are used to divert flows of water, by redirecting rivers, slowing natural changes in embankments and coastlines, or preventing inundation of vulnerable coastlines or floodplains. Dams, Open channel, Dikes, spurs, levees, and seawalls often act as the first line of defense against overflowing rivers, floods, storm surges, and in the longer term rising seas. By keeping water out, flood control structures lessen harm to physical infrastructure and help to ensure continuation of communities’ economic and social activities. (USAID; 2011)

- **Dam:** Is a structure built across a stream, a river, or an estuary to retain water. Dams are built to provide water for human consumption, for irrigating arid and semiarid lands, or for use in industrial processes. They are used to increase the amount of water available for generating hydroelectric power, to reduce peak discharge of floodwater created by large storms or heavy snowmelt, or to increase the depth of water in a river in order to improve navigation and allow barges and ships to travel more easily. Dams can also provide a lake for recreational activities such as swimming, boating, and fishing. Many dams are built for more than one purpose; for example, water in a single reservoir can be used for fishing, to generate hydroelectric power, and to support an irrigation system. Dams are of numerous types, and type classification is sometimes less clearly defined. An initial broad classification into two generic groups can be made in terms of the principal construction material employed:
    - ✓ **Embankment dams** are constructed of earth fill and/or rock fill. Upstream and downstream face slopes are similar and of moderate angle, giving a wide section and a high construction volume relative to height.
    - ✓ **Concrete dams** are constructed of mass concrete. Face slopes are dissimilar, generally steep downstream and near vertical upstream, and dams have relatively slender profiles dependent upon the type.

**Figure 6:** Concrete dam

- **Open channel:** Open channel flow refers to any flow that occupies a defined channel and has a free surface. The flow is classified as a combination of steady or unsteady, and uniform or non-uniform. Steady flow signifies that the mean velocity **V**, as well as the depth **y**, is independent of time, whereas unsteady flow necessitates that time be considered as an independent variable. Uniform flow implies that **V** and **y** are independent of the position coordinate in the direction of flow; non-uniform flow signifies that **V** and **y** vary in magnitude along that coordinate. The possible combinations are shown in Table 3.

| *Type of flow* | *Average velocity* | *Depth* |
|---|---|---|
| Steady, uniform | V = constant | y = constant |
| Steady, non-uniform | V = V(x) | y = y(x) |
| Unsteady, uniform | V = V(t) | y = y(t) |
| Unsteady, non-uniform | V = V(x,t) | y = y(x,t) |

**Table 3**: Combinations of one dimensional free surface flows (Source: Hydraulic structures, Fourth edition, P.Novak, A.I.B Moffat, C.Nalluri and R. Narayanan)

Steady non-uniform flow is a common occurrence in rivers and in man-made channels. In those situations, it will be found to occur in two ways. In relatively short reaches, called transitions, there is a rapid change in depth and velocity; such flow is termed as rapidly varied flow. Examples are the hydraulic jump, flow entering a steep channel from a lake or reservoir, flow close to a free outfall from a channel, and flow in the vicinity of an obstruction such as a bridge pier or a sluice gate.

- **Levees:** It is an embankment designed to prevent the flooding of a river or a wall made of land or other materials that is built next to a river to stop the river from overflowing (Cambridge Advanced learner‘s Dictionary, third edition).

Flood control project can be implemented using various methods like construction of reservoirs and detention basins, embankment or dikes (levees), flood diversion works, water channel improvement (Deeping, narrowing or straightening by river cutoff to eliminate river meandering stagnant zones along the river flow),watershed management (terracing, afforestation, check dams and anti-erosive ditches, ploughing techniques, etc…), flood Zoning, river cutoff ,flood forecasting and flood warning(Non-structural measures)

The positive impacts of flood control project can be underlined like fishery in detention basins, reduction of river sedimentation by river channeling, flooding recharge soil moisture and replenish the rich alluvial soils with flood deposits (Reduction or elimination of flooding has an indirect positive impact of promoting agriculture, natural vegetation and livestock population of floodplains) ,the reservoirs and basins have a positive impact in recharging groundwater aquifers and settling suspended sediments which would flow the river channel, floodways are restricted water ways to protect urban centers or low lying agricultural fields from flooding.

The negative impacts also of flood control project can be mentioned like the high cost to build the flood control structures, overflow basins and reservoirs are usually swampy areas providing habitats for diseases vectors, any method that increases the velocity of flow increases the erosive capacity of the water flow through the river channel.

## CHAPTER 3: METHODOLOGY

### 3.1. Rubyiro catchment description

Rubyiro catchment is located in Rusizi district, in the South-Western part of the country. Rubyiro catchment covers an area of 420 Km$^2$ and extends from 02$^o$ 28’ 56.4’’and 02$^o$ 41’ 45.6’’ South and from 28$^o$ 54’ 12.6’’ and 29$^o$ 08’ 47.6’’ East. The altitude ranges from 954 m above sea level down at the outlet and 2059 m at the water divide location. The figure 1 gives a detailed description of Rubyiro catchment.

Slope map of the Rubyiro catchment is generated from the Digital Representation of Topography (DTM) available at the Rwanda Land Management and Use Authority (RLMA) at a minimum of 90 meter resolution. Slope ranges were calculated as percentage rise by using ArcGIS spatial analysis tools.

According to the figure 7 of Slope Classes of Rubyiro catchment, the dominant slope class is between 16-40%, covering 50% of the catchment. In Rubyiro catchment, slope classes are of 0-6%, 6-16%, 40-60%, and above 60% cover 6.2%, 16.9%, 19.3%, and 8.1%, respectively.

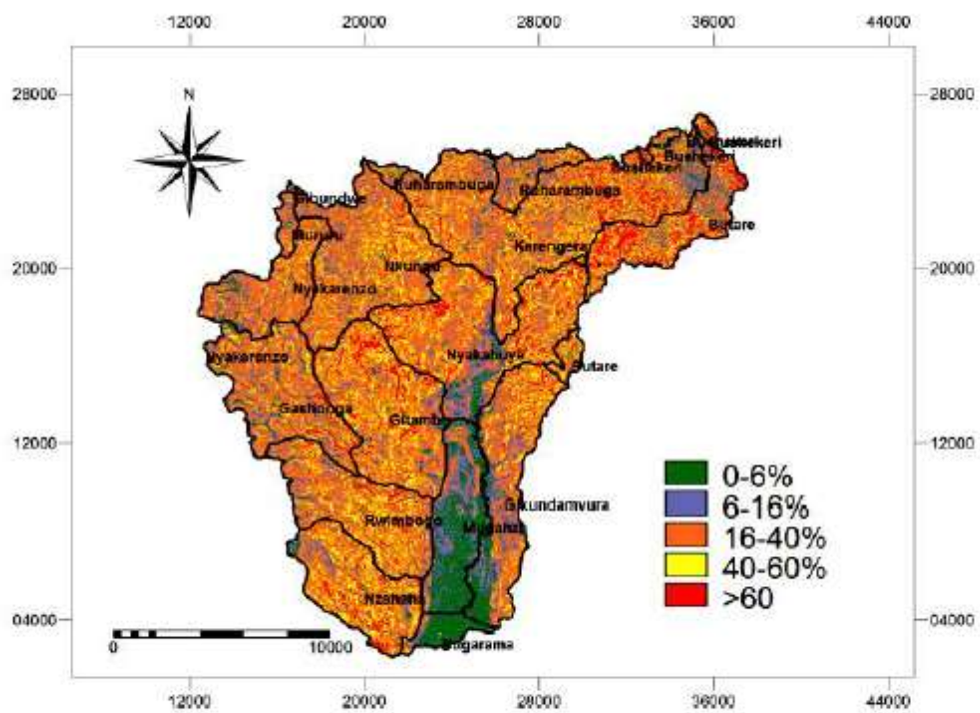


**Figure 7:** Slope Classes of Rubyiro catchment

## 3.2. Katabuvuga Sub catchment description and delineation

Katabuvuga sub catchment covers an area of 39.68 $Km^2$ and extends from 02° 33’ 00.4’’and 02° 40’ 15.6’’ South and from 28° 54’ 58.2’’ and 29° 02’ 17.3’’ East. The figure 9 describes the altitude of katabuvuga sub catchment which ranges from 975 m above sea level down at the outlet and 1825 m at the water divide location.

