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Impact of Climate Change on Water Resources in Rwanda: A Case of Muvumba Catchment

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Abstract

Climate change profoundly impacts water resources, affecting people's well-being, agriculture, industry, and urban development due to altered weather patterns. This study focuses on Rwanda's Muvumba catchment, aiming to assess climate change effects. Analyzing global (World Clim, GCMs, CMIP6) and national data sets, remote sensing (SRTM elevation data, DEM) generated insights on precipitation, evaporation, and temperature changes during 2012-2021 and projected 2021-2040. Employing GIS, HEC-HMS model, and remote sensing, a hydrological model evaluates Muvumba catchment's river discharge, informing effective implementation of mitigation and adaptation strategies. Analysis indicated fluctuating minimum temperatures (14°C to 17°C) and maximum annual temperatures (27°C to 28.3°C) in 2012-2021, with a 0.4°C rise in maximum temperature over the decade. Averaging 21.6°C to 22.5°C, increased evaporation heightened water body depletion, impacting Muvumba catchment's water availability, exacerbating drought and scarcity. Projections for 2021-2040 anticipate March at 15.01°C as the coldest month, while July hits 28.7°C. Mean temperature may range from 21°C to 23.3°C, with a projected 0.82°C increase. Notably, annual precipitation peaked in 2020 at 1176.31 mm and hit a low in 2017 with 628.77 mm, emphasizing the water stress issue. It was found that the impacted location was the Mulindi sub-catchment, which is susceptible to floods and soil erosion, with the silt end up as sediments in rivers and streams. Research indicated the prediction of 1033.68mm annual rainfall in 2012-2040. Over 20 years it is predicted the reduction of 18.76 mm of precipitation, the highest annual evaporation rate was 2013, indicated 3.83mm which led to more water lost from water bodies. From2012 to 2021 water quality level was varied between 7.6 pH and 7.35 pH which facilitated the release of toxic substances from sediments into water further impacting water quality. Future water demand and use scenarios show that water stress in Muvumba will gradually increase, river discharges reduced by 2019 and 2020 due to decreased precipitation, LULCCD showed reduction of 17% of forests which lead to high rises of temperature .The average monthly discharge is projected to decrease from June to August (Long dry season) by variation of 4.7 and 7.8%by 2021-2040. Large increase of stream flow is projected to occur in April and May by variation of 13 and 14.7%. The research recommended the upgrading and maintaining existing stations and calibrating meteorological instruments, including weather radar, to give all climate information required for future observing, climate trend detection, climate variability management, afforestation, early warning, and disaster management.

Keyword: *Climate change, Hydrological Modeling, Temperature, Precipitation, Evaporation and Water resources, Rwanda*

1. Introduction

The most serious problem is drought, but there have also been claims of floods, particularly in the Mulindi area, where runoff has caused silt deposition in the Muvumba basin. Deforestation has compounded the lack of vegetation and forest cover. Water use conflicts between cattle and agricultural producers are regular. There is no robust water cooperation structure because it is transboundary. The burning of fossil fuels, deforestation, and livestock production in the Muvumba catchment are all examples of caused by humans factors that are having an increasing impact on the climate and temperature. This is raising the amount of greenhouse gases already in the atmosphere, thus increasing the effect of greenhouse gases and contributing to global warming (Muvumba Catchment Management plan, 2018).

According to climate model projections, the number of people at danger of water shortages grows rapidly as temperatures rise in the second half of the century, with consequences expected to be substantially more severe in dry and semi-arid countries than suggested by worldwide averages (Ozor, 2013).

According to IPCC report, increases in global mean temperature exceeding 1.5°C are known to cause declines in water supply and quality for many of the water-stressed countries. Warming in recent decades has also been linked to alterations in the a large-scale water cycle including: Only a few of the recent changes have been observed: reduced snow cover and widespread melting of ice, changes in water content in the soil, and changes in patterns of precipitation, intensity, and extremes (IPCC, 2018).

The available data shows that impending climatic changes are already having a significant impact on the water resources of most African countries, even though the continent of Africa contributes negligibly to the greenhouse gas emissions that cause these changes. Sub-Saharan Africa as a whole accounts for 1.59% of global greenhouse gas emissions (Spore, 2008).

Drinking water poses risks even with standard treatment because of how climate change affects stream flow and the quality of water in freshwater ecosystems. Increased warmth, increased sediment, fertilizer, and pollution loadings brought on by excessive rainfall are the origins of the dangers, Pollution reduction Dilution throughout severe droughts and disruption of facilities for treatment during flooding are two changes that can have a negative impact on the quantity as well as the quality of water resources, which can have a negative impact on the social and economic development and the standard of living of those who rely on these resources (UN Water, 2019).

1.2 Research objectives

1.2.1 General objectives

The main objective of this study was to determine climate change impacts on water resources in Rwanda, Muvumba catchment.

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1.2.2 Specific objectives

(i) To assess the climate change in the Muvumba Catchment: temperature, precipitation patterns and evaporation rate.
(ii) To assess water resources variations in terms of water availability and water quality.
(iii) To determine the relationship between Climate change and water resources variations in Muvumba Catchment.

1.3 Research questions

(i) How do changes in weather patterns contribute to climate change, both historically and in the future projection?
(ii) How does climate change in Muvumba catchment affect water resources variations in terms of water availability and quality?
(iii) What are relationship between climate change and water resources variation within Muvumba catchment and what are potential impacts and their adaptation strategies?

2.1 Empirical Review

This part involves the review of observations and experiences based on climate change related studies. It includes Muvumba catchment management plan, Hydrological study in Gilgel Abbay Catchment in Ethiopia, Strengthening Climate resilient WASH Programming in Rwanda and Muvumba Multipurpose Dam Water Resources Development Program.

2.1.1 Muvumba Catchment Management Plan

As the first of its kind, the Muvumba Catchment Management Plan prioritizes issues directly related to water management, such as catchment restoration, optimum water supply, and equitable water distribution to all water users within the watershed, in accordance with the current legal framework, policies, and plans, and other programs. By addressing a wide variety of policy concerns, the catchment plan seeks to provide a holistic approach to the watershed's long-term sustainability (green growth). The following was agreed upon as the overarching goal: "Effectively managed land, water, and associated natural resources that support viable socioeconomic growth and enhanced livelihoods, minimizing water-related calamities while taking into account environmental flow, downstream water demands, and climate change resilience." Its objectives included reduced water consumption, climate change resilience, and water-related calamities (REMA, 2018).

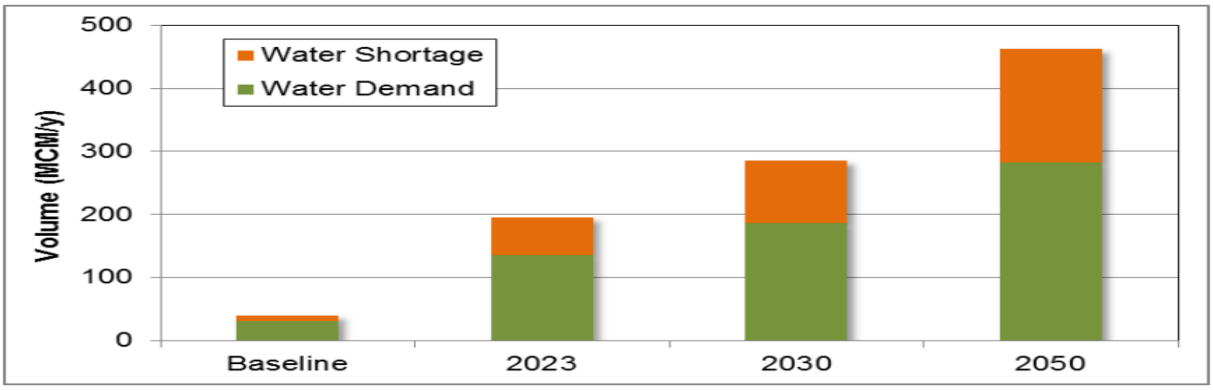

Figure 2.1: Baseline/projections water demand water shortage up to 2050

Source: (Muvumba Catchment Management Plan, 2018).

It is obvious that if not anything is done to control use; there will soon be severe water shortages. In order to prevent future water scarcity and preserve water resources responsibly, a number of water consumption alternatives were devised iteratively and modeled over various time periods. Before unmet demand was completely eliminated, several iterations were required (Muvumba Catchment Management Plan, 2018).

2.1.2 Hydrological study in Gilgel Abbay Catchment in Ethiopia

This study looked into how climate change would affect the Gilgel Abbay Catchment. According to the IPCC's conclusions, emerging countries such as Ethiopia would be more vulnerable to climate change. Climate change may have a substantial influence on Ethiopia due to a variety of variables. Agriculture, which is strongly dependent on climate change, is the country's major economic engine. A sizable portion of the nation is semiarid and arid, making it extremely vulnerable to desertification and drought. Additionally, the nation possesses a delicate highland ecology that is being stressed from population pressure the nation's water, biodiversity, and forest resources are all climate vulnerable. Thus, there is cause for concern regarding climate change. (NMSA, 2001)

Based on the Gilgel Abbay Catchment's The general Circulation Model and Statistical Downscaling Model, the Gilgel Abbay Catchment project aims to create and assess climate-related scenario data for the highest temperatures in order to better comprehend the hydrological effects of climate change, minimum temperature, and precipitation. The seasonal and monthly flow vary significantly, based on the study's findings. During the peak rainy season (June to September), runoff will be reduced by 12% in the 2080s. The outcome of the synthetic (incremental) scenario also demonstrates the watershed's vulnerability to climate change. If the catchment experiences a 2^{o}C increase in temperature and a 20% drop in rainfall at the same time, 33% of seasonal and annual runoff will be decreased (Kedir, 2008).

2.1.3 Strengthening Climate Resilient WASH Programming in Rwanda

The necessity of climate-resilient planning is well acknowledged. Climate resilience prevents deaths, reduces poverty, eliminates underlying disparities, and produces substantial economic gains (OECD, 2018).

Climate change poses a significant threat to the provision of WASH (Water, Sanitation, and Hygiene) services. Damage to infrastructure from floods, water source depletion due to droughts, and alterations in the condition of sources of water and water delivery systems, in relation to rising demand, are just a few of the water supply-related worries.

