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RWANDA

COLLEGE OF SCIENCE AND
TECHNOLOGY

HYDROLOGICAL PROCESSES CLIMATE VARIABILITY IN THE RECENT DECADES IN CASE STUDY OF NYABARONGO CATCHMENT

By

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A dissertation submitted in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE IN ATMOSPHERIC AND CLIMATE SCIENCE in the College of Science and
Technology

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DECLARATION

I, Innocent NIYIBIZI with registration number **221027656**, a student from University of Rwanda, College of Science and Technology (CST), School of Science, Department of Physics (Master of Science in Atmospheric and Climate Sciences). I undersigned, hereby declare that this research entitled “**HYDROLOGICAL PROCESSES CLIMATE VARIABLITY IN THE RECENT DECADES IN CASE STUDY OF NYABARONGO CATCHMENT**” under the supervision of Prof. Bonfils SAFARI is my original work and which has never been presented or submitted by someone else for any academic award in any university or institution of higher learning, and that any work done by others or by myself previously has been acknowledged and referenced accordingly.

NIYIBIZI Innocent

Signature:

Date:...../...../2024

DEDICATION

I humbly raise my dedication to almighty God who kept me with this opportunity to become part of College of Science and Technology student especially in Master of Science in Atmospheric and Climate Sciences, and comforted me to accomplish this final year project.

I would like to dedicate this project to my beloved mother and all friends have been supporting me day to day of my life, all my lecturers and especially my supervisor Prof. SAFARI Bonfils.

CERTIFICATION

This is to certify that the study entitled “**HYDROLOGICAL PROCESSES CLIMATE VARIABILITY IN THE RECENT DECADES IN CASE STUDY OF NYABARONGO CATCHMENT**” is a record of an original work done by NIYIBIZI Innocent (221027656) as partial fulfilment of the requirements of award of Master’s degree of Science in Atmospheric and Climate Sciences in University of Rwanda, College of Science and Technology (CST) during the academic year 2024.

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ABSTRACT

Climate and land use changes affect the hydrological process in the catchment. Hydrometeorological parameters such as rainfall, evaporation, runoff, water level, temperature and water discharge were analysed for investigating the different impacts of climate and land use changes. Water balance equation and statistical analysis was performed using WEAP and Origin Pro Software to determine the yearly amount of those parameters listed above. The analysis shows that the runoff water, water level and water discharge increase with increasing the rainfall.

The high value of rainfall obtained is 10393mm in a single year and the lowest value is around 3218mm; In the Nyabarongo catchment the mean annual evaporation ranges approximately from 2.25 mm to 5.25 mm where the total evaporation within 12 years were 6339.5mm and its corresponding runoff were 67539.5mm.

The results show that in 2020 the mean temperature were high at 27.04 degree Celsius while is low in 2001 at 25.24299 degree Celsius, in 2020 the temperature increase to 1.8 degree Celsius. The calculated high value of discharge were 217mm obtained in the year 2018. The water levels in the Nyabarongo River in 5 years ago varies between 4m and 5m.

LIST OF ACRONYMS

CST- College of Science and Technology

ET- Evapotranspiration

I- Infiltration

P- Precipitation

R- Runoff

RMA- Rwanda Meteorological Agency

RWB- Rwanda Water Resources Board

UR- University of Rwanda

WEAP- Water Evaluation and Planning Software

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CHAPTER ONE: INTRODUCTION

1.1. Background of the study

The variation (changes) of weather and temperature over a long period results the climate change. The changes should depends on the natural phenomenon through the variations of the solar cycle [1]. Daily human activities such as burning fossil fuels like coal, oil and gas; increasing of industries are the key factors that cause the climate change. The land use change means change over time of the distribution of land uses within a specified area.

In Rwanda; fossil fuels is used by more population in daily activities such as cooking and the development of industries and increasing of vehicles release high amount of carbon dioxide in the atmosphere which promote climate change. The poor methodology in agriculture through using the fertilizers also my drive the climate change.

The main causes of hydrological processes are climate change and land use change. Variations or changes in temperature and precipitation is the main factors that influence the hydrological cycle; it affects the availability of water and participates in the production, transformation, or transportation of pollutants [1]. The changes in agriculture activities, urbanization and industrialization are the main causes of land use changes and affect the generation of surface runoff and have then affected the hydrological processes and the transport of pollutants. In the catchment both climate and land use are the main factors controlling the hydrological process [2]. It is important to understand the hydrological responses to these changes to develop strategies for land-use planning and water resource management. It is desirable to make further studies about the quality of water and deep analysis of the hydrological impacts of land use change and climate [3].

Many researchers focused on the impacts of climate and land use change on hydrology [4]. However, few researches have been conducted to investigate changes in hydrological processes and water resulted from impact of climate and land-use changes on global scale [1]. Rwanda has experienced climate change resulted from the increasing of air temperature and more variability of rainfall. Moreover, development of industry and rapid agricultural, as well as population

growth have obtained in recent decades [5]. These changes drives the soil erosion and affect the water quality and availability of water resources in Rwanda.