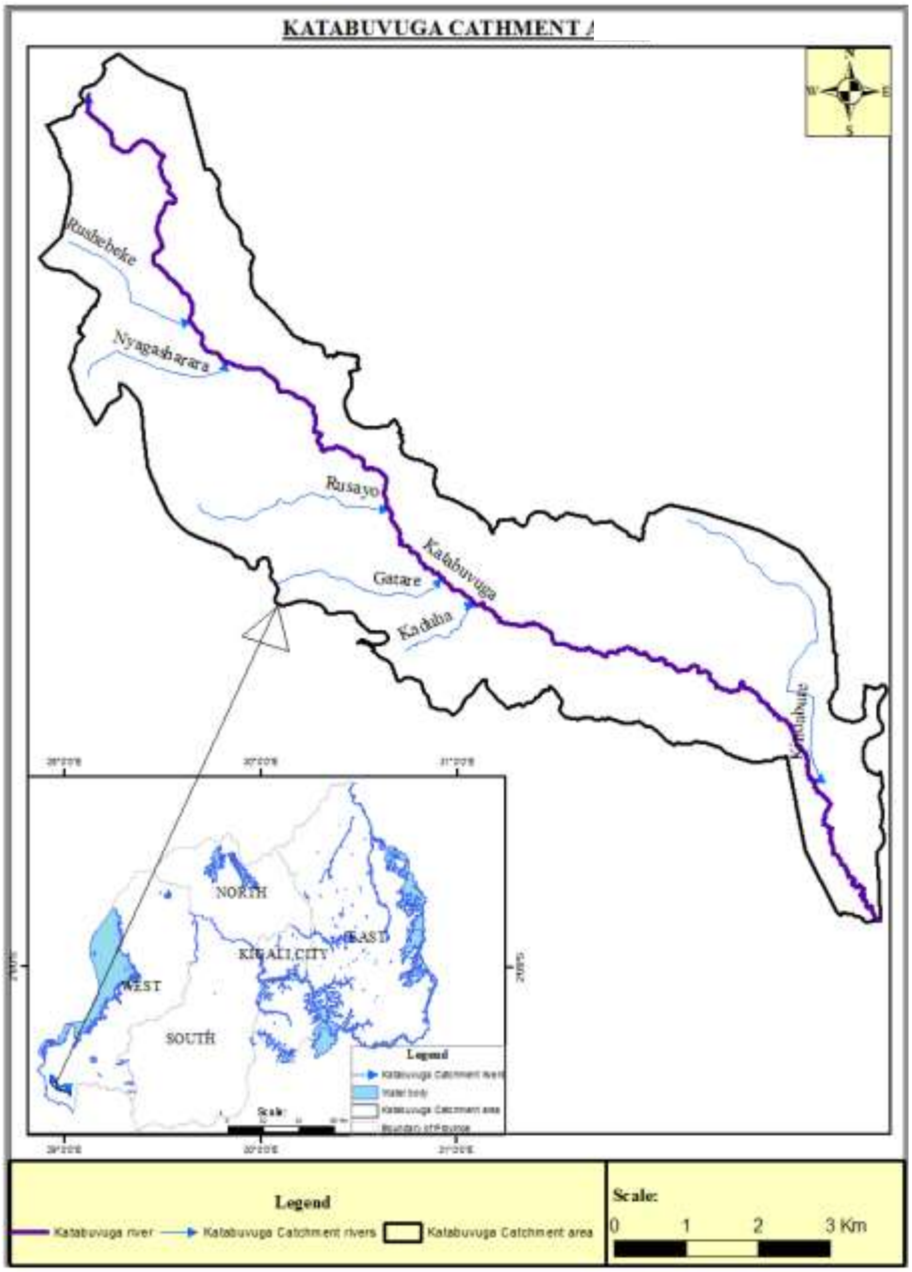


**Figure 8**: Katabuvuga sub catchment

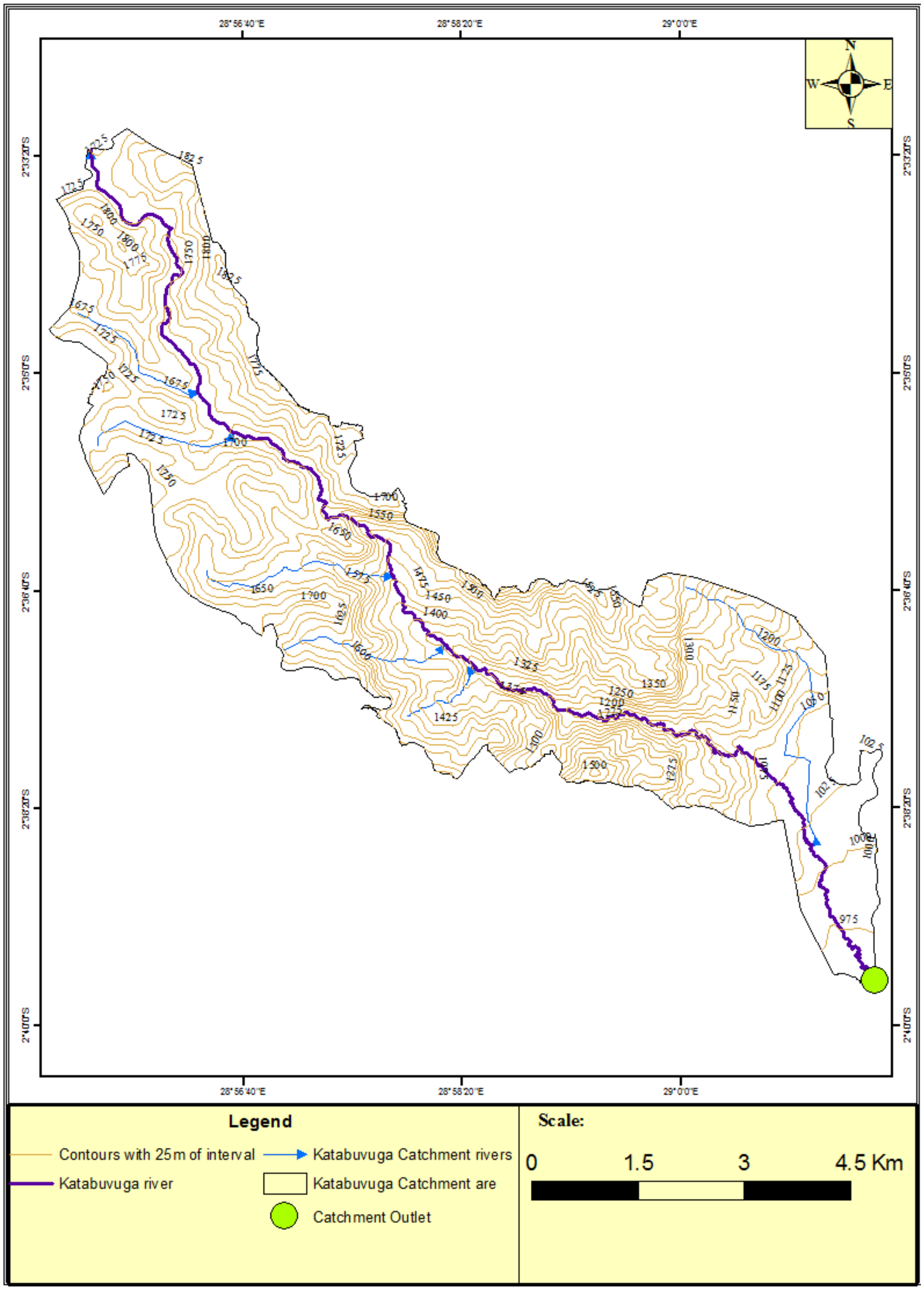


**Figure 9**: The contour lines of the Katabuvuga sub catchment

The figure 9 shows how the topography which vary suddenly from 1825m to 975m has a great impact on the flooding observed down steam on Katabuvuga river and consequently many houses are destroyed , paddy rice, etc.

### 3.2.1. Slope

Slope map of the Katabuvuga sub catchment is generated from the Digital Representation of Topography (DTM) available at the Rwanda Land Management and Use Authority (RLMA) at a minimum of 90 meter resolution. According to the figure 10 of Slope map of Katabuvuga sub catchment, the dominant slope class is between 25.3-48.3%, covering 35% of the catchment. In Katabuvuga sub catchment, slope classes are of 0-10.5%, 10.5-15%, 15-25.3%, 25.3-48.3%, and 48.3-84.4% cover 18.1%, 12.9%, 25.3%, 35% and 8.7%, respectively.

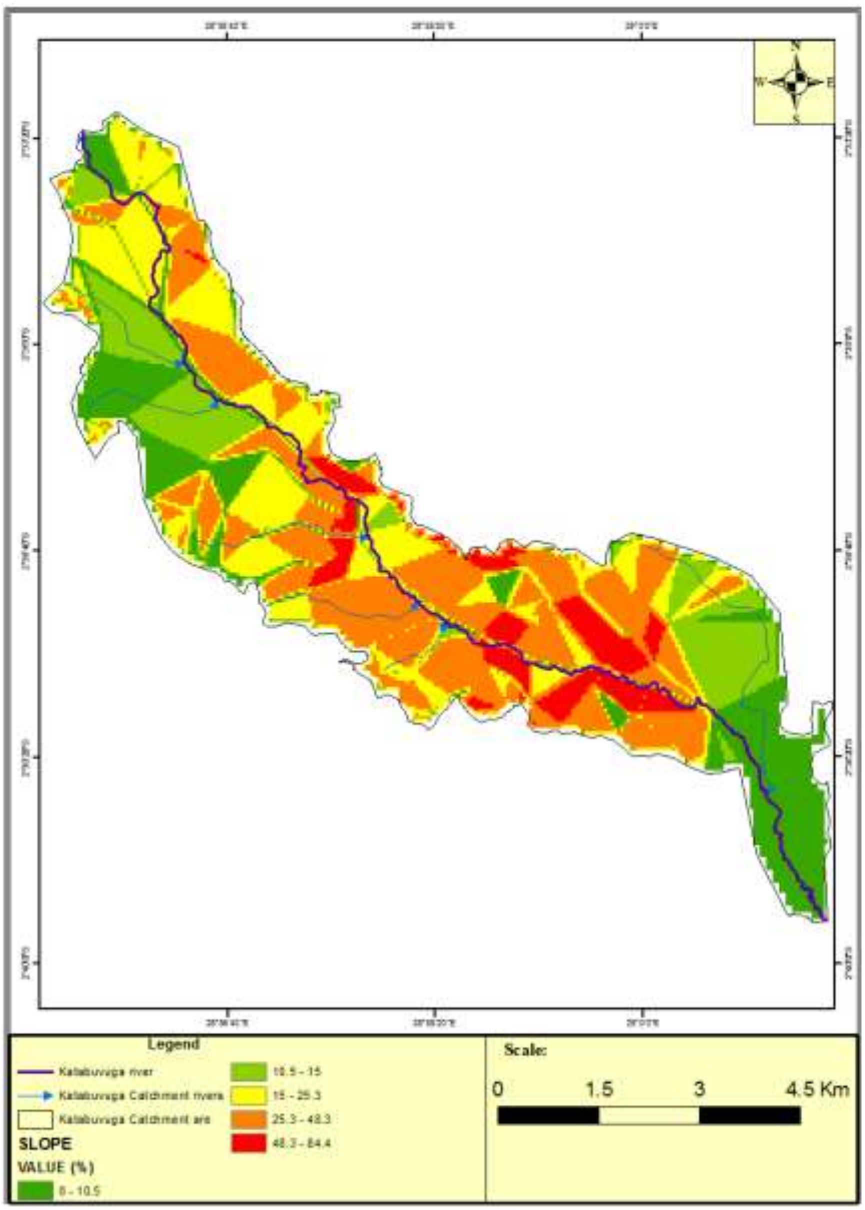


**Figure 10**: The slope map of Katabuvuga sub catchment

### 3.2.2. Land use analysis

The land use of the Katabuvuga sub catchment which is shown in figure 11 is partly dominated by rainfed agriculture in the upper part and cover 80%, open land which cover 5.8%, forest plantation which cover 0.8%,  and a significant part as irrigated or agricultural wetland in valley bottoms which cover 9.2%. Built-up areas are rather limited in size and mostly located in the Bugarama valley and cover an area of 4.2%.