Predictions and climate modeling, according to the study, indicate that the nation's temperatures will have increased by 3.9 °C, or another 1.1 °C, by the century's end. It is anticipated that the increase will be consistent across the country and seasons, but it may be somewhat more significant in the long dry season than in other seasons. Similar to this, average annual rainfall models forecast a change between 2000 and 2050 of between -100mm and +400mmAreas of the eastern and southern provinces are forecast to experience rainfall shortfalls, while the western, northern, and southern regions will likely get enhanced rainfall. The entire water balance of the nation is also expected to change. By the end of the century, long dry spells are anticipated to grow by 0 to 8 days during times of rising aridity (World Bank, 2021).

2.1.5 Muvumba Multipurpose Dam water resources development program

The Muvumba Multipurpose Dam, which is officially located in the Nyagatare District Karama and Gatunda sectors, is anticipated to ensure stable water resources for agricultural use and domestic water supply in the region, and in particular, supplying cattle needs in Musheli, Rwempasha, Tabagwe, Nyagatare, and Rukomo sectors with public water for Nyagatare, Karangazi, and Rwimiyaga sectors.

Analysis, estimation, and updating of the hydrological and meteorological design criteria and variables for the construction of the planned dam, reservoir, spillway, and other hydraulic components was the main goal of the hydrologic and meteorological analysis of the Muvumba MPP project.

Estimate the evaporation from the reservoir, in particular, and the design storm for the watershed and project location. Calculate the reservoir's inflow, determine the reservoir's usable life by estimating sediment movement, deposition, and dispersion therein. Calculations for different spillway capacity to determine the reservoir's maximum water level. Estimate the design flooding for the spillway and conduct out flood routing. Calculate the design flood for the Coffer dam's design and run a routing experiment to determine the maximum water level during construction. Carry out reservoir simulation studies to determine the ideal water level for an energy generation system, water supply system, and environmental release.

By applying the Khosla and Varshney Methods, the Muvumba dam's 964 km^2 catchment area produces an annual sediment input of 558,805 m^3/yr. and 537,399 m^3/yr. The multipurpose dam was upgraded from its original 30 m design to a 39.5 m height in order to cut down on sediment buildup.

2.2 Research Gap

There is a scarcity of data about ground water. As a result, Water for Growth Rwanda has launched an investigation into the underground water bodies of Eastern Province. Ground water could be used to supplement water resource necessities, particularly during the dry season, depending on the results of that evaluation, which is coming later in 2018. There is a scarcity of hydrological data for Rwanda in general, and for the watershed in particular. Data of 2015, 2016, 2017, and 2021 are not available for Muvumba River discharge analysis which will create gap in study analysis.

There is no sufficient data to estimate the reservoir evaporation, the nearest station with sufficient evaporation data is Kigali Aero Meteorological Observation Station. Further downstream there is Kagitumba station on the main River but this station record is modified by the unaccounted abstractions along the river course. The station has daily flow and stage records with many gaps and discontinuity for the period the data is available. Data of water quality (pH) of 2013, 2014 and 2015, are not available on gauging stations around Muvumba like Nyagahanga, Byumba, and Nyagatare same as data for evaporation. Water for Growth Rwanda is receiving assistance from other partners in redeveloping its water monitoring network. And it could be better if RWB maintain and improve gauge stations so that they should record river discharge, water quality data daily, monthly and annually in proper manner for better analysis.

3. Materials and Methods

The Muvumba Level 1 catchment, a part of the Nile River Basin's upstream region in the Kagera sub-basin, spans Rwanda and Uganda. It covers approximately 1.568 km2 of Rwanda's total surface area and begins in the Buberuka highlands. The Muvumba River

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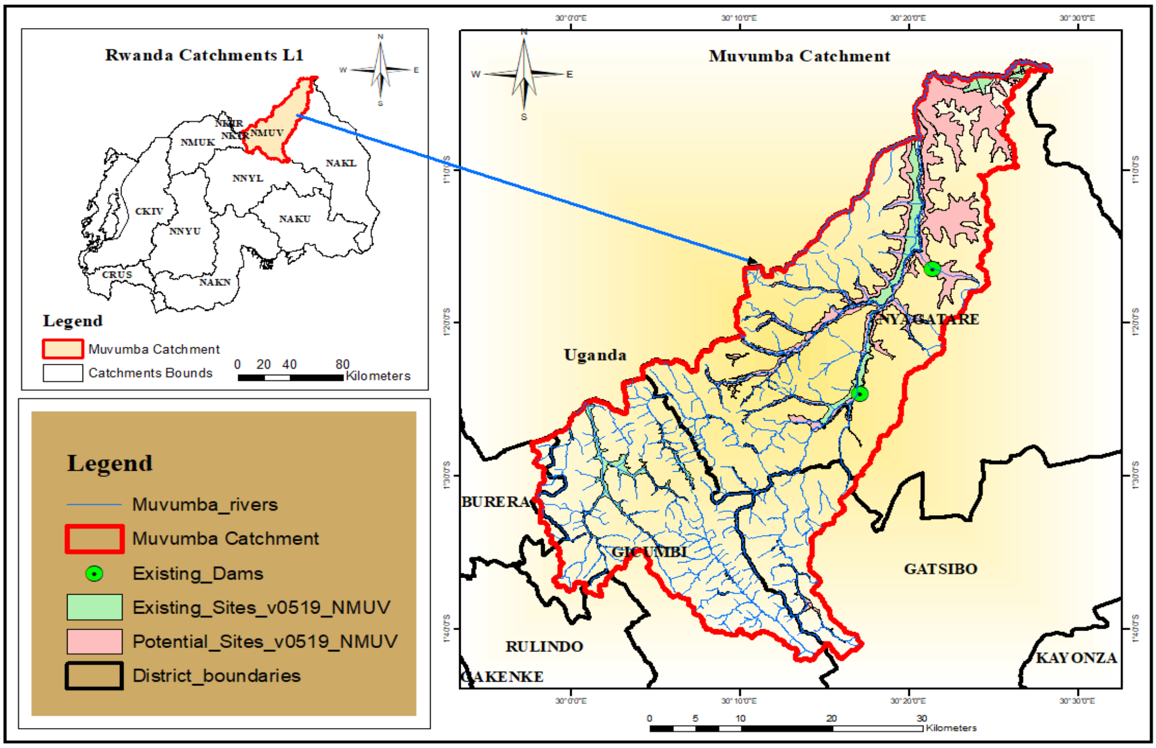
flows through a gentle sloping Eastern Savanna, eventually crossing into Uganda near Kabale before returning to Rwanda. Major tributaries include the Warufu and Ngoma Rivers. Water quality issues in the Muvumba River stem from pesticides, fertilizers, and sediment pollution, with varying annual rainfall, a rainy season from October to December, and a dry season from May to September. Approximately 65% of rainfall is used by vegetation or evaporates, with only 2% available for human use.



The Muvumba basin's economic activities primarily revolve around water resources, including agriculture, livestock, and mineral extraction. With 90% of Rwanda's population employed in agriculture, rain-fed farming is a significant contributor to the region's economy. Various activities such as tea processing, dryland farming, livestock farming, wetlands irrigation, and hydroelectricity production occur in different sub-catchments. Additionally, the basin engages in quarrying and artisanal extraction of minerals like wolfram, cassiterite, and coltan. In the Muvumba watershed, 7.7% of the 600,000 people are urban, with 92.3% rural. The population is predominantly young, with 54% under 20 years old and a notable female majority. The area's high poverty rates are linked to rapid population growth and declining soil fertility (Muvumba Catchment Management Plan, 2018; EICV4; NISR, 2012).

The research methodology involved gathering historical climate data from meteorological stations, DEM, and various input data for hydrological modeling. MeteoRwanda and the Rwanda Water Resources Portal provided crucial weather-related and water quality information. Climate projections for 2021-2040 were obtained from the World Clim database and the CMIP6 model, with a focus on depicting future climate conditions under SSP126 using statistical downscaling. The IDW method was employed for the downscaled GCM data, enabling the interpolation of climatic variables at a 0.5-degree resolution.

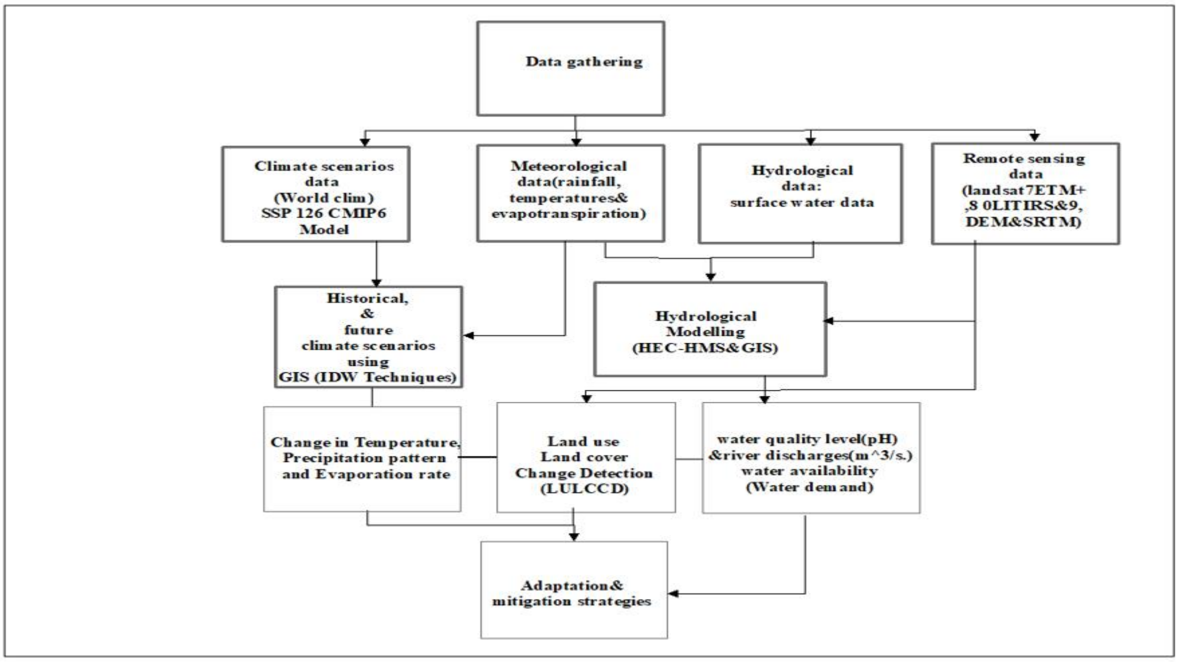


Figure 3.1: Flowchart Methodology
Source: Researcher, 2023

Researchers collected data from various sources, including journals, historical climate records, satellite imagery (such as DEM, Landsat 7ETM+, Landsat 8-9 OLI-TIRS), and climate models like World Clim v.2.1 for future climate projections. Data collection strategies involved using the CMIP6 model and World Clim databases, along with hydrological data from the Rwanda Water Resources Portal and satellite imagery to monitor land use changes. Additionally, temperature, precipitation, and evaporation data were gathered from meteorological stations, and GIS-based models were employed to simulate future climate scenarios and their impact on water resources.