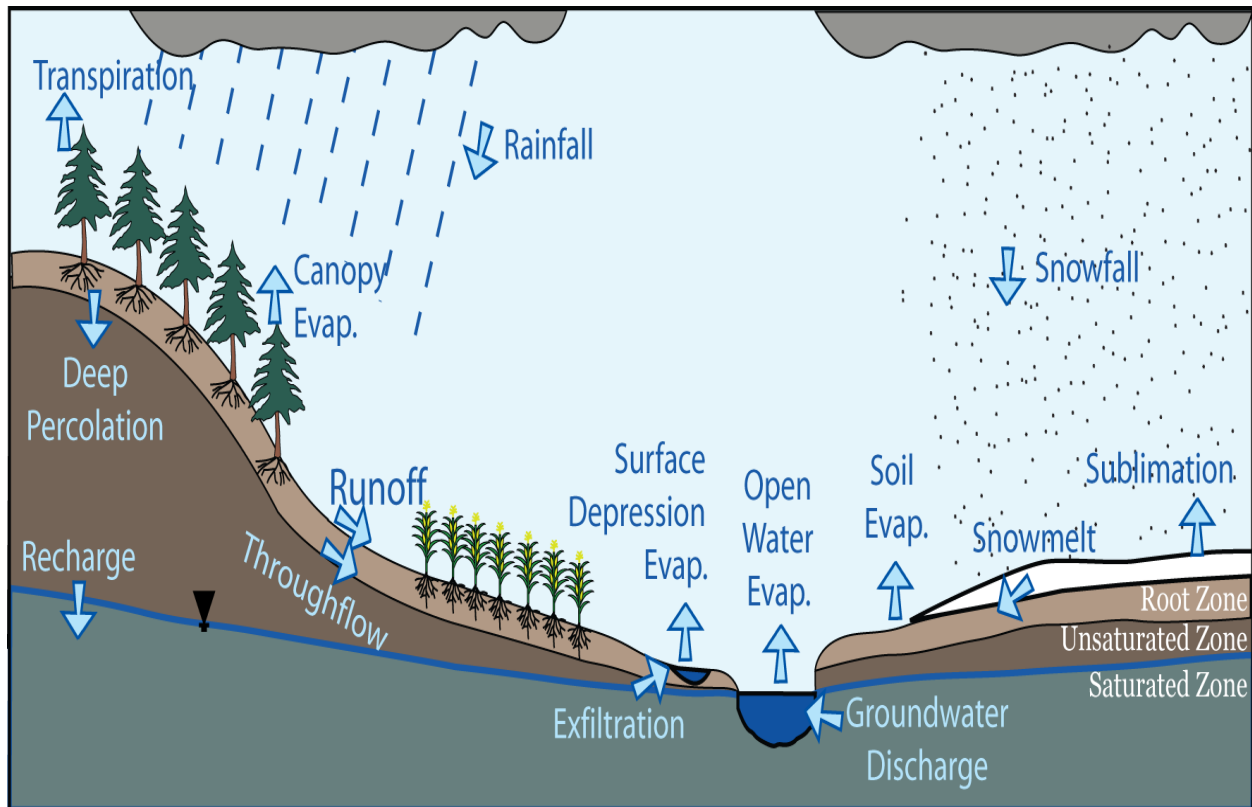


Figure 1: HYDROLOGIC PROCESSES IN A CATCHMENT

Within this project I will investigate and analyze how both climate and land use change affect Nyabarongo Catchment which is important for people living near it.

The Nyabarongo River is a major river in Rwanda included in the catchment, begins in Nyungwe Forest, and flows up to the north-western part of the country, then down through the center to the south-east. The Nyabarongo River is one of the largest river in Rwanda; it begins from the confluence of the Mbirurume and Mwogo rivers and finish at its confluence with the Akanyaru River, pouring into the Akagera River, as one of the biggest rivers that follows into Lake Victoria [6]. The Nyabarongo River is taken as a tributary of the Nile River and as goods and services transport agent. And also serves as source of drinking water, fishery and irrigation to

Rwandese communities; even though, it is facing heavy pollution from landslides, unsustainable agriculture, mining, and domestic industrial wastes.



Figure 2: NYABARONGO RIVER LOCATED IN NYABARONGO CATCHMENT

Land use change results in deforestation, agriculture expansion and urbanization; alongside climate change such as increasing air temperature and variability of precipitation both affect the Nyabarongo River which has more contribution to the life of people and acts as habitant of different living organisms.

1.2. Problem statement

Today Rwanda is a landlocked country facing the challenge of climate change produced by the rising emission of greenhouse gases from the burning of fossil fuels and the increasing of cars; those parameters cause the variation in temperature and precipitation. Nyabarongo catchment has contribution to the economy of the country through the production of hydropower, and irrigation and when recycled in a good way can be a source of water to many people. The rising temperature cause the variability of water discharge reaching in Nyabarongo catchment and also when rainfall increases produce flooding that destructs different properties such as

infrastructures, swamps, and some aquatic animals. Nyabarongo catchment faces both challenges of variation in temperature and rainfall.

The changes in agriculture activities, urbanization and industrialization are the main causes of land use changes and affect the generation of surface runoff and have then affected the hydrological processes and the transport of pollutants. Today Rwanda's government encourages farmers to use fertilizers in agriculture which generates pollutants and also urbanization and industries increase day to day which contributes to the shortage of water. Nyabarongo catchment faces those challenges of climate and land use change which affects the hydrological process.

1.3. Research objectives

1.3.1. General objectives

The main objective of this study is to quantify the impacts of land-use change and climate change on hydrological processes in a case study of Nyabarongo catchment in Rwanda.

1.3.2. Specific objectives

The specific objectives of this research are as follows:

- To calibrate and validate the precipitation, runoff, and evapotranspiration in the Nyabarongo Catchment
- To determine the separate impacts of climate and land-use changes on the hydrological process in Nyabarongo Catchment
- To assess the impacts of combined climate change and land-use change on hydrological processes.
- To analyze the relationship between precipitation, runoff and Evapotranspiration

1.4. Significance of the project

Climate change through increasing of temperature, variability of wind speed and precipitation are the most significant problems that challenges this world. The raising of air temperature and variability of precipitation affect the sources of water; the Nyabarongo River is the main source of water generation and also plays a great role in electricity through hydropower was affected by climate change (temperature and precipitation). Land use such as agriculture activities,

urbanization, and industries affects the availability of water and the transport of different pollutants. The interest of this research is to analyze and identify what rate different climatological and land factors affects the Nyabarongo River; and also to make deep analysis about the impacts of climate and land use change on hydrological process in the case study of Nyabarongo Catchment.

1.5. Scope of the project

According to the time of working the project, the data collected from different locations such as climatological factors (rainfall, temperature, and evapotranspiration) and land use (agriculture activities and urbanization) will show how they impacts hydrological process in Nyabarongo Catchment will be analyzed and discussed; the achievement of the project is to show qualitatively and quantitatively how the climate and land use affect hydrological process especially in Nyabarongo catchment.