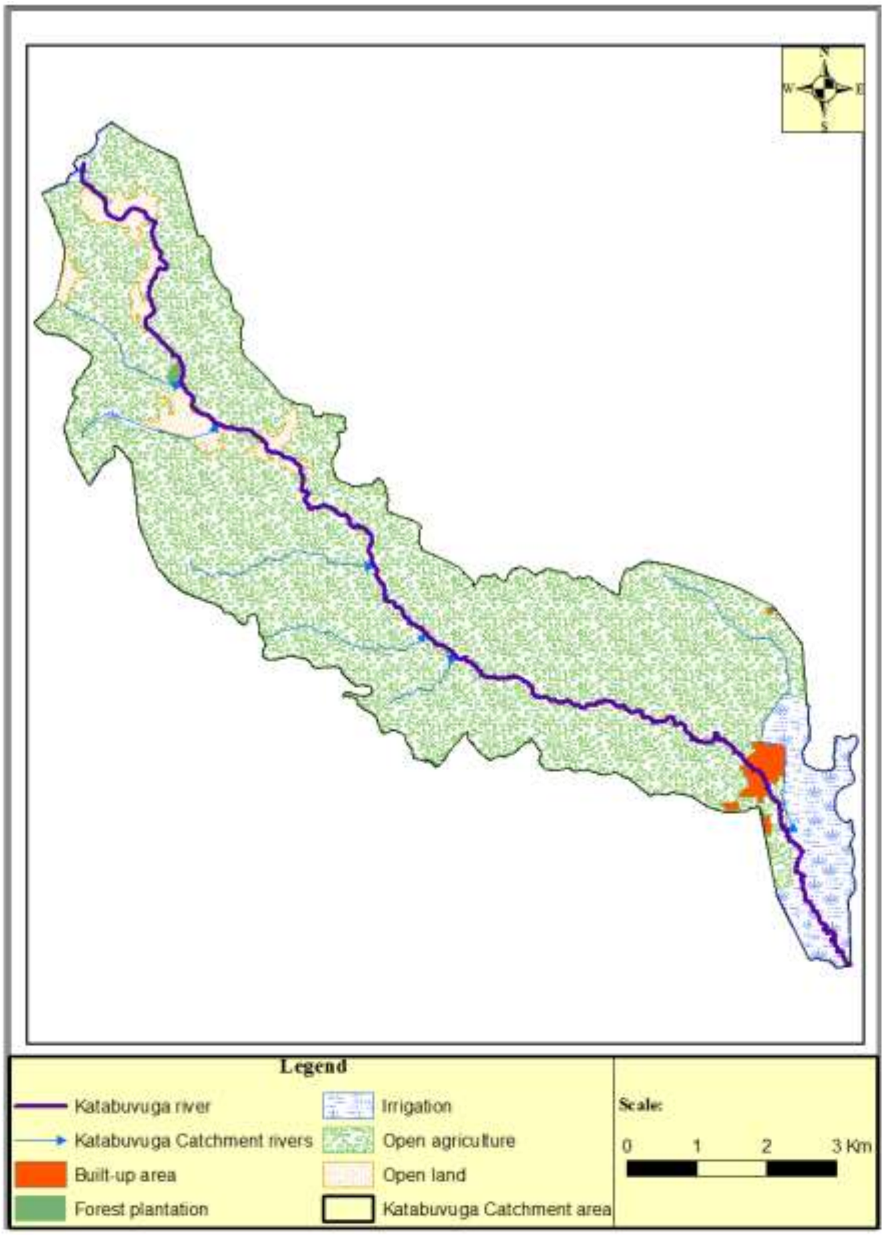


**Figure 11**: The land use map of Katabuvuga sub catchment

### 3.2.3. Soil classes

The soil classes are predominantly the cambisol class found throughout the Rubyiro catchment area. Infiltration rates of these soils are generally high. In Katabuvuga sub catchment; this is obviously not the case for the clay and mineral sols on alluvial flat topography encountered in the Bugarama valley where infiltration rates are very low and histosols are found in some pockets in high altitude in Gishoma.

### 3.2.4. Determination of Rainfall intensity

The rainfall intensity, *I*, is the average rainfall rate in mm/hr for a particular drainage basin or sub-basin. The intensity should be selected on the basis of the design storm duration and return period (Dawod *et al.*, 2011). The design storm duration is equal to the time of concentration for drainage area under consideration. The return period is established by design standards or chosen by the hydrologist as a design parameter. (Munyaneza et al.2012)
Data used to assess the rainfall intensity were collected from Rwanda meteorological Agency in the period of 9 years on daily basis (January 2011-December 2019). For the design purpose, we used the hightest rainfall intensity at the research site.

$$I=P_d/t_c \qquad \text{Equation 1}$$

Where: $P_d$ = the maximum daily precipitation in mm and $t_c$ = The time of concentration

Time of concentration (**$t_c$**) is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet. Time of concentration is generally applied only to surface runoff and may be computed using many different methods. Time of concentration will vary depending upon slope and character of the catchment and the flow path. The Kirpich/Ramser formula is mostly used to calculate the time of concentration (Dawod et al., 2011).

$$t_c = 0.0195\ L^{0.77}\ S^{-0.385} \qquad \text{Equation 2}$$

Where: $t_c$ = Time of concentration [min], *L* = Length of main river [m], *S* = Average slope of main stream [m/m]

### 3.2.5. Estimation of Runoff coefficient

The product of rainfall intensity, I, and watershed area, A, is the inflow rate for the system, IA, and the ration of this rate of peak discharge, Q, (which occurs at time $t_c$) is termed runoff coefficient C ($0 < C \leq 1$) (Mihalik, 2007). The runoff coefficient, C, is the least precise variable of the rational method. Its use in the formula implies a fixed ratio of peak runoff rate to rainfall rate for the drainage basin, which in reality is not the case. All catchment losses are incorporated into the runoff coefficient, which is usually a function of the land use. This means that the magnitude of this coefficient is not constant, but varies with time and in space depending on a number of different factors such as the topography of the catchment, magnitude and intensity of the storm rainfall, vegetation cover and land use, infiltration rate and the initial soil moisture condition, groundwater depths and subsurface flows (e.g. EFM, 1984 in Musoni *et al.*, 2010, Uhlenbrook 2007).

The general runoff coefficient is obtained as weighted average of partial runoff coefficients (Ci)

$$C = \frac{\sum_{i=1}^{n} Ai * Ci}{\sum_{i=1}^{n} Ai}$$

Equation 3

Where, $A_i$ ($km^2$) represents partial areas and $C_i$ the partial runoff coefficients, according to different sub-catchments of a given catchment

The designer must use judgment to select the appropriate "C" value within the range. Generally, larger areas with permeable soils, flat slopes and dense vegetation should have the lowest "C" values. Smaller areas with dense soils, moderate to steep slopes, and sparse vegetation should assigned the highest "C" values. (CIV246; 2009)

The partial runoff coefficients $C_i$ can be found in the table 4 below:

| Land Use | C | Land Use | C |
|---|---|---|---|
| ***Business:*** | | ***Lawns:*** | |
| Downtown areas | 0.70 - 0.95 | Sandy soil, flat, 2% | 0.05 - 0.10 |
| Neighborhood areas | 0.50 - 0.70 | Sandy soil, avg., 2-7% | 0.10 - 0.15 |
| | | Sandy soil, steep, 7% | 0.15 - 0.20 |
| | | Heavy soil, flat, 2% | 0.13 - 0.17 |
| | | Heavy soil, avg., 2-7% | 0.18 - 0.22 |
| | | Heavy soil, steep, 7% | 0.25 - 0.35 |
| ***Residential:*** | | ***Agricultural land:*** | |
| Single-family areas | 0.30 - 0.50 | *Bare packed soil* | |
| Multi units, detached | 0.40 - 0.60 | *Smooth | 0.30 - 0.60 |
| Munti units, attached | 0.60 - 0.75 | *Rough | 0.20 - 0.50 |
| Suburban | 0.25 - 0.40 | *Cultivated rows* | |
| | | *Heavy soil, no crop | 0.30 - 0.60 |
| | | *Heavy soil, with crop | 0.20 - 0.50 |
| | | *Sandy soil, no crop | 0.20 - 0.40 |
| | | *Sandy soil, with crop | 0.10 - 0.25 |
| | | *Pasture* | |
| | | *Heavy soil | 0.15 - 0.45 |
| | | *Sandy soil | 0.05 - 0.25 |
| | | Woodlands | 0.05 - 0.25 |
| ***Industrial:*** | | *Streets:* | |
| Light areas | 0.50 - 0.80 | Asphaltic | 0.70 - 0.95 |
| Heavy areas | 0.60 - 0.90 | Concrete | 0.80 - 0.95 |
| | | Brick | 0.70 - 0.85 |
| Parks, cemeteries | 0.10 - 0.25 | Unimproved areas | 0.10 - 0.30 |
| Playgrounds | 0.20 - 0.35 | Drives and walks | 0.75 - 0.85 |
| Railroad yard areas | 0.20 - 0.40 | Roofs | 0.75 - 0.95 |

**Table 4**: Runoff coefficient with the land use_ Source: (CIV246; 2009)

### 3.2.6. Determination of Peak runoff

After getting the rainfall intensity of the Katabuvuga sub catchment, the runoff coefficient from land cover and hydrological soil group, the peak runoff was calculated using the following form of the rational formula (Haan *et al*., 1982).

$Q_p$=0.00278*C*I*A Equation 4

Where: $Q_p$ = Peak runoff rate [$m^3/s$], C = Runoff coefficient, I = Rainfall intensity [mm/hr], and A = Drainage area/catchment area [ha].

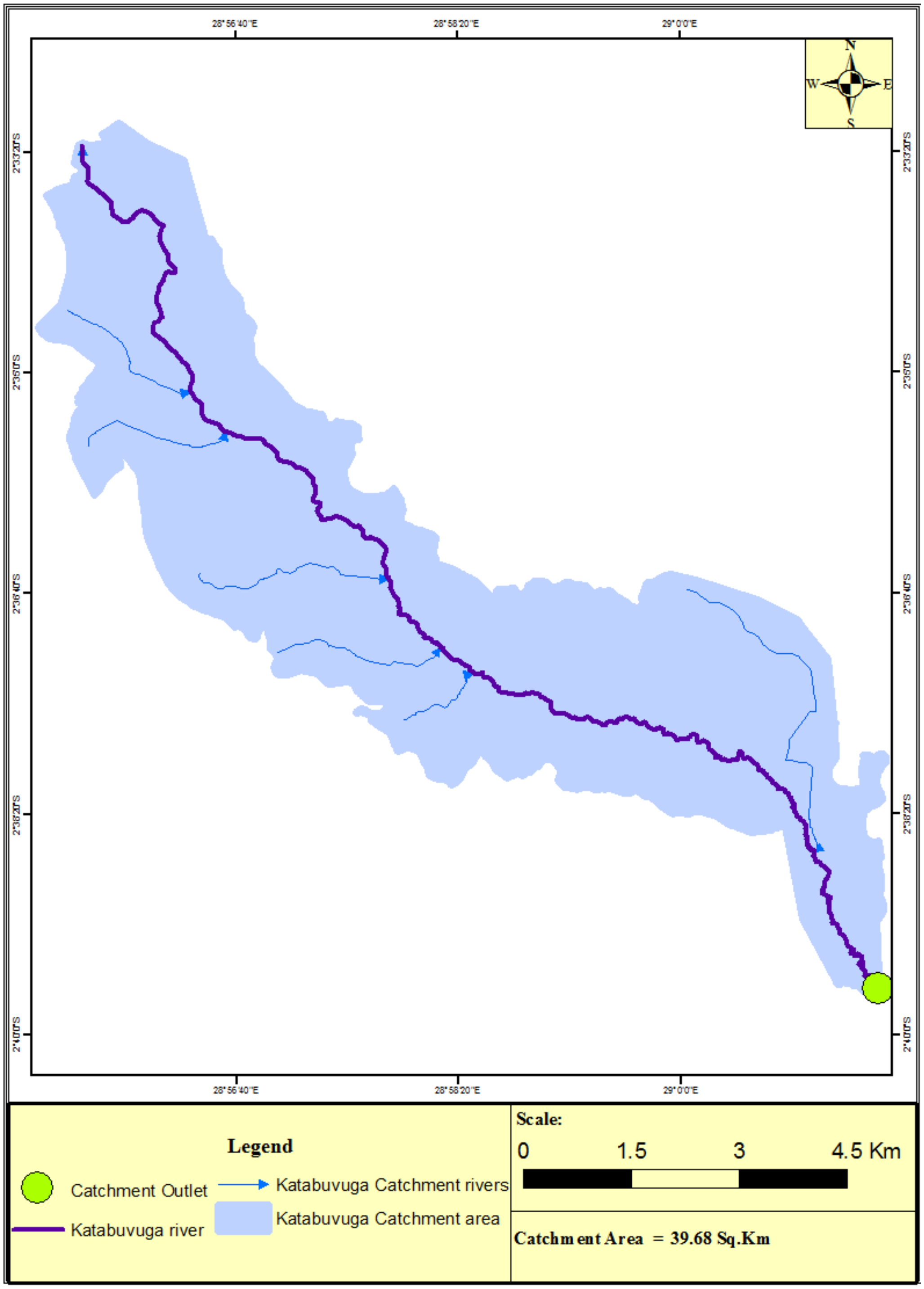


**Figure 12**: The area of Katabuvuga sub catchment

It has been found by experiments that as the catchment area increases (>2km$^2$) the rational formula becomes less accurate (Langousis, 2005). In such case the point area should be multiplied by ARF (Area Reduction Factor) as shown in Figure 13 below. The application of ARF to larger catchments was supported by Chow *et al.* (1988) and its accuracy was tested successfully by Bulter and Davies (2004). Bulter and Davies (2004) said “Point rainfall is not necessarily representative of rainfall over a larger area because average rainfall intensity decreases with increasing area. In order to deal with this problem, and avoid overestimating flows from larger catchments, areal reduction factors (ARF) have been developed. The expression is valid for the storm durations of 5 minutes to 48 hours.