Table3.1: Data type and data source

Data type	Data source	Use	Data type
Meteorological data	Meteo-Rwanda	For analysing climate change scenarios(the level of precipitation, evaporation temperature)	Degree Celsius(ºc),Millimetres(mm)
Rwanda base map	Esri Rwanda	For mapping administrative boundaries	geodatabase
GPS Coordinates	Field data collection using Differential GPS(DGPS)	For positioning location	Shape files
Topographical data	Esri Rwanda	Determination of the nature of terrain	Raster data,Geotiff
Google earth data	Google earth pro	For Navigation area of interest	KMZ
Remote sensing	USGS(United	For image classification in	Raster data

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data	State Geological Survey)	determination of Land use Land(LULC) cover map	
Hydrological data	Rwanda Water Resources Board(RWB)	For developing catchment management plan and analyzing catchment situation	DEM(Digital Elevation Model),xls
Climate change data	MeteoRwanda, World clim,CMIP6 and other relevant authorities	Analyzing the level of climate change scenarios	Geootiff,xls
Existing Literature	Different online and printed published books, reports, theses, Journals, papers and atlas.	For Reviewing the relevant literature to gain further information related to climate change and water resources	Written report, thesis ,journals

Source: Primary data (2023)

Data analysis involves processing collected data to identify patterns and correlations. In the Muvumba catchment, data from seven climate stations were selected, with SPSS and Excel used to analyze temperature, precipitation, and evaporation data recorded since 1981. Averaging techniques were employed for monthly and annual data from multiple stations. For future climate estimates, CMIP6 data was downscaled using WorldClim v2.1 as a baseline. GIS software utilized the IDW technique for spatial interpolation, while monthly climate data from nine GCMs and four SSPs were analyzed for 2021-2040. The Muvumba Catchment shape file was used to extract specific climate data for this time frame.

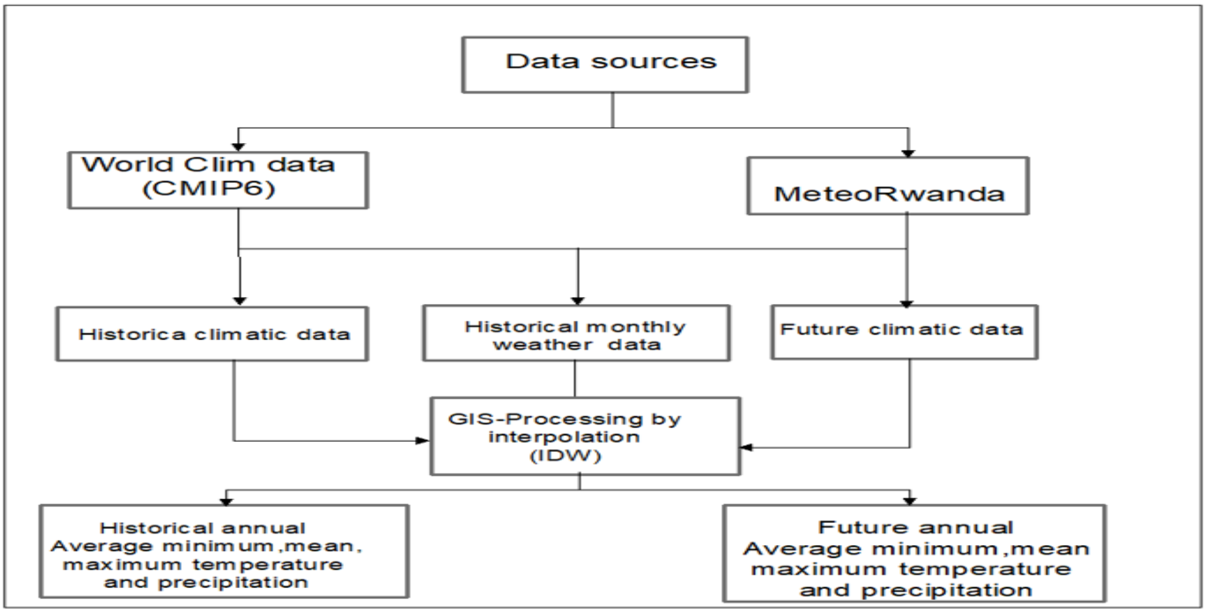

Figure 3.2: Climate scenarios process
Source: Researcher, 2023

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Water contamination, primarily from agricultural and industrial activities, stems from improper waste disposal and management. In developing countries, over 80% of untreated sewage is directly discharged into water bodies (UN-Water, 2019). MeteoRwanda and the Rwanda Water Resources Board provided data for statistical analysis of water quality parameters like pH, as well as water availability and river discharges. Comprehensive evaluation of water availability requires an interdisciplinary analysis of biophysical and social variables, encompassing factors like precipitation, surface water, and groundwater dynamics. Hydrological modeling aids in understanding stream networks and flow processes.

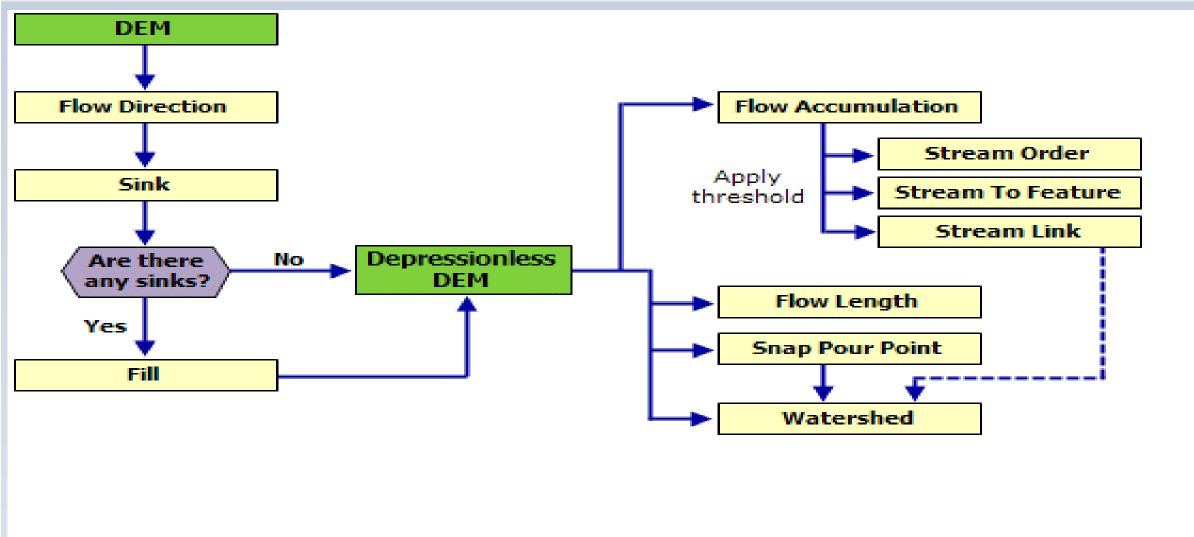

Figure 3.3: Hydrological modeling procedure

Source: (USGS, 2019)

Utilizing Landsat 7ETM+ and Landsat 8-9 ORI-TIRS images, this study applied statistical and logic-based decision rules to classify land use and cover changes from 2012 to 2021. Change detection analysis helped quantify alterations, using the formula $C_i = L_i - B_i$ and $P_i = (L_i - B_i) / C_i * 100$ to assess percentage changes in different land classes. Ensuring research reliability and validity involved eliminating biases, maintaining consistent methods, and employing robust statistical analyses. Ethical considerations encompassed informed consent, respect for local knowledge, privacy, and confidentiality, collaborative engagement, transparency, and responsible data management. These ethical practices aimed to ensure community-centric and accountable research endeavors.

4. Presentation of findings

This section aims to provide a clear understanding of data collected and its implications within the context of the research

4.1 Analyze the climate change in the Muvumba Catchment

The factors including temperature, precipitation patterns and evaporation rate play a crucial role of climate change in Muvumba catchment.

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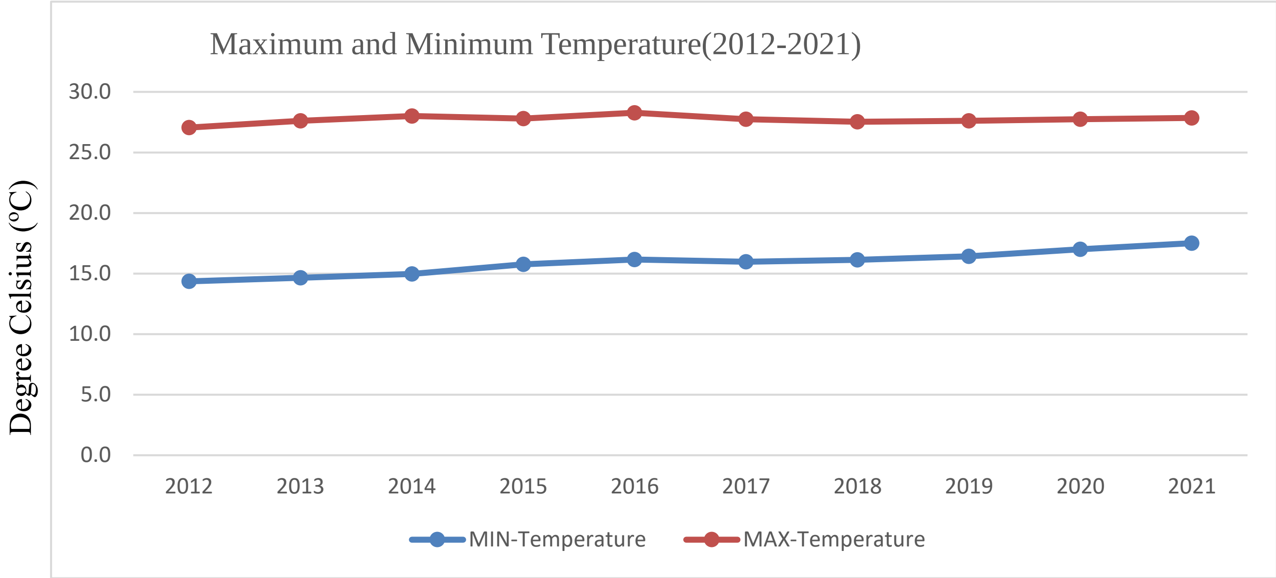
4.1.1 Historical Temperature within Muvumba catchment