CHAPTER 2. LITERATURE REVIEW

2.1. Origin of River Nyabarongo

Nyabarongo River originates in southwestern Rwanda and drives to the east of Lake Kivu. The source of river down in the mountain chain that covers most of the western third of Rwanda, drains to the east of the Albertine Rift [6]. The longest of the streams that feed Mwogo is the Rukarara, which is sourced in the Nyungwe Forest [7]. The Rukarara drains to south and then east, emptying into the Mwogo River. The Mwogo flows north, combining with the Mbirurume River south of Bwakira. From this confluence, the river attains the name Nyabarongo. The source of the Rukarara is a contender for the overall source of the Nile, the most distant headwater [7].

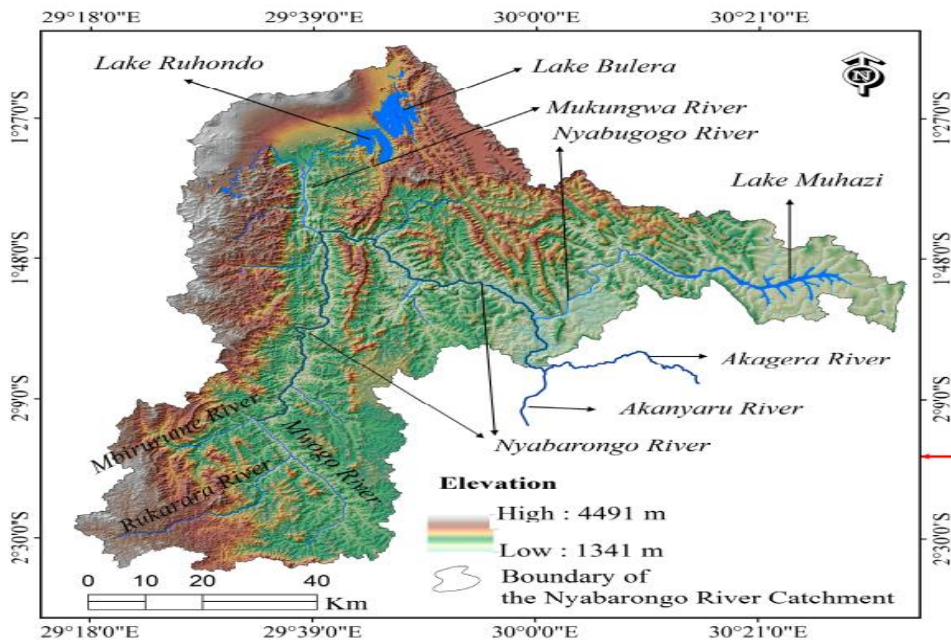


Figure 3: Map of Nyabarongo river and its originate rivers

The Nyabarongo River is the source of the White Nile and crosses all the Provinces of Rwanda. The Nyabarongo river basin has a catchment area of 8,900 sq km, an annual rainfall of about 1,350mm and its altitude varies between 3000m upstream and 1,350m downstream, with an average altitude of 2,176m. The river has a slope of about 0.8% with an annual average discharge of 83 m³/s; the basin runoff coefficient is about 22% and the specific discharge 9.31/s/km²[7].

Climate change in Rwanda is a great challenge resulting from increased temperature and causing abnormal variability in weather variables and threatening the socio-economic welfare of human beings [8]. Water resources have been subjected to degradation and pollution due to intensive and frequent rainfall that have negatively impact on water abstractions in their proximity.

This study aimed at analyzing the impacts of climate and land use change in the Nyabarongo Catchment. The results indicated that climate change and land use change in Rwanda has resulted in extreme weather events that resulted in inundations and floods of Nyabarongo River and its wetland that exacerbated the changes in geophysical status such as river flow pathway and meandering. This has resulted in washing away of some water abstraction facilities around the river and the distancing from such facilities leading to interference with abstraction. It was also found out that dry season's markedly diminished water available for abstraction in the river and impacting negatively on the groundwater recharge.

2.2. Trend in Temperature and Rainfall

Rainfall is the most important limiting factor in East Africa [8]. Since it provides level of soil moisture needed for potential productivity. In addition, the rising of temperature will generates in increased crop stress and crop water needs, with potential impacts on food security [9]. Previous studies have assessed the impact of climate variability through the changes in rainfall and where discharge of some African river basins ranged in 50–100%, and 100–200% for discharge due to changes in precipitation [10]. Uncertainty surrounding the magnitude of climate change impacts remains high and Rwanda is not exceptional to these changes [11].