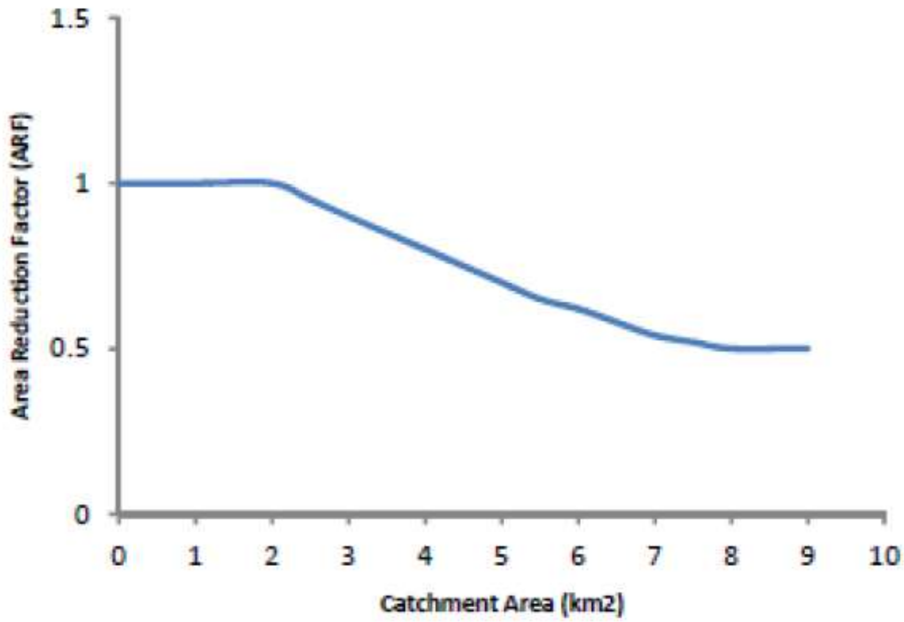


**Figure 13**: Area reduction factor curve for larger catchments (adopted from Langousis, 2005)

## CHAPTER 4: DATA ANALYSIS AND RESULTS INTERPRETATION

### 4.1. Analysis of the causes and impacts of flood in the Katabuvuga sub catchment

Katabuvuga sub catchment is not left out of the effect of this global disaster where almost every year flood events are recorded and its consequences have been evaluated. The causes of flood in Katabuvuga sub catchment and negative consequences of floods on the socio-economic welfare of the population living in this sub catchment have been summarized in the figure 14 below. Different causes of Flood which have been identified in Katabuvuga sub catchment are: poor runoff management, erosion, poor rainwater harvesting technologies, low infiltration, poor drainage systems, poor people settlement, climate change, steep slope, no or inadequate education program for flood control and poor mind set of people.

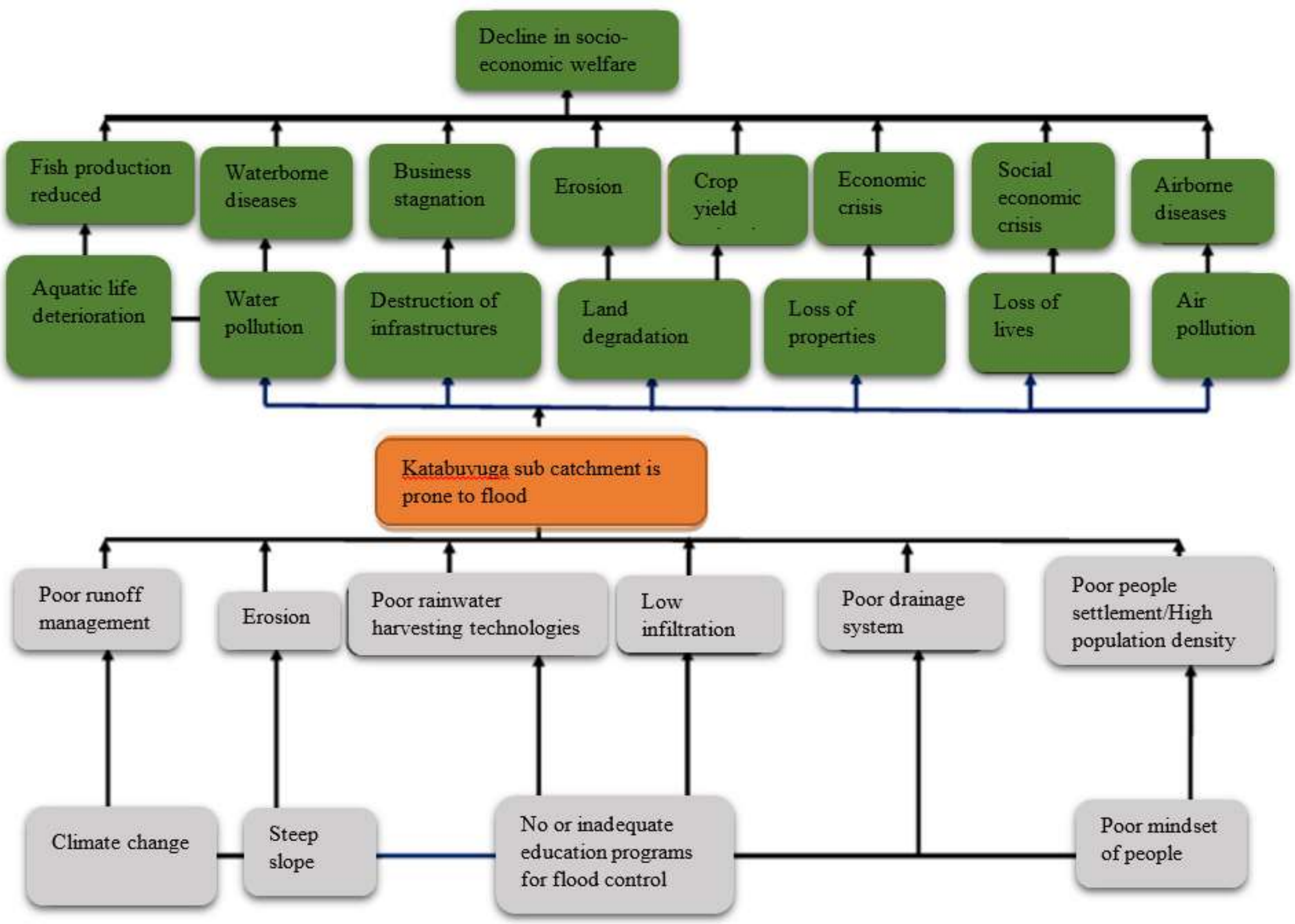


**Figure 14:** Problem tree analysis of Flood in Katabuvuga sub catchment

The negative consequences of floods on the socio-economic welfare of the population living in this sub catchment are: land degradation, loss of properties, loss of lives, water pollution, waterborne diseases, Business stagnation, social economic crisis, population at risk, erosion, crop yield, airborne diseases, fish production reduced, aquatic life deterioration and destruction of infrastructure. In addition its rapid water runoff causes soil erosion and concomitant sediment deposition elsewhere (such as further downstream or down a coast).

### 4.2. Data processing and analysis of Kababuvuga sub catchment

#### 4.2.1. Calculation of time of concentration of Katabuvuga sub catchment

The Time of concentration (**$t_c$**) which is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet is given by the Kirpich/Ramser formula (equation 2) which consider the length of main river and the average slope of main stream.

According to the figure 15 below and figure 9, the length of the main river is L=21.67Km and the mean slope of the main river is S= $\frac{\Delta H}{L} = \frac{(1825m - 975m)}{21670m} = 0.0392 = 3.92\%$

The time of concentration is $t_c = 0.0195L^{0.77}S^{-0.385}$

$t_c = 0.0195(21670)^{0.77}(0.0392)^{-0.385}$

$t_c$ = 147.98 minutes= 02hrs 27min 59sec

The time of concentration for Katabuvuga sub catchment has been found to be 02hrs 27min 59sec. It means that the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet is equal to 02hrs 27min 59sec.