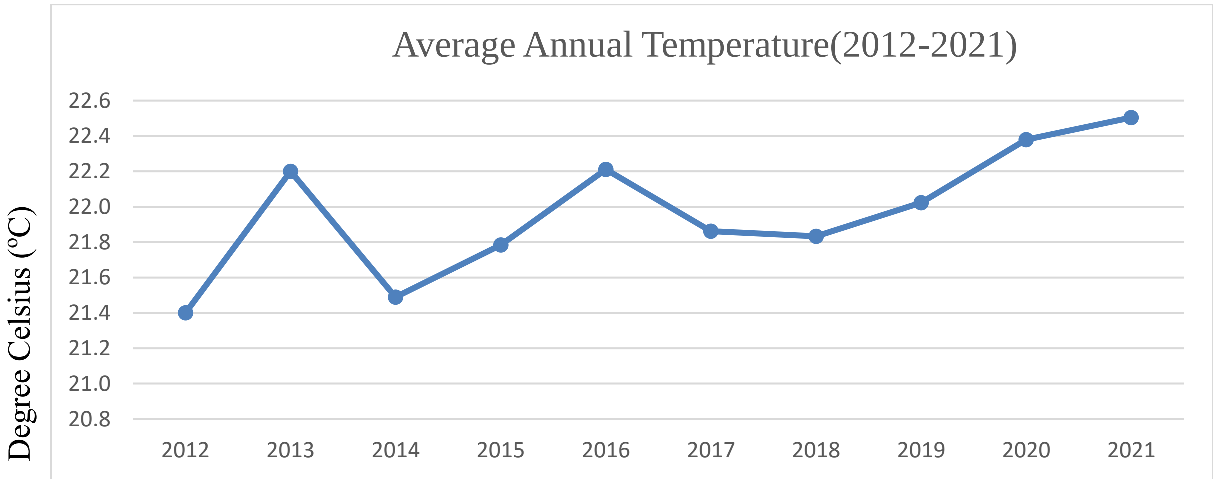
4.1.1.1 Change in temperature



Years

Figure 4.1: Maximum and Minimum Temperature (2012-2021)

Figure 4.1 indicates that the minimum temperature recorded through Muvumba climate stations including:Nyakigarama,Rwempasha,Nyagatare,Kagitumba and Karangazi was averaged and indicated the minimum temperature(2012-2021)varied between 14°C and 17 °C.Research also indicated 2012 as the lowest annual minimum temperature. Figure 4.1 also depicts that Muvumba Maximum annual temperature varied between 27^{O}C and 28.3 ^{O}C**.** 2016 was the annual maximum temperature at 28.3 ^{O}C. Research revealed that From 2012-2021 maximum temperature increased by 0.4°C,the rising temperatures exacerbated drought conditions leading to water scarcity in affected regions Ngoma and Muvumba Upstream sub-catchment among others had an impact on Agriculture,ecosystems,and communities that relied on water resources.



Years

Figure 4.2: Muvumba Mean temperature

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Figure 4.2 indicates that Average temperature of 2012-2021 varied between 21.4 ^{O}C and 22.5 ^{O}C,resulted to more evaporation from water bodies,reducing their water levels and potentially impact on water availability most notably drought and water scarcity in Warufu,Ngoma and Muvumba Downstream Sub-Catchment especially in 2016,2020 and 2021.

2021 was the highest average annual temperature by 22.5 ^{O}C whereas 2012 and 2014 was the lowest annual temperature by 21.4 and 21.5 ^{O}C respectively.

4.1.1.2 Projected temperature change

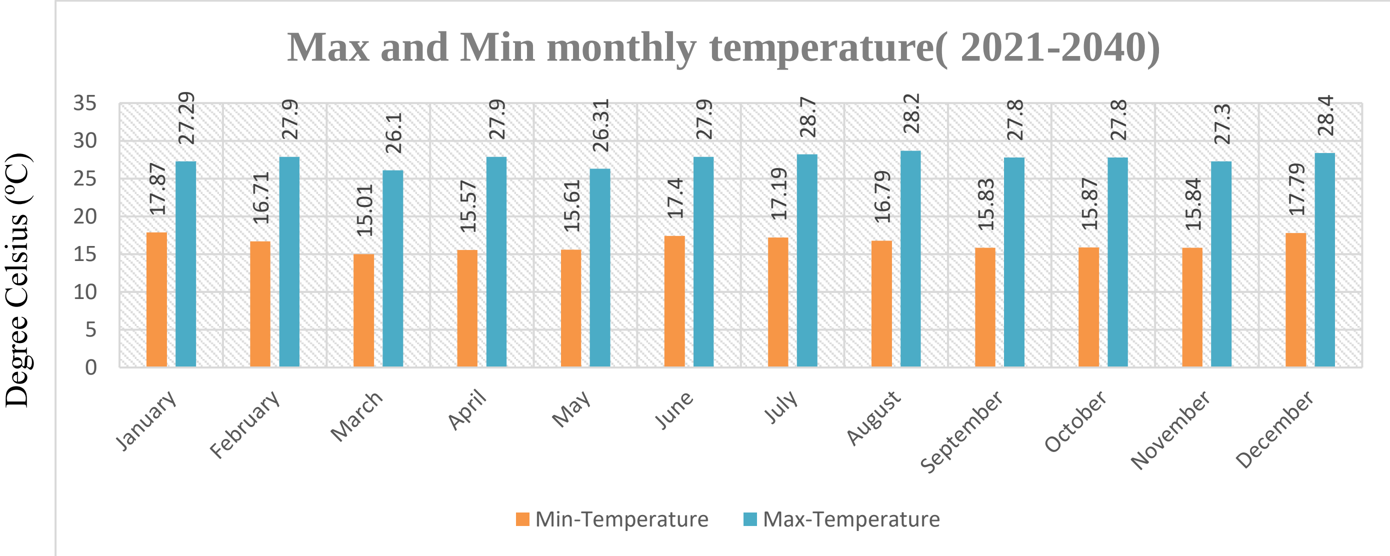

Figure 4.3: Max and Min monthly temperature (2021-2040) Months

In the Figure 4.3 research indicated that Months with minimum temperature 2021-2040 are expected to be between March and May (Long rainy season).Minimum temperature predicted to be varied between 15.01°C and 15.61°C.The months with the highest temperatures ranged between 27.9 °C and 28.7 °C predicted to be June, July, and August (Long Dry Season) will depict reduction in groundwater recharge rates, adding to thermal pollution and heat emitted into water bodies from industrial processes. Especially in Ngoma, Muvumba upstream and Warufu sub-catchment.

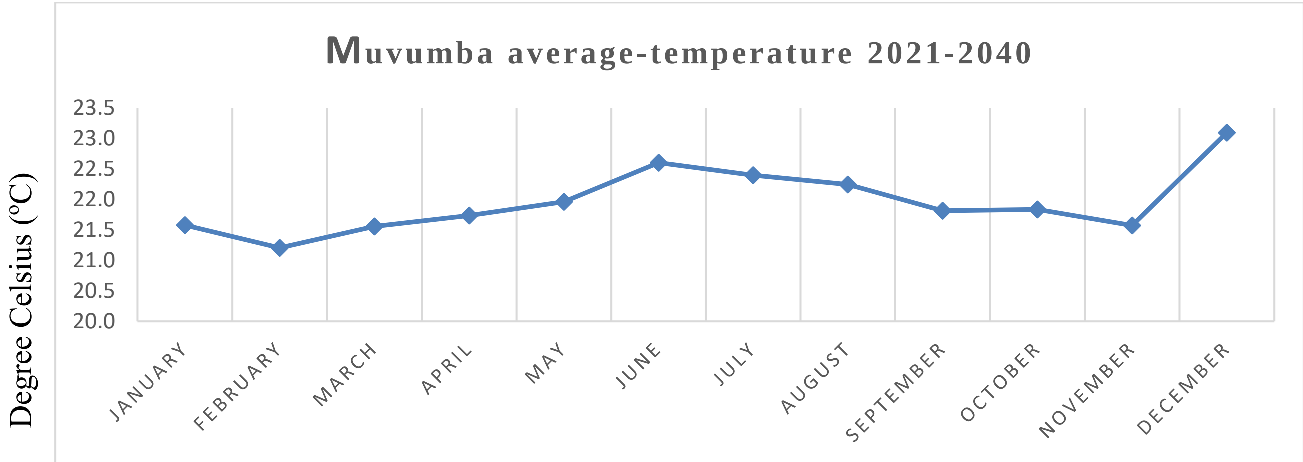

Figure 4.4: Mean temperature (2021-2040) Months

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Figure 4.5 states that Muvumba Average temperature predicted to be varied between 21.6°C and 23.3°C. According to Research with the usage of world Clim data analysis by SSP126, Temperature is projected to be increased by 0.82°C in 2021-2040 in Muvumba catchment. Leading to several impacts on water resources, with drought being a significant concern. Higher temperature can intensify evaporation rates, causing a reduction of water availability in river streams, and reservoirs. This decrease in water supply can exacerbate drought conditions, affecting agriculture, ecosystems and communities that rely on these water sources (Sheffield, 2017).