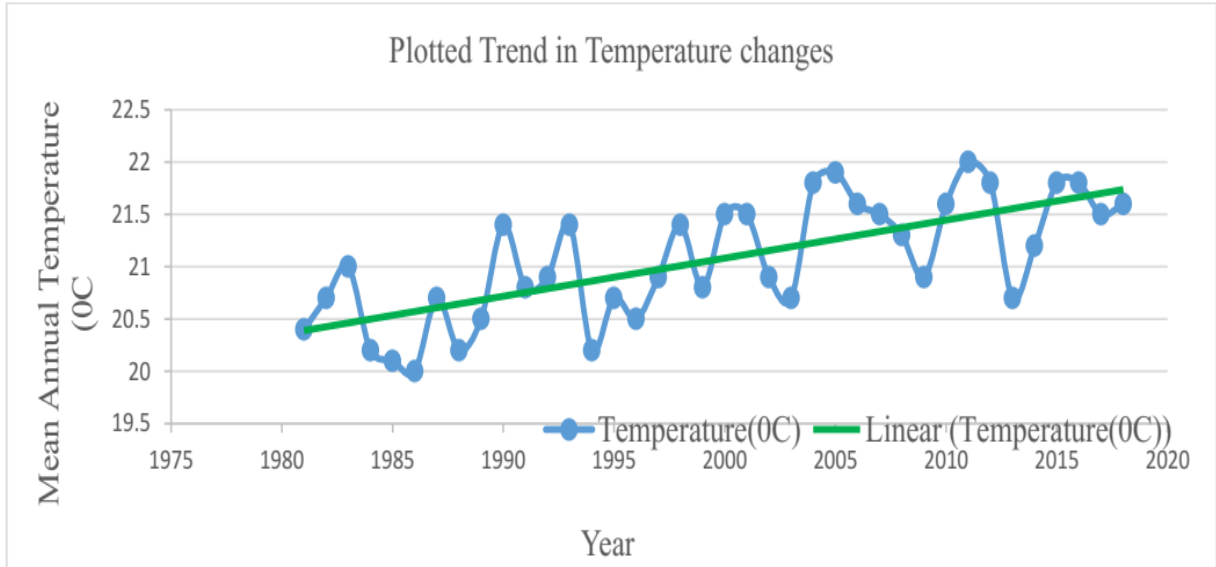


Figure 4: Trend in temperature in Rwanda over 40 years

Rwanda has a stable tropical temperate climate with average temperature of 20 degree Celsius. The annual temperatures in North and North-West range from 16 degree celsius-17 degree Celsius while in the central plateau, the temperature do range from 18⁰C to 20⁰C and eastern and southern lowlands temperatures range from 20⁰C to 24⁰C annually[11].

Using figure 4 the temperature ranges between 20 and 22°C with an increasing variation. Moreover, there was variation in temperature through the increase or decrease with a span of five years for the entire observation period. The evaluated yearly temperatures over Kigali for a period between 1980 and 2018 show that there have been an average increase of approximately 1.4⁰C.

Rwanda has bimodal rainfall regime with average rainfall of 1000 mm annually [8]. The rainfall pattern is characterized by a short rainy season from September to November and a longer season between February and May. Between these seasons are two dry periods, a short one between December and January and a long one from June to September.

Generally, the rainfall is abundant with an average of 1000 m annually but rainfall ranges from about 900 mm in East and South-East to 1500 mm to the North and North-West volcanic highland areas [8]. However, the rains have recently become unreliable and unstable to the extent that some areas are becoming relatively warmer than expected. Indeed, in the last 30 years,

Rwanda has experienced climate changes, with regards to frequencies, intensity and persistence of extremes like heavy rainfalls, waves of heat, drought and climatic variables.

The variation in rainfall changes analyzed over a period of the past 40 years indicate that Rwanda has experienced frequent and intensive rainfalls and occasioning prolonged dry periods and floods. This phenomena is likely to affect water availability for abstraction in terms of quantity and quality.

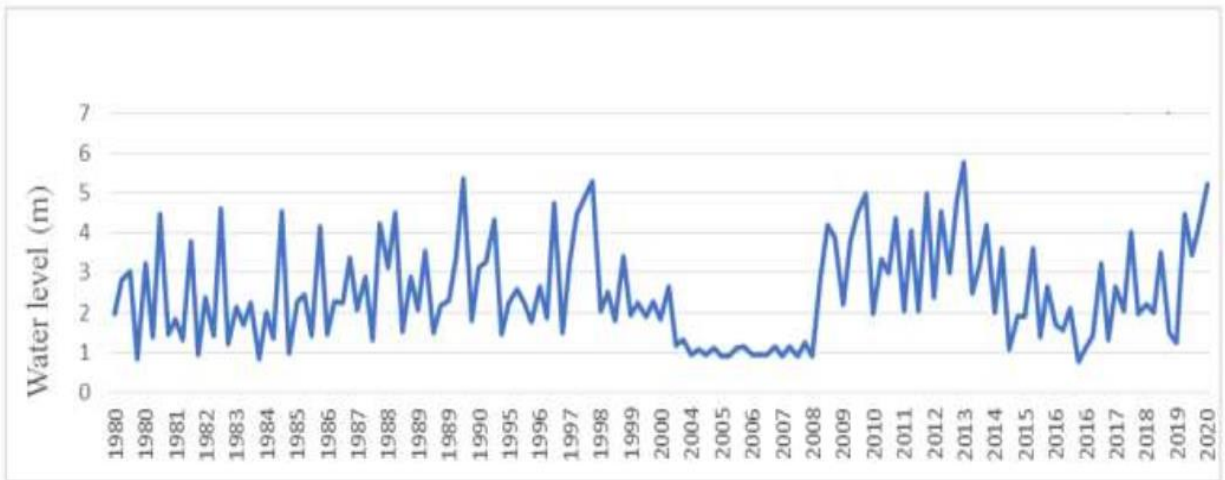


Figure 5: Water level in Nyabarongo River over a period of 40 years

Higher water level in Nyabarongo river were depend on overflow resulted from the long rain periods while lower water level were obtained in dry periods. Water level varies from slightly below 1 m to slightly above 5 m. The results indicated that frequent increase in the water levels resulting in overflow (where the water level achieve 4 to 5 m) during the period of long rain season of March to May and the short rain season of October to December.

CHAPTER 3: METHODOLOGY

3.1. Mathematical Modelling

To characterize data by using the water balance equation: It is useful in the measurement of rainfall, runoff and evapotranspiration.

$$P = R + ET \quad (1)$$

P: Rainfall

R: Runoff

ET: Evapotranspiration

- ❖ **Rainfall:** Is the water that falls from the atmosphere in either liquid or solid form (e.g. rain, snow, ice, etc.). Amount of precipitation is units of depth (e.g. mm).
- ❖ **Evapotranspiration:** is the process by which water is removed from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants. Amount of evapotranspiration is units of depth (e.g. mm, cm, etc)
- ❖ **Runoff** is the total quantity of water draining into a stream, reservoir, river or ocean, expressed as:
 - Cm of water over the area
 - Total volume (m^3) = depth area
 - Stream discharge

✚ **Runoff** is that balance of rainwater, which flows or runs over the natural ground surface after losses by evaporation, interception, and infiltration.

$$R = P - I \quad (2)$$

✚ **Runoff [mm]** is the part of rainfall that appears as stream flow.

✚ **Discharge Q [m^3/s]** is the volume of water flowing through a river cross-section in unit time.

✚ **Stream flow:** General term for water flowing in a stream or river channel.

3.2. Water Evaluation and Planning (WEAP) software

To characterize and analyze data by using WEAP (Water Evaluation and Planning) Software: WEAP is a proprietary software for interactive scientific graphing and data analysis. It is essential to import, graph, explore, analyze, and interpret the data.