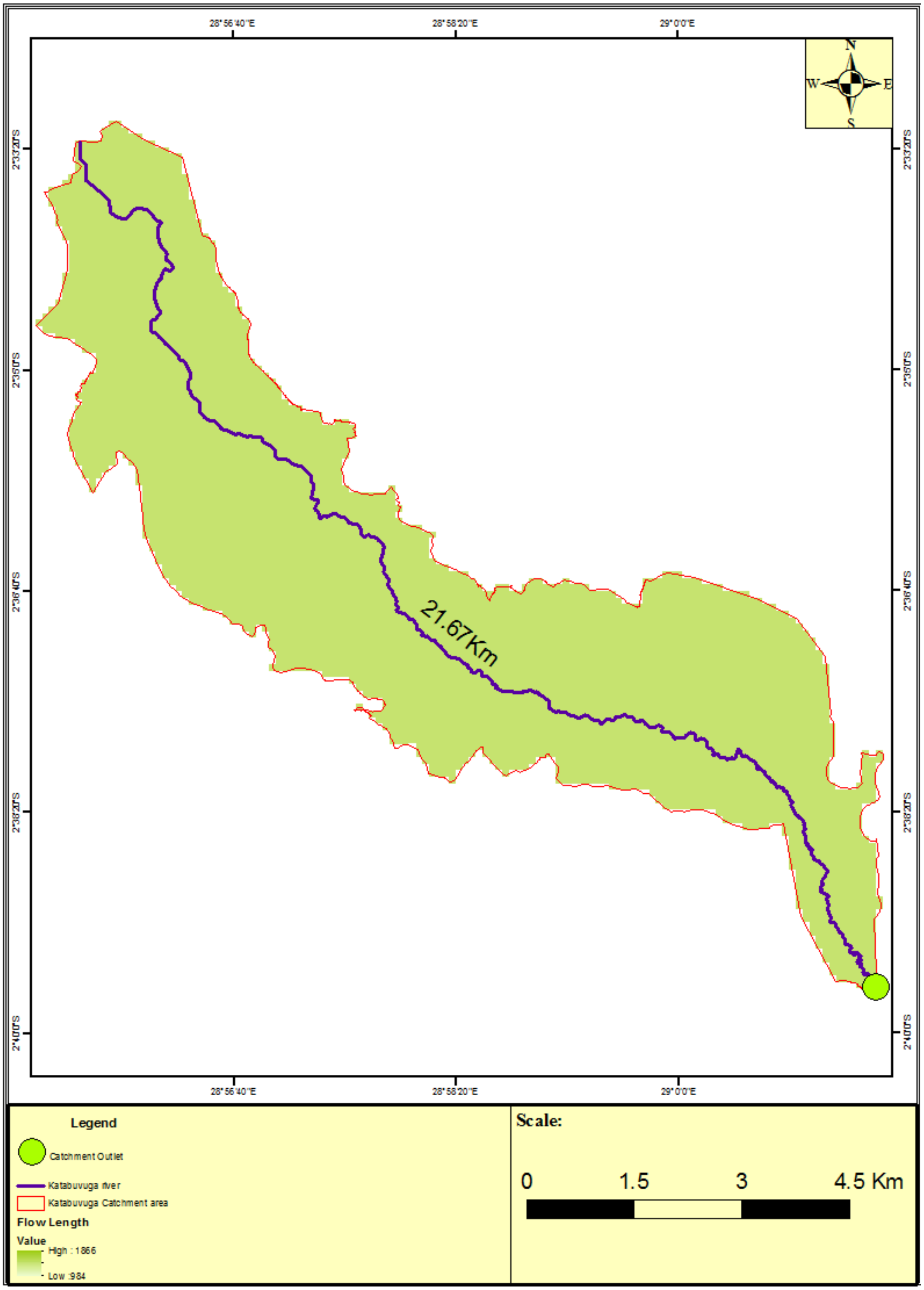


**Figure 15**: The katabuvuga length

### 4.2.2. Calculation of rainfall intensity of Katabuvuga sub catchment

This research has considered the flooding worst case and has considered data from Rwanda meteorological Agency in the period of 9 years on daily basis (January 2011-December 2019). During this period, the maximum rainfall intensity was found to be 2.3 mm per hour which was observed on the 07$^{th}$ March 2016.

### 4.2.3. Determination of the Katabuvuga runoff coefficient

According to the Figure 12 from ArcGIS determining the area of Katabuvuga Sub catchment which is 39.68 $Km^2$, it is observed that the area is more than 2$Km^2$ and from this an area reduction factor (ARF) must be applied using the figure 13. From the figure 13, the ARF was found to be 0.78. So the reduced area of Katabuvuga sub catchment is: 39.68$Km^2$*0.78 = 30.9504 $Km^2$

Using Figure 11 showing the land use map, the Katabuvuga sub catchment is subdivided into five categories according to its land use. There is rainfed agriculture which covers 80% of the studied area, open land which cover 5.8%, forest plantation which cover 0.8%, irrigated or agricultural wetland in valley bottoms which cover 9.2% and Built-up areas which cover an area of 4.2%. Their respective areas are 31.744 $Km^2$, 2.30144 $Km^2$, 0.31744 $Km^2$, 3.65056 $Km^2$, and 1.66656 $Km^2$ respectively.

| **Land use** | **Soil type and/or land use** | **Area $A_i$ in $Km^2$** | **Runoff coefficient $C_i$** |
|---|---|---|---|
| Rainfed agriculture | Heavy soil, with crops | 31.744 | 0.50 |
| Open land | Heavy soil, steep, 7% | 2.30144 | 0.35 |
| Forest plantation | Woodlands | 0.31744 | 0.25 |
| Irrigated or agricultural wetland | Heavy soil, with crops | 3.65056 | 0.50 |
| Built-up areas | Single-family areas | 1.66656 | 0.50 |
| | $\sum$ | 39.68 | |

**Table 5:** Summary of determination of runoff coefficient

The runoff coefficient to be used is then calculated by using the following formula:

$$C=\frac{\sum_{i=1}^{n} Ai*Ci}{\sum_{i=1}^{n} Ai}$$

Where, $A_i$ ($km^2$) represents partial areas and $C_i$ the partial runoff coefficients, according to different sub-catchments of a given catchment

Then $C=\frac{(31.744*0.50)+(2.30144*0.35)+(0.31744*0.25)+(3.65056*0.50)+(1.66656*0.50)}{39.68}=0.48$

#### 4.2.4. Determination of the Katabuvuga peak runoff

The Katabuvuga sub catchment peak runoff was calculated using equation 4 and also considering area reduction factor (Figure 13)

Then, equation 4 is $Q_p$=0.00278*C*I*A

Where: $Q_p$ = Peak runoff rate [$m^3$/s], C = Runoff coefficient, I = Rainfall intensity [mm/hr], and A = Drainage area/catchment area [ha].

$Q_p$= 0.00278 *0.48 *2.3mm/h*3095.04 ha= 9.5 $m^3$/s

The Katabuvuga river peak runoff is 9.5 $m^3$/s.

# CHAPTER 5: PROPOSED APPROPRIATE MEASURES FOR FLOOD CONTROL AND ITS DESIGN

## 5.1. Proposed appropriate measures for flood control and Land use prediction

### 5.1.1. Proposed appropriate measures for flood control in Katabuvuga sub catchment

The figure 15 below summarizes the measure and strategies to be taken in order to make Katabuvuga sub catchment free from flood. Among the proposed measure and strategies there are: Construction of a multipurpose dam, Best runoff management, erosion mitigation, Improvement of rain water harvesting technologies, construction of drainage infrastructures, reduction of population density and amelioration of human settlement, establishment of measures of environmental protection, improve the terracing cultivating methods and education of the population about the danger of flood.

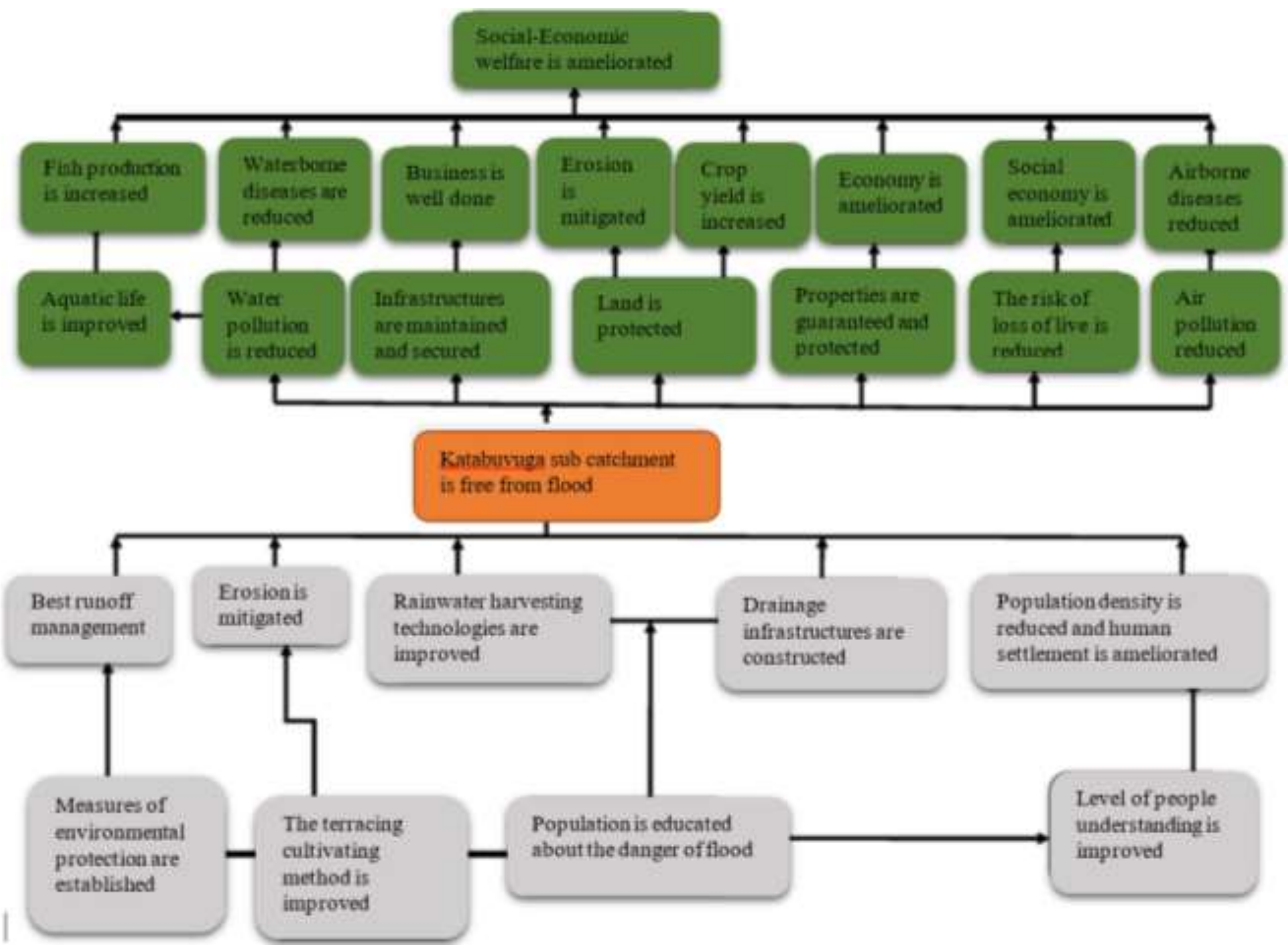


**Figure 16**: Objective tree analysis on Floods in Katabuvuga sub catchment

If the above proposed measure and strategies are applied, the positive consequence to the social economic welfare of the population will be seen like amelioration of Economy, reduction of airborne diseases, no risk of loss of lives, properties will be guaranteed and protected, land will be protected, erosion mitigated, Infrastructure are maintained and secured, reduction of water pollution, improvement of aquatic life, increase in fish production, reduction of waterborne diseases, Business is well done, and crop yield is increased.

### 5.1.2. Land use prediction

The land use prediction has a considerable impact on runoff coefficient and also on runoff discharge prediction. It is calculated using the following formula:

$$L_{i+n} = L_i \left(1+n\frac{a}{100}\right)$$

Where:

- ✓ **$L_i$ :** Built area at year i
- ✓ **$L_{i+n}$ :** Forecasted built area after n years
- ✓ **n :**Design period (years) and
- ✓ **a:** Annual urbanization growth rate (%)

The Katabuvuga sub catchment of **3968 ha,** the land use is partly dominated by rainfed agriculture in the upper part which cover 3174.4 ha (80%), open land which cover 230.144 ha (5.8%), forest plantation which cover 31.744 ha (0.8%), a significant part as irrigated or agricultural wetland in valley bottoms which cover 365.056 ha (9.2%) and a Built-up areas which are rather limited in size and mostly located in the Bugarama valley and cover an area of 166.656 ha (4.2%).