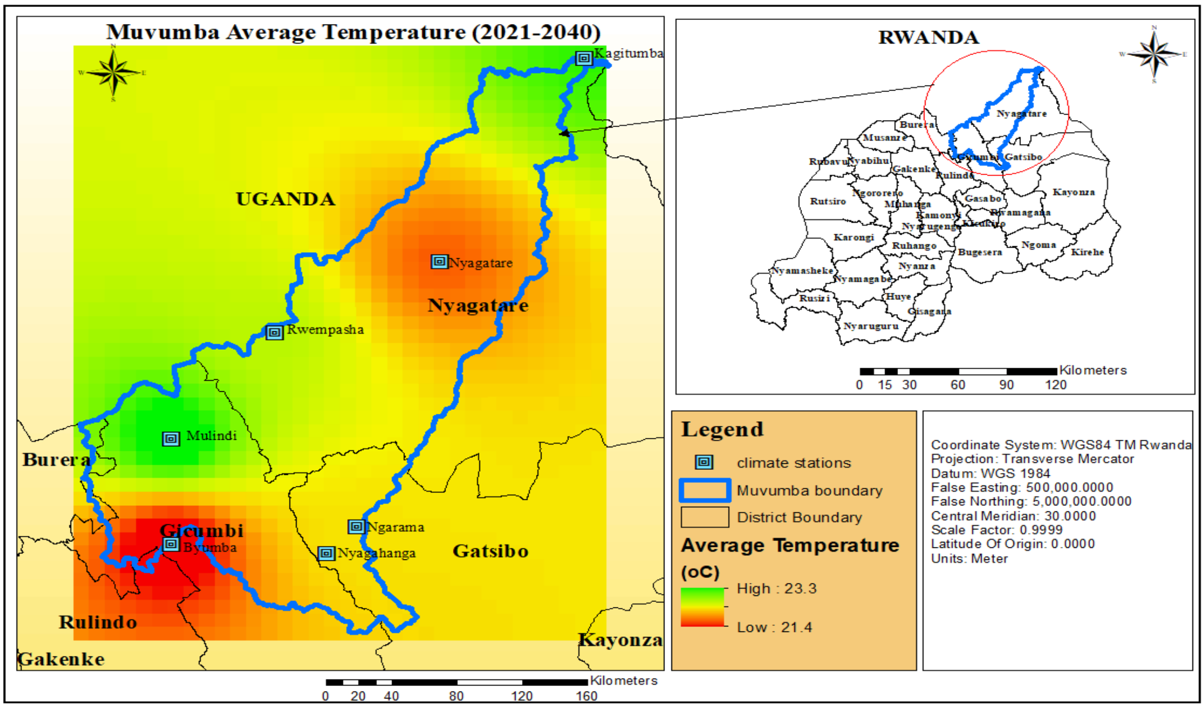

Figure 4.6: Average temperature (°C) 2021-2040

Figure 4.6 shows the south-west part including Warufu, Mulindi sub-catchment, among others would have low average monthly temperature varies between 21.4 °C and 22 °C whereas Muvumba upstream expected to have moderate temperature varied between 22 °C and 22.5°C.Ngoma, Muvumba downstream toward Kagitumba are projected to have highly average temperature varies between 22.5°C and 23.3°C this will cause a reduction of water availability in river streams, and reservoirs under drought conditions.

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4.1.2 Historical Rainfall patterns

4.1.2.1 Change in Historical Rainfall

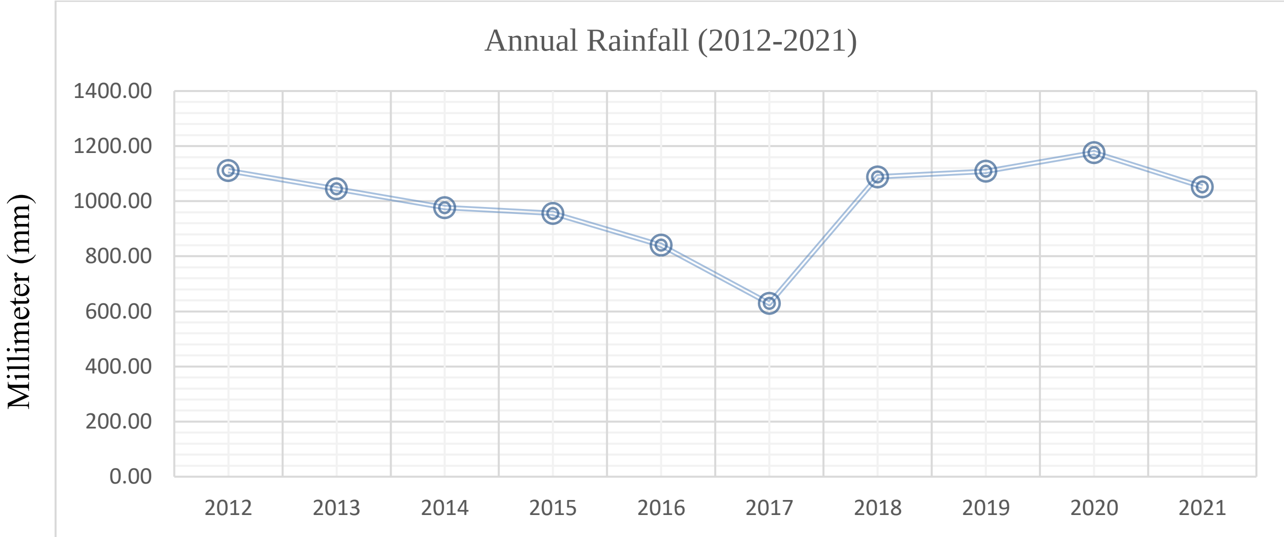

Figure 4.5: Annual Rainfall (2012-2021)

According to the research, the highest annual rainfall year was 2020 with 1176.31 mm, while the lowest was 2017 with 628.77 mm.

The watershed in Rwanda and Uganda is characterized by dispersed, tiny farms on terrain that is steep at high elevation. Because these places receive a lot of rain, they are vulnerable to floods and soil erosion, with dirt ending up as silt in rivers and streams.

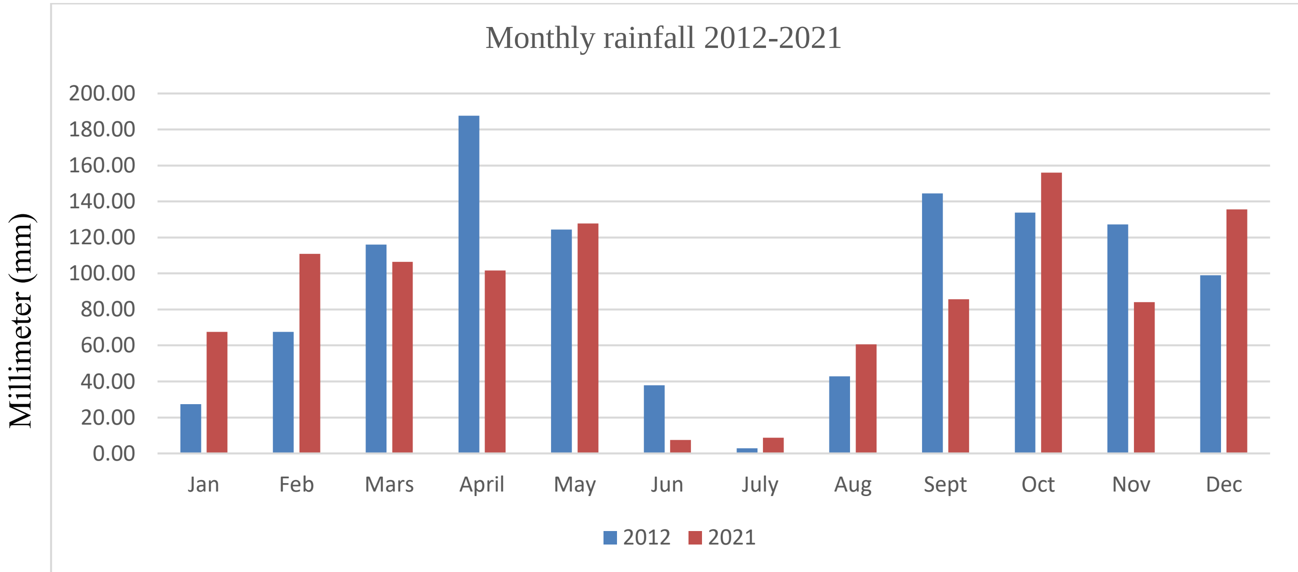

Figure 4.7: Monthly Rainfall (2012-2021) Months

The Figure 4.7 depicts monthly change in rainfall from 2012-2021, where the flood occurred in the highest altitude region particularly in Mulindi Sub-Catchment.

According to the research, the highest rainfall months were April 2012 and October 2021, with 187.59 and 155.97mm, respectively. The highest rainfall had both a positive and negative impact.

For positive side, heavy rain fall replenished water bodies, including reservoirs/dams, improving water availability for drinking, irrigation and hydropower generation in Muvumba catchment, it also helped recharge groundwater aquifers which is essential for sustaining water supplies during dry periods. For negative side, it led to soil erosion and water pollution as run off carries sediments, chemicals and waste into waterways. Additionally, floods disrupted transportation and affect water quality, potentially posing health risks (Muvumba Catchment Management Plan, 2018).

The lowest rainfall months was July2012 and June of 2021 with 2.93 and 7.43mm respectively, it diminished water levels in Muvumba river and reservoirs, led also to decreased water supply for drinking,irrigation,and industrial use, it depleted groundwater and over extraction during drought, long-term consequences for water availability(REMA,2018).

4.1.2.2 Future rainfall Projection Change

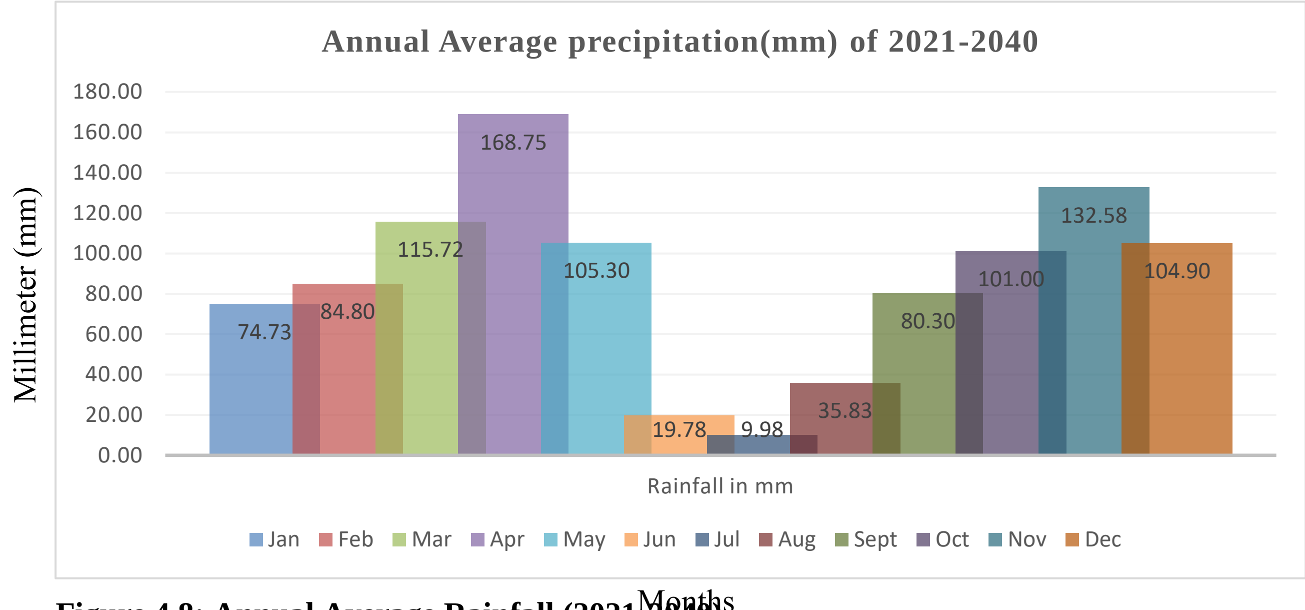

Figure 4.8: Annual Average Rainfall (2021-2040)

SSPs are part of a new paradigm developed by the climate change research community to encourage integrated consideration of future climate effects, vulnerabilities, adaptations, and mitigation (Hijmans, 2012). The concept is based on a matrix that incorporates climatic forcing on one axis (represented by Representative Forcing Pathways) and socioeconomic variables on the other. These two axes together depict scenarios in which mitigation, adaptation, and residual climate harm can be assessed.