The data which includes: rainfall, temperature, evaporation, runoff, evapotranspiration, agriculture, and urbanization will be tested by using WEAP software which provides full information related to variations and distributions.

- WEAP (Water Evaluation and Planning system) is a software tool that takes an integrated approach to water resources planning.
- WEAP operates in many capacities:

1. Water balance database: WEAP provides a system for maintaining water demand and supply information.

2. Scenario generation tool: WEAP simulates water demand, supply, runoff, stream flows, storage, pollution generation, treatment, discharge and in stream water quality.

3. Policy analysis tool: WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems

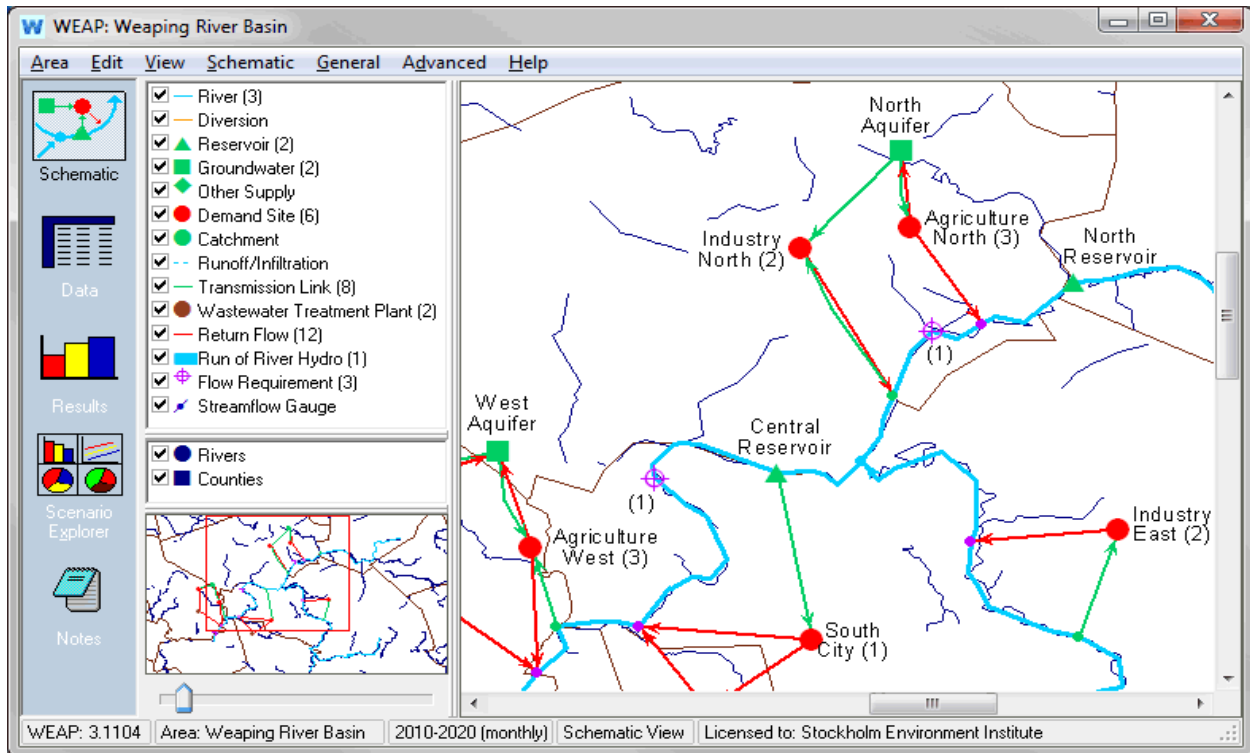


Figure 6: Sample screens of WEAP software

3.3. Data collection

Data of this research were collected from Rwanda Meteorological Agency and Rwanda Water Resources Board. Daily Hydro-meteorological data series such as rainfall, temperature, evaporation, water level and water discharge were analyzed to establish a water balance for the Nyabarongo Catchment and the different land use types such as agriculture (through analysis of infiltration rate) were conducted in this research. We focused on data collected from 1981-2022 in Kigali city which is the location of the catchment to investigate the variability of the parameters listed above and to make an analysis of how they impact the Nyabarongo Catchment. Table 1 shows the location of the sites in which daily rainfall and daily maximum temperature were collected.

Table 1: Location of collected daily rainfall and daily temperature

Station	Latitude(0)	Longitude(o)
RUBUNGORAB	-1.92	30.16
KABUYESW	-1.890556	30.07111
BUTAMWA	-2.016667	30.03333
MULINDI	-1.48	30.05
GITEGA	-1.96	30.06
KIGALIAERO	-1.95	30.11

Table 2: Yearly and Monthly study of collected data of rainfall and temperature

Station	Yearly study	Monthly study
RUBUNGORAB	1981-2021	January -December
KABUYESW	1981-2021	January -December
BUTAMWA	1981-2021	January -December
MULINDI	1981-2021	January -December
GITEGA	1981-2021	January -December
KIGALIAERO	1981-2021	January -December

The daily evaporation used in this research were collected in GITEGA station from 2010 to 2022 while the data analyzed about discharge were collected in the period 1955-2020.

3.4. Data analysis

The data used in this project were analyzed by using Water Evaluation and Planning Software (WEAP) through analysis of discharge of water in Nyabarongo River (volume of water flowing through a river cross section in a unit time).

The water balance equation; $P = R + ET$ were used to calculate the total annual value of rainfall, evaporation and runoff within the period of 12 years. Table 3 shows the relationship between those 3 parameters listed above.

Table 3: Total annual rainfall, evaporation and runoff

Years	Rainfall(mm)	Evaporation(mm)	Runoff(mm)
2010	5740	751.1	4988.9
2011	6649	460.6	6188.4
2012	6895	1119.1	5775.9
2013	6350	1272.1	5077.9
2014	5995	642.6	5352.4
2015	5147	156.6	4990.4
2016	4642	340.9	4301.1
2017	3218	259.2	2958.8
2018	8886	619.4	8266.6
2019	6934	187.5	6746.5
2020	7353	187.5	7165.5
2021	6070	342.9	5727.1

The origin pro is also a software used in this analysis of data through plotting of different graphs such as the variability of rainfall, maximum temperature and evaporation with respect to time (years). The combination of WEAP, Origin Pro and Water balance equation provide full information on the hydro-meteorological parameters used in this project.