The forecast built area have been calculated based on the design period of 30 years for sustainable flood control and using the linear prediction formula.

$$L_{i+n} = L_i \left(1+n\frac{a}{100}\right)$$

Where:

$L_i = L_{2020} = 166.656$ ha

n=30 years

i+n=2020+30=2050

$L_{i+n}=L_{2050}$

a=3.145 % the Rwanda annual urbanization growth rate in 2018 (World Bank, 2018)

$$\mathbf{L_{2050}=166.656(1+30\frac{3.145}{100})=323.895ha}$$

This means that the built up area will increase from166.656 ha (4.2%) in 2020 to 323.895ha (8.16%) in 2050.

The built up area for the whole catchment will in general be composed by Residential houses with multi-unit attached which all have a runoff coefficient equal to 0.75 (from the table 4). Then the runoff coefficient of the Katabuvuga sub catchment has been calculated as:

$$\text{Then } C=\frac{(30.2843*0.50)+(2.2162*0.35)+(0.31734*0.25)+(3.62326*0.50)+(3.2389*0.75)}{39.68}=0.51$$

This means that with a design period of 30 Years, The Katabuvuga sub catchment peak runoff calculated using equation 4 and also considering area reduction factor (Figure 13) for this land use prediction is:

$Q_p$=0.00278*C*I*A

Where: $Q_p$ = Peak runoff rate [m³/s], C = Runoff coefficient, I = Rainfall intensity [mm/hr], and A = Drainage area/catchment area [ha].

$Q_p$= 0.00278 *0.51 *2.3mm/h*3095.04 ha= 10.093 $m^3/s$

The Katabuvuga river peak runoff is 10.093 $m^3/s$ for a design period of 30 Years.

## 5.2. Design of a sustainable multipurpose hydraulic structure for flood control in Katabuvuga sub catchment

Regarding the Proposed appropriate measures for flood control in Katabuvuga sub catchment, the most important among others is the Construction of a multipurpose embankment dam on Katabuvuga River which can serve not only for flood control as retarding reservoir but also for irrigation of more than 300 ha of Bugarama agricultural area, fish farming, recreation and sport, etc. Some of the main advantages of choosing an embankment dam in that area are the availability of construction materials which will make it cheaper that other types of dams and also it resist more earthquake which occur in that area that concrete dams.

### 5.2.1. Hydrology

#### 5.2.1.1. Reservoir Simulation

The reservoir simulation aims at determining the reservoir volume that can meet the irrigation demand at a certain level of reliability.

The permanent environmental flow releases from the reservoir assumed equal to the minimum of 10 l/s.

- ✓ The irrigation demand volumes during the four dry months period (June, July, August and September), as determined by the irrigation system study for the whole command area. These are given in the following table:

| June | July | August | September | Total |
|---|---|---|---|---|
| 380,000 | 420,000 | 515,000 | 215,000 | 1,530,000 |

**Table 6:** Irrigation demand volume ($m^3$)

- ✓ The level of reliability expressed as the percentage of time that an accepted percentage of the total demand is met. In the case of the Katabuvuga sub catchment multipurpose proposed embankment dam, an accepted level of reliability is considered to be achieved when 90% of the total demand is met at 70% of the time.

The simulation calculations resulted in a live storage requirement of 1,600,000 $m^3$ which, if added to the adopted dead storage volume of 220,000 $m^3$, makes a total reservoir volume of 1,820,000 $m^3$. This is the volume used for reservoir and dam design.

The simulation results are presented in the following diagram, where for the total reservoir volume of 1,820,000 $m^3$ and the specified irrigation demand the relationship between the proportions of demand met and years is shown, as well as the fact that the reliability criteria set are met.

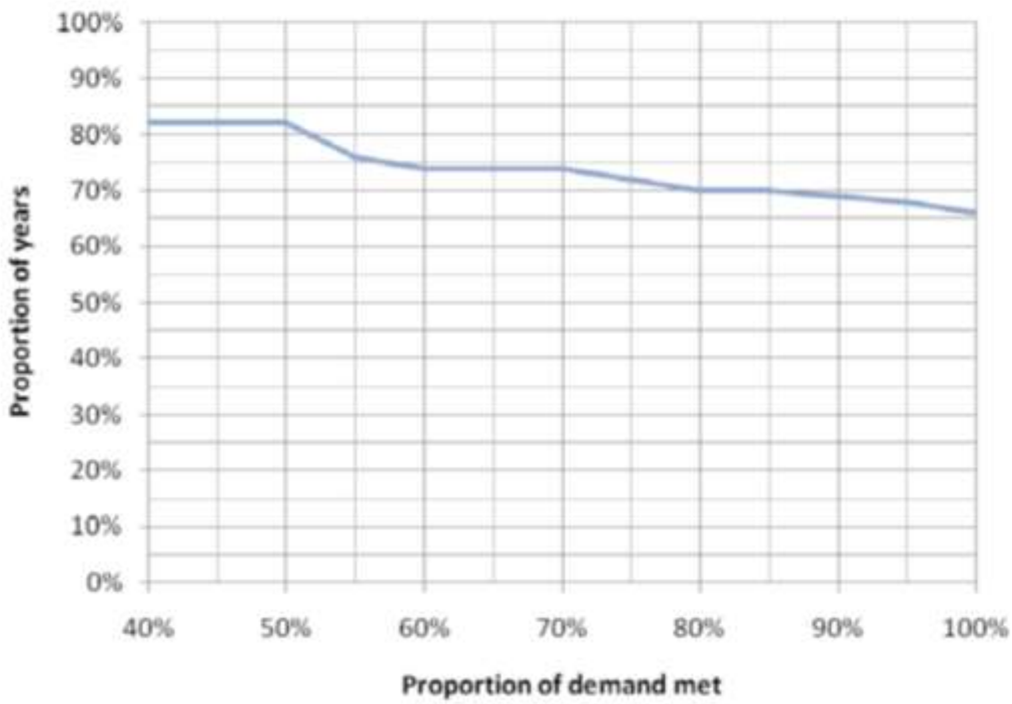


**Figure 17:** Results of simulating modeling

#### 5.2.1.2. Evaporation and potential evapotranspiration

Taking reference to the Table 2 of the Precipitation and Influencing factors for rainwater moisture retention by Altitude zone (Source: UNEP (2009). Rwanda: From Post-conflict to Environmentally Sustainable Development), The Annual reservoir evaporation and potential evapotranspiration depths were estimated equal to 1700mm. These values were reviewed and are adopted for the current design as well.

### 5.2.2. Embankment Dam Design

The proposed embankment dam design will consider this dam as non-over flow dam and the following design criteria will be taken into consideration:

- Sufficient spillway capacity and free board to prevent overtopping
- Seepage flow through the embankment will be controlled so that the amount of water lost does not interfere with the objective of the dam
- Uplift pressure due to the seepage will not be enough to cause piping

- ❖ The slopes of the embankments must meet the stability criteria under all conditions of operation of the dam
- ❖ The upstream and downstream sides of the embankment will be sufficiently protected
- ❖ Stresses in the foundation and body of the dam must be within the allowable values.

#### 5.2.2.1. Dam axis and Geometry

The proposed location of the dam is presented in the design drawings.


The location is favorable for the construction of the dam from both geomorphological and geological point of view. The dam crest is proposed to be at elevation +1099 m. By taking into account that the existing lower ground level on the dam axis is at elevation +1080 m approximately, the dam height is determined to be 19.0 m approximately from the ground level.

The dam crest elevation is fixed on the basis of the following parameters:

## ❖ Stated Maximum Operational Level of the Reservoir

According to the reservoir simulation study this is set at 1096 m, taking into account the active volume required for balancing inflows and irrigation demand and ensuring an acceptable level of reliability, as well as the calculated dead storage volume.

The reservoir elevation – storage curve and specifically its section above the free spillway crest level (1096 m)

For the 1:30 years flood, the maximum flood level is 1096.4 m, corresponding to a maximum discharge of 10.093 $m^3/s$.

## ❖ Wave run-up

**Effective fetch calculation ($F_{eff}$)**

It is calculated from the table below. The data are derived from the simulated reservoir map and considering a range of 45º on the right and left side of the perpendicular axes of the dam. It is noted that the most unfavorable wind direction in relation to the maximum fetch length has been adopted.

| Ø(º) | Cos(Ø) | $X_i$(m) | $X_i$* Cos(Ø) |
|---|---|---|---|
| 45 | 0.7 | 75 | 52.5 |
| 40 | 0.76 | 82 | 62.32 |
| 35 | 0.81 | 90 | 72.9 |
| 30 | 0.86 | 115 | 98.9 |
| 25 | 0.9 | 120 | 108 |
| 20 | 0.93 | 156 | 145.08 |
| 15 | 0.96 | 196 | 188.16 |
| 10 | 0.98 | 234 | 229.32 |
| 5 | 0.99 | 248 | 245.52 |
| 0 | 1 | 275 | 275 |
| 5 | 0.99 | 282 | 279.18 |
| 10 | 0.98 | 260 | 254.8 |
| 15 | 0.96 | 258 | 247.68 |
| 20 | 0.93 | 261 | 242.73 |
| 25 | 0.9 | 248 | 223.2 |
| 30 | 0.86 | 140 | 120.4 |
| 35 | 0.81 | 134 | 108.54 |

| | | | |
|---|---|---|---|
| 40 | 0.76 | 150 | 114 |
| 45 | 0.7 | 161 | 112.7 |
| **TOTAL** | **16.78** | **3485** | **3180.93** |

**Table 7:** Effective fetch calculation

$\mathbf{F_{eff} = \Sigma X_i * Cos Ø_i / \Sigma Cos Ø_i = 318.93/16.78 = 189.56m = 0.189km}$

**Wind design**

According to the Rwanda meteological Agency, the average wind speed at Bugarama station near the dam site in this research is 10 km/h. This cannot be adopted as a design wind speed but is an indication of the general wind regime and shows that not too strong winds blow in the area. From this point of view and based on the general experience from similar cases a wind speed of 70 km/h is adopted for the calculation the wave height and run-up and the rip-rap sizing.