The World Clim platform uses SSPs and Representative Concentration Pathway models (RCPs) to comprehend how our climate may change in the future and predict how we will behave, such as whether we will continue to burn fossil fuels at an increasing rate or shift to renewable energy? The RCP attempts to anticipate these future tendencies. After analysis of future data of wc2_1_10m_prec_ACCESS_CM2_ssp126_2021_2040_wc2_1_2_5m_prec.

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Figure 4.8 indicates the prediction of 1033.68 mm annual rainfall in 2012-2040.Over 20 years it is predicted the decreasing of 18.76 mm of precipitation.

Future climate projections for Rwanda, specifically the Muvumba Catchment, show a tendency toward a wetter and warmer climate. Soil erosion will be exacerbated by heavy rainfall on steep slopes (REMA, 2018).

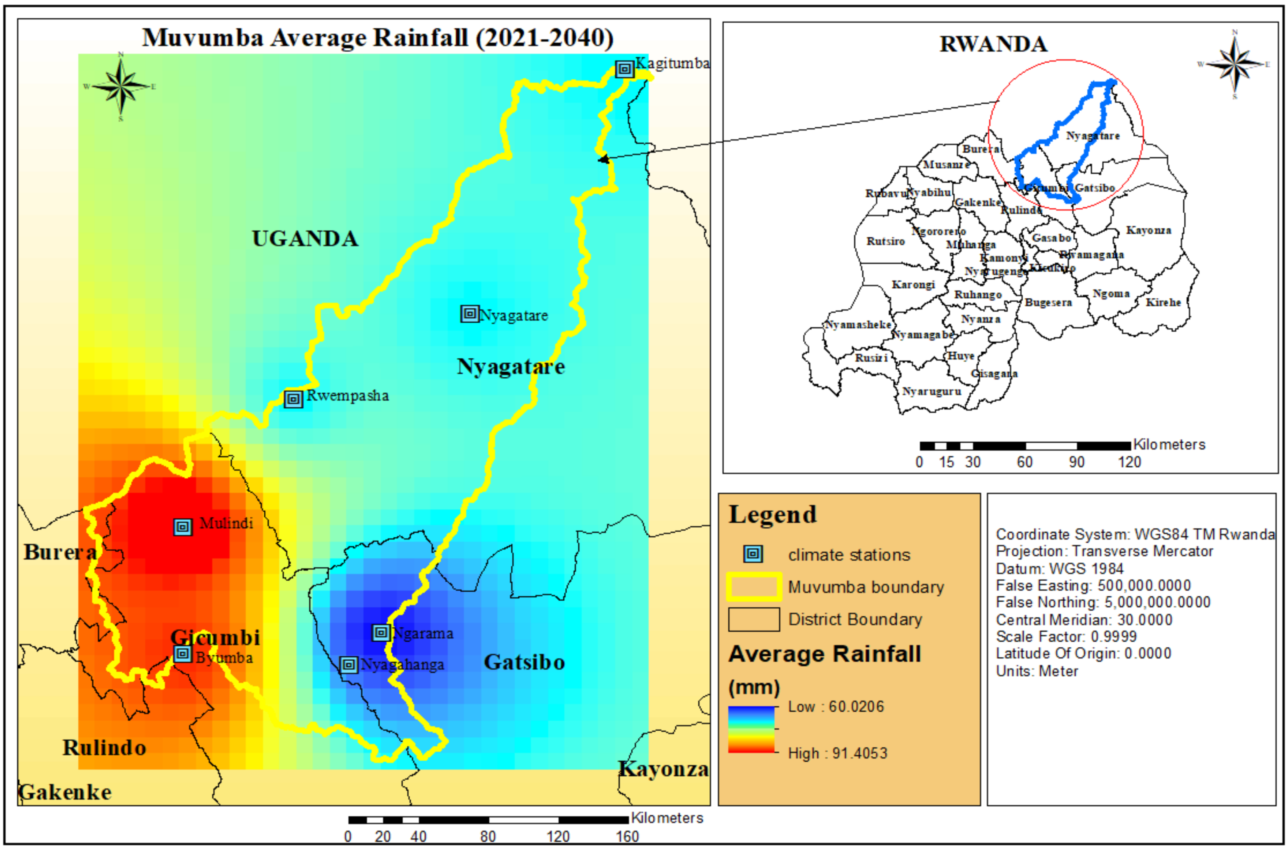

Figure 4.9: Average rainfall (2021-2040)

Research revealed that high average rainfall expected to be varied between 86.67mm and 91.40mm from north-west region of Muvumba most notably Mulindi sub-Catchment located in Gicumbi district. Muvumba Upstream, Ngoma Sub-Catchment would have moderate rainfall varies between 72.5 mm and 86.67 mm whereas Warufu Sub-Catchment and Muvumba downstream would have a little average rainfall varies between 60.02mm and 72.5mm the heavy rainfall is projected in Mulindi Sub-Catchment, which depicts highly surface run off and load of sediment flowing into Muvumba river which will have a significant impact on water quality.

1.1.1 4.1.3 Evaporation rate

This is the measure of how quickly water transforms from liquid state to a vapor in specific area, and it depends on factors including temperature increases, drought intensity and human activities (IPCC, 2014).

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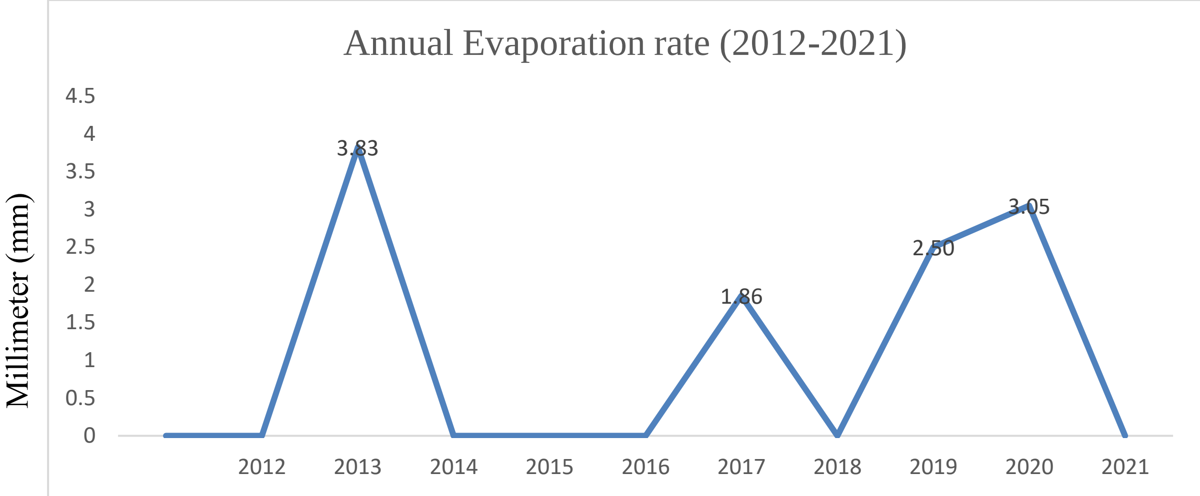

Figure 4.10: Muvumba Evaporation rate (2012-2021)

Research revealed that the greatest annual evaporation rate of 3.83 mm occurred in 2013, leading to increased water loss from water bodies such as reservoirs and rivers, resulting in decreased water levels, which could limit water availability. Furthermore, higher evaporation can exacerbate drought conditions, putting additional strain on water supplies and ecosystems (IPCC, 2014).

The reduction in evapotranspiration rate in 2017 was caused by factors such as lower temperatures or greater cloud cover. While it may conserve water in short term, reduced evaporation can lead to altered weather patterns and reduced rainfall in some regions, this can negatively impact water resources, affecting agriculture, hydropower generation, and overall ecosystem health

(Sheffield, 2008).

4.2 Assessing Hydrological variations

4.2.1 Water quality within the Muvumba catchment

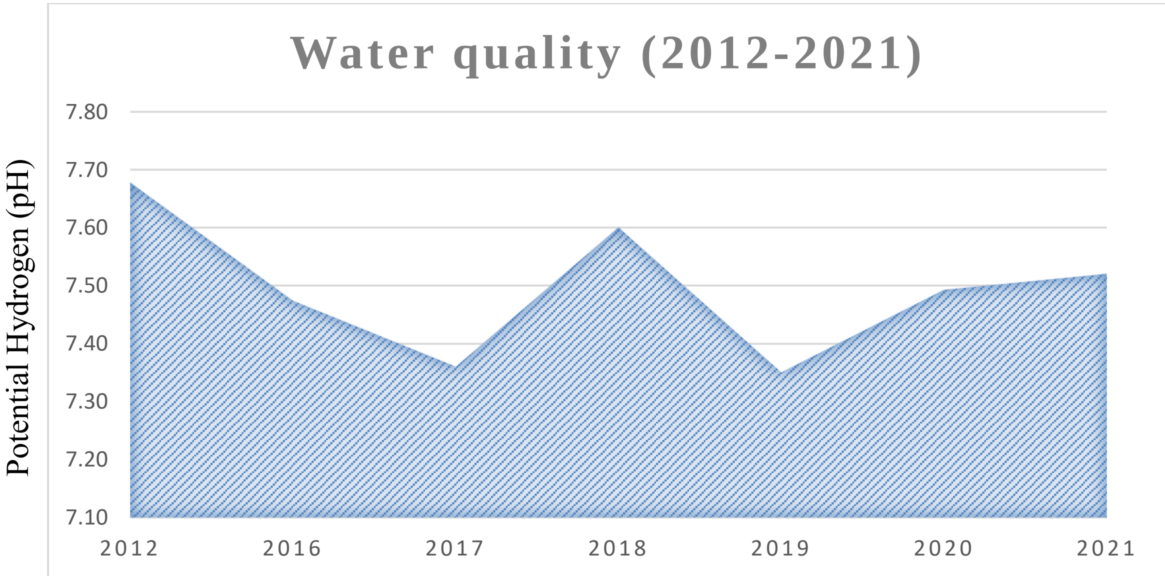

Figure 4.11: Water quality (pH)

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In Rwanda, access to clean water at the district level is between 40 and 50% on average, with 49.2% in Gatsibo and 52.8% in Nyagatare both participating in the Muvumba Catchment. This implies that almost half of the population utilizes contaminated water from streams, dams, valleys, or wetlands and consequently lacks access to clean and dependable water supplies for productive and household purposes.