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1. Experimental Results

The maximum temperature were collected in RMA in 6 different station located in Kigali near the study area within the period of 1983-2021; the daily rainfall also collected in RMA in that station within the period of 1981-2021 both were analyzed in Excel and origin pro software to determine the mean annual maximum temperature and total rainfall in each year. The data of daily evaporation were collected in Gitega station within the period of 2010-2022, discharge of water collected in RWB within the period of 1955-2020 were analyzed in WEAP and Excel to determine the variation and mean annual discharge. The total runoff were obtained by using water balance equation.

4.4.1. Variability of Temperature

The temperature is a major factor that plays a great role in variation of rainfall and evaporation. The rising of temperature in Earth surface results the increasing of evaporation of water from the earth surface which results the increasing of rainfall through the process of water cycle. Figure 7 shows the trend of annual maximum yearly mean temperature; in 2020 the mean temperature were 27.04868 in Celsius while in 2001 were 25.24299 Celsius.

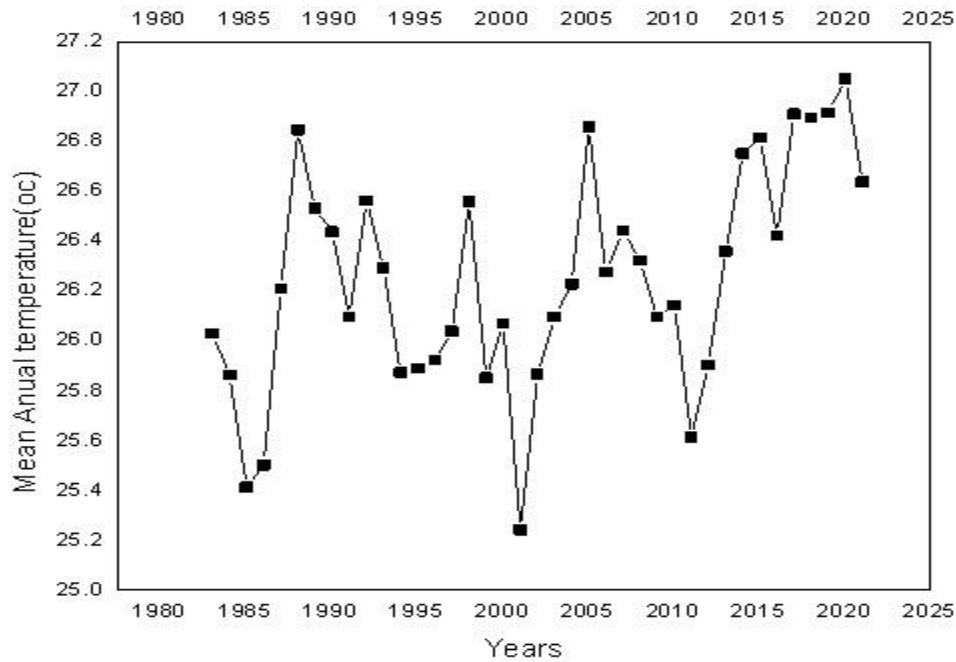


Figure 7: Variation of mean annual maximum temperature

The figure above shows that in 2020 the mean temperature were high at 27.04 degree Celsius while is low in 2001 at 25.24299 degree Celsius, in 2020 the temperature increase to 1.8 degree Celsius. The variation of that temperature results the variation of rainfall, evaporation and runoff that cause the climate change and affects the hydrological process.

4.4.2. Rainfall variability

Total rainfall reaching in the Nyabarongo catchment in every year were found in the figure 8. The high amount of rainfall were 10393 mm in 19997 and the lowest value is around 3218 mm in 2017.

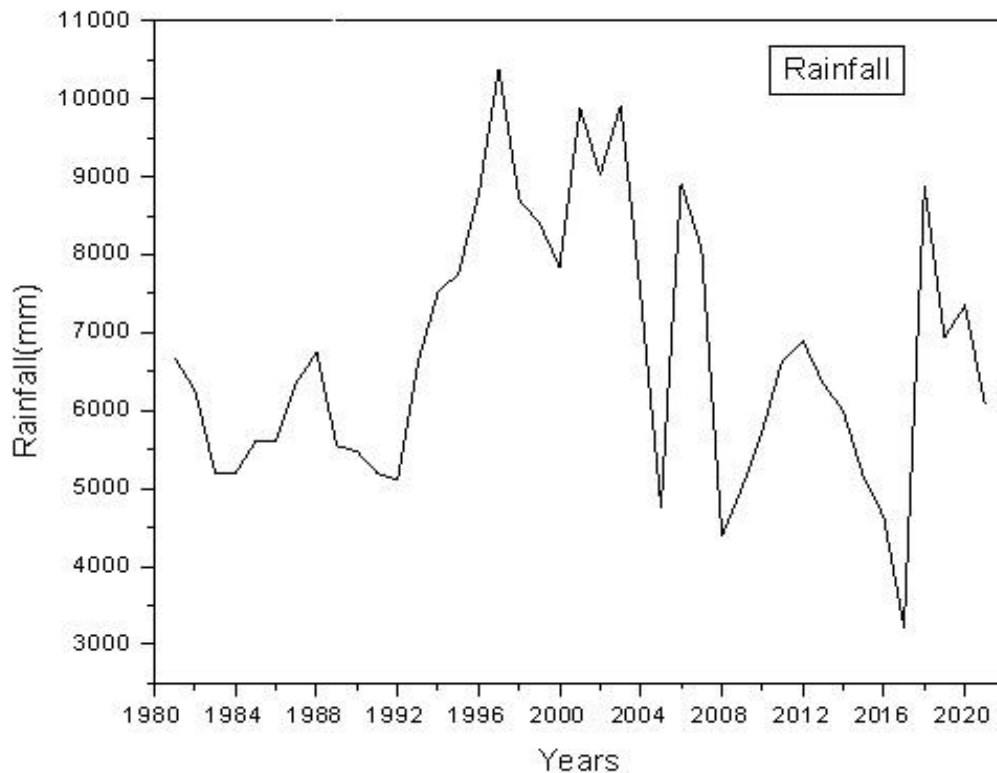


Figure8: Total annual rainfall in Nyabarongo catchment

The catchment received different quantity of rainfall, in 1997 the rainfall were likely to cause the flooding in the catchment due to its high intensity and can affects the agriculture and infrastructures. The range of this rainfall varies from approximately from 3000mm to 11000mm which is essential for hydrological process. When high amount observed is better to store them in order to use it in agriculture through irrigation. The discharge of water in the Nyabarongo River located in this catchment does not varies constantly because of this variation of rainfall.