**Wave height calculation**

By adopting the above effective fetch and wind speed, and using the two below chats,

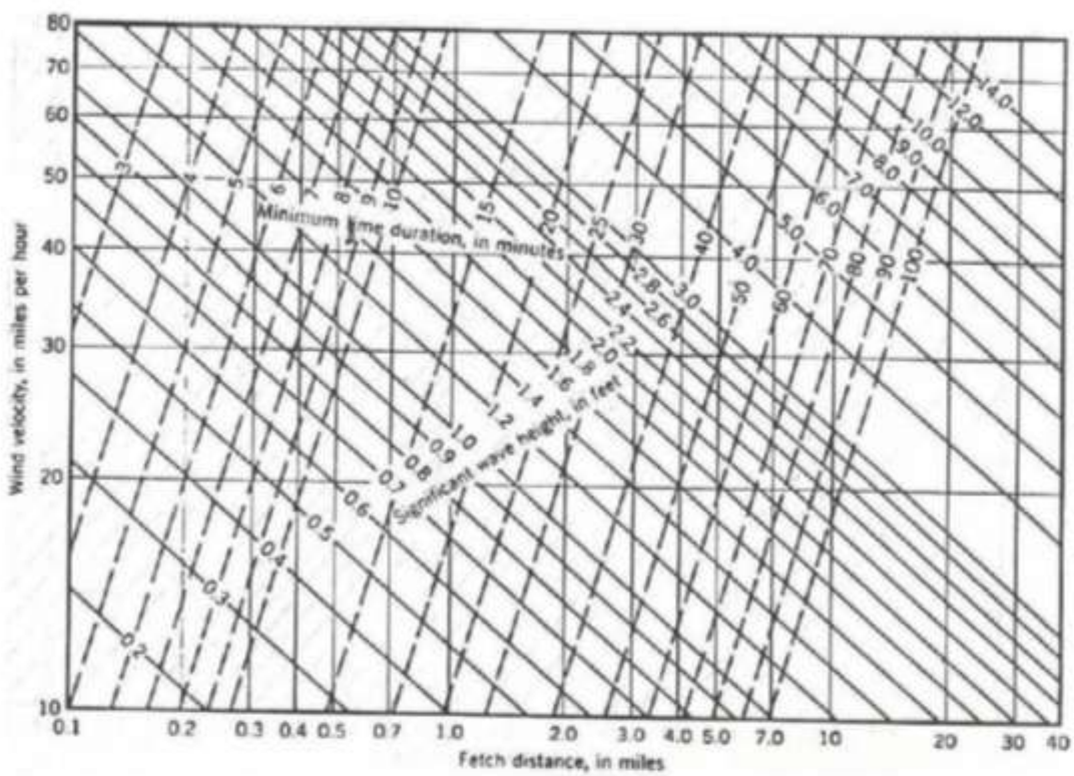


**Figure 18:** Chart for wind velocity and fetch distance

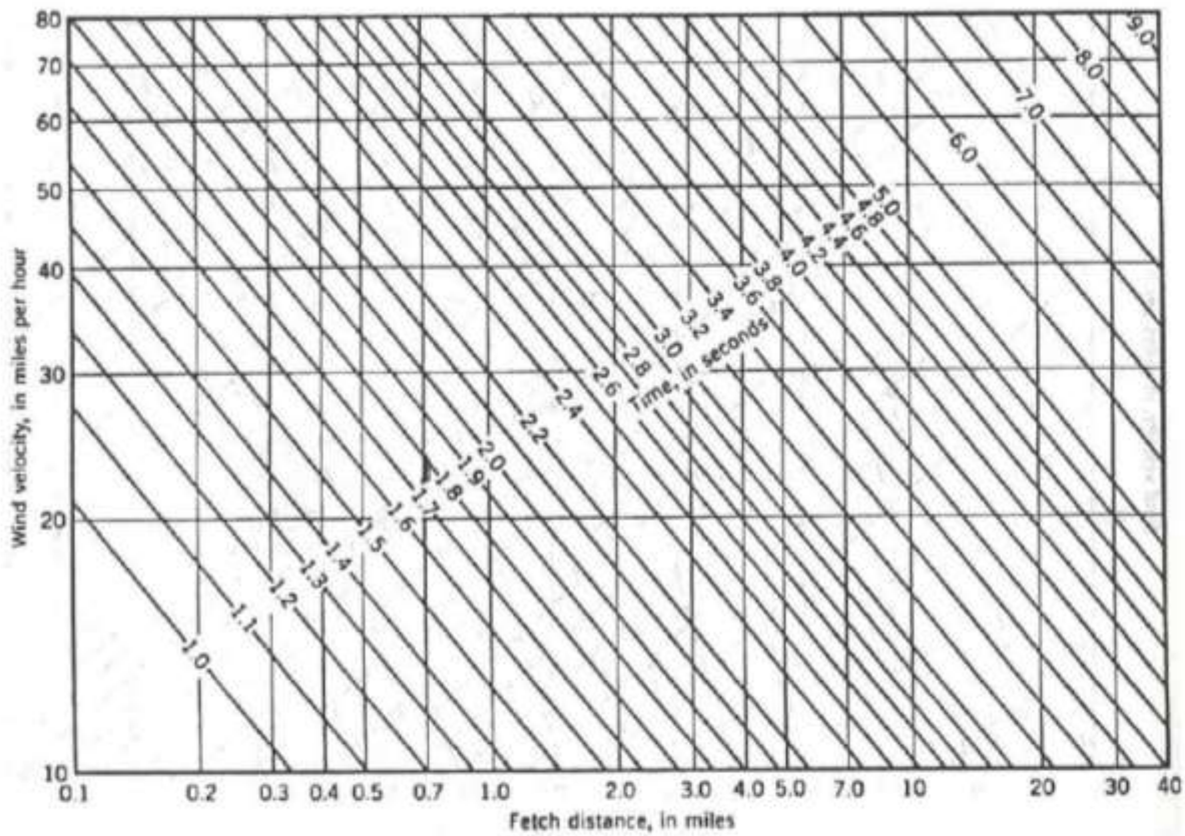


**Figure 19:** Chart for wind velocity and fetch distance

We find that:

Wave period T=1.4sec

Significant waves height $H_s$=0.15 Feet=0.045m

The wave length L is calculated using the following formula:

L=1.56 $T^2$;

Then L=1.56*$(1.4)^2$=3.05m

**Wave run-up calculation**

Wave run-up from a significant wave on an embankment with rip-rap surface underlain by an earth fill embankment is calculated based on the formula:

$$Rs = \frac{\text{Hs}}{0.4 + (Hs/L)^{0.5}\cot\theta}$$

Taking into account that Cot (θ) =2.24 ; θ: the angle of upstream slope to the horizontal

$$Rs = \frac{0.045}{0.4 + ((\frac{0.045}{3.05})^{0.5} * 2.24)} = 0.067m$$

- **Check for the Dam Overtopping**

Maximum water level during the 1:30 year's period flood: 1096.4 m
Maximum water level considering wave height and run-up:
1096.4m + (0.75 x 0.045) m + 0.067m = **1096.5** m.
This elevation is lower than the fixed dam crest level (1,099 m), so the dam is safe against overtopping.

- **Dam crest width**

The dam crest width (w) is related to the dam height (h), according to the generally accepted formula of the "Design of Small Dams" [U.S. Department of Interior, Bureau of Reclamation, 1987]:
w = h/5 + 3.3
Thus, taking into account that the dam height, h, is 19.0 m, the crest width, w, is calculated:
W=19/5+3.3= 7.1m

- **Dam Embankment Slopes**

Using the recommendation of Tarzaghi, The dam embankment slopes are proposed to be 2.5:1 (h:v) for the upstream and 2:1 (h:v) for the downstream face. Downstream face will have one berm 6 m wide at +1089. At the upstream part there is also a berm created by the cofferdam crest. These slopes are determined in relation to the properties of the materials selected for the dam construction and the respective stability requirements.

- **Dam base**

Hence, as the height of the dam is $H_{dam}$=19m;
The base of the dam will be equal to: L= (19m*2.5) + (19m*2) +7.1m=92.6m

❖ **Dam drain**

Let's consider a drainage prism with:

Base width = L/2*0.3=92.6m/2*0.3=13.8m

The level of water at the bottom part of the dam is $H_2$= 1m

If $H_2$ = 2/3h; with h=height of the drain

The height of the drain h =3/2*1m = 1.5m

❖ **Top width of the drain**

In this research, we have assumed that two side slopes of our drain are equal and equal to the side slope of downstream of the dam. Therefore by interpolation, we determine the top width as:

Top width = 6.5 m

Bottom width= 12.8 m

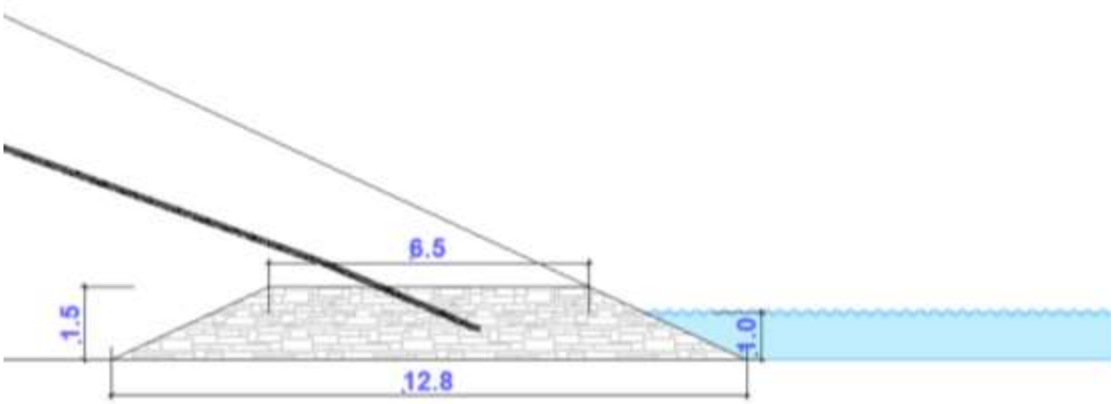


**Figure 20:** The drain of the dam

❖ **Core**

In this research, we have assumed that the top width of screen is 0.3*width of crest