Figure 4.11 study indicated that the level of water quality varied between 7.6 pH and 7.35 pH from 2012 to 2021, resulting in the release of toxic chemicals from sediments into water. Moreover, developing urban areas like as Nyagatare, Yaramba, Rukomo, Miyove, Gatuna and Byumba Developed Urban Areas generates solid waste, storm water, and sewage, and the majority of waste ends up in rudimental drainage systems, affecting key watercourses. Other pollution sources in Gicumbi include industries, mining operations, and some informal settlements. Another significant source of poor quality water in the downstream river section is pollution produced by the use of pesticides and fertilizer in irrigation systems (REMA, 2018).

4.2.2 Water Quantity

Future water demand and usage scenarios imply that water stress within Muvumba will steadily grow, necessitating a balanced approach to watershed protection and water production maximization in order to fulfill vision 2050 targets. One approach would be to calculate a 'value' per unit of water, which is usually expressed in monetary terms. This might eventually result in a water consumption fee linked to water licenses. Rwanda's National Transformation Strategy1 (2018-2024) estimates that water use would over double in the next seven years. The agricultural sector is by far the greatest water consumer, and it is predicted to increase in lockstep with rising water demands from industry, sanitation water sources, urbanization, and hydropower. Domestic and industrial users are consistent and relatively modest, while environmental flow is set at 20% of monthly blue water availability.Peak usage is connected to irrigation programs during the dry months.During the dry season (June to September), water shortage is particularly frequent.

4.3 The relationship between Climate change and water resources variations in Muvumba Catchment

4.3.1 Stream Flow Pattern

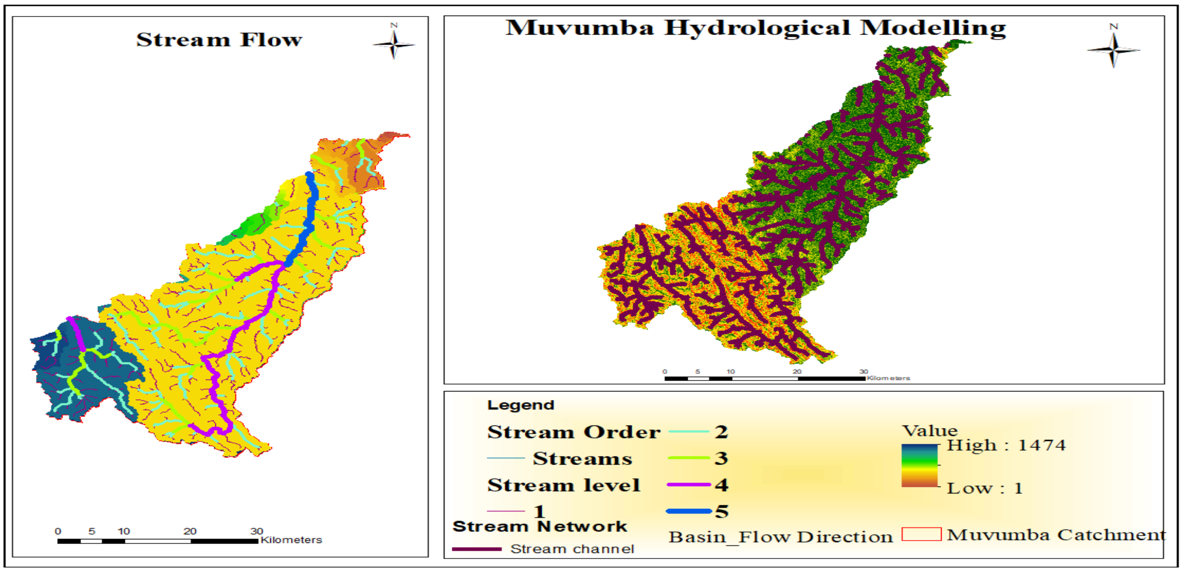

Figure 4.12: Muvumba stream flow pattern

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Hydrological modeling, which simulates hydrologic processes to calculate stream flow (river discharges), is critical in understanding the link between climate change and water resource fluctuations.

These modifications can impact timing and amount of water entering and leaving a particular watershed affecting water availability.

The anticipated stream flow pattern correlates to fluctuations and trends in precipitation and evapotranspiration (Onyutha et al., 2021).

These findings are consistent with mounting evidence that the planet is warming. Studies have been conducted based on present precipitation patterns (Gurara et al, 2021).

Higher temperatures have been demonstrated to increase evaporation rates, reducing stream flow and increasing the incidence of droughts. This will very probably have a detrimental influence on agricultural output and irrigation management in the basin.

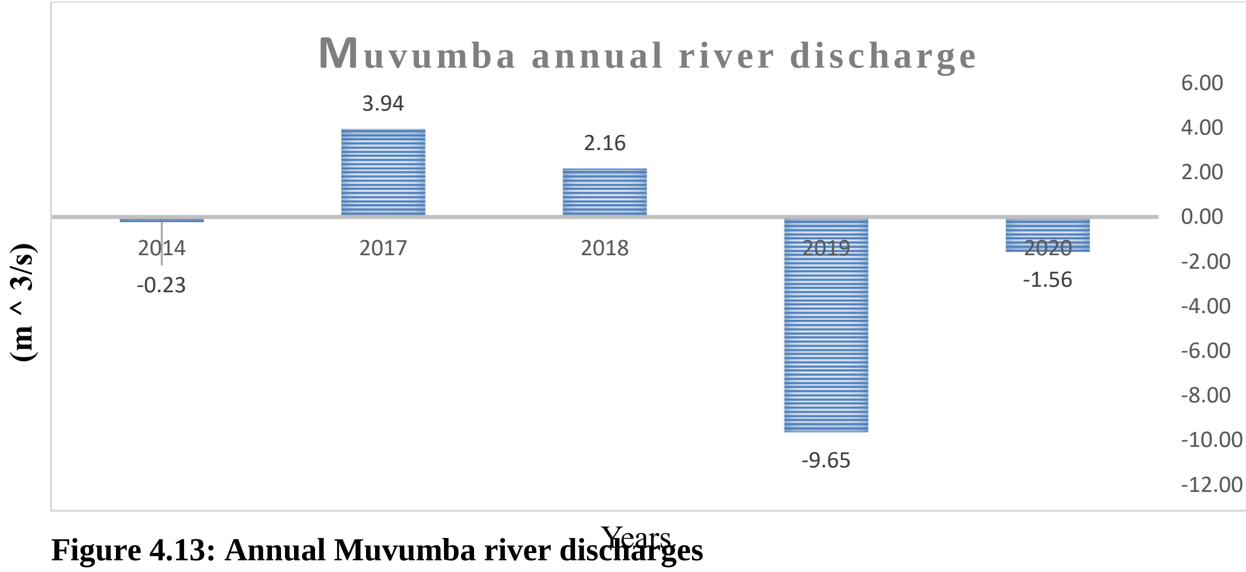

Figure 4.13: Annual Muvumba river discharges

Figure 4.13 indicate dropping down of 0.23m^3/s in 2014 and increasing of 3.94m^3/s after only three years indicated the water level increased by heavy rainfall particularly in 2017, but after two years' river discharge decreased by 7.87m^3/s in Muvumba Catchment due to factors such as drought, decreased precipitation and increase of evaporation. 2019 indicated the highest reduction of river discharge by 9.65 m^3/s whereas high level of discharges occurred in 2017 by 3.94 m^3/s.

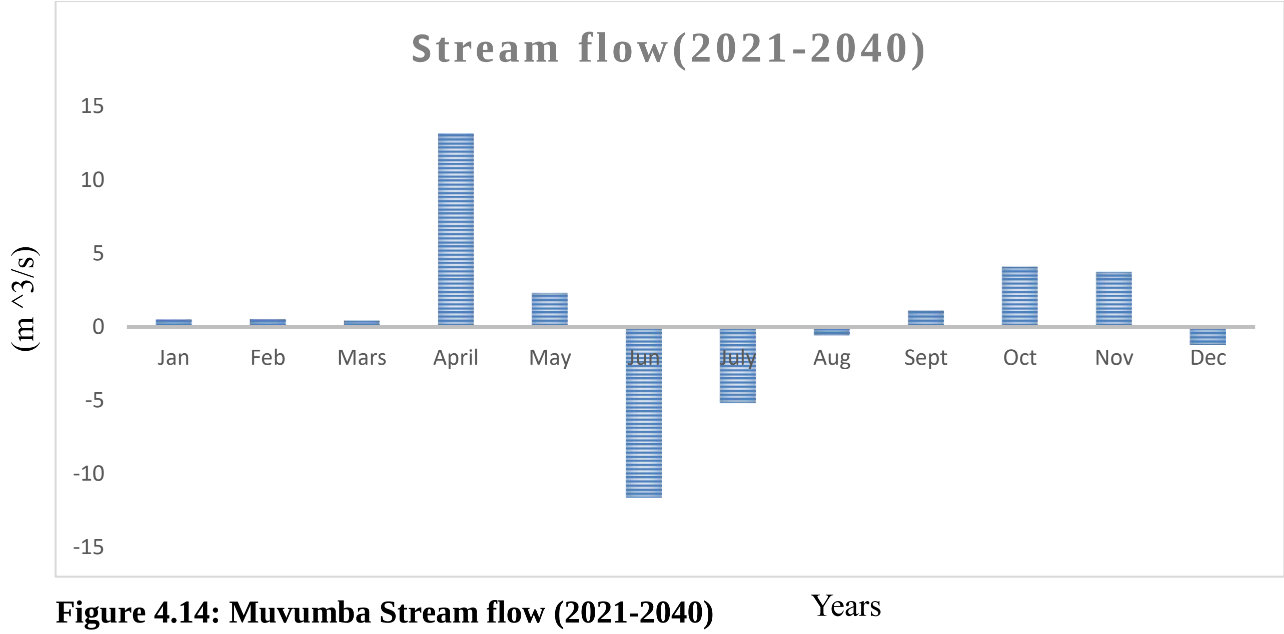

Figure 4.14: Muvumba Stream flow (2021-2040)

Figure 4.14 shows The average monthly discharge is projected to decrease from June to August (Long dry season) by variation of 4.7 and 7.8% by 2021-2040.Large increase of stream flow is projected to occur in April and May by variation of 13 and 14.7%.High evapotranspiration due to the increase in temperature may be the source of reverse trends of precipitation and stream flow in the rain season (Getahun, 2014).