4.4.3. Evaporation

The total evaporation within the period of 12 years in this study is 6339.5 mm. This evaporation depends on the land surface, availability of temperature and the amount of rainfall. The high evaporation increase the amount of rainfall which results the change of weather conditions in

long period. In the Nyabarongo catchment the mean annual evaporation ranges approximately from 2.25 mm to 5.25 mm as shown in the figure 9.

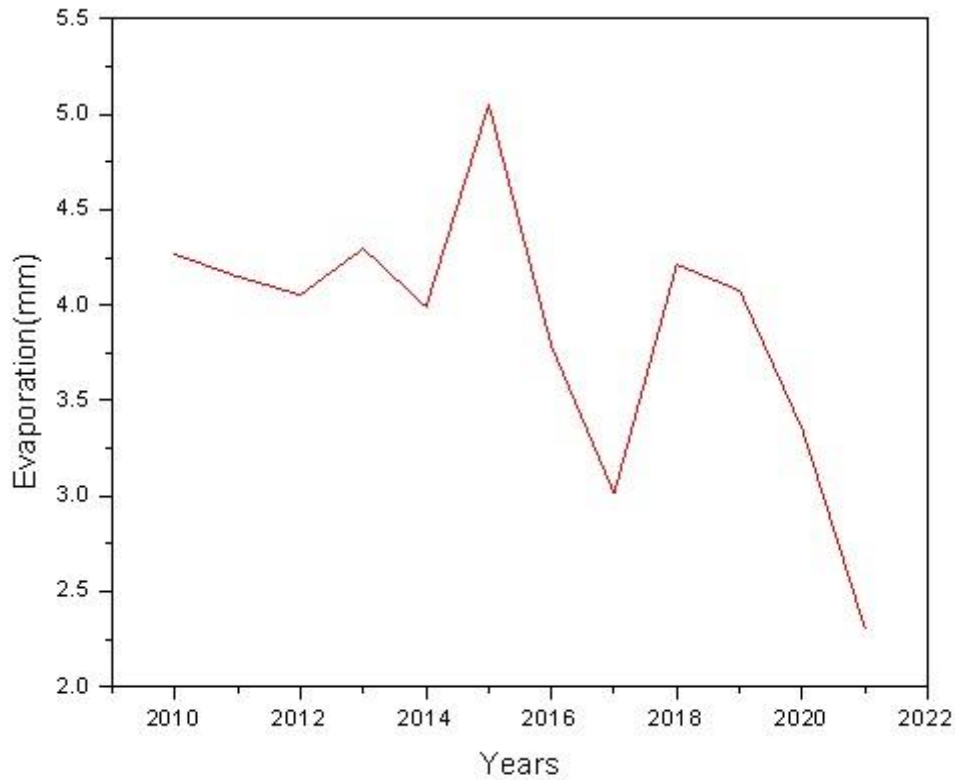


Figure 9: Mean Annual evaporation in the Nyabarongo catchment collected in Gitega station

4.4.4. Runoff

Using equation (1) total amount of water flowing within the catchment in 12 years is 67539.5 mm. When evaporation increases the runoff decrease but runoff increase with increasing rainfall. This variation depends on quantity of rainfall. Figure 10 shows the relationship between runoff, evaporation and rainfall.

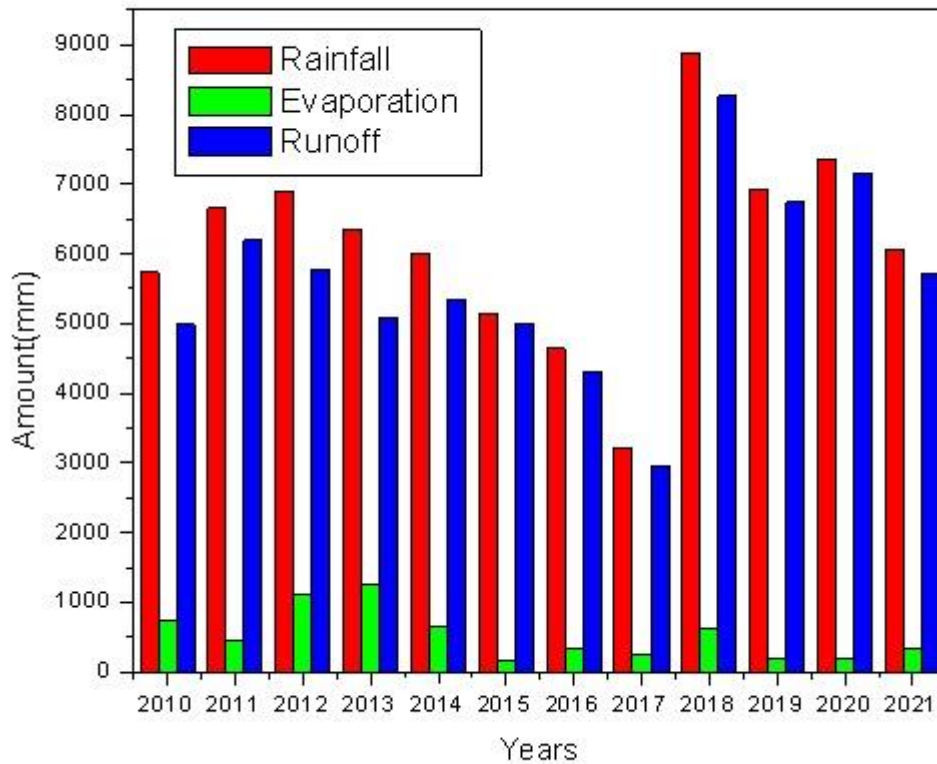


Figure 10: Annual trend of total runoff, evaporation and precipitation

As shown in the figure 10 the high amount of runoff in the Nyabarongo catchment is in 2018 which is 8500mm and is low in 2017 at 3000mm. From 2010 till 2021 both evaporation, runoff and rainfall varies discontinuously; Evaporation varies in small scale but the remaining parameters varies in high scale.