This means that $b_1$=0.3*W

With: **$b_1$:** Top width of the core and **W:** Width of the crest

So, $b_1$=0.3*7.1m = 2.13m

Upstream slope of the screen is tan 80º and downstream slope is tan 85º

$X_1$ = (16.4/tan80º) +1.065 = 3.95m

$X_2 = (16.4/\tan 85^o) + 1.065 = 2.49m$

This means that bottom width of the core $b_2 = X_1 + X_2 = 6.44m$

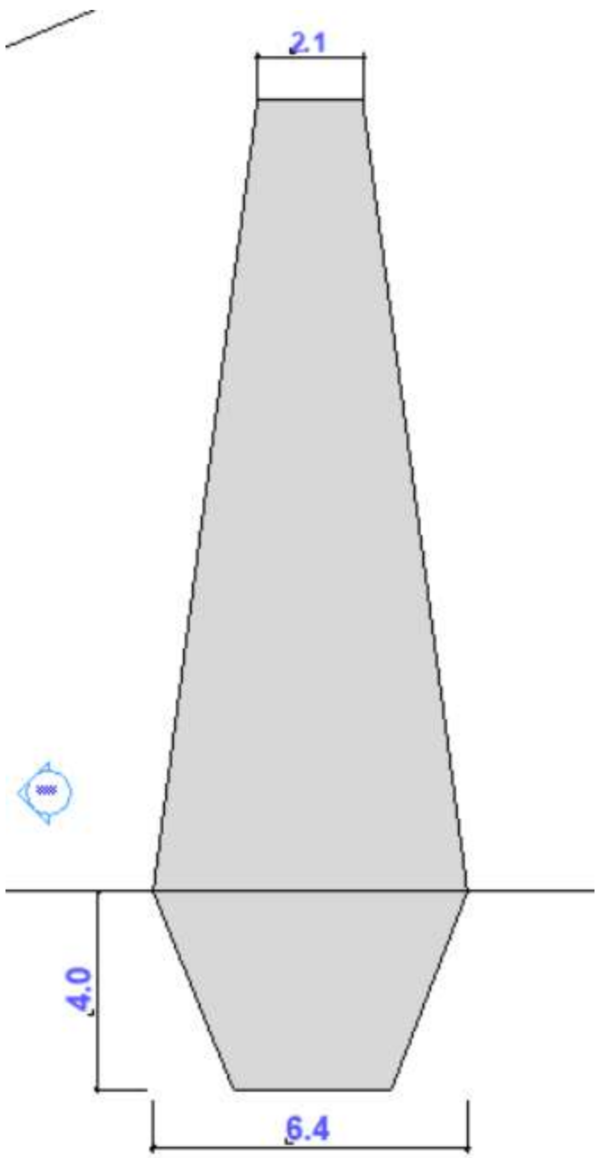


**Figure 21:** The core of the dam

❖ **Cross section of the dam**

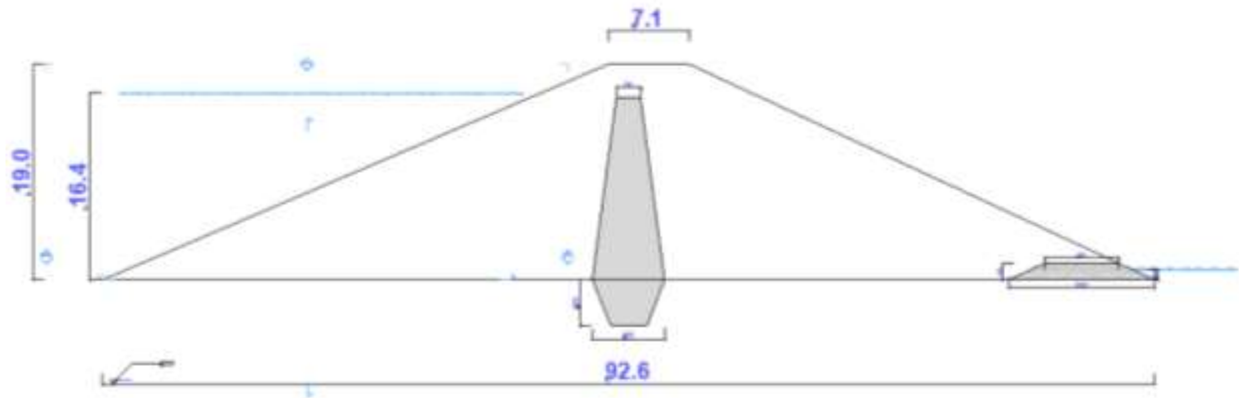


**Figure 22:** The cross section of the dam

### 5.2.2.2. Embankment materials and Cross- section

The dam will be a zoned earthfill dam with a clay core and shoulders built with metasediments and schist material from the reservoir area. In this research, two alternatives were considered: Those of a zoned rockfill dam and a zoned earthfill dam both with a central clay core.

Rockfill material from very good quality quartzite can be found very close to the dam axis in the upper part of the left abutment. Earthfill material from metasediments and schists can be found in the broader reservoir area.

The main advantages of the earthfill dam are the ease of construction and the lower unit cost for the material excavation and the embankment construction. On the other hand the main disadvantage is the increased embankment volume due to the milder slopes. A cost comparison of the two alternatives favors the earthfill dam.

### 5.2.2.3. Determination of Seepage flow

Seepage flow computation is done with the aim to:

- ✓ Determine the position of the depression curve and when necessary to determine its exit position relative to the downstream slope
- ✓ Determine the velocity gradient (hydraulic gradient) and the velocity of seeping water.
- ✓ To determine the seepage flow rate to know the water losses from the reservoir

❖ **Determination of the seepage depression curve**

For dam with core, the method of virtual length is used:

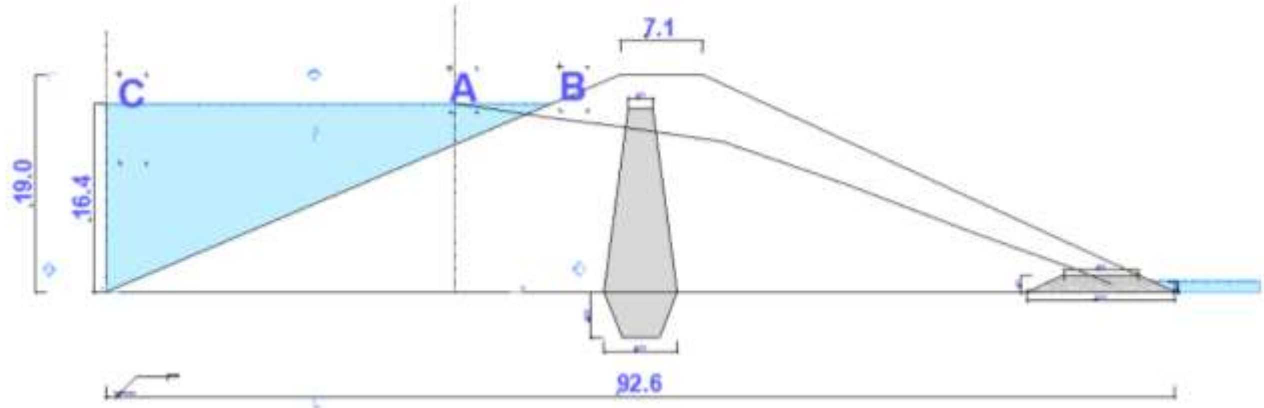


**Figure 23:** Seepage depression curve

$b_{av} = \frac{b_1 + b_2}{2} = \frac{2.13+6.44}{2} = 4.285m$

The equivalent thickness $L_{eq}$ of the core where φ is the average slope of the inclined core is given by:

$L_{eq} = (\frac{b_{av*Kb}}{K_{core}})/sin\varphi = (\frac{4.285*0.25}{0.00015})/sin80 = 7251.8m$

The upstream bottom angle θ is equal to tan θ=19/47.5 = 0.4. This means that **θ = 21.8º**

Tan θ = $\frac{16.4}{CB}$ ; this means that CB = 41m

AB = 0.3 CB = 12.3M

$m_1$=cotan θ= 2.5m

The ordinate of the depression curve is given by:

$Y^2 = \frac{(H_{1-H2})^2}{L_{eq}} x = \frac{15.4}{7251.8}^2 x$

**$Y^2$ = 0.032 X**

$X_1$ = 7251.8 correspond to $Y_1$ = 15.2

$X_2$ = 1000 correspond to $Y_2$ = 5.6

ΔH = $Y_1$- $Y_2$= 9.6m

- **Determination of the seepage volume per day through dam and foundation**

In this research, we have assumed that the dam is constructed on the pervious foundation. In computing seepage of dam on previous foundation, I break the computation into two parts:

1º) previous body of dam with impervious foundation

2º) impervious body of dam with a previous foundation

For previous body of dam with impervious foundation, I found that the seepage volume per day is:

$q_a = \frac{Kb}{2Leq}(H_1^2-H_2^2) \quad = \quad \frac{0.25}{2*7251.8}(16.4^2-1^2) \quad = 0.00461\ m^3/day$

For imprevious body of dam with pervious foundation, I found that the seepage volume per day is:

$q_b = \frac{Kf\,T}{nL}(H_1-H_2)$

Where: $K_f$: Filtration coefficient of materials of foundation =0.1

T: thickness of pervious foundation =4m

n : correction factor for seepage length which depends on $L_1$/T. in this research we take by interpolation technics n =1.06

$q_b = \frac{0.1*4}{1.06*7251.8}(16.4-1) \quad = 0.000801\ m^3/day$

Therefore, the total seepage flow $\mathbf{q_{dam}}$ through the section is:

$\mathbf{q_{dam}} =$ $q_a$+ $q_b$= 0.00461 $m^3$/day + 0.000801 $m^3$/day = **0.00541 $m^3$/day**

**5.2.2.4. Spillway**

Spillway is a passage way to by-pass the dam flood flow that are not be contained in the allowed storage space. Regarding the earth fill dam designed in this research, the side channel spillway is proposed and must be able to evacuate the Katabuvuga river design flood of 10.093 $m^3/s$ calculated for a design period of 30 Years.

This side channel spillway must be done in reinforced concrete. The size of the side channel spillway are:

- Interior width: 3m

- Sides height: 2m
- Thickness of the wall: 0.3m

With this size of the channel, we have an area section of: 3m*2m =6 $m^2$
For the Katabuvuga river design flood of 10.093 $m^3/s$ , I have calculated a velocity of:
V = 10.093/6 = **1.6m/s**

#### 5.2.2.5. Irrigation Outlet

The existing and projected area to be irrigated in Bugarama valley with this dam is 300 hectar of paddy rice. Rice needs 5mm/day of water (www.fao.org). This means that the maximum need for irrigation is $50m^3$/hectar/day which is the equivalent to 173.6 liter/sec of water needed.
A valve chamber well equipped for controlling the flow will be constructed in the eastern part of the dam. For this amount of needed water for irrigation I propose a pipe of HDPE D400 mm nominal diameter and 6 bar nominal pressure for the maximum flow (200 l/sec), velocity v = 1.94 m/sec and i = 9.4‰. As the length of this pipe is 51m, the total head loss is: $0.0094 \times 51 \times 1.1 \sim 0.55$ m. after that length, an existing channel for irrigation can be used.

# CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

## 6.1. Conclusion

The aim of this research was to design a sustainable hydraulic structure for flood control in Rubyiro catchment with focus on Katabuvuga sub catchment. Katabuvuga is a mountainous sub catchment with area of around 39.68 $Km^2$. Daily rainfall data from January 2011 to December 2019 have been collected from two meteorological stations; the Kamembe airport station and Bugarama station. The maximum rainfall intensity was found to be 2.3 mm per hour which was observed on the $07^{th}$ March 2016. The peak runoff water discharge has been calculated by using the rational method and its prediction in 30 years has been calculated by using the linear model ($Q = 10.093\ m^3/s$). For a long term sustainable flood control solution for the Katabuvuga River of the Katabuvuga sub catchment as well as in the Bugarama Valley, a multipurpose embankment dam have been proposed.

The proposed multipurpose embankment dam, once applied will contribute not only to the flood control observed in this sub-catchment but also in other purposes like fishing, support existing irrigation systems, recreation among others for the development of that area and finally a positive socio economic impact.

## 6.2. Recommendations

From the research results, the following recommendations have been proposed:

- The Ministry in Charge of Emergency Management (MINEMA) can establish a flood risk management plan on the basis of the flood hazard maps and flood risk maps at National level including Katabuvuga sub-catchment,
- The reinforcement of the rain water harvesting system in the sub-catchment can contribute in reducing the runoff,
- The Ministry of environment and Rwanda Environmental Management Authority (REMA) have to establish a detailed plan for increasing the infiltration by doing like the afforestation and other techniques,
- Regular and systematic removal of sediments inside the dam for fighting against the clogging,

- Evacuation of the residents along the Katabuvuga river for avoiding flood related risks and rehoused in the safe area according to the master plan but not far from their farms

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