In all scenarios and time periods, a reduction in discharge is expected from June to August, which is connected to a decrease in forecast rainfall. The findings indicate that in the future climate, In the middle and late 20 years, the connection between stream flow and precipitation may change, with a unit fall in precipitation resulting to a bigger decrease in stream flow. Stream flow estimates demonstrate a drop in stream flow owing to lower precipitation and higher temperatures in a catchment, which is consistent with earlier findings. As a result, any change in rainfall will have a significant influence on the flow of watershed (Daba et al., 2020).

The seasonal distribution of the discharge intensities in an annual average flow of roughly 14m3/s.

Variability and patterns of precipitation and evapotranspiration correlate to the expected stream flow arrangement (Tessema, , 2021). These results are consistent with mounting evidence of global warming. Studies are being conducted based on current rainfall trends. Higher temperatures increase evaporation rates, reducing stream flow and increasing the frequency of droughts. This will very probably have a detrimental influence on agricultural output and irrigation management in the catchment (Abate & Dile, 2021).

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1.1.2 4.3.2 Land use Land cover change

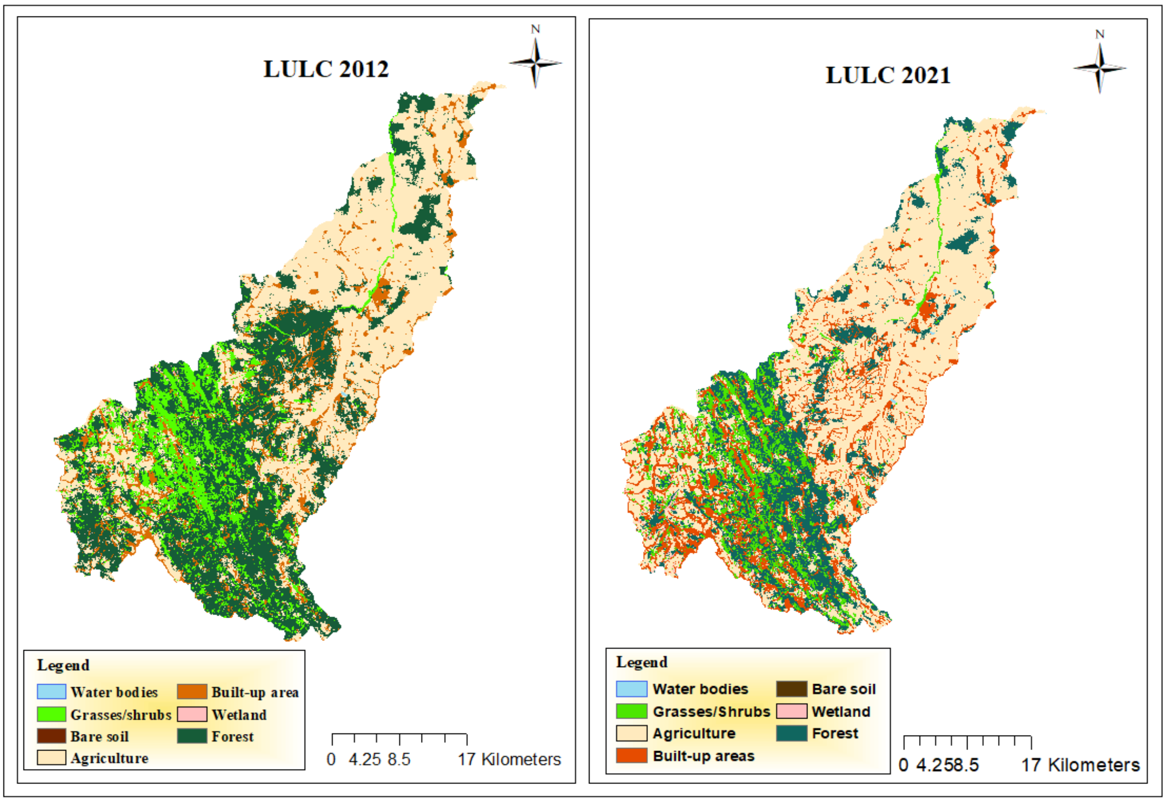

Figure 4.15: Land use Land cover change Detection

LULCCD is relevant in the context of climate change because changes in land use and land cover can have direct and indirect effects on the climate system. For example urbanization Deforestation, and agricultural expansion, can result in increased greenhouse gas emissions and changes within local climate patterns; converting forests to urban areas or agriculture can result in decreased carbon capture and storage capacity and higher heat absorption, boosting the effect of urban heat islands and exacerbating temperature rise.(IPCC, 2021), Accuracy assessment depicted the 2012's Overall accuracy was 80.32% with 0.52 Kappa Coefficient whereas 2021's Overall accuracy was 82.06% with 0.67 Kappa Coefficient.

Table 4.1: Land use land cover Change detection (2012-2021)

Land use Land Cover of different years	**Area in percentages (%)**				**P-Value**
	2012	**2021**	**Changes in %**	**Descriptions**	**Statistical Sig.**
Agriculture	44	53	**9** ***(Increases)***	Perennial, seasonal agriculture	1.7E-06
Built-up	6	16	**10** ***(Increase)***	Infrastructures, houses	1.92E-06
Bare soil	0.0009	0.0015	**0.0006** ***(Increases)***	Mines, quarries	0.0601

Forest	37	20	**17** ***(Decreases)***	Sparse forest, dense forest	0.0002
Grasses	12.34	10.4	1.94 ***(Decreases)***	Gardens, open areas, shrubs	0.05109
Water bodies	0.03	0.1	**0.07** ***(Increases)***	Lakes, pond	0.0513
Wetland	0.3	0.5	**0.2** ***(Increases)***	Swamps, marshland	0.216694
Total					Sign=0.030956

Table 4.1 indicate that Climate change has statistically significant relationship between Land use Land cover at (Sig=0.030956).

The impact of population pressure is very clear with different LULC classes related to agriculture (seasonal or perennial which covers 9% of the increase from 2012 to 2021 and Grasses including gardens, open areas, and shrubs reduced to 1.94%). The dominance of these classes thus reflects the enormous effect of agriculture on land cover and, when combined with high soil erosion risks on steep slope, contributes strongly to sediment ingress from such land into river. Built-up area increased up to 10%, bare soil (mines, quarries) increased up to 0.0006%, contributing to sediment entering into Muvumba river, total forestland including sparse and dense forest decreased to 17%, showing evidence of cutting down trees or other forms of depletion, water bodies (lakes and ponds) increased up to 0.07%, and wetland area (marshland and swamps) increased to 0.2% between 2012 and 2021.

5.1 Conclusion

Muvumba catchment is vulnerable to temperature with Maximum annual temperature varied between 27^{O}C and 28.3 ^{O}C Research revealed that From 2012-2021 maximum temperature increased by 0.4^{o}C,the rising temperatures exacerbated drought conditions leading to water scarcity in affected regions.Ngoma and Muvumba Upstream sub-catchment among others had an impact on Agriculture,ecosystems and communities that relied on water resources. The greatest annual evaporation rate of 3.83 mm occurred in 2013, leading in increased water loss from water bodies such as reservoirs and rivers, resulting in decreased water levels, which could limit water availability.

The level of water quality varied between 7.6 pH and 7.35 pH from 2012 to 2021, resulted to the release of toxic chemicals from sediments into water. The predicted impact of climate change on water resources in Muvumba is remarkable, with a predicted 7% of stream flow during dry season and 14.7% increase during rainy seasons over the 2021-2040 under future climate scenarios, this may exacerbate water stress in the Muvumba watershed, affecting water and food safety in the region. The delicate water balance of water availability is under serious threats.

The anticipated decrease of rainfall by 18.76 mm and rising of temperature by 0.8^{0}C (2021-2040) would result to decrease of water quality/availability in Muvumba river and reservoir potential causing drought conditions. This combination has the ability to stress water supplies for agricultural, water for drinking, and industrial usage, potentially resulting in water shortages. Furthermore, ecosystems and aquatic species may suffer as a result of damaged habitats and diminished water flow. Despite widespread recognition of this region's sensitivity to climate change, research on the influence of future climate change on water supplies remain limited.

5.3 Recommendations

To enhance future studies, integrating Land Use Land Cover changes' influence on water resources is crucial for comprehensive evaluations and the development of adaptation strategies to mitigate climate change impacts, especially on agriculture. Upgrading observation facilities to provide comprehensive climate information and facilitate climate trend detection, variability management, and disaster preparedness is vital. Implementing Integrated Water Resources Management (IWRM) can improve water quantity and quality, boost hydropower development, and ensure climate-resilient infrastructure. Moreover, policies addressing evolving water availability and demand, along with the construction of reservoirs and dams for water storage during extreme weather events, are essential for sustainable water management and adaptation. Encouraging rainwater harvesting can significantly enhance drought resistance and minimize runoff in urban settings, supporting sustainable water resource management.

5.3 Acknowledgement

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5.4 About the principal investigator

Emmanuel Hategekimana, a distinguished Engineer, combines Civil Engineering and Environmental Technology expertise. With an MBA from Mount Kenya University and a diploma in Shared Water Resources Management from Cairo University, his focus on sustainable water practices is evident. His Master's degree in Environmental and Development Studies equipped him with skills in Economics and Natural Resources Management. Notably, his impactful journey began in 2007 as Infrastructure Engineer in Rusizi District, followed by roles in the Ministry of Agriculture and Ministry of Infrastructure. A dedicated member of IER and IRPV, his commitment to innovation and sustainable development fuels Rwanda's progress.

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