4.4.5. Discharge of Nyabarongo River

Nyabarongo River is located in the study area and is likely to be affected by runoff, evaporation and rainfall. Those is found through the analysis of discharge water (volume of water flowing in the river with respect to time). Figure 11 shows the annual variation of discharge from 1951 to 2020.

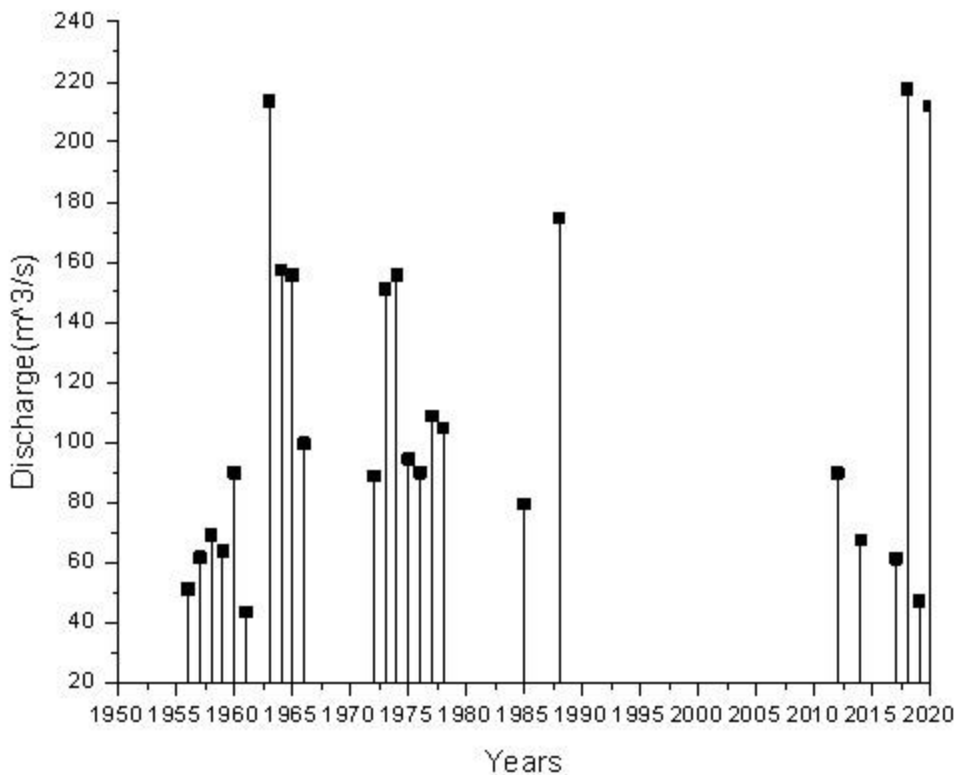


Figure 11. Annual variation of mean Discharge in Nyabarongo River

From figure 11 the high discharge is in the year 1963 and 2018 with their corresponding values 217 meter cube per second. The rising of discharge in 2018 resulted from the increasing amount of rainfall and runoff in that year and the water level were 4m as illustrated in figure 5.

4.4.6. Land Use in the Nyabarongo Catchment

Population living and working in the catchments produce different effects. Waste water released in the house and industry through brick making and plastic materials used in daily activities both are obtained in the catchment and affect the hydrological process. Unorganized agriculture such as sugar cane plantation and exploitation of sand also affects the catchment.

4.2. Discussion

The hydrological process in the catchment depends on hydro- meteorological factors such as rainfall, evaporation, runoff, temperature, water level and water discharge; and also depends on the land use. We have seen that both parameters changes yearly. In this catchment the runoff and rainfall is proportional which direct the water level and discharge. The water levels in the Nyabarongo River in 5 years ago varies between 4m and 5m as we have seen in the literature review and water discharge increases in 2018 and 2020. The increasing of rainfall and runoff in that catchments generates flooding within the long period of rain.

We found that there are years both rainfall, runoff and water discharge are low, these affects the properties in the catchment when takes long period; Land use change such as urbanization and agriculture limit the runoff water and reduce the water level; and discharge in the Nyabarongo river. Shortage of water discharge and water level affect the hydropower generation and daily agriculture activities within the catchment.

CHAPTER 5. CONCLUSION AND RECOMMENDATION

Rainfall, runoff, water level and water discharge is a major factors that plays a great role in the hydrological process. Hydropower production, irrigation, fishing both requires the appearance of water in the earth surface. I conclude that in the Nyabarongo catchment the amount of water present in every year is different which results flooding at a certain period; the increasing of population near or within the catchment results negative impacts through production of carbon dioxide, lack of proper disposal of waste and affects agriculture activities. Climate change resulted from the variation of climatological factors (rainfall, evaporation, temperature, and runoff) and land use changes through urbanization and agriculture reduce the hydrological response within this catchment.

I recommend the Rwanda Water Resources Board to investigate and make deep analysis on the future impacts of hydro-meteorological factors.

I recommend the Rwanda Water Resources Board to collect the infiltration data.

I recommend both Rwanda meteorological Agency and Rwanda Water Resources Board to increase the equipment and sites used in collection of data for reducing the missing of data.

I recommend also the Ministry of Agriculture and Infrastructure to specify the proper activities which is essential within the Nyabarongo Catchment. The disaster also happens in our country through flooding; I recommend the Ministry of Disasters to give an advice to people on how they can protects their life and teach them to make good proper disposal of waste.

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